ECOLOGICAL ATLAS OF THE BERING, CHUKCHI, AND BEAUFORT SEAS

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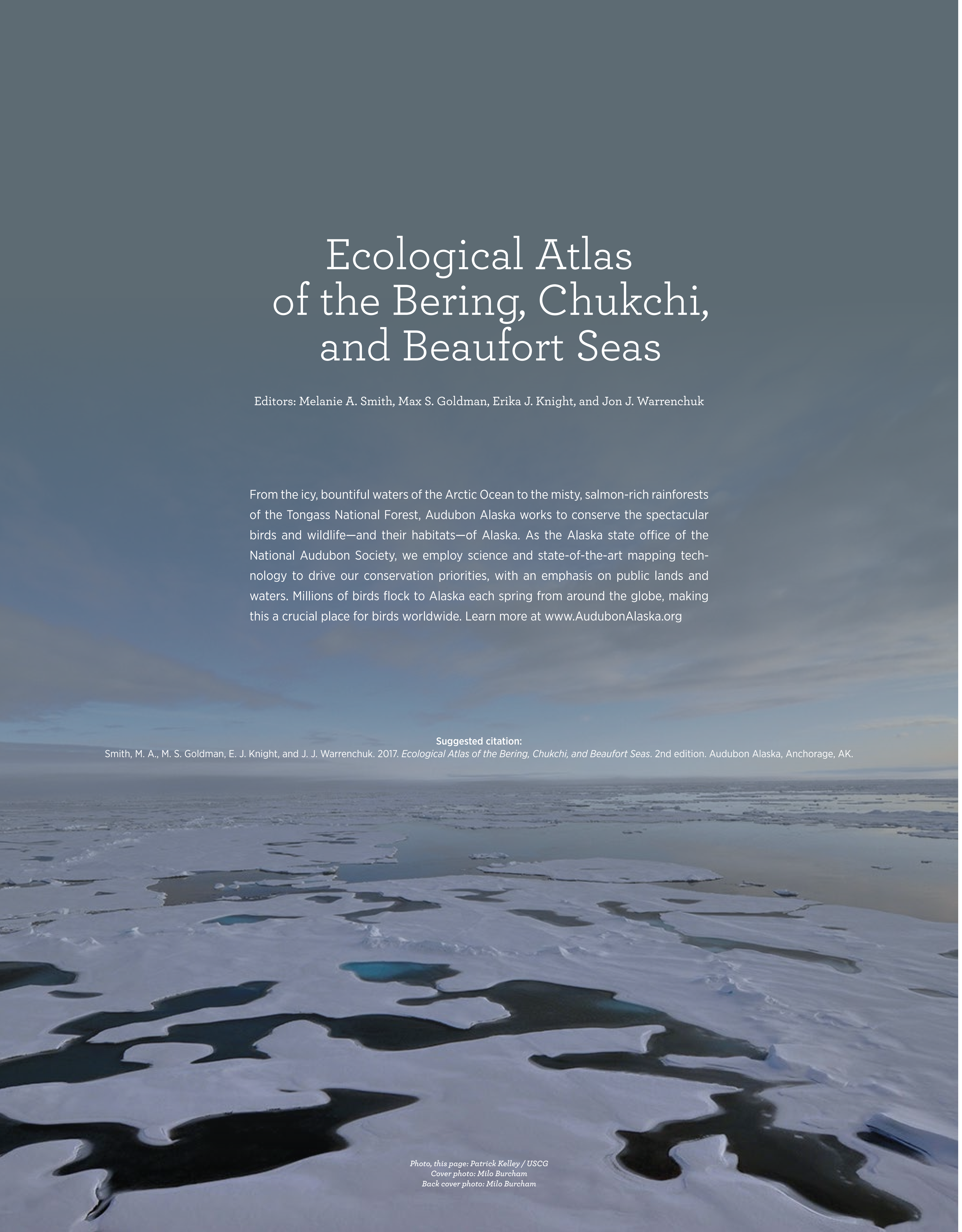

Ecological Atlas of the Bering, Chukchi, and Beaufort Seas

Editors: Melanie A. Smith, Max S. Goldman, Erika J. Knight, and Jon J. Warrenchuk

From the icy, bountiful waters of the Arctic Ocean to the misty, salmon-rich rainforests of the Tongass National Forest, Audubon Alaska works to conserve the spectacular birds and wildlife—and their habitats—of Alaska. As the Alaska state office of the National Audubon Society, we employ science and state-of-the-art mapping technology to drive our conservation priorities, with an emphasis on public lands and waters. Millions of birds flock to Alaska each spring from around the globe, making this a crucial place for birds worldwide. Learn more at www.AudubonAlaska.org

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daniel p huffman
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And assistance from

AOOS Alaska Ocean Observing System

BOEM Bureau of Ocean Energy Management

KAWERAK, INC.

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

TERRAgraphica

U.S. Fish & Wildlife Service Department of the Interior

USGS science for a changing world

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Brianne Mecum / Oceana

Acknowledgments

The *Ecological Atlas of the Bering, Chukchi, and Beaufort Seas* would not be possible without the efforts of many, over a long period of time. The atlas is necessarily a cooperative effort facilitated by the considerable sharing of information from individuals, organizations, and agencies. Hundreds of researchers and a long list of agencies and organizations have contributed to our understanding of the Arctic marine ecosystem through field studies, reports, peer-reviewed papers, theses and dissertations, monitoring programs, spatial databases, and expert advice. We greatly appreciate the many Arctic scientists and experts who advised, reviewed, or provided data to this effort, as well as the scientists and funding agencies and organizations that conducted and supported the original studies that generated the data. Those agencies include, but are not limited to, the Alaska Department of Fish and Game (ADFG), Bureau of Ocean Energy Management (BOEM), Department of Fisheries and Oceans Canada, Environment Canada, Kawerak, Inc., National Oceanic and Atmospheric Administration (NOAA), North Pacific Research Board (NPRB), Institute for Biological Problems of the North, University of Alaska Fairbanks (UAF), US Fish and Wildlife Service (USFWS), and US Geological Survey (USGS).

This publication was extensively peer-reviewed. After undergoing multiple rounds of careful internal review, each map and written summary in this atlas was reviewed by an outside subject-matter expert. Later, each of the six main chapters were shared with additional reviewers to cohesively look at the information, and to identify anything missed in previous rounds of review. More than 80 scientists and traditional knowledge experts offered their advice, review, editing, traditional knowledge, and expertise to make this project happen. We thank numerous agencies and organizations for generously contributing staff time to improving this effort, including ADFG, BOEM, Institute for Biological Problems of the North (on behalf of the Russian Academy of Sciences), Kawerak, NOAA, Ocean Conservancy, Pew Charitable Trusts, The Wilderness Society, University of Alaska Anchorage, UAF, USFWS, USGS, World Wildlife Fund, and others.

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Commonly Used Acronyms

ADFG	Alaska Department of Fish and Game
AGDB	Alaska Geospatial Bird Database
BOEM	Bureau of Ocean Energy Management
DPS	distinct population segment
EBS	eastern Bering Sea
EEZ	exclusive economic zone
EFH	Essential Fish Habitat
ESA	Endangered Species Act
GOA	Gulf of Alaska
IBA	Important Bird Area
IUCN	International Union for Conservation of Nature
MMPA	Marine Mammal Protection Act
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPPSD	North Pacific Pelagic Seabird Database
NSIDC	National Snow and Ice Data Center
OCS	Outer Continental Shelf
TK	Traditional knowledge
US	United States
USCG	United States Coast Guard
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service
WL	Audubon Alaska's WatchList

An October sunset from the Beaufort Sea north of Cape Halkett.

Melanie Smith / USFWS

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MAP ON PAGES 12–13

INTRODUCTION

Melanie Smith

Imagine these Arctic scenes: A mass of sea ice drifts with twenty resting walruses hauled out on top. A bright white Ivory Gull circles a research vessel. A small boat of indigenous hunters quietly approaches a seal. Puffins, full of small fish and too heavy to fly, dart down into the water under an approaching ship. The long, sleek backs of a dozen bowhead whales take turns breaking the surface as they feed. Twenty-foot seas crash ashore a small rocky island creating spray that can be seen from miles away. A Snowy Owl circles 50 miles offshore over open water, landing on a ship's mast in lieu of absent pack ice. A fishing vessel motors toward port with an icy hold full of red salmon. A polar bear and two cubs gnaw on whale bones on the sea ice.

We bring you this Ecological Atlas as a way to help you explore these and other Arctic marine scenes, brought together under one cover. These maps, written summaries, and photographs will take you on a scientific journey through natural history and ecological relationships in the Arctic marine environment. The goal of the *Ecological Atlas of the Bering, Chukchi, and Beaufort Seas* is to create a comprehensive, trans-boundary atlas that represents the current state of knowledge on subjects ranging from physical oceanography to species ecology to human uses.

The Ecological Atlas is organized into six topic areas that build, layer by layer, the ecological foundation of these three seas. Chapter 2 (Physical Setting), explores various climatic attributes and the abiotic processes that perpetuate them. Chapter 3 (Biological Setting), introduces the lower trophic food web. Chapter 4 (Fishes), describes a range of prominent pelagic and demersal fish species. Chapter 5 (Birds), highlights a long list of seabirds and waterbirds that regularly use these waters. Chapter 6 (Mammals), maps out regional use by many cetaceans, pinnipeds, and polar bears. Chapter 7 (Human Uses), covers subsistence, conservation, and economic drivers in the region. These six expansive topic areas culminate in Chapter 8 (Conservation Summary), which shares the key themes and management recommendations stemming from this work.

MANAGEMENT OF THE ARCTIC

The Chukchi and Beaufort Seas are north of the Bering Strait, and within the Arctic Ocean. The Bering Sea, south of the Bering Strait, is technically the northernmost sea of the Pacific Ocean, but ecologically acts like an Arctic sea. Although multiple definitions of the Arctic exist (e.g. Arctic Circle, Arctic Ocean), the US Arctic Research and Policy Act of 1984 (ARPA) defines the Arctic as "including the Arctic Ocean and the Beaufort, Bering and Chukchi Seas; and the Aleutian chain."

The Arctic Council includes all three seas in its definition of the Arctic as well. (Map 1.1 in this chapter gives an overview of the project area, showing the Arctic Council's Conservation of Arctic Flora and Fauna [CAFF] working group's definition of the Arctic boundary.) The Arctic Council is "the leading intergovernmental forum promoting cooperation, coordination and interaction among the Arctic States, Arctic indigenous communities and other Arctic inhabitants on common Arctic issues, in particular on issues of sustainable development and environmental protection in the Arctic." The eight member states of the Council include the United States (US), Canada, the Russian Federation, Finland, Iceland, Norway, Sweden, and the Kingdom of Denmark. In addition, six indigenous organizations are part of the Council as permanent participants. They are the Aleut International Association, the Arctic Athabaskan Council, Gwich'in Council International, the Inuit Circumpolar Council, Russian Association of Indigenous Peoples of the North, and the Saami Council. Additional non-Arctic states and non-governmental organizations have observer status on the Council. Chairmanship of the Arctic Council rotates every two years; the US completed its chairmanship in early 2017, which was then passed onto Finland.

In the US, several agencies manage sustainable use of the Arctic. The Bureau of Ocean Energy Management (BOEM) has a mission to manage development of the Outer Continental Shelf, providing energy and mineral resources in an environmentally and economically responsible way. The Bureau of Land Management (BLM) manages for multiple uses, including oil and gas development in the National Petroleum Reserve—Alaska (NPRA). The State of Alaska's Division of Oil and Gas (ADOG) is responsible for the leasing of state lands for oil, gas, and geothermal exploration, including the Prudhoe Bay oil field and in nearshore marine waters. The mission of the US Fish and Wildlife Service (USFWS) is working with others to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people; USFWS also manages threatened and endangered species and a network of national wildlife refuges. The National Oceanic and Atmospheric Administration's (NOAA's) Fisheries Division is responsible for the stewardship of the nation's ocean resources and their habitat, with a focus on productive and sustainable fisheries, sound science, and an ecosystem-based approach to management; NOAA also manages threatened and endangered species (particularly marine mammals) and a network of marine protected areas (MPAs). The mission of the US Geological Survey (USGS) includes understanding complex biological systems through research, modeling, mapping, and the production of high-quality data. Together, the work of these agencies, under the auspices of the US Department of Interior, directs the management of the Arctic, both onshore and offshore, in the US. Similarly, a host of agencies in Russia and Canada manage terrestrial and marine natural resources, although they are not described here. In addition to the internationally coordinated Arctic Council and a host of federal and state agencies, numerous local governments, indigenous organizations, tribal entities, and non-governmental organizations actively participate in management of the Arctic ecosystem.

To encourage sustainable management in the face of growing human influence, climate change, and development, there is a need to synthesize and disseminate information to policy makers, scientists, and the public in a format that is useful and accessible. To be most comprehensive, the information should transcend jurisdictions, missions, and international boundaries, following ecological patterns instead. This atlas is a step toward that end, by providing a cumulative picture of what is happening in the Bering, Chukchi, and Beaufort Seas to better understand ecological patterns through spatial data, maps, and written summaries. It is our hope that the information included here will aid the variety of entities involved in managing the Arctic to make informed decisions that promote sustainable use and conservation.

HISTORICAL BACKGROUND AND RELATED EFFORTS

In 1988, NOAA published the first comprehensive area-wide marine mapping project for the Arctic—the *Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones Strategic Assessment Atlas*. In 2010, 22 years later, Audubon Alaska published the first edition of this Ecological Atlas, under a slightly different name. The *Arctic Marine Synthesis: Atlas of the Chukchi and Beaufort Seas*, was the first comprehensive atlas of the region since NOAA's atlas, and was completed in cooperation with Oceana, who made valuable contributions by sharing knowledge of marine ecology and biological data layers.

Audubon's first edition Ecological Atlas was met with enthusiasm by a wide variety of users, from local Alaskans to decision-makers in Washington, DC. The work helped inform many other tools and planning processes. USFWS found the polar bear map useful when delineating critical habitat. Alaska Ocean Observing System (AOOS) added the data to its online Arctic mapping portal to make them accessible to various interested users. NOAA used these data in its Environmental Response Management Application (ERMA) for oil spill response planning in Arctic waters. The State of Alaska Department

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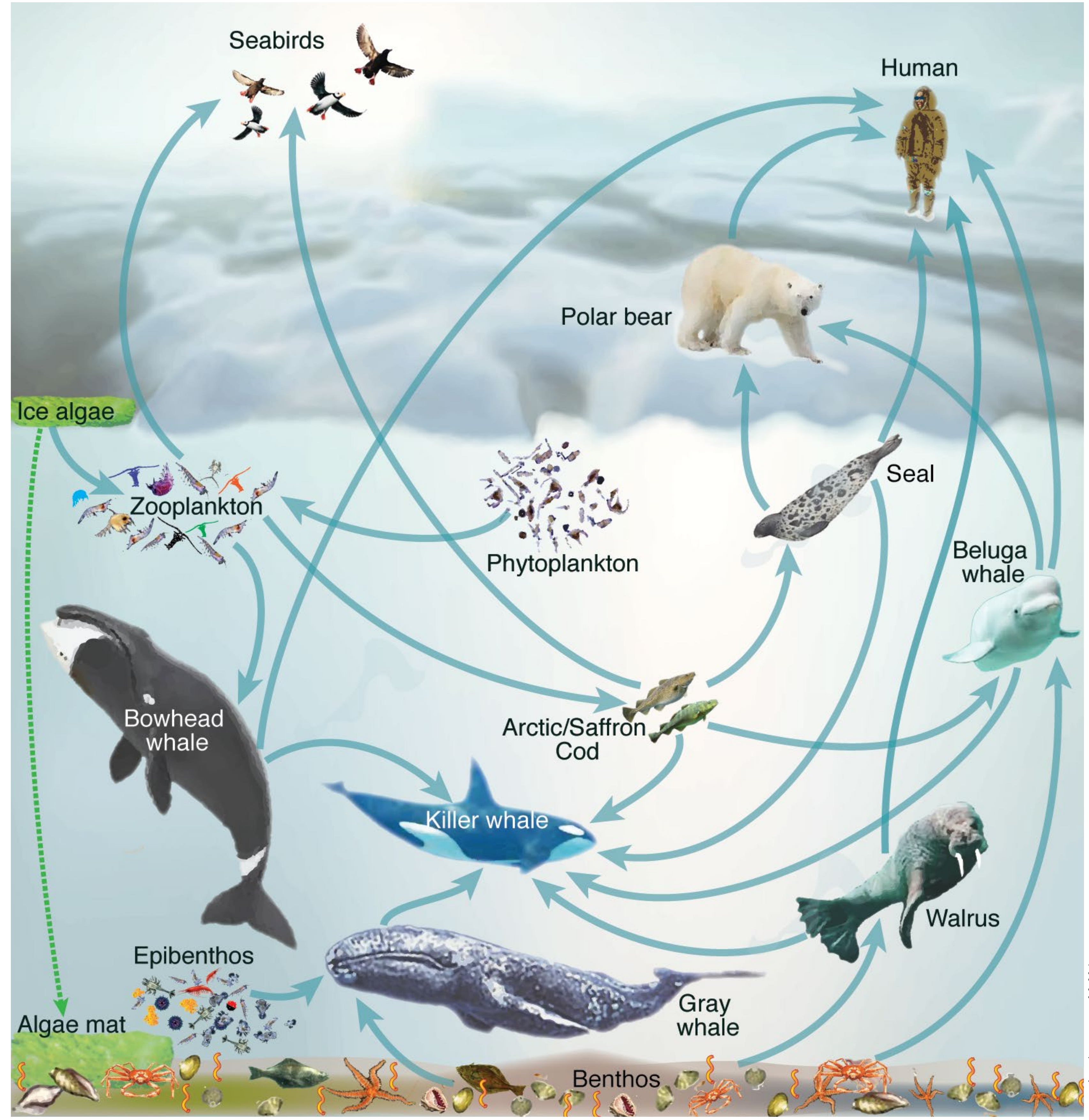

SOAR (2015), Karen Birchfield / NOAA

The dynamic food web of the Pacific Arctic, illustrating complex interactions between trophic levels, from primary productivity to apex predator.

of Environmental Conservation (ADEC) also used these data in its own oil spill response plans. USGS used descriptions from the atlas to summarize data quality in its report to the Secretary of Interior evaluating science needs to inform decisions about Outer Continental Shelf (OCS) energy development. The International Union for the Conservation of Nature (IUCN) relied on the Ecological Atlas to identify several Ecologically and Biologically Significant Areas (EBSAs) in Alaska waters, a designation set up under the United Nations' Convention on Biological Diversity.

Over the years, however, data presented in the atlas aged—newer data became available and other data were improved. To answer that call, we began work on a second edition *Ecological Atlas of the Bering, Chukchi, and Beaufort Seas* in 2015 with a generous grant from the Gordon and Betty Moore Foundation. The second edition Ecological Atlas integrates data from the first, as well as several other intervening projects that used and built upon the original database. This new edition also greatly expanded the geographic extent by adding the southern Bering Sea, the eastern Canadian Beaufort Sea, many new species, and an expanded Human Uses Chapter, including subsistence, vessel traffic, and fisheries management.

Between the first and second editions of this atlas, several other efforts conducted by Audubon and partners were the building blocks for this project.

Audubon Mapping Efforts in the Arctic

Important Bird Areas. From 2010 to 2014, Audubon Alaska developed a revised and expanded set of Important Bird Areas (IBAs) in Alaska (Smith et al. 2014a), with a strong focus on the marine environment. This work included compiling bird survey datasets from across the state and developing new spatial methods to delineate areas of global significance to birds (Smith et al. 2014b). In marine waters, the analysis utilized the USGS North Pacific Pelagic Seabird Database v2 (NPPSD) (Drew and Piatt 2013). In nearshore, coastal, and interior areas, we used Audubon's Alaska Waterbird Dataset (Walker and Smith 2014)—a standardized collection of over 1.5 million bird survey points from the USFWS, National Park Service (NPS), US Forest Service (USFS), and others. This process generated a number of data layers depicting species distribution and concentration across Alaska and yielded a new set of globally significant IBAs (Smith et al. 2014a).

Eastern Bering Sea Shipping Study. In response to the US Coast Guard (USCG) Port Access Route Study (PARS) for the eastern Bering Sea (Unimak Pass to Bering Strait), from 2011 to 2015 Audubon and several partner organizations collaborated to analyze ecological values and ship routing measures, including a series of 40 new maps and a synthesis of scientific and traditional knowledge (TK) information. Key partners in data gathering and synthesis were Oceana, Kawerak, Pew Charitable Trusts, World Wildlife Fund, and Ocean Conservancy. As a result of that work, we recommended an alternate route from the proposed route that ran through critical habitats and subsistence areas, identified and recommended Areas to be Avoided (ATBAs), and recommended speed restrictions in certain whale and seabird concentration areas. In late 2016, the USCG recommended those same ATBAs in their final PARS report.

Synthesis of Existing, Planned, and Proposed Infrastructure. In 2013–2014, Audubon Alaska assisted the University of Alaska Fairbanks and Ocean Conservancy on their report *A Synthesis of Existing, Planned, and Proposed Infrastructure and Operations Supporting Oil and Gas Activities and Commercial Transportation in Arctic Alaska* (Hillmer-Pegram 2014). For this report, Audubon gathered road, pipeline, well, well pad, and facilities locations for current and future development, which are presented on the many maps in that report.

Marine Mammal Core Areas Analysis. This collaboration between Oceana and Audubon Alaska led to a new analysis of summer and fall core areas for marine mammals in the Chukchi and Beaufort OCS Planning Areas. We utilized the extensive Bureau of Ocean Energy Management / NOAA Aerial Survey of Arctic Marine Mammals (ASAMM) dataset to analyze concentration patterns for bowhead, beluga, and gray whales; Pacific walruses; and other pinnipeds. Methods were designed collaboratively with NOAA staff (Krenz et al. 2015). The work began in 2014, and the most recent update of these analyses were completed in 2016 for Audubon and partners' comments on the Draft Programmatic Environmental Impact Statement for the OCS Oil and Gas Leasing Program.

Integrated Arctic Management. In 2015, Audubon Alaska provided the data and maps for Ocean Conservancy's report *The Arctic Ahead: Conservation and Management in Arctic Alaska* (Hartsig 2016). The project included seamless integration of spatial data across marine, coastal, and interior regions for marine mammals, birds, shipping, air traffic, and more. Resulting from a series of North Slope Science Initiative (NSSI) workshops, we overlaid future development scenarios on all maps, providing a broad view to inform integrated management across Alaska's Arctic.

Synthesis of Important Areas in the US Chukchi and Beaufort Seas. From summer 2013 to spring 2016, we and our partners Oceana, Pew Charitable Trusts, World Wildlife Fund, and Ocean Conservancy brought together two synthesis databases, one each for the Chukchi Sea and Beaufort Sea federal OCS Planning Areas. Those data included various ecological layers that we used to generate over 70 new maps, as well as to identify important ecological areas for the US portion of the two seas.

Ecological Atlas of Alaska's Western Arctic. The third edition of this atlas, published in 2016, brought together the latest physical, biological, and human use data for the western North Slope of Alaska, from the Colville River in the east to the Chukchi Sea in the west, and from the crest of the Brooks Range in the south to the Beaufort Sea in the north (Sullender and Smith 2016).

Other Mapping Efforts Used During this Project

Numerous efforts were valuable sources of information for this work. Many additional efforts to collect and analyze spatial data in this region have taken place, and this is not meant to be an exhaustive list. Below are some of the major efforts led by other agencies and organizations that contributed to this atlas.

NOAA's 1988 Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones Strategic Assessment Atlas. In 1988, NOAA produced the first broad-scale spatial synthesis for this region—a set of thematic maps covering physical processes and pelagic, demersal, and benthic fauna, including invertebrates, fishes, birds, and mammals (National Oceanic and Atmospheric Administration 1988). This excellent but now outdated work provided a basis for many species maps in our atlas. In many cases, recent science has advanced beyond the knowledge when the 1988 atlas was created; in other cases, it still captures the best information available.

North Pacific Pelagic Seabird Database (NPPSD). Now in its second version, this product of the USGS (Drew and Piatt 2013) is an extensive collection of at-sea bird survey transects in the marine environment from various survey programs, beginning with the Outer Continental Shelf Environmental Assessment Program (OCSEAP) surveys of the 1970s and 1980s. The database includes data from more than 350,000 transects conducted over 37 years, covering areas of the US, Russia, Canada, and Japan.

Beringian Seabird Colony Catalog. The USFWS, via the Seabird Information Network, has published a database of bird colony surveys across Alaska and eastern Russia. Consisting of surveys conducted between the 1970s and 2011, the catalog includes nearly 900 colonies within our project area, representing some 35 million birds (Seabird Information Network 2011).

USFWS Alaska Bird Surveys. Surveys conducted by the USFWS provided hundreds of thousands of bird observations across the North Slope, many wildlife refuges, and coastal areas. These surveys consisted of Alaska Expanded Breeding Waterbird Surveys, Arctic Coastal Plain Aerial Breeding Pair Survey, Arctic Coastal Plain Aerial Waterbird Surveys, Arctic Coastal Plain Molting Sea Duck Survey, Arctic Coastal Plain Yellow-billed Loon Survey, Beaufort Sea Nearshore and Offshore Waterbird Aerial Survey, Black Scoter Population Aerial Surveys, North Slope Common Eider Aerial Surveys, North Slope Aerial Waterbird Surveys, Seward Peninsula Yellow-billed Loon Aerial Surveys, Southwest Alaska Steller's Eider Aerial Survey, Teshekpuk Lake Molting Goose Surveys, Western Alaska Common Eider Aerial Survey, and Yukon Delta Coastal Zone Aerial Waterbird Surveys, among others. This data collection began in the 1980s and continues annually in some form.

Aerial Survey of Arctic Marine Mammals (ASAMM). This NOAA and BOEM combined survey occurs annually during the summer and fall in the Chukchi and Beaufort Sea OCS Planning Areas. Formerly focused on surveying the fall migration of bowhead whales in the Beaufort Sea, ASAMM dates back to 1979 with expanded geographic and temporal coverage in recent years (National Oceanic and Atmospheric Administration 2015).

Oceana and Kawerak Bering Strait Marine Life and Subsistence Use Data Synthesis. Published in 2014, this synthesis was a collaboration between the conservation group Oceana and the Bering Strait Alaska Native non-profit corporation Kawerak "to better document and map the marine ecosystem of the Bering Strait region" (Oceana and Kawerak 2014). Based on a previous project by Kawerak to document walrus and ice seal use for nine tribes (Kawerak 2013b), this effort added scientific information on whales, birds (Audubon Alaska's IBA species core areas), physical features such as sea ice, and subsistence harvest areas.

MAPPING METHODS

It is challenging to produce static maps that inform decision-makers and capture the dynamic and expansive nature of Arctic marine waters. It is further challenging to collect and synthesize data across multiple studies, species, decades, and seas. In doing so, we made many decisions about the best and most appropriate way to depict spatial patterns. In some cases this meant choosing among similar, competing data; combining data; dissolving arbitrary seams among studies; or creating layers from analysis of survey data ourselves. We strived to manipulate incoming data as little as possible, in favor of directly reflecting the results of original studies. We balanced that with combining and editing data into composite layers to gain a broad-scale perspective on ecological patterns.

Production of this Ecological Atlas and others in our series (Southeast Alaska and the Western Arctic) used a process we call Data to Design, consisting of three phases: data gathering, data synthesis, and atlas design.

Data to Design

Data Gathering. Data gathering involves intensive research and consultation with experts in order to consolidate and analyze the best and most recent data available. We gather spatial data from a variety of sources, then integrate these data into a unified format with standardized attributes that refer back to what was published in the original study. Input data sources may include tracking data, aerial and boat surveys, maps and area descriptions in published papers and reports, scientifically documented TK, and personal communications with experts.

Data Synthesis. In our atlas, data spanning the three seas are often made up of multiple studies. We bring together data from across the region, then composite related polygons into seamless layers. We identify species use patterns using four levels of intensity (extent of range, regular use, concentration, and high concentration). Often this requires both pulling together results of existing studies and performing our own spatial analysis to create the layers from existing data; for example, delineating species distribution and concentration areas from decades of survey observations.

On our maps, we separated known concentration areas from other areas of occurrence to indicate relative importance. We cited existing studies where possible and developed our own methods to define concentration areas as necessary. In some cases, the spatial boundary of a concentration area was not presented in the literature, but written descriptions documented an area as important. In such cases, there was information known to be accurate but not precise (e.g. no exact boundary lines determined). As needed to augment existing spatial data, when adequate information was available to interpret spatial boundaries, our science team drew boundary lines representing those studies. In other cases, we utilized observational data (e.g. aerial survey locations) to conduct primary analysis of distribution patterns. In yet other cases, multiple related data layers required compositing and redrawing boundaries, such as with the spring range for bowhead whales which was presented differently among a few published maps. Such cases are documented on our maps as "based on" a list of multiple sources, rather than being taken directly from a map presented in other sources.

Atlas Design. The Ecological Atlas draws on an extensive literature review and data integration of the current knowledge of the scientific community. Along the way, we have developed robust standards for cartographic design, including colorblindness accessibility. Standardized colors and patterns across maps help the reader interpret the information shown. Species maps visually describe seasonal use, activity, and movement through the project area. Each map is accompanied by a written summary of natural history, mapping methods, conservation issues, map data sources, and references, with graphs and tables as needed.

For this project, we reviewed databases from the previous related efforts described above and built a newer and more complete database from them. We identified the latest research and added more scientific papers and agency reports to our growing electronic library of over 1,200 Arctic marine references. Based on these additional studies, and through our review process, we collected new spatial information and further refined spatial boundaries.

Mapping Species Ranges

Most bird and mammal species maps are shown using four levels of intensity of use: extent of range, regular use, concentration, and high concentration. There are various definitions of each term among the many studies we incorporated. Our definitions of each were necessarily flexible to facilitate the many interpretations among scientists and TK-holders. At the same time, we worked to be consistent in our application of these terms and documented our decisions in the associated spatial database.

Extent of Range. This generally included anywhere a species was known to occur. Often, maps from multiple sources were digitized and combined to delineate this boundary. Where we had extensive spatial observations, such as for seabirds, we used spatial analysis to derive the boundary, then combined the results with other studies to fill in survey data gaps. For example, see the Mapping Methods section of each species summary within the Birds Chapter to read the specifics of our methods.

Regular Use. This was meant to exclude areas of casual or accidental occurrence to reflect the non-extraneous range of a species. Best professional judgment was used to composite existing polygons into regular use areas, which had to do with geographic scale and the intent of the original study. Where spatial observational data were available for analysis, such as for seabirds, we calculated average density, ran a kernel density analysis, and used the 99% contour (i.e. isopleth) to represent regular use. See the Birds Chapter to learn more.

Concentration. This category was the hardest to define and apply. Concentration can be delineated by many different thresholds and is sensitive to the geographic extent applied. For example, core use areas (e.g. 50% isopleths) analyzed at the Holarctic scale will produce broad, smoothed boundaries, while analysis of a sub-region will produce smaller areas with more precise boundaries; both are accurate, but best applied at different scales. Where we conducted our own spatial analysis of observational data, such as when using ASAMM or NPPSD, we used the 50% isopleth from kernel density analysis to represent concentration (see cetacean summaries in the Mammals Chapter for more detailed methods). When incorporating TK, we used the definition from the Oceana and Kawerak (2014) study, defined as places where people reported frequently seeing groups of animals (which was differentiated in their data as a level between regular use and high concentration). When using existing polygons from published scientific studies, we used our best judgment to determine whether that study's version of concentration most closely matched our version of regular use, concentration, or high concentration. This had to do with geographic scale and the authors' understood intent. In situations where the intent was ambiguous, we contacted the author to help us make an appropriate determination. For each polygon in the spatial database, we documented what the original study called the area; this will allow users of the spatial database to see how the original studies correspond to our application of them.

High Concentration. This category reflected areas of exceptionally concentrated use which clearly stood out from concentration areas. For birds within Alaska, we used species core areas in IBAs to indicate high concentration, which are areas where 1% or more of the global population is known to occur. Where we conducted our own spatial analyses of mammal observational data, we most often used the 25% isopleth from kernel density analysis to represent high concentration (see Beluga Whale in the Mammals Chapter for more detailed methods). When incorporating TK, we used the definition from the Oceana and Kawerak (2014) study, defined as places where people reported seeing groups of hundreds to thousands of animals, or where they documented a hotspot (in this case a term applied to the most concentrated area within a larger region of highest concentration). When using

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existing polygons from published scientific studies, we used our best judgment to determine whether high use areas warranted inclusion in this category. Note that this category was not included for all species.

THE SYNTHESIS DATABASE

A principle of this work was tenaciously documenting data sources and cataloging the reports, people, and papers from which they came. Behind the maps is an extensive geodatabase that refers back to the original works and crosswalks those studies into our "synthesis database structure."

In some ways, the maps are just the beginning of what is in the Ecological Atlas. Most maps in this atlas are a composite of multiple data layers, and most often each layer is a composite of data from multiple sources. Using the spatial database, one has the potential to depict or discover far more patterns and relationships from the available data than we were able to incorporate into these static maps. The publically shareable data layers are published alongside this atlas for communities, scientists, managers, and others to explore and use. **We coordinated with AOOS and Axiom Data Science to make these data publically available. AOOS and Axiom integrated our spatial data into their online Arctic Portal, available at http://www.aoos.org/aoos-data-resources/**.

It is also important to note that omission from the database or the maps does not necessarily indicate that an area is considered unimportant or is not used. Additional field data collection from the area or other research could reveal ecological patterns or human uses (e.g. subsistence) that were not available to us.

We strived to make our work objective and transparent. The methods, sources, and attributes for each data layer are tracked in our extensive geodatabase. In the attribute tables, we documented the method we used to acquire each data layer. Those methods include:

- Direct from source (no modifications)
- Direct, with modifications (some modifications from the original source data, e.g. to improve the display of the data)
- Analyzed from raw data (new information based on repeatable spatial analysis)
- Analyzed from intermediate data (new information derived from an existing data product, e.g. isopleths from existing kernel density layers)
- Interpreted from spatial data (new information based on spatial interpretation of other data layers)
- Interpreted from text description (spatial boundaries drawn by interpreting the intent of a textual reference)
- Outside expert (expert opinion from outside our organizations)
- Best professional judgment (expert opinion from within our organizations).

The synthesis database structure includes the above and other standard attributes in the schema to describe the intensity of use, type of use, age and gender of individuals present, applicable seasons, original data source, original study description, and data processing steps.

USE OF TRADITIONAL KNOWLEDGE AND SUBSISTENCE DATASETS

Our maps are based primarily on Western science but also include databases generated from TK. It is important to recognize the contribution that TK has provided to our collective overall understanding of the ecological functioning of the Bering, Chukchi, and Beaufort Seas. Audubon Alaska believes TK has high value and, with respect to Western science, should be incorporated to bring a greater understanding of the natural environment. As such, in the development of this Ecological Atlas, we have attempted to gather and represent TK as expressed in subsistence use-areas and species use patterns to highlight knowledge

Kawerak Social Science

Audubon Alaska staff, along with experts from Diomede, Elim, King Island, Koyuk, Nome, Saint Michael, Savoonga, Shaktoolik, and Stebbins, as well as representatives from the Ice Seal Committee, Eskimo Walrus Commission, and Kawerak reviewed maps during the Traditional Knowledge-Holder Map Review Workshop, February 21st and 22nd, 2017 in Nome, AK.

1.2

KAWERAK'S CONTRIBUTION OF TRADITIONAL KNOWLEDGE

A Closer Look: Kawerak's Contribution of Traditional Knowledge

Kawerak, Inc.

This Atlas contains spatial information derived from Kawerak's Ice Seal and Walrus Project (ISWP). The ISWP was a large, multi-year mapping and traditional knowledge (TK) documentation project carried out by Kawerak in collaboration with nine tribes in the Bering Strait region. The project resulted in a number of publications and products that have been widely used within our region and beyond (e.g. Gadamus 2013; Kawerak 2013a, b, c, d; Oceana and Kawerak 2014; Gadamus and Raymond-Yakoubian 2015a, b; Gadamus et al. 2015; Raymond-Yakoubian 2016).

One of the results of the ISWP was a collaboration with Oceana which resulted in a data synthesis document, based on a workshop and review by the ISWP tribes and TK experts (Oceana and Kawerak 2014). With permission from Kawerak and Oceana, Audubon used the ISWP and Oceana/Kawerak spatial information as a starting point for many of the marine mammal and subsistence maps in this Atlas in conjunction with data from multiple other sources. ISWP and other Bering Strait TK experts reviewed these draft maps during a 2017 map review workshop. See Audubon's section on the Use of Traditional Knowledge and Subsistence Datasets for more information, including a summary of the TK map review workshop.

Some of the original spatial data collected during the ISWP and data from the Oceana/Kawerak collaboration was updated at that time. As one 2017 workshop participant noted, "Our world is changing." The original ISWP data and the Synthesis data were not incorrect; however, they have changed in the intervening period leading up to the 2017 workshop. These revisions and updates were necessary because of the dynamic nature of the marine environment, and because of the many and varied changes that Bering Strait region communities are experiencing and which are impacting marine species. Like the environment itself, cultures are not static, and are constantly changing. This dynamism is true for bodies of knowledge, as well.

Kawerak defines TK as:

A living body of knowledge which pertains to explaining and understanding the universe, and living and acting within it. It is acquired and utilized by indigenous communities and individuals in and through long-term sociocultural, spiritual, and environmental engagement. TK is an integral part of the broader knowledge system of indigenous communities, is transmitted intergenerationally, is practically and widely applicable, and integrates personal experience with oral traditions. It provides perspectives applicable to an array of human and non-human phenomena. It is deeply rooted in history, time, and place, while also being rich, adaptable, and dynamic, all of which keep it relevant and useful in contemporary life. This knowledge is part of, and used in, everyday life, and is inextricably intertwined with peoples' identity, cosmology, values, and way of life. Tradition—and TK—does not preclude change, nor does it equal only 'the past'; in fact, it inherently entails change (Raymond-Yakoubian et al. 2017).

The TK that our communities have is ever-changing in order to incorporate new knowledge and remain relevant in contemporary life. Kawerak and our tribes believe that TK is equal to scientific knowledge, and should be respected, sought out, and utilized extensively. While TK can be used to validate and support scientific information—and vice versa—that should not be the only purpose behind its use by others. TK, and the individuals and communities that care-take it, have valuable and extensive contributions to make to our understanding of the world.

Maps in this Ecological Atlas which have a Kawerak logo include spatial TK from many of our communities. In order for readers to get the most out of this Atlas, there are several points that Kawerak suggests readers to keep in mind. It is important to keep in mind when viewing maps with Kawerak-derived TK spatial data that representation of particular areas (e.g. as species abundance, or harvest areas) should not be taken to be equivalent with a holistic representation of "importance". While these depicted areas are indeed important, from the perspective of TK-holders, "Everywhere is important."

Another important caveat for readers to keep in mind is that Audubon's representation of the Kawerak data differs from how they were collected and how they have been represented elsewhere. One key distinction is that Kawerak's data regarding the natural history maps (displaying species ranges and concentrations) were provided by TK experts, collected, and organized largely by season, whereas Audubon grouped seasons together in their representation of this and other data. It is important to keep in mind, therefore, that the way these data are visually depicted in this Atlas may entail a compilation of differently organized underlying data. For example, winter/spring shapes may involve data TK experts identified as being true only for winter, or year-round shapes may either hold true for the entire year or alternately for two or three seasons which cross seasonal groupings. Additionally, the data as depicted in this Atlas often differs from how TK-holders perceive this information in the real world.

Maps are valuable tools for communicating complex information and for contributing to natural resource policy and management actions. We hope the maps in this Ecological Atlas are of use to a wide variety of individuals, agencies, and bodies in understanding our region and the other regions included in the document. Kawerak and our tribes strongly believe that maps are not a substitute for consultation. Use of TK, spatial or otherwise, should always be verified, interpreted, and used in collaboration with TK-holders themselves and their communities. We encourage anyone who finds the information in this document useful or interesting to consult Kawerak, Bering Strait tribes, and TK-holders about how to best use it.

Acknowledgments

The tribes that collaborated with Kawerak during the ISWP and contributed spatial data and TK to that project are: King Island Native Community, Native Village of Diomede, Native Village of Elim, Native Village of Koyuk, Native Village of St. Michael, Native Village of Savoonga, Native Village of Shaktoolik, Nome Eskimo Community, and Stebbins Community Association. Kawerak's ISWP would not have been possible without the contributions of time and expertise provided by the TK experts we collaborated with, and we thank them again for their participation. For full acknowledgments, we ask readers to consult the Bering Strait Marine Life and Subsistence Use Data Synthesis (Oceana and Kawerak 2014) and Seal and Walrus Harvest and Habitat Areas for Nine Bering Strait Region Communities (Kawerak 2013b).

Kawerak's Ocean Currents Project worked with the tribes in Diomede, Wales, and Shishmaref, and ocean currents experts from those communities. The project also involved a collaboration with colleagues and communities in Chukotka (through the Chukotka Branch of Pacific Scientific Research Fisheries Center in Anadyr, Chukotka, Russia). The project would not have been possible without the contributions of the TK experts from these communities, and we thank them again for their participation. For more information about this project, please consult Indigenous Knowledge and Use of Bering Strait Region Ocean Currents (Raymond-Yakoubian et al. 2014). Additional information about both projects can be found at www.kawerak.org/socialsci.html.

Kawerak would like to thank the 2017 Audubon map review workshop participants: Orville Ahkinga (Diomede), Austin Ahmasuk (Nome), Roy Ashenfelter (Ice Seal Committee), Allen Atchak (Stebbins), Charles Ellanna (King Island), Rose Fosdick (Kawerak), Merlin Henry (Koyuk), Axel Jackson (Shaktoolik), Kenneth Kingeekuk (Savoonga), Vera Metcalf (Eskimo Walrus Commission), Paul Nagaruk (Elim), and James Niksik Sr. (St. Michael).

We also thank Brenden Raymond-Yakoubian of Sandhill.Culture.Craft for facilitating the workshop and Cindy Wieler and Niviaaluk Brandt for assisting with the workshop. Kawerak also thanks Audubon for their participation in the workshop (Melanie Smith, Max Goldman, and Erika Knight) and for funding the 2017 map review workshop and a portion of Julie Raymond-Yakoubian's time.

1.1 MAP ON PAGES 12–13

and concerns about environmental change and other issues affecting subsistence in the Bering, Chukchi, and Beaufort Seas.

To that end, we worked with Kawerak, Inc.; Sandhill.Culture.Craft; and Stephen R. Braund and Associates. Our maps show the TK data that were made available to us through cooperative agreements for data on the North Slope and with Kawerak in the Bering Strait region. In presenting subsistence use areas, we did not attempt to assign any weight or priority within the harvest areas. **It is important to note that not all tribes in these regions have participated, not all species have been documented, and more research could supplement what is presented. As well, there are additional traditional knowledge and subsistence datasets within the project area that we did not have access to for this project.**

Review by Bering Strait Tribes

Audubon collaborated with the Social Science Program of Kawerak, Inc., the Alaska Native non-profit for the Bering Strait region, to utilize scientifically documented TK for this Ecological Atlas. Audubon utilized spatial data from two of Kawerak's projects, the Ice Seal and Walrus Project (and that data's incorporation into a Synthesis in collaboration with Oceana), and the Ocean Currents project (Kawerak Inc. 2013, Oceana and Kawerak 2014, Raymond-Yakoubian et al. 2014). Kawerak and Kawerak-region tribes strongly feel that TK, especially as it pertains to documentation on maps, requires consultation with the relevant Alaska Native TK-holders prior to their use and interpretation.

As such, Audubon Alaska, and its social science consultant Sandhill.Culture.Craft, partnered with Kawerak to hold a workshop in February 2017 in Nome to review draft maps and associated text with TK-holders from the Bering Strait region. These experts were representatives of the nine tribes who participated in Kawerak's Ice Seal and Walrus Project (Diomede, Elim, King Island, Koyuk, Nome, Saint Michael, Savoonga, Shaktoolik, and Stebbins). Additionally, representatives from the Ice Seal Committee, Eskimo Walrus Commission, and Kawerak were also present, as well as three Audubon Alaska staff leading the creation of this Atlas. Anthropologists from Sandhill.Culture.Craft and Kawerak facilitated the two-day workshop to discuss the accuracy of, and suggest revisions to, Audubon's draft maps related to walrus, bearded seal, spotted seal, ringed seal, marine subsistence harvests, sea ice, and to a lesser extent, ribbon seal, beluga whale, bowhead whale, and humpback whale. Additionally, Audubon consulted with Kawerak regarding the utilization of spatial data from Kawerak's project on knowledge of Bering Strait ocean currents (Raymond-Yakoubian et al. 2014).

Kawerak Social Science

Participants in the Traditional Knowledge-Holder Map Review Workshop, Nome, AK, February 21st and 22nd, 2017.

This highly productive workshop resulted in revisions in Audubon's draft maps to most accurately represent the state of current TK about these species and topics. TK experts utilized the definitions of concentration levels used in the 2014 Oceana and Kawerak Synthesis, while also adding additional layers of information about the range and regular occurrence of species (as well as other topics, such as the best way to visually represent the data). This information was documented by Sandhill.Culture.Craft and Kawerak's anthropologist (as well as Audubon staff), analyzed by these anthropologists, and resulted in changes to the maps to address the experts' feedback. Revised maps were later distributed to workshop participants for their final review before incorporating them into the final Atlas. This workshop is cited as: Audubon Alaska, Kawerak, and Sandhill.Culture.Craft. 2017. Traditional Knowledge-Holder Map Review Workshop. February 21–22, 2017. Nome, AK.

Audubon thanks the participants in the workshop for their time, knowledge, and willingness to share this valuable information in order to improve the maps for this Ecological Atlas. The workshop participants were as follows:

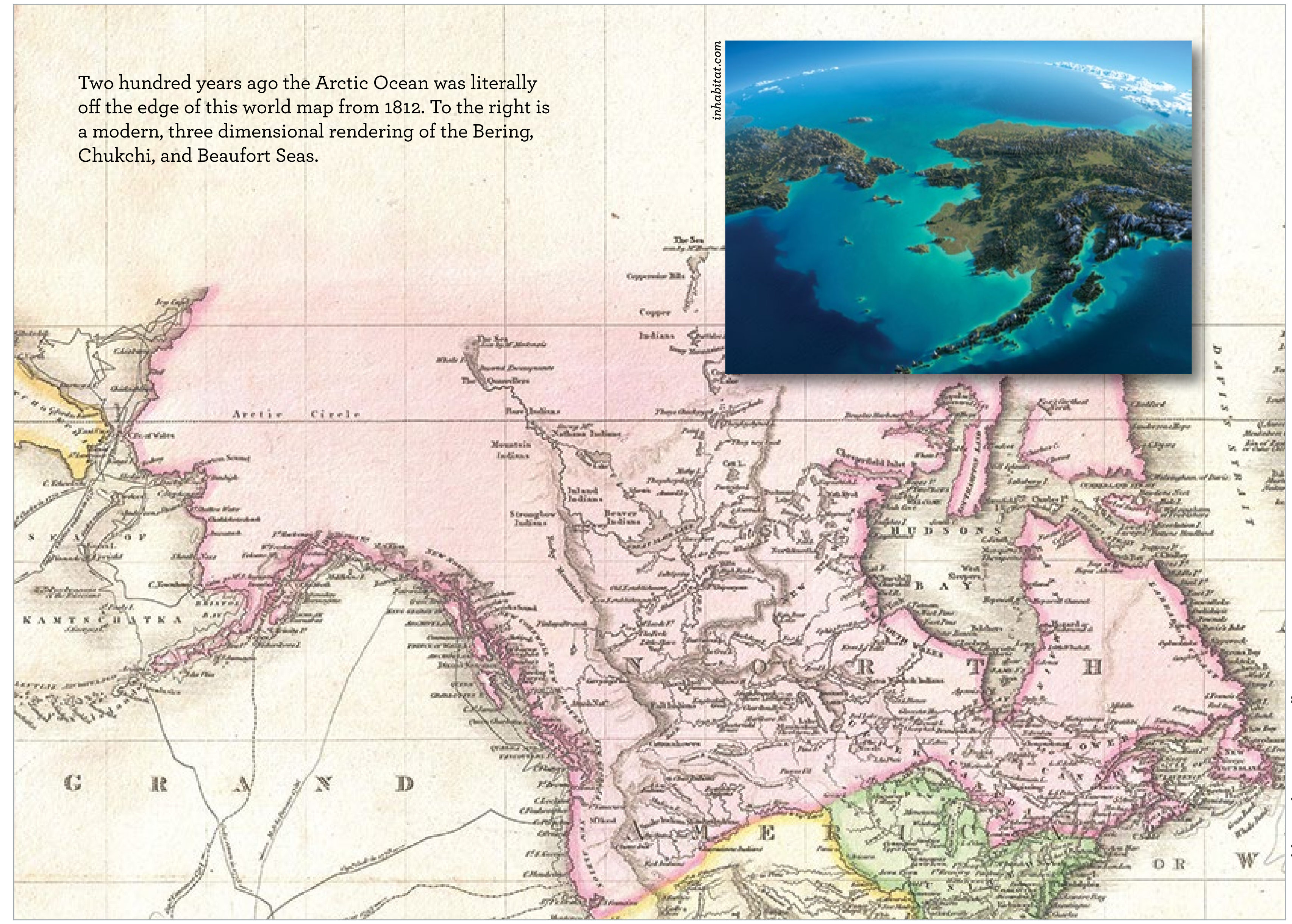
- Orville Ahkinga (Diomede)
- Austin Ahmasuk (Nome)
- Roy Ashenfelter (Ice Seal Committee)
- Allen Atchak, Sr. (Stebbins)
- Niviaaluk Brandt (Kawerak Social Science Program)
- Charles Ellanna (King Island)
- Rose Fosdick (Kawerak Natural Resources Division)
- Max Goldman (Audubon Alaska)
- Merlin Henry (Koyuk)
- Axel Jackson (Shaktoolik)
- Kenneth Kingeekuk (Savoonga)
- Erika Knight (Audubon Alaska)
- Vera Metcalf (Eskimo Walrus Commission)
- Paul Nagaruk (Elim)
- James Niksik, Sr. (St. Michael)
- Brenden Raymond-Yakoubian (Sandhill.Culture.Craft)
- Julie Raymond-Yakoubian (Kawerak Social Science Program)
- Melanie Smith (Audubon Alaska)
- Cindy Wieler (Kawerak Social Science Program)

DATA QUALITY

Recently, scientists and managers have synthesized physical and biological data across disciplines to better understand the relationships among species and trophic levels, and the mechanistic functioning of the Arctic marine ecosystem. Such efforts include the Synthesis of Arctic Research (SOAR) funded by BOEM (Moore and Stabeno 2015); the Pacific Marine Arctic Regional Synthesis (PacMARS) funded by Shell and ConocoPhillips and managed by the North Pacific Research Board (NPRB) (Grebmeier et al. 2015); and the Bering Sea Integrated Ecosystem Research Program (BSIERP) managed and funded by NPRB. These types of broad, integrative efforts are the right track for managing the Arctic. This *Ecological Atlas of the Bering, Chukchi, and Beaufort Seas* is our own effort to contribute broad, integrative synthesis of the available spatial information for this region.

Although a wide range of scientific research has been conducted in US, Canadian, and Russian Arctic waters, many fundamental knowledge gaps remain that limit our understanding of Arctic marine ecosystems. Often, information is not readily presented at a sufficient resolution for development planning or for the detection and/or measurement of direct, indirect, and cumulative impacts. Although millions of dollars have been spent on Arctic marine research, this does not necessarily constitute a complete scientific program of study. Data gaps of several types still warrant greater attention by the scientific community and managers of ocean resources. An overarching and coordinated plan across agencies and jurisdictions is warranted, to guide the research needed for responsible planning, decision-making, and ecosystem sustainability.

1.1 MAP ON PAGES 12–13



Two hundred years ago the Arctic Ocean was literally off the edge of this world map from 1812. To the right is a modern, three dimensional rendering of the Bering, Chukchi, and Beaufort Seas.

inhabitat.com

Courtesy of the David Rumsey Map Collection.

All of the maps in this atlas are subject to issues with data quality and gaps. Data quality usually refers to the robustness or certainty of existing information, while the term data gap refers to one or more types of information that are lacking. For each map in the atlas, we discuss known issues with data quality and gaps. When assessing gaps in knowledge, it is important to consider the various types of data gaps that exist. Marine data are available in a variety of forms such as hard copy maps, peer-reviewed white papers, agency reports, spreadsheets, spatial databases, and TK. Collectively, these data sources can be used to map the marine system, but often with essential information missing. Several distinct knowledge gap types are identified here.

- In the Arctic Ocean, some subjects are better understood than others. Little-studied species or ecosystem features make up a kind of information deficiency called a Subject Data Gap because we simply do not know much about the subject.

- When dealing with spatial data layers, multiple survey efforts from different locations can be pieced together to represent the

TABLE 1.1-1. Types of data gaps in current knowledge of the Pacific Arctic marine ecosystem.

Type of Gap	Explanation
Subject Data Gap	Within the project area, some resources have not been studied, or species have little basic life history information.
Spatial Coverage Data Gap	Many resources studied in depth still lack complete coverage across the region.
Seasonal Data Gap	Most surveys occur June through October when weather, sea ice, and snow conditions are optimal; direct observation is difficult at other times of the year. Most species lack adequate seasonal distribution data.
Temporal Data Gap	Except for remotely sensed satellite information (ice, temperature, chlorophyll-a, etc.), few resources in the Pacific Arctic have adequate data to detect change over annual or decadal time periods.
Population Abundance Data Gap	For most species or species groups, little information is available on population size, relative abundance, and/or distribution, and trends are not detectable.
Data Congruency Gap	Some studies have collected data on the same subjects using different methods which render data incomparable; standardization is needed to address this problem.
Planning Scale Data Gap	Planning efforts require data collected at a scale consistent with the proposed action. Oftentimes, broad-scale information cannot be adequately paired with detailed environmental analyses, while fine-scale data collected for a small area are usually inadequate for larger environmental studies.

1.1
MAP ON PAGES 12–13

distribution and concentration of a species across the area of interest. When looking broadly at the Arctic marine environment, distribution information is usually incomplete. Remotely sensed satellite data, which generally have reliable and regularly repeated worldwide coverage have very good spatial coverage while virtually all other layers of biological information are subject to a Spatial Coverage Data Gap.

- For those subjects that have reliable data, most information is viewed through a seasonal lens, being collected during summer and fall, most often June through October. Direct observation of Arctic environments during winter, early spring, and late fall is often lacking, creating a Seasonal Data Gap.

- Many data collection efforts have not been repeated with regularity. This unrepeated coverage makes the data difficult to use for trend analysis. Many Arctic marine data are not in a condition to assess temporal change, constituting a Temporal Data Gap.

- For many species, for which we may have a decent understanding of seasonal habitat usage patterns and concentration areas, we may still have a rudimentary understanding of the abundance of the species. The Population Abundance Data Gap makes population trends and cumulative effects difficult or impossible to assess.

- A Data Congruency Gap exists when repeated measurements are collected using incongruent methods, making reconciliation of multiple studies either not possible or very challenging. An example is using various sizes of mesh nets to collect zooplankton, reducing data compatibility to the least common denominator of the largest mesh size.

- A Planning Scale Data Gap occurs when available data are not consistent with the geographic scope or scale of the proposed action. Data collected on a broad scale may be unfit for detailed effects analysis. Similarly, fine-scale survey data collected in disaggregated project areas locations can be too narrowly focused for large-scale planning. Mid-scale data with full spatial coverage often are needed to make management decisions. A good example of this was the Outer Continental Shelf Environmental Assessment Program (OCSEAP) of the 1970s to 1980s.

Many, if not most, of the maps and written summaries in this atlas are subject to these various types of data gaps. Overall data quality varies by topic or species and should be carefully considered when interpreting the data presented. More information is available in the Mapping Methods section of each summary, in the sources cited, and in the associated spatial database. However, to truly understand those issues, one should refer back to the original datasets and publications that each map is based upon. **It is incumbent upon the user of this publication to take proper consideration of the limitations of these data when interpreting them or utilizing them for other purposes.**

CONCLUSION

Like Audubon Alaska itself, the Ecological Atlas is rooted in science and communicated through maps and writing. Blended in are bits of natural and human history, and perspectives on conservation issues to consider as we learn from the past and look to the future.

The Arctic marine environment is home to many people, and inspires awe in many more around the world. The Arctic, especially the ocean, is a frontier in many ways, including scientific knowledge and various types of economic development. We encourage use of this Ecological Atlas as a resource to better understand the biological functions and ecological patterns of the Bering, Chukchi, and Beaufort Seas; to inform management decisions at a variety of scales from local to international; and to promote sustainable use and conservation.

REFERENCES

Audubon Alaska, Kawerak, and Sandhill.Culture.Craft. 2017. Traditional Knowledge-Holder Map Review Workshop. February 21-22, 2017. Nome, AK.

Drew, G. F. and J. Piatt. 2013. North Pacific Pelagic Seabird Database (NPPSD) v2. US Geological Survey Alaska Science Center and US Fish and Wildlife Service, Anchorage, AK.

Gadamus, L. 2013. Linkages between human health and ocean health: A participatory climate change vulnerability assessment for marine mammal harvesters. *International Journal of Circumpolar Health* 72:20715.

Gadamus, L. and J. Raymond-Yakoubian. 2015a. A Bering Strait indigenous framework for resource management: Respectful seal and walrus hunting. *Arctic Anthropology* 52:87-101.

Gadamus, L. and J. Raymond-Yakoubian. 2015b. Qualitative participatory mapping of seal and walrus harvest and habitat areas: Documenting indigenous knowledge, preserving local values, and discouraging map misuse. *International Journal of Applied Geospatial Research* 6:76-93.

Gadamus, L., J. Raymond-Yakoubian, R. Ashenfelter, A. Ahmasuk, V. Metcalf, and G. Noongwook. 2015. Building an indigenous evidence-base for tribally-led habitat conservation policies. *Marine Policy* 62:116-124.

Grebmeier, J. M., L. W. Cooper, C. A. Ashjian, B. A. Bluhm, R. B. Campbell, K. E. Dunton, J. Moore, S. Okkonen, G. Sheffield, J. Trefry, and S. Y. Pasternak. 2015. Pacific Marine Arctic Regional Synthesis (PacMARS) Final Report. North Pacific Research Board, Anchorage, AK.

Hartsig, A. 2016. The Arctic Ahead: Conservation and Management in Arctic Alaska. Ocean Conservancy, Washington, DC.

Hillmer-Pegram, K. 2014. A Synthesis of Existing, Planned, and Proposed Infrastructure and Operations Supporting Oil and Gas Activities and Commercial Transportation in Arctic Alaska. University of Alaska Fairbanks, Fairbanks, AK.

Kawerak. 2013a. Policy-based Recommendations from Kawerak's Ice Seal and Walrus Project. Kawerak Social Science Program, Nome, AK.

______. 2013b. Seal and Walrus Harvest and Habitat Area for Nine Bering Strait Region Communities. Kawerak Social Science Program, Nome, AK.

______. 2013c. Seal and Walrus Hunting Safety: Traditional Knowledge from Kawerak's Ice Seal and Walrus Project. Kawerak Social Science Program, Nome, AK.

______. 2013d. Traditions of Respect: Traditional Knowledge from Kawerak's Ice Seal and Walrus Project. Kawerak Social Science Program, Nome, AK.

Krenz, C., M. Smith, N. Walker, K. Livingston, R. Daniel, and B. Robson. 2015. Identifying marine mammal fall migration core areas in the US Beaufort Sea, *Alaska Marine Science Symposium*. Anchorage, AK.

Moore, S. E. and P. J. Stabeno. 2015. Synthesis of Arctic Research (SOAR) in marine ecosystems of the Pacific Arctic. *Progress in Oceanography* 136:1-11.

National Oceanic and Atmospheric Administration. 1988. Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones: Strategic Assessment Data Atlas. National Oceanic and Atmospheric Administration, Rockville, MD.

______. 2015. Aerial Survey of Arctic Marine Mammals, 1979-2014 (ASAMM; including the Historical BWASP and COMIDA Databases). NOAA Fisheries, Alaska Fisheries Science Center, National Marine Mammal Labratory, Anchorage, AK. Accessed online December 2015 at http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php.

Oceana and Kawerak. 2014. Bering Strait Marine Life and Subsistence Use Data Synthesis. Oceana and Kawerak, Juneau, AK.

Raymond-Yakoubian, J. 2016. Conceptual and institutional frameworks for protected areas, and the status of indigenous involvement: Considerations for the Bering Strait region of Alaska, *In Indigenous Peoples' Governance of Land and Protected Territories in the Arctic*. T. Hermann and T. Martin eds., pp. 83-103. Springer, Switzerland.

Raymond-Yakoubian, J., Y. Khokhlov, and A. Yarzutkina. 2014. Indigenous Knowledge and Use of Bering Strait Region Ocean Currents. Kawerak, Inc., Nome, AK.

Raymond-Yakoubian, J., B. Raymond-Yakoubian, and C. Moncrieff. 2017. The incorporation of traditional knowledge into Alaska federal fisheries management. *Marine Policy* 78:132-142.

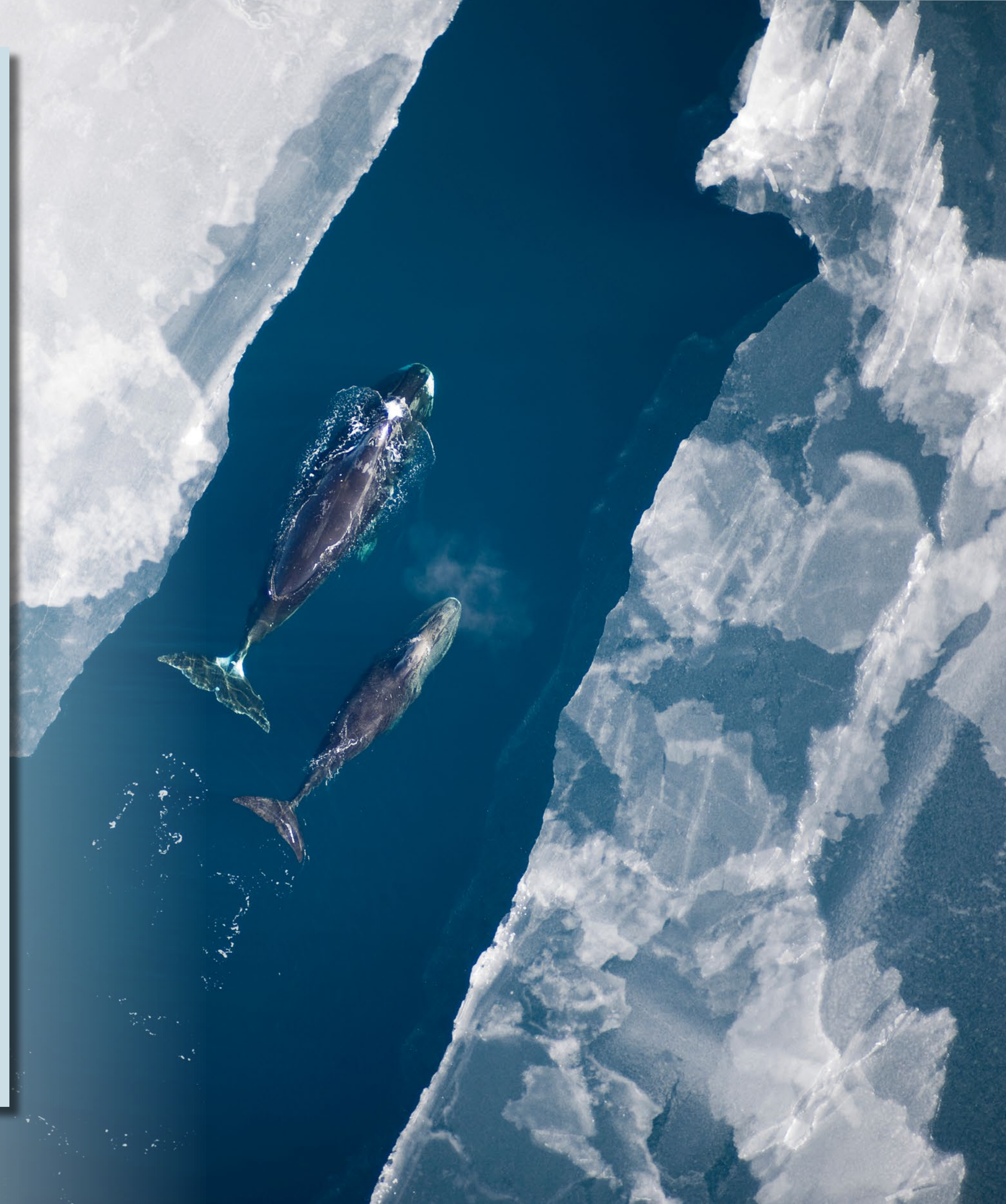
Seabird Information Network. 2011. North Pacific Seabird Data Portal. Accessed online at http://axiom.seabirds.net/maps/north-pacific-seabirds/.

Smith, M., N. J. Walker, I. J. Stenhouse, C. M. Free, M. Kirchhoff, O. Romanenko, S. Senner, N. Warnock, and V. Mendenhall. 2014a. A new map of Important Bird Areas in Alaska, *In 16th Alaska Bird Conference*. Juneau, AK.

Smith, M. A., N. J. Walker, C. M. Free, M. J. Kirchhoff, G. S. Drew, N. Warnock, and I. J. Stenhouse. 2014b. Identifying marine Important Bird Areas using at-sea survey data. *Biological Conservation* 172:180-189.

Sullender, B. and M. Smith. 2016. Ecological Atlas of Alaska's Western Arctic. Audubon Alaska, Anchorage, AK.

Walker, N. J. and M. A. Smith. 2014. Alaska Waterbird Database v1. Audubon Alaska, Anchorage, AK.



Amelia Brower / NOAA

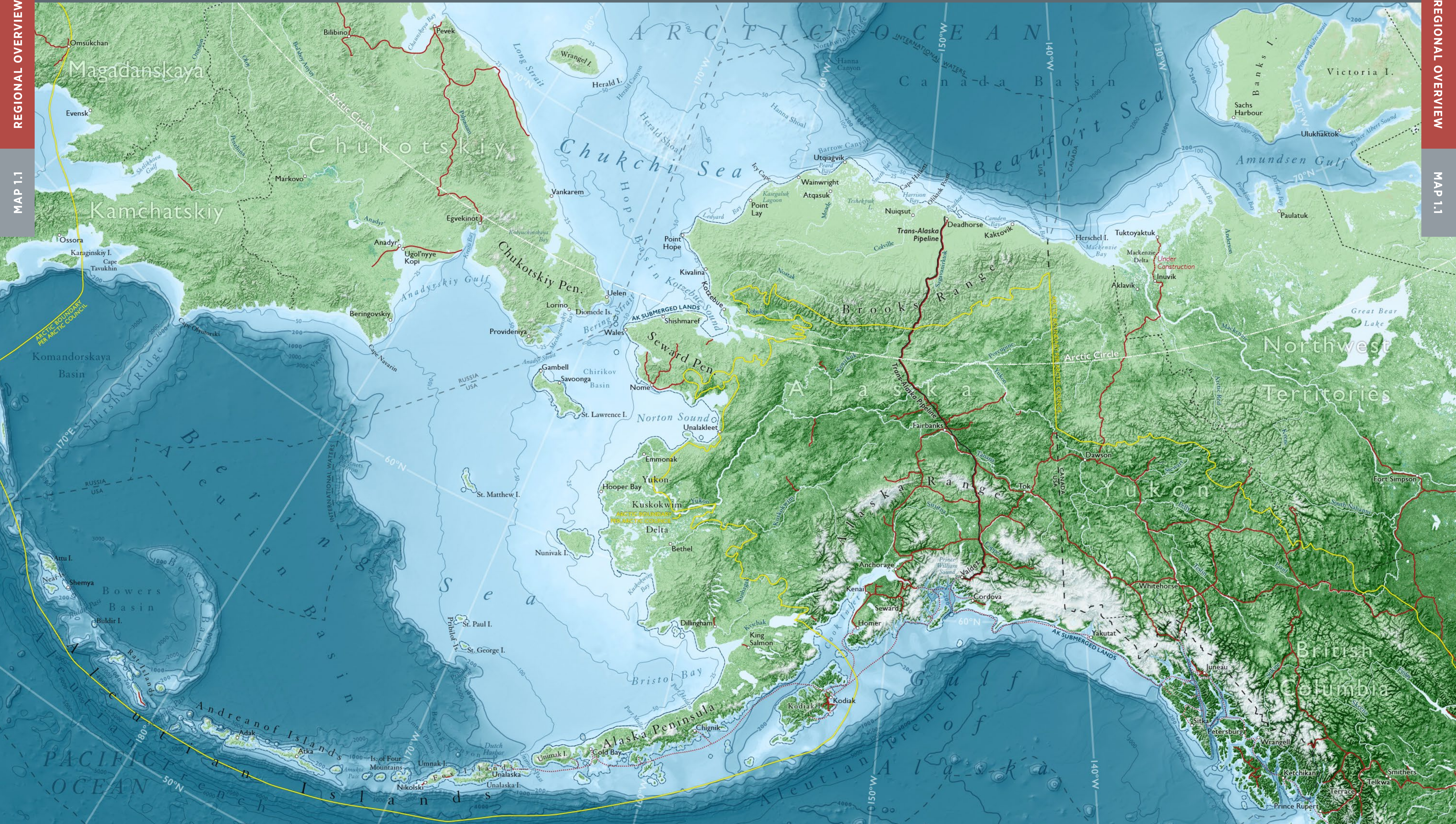
1.1
MAP ON PAGES 12–13

Regional Overview

Map Authors: Daniel P. Huffman, Melanie Smith, and Erika Knight
Cartographer: Daniel P. Huffman

0 100 200 mi
0 100 200 km

Audubon ALASKA



Click a chapter heading to take a shortcut.

PHYSICAL SETTING

John Schoen

PHYSICAL SETTING MAP INDEX

Ocean Currents

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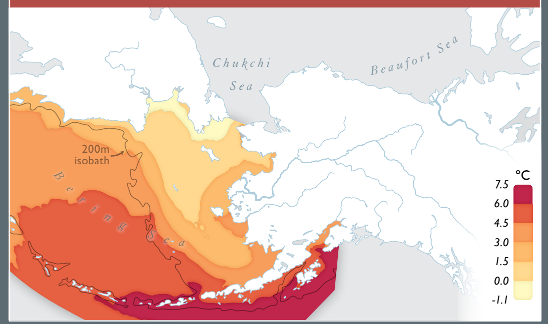
Sea Ice

MAPS 2.2a–b / PAGES 26–29

Sea Water Temperature



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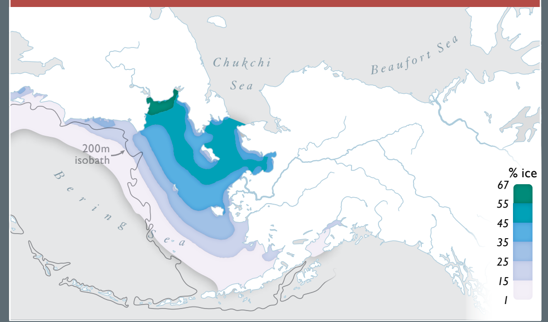
Sea Ice Concentration



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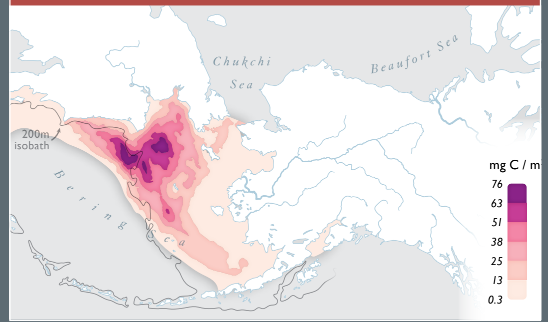
Ice Phytoplankton Concentration



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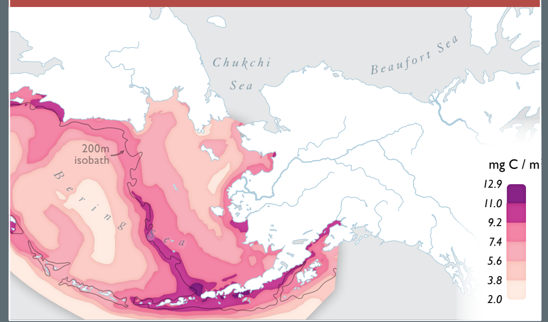
Microzooplankton Concentration



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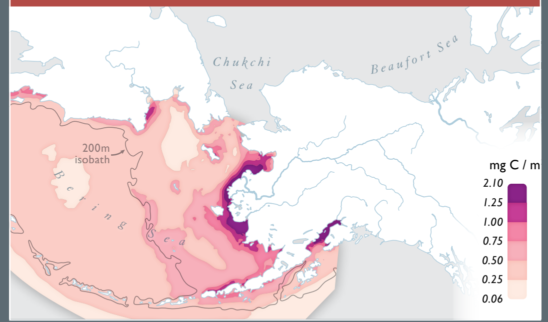
Large Neritic Copepod Concentration



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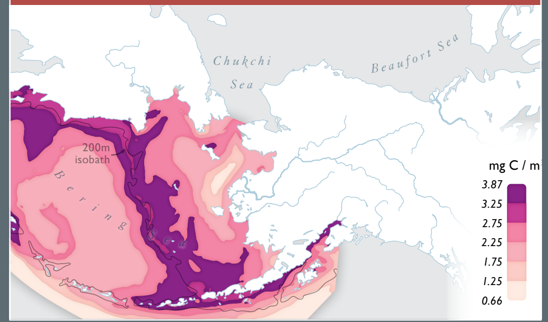
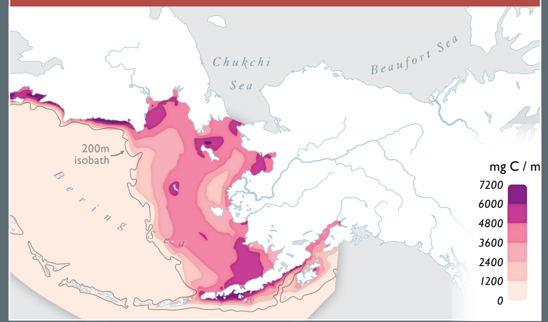
Euphausiid Concentration



MAPS 2.3m–n / PAGE 37

Benthic Infaunal Biomass Concentration



MAPS 2.3o–p / PAGE 37

2.1 OCEAN CURRENTS MAP ON PAGES 20–21

Ocean Currents

Erika Knight and Skye Cooley

Ocean currents are continuous, directed movements of ocean water masses that flow at local or global scales at the ocean surface or at depth (National Oceanic and Atmospheric Administration 2017). Current movement is driven by a variety of factors, such as wind forcing, water density, tidal influence, and the Coriolis Effect—an inertial force generated by the Earth's rotation that deflects ocean currents (and weather) to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere. Currents can also be driven by sea-level differences. For example, northward transport of Pacific Ocean water through the Bering Strait is driven by a sea-level difference of approximately 1.3 feet (0.4 m) between the Bering Sea and Arctic Ocean (Stabeno et al. 1999).

Each ocean current has similar properties—temperature, salinity, carbon, nutrients, and bioproductivity of organisms—that impart a distinct signature to the water mass (Weingartner et al. 2012). Taken together, this group of properties influences how water masses interact with each other. Water density is dependent upon temperature and salinity; therefore the freshwater content of ocean current flow through the Bering Strait influences where this water is transported as it enters the Arctic Ocean (Weingartner 2008). Due in part to the many major rivers that drain the fresh waters of central Alaska westward into the Bering Sea, flow from the Bering Strait into the Arctic Ocean "provides nearly 50% of the total freshwater input to the Arctic Ocean," making it the largest source of fresh water for the Arctic Ocean (Weingartner 2008).

Due to the distinct properties of each water mass, the vertical lifting of bottom water to the surface, known as upwelling, is an important phenomenon associated with high bioproductivity. Upwelled water is often characterized by its relatively low temperature, high salinity, and high nutrient content. When this water is brought to the ocean surface, often via the movement of ocean currents onto a continental shelf, or by winds pushing surface water away so deeper waters rise to replace the surface-water void, it fuels productivity, which forms the energy base for higher trophic-level consumers (National Oceanic and Atmospheric Administration 2017).

Ocean currents can have a profound effect on sea ice. Likewise, sea ice also affects ocean currents. Pacific Ocean waters transport heat into upper levels of the Arctic Ocean, providing up to 20% of the oceanic heat flux (Weingartner 2008). This transported, warmer water likely plays an important role in the recent retreat of Arctic sea ice, both as a trigger for seasonal sea-ice melt and as a year-round warming agent that may thin the Arctic ice pack in winter (Weingartner 2008, Woodgate et al. 2010). In turn, the formation of sea ice can drive flow. When seawater freezes into ice, the salt remains in the surrounding water through a process called brine rejection, causing the water to become saltier and denser and sink toward the ocean bottom (National Oceanic and Atmospheric Administration 2017). Surface water flows in to replace the sinking water before it, too, becomes colder and salty enough to sink in a process referred to as thermohaline circulation (National Oceanic and Atmospheric Administration 2017). These ocean current / sea ice interactions, combined with seasonal weather patterns, contribute to a dynamic and seasonally variable circulation pattern in the Bering, Chukchi, and Beaufort Seas.

SETTING

Water flows into the Bering Sea from the Pacific Ocean primarily through Near Strait, at the western end of the Aleutian Islands. Farther west, deep water from the Pacific enters the Bering Sea at depths greater than 6,500 feet (2,000 m) through the Kamchatka Strait, the only underwater pass into the Bering Sea deep enough to permit this deep Pacific water to enter (Stabeno et al. 1999). More water from the Pacific enters the Bering Sea through other passes in the Aleutian Islands.

Within the Bering Sea, water circulates in a counter-clockwise pattern, referred to as the Bering Gyre, with some water exiting the Bering Sea via the shallower (less than 4,900 feet [1,500 m]) portion of Kamchatka Strait, and some leaving the Bering Gyre to flow northward toward the Bering Strait. Local transport volume of the gyre varies widely—up to approximately 50%—with variations associated with the inflow of the Alaskan Stream current and with changes in wind-driven transport through the Bering Strait (Stabeno et al. 1999).

Flow through the Bering Strait is largely driven by an approximate mean sea-level difference of 1.3 feet (0.4 m) between the Bering Sea and Arctic Ocean (Stabeno et al. 1999). The volume and properties of water flowing through the Bering Strait influences physical and biogeochemical properties throughout much of the northern Bering shelf; the high productivity of the southern Chukchi Sea is sustained by the low salinity, nutrient-rich waters flowing into the Chukchi Sea from the Bering Strait (Weingartner 2008).

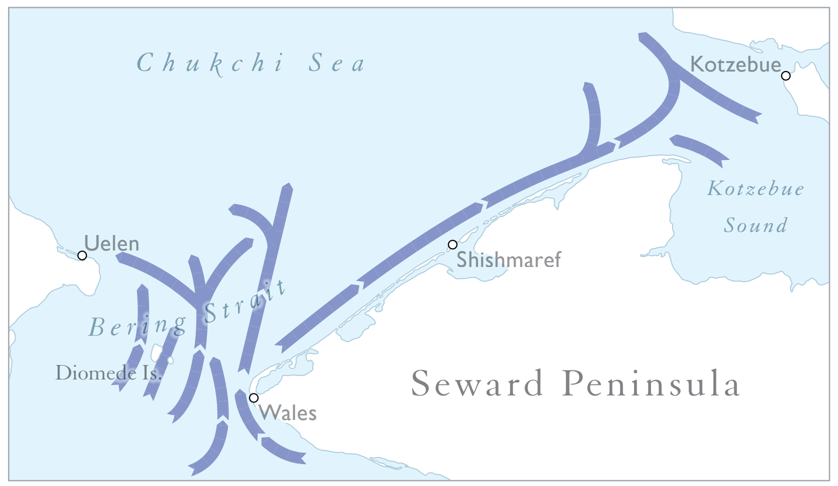


FIGURE 2.1-1. Ocean currents in the Bering Strait region, generalized from traditional knowledge of Bering Strait ocean currents documented by Kawerak, Inc. in Raymond-Yakoubian et al. (2014).

North of the Bering Strait, water flows in three main branches (see Map 2.1). A western, cold, salty, nutrient-rich branch, largely the continuation of the Anadyr Current, exits the Chukchi Shelf through Herald Canyon. An eastern, relatively lower-nutrient and lower-salinity branch, a continuation of the Alaska Coastal Current, continues northeastward along the Alaska coastline toward Barrow Canyon. The third branch of Bering shelf water flows northward through the Central Channel between the other two branches before splitting, with some water exiting the shelf into the Canada Basin, and some water flowing eastward to join the Alaska Coastal Current in Barrow Canyon (Weingartner 2008, Weingartner et al. 2013). In the western portion of the Chukchi Sea, along the northern coast of Chukotka, the Siberian Coastal Current flows onto the Chukchi shelf from the East Siberian Sea. North of the Bering Strait, this water mixes with waters flowing northward through the Strait from the Bering Sea (Weingartner 2008, Weingartner et al. 2013). Variability in flow across the Chukchi shelf is principally caused by wind forcing, which is especially influential in fall and winter. During these seasons, winds can redistribute flow from one branch to another or reverse the flow entirely (Weingartner 2008).

Pacific Ocean waters, modified by traveling across the Bering and Chukchi shelves, split after exiting the Chukchi shelf via Barrow Canyon. Some water travels west, perhaps carried by the newly discovered Chukchi Slope Current (Pickart and Corlett 2016). Some water is caught in eddies that spin into the Arctic Basin, and some continues eastward from the Canyon along the Beaufort shelf break (Weingartner 2008, Nikolopoulos et al. 2009). Eastward flow along the Beaufort shelf (often referred to as the Shelfbreak Jet or Beaufort Undercurrent) is

2.1 OCEAN CURRENTS MAP ON PAGES 20–21

NASA

This view of the Bering Strait region was captured on August 18, 2000. The Anadyr, Bering Shelf, and Alaska Coastal Currents are visible as they converge and carry productivity north through the Bering Strait.

subject to frequent, wind-driven upwelling due to prevailing winds from the northeast and is highly variable, with numerous eddies and changes in flow due to pack ice and landfast ice conditions and inflow from the Mackenzie River. Water properties vary seasonally, controlled in part by freshwater inflows from smaller Arctic rivers along the Beaufort coast, which tend to have high discharge in the spring thaw, but no measurable winter discharge (Weingartner 2008).

ECOLOGICAL ROLE

Alaska Coastal Current
The Alaska Coastal Current, a year-round, wind- and buoyancy-driven jet, flows northward along the inner shelf passages of Southeast Alaska before turning west along the south coast of mainland Alaska and eastern Aleutian Islands (Weingartner et al. 2005b). The Alaska Coastal Current enters the Bering Sea through Unimak Pass (Stabeno et al. 1999), delivering Pacific-origin zooplankton seasonally to the Bering Sea (Weingartner et al. 2005b). Upon entering the southern Bering Sea, a portion of the current turns to the northwest and moves across the Bering shelf (Stabeno et al. 1999). The main current swings abruptly east and north (Grebmeier et al. 2015). As it flows north along the coast of Alaska, the Alaska Coastal Current collects fresh, buoyant, low-nutrient water discharged from large rivers—including the Nushagak, Kvichak, Kuskokwim, Yukon, Kobuk, and Noatak—that drain central Alaska (Arctic Monitoring and Assessment Programme 1998). The Alaska Coastal Current delivers its water to the Chukchi Sea via the Bering Strait and eventually exits the Chukchi Sea via Barrow Canyon (Weingartner et al. 2013).

Alaskan Stream
The Alaskan Stream is the name given to a westward-flowing current that provides the majority of water entering the Bering Sea from the Pacific Ocean. The current begins in the Gulf of Alaska and flows westward along the Aleutian Arc, where it enters the Bering Sea through several passages in the island chain, including Unimak Pass, Amutka Pass, Amchitka Pass, and Near Strait (Reed and Stabeno 1997, Stabeno et al. 1999, Grebmeier et al. 2015). It forms the northern boundary of the counterclockwise North Pacific Gyre. While it is depicted as both independent of and contiguous with the Alaska Coastal Current along the Alaska Peninsula, the Alaskan Stream is distinctly separate from the Alaska Coastal Current west of Amutka Pass. It is a narrow, fast current that generally maintains its position year-round (Reed and Stabeno 1997, Stabeno et al. 1999).

Aleutian North Slope Current
This current, some 12 miles (20 km) wide with a total transport of 3 x 10^6 m^3/s to 5.5 x 10^6 m^3/s, flows on an eastward course along the northern side of the Aleutian Islands. The current originates from water flowing into the Bering Sea through Amchitka and Amukta Passes and feeds the Bering Slope Current (Stabeno et al. 1999).

Anadyr Current
The Anadyr Current begins along the Siberian coast at the northern end of the Bering shelf break. This surface current brings warm, salty, nutrient-rich water from the central Bering shelf eastward through the Gulf of Anadyr, then northward through Bering Strait and into the Chukchi Sea (Nihoul et al. 1993, Stabeno et al. 1999). Water generally exits to the Arctic Basin via Herald Canyon, although some may spread across the Chukchi shelf (Weingartner 2008). The nutrient-rich waters of this current drive high primary productivity in the northern Bering and Chukchi Seas (Nihoul et al. 1993, Weingartner et al. 2013). Flow is generally stable and is greatest in summer. Winter variations are not well understood.

Arctic Circumpolar Boundary Current
Although primarily located outside the map area, the Arctic Circumpolar Boundary Current circulates Atlantic Ocean water through the Arctic Basin into the western Chukchi Sea along the shelf break north of Wrangel Island. The current flows eastward toward the northwest coast of Alaska, where the majority of this Atlantic water continues to flow along the Beaufort slope (Weingartner 2006, Aksenov et al. 2011).

Bering Slope Current
The Bering Slope Current (3 x 10^6 m^3/s to 6 x 10^6 m^3/s) forms the eastern boundary of the Bering Gyre, carrying water from the Aleutian North Slope Current and Alaska Coastal Current northwest across the Bering Sea along the Bering shelf break (Stabeno et al. 1999). As the Bering Slope Current flows along the shelf break, its flow is disrupted and complicated by several large canyons. The current is broken into large eddies (approximately 60 miles [100 km] in diameter) that carry nutrients across the shelf in both directions, increasing primary productivity in the region (Stabeno et al. 1999). At the northern end of the shelf break near Cape Navarin, the Bering Slope Current divides into the westward-flowing Kamchatka Current and the eastward-flowing Anadyr Current (Stabeno et al. 1999, Grebmeier et al. 2015).

Bering Shelf Water (Central Channel)
North of St. Lawrence Island, the Central Channel flows north across the Chukchi shelf and into the Canada Basin. The current carries productive, shelf-modified (low salinity, nutrient-rich) Pacific water into the Chukchi Sea. Reversals of the northward flow occur during periods of strong southward winds, which occur primarily in fall and winter (Stabeno et al. 1999).

Commander Current
Most of the inflow into the Bering Sea through Near Strait turns eastward, forming the Commander Current, which flows along the north side of the Aleutian Island chain, gathering inflow from other passes. East of Amchitka Pass, this current is referred to as the Aleutian North Slope Current (Arctic Monitoring and Assessment Programme 1998).

Kamchatka Current
The Kamchatka Current (7 x 10^6 m^3/s to 15 x 10^6 m^3/s) begins at Cape Navarin, where the Bering Slope Current terminates. Forming the western boundary current of the Bering Gyre, the current flows southward along the Siberian coast (Stabeno et al. 1999). The Kamchatka Current generally flows across Shirshov Ridge and out of the Bering Sea through Kamchatka Strait, re-entering the North Pacific where it contributes to the southbound Oyashio Current; however, at times, a portion of the Kamchatka Current recirculates in the Bering Sea rather than flowing through Kamchatka Strait. Beneath the Kamchatka Current in Kamchatka Strait, deep Pacific water enters the Bering Sea (Stabeno et al. 1999).

Shelfbreak Jet/Beaufort Undercurrent
The Shelfbreak Jet, or Beaufort Undercurrent (approximately 0.13 x 10^6 m^3/s), flows east in a narrow 6–9 mile (10–15 km) swath along the shallow Beaufort shelf, turning northeast at Mackenzie Delta and moving along the Canadian Arctic islands (Nikolopoulos et al. 2009). The jet carries water from the Alaska Coastal Current, which brings North Pacific water through the Bering Strait and onto the Beaufort shelf. However, studies indicate that less than 20% of water passing through the Bering Strait enters the Shelfbreak Jet, depending on several factors including the season, presence of sea ice, and vertical structure of the water column over the shelf (Nikolopoulos et al. 2009). Near Barrow Canyon, eddies form and spin into the Arctic Basin, a phenomenon that may explain the loss of Chukchi-Bering water from the Beaufort shelf. In summer, terrestrial inputs from the Mackenzie River contribute to large, nutrient-rich surface plumes that move both east and west along the Beaufort shelf. Terrestrial sediment inputs from the many rivers along the Beaufort coast are an important source of carbon to nearshore Beaufort shelf regions (Dunton et al. 2012). In the fall and winter, strong easterly winds can temporarily reverse the flow of the Shelfbreak Jet and mix the water column, causing upwelling (Nikolopoulos et al. 2009, Pickart et al. 2011).

Siberian Coastal Current
The Siberian Coastal Current transports cold, low-salinity, nutrient-poor water that originates on the East Siberian shelf to the southeast along the northern coast of Chukotka. The current stays within approximately 37 miles (60 km) of the shoreline before turning northward at the Bering Strait to mix with Bering Strait waters. In some years, winds along the Chukotkan coast prevent the Siberian Coastal Current from entering the Chukchi Sea (Weingartner 2008).

Image and caption by: NASA Earth Observatory (Jesse Allen and Robert Simmon) using Landsat data provided by USGS.

The Yukon River originates in British Columbia, Canada, and flows through Yukon Territory before entering Alaska. In southwestern Alaska, the Yukon Delta spreads out in a vast tundra plain, where the Yukon and Kuskokwim Rivers meander toward the Bering Sea. This natural-color image of the Yukon Delta on September 22, 2002, looks a little like branching and overlapping blood vessels. The rivers and streams flow through circuitous channels toward the sea, passing and feeding a multitude of coastal ponds and lakes. The Yukon Delta is an important habitat for waterfowl and migratory birds, and most of the protected refuge is less than 100 feet (30 m) above sea level. Over such low-lying, mostly treeless terrain, the rivers can change course frequently and carve new channels to find the fastest route toward the sea. The pale color of the sea water around the delta testifies to the heavy sediment load carried by the rivers. People have lived here for thousands of years, and the Yukon Delta is one of Alaska's most populated rural areas, home to thousands of Yup'ik people.

CONSERVATION ISSUES

Ocean currents are important for both humans and marine life. In addition to influencing sea-ice conditions through the transport of heat to the Arctic Ocean (Woodgate et al. 2010), currents transport nutrients and zooplankton to the region. Along with upwelling, this nutrient transport influences the distribution of marine resources such as fishes, birds, and marine mammals. Seabirds, for example, congregate in Aleutian passes where water masses frequently converge and mix (Ladd et al. 2005). On the Bering shelf, pelagic seabird species tend to treat water masses as separate habitat types (Elphick and Hunt 1993). Areas with frequent upwelling events, such as the eastern Beaufort Sea, near Liverpool Bay and the community of Tuktoyaktuk, are often important feeding areas for bowhead whales and other marine mammals, as well as marine birds (Walkusz et al. 2012).

While ocean currents play a major role in the distribution of marine resources, which is important for human activities such as commercial fishing and subsistence hunting, they also affect navigation, safety, and boat travel at both the regional level (e.g. shipping) and local level (e.g., subsistence hunting) (National Oceanic and Atmospheric Administration 2017). Kawerak, for example, has documented traditional knowledge regarding ocean currents in the Bering Strait region, including information about characteristics and locations of currents, use of currents for travel and hunting, and changes to currents (Raymond-Yakoubian et al. 2014).

As oil-and-gas activity and shipping increase in the Arctic, the likelihood of a spill also increases. Knowledge of ocean currents is an important aspect of predicting where spilled hazardous materials may be transported.

MAPPING METHODS (MAP 2.1)

This map shows a generalized representation of typical surface flow patterns across the project area, with deep circulation noted where known. Terrestrial influence on ocean currents is depicted by indicating inputs of fresh water and terrestrial organic matter.

Ocean current data were compiled from several publications including Aksenov et al. (2011), Arctic Monitoring and Assessment Programme (1998), Brugler et al. (2014), Coachman et al. (1975), Grebmeier et al. (2015), Pickart and Corlett (2016), Pisareva et al. (2015), Spall et al. (2008), Stabeno et al. (1999), Takahashi et al. (2011), University of Alaska Fairbanks Institute of Marine Science (2009), Weingartner (2006), Weingartner et al. (2005a), and Weingartner et al. (2005b), as well as based on personal communication with oceanographers Seth Danielson and Phyllis Stabeno.

Locations where upwelling frequently occurs were compiled from Llinás et al. (2009), Pickart et al. (2009), Pickart et al. (2013), Sapozhnikov et al. (2011), and Walkusz et al. (2012).

Because of the importance of terrestrial inputs of fresh water and dissolved and particulate carbon and nitrogen to ocean ecosystems (e.g. Dunton et al. (2012), McClelland et al. (2016)), we have shown annual average discharge of major rivers. These data are based on US Geological Survey streamflow data from gauging stations as close to river mouths as available (US Geological Survey 2016) and annual discharges published in Benke and Cushing (2005). In addition, we have shown interpolated measurements of ^{13}C depletion—an indication of terrestrial versus marine carbon—in sediments across the Beaufort and Chukchi shelves (Dunton et al. 2012). Sediment sampling data from Dunton et al. (2012) were interpolated by Audubon Alaska (2016a) using the inverse distance weighted tool in ArcGIS 10.3 Spatial Analyst with a power of one and nine nearest neighbors.

Data Quality
The generalized approach to displaying ocean current data on this map means that seasonal shifts in the positions of currents, as well as local flow variations, were omitted to preserve clarity at the scale of the entire map. The generalized surface current data are comprehensive across the project area. Deep circulation, however, is less well understood and information on this map is incomplete. Upwelling is shown in areas where it is known to commonly occur; upwelling likely also occurs in areas not depicted on the map. The δ^{13}C sediment data cover the Beaufort and Chukchi shelves but were unavailable for other portions of the map.

Reviewer
- Tom Weingartner

MAP DATA SOURCES

Ocean Currents: Aksenov et al. (2011); Arctic Monitoring and Assessment Programme (1998); Brugler et al. (2014); Coachman et al. (1975); Grebmeier et al. (2015); P. Stabeno (pers. comm.); Pickart and Corlett (2016); Pisareva et al. (2015); S. Danielson (pers. comm.); Spall et al. (2008); Stabeno et al. (1999); Takahashi et al. (2011); University of Alaska Fairbanks Institute of Marine Science (2009); Weingartner (2006); Weingartner et al. (2005a, b)

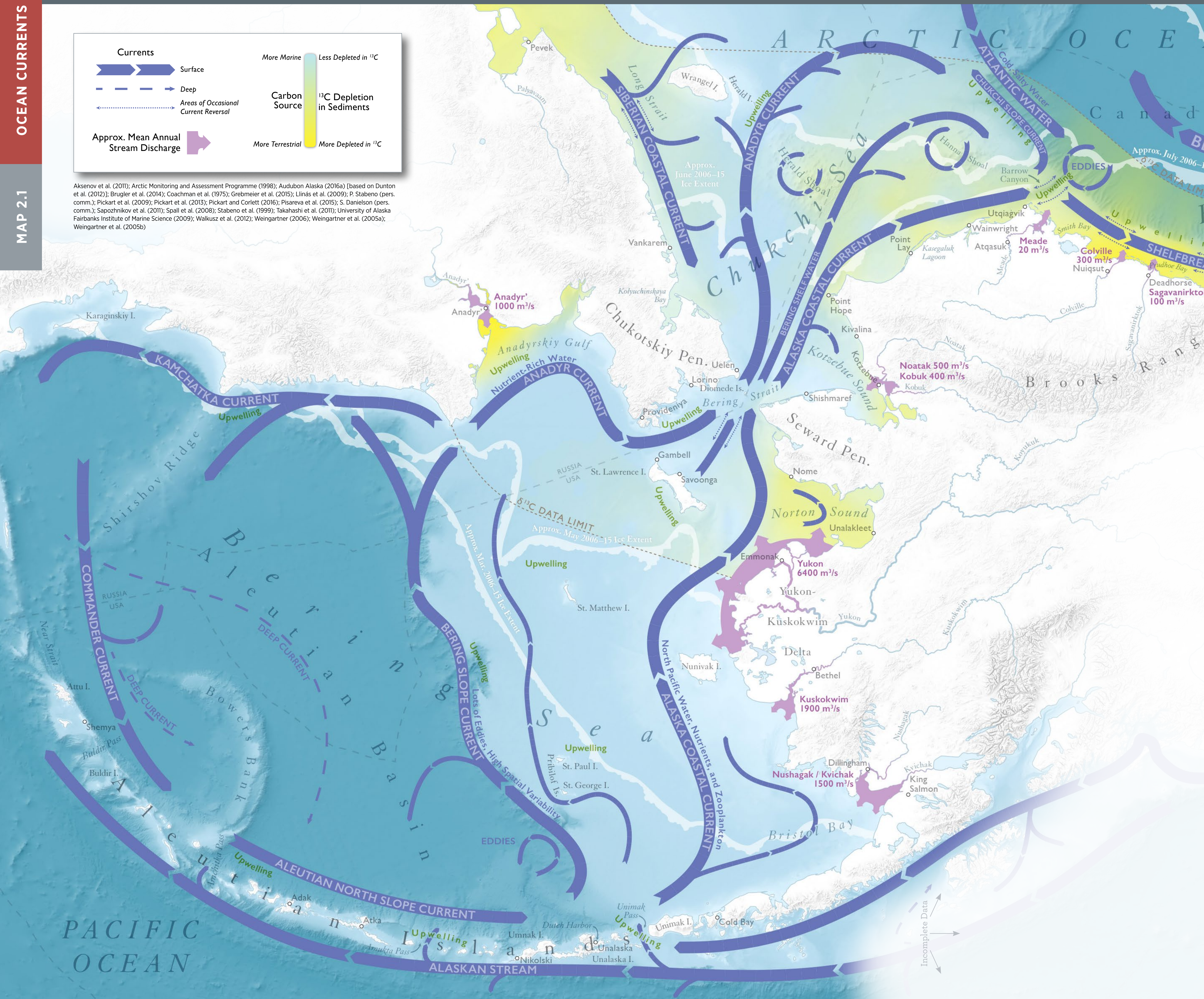
Upwelling: Llinás et al. (2009); Pickart et al. (2009, 2013); Sapozhnikov et al. (2011); Walkusz et al. (2012)

^{13}C Depletion in Sediments: Audubon Alaska (2016a) based on Dunton et al. (2012)

Ocean Currents

Map Authors: Skye Cooley, Erika Knight, and Melanie Smith
Cartographer: Daniel P. Huffman

Audubon ALASKA



Aksenov et al. (2011); Arctic Monitoring and Assessment Programme (1998); Audubon Alaska (2016a) [based on Dunton et al. (2012)]; Brugler et al. (2014); Coachman et al. (1975); Grebmeier et al. (2015); Llinás et al. (2009); P. Stabeno (pers. comm.); Pickart et al. (2009); Pickart et al. (2013); Pickart and Corlett (2016); Pisareva et al. (2015); S. Danielson (pers. comm.); Sapozhnikov et al. (2011); Spall et al. (2008); Stabeno et al. (1999); Takahashi et al. (2011); University of Alaska Fairbanks Institute of Marine Science (2009); Walkusz et al. (2012); Weingartner (2006); Weingartner et al. (2005a); Weingartner et al. (2005b)

Neal Herbert / National Park Service

Ocean Currents

This map depicts typical surface current patterns with blue arrows, while deep circulation, which is less well understood, is shown with dashed lines. Freshwater inputs from major rivers are also shown, along with marine areas that are strongly influenced by terrestrial inputs of organic matter (as indicated by measurements of depleted ^{13}C in sediments).

Three water masses—the Alaska Coastal Current, the Bering Slope Current, and the Anadyr Current—flow north from the Bering Sea through the Bering Strait, carrying heat and nutrients north from the Pacific Ocean across the Chukchi shelf and into the Arctic Ocean. The low salinity, nutrient-rich waters of the Bering Sea help drive some of the world's highest marine productivity by bringing zooplankton and particulate organic carbon into the Bering Strait and the southern Chukchi Sea. Because of these circulation patterns, the Bering Strait is an important migratory corridor for birds and marine mammals.

Upwelling, the process by which bottom water is lifted to the surface, is also associated with high biological productivity. Areas with frequent upwelling events, such as the Bering Sea shelf break on the eastern Beaufort Sea near the community of Tuktoyaktuk, are often important feeding areas for bowhead whales and other marine mammals, as well as marine birds.

MAPS ON PAGES 26–29

Sea Ice

Max Goldman and Erika Knight

Sea ice is a defining component of the Arctic. As habitat for many species, sea ice and the freezing waters in which it forms are integral to the persistence of the Arctic ecosystem. Sea-ice extent—the location of the ice margin—is a commonly used quantitative means of assessing changes in Arctic sea ice (Weeks 2010, Perovich et al. 2015). The ice margin reaches its southernmost maximum extent in March. Spring warming drives the margin northward over 1,000 miles (1,600 km) toward its September minimum extent (Gradinger 2008). Satellite-based passive microwave instruments (radar) have been used to map sea-ice extent and change since 1979 (Tschudi et al. 2015). Daily and monthly data on ice extent are available from the National Snow and Ice Data Center (NSIDC). The NSIDC satellite data show that freeze-up is arriving later by one to two weeks per decade for the Chukchi and Beaufort Seas and break-up is arriving earlier by a week or more every decade (Johnson and Eicken 2016)

Age is another important sea-ice metric. Older ice tends to be thicker and less susceptible to melting by solar radiation and warm currents than younger ice, or first-year ice. Age is determined using satellite observations and drifting buoy records that track ice over several years (Tschudi et al. 2010, Maslanik et al. 2011).

SETTING

Sea-ice margins are not only found at the extent of the ice, but they are also present throughout the pack ice in leads (large fractures in the ice) and polynyas (recurring areas of open water within the ice floe). Leads and polynyas are critical to many Arctic species. Leads are formed when wind or current-induced stress causes a crack to form in an expanse of ice. These cracks can range from a few feet to hundreds of feet wide. They are heavily utilized by seabirds and marine mammals, which rely on them to access forage resources beneath the ice, or as breathing holes while foraging (Divoky 1979, Perovich et al. 2013, Rode et al. 2014).

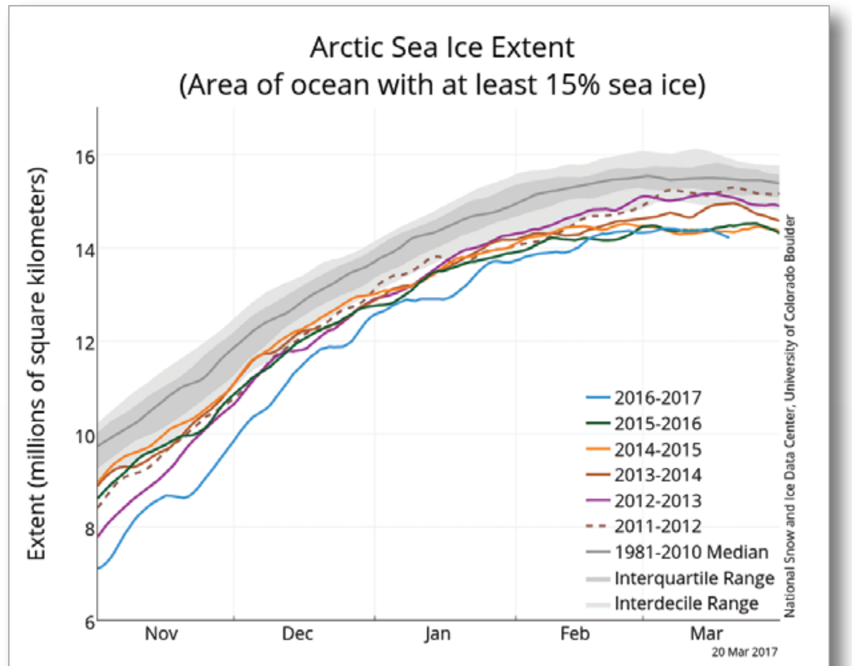
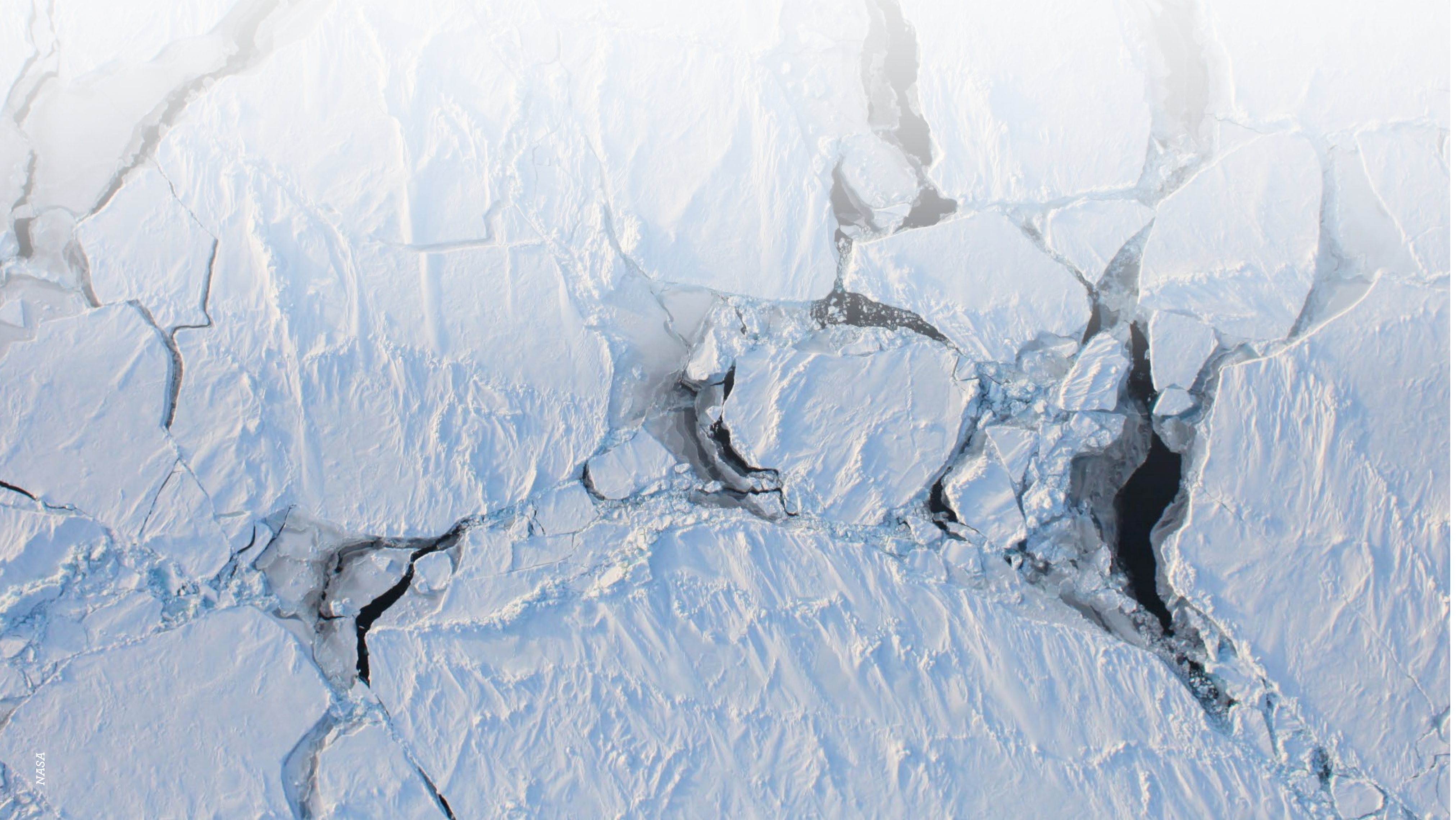


FIGURE 2.2-1. The graph above shows Arctic sea ice extent as of March 20, 2017, along with daily ice extent data for five previous years. The line for 2016 to 2017 is shown in blue, 2015 to 2016 in green, 2014 to 2015 in orange, 2013 to 2014 in brown, 2012 to 2013 in purple, and 2011 to 2012 in dashed brown. The 1981 to 2010 median is in dark gray. The gray areas around the median line show the interquartile and interdecile ranges of the data.



A polynya is an expanse of open water caused either by an upwelling of warm-water currents, by wind, or by a combination of these (Weeks 2010). Because polynyas are caused by perpetuating features, they tend to stay open much longer than leads, and often occur in the same places year after year, such as near St. Lawrence Island, Wrangel Island, Hanna Shoal, and the Yukon-Kuskokwim (Y-K) Delta. Polynyas are used by seabirds, waterfowl, seals, walrus (*Odobenus rosmarus divergens*), whales, and polar bears (*Ursus maritimus*) (Divoky 1979, Perovich et al. 2013, Rode et al. 2014).

ECOLOGICAL ROLE

The Bering-Chukchi-Beaufort Seas region is characterized by divergent sea-ice conditions (Amstrup et al. 2008). As temperatures cool in the fall, the sea-ice margin pushes south toward the Bering Strait. Land-fastened, or "fast" ice forms in early winter when surface winds and air temperatures freeze the relatively shallow waters near the coast. As fast ice merges with sea ice (pack ice), ice-obligate species, such as the polar bear, follow the south-moving ice edge where their prey species feed at the especially productive margins of ice and water (Rode et al. 2014). This productivity is due in large part to the available sunlight required to fuel photosynthesis in the water column, as well as the wind-shear-driven, strong currents near the ice edge, which drives upwelling, an important component to productivity. As the ocean surface freezes and ice accumulates, life in the Bering, Chukchi, and Beaufort Seas begins to concentrate at the sea-ice margins.

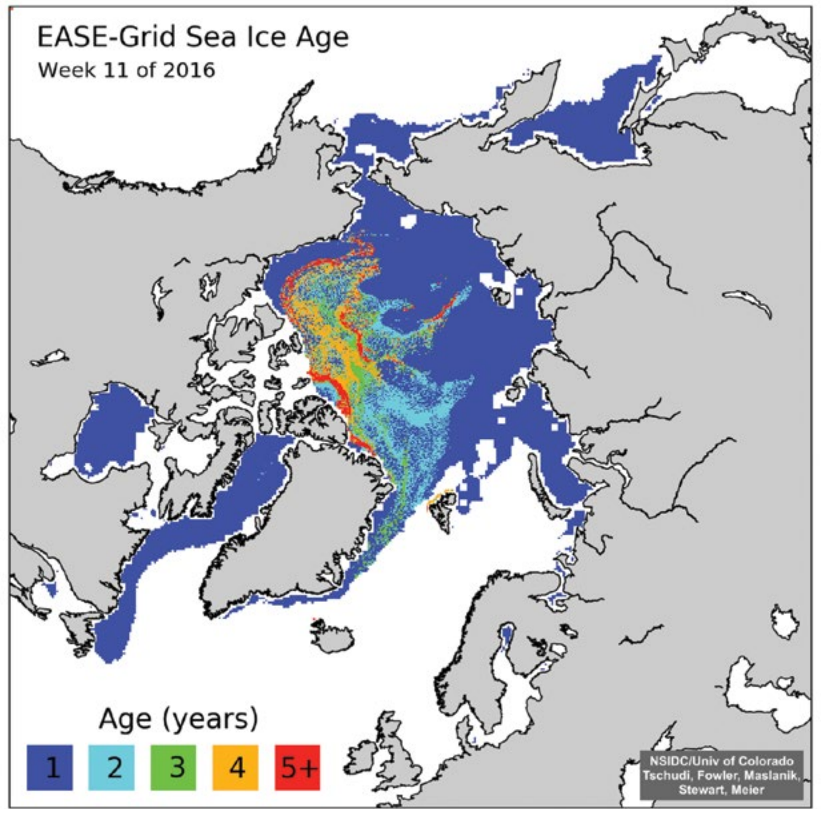
Sea ice in the Bering Sea is composed entirely of first-year ice (ice that formed in the current year, which is less than 3–6 feet [1–2 m thick]). As the weather warms in the spring, the southern ice extent recedes toward the northern Bering Sea. By late spring/early summer, fast ice begins to melt in the Bering Strait. The ice edge continues to move northward, and over the course of the summer, the ice pulls away (diverges) from the northeast Chukotka Peninsula, Wrangel Island, and northwest Alaska.

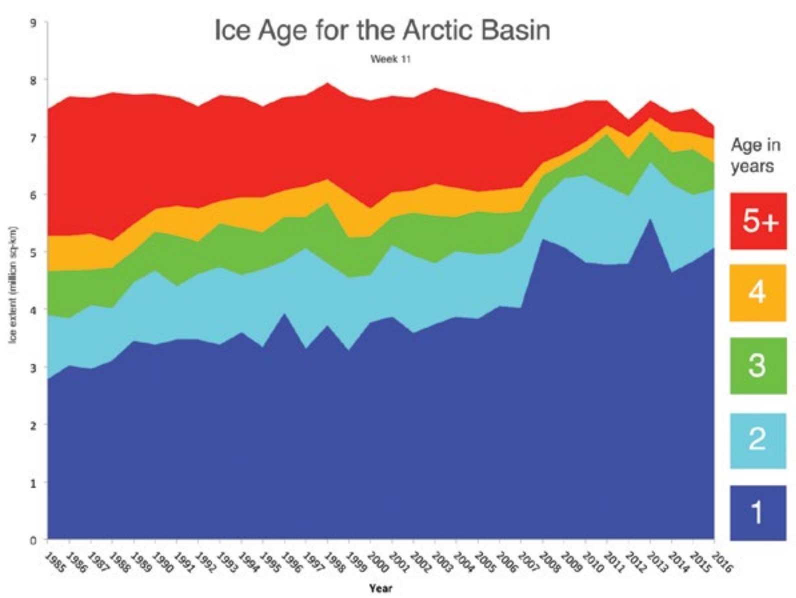
Ice in the Chukchi and Beaufort Seas is made up of first-year and multi-year ice about 5–10 feet (1.5–3 m) thick. By late summer, the ice diverges from the Canadian Beaufort Sea and little to no ice lingers atop the continental shelf in any of the three seas. Ice divergence from land affects ice-obligate species most intensely during late summer, as the ice margin recedes northward hundreds of miles from the coastline. These species then must either remain ashore and face potential conflicts with brown bears and humans, or follow the ice as it continues to retreat northward over deeper, less productive waters. In fall and winter, the process reverses as cold, dark days produce new ice that first expands into the southern Beaufort Sea, then the Chukchi Sea, and finally back through the Bering Strait into the Bering Sea.

CONSERVATION ISSUES

Sea ice is often used as a herald of global climate change. As air and sea-surface temperatures continue to warm, the annual sea-ice maximum and minimum extents in the Arctic continue to trend toward less coverage, with more open water and less multi-year ice (National Snow and Ice Data Center 2016). Even though the winter ice maximum reaches similar southern latitudes each year, the extent is not indicative of overall ice quality in the Arctic, which has continued to trend toward thinner and younger pack ice. These trends have resulted in an overall decrease in the quality of ice in the Arctic, as the core region of old, multi-year pack ice is thinning and melting each summer, and returning as first-year ice each winter.

Over the past decade, bottom melting in the Beaufort and Chukchi Seas has increased substantially. While ice-melt measurements dating back to 1959 indicate that more than half of the overall ice-melt happened on the surface, recent data show a shift in that paradigm. In the last ten years, bottom melting accounts for at least twice as much ice loss as surface melting, and is enough to remove much of the multi-year ice in the region. The greater amount of bottom melting in the Beaufort and Chukchi Seas is directly related to the solar heating of the upper ocean (Perovich and Richter-Menge 2015). Since ice and cold waters trap more carbon from the atmosphere than do warm waters, the Arctic Ocean is precariously positioned as the first to be impacted by changes in global temperature. This characteristic of sea ice, in turn, exacerbates the problem as even more sequestered carbon is released by the warming waters (Bouttes et al. 2010, Sigman et al. 2010, Sun and Matsumoto 2010, Parrenin et al. 2013, Abelmann et al. 2015).





FIGURES 2.2-2 (TOP), 2.2-3 (BOTTOM). These figures show Arctic sea ice age from March 4 to 10, 2016. The top graph shows ice age distribution for that week alone and the bottom graph shows ice age distribution for that week from 1985 to 2016.

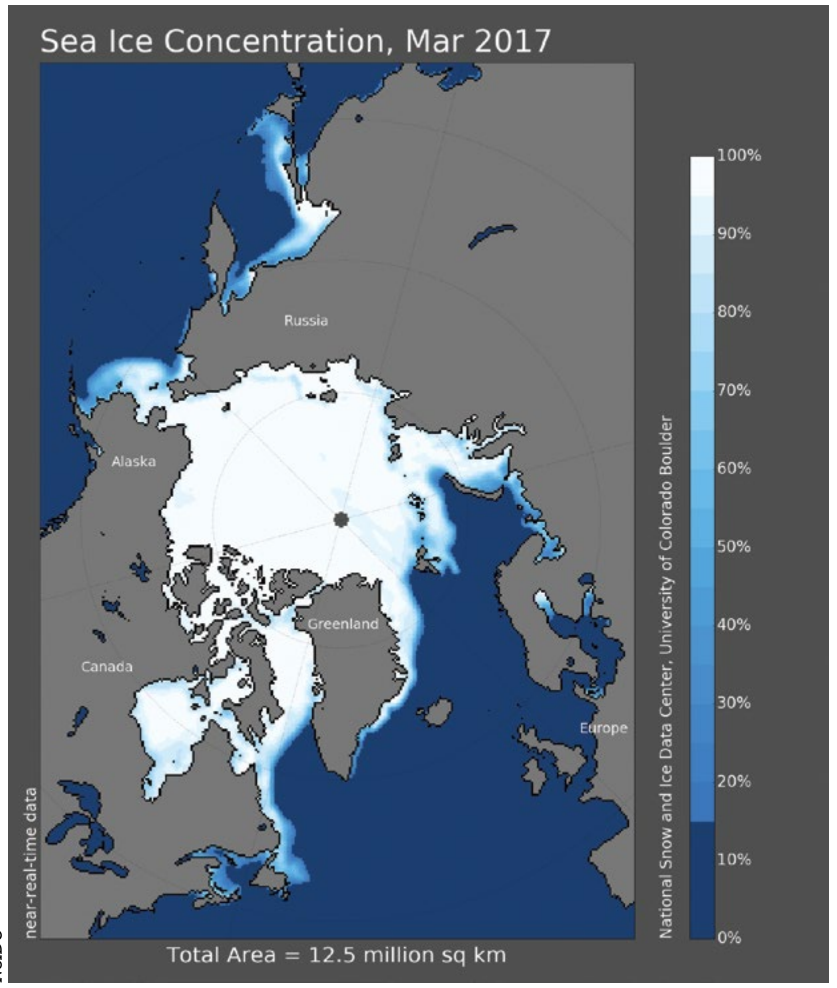
MAPPING METHODS (MAPS 2.2a–2.2.b)

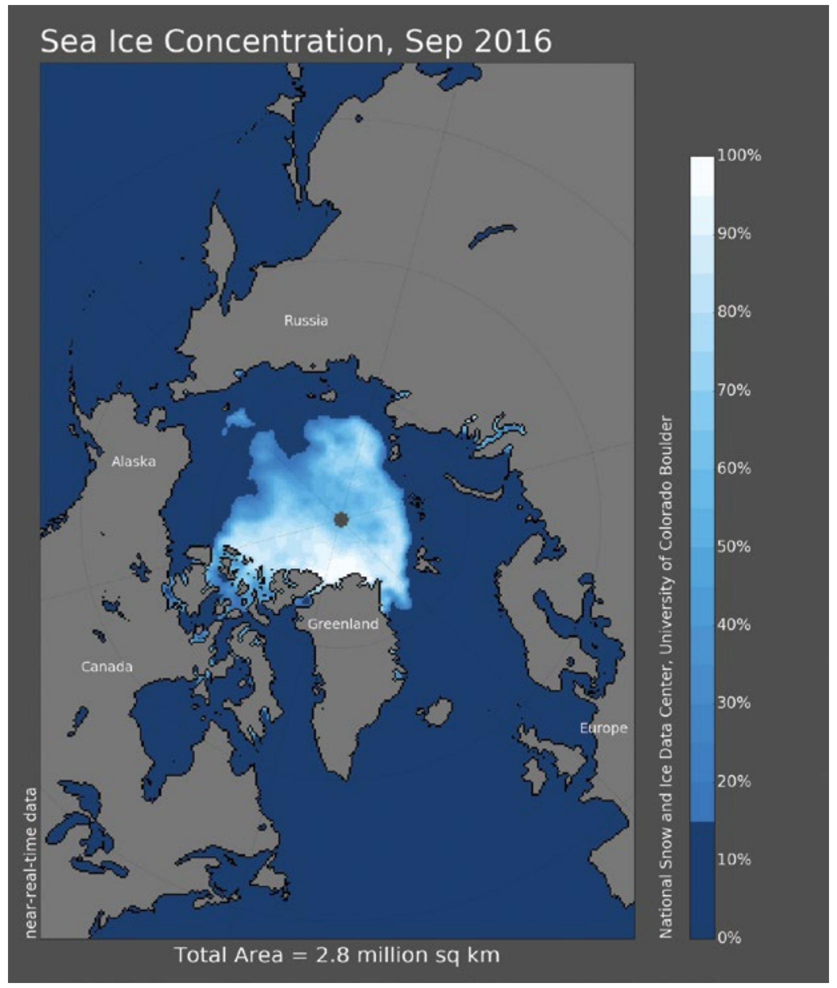
Sea ice data are shown on two seasonal maps, one showing spring and summer sea ice retreat (March–September) and the other showing fall and winter sea ice advance (September–March). Each map shows monthly ice extent lines from two time periods: 2006–2015 and 1981–2010. In addition, historical March and September monthly ice extents from 1850 are shown. Areas where polynyas, recurring leads, or landfast ice occur are also shown.

Approximate median monthly sea-ice extent lines for 2006–2015 were analyzed by Audubon Alaska (2016c) using monthly sea-ice extent data downloaded from the NSIDC (Fetterer et al. 2016). For each month, the downloaded monthly ice-extent line shapefiles were merged across years (2006–2015) and converted to points, generating

MAPS ON PAGES 26–29

2.2 SEA ICE MAPS ON PAGES 26–29





NSIDC

FIGURES 2.2-4 (LEFT), 2.2-5 (RIGHT). The monthly concentration images show a particular month's ice concentration with each 25-km data cell color-coded in shades of blue to white, where dark blue is 0% ice (ocean) and white is 100% ice. The area around the North Pole that is not imaged by the satellite is left out of the figures.

a point cloud for each month during this time period. Within each monthly point cloud, we found the midpoint of the northernmost and southernmost points along each 1-degree line of longitude across the project area; the midpoints were then connected and the resulting line smoothed.

The 1981–2010 median monthly sea-ice extent lines were downloaded from NSIDC (Fetterer et al. 2016). The southernmost winter ice-extent line was compiled from the Fetterer et al. (2016) 1980–2015 monthly ice-extent medians by Audubon Alaska (2016d). Historical ice extents from March and September 1850 were downloaded from Scenarios Network for Alaska and Arctic Planning (2016).

The polynyas and recurring leads data show the maximum areas in which polynyas and recurring leads are known to occur. The data come from several sources: Audubon Alaska et al. (2017), Carmack and MacDonald (2002), Oceana and Kawerak (2014), Stringer and Groves (1991), and an Audubon Alaska (2009) compilation of data from Eicken et al. (2005).

Landfast ice data were compiled by Audubon Alaska (2016b) based on landfast ice data available from Audubon Alaska et al. (2017), Carmack and MacDonald (2002), Eicken et al. (2009), National Oceanic and Atmospheric Administration (1988), National Snow and Ice Data Center et al. (2006), National Snow and Ice Data Center and Konig Beatty (2012), Oceana and Kawerak (2014), Satterthwaite-Phillips et al. (2016), and Spiridonov et al. (2011).

Data Quality

Sea-ice extent data are of high quality, based on remote sensing images covering the entire project area, at a spatial resolution of 15.5 miles (25 km). The extents encompass the area where the sea-ice concentration is measured at 15% or greater.

The polynya, recurring leads, and landfast ice data are of medium quality, compiled from several sources that have only partial coverage of the map area. Taken together, these data sources have good coverage of the map area with the exception of the Russian portion of the Bering Sea.

Reviewers

- Bering Strait Traditional Knowledge-Holder Map Review Workshop participants
- Mark Johnson

MAP DATA SOURCES

Approximate Monthly Sea-Ice Extent (2006–2015): Audubon Alaska (2016c) based on Fetterer et al. (2016)

Median Monthly Sea-Ice Extent (1981–2010): Fetterer et al. (2016)

Southernmost Winter Sea-Ice Extent (1980–2015): Audubon Alaska (2016d) based on Fetterer et al. (2016)

Historic (1850) March and September Ice Extents: Scenarios Network for Alaska and Arctic Planning (2016)

Polynyas and Recurring Leads: Audubon Alaska (2009) based on Eicken et al. (2005); Audubon Alaska et al. (2017); Carmack and MacDonald (2002); Oceana and Kawerak (2014); Stringer and Groves (1991)

Landfast Ice: Audubon Alaska (2016b) based on Carmack and MacDonald (2002), Eicken et al. (2009), National Oceanic and Atmospheric Administration (1988), and National Snow and Ice Data Center et al. (2006); Audubon Alaska et al. (2017); National Snow and Ice Data Center and Konig Beatty (2012); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016); Spiridonov et al. (2011)

2.2 SEA ICE MAPS ON PAGES 26–29

The close-up view of the ice shows a wide range of sea ice types. Blue ice in the lower right corner is thicker ice that is several years old; it contains fewer and smaller pockets of air, which causes the ice to reflect blue light. Adjacent to the open water of the Amundsen Gulf is first-year ice, which grows in just one winter. The dark grey ice is even younger and thinner, and might represent an area of recently open water that refroze. Finally, brash ice—wreckage of various ice types afloat in the water—is seen drifting in the gulf's open water. Snow on top of the sea ice accounts for some of the white areas. *Caption by: Kathryn Hansen*

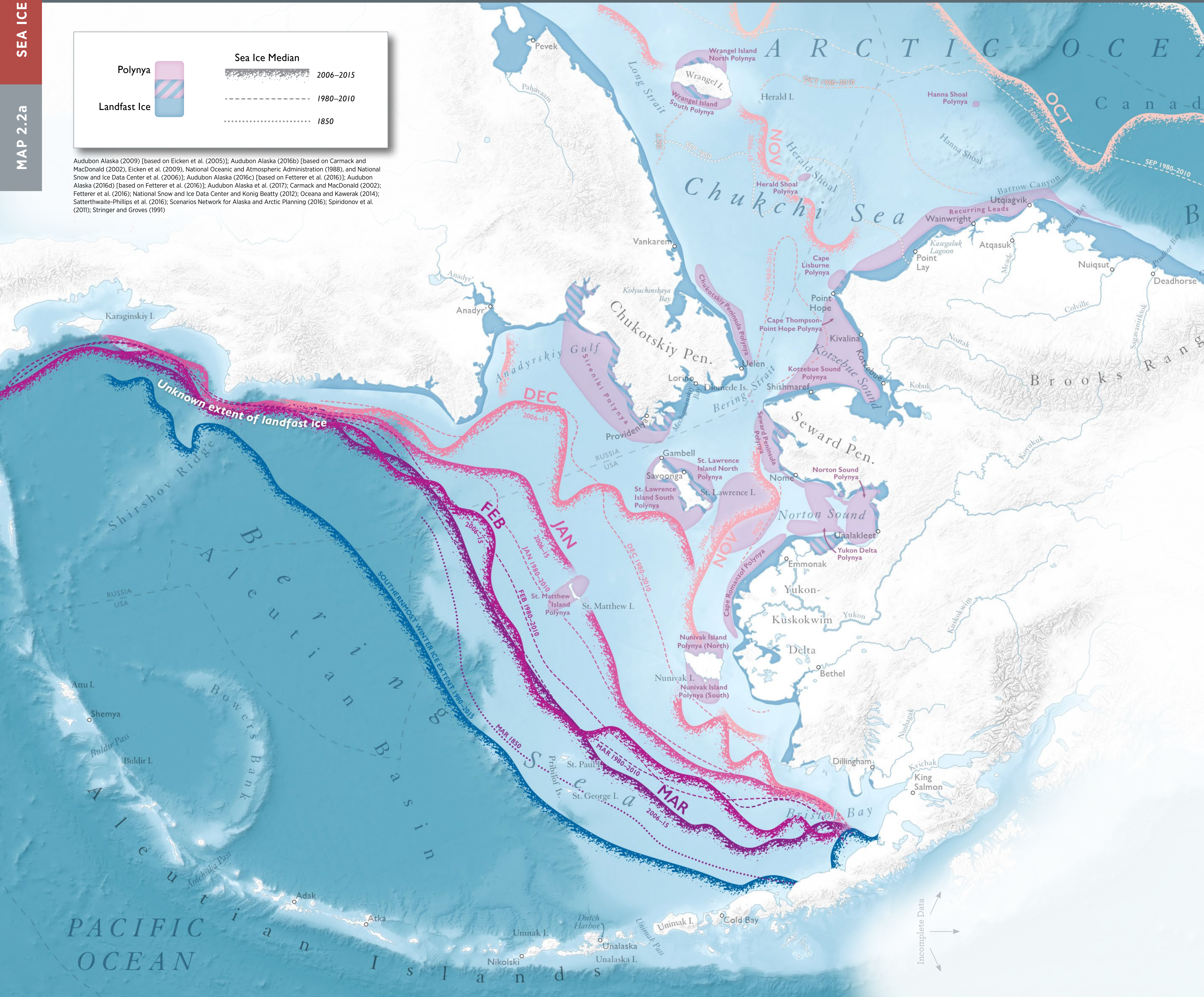
NASA Earth Observatory (Jesse Allen and Robert Simmon) using Landsat data provided by USGS

Sea Ice Advance

Map Authors: Erika Knight, Skye Cooley, Melanie Smith, and Max Goldman
Cartographer: Daniel P. Huffman

KAWERAK, INC.

Audubon ALASKA



Audubon Alaska (2009) [based on Eicken et al. (2005)]; Audubon Alaska (2016b) [based on Carmack and MacDonald (2002), Eicken et al. (2009), National Oceanic and Atmospheric Administration (1988), and National Snow and Ice Data Center et al. (2006)]; Audubon Alaska (2016c) [based on Fetterer et al. (2016)]; Audubon Alaska (2016d) [based on Fetterer et al. (2016)]; Audubon Alaska et al. (2017); Carmack and MacDonald (2002); Fetterer et al. (2016); National Snow and Ice Data Center and Konig Beatty (2012); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016); Scenarios Network for Alaska and Arctic Planning (2016); Spiridonov et al. (2011); Stringer and Groves (1991)

National Park Service

Sea Ice Advance

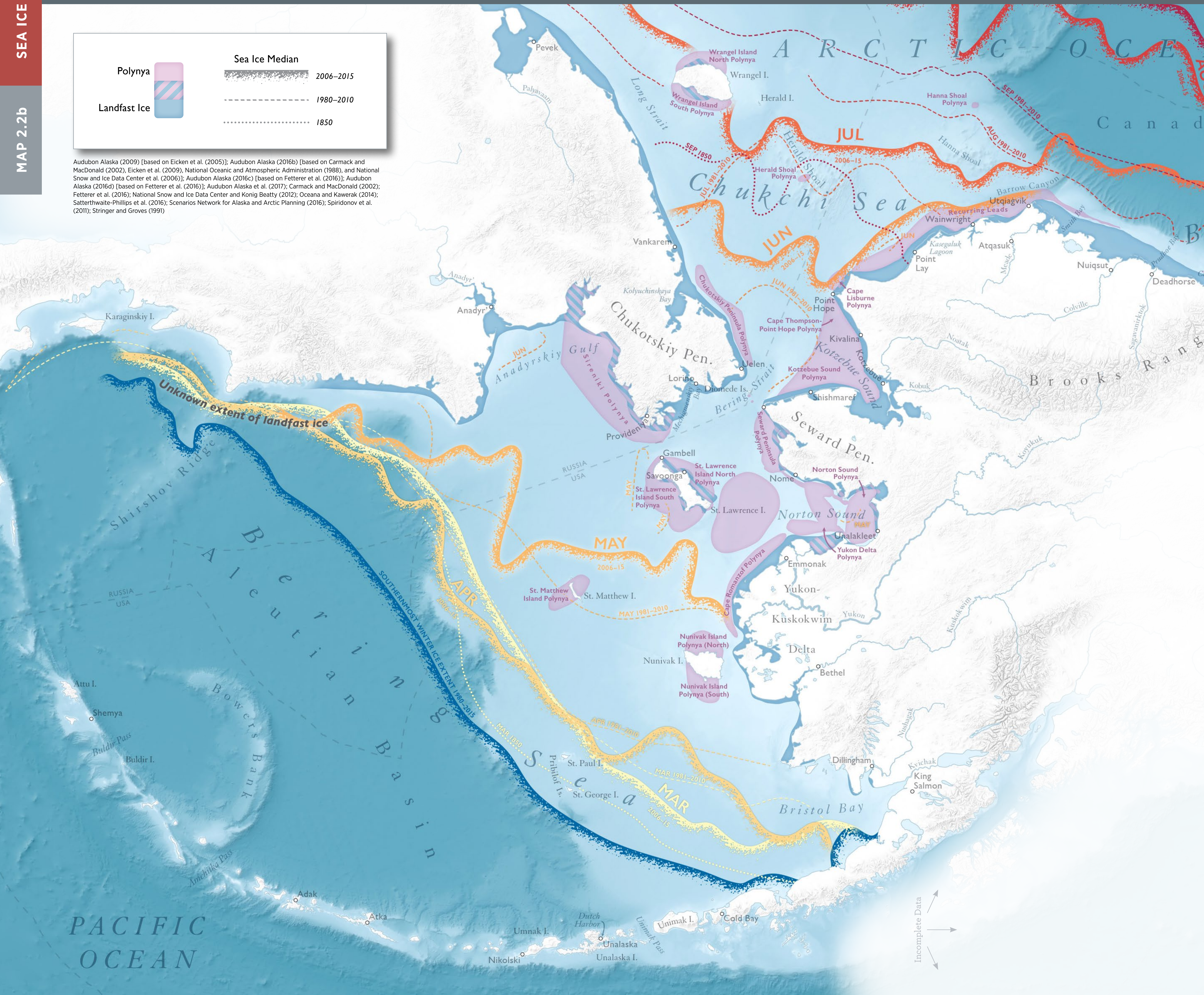
As temperatures cool in the fall, the sea-ice margin advances south from the September minimum extent toward the Bering Strait. The sea-surface temperature drops as air temperature and photoperiod decrease, and ice begins to form in protected inlets and bays along the coastline. As the open ocean cools, needle-like ice crystals called frazil begin to turn the water into slush. As the temperature continues to drop and the ice floats to the surface, the frazil begins to accumulate and bond, eventually forming a solid sheet of ice. The ice crystals force the salt out into the water, resulting in sea ice consisting of mainly fresh water. As the ocean surface freezes and ice accumulates, life in the Bering, Chukchi, and Beaufort Seas begins to concentrate again at the sea-ice margin. Ice-obligate and ice-associated species follow the south-moving ice edge and seek out leads (large fractures in the ice caused by wind or pressure) and polynyas (recurring areas of open water formed by water currents and wind), as their prey species feed at the especially productive margin of ice and water.

Along the coastline in the Arctic, ice forms as water or drift ice freezes to the edge of the land. Land-fastened (fast) ice generally forms in early winter and unlike pack ice, is not impacted by the tides. Wind and currents dictate whether the pack ice will combine with the fast ice, and are responsible for the formation of polynyas. Leads can range from a few feet wide to hundreds of feet wide, and along with polynyas ensure that ice margins, and the life that relies on them, are present throughout winter. The ice margin continues to advance until late February or early March, when the maximum annual sea-ice extent is reached.

Sea Ice Retreat

Map Authors: Erika Knight, Skye Cooley, Melanie Smith, and Max Goldman
Cartographer: Daniel P. Huffman

KAWERAK, INC.
Audubon ALASKA



Audubon Alaska (2009) [based on Eicken et al. (2005)]; Audubon Alaska (2016b) [based on Carmack and MacDonald (2002), Eicken et al. (2009), National Oceanic and Atmospheric Administration (1988), and National Snow and Ice Data Center et al. (2006)]; Audubon Alaska (2016c) [based on Fetterer et al. (2016)]; Audubon Alaska (2016d) [based on Fetterer et al. (2016)]; Audubon Alaska et al. (2017); Carmack and MacDonald (2002); Fetterer et al. (2016); National Snow and Ice Data Center and Konig Beatty (2012); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016); Scenarios Network for Alaska and Arctic Planning (2016); Spiridonov et al. (2011); Stringer and Groves (1991)

Patrick Kelley / USCG

Sea Ice Retreat

The Bering, Chukchi, and Beaufort Seas host a dynamically changing ice margin. As the weather warms in the spring and summer, the ice pack recedes north from the maximum annual sea-ice extent in the Bering Sea that occurs each March. Pack ice first begins to melt as sunlight and air temperatures melt the surface, forming freshwater melt ponds atop the ice until it breaks, and the melted fresh water and salty seawater mix. Later, when seawater temperatures have also increased, sea ice will begin to melt from the bottom and top simultaneously, causing the margin to recede more quickly.

After the pack ice has begun to break up and recede, fast ice begins to melt. It melts first along the coasts of Russia and Alaska in the Bering Sea, then through the Bering Strait, then along the northeast Chukotka Peninsula, Wrangel Island, and northwest Alaska, and finally through the Beaufort Sea until the ice margin has fully pulled away from the Arctic coastline in September. As the ice quality degrades, the pack ice and ice floes break up due to rough seas and collision, increasing the surface area exposed to warming air temperature. The degradation of the ice allows sunlight to penetrate to the water column and primary productivity begins with blooms of photosynthetic life. This surge of life ripples throughout the food web, all the way to the apex predators that follow their prey, and to the ice margins, as they all move farther and farther north. Each decade the minimum ice extent recedes farther north due to global climate change, beyond Alaska's continental shelf. Benthic feeders are forced to choose to either follow the ice off of the continental shelf and risk starvation, or come ashore and face other risks.

Climate

Melanie Smith

The Bering, Chukchi, and Beaufort Seas are considered Arctic seas based on physical climate characteristics. Starting with seawater temperature and sea ice, the physical climate is a determining factor in the ecology and distribution of organisms that inhabit marine waters.

The southernmost of the three seas, the Bering Sea is technically the northernmost sea of the Pacific Ocean, but ecologically it acts like an Arctic sea. For purposes of policy and decision-making, the Bering Sea is an Arctic sea as well. Although multiple definitions of the Arctic exist (e.g. Arctic Circle, Arctic Ocean), the US Arctic Research and Policy Act of 1984 (ARPA) defines the Arctic as "including the Arctic Ocean and the Beaufort, Bering and Chukchi Seas; and the Aleutian chain."

SETTING

The Bering Sea is north of the Gulf of Alaska and south of the Arctic Ocean, separated from the rest of the North Pacific by the Aleutian Island chain. The US (Alaska) lies to the east and Russia lies to the west. The Bering Sea covers 590 million acres (2.4 million sq km). For comparison, the landmass of Alaska is 425 million acres (1.7 million sq km). In the eastern Bering Sea (EBS), the continental shelf extends 300–450 miles (480–725 km) west from the Alaska mainland. Around a depth of 650 feet (200 m), the shelf breaks abruptly to much greater depths, to below 10,000 feet (3,050 m) in the Aleutian Basin. These deep waters characterize the western Bering Sea. The volcanic chain of the Aleutian Islands rises sharply from the seafloor below. At the subducting edge of the Pacific Plate, these undersea mountains emerge at the edge of the Aleutian Trench. At nearly 5 miles (8 km) deep, the Trench is one of the deepest parts of the world's oceans.

At the north end of the Bering Sea, the Bering Strait is a 53-mile-wide (85-km) passage, which is the only marine connection between the Pacific and Arctic Oceans. All of the physical properties and marine life exchanged between the two oceans are facilitated by and through the Strait. To the north of the Bering Strait lies the Chukchi Sea. This shallow Arctic sea spans waters from Point Barrow, Alaska, to Wrangel Island, Chukotka (Russia). Two prominent shoals, Hanna and Herald, influence ice patterns and water mass movement. The Chukchi Sea covers 153 million acres (240,000 sq km).

At the seam between the Chukchi and Beaufort Seas, Barrow Canyon cuts a deep trough through the continental shelf, creating an area of mixing and upwelling of significant productivity. The Beaufort Sea stretches from Point Barrow east to the Amundsen Gulf in Canada. In the Beaufort, the continental shelf stretches only about 60 miles (100 km) offshore before descending steeply into the Canada Basin, reaching 12,500 feet (3,800 m) deep, or about 2.4 miles (3.8 km). The Beaufort Sea covers 45 million acres (184,000 sq km).

ECOLOGICAL ROLE

Based on an analysis of associations of zooplankton, fishes, and birds, Sigler et al. (2011) described three major biogeographic provinces in the Alaska marine domain that loosely align with the geographic boundaries of these seas, but with some important differences.

- The Eastern Bering Shelf Province covers the continental shelf waters of the central and southern Bering Sea, a predominantly subarctic pelagic system not as dominated by sea ice as areas farther north. This is a region of very high productivity for both pelagic and demersal fishes, which are limited in their northern distribution by the "cold pool" that forms from annual ice melt.

- The Chirikov-Chukchi Province includes Bering Sea waters north of St. Lawrence Island and waters of the Chukchi Sea. This is a shallow, benthic-dominated, ice-driven system heavily influenced by nutrients and productivity carried north from the Bering Sea (Grebmeier et al. 2006). This region has some of the highest water-column production (Springer and McRoy 1993) and benthic infaunal biomass (fauna that lives within the ocean floor) in the world (Grebmeier et al. 2006).

- The third province, the Beaufort Sea, is a narrow shelf area with ecological patterns driven by winds, upwellings, and river inputs. This region is largely isolated from the influence of the Bering Sea, instead receiving inputs from the Canada Basin and Amundsen Gulf regions. Although this region has lower overall productivity, benthic-pelagic coupling is strong, providing ample food resources for bottom feeders, including a high abundance of sea ducks.

The Marine Ecoregions of Alaska (Piatt and Springer 2007) further divide these biogeographic provinces into more than 20 subregions of ecological similarity. These subdivisions are useful for characterizing the physical and biological setting of this region at a finer scale, and for comparison among subregions.

Change

Using data from the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (PMEL) (Hermann et al. 2013), Smith and Koeppen (2016) analyzed data representing recent and future predicted conditions across the Bering Sea (not available for the Chukchi and Beaufort Seas). Data for recent conditions are annual averages from a hindcast model covering 1965–2009, and data for future conditions represent the projected average total change from 2003–2040. These model results will be referred to throughout this summary. Read the Mapping Methods section for details on the models and methods used.

Seawater Temperature (Maps 2.3a–2.3d)
Seawater temperature is influenced by depth, ocean currents, and sea ice, as well as tides and surface winds that move and mix the water column. Deeper water tends to be cooler than shallow water at the same location. A defining feature is the cold pool, which forms over the EBS shelf as a consequence of melting sea ice. Commonly defined as the 35.6° F (2° C) isotherm, the cold pool has shifted northward over the last 3 decades by approximately 143 miles (230 km) (Mueter and Litzow 2008). This feature determines the distribution of Arctic and subarctic fishes and invertebrates, and its migration has caused a shift in species' ranges. Further projected warming in the EBS of up to +3.1° F (+1.7° C) by 2040 (Hermann et al. 2013, Smith and Koeppen 2016) will likely continue the trend of northward movement of some Arctic, cold-adapted organisms, with replacement by other subarctic, warmer-water organisms, although species-specific responses are hard to predict (Mueter and Litzow 2008).

Based on the average annual temperature in the top 200 feet (60 m) of the water column, the warmest waters in the Bering Sea are in the Central Aleutians at 42.8° F (6.0° C), as well as the Aleutian Arc (41.4° F [5.2° C]) and Western Aleutians ecoregions (40.6° F [4.8° C]). The coolest waters are in the Anadyr Stream at just above freezing (32.5° F [0.3° C]). These shallow waters are expected to increase in temperature across the entire Bering Sea, with the exception of the Western Aleutians, which indicate a cooling of -0.2° F (-0.1° C). The greatest warming is predicted for the Bering Sea Shelf Edge ecoregion, also known as the Green Belt, and the neighboring EBS Outer Domain, with temperatures rising by +2.3° F (+1.3° C).

In deeper waters, 250–650 feet (75–200 m), overall temperatures are 0.7° to 2.0° F (0.4° to 1.1° C) cooler than shallow waters within the same ecoregion. Similar to the shallow waters, the Eastern Aleutians (42.1° F [5.6° C]), Central Aleutians (41.5° F [5.3° C]), and Aleutian Arc (39.4° F [4.1° C]) are the warmest ecoregions in the Bering Sea. The coolest ecoregion is again the Anadyr Stream, which is below

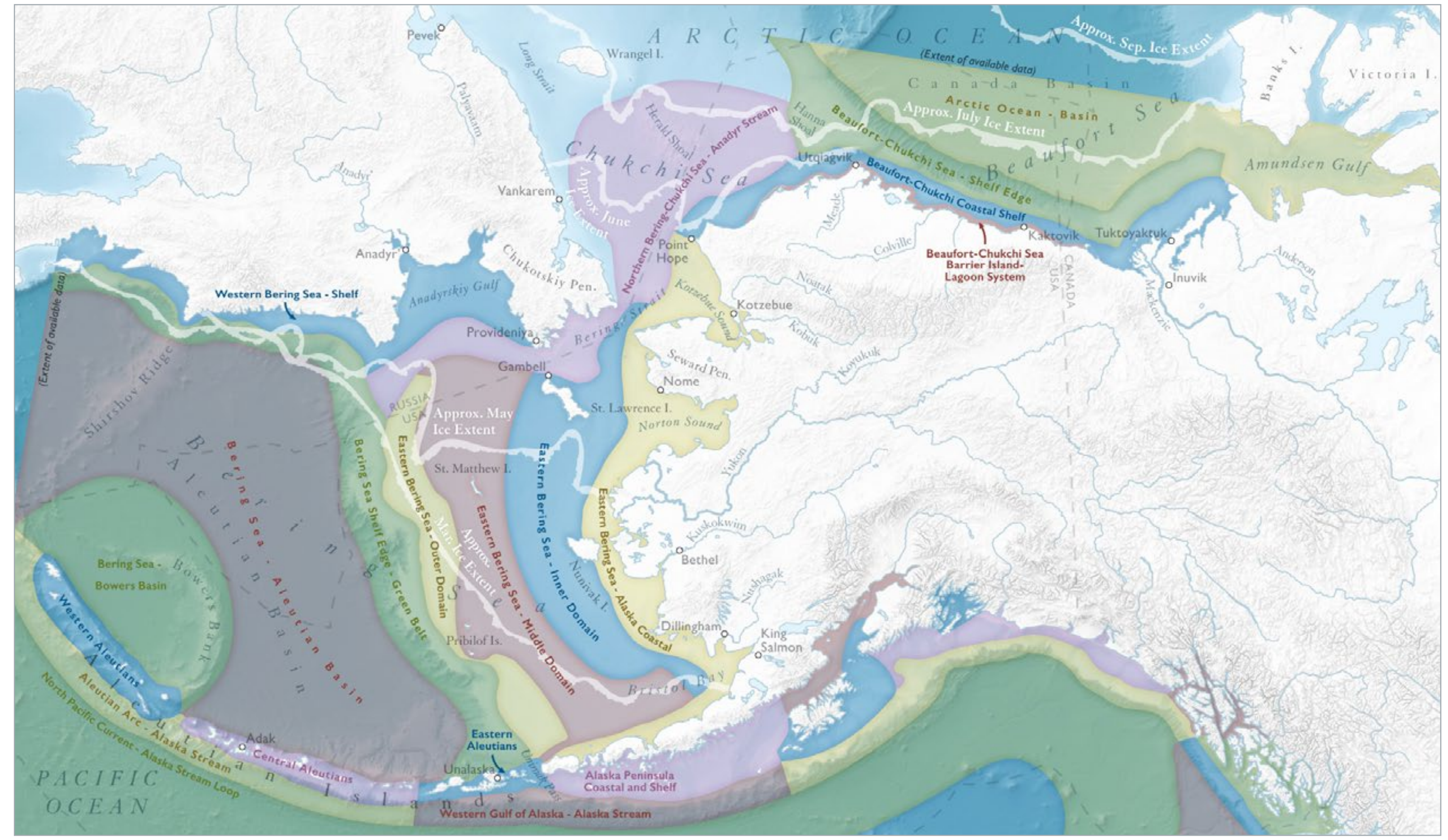


FIGURE 2.3-1. The Marine Ecoregions of Alaska (Piatt and Springer 2007) divide the Bering, Chukchi, and Beaufort Seas into more than 20 biogeographic provinces of ecological similarity. These subdivisions are useful for summarizing the physical and biological setting of smaller regions, and for characterizing differences between regions.

freezing on an annual basis, at 31.8° F (-0.1° C). In the future, the Western Aleutians and Aleutian Arc ecoregions may cool slightly, by -0.4° F (-0.2° C). However, the deep waters as a whole will experience considerable warming of up to +2.2° F (+1.2° C) along the Green Belt, and +1.8° F (+1.0° C) in the neighboring EBS Outer Domain.

Sea Ice (Maps 2.3e–2.3f)
Sea ice is a driving factor in the distribution of wildlife in the Bering, Chukchi, and Beaufort Seas. Sea ice can be a welcome platform for resting (e.g. Pacific walrus [*Odobenus rosmarus divergens*]) or an impediment to reaching foraging areas beneath (e.g. ringed seals [*Pusa hispida*]). Most activity occurs at the ice edge. Sea ice is in significant decline in concentration, extent, thickness, and timing of coverage (Meier et al. 2014). Experts predict an ice-free Arctic Ocean sometime this century (Wang and Overland 2009, Wang and Overland 2015). The timing of sea ice is changing, such that ice is arriving later and departing earlier. Declines have occurred in all months, with the smallest declines in winter and the largest declines in summer (Meier et al. 2014). Bering Sea ice is first-year ice that is pushed south from higher latitudes by winds, translating into less change to the sea-ice maximum extent that occurs each March. Arctic seas have historically been covered in multi-year pack ice, which is today greatly diminished, resulting in the greatest change in the sea-ice minimum extent each September.

In the Bering Sea, sea ice is most concentrated in the Anadyr Stream ecoregion (42% annual average concentration across the ecoregion), followed by the EBS Inner Domain (36%) and the Western Bering Sea Shelf ecoregion (35%). The Aleutian Basin, Aleutian Islands, and Gulf of Alaska are ice-free all year. Predicted changes in sea ice indicate loss across all ecoregions. The EBS Middle Domain ice concentration will decline the most (-9%), followed by the neighboring EBS Inner Domain to the east (-8%), and the Western Bering Sea Shelf (-7%) along the Russian coast. Overall, the combined Bering Sea continental shelf ecoregions will see an average of -7% sea-ice concentration as an annual average.

Phytoplankton (Maps 2.3g–2.3h)
When sea ice melts, it leaves behind nutrients in the form of ice algae, and kickstarts primary production in newly open waters (Horner and Schrader 1982). These two sources of phytoplankton are the basis of the food chain that fuels the Arctic ecosystem, feeding zooplankton that in turn feed fishes, marine birds, and marine mammals (Divoky 1979, Bradstreet and Cross 1982). Due to short food chains and tight pelagic-benthic coupling in these Arctic waters, changing sea-ice extent and timing can rapidly ripple throughout the marine ecosystem from primary production to higher trophic levels and is a major concern surrounding a changing climate (Grebmeier et al. 2006, Moline et al. 2008).

Specific to ice algae in the Bering Sea, average ecoregional productivity is highest in the Anadyr Stream, at 31 mg C / m^3. This area is followed by the EBS Outer Domain (29 mg C / m^3) and the neighboring EBS Middle Domain (25 mg C / m^3). Looking forward to 2040, ice phytoplankton will, as a spatial average, decrease for all ecoregions. The greatest loss of productivity is expected for the EBS Outer Domain (-20 mg C / m^3), which will lose two-thirds of its phytoplankton biomass. The Green Belt will be also highly affected, losing virtually all of the ice phytoplankton productivity received in the past (-16 mg C / m^3).

Microzooplankton (Maps 2.3i–2.3j)
Microzooplankton are a group of planktonic grazers ranging from 0.0008–0.008 inches (20–200 μm) in size. This group includes both single-celled (protist) and multi-celled (metazoan) organisms such as dinoflagellates, ciliates, radiolarians, foraminiferans, rotiferans, and mesoplanktonic larvae, among others (Calbet 2008). Microzooplankton are an important yet understudied link in the food chain as primary grazers of phytoplankton, which are consumed by larger meso-zooplankton. Microzooplankton graze heavily on phytoplankton, consuming on average 57% of the primary production per day in the Arctic (Schmoker et al. 2013).

2.3 CLIMATE MAPS ON PAGES 36–37

In the Bering Sea, microzooplankton production in the top 200 feet (60 m) of the water column is highest in Unimak Pass and the surrounding Eastern Aleutians ecoregion (10.0 mg C / m^3), and along the Bering Sea Shelf Edge Green Belt (9.2 mg C / m^3) and the neighboring EBS Outer Domain (9.0 mg C / m^3). Future production is predicted to stay the same or somewhat decrease in these areas of recent highest productivity (0 to -0.2 mg C / m^3), while the Western Aleutians (+1.7 mg C / m^3; +23%) and Aleutian Arc ecoregions (+1.5 mg C / m^3; +26%) are expected to see the largest increases in microzooplankton production.

Copepods (Maps 2.3k–2.3L)
Copepods are a type of aquatic mesozooplankton—small crustaceans commonly <0.1 to 0.3 inches (1 to 8 mm) in size. Calanoid copepods are large, energy-rich copepods of the genera *Neocalanus* and *Calanus*, which dominate open waters of the North Pacific. Copepods are adapted to capitalize on the intense primary productivity in the water column associated with the moving sea-ice edge (Conover 1988). They are an important link in the food chain, grazing on phytoplankton and (to a lesser extent) other zooplankton, and providing a major food source for fishes, birds, and whales. Some upper-trophic species, like North Pacific right whales (*Eubalaena japonica*) and Least Auklets (*Aethia pusilla*), feed almost exclusively on *Neocalanus* in the Bering Sea (National Oceanic and Atmospheric Administration 2006, Bond et al. 2013).

On average, the EBS Alaska Coastal ecoregion has the highest biomass of large copepods in the upper 200 feet (60 m) of the Bering Sea (1.0 mg C / m^3). The neighboring EBS Inner Domain is next in copepod biomass (0.5 mg C / m^3), followed by the Eastern Aleutians ecoregion (0.5 mg C / m3). Copepod biomass is expected to decline slightly in the Eastern Aleutians (< -0.1 mg C / m^3) with other areas maintaining similar levels of productivity or seeing an increase. The greatest increase (< +0.1 mg C / m^3) will be in the Aleutian Arc. Overall, copepod productivity appears relatively stable across space and time.

Euphausiids (Maps 2.3m–2.3n)
Euphausiids are small, shrimp-like crustaceans, also known as krill (*Thysanoessa* spp.), about 0.8–1.0 inch (20–25 mm) in size. Like copepods, they feed on phytoplankton and, to a lesser extent, other zooplankton, and provide a highly important food source for upper trophic species. Euphausiids are the main prey of baleen whales, as well as many species of marine birds and fishes.

The Green Belt is the top area for euphausiid production, averaging 3.1 mg C / m^3 throughout waters to 200 feet (60 m) depth. Similar in productivity to the Green Belt is the Eastern Aleutians ecoregion, including Unimak Pass (3.1 mg C / m^3). Both areas are well known for the incredibly high densities of foraging seabirds such as shearwaters (*Puffinus* spp.) as well as fin (*Balaenoptera physalus*), gray (*Eschrichtius robustus*), and North Pacific right whales. The lesser-studied Western Bering Sea Shelf ecoregion also shares densities on par with these areas (2.9 mg C / m^3). The Green Belt is predicted to see the greatest loss in euphausiid productivity (-0.20 mg C / m^3; -6%), followed by the neighboring EBS Outer Domain (-0.12 mg C / m^3; -4%). The greatest increase in euphausiid productivity will be in the Aleutian Arc (+0.44 mg C / m^3; +23%) and Western Aleutians ecoregions (+0.43 mg C / m^3; +17%).

Benthic Infauna (Maps 2.3o–2.3p)
These Arctic seas, especially from St. Lawrence Island and north, are highly productive benthic ecosystems founded on the massive amounts of primary productivity at the migrating sea-ice edge. Including ice algae and water column blooms, more phytoplankton are produced than are utilized by water-column grazers (micro- and mesozooplankton). This unexploited nutrient source instead falls to the bottom of the sea, fertilizing an abundance of benthic organisms (Grebmeier et al. 2006). As a result, the northern Bering and Chukchi Seas have some of the highest benthic biomasses in the world (Grebmeier et al. 2006). The Chukchi Sea benthic infaunal assemblage is dominated by polychaetes, mollusks, and crustaceans, providing important food sources for Pacific walrus, gray whales, and eiders (Schonberg et al. 2014).

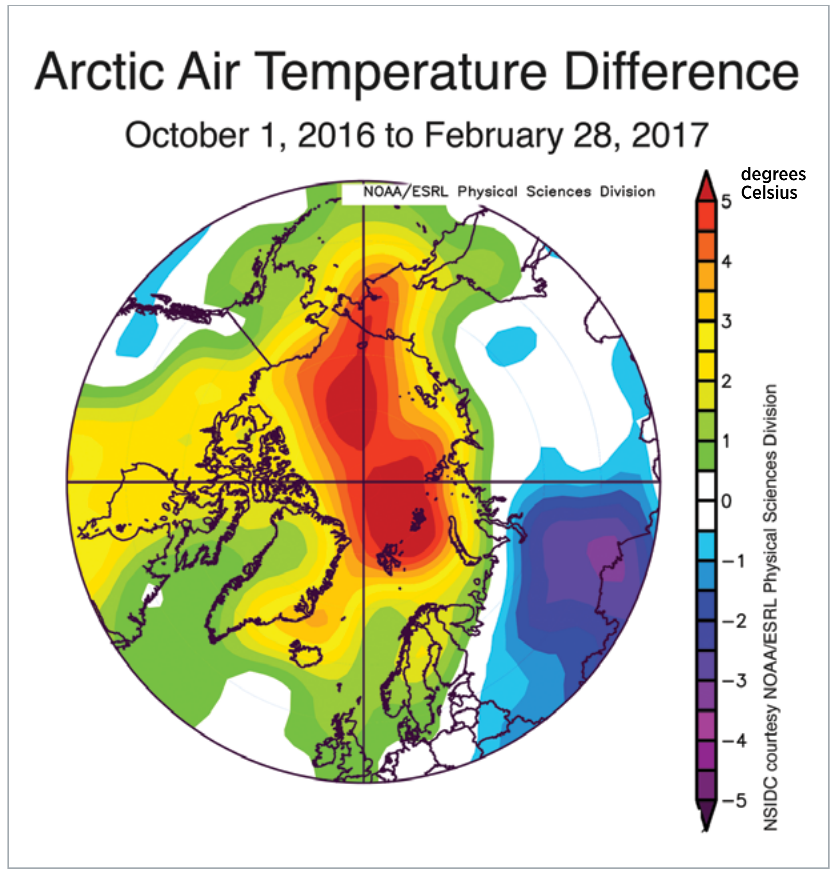


FIGURE 2.3-2. The plot shows Arctic air temperature differences at the 925 hPa level (about 2,500 feet [760 m] above sea level) in degrees Celsius from October 1, 2016 to February 28, 2017. Yellows and reds indicate temperatures higher than the 1981 to 2010 average; blues and purples indicate temperatures lower than the 1981 to 2010 average.

In the Bering Sea, benthic infaunal biomass is highest, on average, across the Western Bering Sea Shelf ecoregion (4542 mg C / m^2), followed by the EBS Alaska Coastal region (4085 mg C / m^2), and the EBS Middle Domain (4028 mg C / m^2). Modeled future values indicate that benthic biomass will be redistributed across the region, with both large gains and losses expected. In the Bering Sea, the greatest negative change in benthic infaunal biomass is predicted for the EBS Alaska Coastal ecoregion (-359 mg C / m^2) and the EBS Outer Domain (-175 mg C / m^2); the greatest increase is expected in the Anadyr Stream (+371 mg C / m^2) and Western Bering Sea Shelf (+293 mg C / m^2), already among the most productive areas. The Aleutian Islands and deeper off-shelf areas are expected to hold steady.

CONSERVATION ISSUES

Climate is a fundamental determining factor in the ecology and natural history of species. Conservation issues related to climate are a function of anticipated changes from a warming planet. The Arctic is warming at twice the rate of the global average. Experts predict that climate change will have major effects on physical, ecological, social, and economic systems around the world over the next century.

Physical changes include melting permafrost, sea ice, and glaciers; loss of ice on the surface reduces the planet's reflectance (albedo), causing additional warming than by atmospheric forcing alone. Melting also freshens ocean waters and changes salinity. Melting glacial ice causes sea levels to rise, while melting sea ice opens vast stretches of ocean, allowing greater storm surges to occur. Sea-level rise, storm surges, permafrost thaw and slumping, and stronger storms cause coastal erosion and inundation of low-lying areas or villages (Arctic Climate Impact Assessment 2004).

Social and economic impacts of climate change are both positive and negative, depending on the perspective. Increased flooding will cost communities and force them to relocate at very high expense, bringing great cultural losses associated with moving from a place of long-standing traditional use. Food security may be compromised due to

2.3 CLIMATE MAPS ON PAGES 36–37

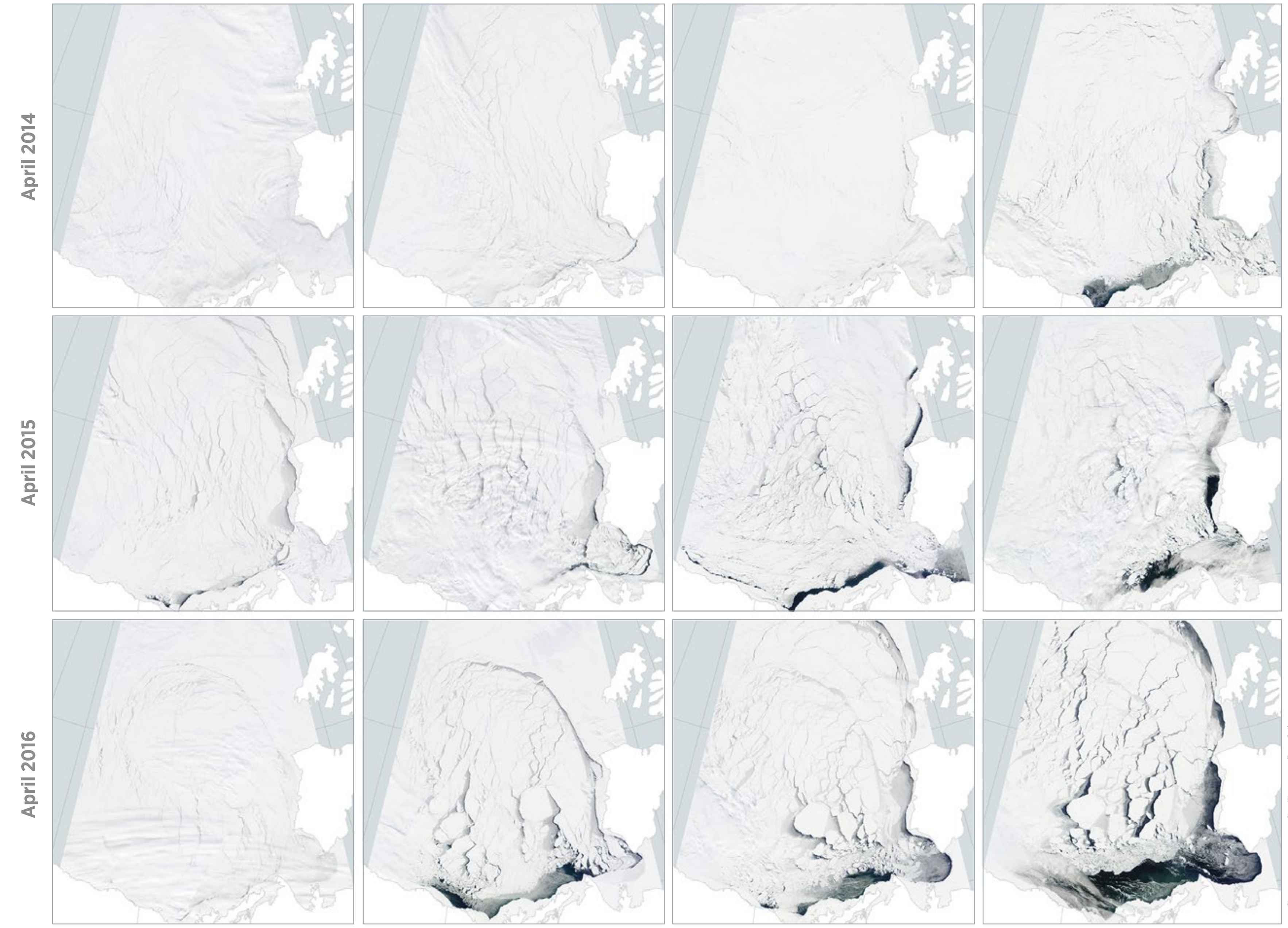


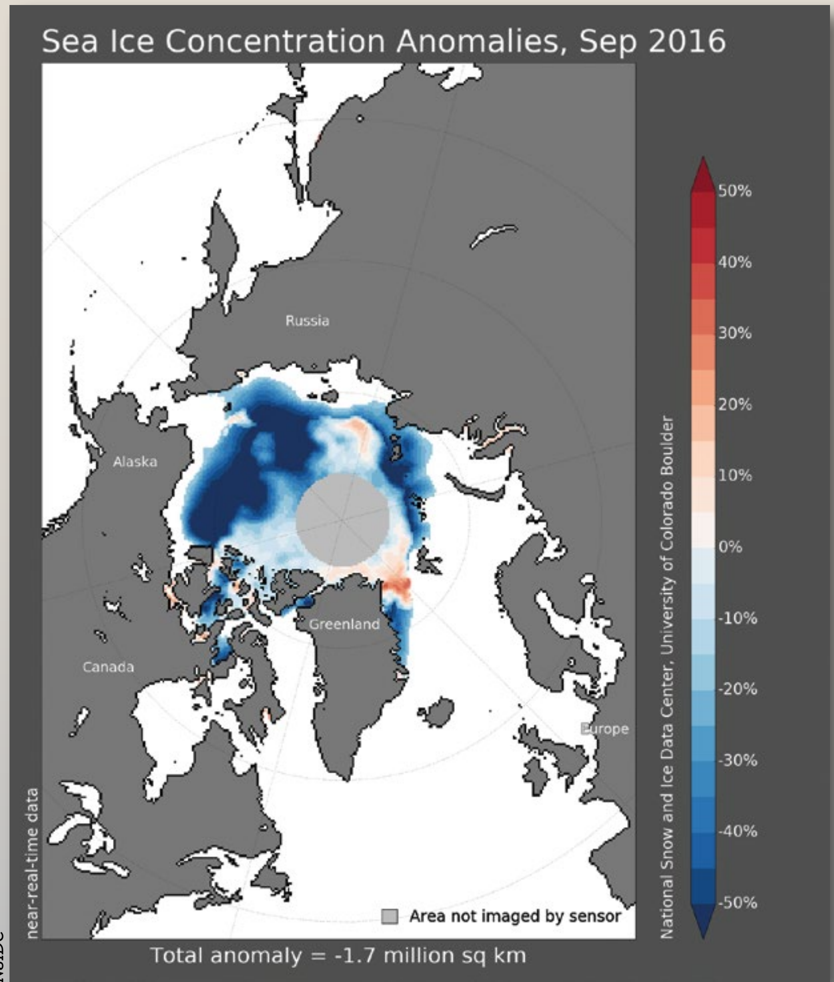
FIGURE 2.3-3. Every spring, the expansive pack of sea ice that covers the Beaufort Sea during the winter starts to thin and break up when the spring sunlight arrives and temperatures rise. Normally, that breakup does not reach full swing until late May. In 2016, unusually warm temperatures during the first few months of the year set the stage for early breakup. In April, a high-pressure system producing strong southeasterly winds parked itself over the Beaufort Sea and sent chunks of ice swirling in a clockwise direction in the Beaufort Gyre. The lower images show different stages of the ice breakup in April 2016. For comparison, the upper two strips show what conditions were like in April 2014 and April 2015. Notice how much more open water appears in 2016 than in the other years.

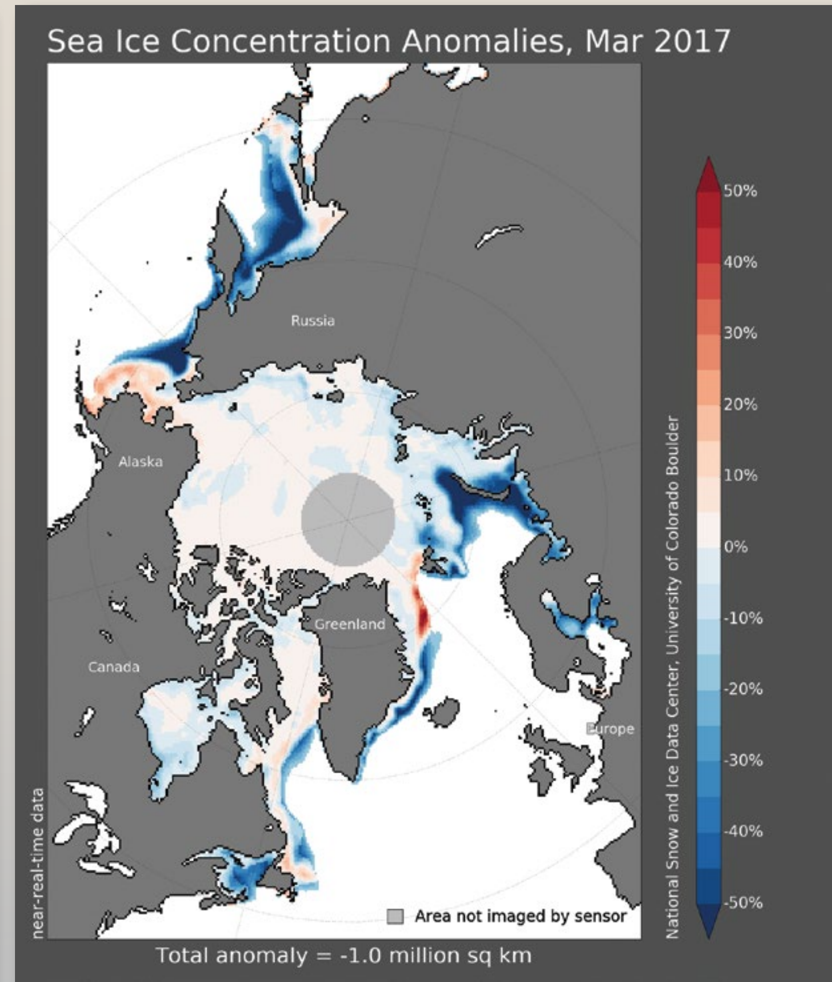
changing conditions (timing of ice, shore ice too weak for hunting, and stronger storms), as well as shifting of wildlife ranges (Marine Mammal Commission 2000). There may be an increase in vessel traffic in Arctic waterways and greater access to natural resources, bringing new ports, roads, pipelines, and jobs. Fisheries may be enhanced (Arctic Climate Impact Assessment 2004). Native communities are facing challenges to their traditional ways of life, and stand to bear the most immediate and acute effects from a changing climate. Native people should be consulted and included in ecological studies and policy decisions affecting the natural resources in their respective regions (Marine Mammal Commission 2000, Moller et al. 2004, Martello 2008, Laidre et al. 2015).

Ecological impacts will be widespread, and while some are already occurring or reasonably foreseeable, many others will be difficult or impossible to predict. The timing of spring primary production is regulated by climate conditions that control the timing of sea-ice retreat. This, in turn, has a major effect on ecological relationships at the base of the food chain. Under cool conditions, sea ice is more extensive and thicker, and melts later in the spring (late March or later). The nutrients released by the ice in the form of under-ice algae disperse at a time when there is ample daylight to warm the water and fuel a massive ice-edge phytoplankton bloom (April–May). Under these conditions, cooler water inhibits the production of zooplankton and recruitment of fish, and consequently the grazing of phytoplankton; more of the productivity sinks to the benthos. Under warm conditions, ice melts earlier (mid-March or before), when there is not enough daylight to support a bloom, and instead the bloom happens later in the summer (May–June), when water column conditions are right. Under these conditions, zooplankton and fishes thrive and more of the productivity flows into the pelagic food chain (Hunt et al. 2002, Hermann et al. 2013). The reorganization from a benthic-driven to pelagic-driven food web in sea-ice regions is a major shift in the ecology of Arctic seas, and the vulnerability of the ecosystem is thought to be high. With short food chains, changes in lower trophic levels can rapidly impact higher trophic levels, especially for benthic-feeding seabirds and marine mammals (Grebmeier et al. 2006).

Warming water temperatures can have unanticipated consequences, such as with walleye pollock (*Gadus chalcogrammus*) productivity (Sigler et al. 2011). This Subarctic species was expected to increase in abundance in warmer waters, but instead, warmer years led to a large decrease in pollock productivity, while cooler years led to an increase. In warm years, the ice-associated spring bloom led to a major decline

2.3 CLIMATE MAPS ON PAGES 36–37





NSIDC

FIGURES 2.3-4 (LEFT), 2.3-5 (RIGHT). These images of anomalies in ice concentration show, in percent color-coded in shades of blue (negative anomaly) to red (positive anomaly), how much the ice concentration for a month differs from the mean calculated for that month over the 1981 through 2010 time range. The total anomalous area of sea ice for that month is also shown in the bottom margin of the image. The area around the North Pole that is not imaged by the satellite is left out of the images.

Sunrise from the Chukchi Sea just offshore of Point Hope.

Melanie Smith / USFWS

2.3 CLIMATE MAPS ON PAGES 36–37

in copepod and euphausiid abundance—key forage for juvenile pollock. Additionally, other larger fish accustomed to foraging on zooplankton took to foraging more intensely on juvenile pollock.

Species ranges are already shifting in response to climate changes. Mueter and Litzow (2008) found that the center of distribution for the 40 taxa they studied moved northward an average of 21 miles (34 km), including Arctic cod (*Arctogadus glacialis*), walleye pollock, Pacific halibut (*Hippoglossus stenolepis*), and snow crab (*Chionoecetes opilio*), in response to a northward shift in the Bering Sea cold pool. They also found that 57% of the variability in commercial snow crab catch is explained by winter sea-ice extent, and a warming climate is the cause of changes in distribution. As the system fluctuates, upper-trophic ice-dependent and ice-associated species will be challenged, and those with restricted ranges and diets will be less resilient than those with greater adaptability (Laidre et al. 2008, Moore and Huntington 2008).

As suggested for marine mammals (Moore and Huntington 2008), some seasonally migrant seabirds may stand to gain from reduced sea ice and an increase in pelagic food sources (e.g. Gall et al. 2012). Crested Auklets (*Aethia cristatella*) appear to have increased their use of the Chukchi Sea in late summer, although the reason is not known; it may be due to improving conditions, population increases, or previous underestimation of use (Maftei and Russ 2014). On the other hand, there is greater evidence of troubling futures for marine birds. Benthic-feeders, such as sea ducks, are likely to lose out. A study by Audubon Alaska and the US Fish and Wildlife Service found that climate models predict a significant decrease in benthic infaunal biomass in waters used by globally significant concentrations of Steller's Eiders (*Polysticta stelleri*), a threatened species under the Endangered Species Act (ESA) (Koeppen et al. 2016). In 2014, an "unprecedented" number (50,000–100,000) of Cassin's Auklets (*Ptychoramphus aleuticus*) washed up on beaches from British Columbia to California (Welch 2015). The recent alarming mass die-off of more than 500,000 Common Murres (*Uria aalge*) in Alaska waters in 2015–2016 initially left scientists puzzled (US Fish and Wildlife Service 2016); it has since been linked to climate change. A redistribution of forage fish in response to a large mass of warm water in the Gulf of Alaska known as "the blob" left the murres starving, with some flying as far inland as Fairbanks in search of food (Farzan 2017). In late 2016, a die-off of several thousand starving Tufted Puffins (*Fratercula cirrhata*) at the Pribilof Islands may also be linked to warmer seas (Welch 2016).

Some marine mammals also face challenges (Laidre et al. 2008, Moore and Huntington 2008). Loss of ice cover on the continental shelf in late summer is a problem for Pacific walrus, which need the ice to haul out and use as a resting platform. When the last of the lingering ice near Hanna Shoal has melted, walrus spend less time foraging and less time hauled out, indicating greater energy expenditure to access food resources due to climate warming (Jay et al. 2017). Additionally, ice seals need sea ice at certain times of the year for whelping, nursing, mating, and molting. There is concern that the changes in the timing of sea-ice availability may affect the ability of ice seals to perform vital life events (Boveng et al. 2009, Cameron et al. 2010, Kelly et al. 2010, Boveng et al. 2013). This has led to an ESA listing of threatened for the Arctic subspecies of ringed seal and the Beringia distinct population segment of bearded seal (*Erignathus barbatus*). Similar concerns led to the listing of the polar bear (*Ursus maritimus*) as threatened (US Fish and Wildlife Service 2015).

Overall, climate is the principal driver of ecological organization, relationships, and changes. While many effects are currently being experienced, many more changes to come are not yet known.

MAPPING METHODS (MAPS 2.3a–p)

We assessed climate using downscaled, four-dimensional, coupled physical/biological models of ocean variables created by NOAA PMEL (Hermann et al. 2013) available from the Alaska Ocean Observing System (AOOS) Arctic Data Portal. Data were available only for the Bering Sea portion of our project area. These projections were based on ocean climate models that pair a Regional Ocean Modeling System (ROMS) with climate model output extracted for the North Pacific from Coupled Model Intercomparison Project 3 (CMIP3) bias-corrected global climate models (GCMs). The downscaled variables have a spatial resolution of 6x6 miles (10x10 km) and many variables also include projections for multiple depth classes (e.g, density of euphausiids in different sections of the water column). Hermann et al. (2013) describe these downscaled models and compare projections from the Canadian Centre for Climate Modelling and Analysis (CCCma) projection model (2003–2040) to the Coordinated Ocean-Ice Reference Experiments (CORE) hindcast climate model (1965–2009) (Large and Yeager 2008).

We selected seven physical and biological variables. Four of the selected variables were assessed by combining multiple depth classes. We analyzed seawater temperature, large microzooplankton, *Neocalanus* (i.e. large neritic copepods), and euphausiids for shallow waters only (0–200 feet [0–60 m] depth); we also analyzed sea water temperature for deep waters (250–650 feet [75–200 m] depth). The other three variables represented surface (sea-ice area fraction, ice phytoplankton) or bottom (benthic infauna) values.

We used the NetCDF Operator Suite to statistically analyze and summarize the time-series data for each model for each 6x6 mile (10x10 km) raster cell. Using the CORE hindcast model, we analyzed all available time steps (weekly) across the entire model time period to summarize average annual values for each variable. Using the CCCma projection model, we compared the recent time period (26 January 2003 to 30 December 2012) to a future time period (6 January 2030 to 4 December 2039) within the model, summarizing total anticipated change from recent conditions to 2040.

Data Quality

For both hindcast and projection, we used a single GCM and have not expressed uncertainty based on variability among models. Models did not include variables related to fish which is a major limiting factor in understanding coming changes in Bering Sea ecology. For an in-depth discussion of the models and their limitations, see Hermann et al. (2013).

Reviewer

- Jeremy Littell

MAP DATA SOURCES

Hindcast and Projection Summaries: Smith and Koeppen (2016) based on Hermann et al. (2013)

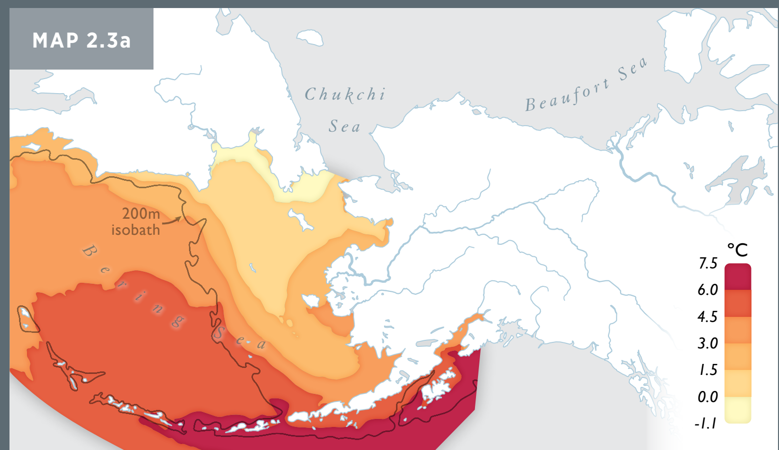
Climate

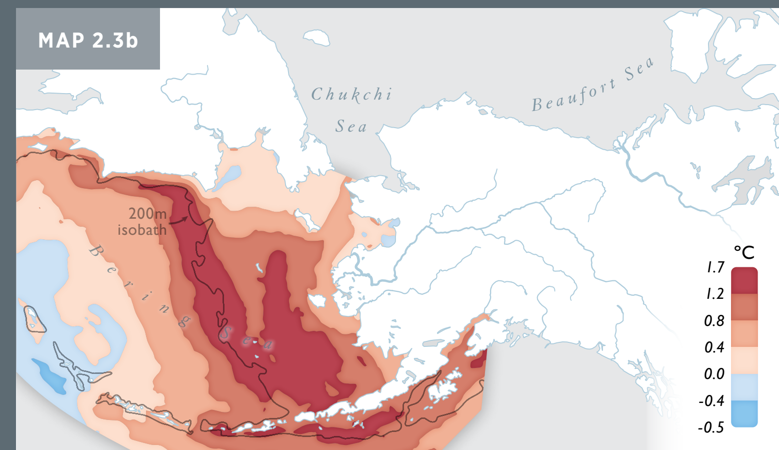
Map Authors: Melanie Smith and Will Koeppen
Cartographer: Daniel P. Huffman

Audubon ALASKA

Shallow Sea Water Temperature 0–200 feet (0–60 m)

Annual Average (1965–2009)

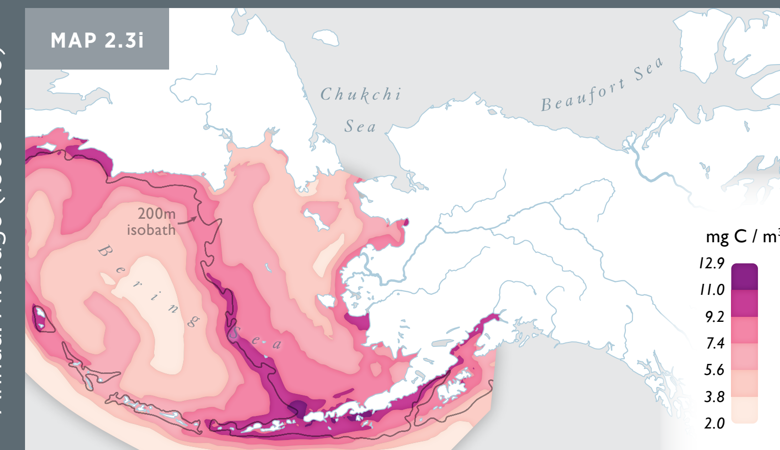




Total Projected Change by 2040

Microzooplankton Concentration 0–200 feet (0–60 m)

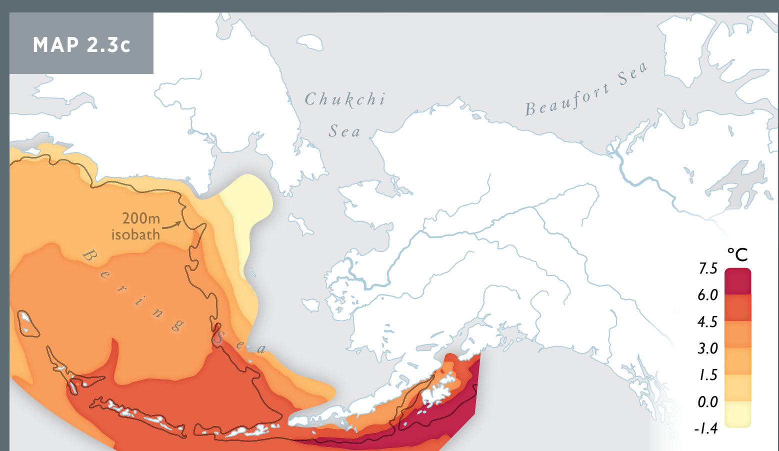
Annual Average (1965–2009)

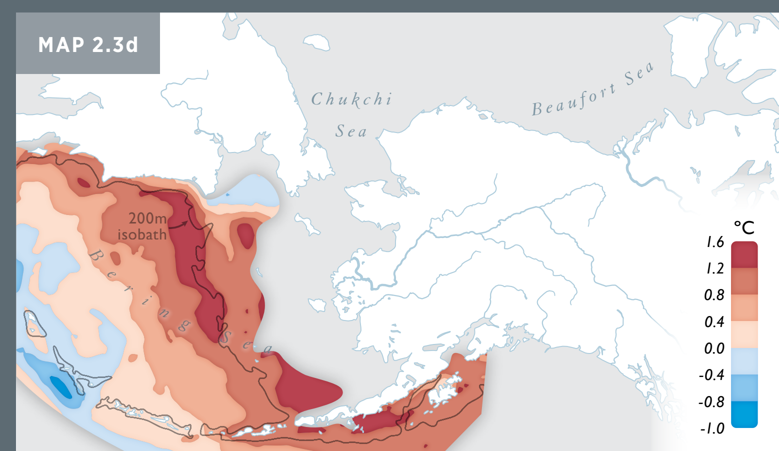


Total Projected Change by 2040

Deep Sea Water Temperature 250–650 feet (75–200 m)

Annual Average (1965–2009)

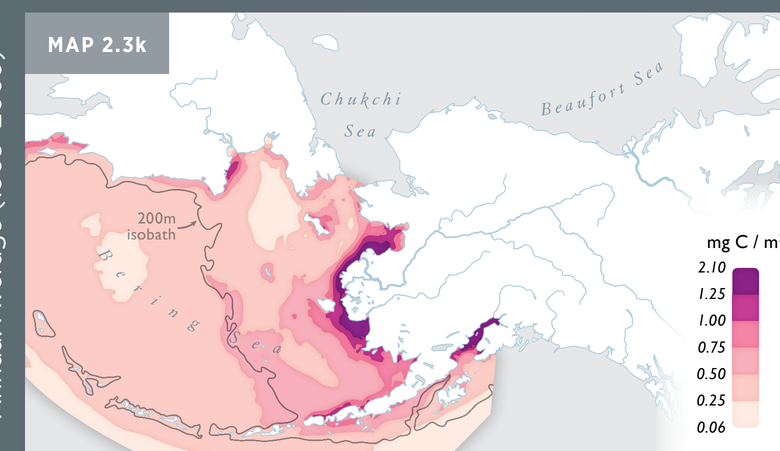


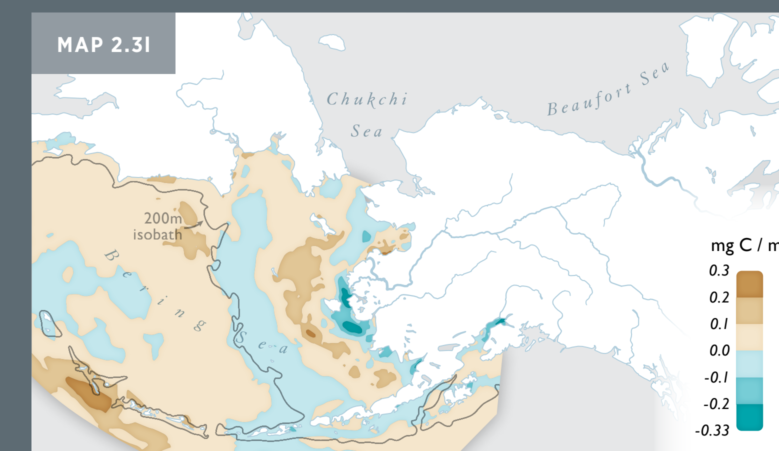


Total Projected Change by 2040

Large Neritic Copepod Concentration 0–200 feet (0–60 m)

Annual Average (1965–2009)

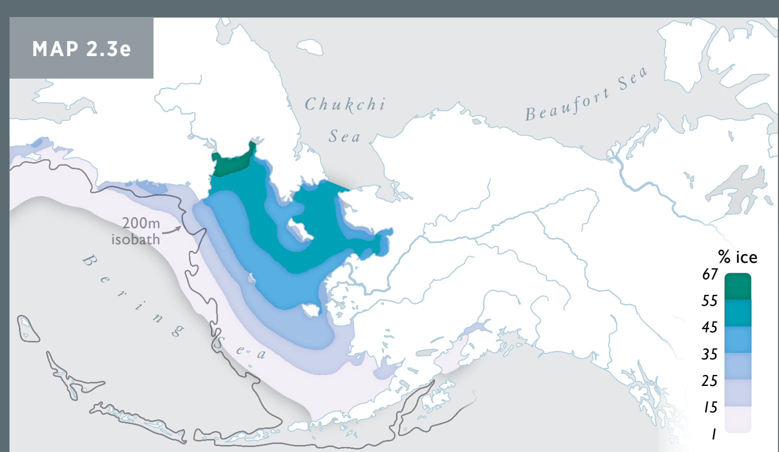


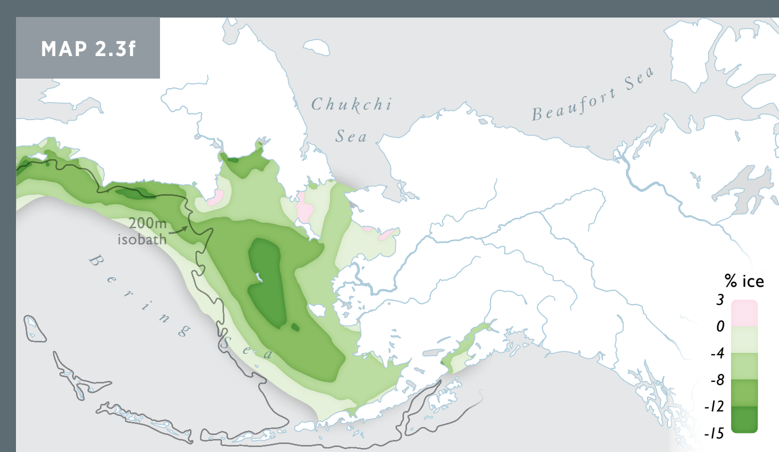


Total Projected Change by 2040

Sea Ice Concentration

Annual Average (1965–2009)

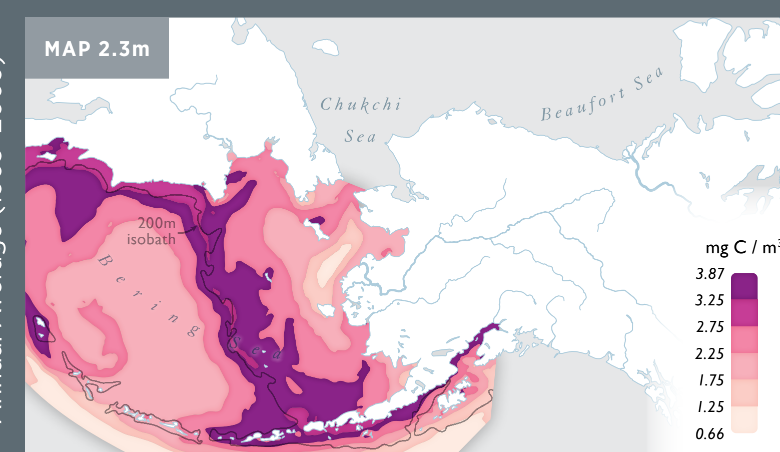




Total Projected Change by 2040

Euphausiid Concentration 0–200 feet (0–60 m)

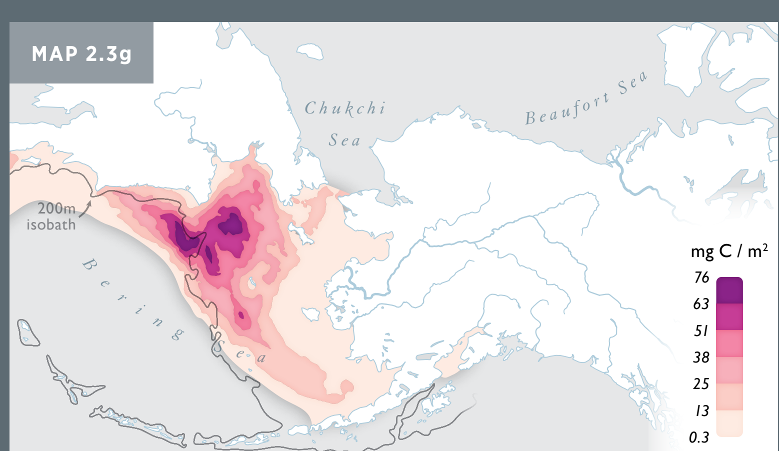
Annual Average (1965–2009)

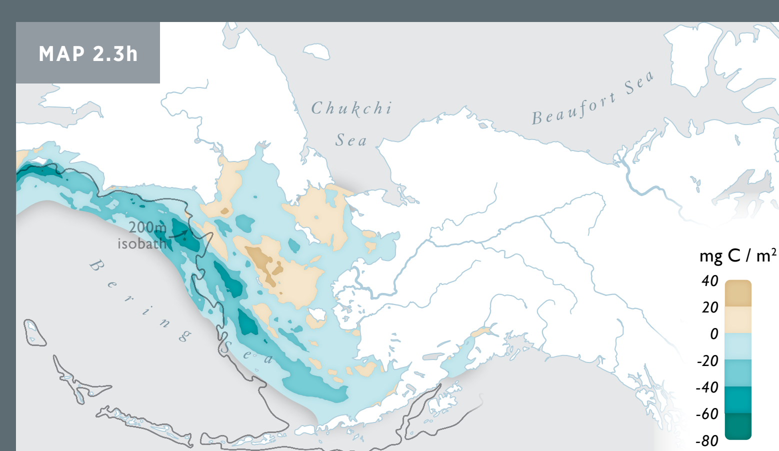


Total Projected Change by 2040

Ice Phytoplankton Concentration

Annual Average (1965–2009)

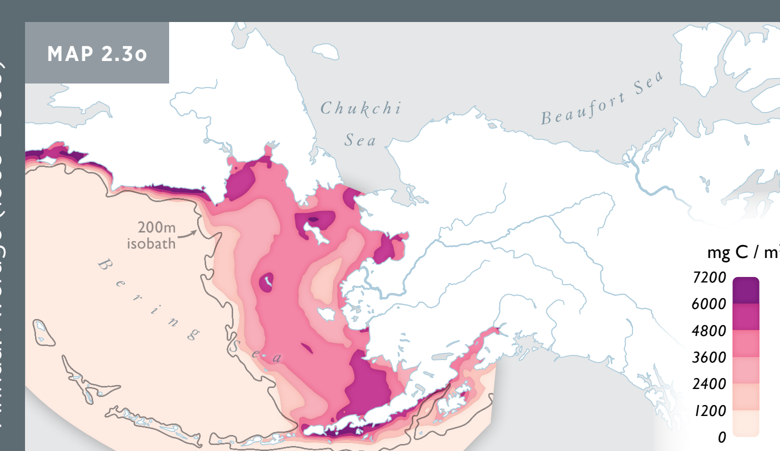


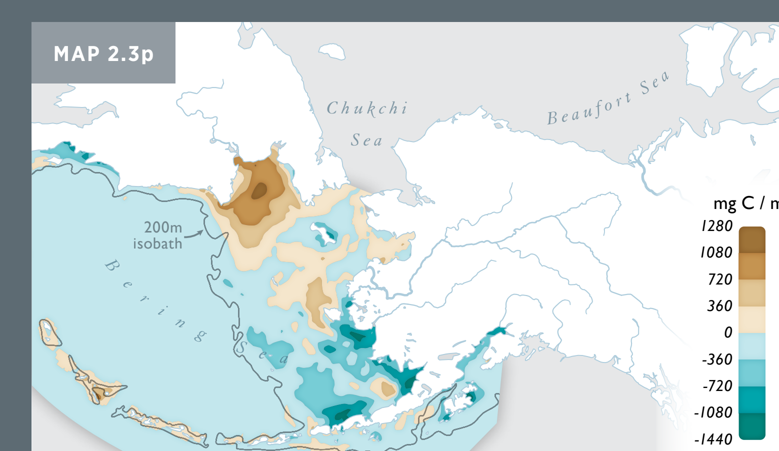


Total Projected Change by 2040

Benthic Infaunal Biomass Concentration

Annual Average (1965–2009)





Total Projected Change by 2040

Smith and Koeppen (2016) [based on Hermann et al. (2013)]

A Closer Look: Bering Sea Weather

Max Goldman

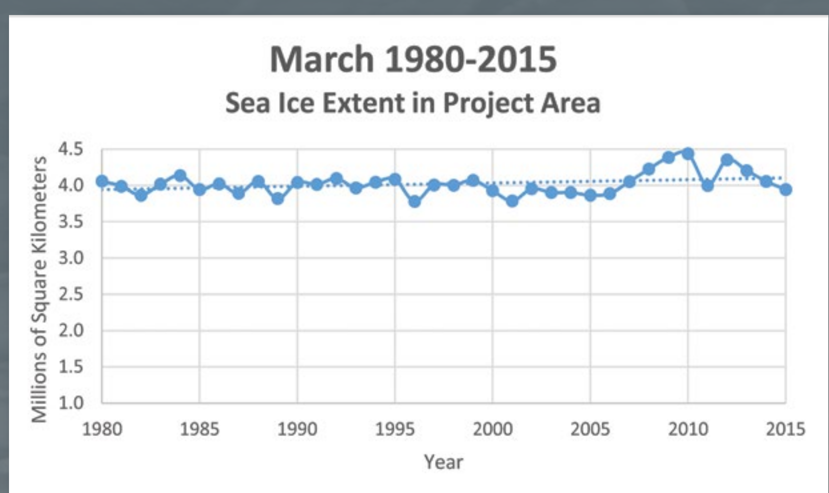
The weather of the Bering Sea changes dramatically on time scales ranging from days to decades (Overland et al. 1999). These changes are closely tied to the physical properties of the ocean, resulting in variations and fluctuations in the marine populations (Overland and Stabeno 2004). By evaluating the nature of weather in the Bering Sea, we can gain an understanding of how this environment influences, and is influenced by, patterns and fluctuations in the global seascape.

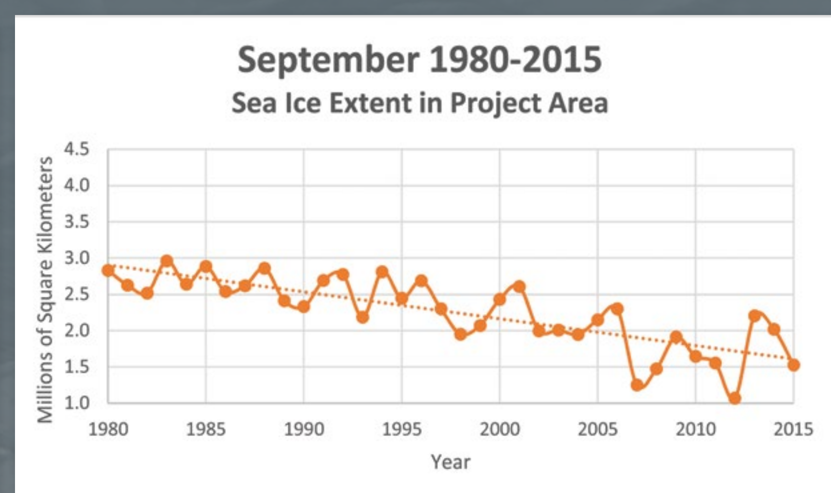
The Bering Sea is one of the stormiest places on the planet through much of the winter, with three to five storms per month during the winter, and gale-force winds that occasionally push sea surface heights up to 40 feet (12 m) (Stabeno et al. 2001, Bond 2005). Although the nature of these storms is highly variable, there are basically two types that typify Bering Sea weather, and perpetuate the systems within. One of the common Bering Sea storms includes an atmospheric circulation pattern moving in from lower latitudes, which produces repeated systems of tight rotation and low-pressure, typically resulting in high winds and moderate temperatures (Bond 2005). This common pattern is perpetuated by the North Pacific High, a high-pressure system generally occurring in summer months between Hawaii and California that leads to Arctic sea-ice retreat.

The other common circulation pattern brings intense bouts of Arctic air from the north during the winter, which pushes the ice-edge south with cold air temperatures (Weeks 2010) and high winds. This pattern is perpetuated by the Aleutian Low (Figure 2.4-3), a seasonal low-pressure system located near the Aleutian Islands in winter that is one of the largest atmospheric circulation patterns in the Northern Hemisphere (Rodionov et al. 2005, Rodionov et al. 2007). Because the typical direction of winds associated with this system has undergone no substantial change in recent decades, winter sea-ice extent in the Bering Sea has also remained relatively steady over the satellite record (1979–present) (National Snow and Ice Data Center 2016, Walsh et al. 2017, Gan et al. 2017).

The Bering Sea ice cover is driven by atmospheric circulation and can be compared to a "conveyor belt," as sea ice forms in the northern Bering Sea and is pushed south by northerly winds (Pease 1980, Weeks 2010). Where it contacts warm shelf waters, the ice melts and cools the water column, facilitating further sea-ice advance. The winds in winter reflect the location of storms associated with the Aleutian Low pressure system. When storm tracks are displaced to the east, winds over the Bering Sea shelf are more northerly, driving expanded sea-ice extent (Bond 2005, Rodionov et al. 2007).

The annual or decadal winter weather conditions in the Bering Sea depend on the tendency for one type of pattern versus the other (Overland et al. 1999, Bond 2005). Many factors, known and unknown, feed the propensity for one system over the other, and long time scales can be dominated by warmer or colder systems. The early 1970s were dominated by colder winds from the north and extensive, long-lasting ice packs. This period was followed by a warm period of reduced ice cover from the late 1970s through much of the 1980s. For example, at St. Paul in the Pribilof Islands, the average winter air temperatures warmed 14.5° F (8° C) during this transition (Reynolds and Smith 1994). This cyclical, decadal shift in weather/climate regimes is known as the Pacific Decadal Oscillation, or PDO. Even when accounting for the PDO, the winters of recent decades have been warmer than normal on average (see Climate Summary), with earlier sea-ice retreat, diminishing multiyear pack ice, and later freeze-up.





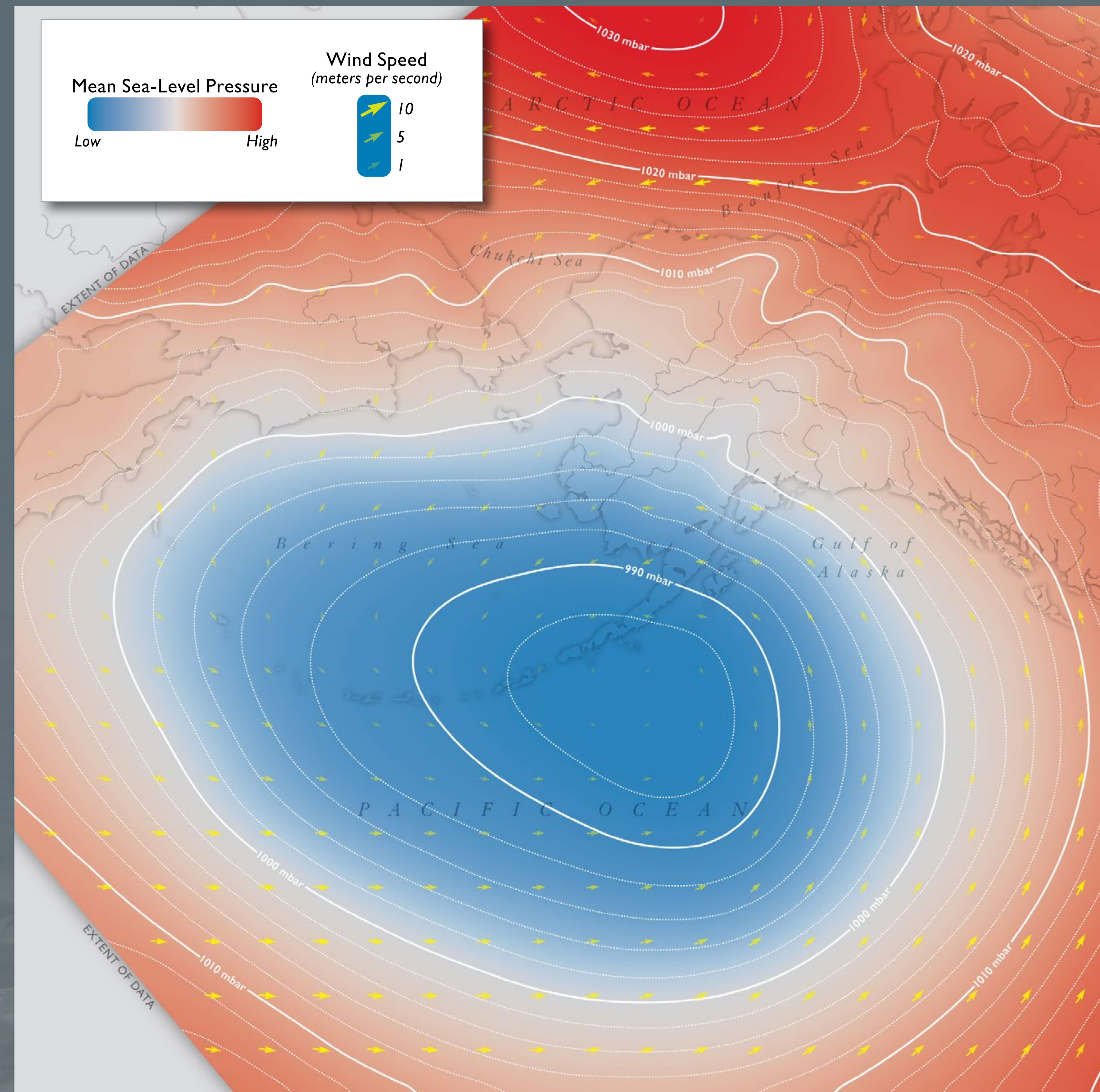
Based on data from Fetterer et al. (2016).

FIGURES 2.4-1 (LEFT), 2.4-2 (RIGHT). The graphs show average March and September sea ice extent (millions of square kilometers) within the project area for each year between 1980 and 2015. March sea ice extent has remained relatively constant over this time period, while September sea ice extent has decreased.

Tim Sullivan / USCG

Map Author: Max Goldman
Cartographer: Daniel P. Huffman

Audubon ALASKA



Based on data from NOAA Earth System Research Laboratory-Physical Sciences Division (2017).

FIGURE 2.4-3. ALEUTIAN LOW-PRESSURE SYSTEM

Among the stormiest places on the planet, winter weather in the Bering Sea is driven in large part by a semipermanent, low-pressure system called the Aleutian Low. This map shows an example of that system from February of 2016, illustrating the area of low pressure situated over the Aleutian Island chain. The Aleutian Low produces heavy rain and strong, cyclonic winds that push sea ice, formed annually in the colder, northern part of the Bering Sea, southwest over the Bering shelf.

REFERENCES

Abelmann, A., R. Gersonde, G. Knorr, X. Zhang, B. Chapligin, E. Maier, O. Esper, H. Friedrichsen, G. Lohmann, and H. Meyer. 2015. The seasonal sea-ice zone in the glacial Southern Ocean as a carbon sink. *Nature Communications* 6.

Arctic Climate Impact Assessment. 2004. Impacts of a Warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press, Cambridge, United Kingdom.

Aksenov, Y., V. V. Ivanov, A. J. G. Nurser, S. Bacon, I. V. Polyakov, A. C. Coward, A. C. Naveira-Garabato, and A. Beszczynska-Moeller. 2011. The Arctic Circumpolar Boundary Current. *Journal of Geophysical Research Atmospheres* 116:C09017.

Amstrup, S. C., B. G. Marcot, and D. C. Douglas. 2008. A Bayesian network modeling approach to forecasting the 21st century worldwide status of polar bears, *In Arctic Sea Ice Decline: Observations, Projections, Mechanisms, and Implications*. pp. 213-268. American Geophysical Union, Washington, DC.

Arctic Monitoring and Assessment Programme. 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme, Oslo, Norway.

Audubon Alaska. 2009. Recurring Leads (Average Extent 1993-2004) GIS File. Audubon Alaska, Anchorage, AK.

_____. 2016a. Distribution of $\delta^{13}C$ in Surface Sediments GIS file. Audubon Alaska, Anchorage, AK.

_____. 2016b. Landfast Ice GIS File. Audubon Alaska, Anchorage, AK.

_____. 2016c. Monthly Sea Ice Approximate 2006-2015 Medians GIS File. Audubon Alaska, Anchorage, AK.

_____. 2016d. Southernmost Ice Extent GIS File. Anchorage, AK.

Audubon Alaska, Kawerak, and Sandhill.Culture.Craft. 2017. Traditional Knowledge-Holder Map Review Workshop. February 21-22, 2017. Nome, AK.

Benke, A. C. and C. E. Cushing. 2005. *Rivers of North America*. Elsevier Academic Press, Burlington, MA.

Bond, A. L., I. L. Jones, S. S. Seneviratne, and S. B. Muzaffar. 2013. Least Auklet (*Aethia pusilla*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/leaauk/introduction.

Bond, N. A. 2005. What differences have occurred in summer and winter weather in the Bering Sea in the past 30 years? National Oceanic and Atmospheric Administration. Accessed online 20 May 2017 at http://www.beringclimate.noaa.gov/essays_bond.html.

Bouttes, N., D. Paillard, and D. M. Roche. 2010. Impact of brine-induced stratification on the glacial carbon cycle. *Climate of the Past* 6:575-589.

Boveng, P. L., J. L. Bengtson, T. W. Buckley, M. F. Cameron, S. P. Dahle, B. P. Kelly, B. A. Megrey, J. E. Overland, and N. J. Williamson. 2009. Status Review of the Spotted Seal (*Phoca largha*). NOAA Technical Memorandum NMFS-AFSC-200. US Department of Commerce, National Oceanic and Atmospheric Administration, Seattle, WA.

Boveng, P. L., J. L. Bengtson, M. F. Cameron, S. P. Dahle, E. A. Logerwell, J. M. London, J. E. Overland, J. T. Sterling, D. E. Stevenson, B. L. Taylor, and H. L. Ziel. 2013. Status Review of the Ribbon Seal (*Histriophoca fasciata*). NOAA Technical Memorandum NMFS-AFSC-255. National Oceanic and Atmospheric Administration, Seattle, WA.

Bradstreet, M. S. W. and W. E. Cross. 1982. Trophic relationships at high Arctic ice edges. *Arctic* 35:1-12.

Brugler, E. T., R. S. Pickart, G. W. K. Moore, S. Roberts, T. J. Weingartner, and H. Statscewich. 2014. Seasonal to interannual variability of the Pacific water boundary current in the Beaufort Sea. *Progress in Oceanography* 127:1-20.

Calbet, A. 2008. The trophic roles of microzooplankton in marine systems. *ICES Journal of Marine Science* 65:325-331.

Cameron, M. F., J. L. Bengtson, P. L. Boveng, J. Jansen, B. P. Kelly, S. Dahle, E. Logerwell, J. Overland, C. Sabine, and G. Waring. 2010. Status Review of the Bearded Seal (*Erignathus barbatus*). NOAA Technical Memorandum NMFS-AFSC-211. National Oceanic and Atmospheric Administration, Seattle, WA.

Carmack, E. C. and R. W. MacDonald. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: A setting for marine life. *Arctic* 55:29-45.

Coachman, L. K., K. Aagaard, and R. B. Tripp. 1975. *Bering Strait: The Regional Physical Oceanography*. University of Washington Press, Seattle, WA.

Conover, R. J. 1988. Comparative life histories in the genera *Calanus* and *Neocalanus* in high latitudes of the northern hemisphere. *Hydrobiologia* 167:127-142.

Divoky, G. J. 1979. Sea ice as a factor in seabird distribution and ecology in the Beaufort, Chukchi, and Bering Seas, *In Conservation of Marine Birds of Northern North America. Wildlife Research Report No. 11*. J. C. Bartonek and D. N. Nettleship eds. US Fish and Wildlife Service, Washington, DC.

Dunton, K. H., S. V. Schonberg, and L. W. Cooper. 2012. Food web structure of the Alaskan nearshore shelf and estuarine lagoons of the Beaufort Sea. *Estuaries and Coasts* 35:416-435.

Eicken, H., L. Shapiro, A. G. Gaylord, A. Mahoney, and P. W. Cotter. 2009. Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas, 1993–2004. National Snow and Ice Data Center, Boulder, CO.

_____. 2005. Mapping and Characterization of Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas. Minerals Management Service, Alaska OCS Region, Anchorage, AK.

Elphick, C. S. and G. L. Hunt. 1993. Variations in the distributions of marine birds with water mass in the northern Bering Sea. *Condor* 95:33-44.

Farzan, S. 2017. Murre Die-Off Linked To Warm Water Temperatures. KBBI, Homer, AK.

Fetterer, F., K. Knowles, W. Meier, and M. Savoie. 2016. Sea Ice Index, Version 2. National Snow and Ice Data Center, Boulder, CO.

Gall, A. E., R. H. Day, and T. J. Weingartner. 2013. Structure and variability of the marine-bird community in the northeastern Chukchi Sea. *Continental Shelf Research* 67:96-115.

Gan, B., L. Wu, F. Jia, S. Li, W. Cai, H. Nakamura, M. A. Alexander, and A. J. Miller. 2017. On the response of the Aleutian Low to greenhouse warming. *Journal of Climate* 30:3907-3925.

Gradinger, R. 2008. Sea ice, *In Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research*. R. Hopcroft, B. Bluhm, and R. Gradinger eds. University of Alaska Fairbanks, Institute of Marine Science, Fairbanks, AK.

Grebmeier, J. M., L. W. Cooper, C. A. Ashjian, B. A. Bluhm, R. B. Campbell, K. E. Dunton, J. Moore, S. Okkonen, G. Sheffield, J. Trefry, and S. Y. Pasternak. 2015. Pacific Marine Arctic Regional Synthesis (PacMARS) Final Report. North Pacific Research Board, Anchorage, AK.

Grebmeier, J. M., L. W. Cooper, H. M. Feder, and B. I. Sirenko. 2006. Ecosystem dynamics of the Pacific-influenced northern Bering and Chukchi Seas in the Amerasian Arctic. *Progress in Oceanography* 71:331-361.

Hermann, A. J., G. A. Gibson, N. A. Bond, E. N. Curchitser, K. Hedstrom, W. Cheng, M. Wang, P. J. Stabeno, L. Eisner, and K. D. Cieciel. 2013. A multivariate analysis of observed and modeled biophysical variability on the Bering Sea shelf: Multidecadal hindcasts (1970–2009) and forecasts (2010–2040). *Deep Sea Research Part II: Topical Studies in Oceanography* 94:121-139.

Horner, R. and G. C. Schrader. 1982. Relative contributions of ice algae, phytoplankton, and benthic microalgae to primary production in nearshore regions of the Beaufort Sea. *Arctic* 35:485-503.

Hunt, G. L., P. Stabeno, G. Walters, E. Sinclair, R. D. Brodeur, J. M. Napp, and N. A. Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. *Deep Sea Research Part II: Topical Studies in Oceanography* 49:5821-5853.

Jay, C. V., R. L. Taylor, A. S. Fischbach, M. S. Udevitz, and W. S. Beatty. 2017. Walrus haul-out and in water activity levels relative to sea ice availability in the Chukchi Sea. *Journal of Mammalogy* 98:386-396.

Johnson, M. and H. Eicken. 2016. Estimating Arctic sea-ice freeze-up and break-up from the satellite record: A comparison of different approaches in the Chukchi and Beaufort Seas. *Elementa Science of the Anthropocene* 4:124.

Kelly, B. P., J. L. Bengtson, P. L. Boveng, M. F. Cameron, S. P. Dahle, J. K. Jansen, E. A. Logerwell, J. E. Overland, C. L. Sabine, and G. T. Waring. 2010. Status Review of the Ringed Seal (*Phoca hispida*). NOAA Technical Memorandum NMFS-AFSC-212. National Oceanic and Atmospheric Administration, Springfield, VA.

Koeppen, W., K. Kuletz, A. Poe, H. Renner, M. Smith, T. Van Pelt, N. Walker, and J. Williams. 2016. Chapter 6: Exploring vulnerabilities of seabirds using projected changes in climate in the Aleutian Islands and Bering Sea, *In The Aleutian-Bering Climate Vulnerability Assessment. Final Report*. A. Poe, T. Van Pelt, and J. Littell eds. Aleutian and Bering Sea Islands Landscape Conservation Cooperative, Anchorage, AK.

Ladd, C., J. Jahncke, G. L. Hunt, K. O. Coyle, and P. J. Stabeno. 2005. Hydrographic features and seabird foraging in Aleutian passes. *Fisheries Oceanography* 14:178-195.

Laidre, K. L., H. Stern, K. M. Kovacs, L. F. Lowry, S. E. Moore, E. V. Regehr, S. H. Ferguson, O. Wiig, P. Boveng, R. P. Angliss, E. W. Born, D. Litovka, L. T. Quakenbush, C. Lydersen, D. Vongraven, and F. Ugarte. 2015. Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. *Conservation Biology* 29:724-737.

Laidre, K. L., I. Stirling, L. F. Lowry, Ø. Wiig, M. P. Heide-Jørgensen, and S. H. Ferguson. 2008. Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. *Ecological Applications* 18:S97-S125.

Large, W. G. and S. G. Yeager. 2008. The global climatology of an interannually varying air-sea flux dataset. *Climate Dynamics* 33:341-364.

Llinás, L., R. S. Pickart, J. T. Mathis, and S. L. Smith. 2009. Zooplankton inside an Arctic Ocean cold-core eddy: Probable origin and fate. *Deep Sea Research Part II: Topical Studies in Oceanography* 56:1290-1304.

Maftei, M. and R. Russ. 2014. A mass post-breeding movement of Crested Auklets *Aethia cristatella* in the Chukchi Sea. *Marine Ornithology* 42:31-34.

Marine Mammal Commission. 2000. Impacts of changes in sea ice and other environmental parameters on marine mammals. Marine Mammal Commission Workshop, Girdwood, AK.

Martello, M. L. 2008. Arctic indigenous peoples as representations and representatives of climate change. *Social Studies of Science* 38:351-376.

Maslanik, J., J. Stroeve, C. Fowler, and W. Emery. 2011. Distribution and trends in Arctic sea ice age through spring 2011. *Geophysical Research Letters* 38:L13502.

McClelland, J. W., R. M. Holmes, B. J. Peterson, P. A. Raymond, R. G. Striegl, A. V. Zhulidov, S. A. Zimov, N. Zimov, S. E. Tank, R. G. M. Spencer, R. Staples, T. Y. Gurtovaya, and C. G. Griffin. 2016. Particulate organic carbon and nitrogen export from major Arctic rivers. *Global Biogeochemical Cycles* 30:629-643.

Meier, W. N., G. K. Hovelsrud, B. E. H. Oort, J. R. Key, K. M. Kovacs, C. Michel, C. Haas, M. A. Granskog, S. Gerland, and D. K. Perovich. 2014. Arctic sea ice in transformation: A review of recent observed changes and impacts on biology and human activity. *Reviews of Geophysics* 52:185-217.

Moline, M. A., N. J. Karnovsky, Z. Brown, G. J. Divoky, T. K. Frazer, C. A. Jacoby, J. J. Torres, and W. R. Fraser. 2008. High latitude changes in ice dynamics and their impact on polar marine ecosystems. *Annals of the New York Academy of Sciences* 1134:267-319.

Moller, H., F. Berkes, P. O. B. Lyver, and M. Kislalioglu. 2004. Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society* 9:2.

Moore, S. E. and H. P. Huntington. 2008. Arctic marine mammals and climate change: Impacts and resilience. *Ecological Applications* 18:S157-S165.

Mueter, F. J. and M. A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. *Ecological Applications* 18:309-320.

National Oceanic and Atmospheric Administration. 1988. Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones: Strategic Assessment Data Atlas. National Oceanic and Atmospheric Administration, Rockville, MD.

_____. 2006. Review of the Status of the Right Whales in the North Atlantic and North Pacific Oceans. National Oceanic and Atmospheric Administration Alaska Regional Office, Juneau, AK.

_____. 2017. Ocean Currents. National Oceanic and Atmospheric Administration. Accessed online 15 April 2017 at http://www.noaa.gov/resource-collections/ocean-currents.

National Oceanic and Atmospheric Administration Earth System Research Laboratory—Physical Sciences Division. 2017. NCEP North American Regional Reanalysis. National Oceanic and Atmospheric Administration, Boulder, CO. Accessed online at https://www.esrl.noaa.gov/psd/data/gridded/data.narr.html.

National Snow and Ice Data Center. 2016. IMS Daily Northern Hemisphere Snow and Ice Analysis at 4 km and 24 km Resolution. National Snow and Ice Data Center, Boulder, CO. Accessed online at http://nsidc.org/data/docs/noaa/g02156_ims_snow_ice_analysis/index.html#acq_proc.

National Snow and Ice Data Center, F. Fetterer, and C. Fowler. 2006. National Ice Center Arctic Sea Ice Charts and Climatologies in Gridded Format. National Snow and Ice Data Center, Boulder, CO.

National Snow and Ice Data Center and C. S. Konig Beatty. 2012. Arctic Landfast Sea Ice 1953-1998, Version 1. National Snow and Ice Data Center, Boulder, CO.

Nihoul, J. C. J., P. Adam, P. Brasseur, E. Deleersnijder, S. Djenidi, and J. Haus. 1993. Three-dimensional general circulation model of the northern Bering Sea's summer ecohydrodynamics. *Continental Shelf Research* 13:509-542.

Nikolopoulos, A., R. S. Pickart, P. S. Fratantoni, K. Shimada, D. J. Torres, and E. P. Jones. 2009. The western Arctic boundary current at 152°W: Structure, variability, and transport. *Deep Sea Research Part II: Topical Studies in Oceanography* 56:1164-1181.

Oceana and Kawerak. 2014. Bering Strait Marine Life and Subsistence Use Data Synthesis. Oceana and Kawerak, Juneau, AK.

Overland, J. E., J. M. Adams, and N. A. Bond. 1999. Decadal variability of the Aleutian Low and its relation to high-latitude circulation. *Journal of Climate* 12:1542-1548.

Overland, J. E. and P. J. Stabeno. 2004. Is the climate of Bering Sea warming and affecting the ecosystem? *EOS* 85:309-316.

Parrenin, F., V. Masson-Delmotte, P. Köhler, D. Raynaud, D. Paillard, J. Schwander, C. Barbante, A. Landais, A. Wegner, and J. Jouzel. 2013. Synchronous change of atmospheric CO_2 and Antarctic temperature during the last deglacial warming. *Science* 339:1060-1063.

Pease, C. H. 1980. Eastern Bering Sea ice processes. *Monthly Weather Review* 108:2015-2023.

Perovich, D. K., S. Gerland, S. Hendricks, W. Meier, M. Nicolaus, J. A. Richter-Menge, and M. Tschudi. 2013. Sea ice, *In Arctic Report Card 2013*. M. O. Jeffries, J. A. Richter-Menge, and J. E. Overland eds. Accessed online at http://www.arctic.noaa.gov/reportcard.

Perovich, D. K., S. Gerland, S. Hendricks, W. N. Meier, M. Nicolaus, and M. Tschudi. 2015. The Arctic: Sea ice cover [in "State of the Climate 2014"]. *Bulletin of the American Meteorological Society* 96:S145-S146.

Perovich, D. K. and J. A. Richter-Menge. 2015. Regional variability in sea ice melt in a changing Arctic. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 373:20140165.

Piatt, J. F. and A. M. Springer. 2007. Marine ecoregions of Alaska, *In Long-term Ecological Change in the Northern Gulf of Alaska*. R. B. Spies ed., pp. 522–526. Elsevier, Amsterdam, Netherlands.

Pickart, R. and B. Corlett. 2016. Closing the mass budget between Bering Strait and the Arctic Basin: The Chukchi slope current. *In Alaska Marine Science Symposium*. Anchorage, AK.

Pickart, R. S., G. W. K. Moore, D. J. Torres, P. S. Fratantoni, R. A. Goldsmith, and J. Yang. 2009. Upwelling on the continental slope of the Alaskan Beaufort Sea: Storms, ice, and oceanographic response. *Journal of Geophysical Research: Oceans* 114:C00A13.

Pickart, R. S., L. M. Schulze, G. W. K. Moore, M. A. Charette, K. R. Arrigo, G. van Dijken, and S. L. Danielson. 2013. Long-term trends of upwelling and impacts on primary productivity in the Alaskan Beaufort Sea. *Deep Sea Research Part I: Oceanographic Research Papers* 79:106-121.

Pickart, R. S., M. A. Spall, G. W. K. Moore, T. J. Weingartner, R. A. Woodgate, K. Aagaard, and K. Shimada. 2011. Upwelling in the Alaskan Beaufort Sea: Atmospheric forcing and local versus non-local response. *Progress in Oceanography* 88:78-100.

Pisareva, M. N., R. S. Pickart, M. A. Spall, C. Nobre, D. J. Torres, G. W. K. Moore, and T. E. Whitledge. 2015. Flow of Pacific water in the western Chukchi Sea: Results from the 2009 RUSALCA expedition. *Deep Sea Research Part I: Oceanographic Research Papers* 105:53-73.

Raymond-Yakoubian, J., Y. Khokhlov, and A. Yarzutkina. 2014. Indigenous Knowledge and Use of Bering Strait Region Ocean Currents. Kawerak, Inc., Nome, AK.

Reed, R. K. and P. J. Stabeno. 1997. Long-term measurements of flow near the Aleutian Islands. *Journal of Marine Research* 55:565-575.

Reynolds, R. W. and T. M. Smith. 1994. Improved global sea surface temperature analyses using optimum interpolation. *Journal of Climate* 7:929-948.

Rode, K. D., E. V. Regehr, D. C. Douglas, G. Durner, A. E. Derocher, G. W. Thiemann, and S. M. Budge. 2014. Variation in the response of an Arctic top predator experiencing habitat loss: Feeding and reproductive ecology of two polar bear populations. *Global Change Biology* 20:76-88.

Rodionov, S. N., N. A. Bond, and J. E. Overland. 2007. The Aleutian Low, storm tracks, and winter climate variability in the Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 54:2560-2577.

Rodionov, S. N., J. E. Overland, and N. A. Bond. 2005. The Aleutian Low and winter climatic conditions in the Bering Sea. Part I: Classification. *Journal of Climate* 18:160-177.

Sapozhnikov, V. V., O. S. Ivanova, and N. V. Mordasova. 2011. Identification of local upwelling zones in the Bering Sea using hydrochemical parameters. *Oceanology* 51:247-254.

Satterthwaite-Phillips, D., C. Krenz, G. Gray, and L. Dodd. 2016. Iñuuniaļiqput Iḷiļugu Nunaŋŋuanun: Documenting Our Way of Life through Maps. Northwest Arctic Borough, Kotzebue, AK.

Scenarios Network for Alaska and Arctic Planning. 2016. Historical Sea Ice Atlas: Observed Estimates of Sea Ice Concentration in Alaska Waters. University of Alaska Fairbanks. Accessed online at http://ckan.snap.uaf.edu/dataset/historical-sea-ice-atlas-observed-estimates-of-sea-ice-concentration-in-alaska-waters.

Schmoker, C., S. Hernández-León, and A. Calbet. 2013. Microzooplankton grazing in the oceans: Impacts, data variability, knowledge gaps and future directions. *Journal of Plankton Research* 35:691-706.

Schonberg, S. V., J. T. Clarke, and K. H. Dunton. 2014. Distribution, abundance, biomass and diversity of benthic infauna in the northeast Chukchi Sea, Alaska: Relation to environmental variables and marine mammals. *Deep Sea Research Part II: Topical Studies in Oceanography* 102:144-163.

Sigler, M. F., M. Renner, S. L. Danielson, L. B. Eisner, R. R. Lauth, K. J. Kuletz, E. A. Logerwell, and G. L. Hunt, Jr. 2011. Fluxes, fins, and feathers: Relationships among the Bering, Chukchi, and Beaufort Seas in a time of climate change. *Oceanography* 24:250-265.

Sigman, D. M., M. P. Hain, and G. H. Haug. 2010. The polar ocean and glacial cycles in atmospheric CO_2 concentration. *Nature* 466:47-55.

Smith, M. A. and W. Koeppen. 2016. Analysis of PMEL Models CORE and CCCma to Summarize Past and Future Conditions in the Bering Sea. Audubon Alaska and Axiom Data Science, Anchorage, AK.

Spall, M. A., R. S. Pickart, P. S. Fratantoni, and A. J. Plueddemann. 2008. Western Arctic shelfbreak eddies: Formation and transport. *Journal of Physical Oceanography* 38:1644-1668.

Spiridonov, V. A., M. V. Gavrilo, E. D. Krasnova, and N. G. Nikolaeva. 2011. Atlas of Marine and Coastal Biological Diversity of the Russian Arctic. WWF Russia, Moscow, Russia.

Springer, A. M. and C. P. McRoy. 1993. The paradox of pelagic food webs in the northern Bering Sea—III: Patterns of primary production. *Continental Shelf Research* 13:575-599.

Stabeno, P. J., N. A. Bond, N. B. Kachel, S. A. Salo, and J. D. Schumacher. 2001. On the temporal variability of the physical environment over the south-eastern Bering Sea. *Fisheries Oceanography* 10:81-98.

Stabeno, P. J., J. D. Schumacher, and K. Ohtani. 1999. The physical oceanography of the Bering Sea, *In Dynamics of the Bering Sea: A Summary of Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea*. T. R. Loughlin and K. Ohtani eds. North Pacific Marine Science Organization (PICES), University of Alaska Sea Grant AK-SG-99-03, Fairbanks, AK.

Stringer, W. J. and J. E. Groves. 1991. Location and areal extent of polynyas in the Bering and Chukchi Seas. *Arctic* 44:164-171.

Sun, X. and K. Matsumoto. 2010. Effects of sea ice on atmospheric pCO_2: A revised view and implications for glacial and future climates. *Journal of Geophysical Research: Biogeosciences* 115:G02015.

Takahashi, K., A. C. Ravelo, C. A. Alvarez Zarikian, and Expedition 323 Scientists. 2011. Expedition 323 Summary. Proceedings of the Integrated Ocean Drilling Program (IODP).

Tschudi, M., C. Fowler, and J. Maslanik. 2015. EASE-Grid Sea Ice Age, Version 2. NASA National Snow and Ice Data Center Distributed Active Archive Center, Boulder, CO. Accessed online at http://nsidc.org/data/docs/daac/nsidc0611-sea-ice-age/.

Tschudi, M., C. Fowler, J. Maslanik, and J. Stroeve. 2010. Tracking the movement and changing surface characteristics of Arctic sea ice. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 3:536-540.

University of Alaska Fairbanks Institute of Marine Science. 2009. Chukchi Sea Circulation. Accessed online at http://www.ims.uaf.edu/chukchi.

US Fish and Wildlife Service. 2015. Polar Bear (*Ursus maritimus*) Conservation Management Plan, Draft. US Fish and Wildlife, Region 7, Anchorage, AK.

_____. 2016. Alaska Seabird Die-off. US Fish and Wildlife Service, Anchorage, AK.

US Geological Survey. 2016. USGS Current Water Data for Alaska. US Geological Survey. Accessed online at https://waterdata.usgs.gov/ak/nwis/rt.

Walkusz, W., W. J. Williams, L. A. Harwood, S. E. Moore, B. E. Stewart, and S. Kwasniewski. 2012. Composition, biomass and energetic content of biota in the vicinity of feeding bowhead whales (*Balaena mysticetus*) in the Cape Bathurst upwelling region (south eastern Beaufort Sea). *Deep Sea Research Part I: Oceanographic Research Papers* 69:25-35.

Walsh, J. E., F. Fetterer, J. Scott Stewart, and W. L. Chapman. 2017. A database for depicting Arctic sea ice variations back to 1850. *Geographical Review* 107:89-107.

Wang, M. and J. E. Overland. 2009. A sea ice free summer Arctic within 30 years? *Geophysical Research Letters* 36:L07502.

_____. 2015. Projected future duration of the sea-ice-free season in the Alaskan Arctic. *Progress in Oceanography* 136:50-59.

Weeks, W. 2010. *On Sea Ice*. University of Alaska Press, Fairbanks, AK.

Weingartner, T. 2006. Circulation, Thermohaline Structure, and Cross-shelf Transport in the Alaskan Beaufort Sea. School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, AK.

_____. 2008. Physical oceanography, *In Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research*. R. Hopcroft, B. Bluhm, and R. Gradinger eds. University of Alaska Fairbanks, Institute of Marine Science, Fairbanks, AK.

Weingartner, T., E. Dobbins, S. Danielson, P. Winsor, R. Potter, and H. Statscewich. 2013. Hydrographic variability over the northeastern Chukchi Sea shelf in summer-fall 2008–2010. *Continental Shelf Research* 67:5-22.

Weingartner, T., W. Maslowski, S. Okkonen, R. Pickart, J. Trefey, and R. Woodgate. 2012. Chukchi/Beaufort physical oceanographic overview. *In* Synthesis of Arctic Research (SOAR) Workshop. Anchorage, AK.

Weingartner, T. J., K. Aagaard, R. Woodgate, S. Danielson, Y. Sasaki, and D. Cavalieri. 2005a. Circulation on the north central Chukchi Sea shelf. *Deep Sea Research Part II: Topical Studies in Oceanography* 52:3150-3174.

Weingartner, T. J., S. L. Danielson, and T. C. Royer. 2005b. Freshwater variability and predictability in the Alaska Coastal Current. *Deep Sea Research Part II: Topical Studies in Oceanography* 52:169-191.

Welch, C. 2015. Mass Death of Seabirds in Western US Is 'Unprecedented'. National Geographic, Washington, DC. Accessed online 4 April 2017 at http://news.nationalgeographic.com/news/2015/01/150123-seabirds-mass-die-off-auklet-california-animals-environment/.

_____. 2016. Huge Puffin Die-off May be Linked to Hotter Seas. National Geographic, Washington, DC. Accessed online 4 April 2017 at http://news.nationalgeographic.com/2016/11/tufted-puffins-die-off-bering-sea-alaska-starvation-warm-water-climate-change/.

Woodgate, R. A., T. Weingartner, and R. Lindsay. 2010. The 2007 Bering Strait oceanic heat flux and anomalous Arctic sea-ice retreat. *Geophysical Research Letters* 37:L01602.

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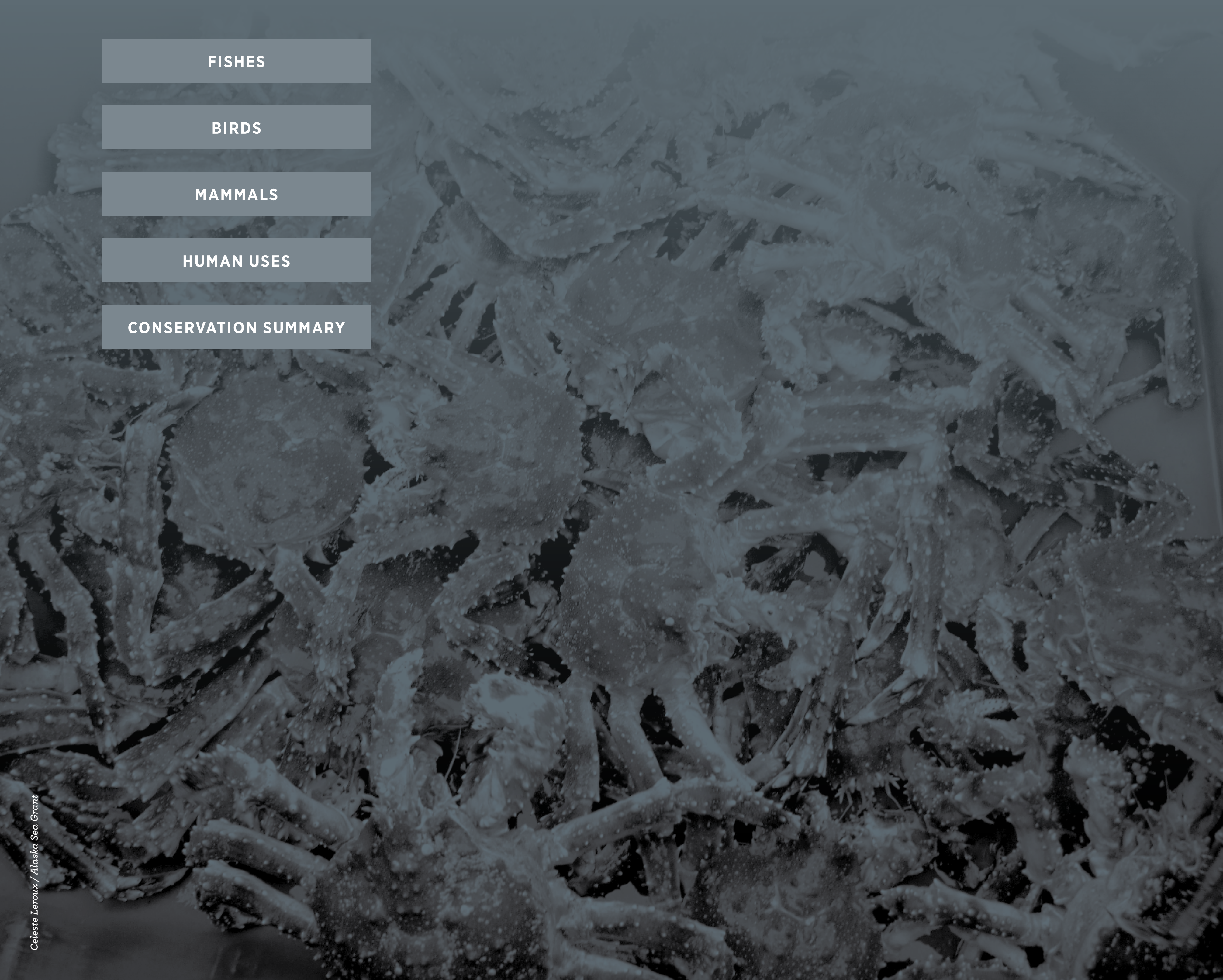

Celeste Leroux/Alaska Sea Grant

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Primary Productivity

Melanie Smith, Max Goldman, Jon Warrenchuk, and Erika Knight

Primary productivity is the rate at which carbon dioxide is converted into organic material by autotrophs, or primary producers. Autotrophs collectively produce ecosystem food that supports the food chain, hence they are referred to as primary producers. This conversion from the simple into the complex happens via two key processes: photosynthesis and chemosynthesis. Primary production via photosynthesis forms the base of the entire food web, both on land and in the oceans.

DISTRIBUTION

In the ocean, photosynthesis only happens in the top 650 feet (200 m) of the water column, as adequate sunlight cannot penetrate any deeper. Below the 200 meter isobath, primary producers rely on the process of chemosynthesis for energy production, through which inorganic compounds such as hydrogen sulfide, sulfur, iron, hydrogen, or ammonia are used in place of sunlight as a catalyst for energy production. Chemosynthesis is rare, and is only common among extremophilic and deep-sea organisms.

In the Arctic, primary production is mostly generated from single-celled microscopic algae in ice and sea water, collectively known as phytoplankton (Frey et al. 2012, Frey et al. 2015). This marine phytoplankton community is a diverse group that includes species of diatoms (symmetrical, silica-based, single-celled algae), dinoflagellates ("tailed" protists), coccolithophrids (calcium carbonate–based algae), and others. Seaweeds and photosynthetic bacteria are also substantial contributors to primary productivity (Duggins et al. 1989, Frey et al. 2015). Measurements of the algal pigment chlorophyll (chlorophyll-a) serve as a proxy for the amount of algal biomass present, as well as overall plant health.

ECOLOGICAL ROLE

Phytoplankton are the basic building block of the marine food web. Some of the energy produced via photosynthesis is consumed during the process; however, most of this energy contributes to the organism's growth, which later becomes available energy to water column grazers that eat phytoplankton. Net primary productivity (NPP) refers to the productivity available to support consumers and the benthos in the sea. Phytoplankton are responsible for nearly all of the primary production in marine ecosystems and almost half of the total photosynthesis on the planet, with 10–15% of global production occurring on the continental shelves alone (Falkowski et al. 1998, Morel and Antoine 2002, Muller-Karger et al. 2005).

Sea-Ice Habitat

Primary production is highly seasonal in the Arctic and subarctic region due to the seasonal nature of light availability and presence of appropriate nutrients (Loeng et al. 2005). Each spring, sea-ice margins begin to retreat and daylight hours lengthen, exposing the water column to the sunlight that was not available all winter (Barber et al. 2015, Leu et al. 2015). In the eastern Bering Sea, the timing of the sea-ice retreat influences the timing of a spring phytoplankton bloom (Sigler et al. 2014). A second phytoplankton bloom occurs in the fall (possibly triggered by re-suspension of nutrients from storms) and the magnitude of the fall bloom is related to the strength of the spring bloom (Sigler et al. 2014). The timing of the sea ice retreat also influences the species composition of the phytoplankton community (Schandelmeier and Alexander 1981, Olson and Strom 2002).

Ice does not have to be completely absent in order for photosynthesis to occur; ice algae has proven to be an integral component of Arctic ecosystem functions. Similarly, under-ice algal blooms are becoming more prevalent, as evidenced by recent observations of massive under-ice blooms, which are likely resulting from diminished ice conditions and the near disappearance of snow-covered, multi-year ice (Frey et al. 2011, Arrigo et al. 2012, Arrigo 2014, Arrigo and van Dijken 2015). A study in the nearshore Beaufort Sea suggests that ice algae provides about two-thirds and phytoplankton provides about one-third of spring NPP (Horner and Schrader 1982). A second Arctic-wide study found that ice algae makes up on average 57% of the water column and sea ice productivity (Gosselin et al. 1997).

Variation in ice cover is the dominant factor in the spatial pattern of primary production from phytoplankton (Wang et al. 2005, Stabeno et al. 2012). In the northern Bering and Chukchi Seas, chlorophyll-a and NPP are tightly coupled with benthic biomass (Grebmeier et al. 1988, Springer and McRoy 1993, Dunton et al. 2005, Grebmeier et al. 2006a, Grebmeier et al. 2006b). Chlorophyll-a and NPP in the Beaufort Sea are less closely linked, except around Barter Island where both relatively high biomass and chlorophyll-a are found (Dunton et al. 2005, Grebmeier and Harvey 2005).

Under cool conditions, sea ice melts later in the spring. The nutrients released by the ice disperse over a larger spatial extent as the sea ice slowly retreats, at a time when there is ample daylight to fuel an ice-edge or under-ice phytoplankton bloom. Under these conditions, the spatial and temporal extent of the spring bloom favor the production of large, lipid-rich copepods and euphausiids, and this provides a food source that increases the survival of juvenile pollock (Hunt et al. 2011, Sigler et al. 2016).

CONSERVATION ISSUES

Grebmeier et al. (2006b) show that the northern Bering and Chukchi Seas are shifting away from tight coupling of pelagic-benthic productivity, coinciding with lower benthic prey populations, higher pelagic fish populations, reduced sea ice, and increased air and ocean temperatures (Grebmeier 2012). Decline in sea-ice extent and warming seawater exacerbate environmental change in this already vulnerable ecosystem (Grebmeier 2012). Climate change may potentially break this short link between primary productivity and the benthos, converting the area to a pelagic- rather than benthic-oriented system (Grebmeier 2012, Grebmeier et al. 2014, Grebmeier et al. 2015b). Understanding the relationship between ice cover and productivity is essential in understanding Arctic marine ecology under reduced ice thickness and extent (Stockwell 2008).

The Arctic Ocean has experienced substantial warming in all seasons (Bekryaev et al. 2010) with huge increases to its annual mean open-water area and surface air temperature (Arrigo and van Dijken 2011). In the Bering Sea, however, warming has been mainly limited to summer, with little to no change to its open-water area (Brown et al. 2011). Ice coverage in the Bering Sea is more closely tied to atmospheric circulation and bathymetry than elsewhere, though the cold water and surface air from the nearby Arctic influence the formation of ice in the Bering Sea, so continued warming in the Arctic will likely lead to diminished ice coverage in the Bering Sea (Brown and Arrigo 2012, 2013).

MAPPING METHODS (MAP 3.1)

Map 3.1 shows maximum measured integrated chlorophyll content (mg/m^2) for the top 330 feet (100 m) of water-column depth during the open-water season. Chlorophyll is used as a proxy for primary productivity because it is found in phytoplankton and algae, which are estimated to make up approximately 57–67% of water-column and sea-ice productivity in the Arctic (Horner and Schrader 1982, Gosselin et al. 1997).

Our map is based on data from water-column samples collected and analyzed for chlorophyll content across the Beaufort and Chukchi Seas, and the eastern portion of the Bering Sea. These samples were collected over several decades (1959–2012) and compiled into two datasets (Ashjian 2013, Grebmeier and Cooper 2014b) in the Earth Observing Laboratory online database as part of the Pacific Marine Arctic Regional Synthesis (PacMARS) project.

MAP ON PAGES 46–47

To produce the primary productivity map, we interpolated the chlorophyll sample data in Esri's Geostatistical Analyst extension using empirical Bayesian kriging with four sectors. In instances where there were multiple sample values in one location, we used only the maximum value at that location for the interpolation. The resulting raster was clipped to a 62-mile (100-km) buffer around the sample points.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality

Integrated water column chlorophyll data are likely the best proxy available for the project area. However, much of the data used in this interpolation are old, as they were gathered as long ago as 1959 (Ashjian 2013). The open-water season is an important time for production, as sea-ice cover does not limit light penetration into the water column. While algal growth at the ice edge, in polynyas, in and under the ice, and in melt ponds may also contribute significantly to primary productivity, accurate measurements are not available for the project area (Krembs et al. 2000, Hill and Cota 2005, Arrigo et al. 2012, Frey et al. 2012, Boetius et al. 2013). Kelp forests may also significantly increase primary production in nearshore environments, especially along the Aleutian Islands (Duggins et al. 1989). However, we were unable to find spatial information regarding kelp forests in our project area.

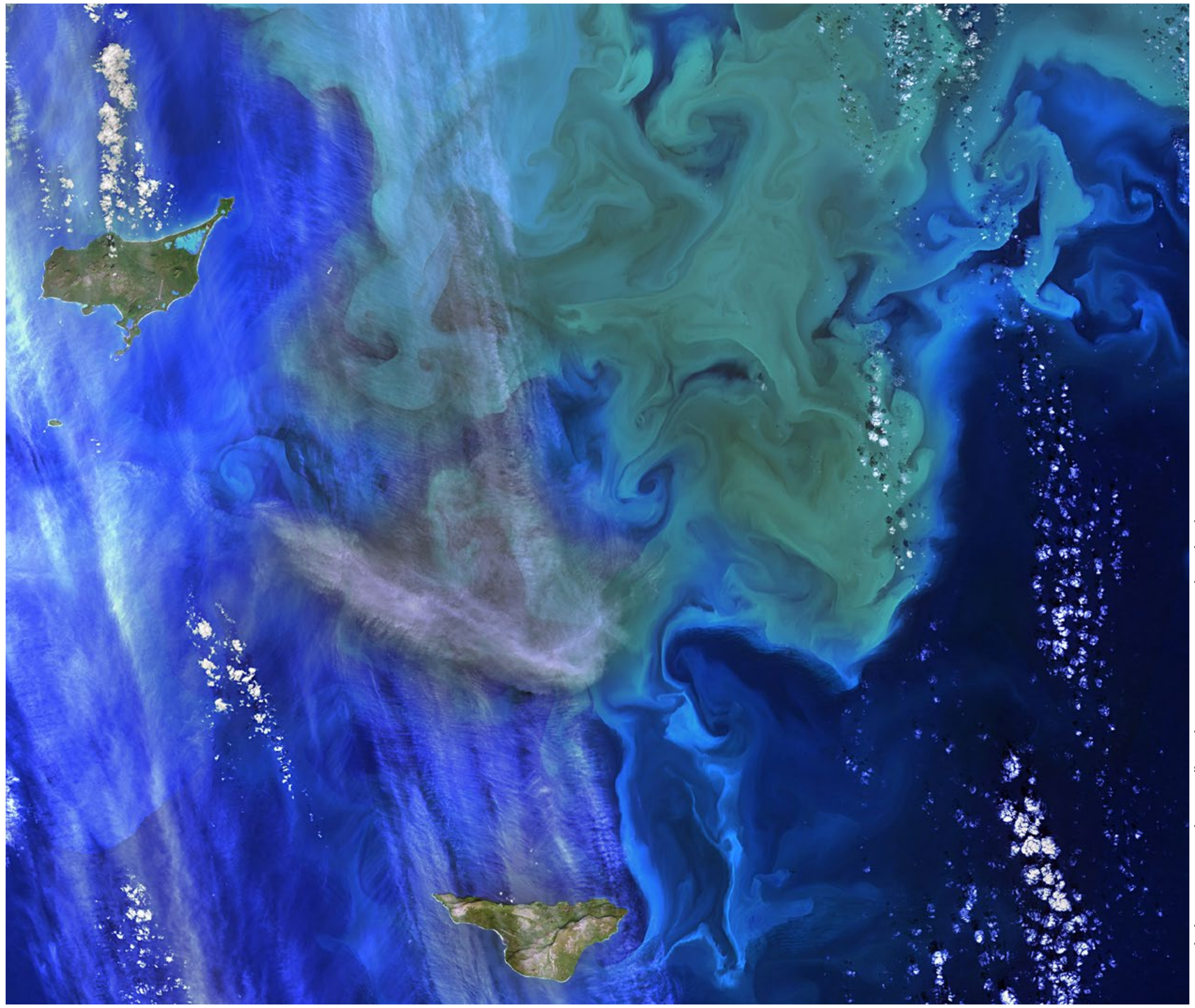
While there are satellite data available for the region, these data may not reflect biomass accurately because of subsurface plumes of phytoplankton and, in coastal waters, the turbidity and dissolved organic matter content of river inputs (Chaves et al. 2015, Tremblay et al. 2015).

Reviewer
- Michael Sigler

MAP DATA SOURCES

Integrated Chlorophyll Sample Data (mg/m^2) for 0–100 m Depth: Audubon Alaska and Oceana (2017) based on Ashjian (2013) and Grebmeier and Cooper (2014b)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)



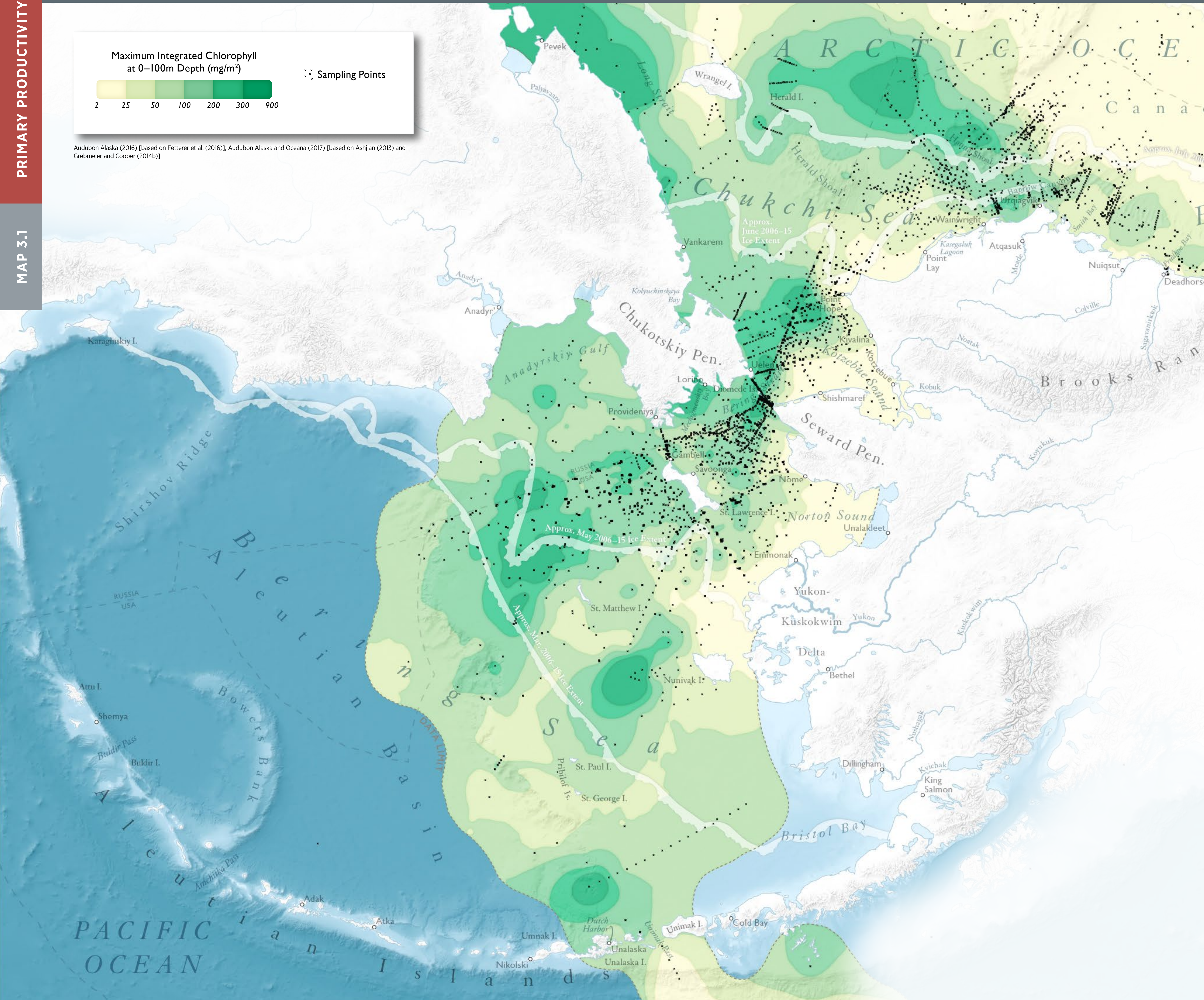
NASA Earth Observatory images by Jesse Allen and Norman Kuring, using Landsat 8 data from USGS.

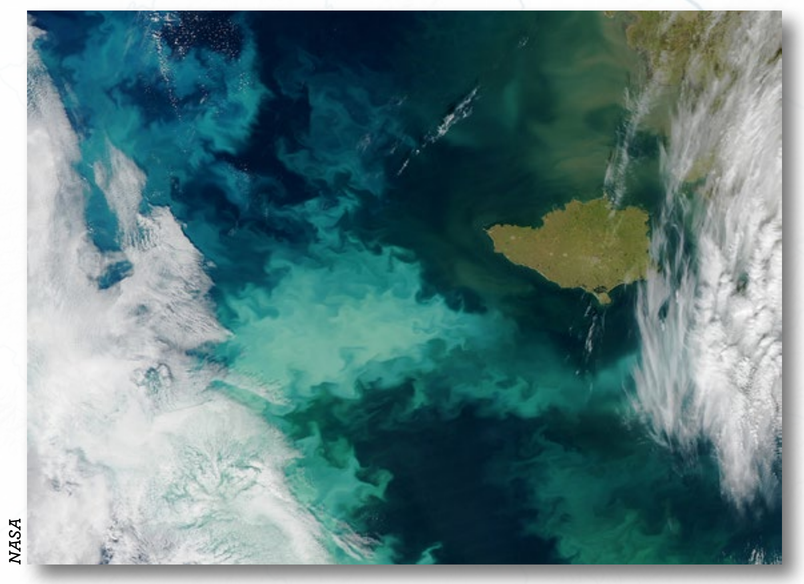
The aquamarine color is a coccolithophorid phytoplankton bloom that occurred around the Pribilof Islands in the eastern Bering Sea in 2014. Coccolithophore blooms of this size and duration are becoming more common and may be a result of changing climate conditions.

Primary Productivity

Map Authors: Erika Knight, Brianne Mecum, and Melanie Smith
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA





Primary Productivity

The primary productivity map shows maximum measured integrated chlorophyll content (mg/m²) for the top 330 feet (100 m) of water-column depth during the open-water season. Chlorophyll is used as a proxy for primary productivity because it is found in phytoplankton and algae, which make up the majority of water-column and sea-ice productivity in the Arctic. Throughout the winter, primary productivity in the Arctic is limited by available sunlight and sea ice coverage. As spring arrives, warming temperatures and longer days reduce ice coverage and allow sunlight to penetrate the water column to 650 feet (200 m), supplying photosynthetic organisms with the energy they need to turn carbon dioxide into organic material. This organic material forms the basis of the marine food web.

This region has recently experienced a much longer open-water period, with sea-ice retreat happening earlier and retreating farther, resulting in substantial changes in primary productivity. When ice retreat is later, phytoplankton is under-utilized by water column grazers, and nutrients fall to the bottom of the sea, fertilizing benthic organisms. When the ice retreat is early, there is not enough sunlight to create a large ice-edge bloom. In that case, the bloom happens later and is utilized by zooplankton and fish, leaving little for the benthos. In this way, sea ice timing determines primary productivity patterns, timing, and abundance, driving the dynamics of a pelagic- versus benthic-dominated system.

Zooplankton

Marilyn Zaleski and Brianne Mecum

Zooplankton are tiny animals living and swimming in the water column that link primary producers to most other animals in the marine ecosystem. Zooplankton include a diverse assemblage of larval fishes (called ichthyoplankton), larval crabs, pelagic snails (pteropods), arrow worms, krill, and other small crustaceans such as bottom-dwelling amphipods. Zooplankton are abundant, widely distributed, and encompass thousands of species across multiple phyla. Two zooplankton groups of particular importance are crustaceans: krill, also known as "euphausiids," and copepods (Hopcroft et al. 2008). Many species of copepods and krill store lipids and therefore supply their predators with an energy-rich food source (Davis et al. 1998).

DISTRIBUTION

The entire North Pacific Ocean is home to a dynamic zooplankton community that differs in abundance and species composition over time and space. Major zooplankton species in the shelf region of the North Pacific include copepods (*Calanus marshallae* and *C. glacialis*, *Neocalanus cristatus*, and *Pseudocalanus* spp.), krill (*Thysanoessa* spp.), amphipods (*Themisto* spp.), and larval walleye pollock (*Gadus chalcogrammus*) (Hopcroft et al. 2005, Coyle et al. 2008, Eisner et al. 2014, Sigler et al. 2016). Different species of zooplankton are found in waters farther offshore; these include the copepods *Neocalanus* spp., *Eucalanus bungii*, and *Metridia pacifica*, and krill *Thysanoessa raschii* (Eisner et al. 2014). In contrast, smaller zooplankton, like bivalve larvae, keep to inshore waters (Eisner et al. 2013).

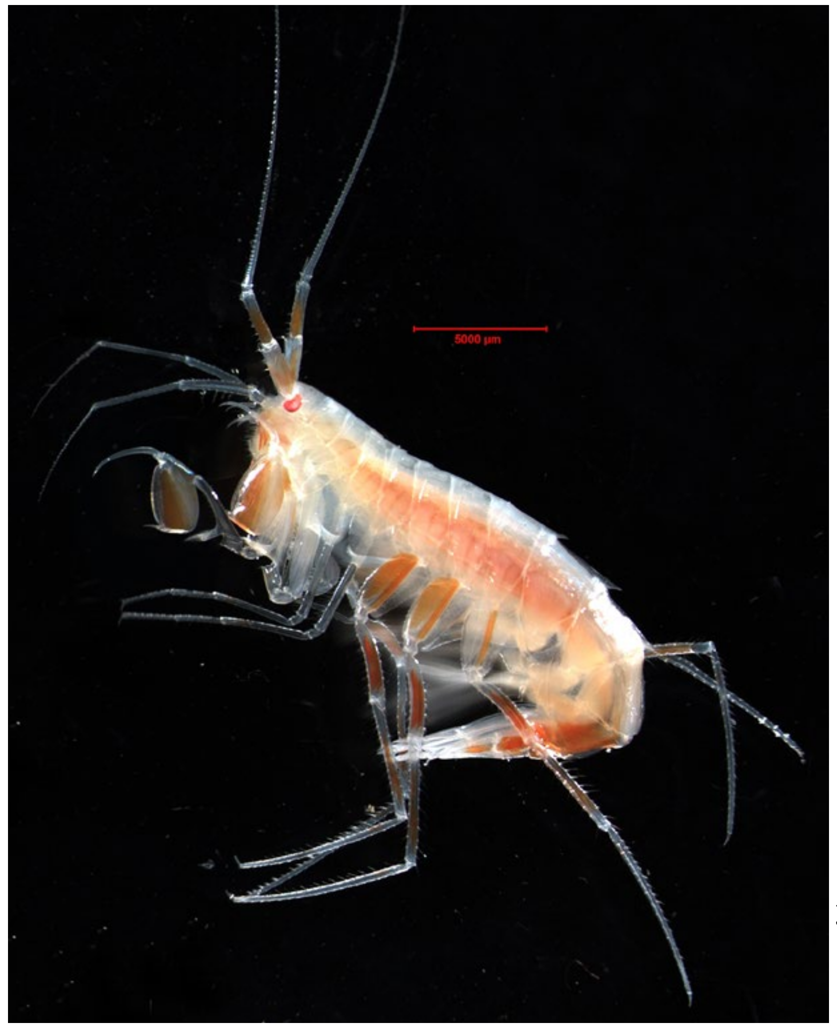
Zooplankton distribution changes over time and is strongly influenced by ocean conditions, ice coverage, and phytoplankton blooms (Hunt et al. 2002, Coyle et al. 2008, Ohashi et al. 2013, Sigler et al. 2016). Late sea-ice retreats, caused by a colder winter/spring, lead to early spring phytoplankton blooms; whereas early ice retreats, caused by a warmer winter/spring, lead to later open-water blooms (Hunt et al. 2002, Sigler et al. 2016). Warmer waters and earlier sea-ice retreats favor the production of jellyfish and small copepods like *Pseudocalanus* spp.; colder waters favor larger zooplankton such as copepods (*C. marshallae* and *C. glacialis*), and krill (Coyle et al. 2008, Ohashi et al. 2013, Eisner et al. 2014).

ECOLOGICAL ROLE

Zooplankton bridge the trophic gap between primary producers and larger predators, and represent nearly every taxonomic group of fish and invertebrates during part, if not all, of their lifecycle (Sigler et al. 2016). They repackage the energy fixed by photoplankton and provide a prey base that is diverse in size and nutritional quality to larger predators (Hunt et al. 2002). For example, walleye pollock, as a predator, benefits from diets with energy-rich zooplankton (Siddon et al. 2014, Moss et al. 2016). Major prey items for walleye pollock, a commercially important groundfish, are *C. marshallae* copepods, krill, *Sagitta elegans* arrow worms, the pteropod *Limacina helicina*, amphipods, and larval decapod crustaceans (Coyle et al. 2008, Moss et al. 2016).

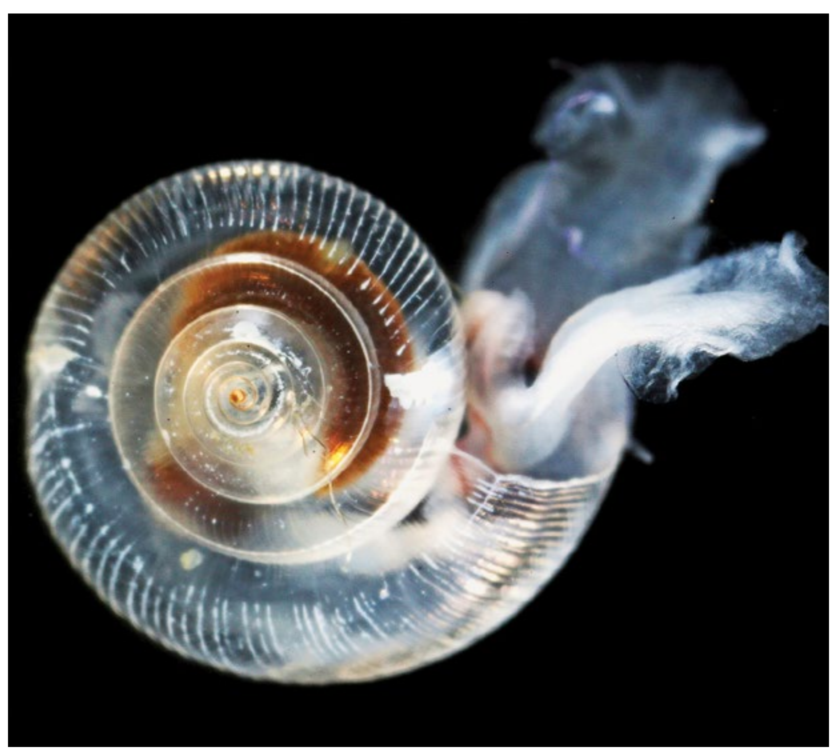
CONSERVATION ISSUES

Changes to zooplankton communities can lead to changes at higher trophic levels that ultimately affect commercial fisheries and subsistence harvests (Hopcroft et al. 2008, Eisner et al. 2014). As the climate changes, the ocean absorbs more heat and CO_2 from the atmosphere, which affects the productivity and physiology of all marine life including zooplankton (see also the summary and maps of Climate in the Physical Settings Chapter). Ocean acidification is of particular concern to animals with calcium-carbonate shells, such as pteropods (Fabry et al. 2009). These planktonic snails are important prey items for juvenile fishes including pink salmon (*Oncorhynchus gorbuscha*), Pacific cod (*Gadus macrocephalus*), walleye pollock, Atka mackerel (*Pleurogrammus monopterygius*), and several rockfish species



Russ Hopcroft / NOAA

This species of amphipod, *Eusirus holmii*, was found in the Alaska Beaufort Sea north of Point Barrow, and is found in association with sea ice and at more than 6,500 feet (2,000 m) depth.



NOAA

This pteropod is showing some effects of ocean acidification on its calcareous shell including ragged, dissolving shell ridges, severe abrasions, and weak spots of the surface.

(Armstrong et al. 2005, Yang et al. 2006, Coyle et al. 2008, Boldt and Rooper 2009). When the pteropods are exposed to acidified waters, their shells dissolve (Orr et al. 2005), hindering their health and protection from predators.

Crustacean zooplankton species will also be vulnerable to the effect of ocean acidification. Larval Antarctic krill (*Euphausia superba*) experienced shell dissolution and growth irregularities under acidified conditions (Kawaguchi et al. 2010). Juvenile red king crabs (*Paralithodes camtschaticus*) and Tanner crabs (*Chionoecetes bairdi*) grew slower and ultimately had decreased survival rates when exposed to projected future levels of ocean acidification (Long et al. 2013). These impacts to important prey items for the marine ecosystem and important harvest species for Alaskan communities need to be considered for future management plans.

MAPPING METHODS (MAP 3.2)

All zooplankton data for the study region were obtained from *COPEPOD: The Global Plankton Database* (National Oceanic and Atmospheric Administration 2012). This database is a synthesis of zooplankton data collected from various studies. Details on how zooplankton data were combined and calculated can be found in Moriarty and O'Brien (2013). Sample points for average annual zooplankton total carbon mass were extracted from the database and mapped. A 60x60 km grid was then overlaid on data points within the extent of the study area. The average carbon mass (measured in mg carbon per m^3) per grid cell was then calculated. Those grid cells with associated average values were then converted to points based on the centroid of each grid cell. To create a continuous coverage over the entire study area, those points were interpolated using the Inverse Distance Weighted tool in ArcMap version 10.5 using a power of 2 and a search radius of 12 points.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality

Because this dataset was created with the express purpose of creating a continuous global coverage for zooplankton biomass, this dataset generally has excellent spatial coverage. Some of the more remote, offshore areas may be represented by only a few data points, which may be the case in the far western Bering Sea. In this case, small hotspots may likely be represented by single measurements at historical sampling locations. There were no sample points for the waters of the Beaufort Sea and the western Chukchi Sea. We suspect that weather, ice conditions, and remoteness play the largest role in this lack of data and that this is not an indication of low zooplankton productivity. As climate change continues to impact ice conditions in the Arctic it is possible that future researchers will have increased sampling opportunities to measure zooplankton abundance in this region.

Reviewer

- David Kimmel

MAP DATA SOURCES

Zooplankton: Oceana (2017b) based on Moriarty and O'Brien (2013) and National Oceanic and Atmospheric Administration (2012)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)

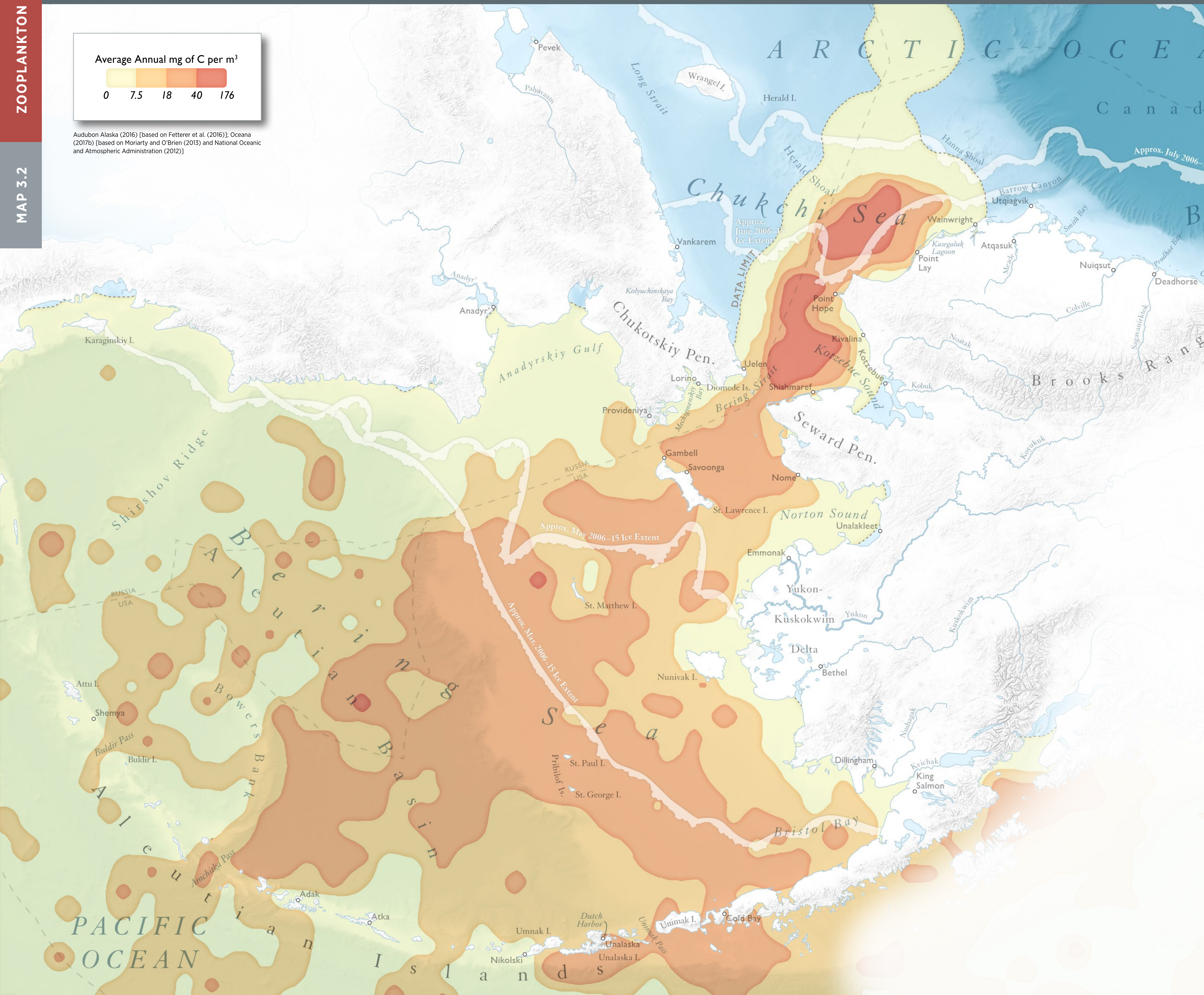
Eric Vance / US Environmental Protection Agency

A zooplankton sample with bright orange krill amongst ctenophores (otherwise known as comb jellies). These planktonic species were caught off of Maine, but krill and ctenophores are ubiquitous in the Arctic and occur worldwide.

Zooplankton

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA



Audubon Alaska (2016) [based on Fetterer et al. (2016)]; Oceana (2017b) [based on Moriarty and O'Brien (2013) and National Oceanic and Atmospheric Administration (2012)]

Crew and officers of NOAA ship Miller Freeman

Zooplankton

Zooplankton are tiny animals, living and swimming in the water column, that link primary producers to most other animals in the marine ecosystem. Zooplankton include a diverse assemblage of larval fishes (called ichthyoplankton), larval crabs, pelagic snails (pteropods), arrow worms, krill (euphausiids), and other small crustaceans such as copepods and bottom-dwelling amphipods. The entire North Pacific Ocean is home to a dynamic zooplankton landscape with species composition diversity, seasonal distributions, and a range of densities in different regions. Overall, major zooplankton species in the North Pacific include copepods (*Calanus marshallae* and *C. glacialis*, *Neocalanus cristatus*, and *Pseudocalanus* spp.), krill (*Thysanoessa* spp.), amphipods (*Themisto* spp.), and larval walleye pollock (*Gadus chalcogrammus*).

3.3 BENTHIC BIOMASS MAP ON PAGES 56–57

Benthic Biomass

Marilyn Zaleski and Brianne Mecum

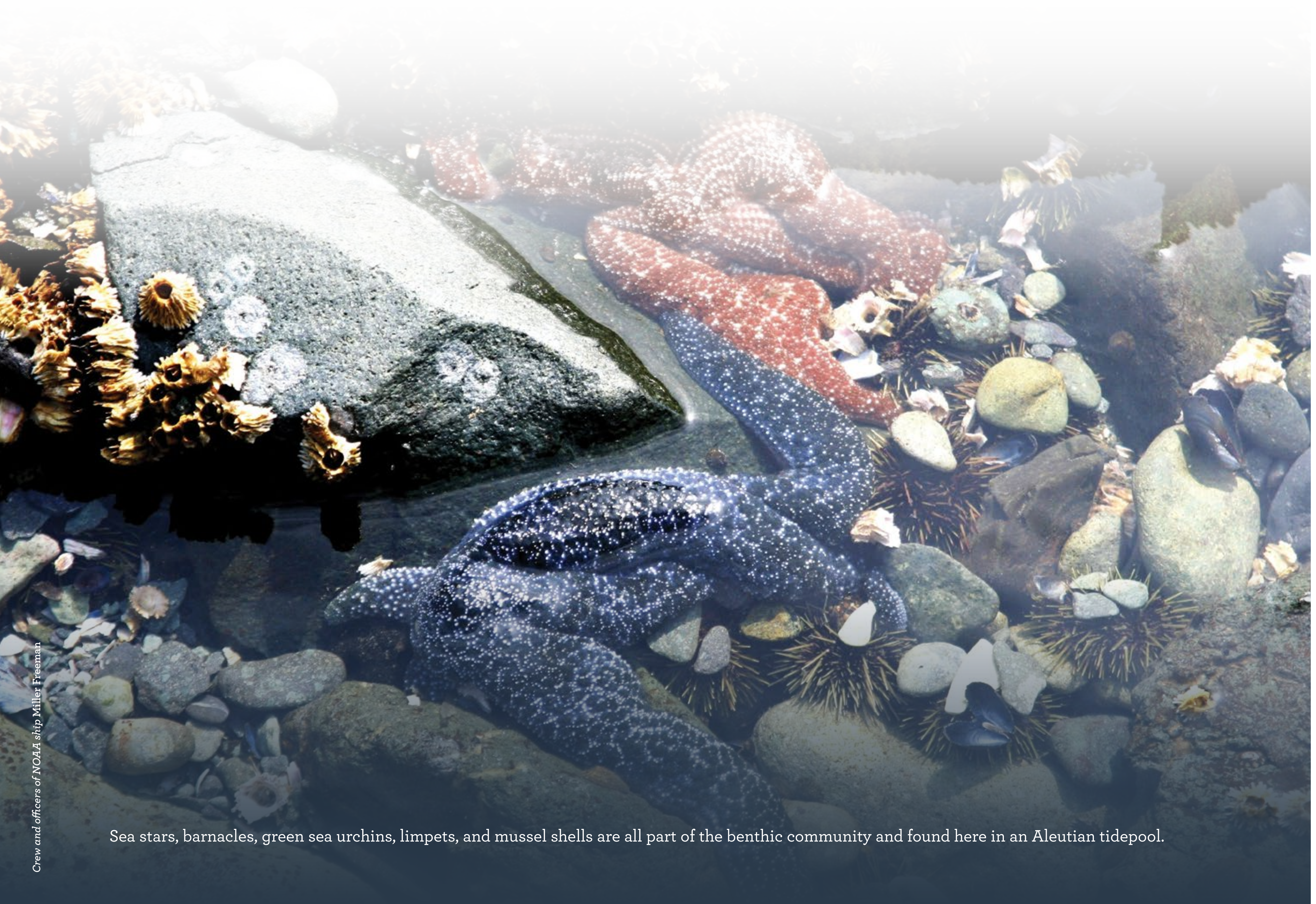
Benthic invertebrates live on or in the seafloor. Some benthic invertebrates form structures that become habitats, others live in the substrate, and some are mobile and travel on the surface of the seafloor. Benthic invertebrates comprise a large proportion of the total marine biomass and species diversity in the eastern Bering Sea (EBS), Chukchi Sea, and Beaufort Sea. Their aggregate role in the ecosystem is an important transfer of energy from lower to upper trophic levels (Coyle et al. 2007). They also form Essential Fish Habitat (EFHs) (see Ecological Role).

Corals, anemones, sponges, and tunicates are components of the benthic landscape. These sessile invertebrates offer refuge from ocean currents and protection from predators, and, in doing so, offer nursery habitats for other invertebrates and for several fish species. Habitat-forming benthic invertebrates are highly diverse (Table 3.3-1). The Aleutians contain the most diverse and dense aggregations of sponges (Lehnert and Stone 2014) and support the most abundant deep-water corals of any high latitude ecosystem (Heifetz et al. 2005, Stone 2014), with higher coral diversity than some tropical reefs (Stone 2014). Of the 88 species or subspecies of corals reported from the Aleutian Islands (Stone and Cairns 2017), more than 50 may be endemic to the region (Stone and Rooper 2017). Tunicates belong in the phylum Urochordata, closely related to the phylum Chordata which includes all vertebrates.

The benthic community is dominated by several species of crustaceans, echinoderms (mainly urchins and sea stars), gastropods (mainly *Neptunea* spp. or true whelks), and bivalve mollusks (mainly *Macoma calcarea*) (Feder et al. 2005, Sirenko and Gagaev 2007, Bluhm et al. 2009, Logerwell et al. 2010, Smith et al. 2011, Goddard et al. 2014, Grebmeier et al. 2015a, National Oceanic and Atmospheric Administration 2016a). Common epifaunal species in the Chukchi Sea include the green sea urchin (*Strongylocentrotus droebachiensis*), purple-orange sea star (*Asterias amurensis*), and fuzzy hermit crab (*Pagurus trigonocheirus*) (Goddard et al. 2014). Common Beaufort Sea species include brittle stars (class Ophiuroidea), mussels (*Musculus* spp.), and the peanut worm (*Golfingia margaritacea*) (Logerwell et al. 2010). In the EBS, purple-orange sea stars, basket stars (*Gorgonocephalus eucnemis*), and sponges make up the majority of surveyed benthic organisms (National Oceanic and Atmospheric Administration 2016a). Snow crab (*Chionoecetes opilio*) and Tanner crab (*C. bairdi*), along with red king crab (*Paralithodes camtschaticus*), are also important benthic invertebrates and are summarized separately in this Atlas.

DISTRIBUTION

The shelf environment of the EBS, north through the Bering Strait, in Norton Sound, and alongshore of the Chukchi Sea supports relatively high benthic biomass comprised of, but not limited to, the animals listed in Table 3.3-1 (Logerwell et al. 2010, Goddard et al. 2014, National Oceanic and Atmospheric Administration 2016a). The species composition differs depending upon sediment type and depth, with the 165-foot (50-m) isobath generally dividing a benthic community of sea stars from a deeper benthic community of crabs and gastropods (Yeung and McConnaughey 2006).



Sea stars, barnacles, green sea urchins, limpets, and mussel shells are all part of the benthic community and found here in an Aleutian tidepool.

Crew and officers of NOAA ship Miller Freeman

3.3 BENTHIC BIOMASS MAP ON PAGES 56–57

TABLE 3.3-1. Habitat-forming invertebrates species diversity, showing species commonly identified in the National Marine Fisheries Service Trawl Surveys (National Oceanic and Atmospheric Administration 2016a).

Corals	Anemones	Sponges	Tunicates
Sea raspberry *Gersemia rubiformis*	White-plumed anemone *Metridium farcimen*	Clay pipe sponge *Aphrocallistes vastus*	Sea potato *Styela rustica*
Deep-sea fan coral *Fanellia compressa*	Tentacle-shedding anemone *Liponema brevicornis*	Barrel sponge *Halichondria panacea*	Sea onion *Boltenia ovifera*
Bubblegum coral *Paragorgia arborea*	Reticulate anemone *Actinauge verrilli*	Tree sponge *Suberites montalbidus*	Sea peach *Halocynthia aurantium*
Alaska sea whip *Halipteris willemoesi*	Swimming anemone *Stomphia coccinea*	Scapula sponge *Stelodoryx oxeata*	Sea grape *Molgula griffithsii*
Red tree coral *Primnoa willeyi*	Christmas anemone *Urticina crassicornis*	Cloud sponge *Rhabdocalyptus* spp.	Hairy tunicate *Halocynthia hispidus*
Orange sea pen *Ptilosarcus gurneyi*	Rough purple anemone *Paractinostola faeculenta*	Stone sponge *Stelletta* spp.	Glassy tunicate *Ascidia paratropa*
Red mushroom coral *Anthomastus* spp.	Chevron-tentacled anemone *Cribrinopsis fernaldi*	Spud sponge *Histodermella kagigunensis*	Sea pork *Aplidium californicum*
Articulated bamboo coral *Isidella* spp.	Frilled anemone *Metridium senile*	Club sponge *Tedania kagalaskai*	Broad-base tunicate *Cnemidocarpa finmarkiensis*
Pink orange mushroom coral *Alcyonium* spp.	Hot dog anemone *Bathyphelia australis*	Calcareous finger sponge *Geodinella robusta*	Sea glob *Aplidium* spp.
Alaska cup coral *Caryophyllia alaskensis*	Cowardly anemone *Stomphia didemon*	Lacy basket sponge *Regadrella okinoseana*	Sea blob *Synoicum* spp.

While survey data are more limited in the Arctic compared to the EBS, sediment size and composition, along with zooplankton populations, water temperature and salinity, and ice gouging, are major factors regulating benthic community structure and diversity (Grebmeier et al. 1989, Barber et al. 1994, Bluhm et al. 2008, Pisareva et al. 2015).

Corals are widespread throughout the Aleutian Islands, Bering Sea, and Chukchi Sea. Coral gardens, composed of a variety of coral and sponge assemblages differentiated by species diversity and densities, are found in shallow and deep-sea rocky substrates of the Aleutian Islands (Stone 2014). In the mud/sand/gravel substrates of the Bering Sea, sea whips dominate the middle domain, and soft corals such as sea raspberries populate the relatively shallow inner and middle domains (Logerwell et al. 2010, Goddard et al. 2014, National Oceanic and Atmospheric Administration 2016a). Tunicates have a distribution similar to the soft corals, while anemones are more consistently found along the middle and outer domain of the EBS (Logerwell et al. 2010, Goddard et al. 2014, National Oceanic and Atmospheric Administration 2016a). The Aleutian Islands benthic environment is heavily structured with sponges (Stone et al. 2011).

ECOLOGICAL ROLE

Benthic organisms provide and create habitat essential to fish and crabs. They rely on high primary production from the water column and are less affected by seasonal and annual variability than pelagic species (Bluhm et al. 2008). Areas of very high primary productivity, such as Anadyr waters north of the Bering Strait, produce far more biomass than is consumed by zooplankton (Springer et al. 1989). This excess biomass falls to the seafloor, providing food for the benthos (Grebmeier et al. 1988).

Habitat-forming invertebrates provide EFH for many commercially important species (Stone 2014). These include but are not limited to Atka mackerel (*Pleurogrammus monopterygius*) (Malecha et al. 2005, Stone 2006), red king crab (Pirtle and Stoner 2010), and several rockfishes (Stone et al. 2017). Corals, in particular, are long-lived and grow slowly (Andrews et al. 2002), so it takes years before a colony effectively becomes fish habitat (Stone et al. 2017). The animals that rely on these structural invertebrates use them for both shelter and food.

Some benthic invertebrates are preyed upon by marine mammals: *Macoma* bivalves are important food for walruses (*Odobenus rosmarus divergens*) (Fukuyama and Oliver 1985) while amphipods (small infaunal crustaceans) are preyed upon by gray whales (*Eschrichtius robustus*) and bearded seals (*Erignathus barbatus*) (Kim and Oliver 1989, Brower et al. 2017).

ECONOMIC IMPACT

In addition to the economic value of commercially important species that rely on benthic invertebrates, there is subsistence harvest for human use. Alaska Native communities harvest invertebrates like the orange tunicates known as sea peaches that are pushed up to the shore by sea ice and storms (Raymond-Yakoubian et al. 2014). The economic role of snow crab, Tanner crab, and red king crab are summarized later in this chapter.

CONSERVATION ISSUES

Although water temperatures are rising, evidence is inconclusive about how benthic biomass will be affected (see also the discussion and climate projection map for benthic infauna under Climate in the previous chapter). One study showed that benthic organisms were more abundant in colder years compared to average years, suggesting that as temperatures increase and are anomalously high, benthic biomass may decrease (Coyle et al. 2007). However, in northern latitudes, changing species composition and range expansions northward may increase benthic biomass. Historical epibenthic sampling between the 1970s and 1990s revealed increased abundance and biomass for the northeastern Bering and Chukchi Seas (Feder et al. 2005), and warmer-water species were found in the northern Bering and Chukchi Seas, a potential outcome of a warming climate (Sirenko and Gagaev 2007). Climate change may also affect the trophic linkages between benthic invertebrates and primary production (Grebmeier et al. 2006b).

Ocean acidification could negatively affect many of the benthic organisms that require calcium carbonate to make their tests or shells. The Arctic is affected by ocean acidification more so than other areas with longer periods where the water is so acidic it can dissolve calcium carbonate (Bates et al. 2009, Fabry et al. 2009).

3.3 BENTHIC BIOMASS MAP ON PAGES 56–57

Commercial fishing gears, particularly bottom trawls, can have long-term impacts on benthic habitat (Heifetz 2002, Witherell and Coon 2002, Rooper et al. 2016, Stone et al. 2017). It is important to consider the time necessary for slow-growing, long-lived corals and sponges to rebuild or replace damaged structures when assessing habitat degradation and subsequent recovery (McConnaughey and Smith 2000, Andrews et al. 2002, Rooper et al. 2011). When corals are damaged by fishing gear, they can take decades to recover, and repeated fishing disturbances in an area can slow growth rates further (Stone et al. 2017). Additionally, some coral growth is negatively affected by warmer waters (Stone et al. 2017) and ocean acidification (Fabry et al. 2009), so as ocean temperatures rise, the effect from fishing will be exacerbated and increase recovery time.

MAPPING METHODS (MAP 3.3)

Benthic biomass was estimated by combining two datasets: one with robust spatial coverage in the Chukchi, Beaufort, and northern Bering Seas and another with robust spatial coverage from the northern Bering Sea to the Aleutian Islands. Combining these two datasets provided us with survey data for benthic invertebrates throughout the majority of our study area. Those two studies, as well as the methods used to combine them, are outlined below.

Also shown on Map 3.3 are the locations of documented coral and sponge gardens in the Aleutian Islands. Those locations are from Stone (2014) and National Oceanic and Atmospheric Administration (2016a).

The sea-ice data shown on Map 3.3 approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Trawl Survey Data (National Oceanic and Atmospheric Administration 2016a)

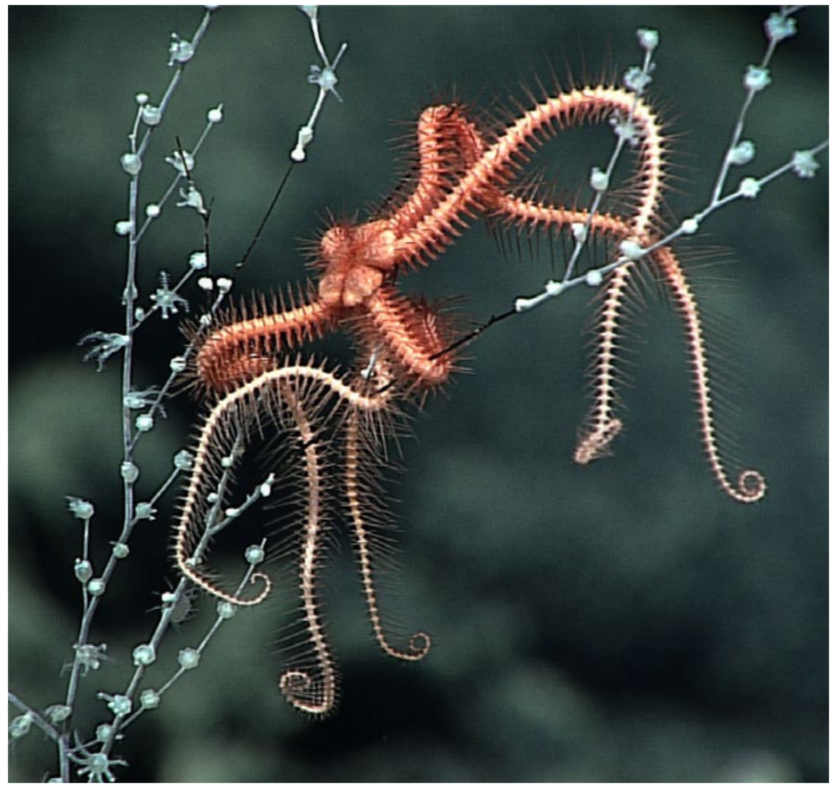
A trawl survey database was created by combining multiple bottom trawl surveys which employed consistent methodologies and sampled waters within the US exclusive economic zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell et al. 2010). This database contained 29,296 sample points and has excellent spatial and temporal coverage for much of our study area, though less so in the Arctic.

From that database, the catches of all benthic invertebrates were summed for each haul of the trawl surveys. Catches included 1,356 benthic species or species groups recorded from the trawl survey samples. These included crabs, echinoderms (sea stars, sea urchins, sea cucumbers), bivalves, sponges, corals, tunicates, anemones, worms, snails, and octopus. Not included were jellyfish and ctenophores, salps, and squids since these are pelagic rather than benthic organisms.

Of the observations made (species or species groups caught, identified, and weighed), there were:

- 216,138 in the EBS
- 79,674 in the Gulf of Alaska
- 60,301 in the Aleutian Islands
- 9,749 in the northern Bering Sea
- 3,269 in the Bering Sea slope
- 2,705 in the Chukchi Sea
- 387 in the Beaufort Sea

The most common species of benthic invertebrates were basketstars *Gorgonocephalus eucnemis* (n = 11,549), Tanner crabs *Chionoecetes bairdi* (n = 10,566), snow crabs *Chionoecetes opilio* (n = 9,840), purple-orange sea stars *Asterias amurensis* (n = 8,185), and Oregon tritons *Fusitriton oregonensis* (n = 7,865).


NOAA

Brittle stars are predominant in the Beaufort Sea as well as the outer domain of the eastern Bering Sea. Here one is climbing on a dead octocoral.

PacMARS Benthic Infaunal Parameters (Grebmeier and Cooper 2014a)

This dataset contained 2,015 unique sample points with summary measurements of average benthic macroinfaunal taxa to the family level collected using a van Veen grab (0.1 m^2 sediment grab). Three to five samples were taken at each station and parameters of station, abundance, wet weight biomass, carbon dry weight biomass, number of taxa, Shannon-Weaner diversity and evenness indices, and number of grabs collected per station were recorded for each sample. For the purposes of combining this dataset with trawl survey sample data, this dataset was mapped based on wet weight biomass (gww/m^2).

Analysis

To obtain a continuous coverage estimate of the relative benthic biomass for our entire study area, we combined the macroinfaunal benthic survey data from Grebmeier and Cooper (2014a) and a compilation of benthic invertebrate samples from the National Marine Fisheries Service trawl survey data (discussed above). Both datasets measured benthic biomass; however, because their survey methods and measurements differ, simply combining the datasets would be inappropriate. Instead, the Oceana Important Ecological Area approach was used (Oceana and Kawerak 2014). This method provides a framework for combining multiple types of data regardless of their sample design, measurements, units, or whether they are quantitative or qualitative in nature. Using this method allows us to see those areas which are above average, or those areas with the highest benthic productivity.

The steps for the Important Ecological Area approach were:

- Overlay 60x60 km grid on top of entire extent of all survey points
- Calculate the average value of all sample points within each grid cell for each dataset separately
  - For the PacMARS data, average biomass of macrofauna in grams wet weight per meter squared (gww/m^2)
  - For the trawl survey data, average kilograms per hectare (kg/ha)
- Calculate the standard deviate per grid cell for each dataset separately
  - To calculate the standard deviate per grid cell for each dataset, the following formula was used:

$$Z_{ij} = \frac{X_{ij} - \overline{X}_i}{\sigma_i}$$

Where (Z_{ij}) is the standard deviate of grid cell j for the ith dataset, (X_{ij}) is the average value for grid cell j for the ith dataset, and (X_i) and (σ) are the overall mean and overall standard deviation of all the calculated grid cell average values for the ith dataset.

- Join the two datasets together using the grid cell unique identifier to ensure both datasets align properly, and then calculate the weighted average standard deviate, weighted by sample size, per grid cell of the two datasets
- Join the weighted average standard deviate values back to the 60x60 km grid to view spatial distribution
- Convert grid cells to points based on the center of each cell
- To obtain continuous coverage, interpolate those points using the Inverse Distance Weighted tool with the following parameters in ArcMap version 10.5:
  - Power = 2
  - Search radius = variable
  - Maximum search radius = 12 points

Converting grid cell values to standard deviates allows us to see how far above or below average each value is from the mean relative to the dispersion of the data. A standard deviate close to zero means the value is close to average, while a large standard deviate means the value is well above average. Similarly, a negative standard deviate indicates the value is below average (Oceana and Kawerak 2014).

Data Quality

The NOAA trawl database contained 29,296 sample points and had excellent spatial and temporal coverage for much of our study area, though less so in the Arctic. Bottom trawl surveys in the Aleutian Islands were conducted every 3 years from 1983 to 2000 and on even years from 2002 to 2016. Surveys on the Bering Sea slope were conducted on even years from 2002 to 2016, except for 2006 and 2014. Surveys on the EBS shelf were conducted from 1982 to 2016. Surveys in the northern Bering Sea occurred from 1982 to 2010. Gulf of Alaska surveys were conducted in 1984 and 1987, every 3 years from 1990 to 1999, and on odd years between 2001 and 2015.

The PacMARS infaunal biomass dataset contained 2,015 unique sample points with summary measurements of average benthic macroinfaunal taxa to the family level. This dataset had excellent spatial coverage from 1970 to 2012 in the northern Bering Sea and Chukchi Sea, including both US and Russian waters. Sample data also included some coverage in the nearshore Beaufort Sea, in both US and Canadian waters. This dataset, however, lacked sample data in the southern Bering Sea and Aleutian Islands.

These two datasets were combined to utilize the best of both, as described above.

Reviewers

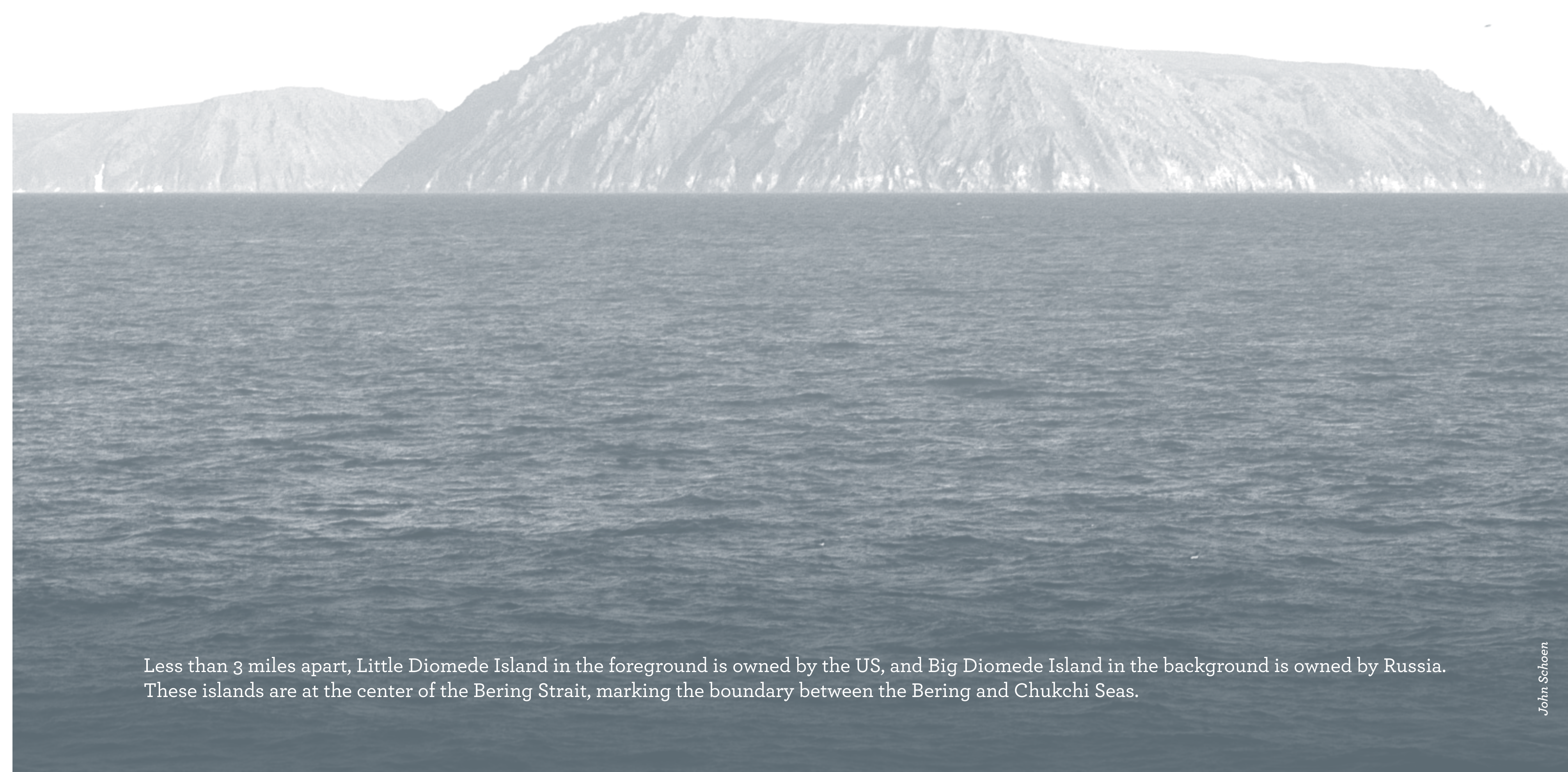
- Robert Stone
- Cynthia Yeung
- Jacqueline Grebmeier

MAP DATA SOURCES

Benthic Biomass: Oceana (2017a) based on Conner and Lauth (2016), Goddard et al. (2014), Grebmeier and Cooper (2014a), Hoff (2016), Logerwell et al. (2010), Oceana and Kawerak (2014), Raring et al. (2016), and von Szalay and Raring (2016)

Coral and Sponge Gardens in the Aleutian Islands: National Oceanic and Atmospheric Administration (2016a); Stone (2014)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)



Less than 3 miles apart, Little Diomede Island in the foreground is owned by the US, and Big Diomede Island in the background is owned by Russia. These islands are at the center of the Bering Strait, marking the boundary between the Bering and Chukchi Seas.

John Schoen

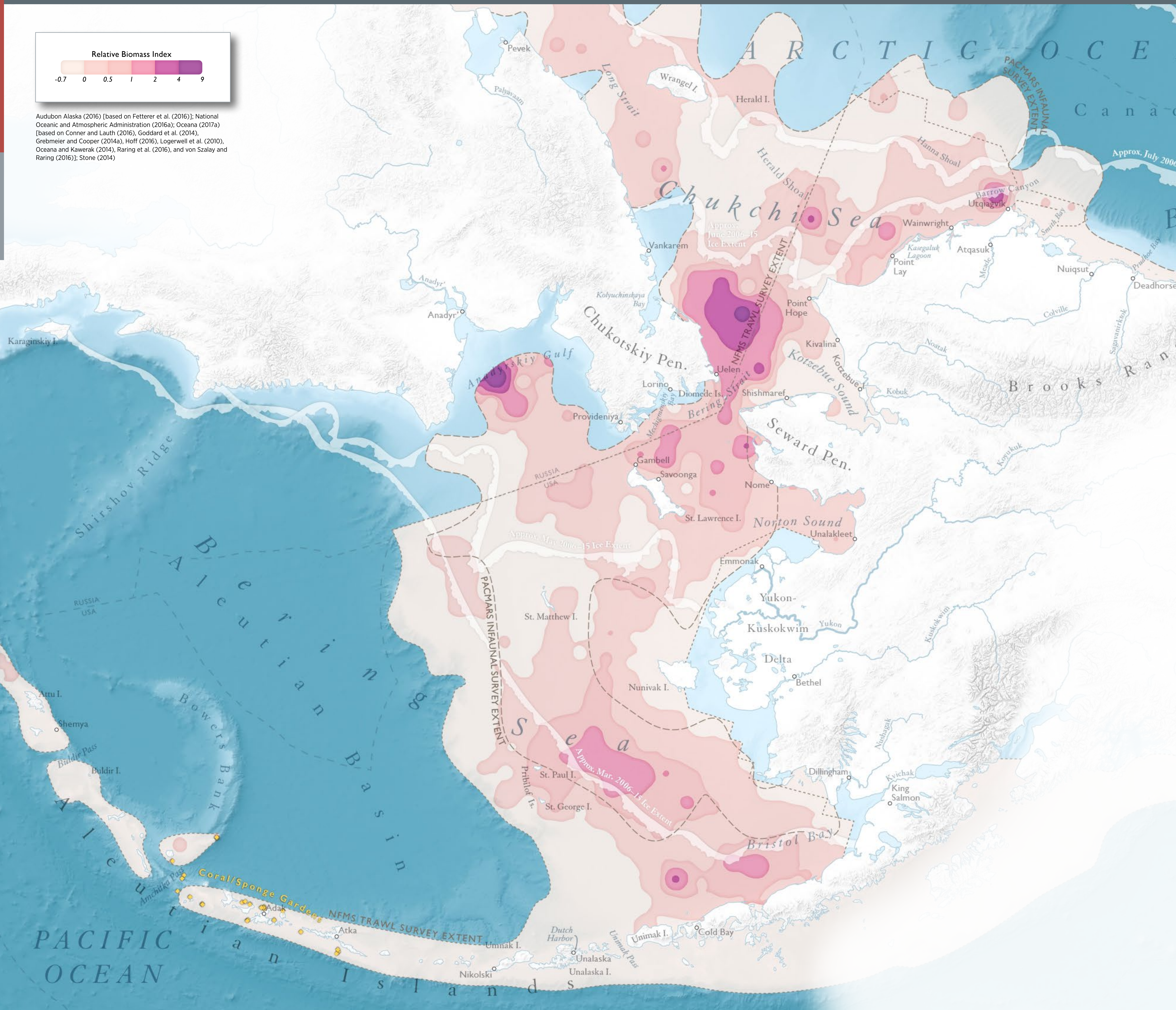
3.3 BENTHIC BIOMASS MAP ON PAGES 56–57

BIOLOGICAL SETTING 57

Benthic Biomass

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA



Audubon Alaska (2016) [based on Fetterer et al. (2016)]; National Oceanic and Atmospheric Administration (2016a); Oceana (2017a) [based on Conner and Lauth (2016), Goddard et al. (2014), Grebmeier and Cooper (2014a), Hoff (2016), Logerwell et al. (2010), Oceana and Kawerak (2014), Raring et al. (2016), and von Szalay and Raring (2016)]; Stone (2014)


NOAA

Benthic Biomass

Benthic invertebrates live on, in, or just above the seafloor. Some form structures that become habitats (epifauna), others live in the substrate (infauna), while mobile benthic invertebrates travel on the surface of the seafloor. Benthic invertebrates comprise a large proportion of the biomass and species diversity in the eastern Bering Sea (EBS), Chukchi Sea, and Beaufort Sea, and include crustaceans, sea stars, bivalves, snails, corals, and sponges. Here, the combined biomass of benthic invertebrates is displayed from two survey datasets as a relative biomass index using standard deviates: a value near zero represents an area with approximate average biomass, a negative value represents an area with relatively low benthic biomass, and a positive value represents an area with relatively high benthic biomass. The higher the relative biomass index, the greater the relative benthic biomass. Hot spots of benthic biomass in the shelf environment of the EBS middle domain, the Bering Strait, and alongshore of the Chukchi Sea are comprised of, but not limited to, sea stars, corals, sponges, tunicates, snails, bivalves, and crabs. Coral gardens are found in shallow and deep-sea environments; hard corals and sponges are found along the Aleutians and at depth along the Bering Sea shelf break, and soft corals populate the EBS inner and middle domains.

3.4
SNOW AND TANNER CRABS
MAP ON PAGES 62–63

Chionoecetes Crabs

Marilyn Zaleski and Brianne Mecum

Snow Crab

Chionoecetes opilio

Tanner Crab

C. bairdi

Snow crab (*Chionoecetes opilio*), also known as opilio crab, is the most valuable commercial crab species in North Pacific (North Pacific Fishery Management Council 2015) and North Atlantic waters (Hébert et al. 2014). They are well known by American consumers as the animal behind "all-you-can-eat" crab legs at popular seafood restaurants and as "opies" on the reality TV series *Deadliest Catch*. Their congener (same genus, different species) the Tanner crab (*C. bairdi*), is a lesser-known, albeit slightly larger crab found in both the eastern Bering Sea (EBS) and the Gulf of Alaska. While Tanner crabs are discussed in this summary and their distribution is mapped in Figure 3.4-1, they are not mapped on a large scale in this atlas.

These crabs are brachyurans, or true crabs, with a body covered in a hard exoskeleton that they must shed, or molt, in order to grow larger (Moriyasu and Mallet 1986). Molting is instrumental in crab survival as it also enables them to repair any damaged or lost limbs. In contrast to other crabs, snow and Tanner crabs experience a terminal, or final molt after which they live out their lives without molting for seven to ten more years (Kon et al. 2010). Due to the lack of further molting, these crabs are unable to replace any loss or damage to the carapace, claws, or legs (Conan and Comeau 1986). The terminal molt also essentially marks the beginning of their adulthood (see Life Cycle section).

Snow and Tanner crabs differ from each other visually by their eye color, shape, and size. Snow crabs have green eyes while Tanner crabs have red eyes. Snow crab bodies are approximately equal in width and length, while Tanner crab bodies are wider than they are long (Jadamec et al. 1999). Tanner crabs were targeted for commercial fishing in the Bering Sea before snow crab, with a shift to snow crab as Tanner crab abundance decreased (Figure 3.4-2) (North Pacific Fishery Management Council 2015).

Adult male snow and Tanner crabs are larger than females of the same species (Table 3.4-1), a pattern known as sexual dimorphism. This size difference allows for males to grasp and protect smaller females during the mating process.

DISTRIBUTION

In Alaska, snow crabs are predominately found in the EBS, although their range extends north into the Chukchi and Beaufort Seas (Bluhm et al. 2009, Hardy et al. 2011, Rand and Logerwell 2011, Ravelo et al. 2015). Other populations of snow crab occur off of Russia, Japan, and Greenland, and in the Canadian North Atlantic. A small population, likely introduced, has also been discovered in the Barents Sea, north of Russia (Alvsvåg et al. 2009, Agnalt et al. 2011). Although snow crabs are not directly associated with sea ice, they are affected by how changes in sea ice impact bottom temperatures. With sea-ice coverage contracting, the Bering Sea cold pool (a mass of water less than 35° F [2° C]), also shrinks and is limited to the northern Bering Sea (Orensanz et al. 2004). This northward contraction of the cold water preferred by juvenile snow crabs (Dionne et al. 2003) has subsequently led to a northward shift in their distribution (Orensanz et al. 2004, Zheng and Kruse 2006, Burgos et al. 2013).

There are an estimated 897,000 metric tons, or roughly 17.4 billion individual snow crab in the EBS as of 2015 (North Pacific Fishery Management Council 2015). Snow crab biomass is estimated at 30,000 metric tons in the Beaufort Sea (North Pacific Fishery Management Council 2009) and 161,000 metric tons, which is roughly 4.5 billion crabs, in the Alaska Chukchi Sea (Goddard et al. 2014).

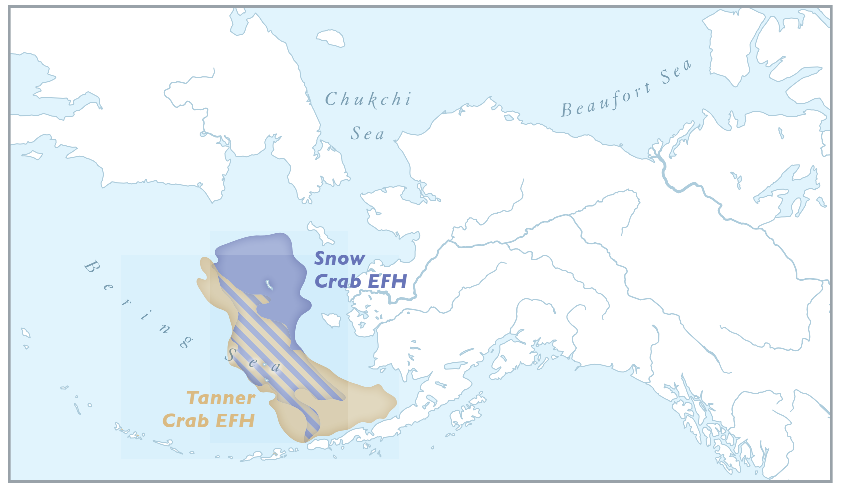


FIGURE 3.4-1. Snow crab and Tanner crab Essential Fish Habitats, showing overlapping distributions which offer opportunities for hybridization. Figure adapted from National Oceanic and Atmospheric Administration (2016b).

TABLE 3.4-1. Comparative body measurements and clutch sizes between snow and Tanner crabs.

	Snow Crab (*Chionoecetes opilio*)	Tanner Crab (*C. bairdi*)
Average size (mature males)	3.8 inches (96 mm) carapace width[1]	3.6 inches (91 mm) carapace width[1]
Average size (mature females)	1.9 inches (48 mm) carapace width[1]	2.7 inches (68 mm) carapace width[1]
Clutch size (number of eggs)	88,500–116,000[2]	89,000–424,000[1]

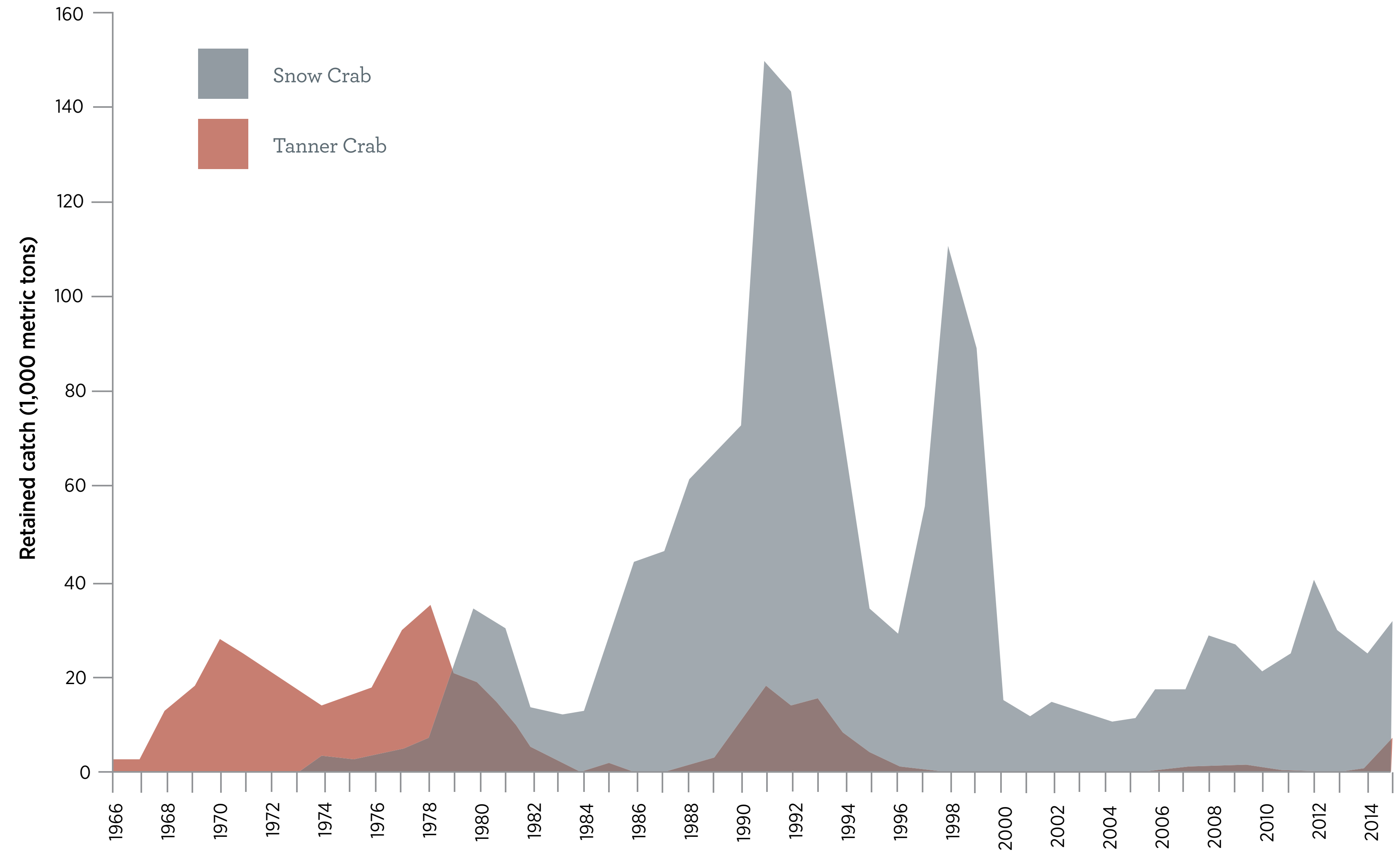
Sources: [1] North Pacific Fishery Management Council (2016); [2] Conan et al. (1989) and Comeau et al. (1999)

Tanner crabs range across the EBS in a similar, although more southerly, distribution to snow crabs, and they are also found in the Gulf of Alaska. Snow crab habitat in the Arctic is defined as inner to middle shelf waters (0–326 ft; 0–100 m depth) with muddy substrates in high-latitude, continental-shelf regions (North Pacific Fishery Management Council 2009). Throughout their range, snow and Tanner crabs prefer seafloor areas of sand and mud so they can quickly burrow to escape from predators (Stevens et al. 1994, Conan et al. 1996). Snow and Tanner crabs produce hybrid offspring in the area of their distributional overlap (Merkouris et al. 1998, Urban et al. 2002) (Figure 3.4-1).

LIFE CYCLE

A male will mate with a female for the first time after her terminal molt, which happens in the winter (Ernst et al. 2005). Males fight for the opportunity to mate by grasping a female prior to her molting and protecting her through the molt. Both snow and Tanner crab females can store sperm in excess of what is needed for fertilization of a given clutch; during subsequent mating seasons females can either mate again as a hard-shelled adult or fertilize a clutch with the stored sperm (Paul 1984, Sainte-Marie and Carriére 1995). Each fertilized clutch, whether from fresh or stored sperm, can produce tens to hundreds of thousands of embryos, a number that increases with female size and is greater in the larger Tanner crabs than smaller snow crabs (Webb and Bednarski 2010, Webb et al. 2016).

FIGURE 3.4-2. Historical total retained catch of eastern Bering Sea snow and Tanner crabs. Adapted from North Pacific Fishery Management Council (2016).



Pictured is a pair of mating snow crabs in Bonne Bay, Newfoundland, Canada. Snow crab males grasp and guard their smaller female mates. Note the tiny anemone that is living on the back of the female.

3.4
SNOW AND TANNER CRABS
MAP ON PAGES 62–63

Brooding female snow and Tanner crabs will often mound together prior to releasing their hatched babies (Stevens et al. 1994, Sainte-Marie et al. 2008). Females of both species will incubate clutches for one year in normal conditions (30–34 °F; -1 to 1 °C) but female snow crabs, who occupy colder waters in the EBS compared to Tanner crabs, will brood for 2 years in water < 34 °F (1 °C) (Moriyasu and Lanteigne 1998). After hatching, the free-swimming larvae have two zoeal larval stages, in which they stay in the upper mixed layer of the water column, and one megalopae larval stage, when they begin to seek out suitable nursery habitat before settling to the bottom as benthic juveniles (Kruse et al. 2007). The larvae molt from one stage to the next as they grow, just as juveniles and adults molt to grow. For larval crabs, it takes two to six months to go from the first zoeal stage to the first benthic juvenile stage (Kruse et al. 2007, Yamamoto et al. 2014). Once they have settled, juvenile crabs look just like mini versions of the adults.

Snow and Tanner crabs are reproductively mature after they molt for the last time (Otto 1998), but this terminal molt is not dependent on size. The terminal molt may be triggered by age, but growth is temperature-dependent so there is variability in the size at maturity for the crabs based, in part, on the temperature at which they live (Orensanz et al. 2007, Ernst et al. 2012). They therefore generally mature smaller at higher latitudes (Burmeister and Sainte-Marie 2010), so average Chukchi and Beaufort snow crabs are smaller than their Bering Sea counterparts (Hardy et al. 2011). While the average life span of snow and Tanner crabs is uncertain, aging crabs is a current research topic (Fonseca et al. 2008, Allain et al. 2011, Kilada et al. 2017) and researchers estimate that both crab species may live up to 20 years (Turnock and Rugolo 2011).

ECOLOGICAL ROLE

Tanner crabs are benthic forage feeders. They primarily eat polychaete worms and bivalves, but also brittle stars, snails, and other crustaceans (Squires and Dawe 2003, Divine et al. 2017). Among the "other crustaceans" they eat, snow crabs have been recorded cannibalizing other snow crabs (Lovrich and Sainte-Marie 1997). Another prominent predator of snow and Tanner crabs is the Pacific cod (*Gadus macrocephalus*). Their stomach contents have contained up to 22% juvenile snow crabs and up to 10% juvenile Tanner crabs (Livingston 1989). In fact, predation by Pacific cod on snow crab in the EBS has been hypothesized to influence the strength of recruitment to the fishery (Burgos et al. 2013). Marine mammals, including walrus (*Odobenus rosmarus divergens*) and bearded seals (*Erignathus barbatus*), feed on Arctic snow crabs; in fact, snow crabs make up close to 20% of bearded seal diets in the Chukchi Sea (Whitehouse 2013).

ECONOMIC IMPACT

The commercial fishery for snow crabs occurs in the EBS and represents the largest and most valuable crab fishery in the US (North Pacific Fishery Management Council 2010). During the 2014–2015 season, 34,300 metric tons of male snow crabs were caught and retained (North Pacific Fishery Management Council 2015). After a peak in catches in the early-to-late 1990s, the snow crab population started to decline and the fishery collapsed by 1999 and went through a rebuilding period (Zheng et al. 2002). The population was declared rebuilt in 2011 (North Pacific Fishery Management Council 2011). Currently, there is no commercial fishing for any species in the Arctic, and for snow crabs a fishery is unlikely due to the small size of the crabs (most are smaller than the commercially desired 4-inch [10-cm] width) (North Pacific Fishery Management Council 2009).

Michael Theberge, 2nd Mate Coastal Nomad / NOAA

3.4
SNOW AND TANNER CRABS
MAP ON PAGES 62–63

USFWS

A Tanner crab on deck showing its wide carapace and red-tinted eyes.

Just like the snow crab, Tanner crabs have experienced high and low stock abundance. The EBS stock has a single overfishing limit, but separate total allowable catches are set for crabs east and west of 166° W longitude, and both fisheries have been intermittently opened and closed for the past two decades. Currently, the female population is below the threshold needed for a commercially viable total allowable catch, so a multi-year closure of the EBS fishery until 2019 is being discussed (North Pacific Fishery Management Council 2016).

CONSERVATION ISSUES

A primary management concern for snow and Tanner crabs is proper management of current and future fisheries. Oil spills are another potential human-caused impact on snow crabs in the Arctic as oil and gas exploration and extraction activity increase in the region. Not only is there a probability for immediate effects from an oil spill, but lingering oil can affect the benthic environment beyond the initial event (Jewett et al. 1996).

Tanner crabs can be infected by a parasitic dinoflagellate, *Hematodinium* sp., which causes bitter crab syndrome (Meyers et al. 1996). The infection leads to a high mortality rate and, while the tissue is not harmful to humans, it causes the crabs to taste bitter and therefore lose their market value (Meyers and Burton 2009). As seen elsewhere, rising ocean temperatures have increased harmful algal blooms (Patterson 2015), so managers must watch for a rise in dinoflagellate production and cases of bitter crab syndrome.

A final concern is how ocean acidification will affect snow and Tanner crab productivity. Ocean acidification affects any animal with calcium carbonate shells by dissolving their exoskeletons; this dissolution can affect larval snow and Tanner crabs by slowing their growth and reducing their calcium content (Long et al. 2013). For many animals, the larval stage of development is their most vulnerable life history stage and less protection could mean lower survival, which would subsequently reduce recruitment to adulthood and the fishery (Punt et al. 2016).

MAPPING METHODS (MAP 3.4)

The relative abundance of snow crab was estimated by interpolating datasets from bottom trawl surveys which employed similar and consistent methodologies and sampled waters within the US exclusive economic zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell et al. 2010). Data points for snow crab presence and absence were extracted and mapped based on catch per unit effort (CPUE) in kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted tool in ArcGIS version 10.5 based on CPUE values. A radius of the 12 nearest points was set as the search distance and interpolation was limited to the study area boundaries of the trawl surveys.

Possible nursery sites for snow crab were digitized directly from Figure 9 in Parada et al. (2010) which depicts the centroids of areas of potential larval settlements based on a model of individual-based larval transport from 1978 to 2002. The south and southwesterly migration arrows were digitized from Figure 7 in the same study which summarizes the general migration patterns of female snow crab.

The general distribution of snow crab is based on adult and juvenile snow crab Essential Fish Habitat (EFH) areas which were obtained directly from National Oceanic and Atmospheric Administration (2016b). Snow crab EFH is described as habitats along the inner (0–165 feet [0–50 m]), middle (165–330 feet [50–100 m]), and outer shelf (330–660 feet [100–200 m]) throughout the Bering Sea and Aleutian Islands wherever there are substrates consisting mainly of mud. Due to their smaller overall population, limited distribution in the EBS, smaller commercial harvest, and limited range, only Tanner crab EFH is mapped (Figure 3.4-1).

Data Quality

Trawl survey data sampling was conducted within the US EEZ, therefore there is little to no coverage on the Russian side of the Bering Sea. The interpolation of the trawl survey data estimates the distribution of snow crab during the summer months and may not represent the year-round distribution.

Bottom trawl surveys in the Aleutian Islands were conducted every three years from 1983 to 2000 and on even years from 2002 to 2016. Surveys on the Bering Sea slope were conducted on even years from 2002 to 2016 except for 2006 and 2014. Surveys on the EBS shelf were conducted from 1982 to 2016. Surveys for the northern Bering Sea occurred from 1982 to 2010. Gulf of Alaska surveys were conducted in 1984 and 1987, every 3 years from 1990 to 1999, and on odd years from 2001 to 2015. Bottom trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewer

- Joel Webb

MAP DATA SOURCES

Trawl Density: Oceana (2017d) based on Conner and Lauth (2016), Goddard et al. (2014), Hoff (2016), Logerwell et al. (2010), Raring et al. (2016), and von Szalay and Raring (2016)

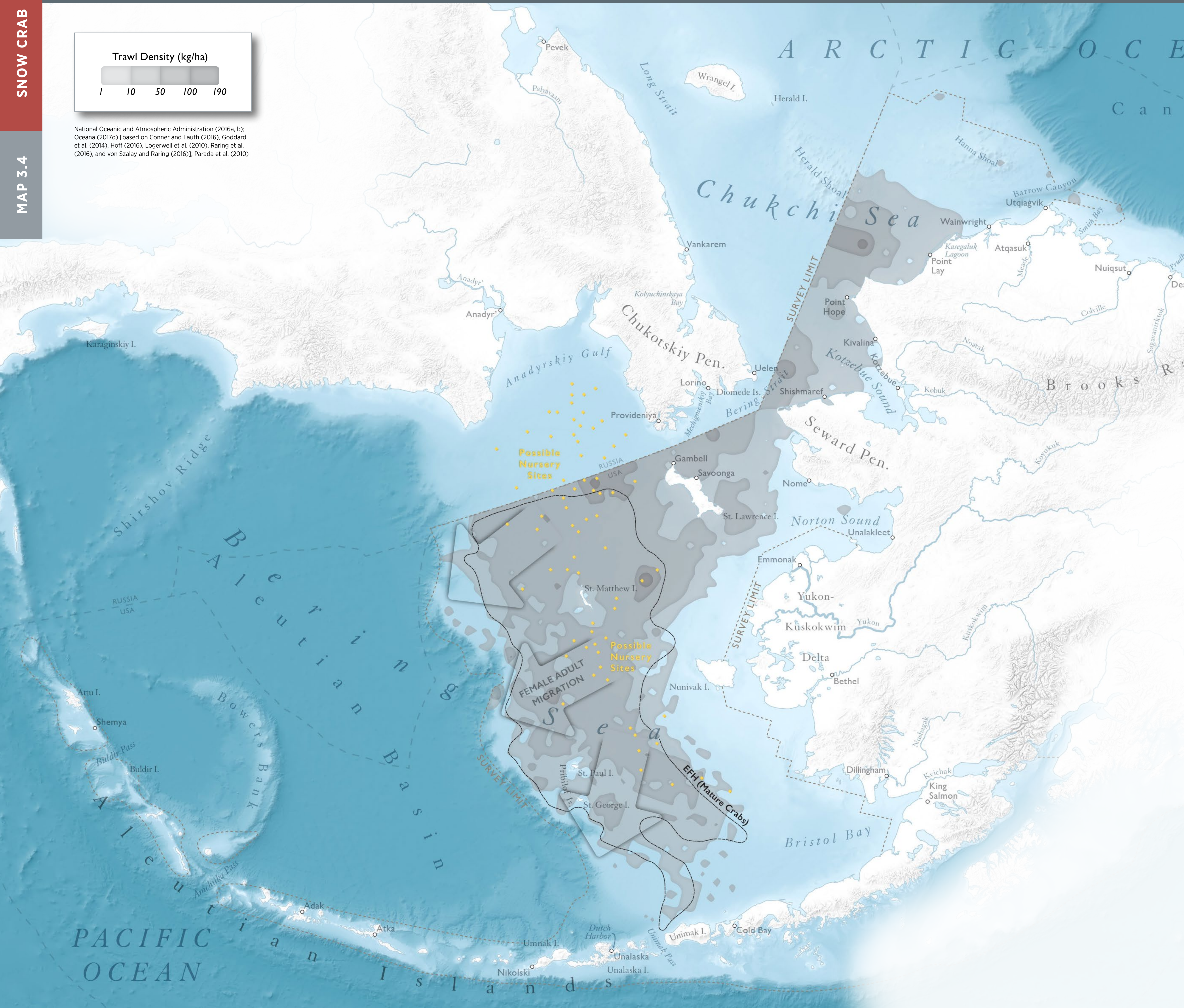
Possible Nursery Sites: Parada et al. (2010)

Essential Fish Habitat: National Oceanic and Atmospheric Administration (2016b)

Management Areas: National Oceanic and Atmospheric Administration (2016a)

Snow Crab

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman



National Oceanic and Atmospheric Administration (2016a, b); Oceana (2017d) [based on Conner and Lauth (2016), Goddard et al. (2014), Hoff (2016), Logerwell et al. (2010), Raring et al. (2016), and von Szalay and Raring (2016)]; Parada et al. (2010)

Snow Crab (*Chionoecetes opilio*)

Snow crab, also known as opilio crab, is the most commercially important crab species in North Pacific and North Atlantic waters. In Alaska, snow crabs are predominately found in the eastern Bering Sea, although their range extends north into the Chukchi and Beaufort Seas. Other populations of snow crab occur off of Russia, Japan, and Greenland, and in the Canadian North Atlantic. Throughout their range, snow crabs prefer seafloor areas of sand and mud. Although snow crabs are not directly associated with sea ice, they are affected by how changes in sea ice impact bottom temperatures. With sea-ice coverage contracting, the Bering Sea cold pool (a mass of cold water near the seafloor less than 35 °F [2 °C]), also shrinks and is limited to the northern Bering Sea. Juvenile snow crabs thrive in the cold pool and model predictions identify several locations for possible larval settlement in that area. However, the northward contraction of the cold pool has subsequently led to a northward shift in snow crab distribution. Snow crab habitat in the Arctic is defined as inner to middle shelf waters (0–330 feet [0–100 m] depth) with muddy substrates in high-latitude, continental-shelf regions.

3.5 RED KING CRAB MAP ON PAGE 67

Red King Crab

Paralithodes camtschaticus

Brianne Mecum and Marilyn Zaleski

Red king crabs (*Paralithodes camtschaticus*) are the largest crab species in Alaska waters and have historically dominated Bristol Bay (North Pacific Fishery Management Council 2016). They are commercially valuable, although their stocks throughout Alaska have experienced highs and lows (North Pacific Fishery Management Council 2016), and their harvest affects the benthic community food web.

Red king crabs have a hard exoskeleton made out of chitin and grow by molting. Unlike snow and Tanner crabs (*Chionoecetes opilio* and *C. bairdi*, respectively), which have a terminal molt to maturity (see Snow and Tanner Crabs Summary), king crabs continue molting throughout their lifecycle after maturing (McCaughran and Powell 1977). This is one reason red king crabs are relatively large in size compared to other crab species in the shared marine ecosystem. Another difference between king crabs and snow crabs is the number of legs they have, signifying the infraorder they are in from Order Decapoda; king crabs are Anomurans and have six walking legs, while snow crabs are Brachyurans and have eight walking legs.

Red king crabs are closely related to blue king crabs (*Paralithodes platypus*) and golden king crabs (*Lithodes aequispinus*) but differ in their range, physical appearance, and physiologic attributes. Aside from the differences in coloration, there are also differences in number and morphology of spines on their carapaces, shape to their rostrum (central forward-pointing spine above the eyes), and overall different average sizes which direct their legal harvest size limits (see Table 3.5-1).

DISTRIBUTION

Red king crabs are generally distributed throughout the North Pacific from deep shelf waters (<820 feet or 250 m) to shallow, nearshore, intertidal environments (Stone et al. 1992, Zheng and Kruse 2006). They range from Southeast Alaska, along the Aleutian Islands, throughout Bristol Bay and the eastern Bering Sea (EBS), north to Kotzebue Sound, and westward toward Japan and Russia. Red king crabs are harvested in Kotzebue Sound (Georgette and Loon 1993) at the northern range limit of the species in Alaska. Globally, the northernmost red king crab stock is an introduced population in the Barents Sea off the coasts of Norway and Russia (Britayev et al. 2010). Bristol Bay is home to the most abundant, actively fished population of red king crab in the world (Daly et al. 2016). The majority of large males targeted by the fishery are found in the central and southern areas of Bristol Bay near the Alaska Peninsula (Daly et al. 2016).

LIFE CYCLE

Females mature between five to nine years old (Powell 1967, Loher et al. 2001) and are then reproductively active for up to ten more years (Hoopes and Karinen 1972). Depending on their size, mature females produce 7,000–490,000 eggs in a single clutch, with larger females producing more offspring (Swiney et al. 2012). Once red king crabs become reproductively active, they begin seasonal migrations. They spend their winters in nearshore Bristol Bay along the north shore of the Alaska Peninsula in order to molt and mate, then move into deeper offshore waters in the spring after mating and egg extrusion

David Csepp / NOAA

A red king crab showing its abdominal flap and stretching its long legs while standing atop a pile of sea stars.

3.5 RED KING CRAB MAP ON PAGE 67

TABLE 3.5-1. Morphological differences in harvestable red, blue, and golden king crabs.

Red and golden king crab: NOAA Alaska Fisheries Science Center

Blue king crab: Celeste Leroux / Alaska Sea Grant



	Red King Crab *Paralithodes camtschaticus*	Blue King Crab *P. platypus*	Golden King Crab *Lithodes aequispinus*
Legal Size Carapace Width	6.5 inches (165 mm)[1]	5.5 inches (140 mm)[2]	5.7 inches (145 mm)[3]
Mid-Dorsal Spines	3 pairs[4]	2 pairs[4]	5–9[4]
Rostrum Description	Single sharp spine[4]	Biramous spine, 2 prongs[4]	Down-curved with paired tip[4]

Sources: [1]Alaska Fisheries Science Center (2010c); [2]Alaska Fisheries Science Center (2010a); [3]Alaska Fisheries Science Center (2010b); [4]Donaldson and Byersdorfer (2005).

(Stone et al. 1992, Zheng and Kruse 2006, Chilton et al. 2010). For mature females, mating occurs in the spring in shallow water within hours of molting. Large hard-shell males will grasp females during the pre-molt period, assist with molting, mate with the female, and guard the females after mating for hours or days (Powell et al. 1974, Webb et al. 2014).

After red king crab eggs hatch, the swimming larvae go through four zoeal stages, then settle to the bottom as postlarval glaucothoe, and finally molt into the first juvenile crab stage to begin their lives on the seafloor (Stevens and Kittaka 1998). The juveniles hide amongst algae and habitat-forming invertebrates such as sponges, bryozoans, and hydroids (Sundberg and Clausen 1977, Stevens and Kittaka 1998, Stoner 2009, Pirtle and Stoner 2010). These benthic invertebrates offer important nursery habitat for the first year and a half of a red king crab's life, after which the crab begins podding behavior on the seafloor (Dew 1990).

Podding behavior is unique to red king crabs and involves hundreds to thousands of crabs clustering together in dense aggregations grouped by maturity (juvenile vs. adult) and sex (Dew 1990, Dew 2010). Red king crab pods can cover vast areas of the seafloor, with one such aggregation in southern Bristol Bay estimated around 90,000 acres (36,500 ha) (Dew 2010). Unlike other crabs, these pods occur year-round and are not specifically tied to mating or molting behaviors, but rather may offer safety in numbers while resting between daily foraging excursions (Dew 1990, Dew 2010).

Red king crabs molt to grow, molting numerous times (8–11) in their first year (Westphal et al. 2014). They continue to molt several times per year in the following two to three years post-settlement, after which they molt annually in the spring (Dew 1990). Growth is temperature-dependent, and they grow faster at higher temperatures, attaining larger sizes at similar ages (Stoner et al. 2010). On average, they can grow up to 0.5 inch (11 mm) during their first year, and as the juveniles get larger, their growth increments increase (Westphal et al. 2014).

The molting process makes crabs vulnerable to predators while they are still in the soft-shell phase. Red king crabs off of Kodiak were observed molting at night (Dew 1990) and female molting happens relatively synchronously, which likely offers some protection from visual predators. Male attendance during the female molting and mating period may also reduce predation during this vulnerable period.

ECOLOGICAL ROLE

As juveniles, red king crabs forage on algae and the habitat-forming invertebrates they use for their nursery environment (Pirtle and Stoner 2010). Once they grow larger and shift into podding behavior and seasonal migrations, they eat benthic invertebrates, including bivalves, snails, polychaete worms, sea stars, and anemones, as well as smaller red king crabs (Dew 1990, Stoner 2009, Britayev et al. 2010). If the red king crabs are in a pod, they will disperse in order to forage at night then cluster back together during the day (Dew 1990).

Red king crabs are vulnerable to predation by other crabs and fishes sharing their nursery habitat, including Pacific halibut (*Hippoglossus stenolepis*), northern rock sole (*Lepidopsetta polyxystra*), and kelp greenlings (*Hexagrammos decagrammus*) (Dean et al. 2000, Stoner 2009, Daly et al. 2012). Although Pacific cod (*Gadus macrocephalus*) are important predators of snow crabs in the Bering Sea (Burgos et al. 2013), they were found to eat less than 4% of the female red king crab stock during a 1980s study (Livingston 1989) and so may pose little threat to juvenile red king crabs (Stoner 2009). Diet analysis and trophic modeling of the invasive red king crab in the Barents Sea showed that they eat similar prey items to large sea stars and snails, introducing resource competition into the ecosystem, but that they are unlikely to compete for prey with most fish species (Fuhrmann et al. 2017).

ECONOMIC IMPACT

Red king crabs are currently harvested commercially in Bristol Bay and Norton Sound (North Pacific Fishery Management Council 2016). Fisheries in the Pribilof Islands and Western Aleutian Islands were active historically but closed in 1999 and 2004, respectively (North Pacific Fishery Management Council 2016). Norton Sound supports summer and winter commercial fisheries as well as a winter subsistence fishery (Ahmasuk et al. 2008, North Pacific Fishery Management Council 2016). Bristol Bay is the largest fishery with harvests around 1.5 million crabs, although historically the peak catch was larger, with over 20 million crabs caught in the 1980 season (North Pacific Fishery Management Council 2016). The Bristol Bay fishery is worth $50–100 million in gross revenue and provides $10–15 million in fishing crew and processing wages (North Pacific Fishery Management Council 2015).

Subsistence catch of king crab from Nome and the Seward Peninsula is a historically important community harvest, and the crab are used both locally and in sharing or trading for other resources with Kotzebue residents, and similar communities away from king crab habitats (Georgette and Loon 1993, Ahmasuk et al. 2008).

CONSERVATION ISSUES

Many crab populations in Alaska have declined in part due to fishing harvests that were too high in the past. Efforts to rebuild crab populations have met with varying degrees of success in Alaska, and currently only two out of eight historical red king crab fisheries are still open (North Pacific Fishery Management Council 2016). The Bristol Bay stock is in decline with survey results of both males and females below the 10-year average, and an estimated 21% decrease in mature male biomass between 2015 and 2016 (North Pacific Fishery Management Council 2016).

Red king crabs are protected from trawling year-round in the Red King Crab Savings Area and seasonally (March 15–June 15) in Area 516, spatial management areas in Bristol Bay (see Map 3.5). Both areas were established to reduce bycatch and protect migration of red king crab from shallow to deeper waters after molting and mating (North Pacific Fishery Management Council 2016). Despite these protections, the Bristol Bay red king crab stock is in decline and the fishery, as well as other EBS crab fisheries, are being more conservatively managed (North Pacific Fishery Management Council 2016).

Another protected area is the Pribilof Islands Habitat Conservation Zone, which was established to protect the overfished blue king crab population (Figure 3.5-1). The directed fishery for blue king crab off of the Pribilof Islands has been closed since 1999 and does not show signs of rebuilding (Daly et al. 2016). Blue king crab bycatch is therefore a limiting factor in the ability to catch red king crab in areas where their populations overlap.

A final conservation issue for red king crabs, and all crustaceans, is the effect of ocean acidification on their exoskeletons.

MAP ON PAGE 67

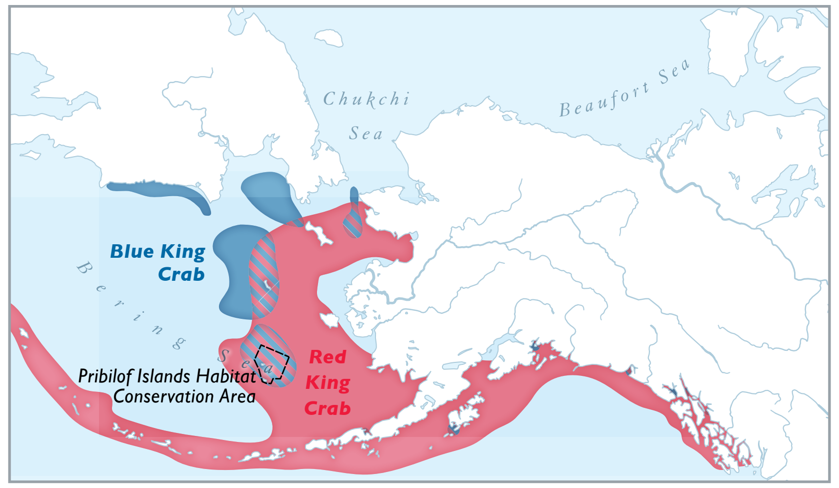


FIGURE 3.5-1. Red king crab and blue king crab Essential Fish Habitat, showing overlap including around the Pribilof Islands. Interactions with blue king crabs precipitated the establishment of the Pribilof Islands Habitat Conservation Zone. Figure adapted from National Oceanic and Atmospheric Administration (2016b).

MAPPING METHODS (MAP 3.5)

The relative abundance of red king crab was estimated by interpolating datasets from bottom trawl surveys which employed similar and consistent methodologies and sampled waters within the US EEZ of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell et al. 2010). Data points for red king crab presence or absence were extracted and mapped based on catch per unit effort (CPUE) in kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted (IDW) tool in ArcGIS version 10.5 based on CPUE values. A radius of the 12 nearest points was set as the search distance and interpolation was limited to the study area boundaries of the trawl surveys.

The red king crab generalized distribution polygon was digitized from North Pacific Fishery Management Council (2015) which broadly describes the range of red king crab in Alaskan waters.

Essential Fish Habitat (EFH) areas for red king crab were obtained directly from National Oceanic and Atmospheric Administration (2016b). These EFH areas are considered to be the general distribution for late juvenile and adult red king crab. These areas are described as being located in bottom habitats along the nearshore (spawning aggregations) and the inner (0–165 feet [0–50 m]), middle (165–330 feet [50–100 m]), and outer shelf (330–660 feet [100–200 m]) throughout the Bering Sea and Aleutian Islands wherever there are substrates consisting of sand, mud, cobble, and gravel.

Management area polygons were all obtained directly from National Oceanic and Atmospheric Administration (2016a). These areas were displayed because they are known important areas for red king crab spawning or migration. National Marine Fisheries Service Management Area 516 is closed to commercial bottom trawling from March 15 to June 15 to protect spawning stock of red king crab. The Red King Crab Savings Area is closed year-round to commercial bottom trawling to protect important red king crab habitat and migration area and to protect spawning stock biomass. Additionally, the Pribilof Islands Habitat Conservation Area is closed year-round to commercial bottom trawling to protect blue king crab from overexploitation as bycatch.

Data Quality

Trawl survey data sampling was conducted within the US EEZ, therefore there is little to no coverage on the Russian side of the Bering Sea for red king crab. The interpolation of the trawl survey data estimates the distribution of red king crab during the summer months and may not represent the year-round distribution.

Bottom trawl surveys in the Aleutian Islands were conducted every 3 years from 1983 to 2000 and on even years from 2002 to 2016. Surveys on the Bering Sea slope were conducted on even years from 2002 to 2016 except for 2006 and 2014. Surveys on the EBS shelf were conducted from 1982 to 2016. Surveys for the northern Bering Sea occurred from 1982 to 2010. Gulf of Alaska surveys were conducted in 1984 and 1987, every 3 years from 1990–1999, and on odd years from 2001 to 2015. Bottom trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewer

- Joel Webb

MAP DATA SOURCES

Trawl Density: Oceana (2017c) based on Conner and Lauth (2016), Goddard et al. (2014), Hoff (2016), Logerwell et al. (2010), Raring et al. (2016), and von Szalay and Raring (2016)

Distribution: North Pacific Fishery Management Council (2015)

Essential Fish Habitat: National Oceanic and Atmospheric Administration (2016b)

Management Areas: National Oceanic and Atmospheric Administration (2016a)

Red King Crab

OCEANA Audubon ALASKA

Red King Crab (*Paralithodes camtschaticus*)

Red king crabs are the largest-sized crab species in Alaska waters. Red king crabs are generally distributed throughout the North Pacific from deep shelf waters (<820 ft or 250 m) to shallow, nearshore, intertidal environments. They range from Southeast Alaska, along the Aleutian Islands, throughout Bristol Bay and the eastern Bering Sea, north to Kotzebue Sound, and westward toward Japan and Russia. Bristol Bay is home to the most abundant actively fished population, though the stock is currently in decline and the fishery is being conservatively managed. The majority of large males targeted by the fishery are found in the central and southern areas of Bristol Bay near the Alaska Peninsula. Molting and mating red king crabs are protected from trawling year-round in the Red King Crab Savings Area and seasonally in Area 516. Another protected area is the Pribilof Islands Habitat Conservation Zone, which was established to protect the overfished blue king crab (*P. platypus*).

National Oceanic and Atmospheric Administration (2016a, b); North Pacific Fishery Management Council (2015); Oceana (2017c) [based on Conner and Lauth (2016), Goddard et al. (2014), Hoff (2016), Logerwell et al. (2010), Raring et al. (2016), and von Szalay and Raring (2016)]

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

REFERENCES

Agnalt, A.-L., V. Pavlov, K. E. Jørstad, E. Farestveit, and J. Sundet. 2011. The snow crab, *Chionoecetes opilio* (Decapoda, Majoidea, Oregoniidae) in the Barents Sea, *In In the Wrong Place – Alien Marine Crustaceans: Distribution, Biology and Impacts*. B. S. Galil, P. F. Clark, and J. T. Carlton eds., pp. 283-300. Springer, Dordrecht, Netherlands.

Ahmasuk, A., E. Trigg, J. Magdanz, and B. Robbins. 2008. Bering Strait Region Local and Traditional Knowledge Pilot Project: A Comprehensive Subsistence Use Study of the Bering Strait Region. North Pacific Research Board Final Report #643. Kawerak, Inc., Nome, AK.

Alaska Fisheries Science Center. 2010a. Blue King Crab. NOAA Fisheries Service Alaska Fisheries Science Center. National Oceanic and Atmospheric Administration, Seattle, WA.

_____. 2010b. Golden King Crab. NOAA Fisheries Service Alaska Fisheries Science Center. National Oceanic and Atmospheric Administration, Seattle, WA.

_____. 2010c. Red King Crab. NOAA Fisheries Service Alaska Fisheries Science Center. National Oceanic and Atmospheric Administration, Seattle, WA.

Allain, R. N., M. Moriyasu, B. D. Crawford, and S. C. Courtenay. 2011. Lipofuscin quantification as a potential tool for age estimation in snow crabs, (*O. Fabricius*, 1788) (Decapoda, Oregoniidae). *Crustaceana* 84:1441-1463.

Alvsvåg, J., A.-L. Agnalt, and K. E. Jørstad. 2009. Evidence for a permanent establishment of the snow crab (*Chionoecetes opilio*) in the Barents Sea. *Biological Invasions* 11:587-595.

Andrews, A. H., E. E. Cordes, M. M. Mahoney, K. Munk, K. H. Coale, G. M. Cailliet, and J. Heifetz. 2002. Age, growth and radiometric age validation of a deep-sea, habitat-forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska. *Hydrobiologia* 471:101-110.

Armstrong, J. L., J. L. Boldt, A. D. Cross, J. H. Moss, N. D. Davis, K. W. Myers, R. V. Walker, D. A. Beauchamp, and L. J. Haldorson. 2005. Distribution, size, and interannual, seasonal and diel food habits of northern Gulf of Alaska juvenile pink salmon, *Oncorhynchus gorbuscha*. *Deep Sea Research Part II: Topical Studies in Oceanography* 52:247-265.

Arrigo, K. R. 2014. Sea ice ecosystems. *Annual Review of Marine Science* 6:439-467.

Arrigo, K. R., D. K. Perovich, R. S. Pickart, Z. W. Brown, G. L. van Dijken, K. E. Lowry, M. M. Mills, M. A. Palmer, W. M. Balch, and F. Bahr. 2012. Massive phytoplankton blooms under Arctic sea ice. *Science* 336:1408-1408.

Arrigo, K. R. and G. L. van Dijken. 2011. Secular trends in Arctic Ocean net primary production. *Journal of Geophysical Research: Oceans* 116:C09011.

_____. 2015. Continued increases in Arctic Ocean primary production. *Progress in Oceanography* 136:60-70.

Ashjian, C. J. 2013. Integrated Chlorophyll (0-100 m, mg/m^2), All Data. Version 1.0. UCAR/NCAR - Earth Observing Laboratory, Accessed online at https://doi.org/10.5065/D69C6VFZ.

Audubon Alaska. 2016. Monthly Sea Ice Approximate 2006-2015 Medians GIS File. Audubon Alaska, Anchorage, AK.

Audubon Alaska and Oceana. 2017. Interpolated Primary Productivity GIS File. Audubon Alaska, Anchorage, AK.

Barber, D. G., H. Hop, C. J. Mundy, B. Else, I. A. Dmitrenko, J.-E. Tremblay, J. K. Ehn, P. Assmy, M. Daase, and L. M. Candlish. 2015. Selected physical, biological and biogeochemical implications of a rapidly changing Arctic Marginal Ice Zone. *Progress in Oceanography* 139:122-150.

Barber, W. E., R. L. Smith, and T. J. Weingartner. 1994. Fisheries Oceanography of the Northeast Chukchi Sea - Final Report. OCS MMS 93-0051. Minerals Management Service, Alaska OCS Region, Anchorage, AK.

Bates, N. R., J. T. Mathis, and L. W. Cooper. 2009. Ocean acidification and biologically induced seasonality of carbonate mineral saturation states in the western Arctic Ocean. *Journal of Geophysical Research: Oceans* 114.

Bekryaev, R. V., I. V. Polyakov, and V. A. Alexeev. 2010. Role of polar amplification in long-term surface air temperature variations and modern Arctic warming. *Journal of Climate* 23:3888-3906.

Bluhm, B., K. Dunton, J. Grebmeier, and B. Sirenko. 2008. Benthos, *In Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research*. R. Hopcroft, B. Bluhm, R. Gradinger, T. E. Whitledge, T. Weingartner, B. Norcross, and A. Springer eds., pp. 56-65. University of Alaska Fairbanks, Institute of Marine Science, Fairbanks, AK.

Bluhm, B. A., K. Iken, S. Mincks Hardy, B. I. Sirenko, and B. A. Holladay. 2009. Community structure of epibenthic megafauna in the Chukchi Sea. *Aquatic Biology* 7:269-293.

Boetius, A., S. Albrecht, K. Bakker, C. Bienhold, J. Felden, M. Fernández-Méndez, S. Hendricks, C. Katlein, C. Lalande, and T. Krumpen. 2013. Export of algal biomass from the melting Arctic sea ice. *Science* 339:1430-1432.

Boldt, J. L. and C. N. Rooper. 2009. Abundance, condition, and diet of juvenile Pacific Ocean perch (*Sebastes alutus*) in the Aleutian Islands. *Fishery Bulletin* 107:278-285.

Britayev, T. A., A. V. Rzhavsky, L. V. Pavlova, and A. G. Dvoretskij. 2010. Studies on impact of the alien red king crab (*Paralithodes camtschaticus*) on the shallow water benthic communities of the Barents Sea. *Journal of Applied Ichthyology* 26:66-73.

Brower, A. A., M. C. Ferguson, S. V. Schonberg, S. C. Jewett, and J. T. Clarke. 2017. Gray whale distribution relative to benthic invertebrate biomass and abundance: Northeastern Chukchi Sea 2009–2012. *Deep-Sea Research Part II: Topical Studies in Oceanography*.

Brown, Z. W. and K. R. Arrigo. 2012. Contrasting trends in sea ice and primary production in the Bering Sea and Arctic Ocean. *ICES Journal of Marine Science* 69:1180-1193.

_____. 2013. Sea ice impacts on spring bloom dynamics and net primary production in the eastern Bering Sea. *Journal of Geophysical Research: Oceans* 118:43-62.

Brown, Z. W., G. L. van Dijken, and K. R. Arrigo. 2011. A reassessment of primary production and environmental change in the Bering Sea. *Journal of Geophysical Research: Oceans* 116:C08014.

Burgos, J., B. Ernst, D. Armstrong, and J. Orensanz. 2013. Fluctuations in range and abundance of snow crab (*Chionoecetes opilio*) from the eastern Bering Sea: What role for Pacific cod (*Gadus macrocephalus*) predation? *Bulletin of Marine Science* 89:57-81.

Burmeister, A. and B. Sainte-Marie. 2010. Pattern and causes of a temperature-dependent gradient of size at terminal moult in snow crab (*Chionoecetes opilio*) along West Greenland. *Polar Biology* 33:775-788.

Chaves, J. E., P. J. Werdell, C. W. Proctor, A. R. Neeley, S. A. Freeman, C. S. Thomas, and S. B. Hooker. 2015. Assessment of ocean color data records from MODIS-Aqua in the western Arctic Ocean. *Deep Sea Research Part II: Topical Studies in Oceanography* 118, Part A:32-43.

Chilton, E. A., R. J. Foy, and C. E. Armistead. 2010. Temperature effects on assessment of red king crab in Bristol Bay, Alaska, *In Biology and Management of Exploited Crab Populations under Climate Change*. G. H. Kruse, G. L. Eckert, R. J. Foy, R. N. Lipcius, B. Sainte-Marie, D. L. Stram, and D. Woodby eds. Alaska Sea Grant AK-SG-10-01, University of Alaska Fairbanks, Fairbanks, AK.

Comeau, M., M. Starr, G. Y. Conan, G. Robichaud, and J.-C. Therriault. 1999. Fecundity and duration of egg incubation for multiparous female snow crabs (*Chionoecetes opilio*) in the fjord of Bonne Bay, Newfoundland. *Canadian Journal of Fisheries and Aquatic Sciences* 56:1088-1095.

Conan, G. Y. and M. Comeau. 1986. Functional maturity and terminal molt of male snow crab, *Chionoecetes opilio*. *Canadian Journal of Fisheries and Aquatic Sciences* 43:1710-1719.

Conan, G. Y., M. Moriyasu, D. R. Maynard, and Y. Chiasson. 1989. Factors influencing egg production in decapod Crustacea with two case studies: *Chionoecetes opilio* and *Homarus americanus* in the Gulf of St. Lawrence. *ICES CM 1989/Mini 04*.

Conan, G. Y., M. Starr, M. Comeau, J. C. Therriault, G. Robichand, and F. X. M. Hernàndez. 1996. Life history strategies, recruitment fluctuations, and management of the Bonne Bay Fjord Atlantic snow crab (*Chionoecetes opilio*), *In Proceedings of the International Symposium on the Biology, Management and Economics of Crabs from High Latitude Habitats*. October 1995, Anchorage, AK.

Conner, J. and R. R. Lauth. 2016. Results of the 2013 Eastern Bering Sea Continental Shelf Bottom Trawl Survey of Groundfish and Invertebrate Resources. NOAA Technical Memorandum NMFS-AFSC-331. National Oceanic and Atmospheric Administration, Seattle, WA.

Coyle, K. O., B. Konar, A. Blanchard, R. C. Highsmith, J. Carroll, M. Carroll, S. G. Denisenko, and B. I. Sirenko. 2007. Potential effects of temperature on the benthic infaunal community on the southeastern Bering Sea shelf: Possible impacts of climate change. *Deep Sea Research Part II: Topical Studies in Oceanography* 54:2885-2905.

Coyle, K. O., A. I. Pinchuk, L. B. Eisner, and J. M. Napp. 2008. Zooplankton species composition, abundance and biomass on the eastern Bering Sea shelf during summer: The potential role of water-column stability and nutrients in structuring the zooplankton community. *Deep Sea Research Part II: Topical Studies in Oceanography* 55:1775-1791.

Daly, B., G. L. Eckert, and T. D. White. 2012. Predation of hatchery-cultured juvenile red king crabs (*Paralithodes camtschaticus*) in the wild. *Canadian Journal of Fisheries and Aquatic Sciences* 70:358-366.

Daly, B. J., C. E. Armistead, and R. J. Foy. 2016. The 2016 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. NOAA Technical Memorandum NMFS-AFSC. National Oceanic and Atmospheric Administration, Kodiak, AK.

Davis, N. D., K. W. Myers, and Y. Ishida. 1998. Caloric value of high-seas salmon prey organisms and simulated salmon ocean growth and prey consumption. *North Pacific Anadromous Fish Commission Bulletin No.* 1:146-162.

Dean, T. A., L. Haldorson, D. R. Laur, S. C. Jewett, and A. Blanchard. 2000. The distribution of nearshore fishes in kelp and eelgrass communities in Prince William Sound, Alaska: Associations with vegetation and physical habitat characteristics. *Environmental Biology of Fishes* 57:271-287.

Dew, C. B. 1990. Behavioral ecology of podding red king crab, *Paralithodes camtschatica*. *Canadian Journal of Fisheries and Aquatic Sciences* 47:1944-1958.

_____. Podding behavior of adult king crab and its effect on abundance-estimate precision, *In Biology and Management of Exploited Crab Populations Under Climate Change*. G. H. Kruse, G. L. Eckert, R. J. Foy, R. N. Lipcius, B. Sainte-Marie, D. L. Stram, and D. Woodby eds. Alaska Sea Grant, University of Alaska Fairbanks, Fairbanks, AK.

Dionne, M., B. Sainte-Marie, E. Bourget, and D. Gilbert. 2003. Distribution and habitat selection of early benthic stages of snow crab *Chionoecetes opilio*. *Marine Ecology Progress Series* 259:117-128.

Divine, L. M., B. A. Bluhm, F. J. Mueter, and K. Iken. 2017. Diet analysis of Alaska Arctic snow crabs (*Chionoecetes opilio*) using stomach contents and $\delta^{13}C$ and $\delta^{15}N$ stable isotopes. *Deep Sea Research Part II: Topical Studies in Oceanography* 135:124-136.

Donaldson, W. E. and S. C. Byersdorfer. 2005. Biological Field Techniques for Lithodid Crabs. Alaska Sea Grant College Program AK-SG-05-03, University of Alaska Fairbanks, Fairbanks, AK.

Duggins, D. O., C. A. Simenstad, and J. A. Estes. 1989. Magnification of secondary production by kelp detritus in coastal marine ecosystems. *Science* 245:170-173.

Dunton, K. H., J. L. Goodall, S. V. Schonberg, J. M. Grebmeier, and D. R. Maidment. 2005. Multi-decadal synthesis of benthic-pelagic coupling in the western Arctic: Role of cross-shelf advective processes. *Deep Sea Research Part II: Topical Studies in Oceanography* 52:3462-3477.

Eisner, L., N. Hillgruber, E. Martinson, and J. Maselko. 2013. Pelagic fish and zooplankton species assemblages in relation to water mass characteristics in the northern Bering and southeast Chukchi seas. *Polar Biology* 36:87-113.

Eisner, L. B., J. M. Napp, K. L. Mier, A. I. Pinchuk, and A. G. Andrews III. 2014. Climate-mediated changes in zooplankton community structure for the eastern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 109:157-171.

Ernst, B., D. A. Armstrong, J. Burgos, and J. M. Orensanz. 2012. Life history schedule and periodic recruitment of female snow crab (*Chionoecetes opilio*) in the eastern Bering Sea. *Canadian Journal of Fisheries and Aquatic Sciences* 69:532-550.

Ernst, B., J. M. Orensanz, and D. A. Armstrong. 2005. Spatial dynamics of female snow crab (*Chionoecetes opilio*) in the eastern Bering Sea. *Canadian Journal of Fisheries and Aquatic Sciences* 62:250-268.

Fabry, V. J., J. B. McClintock, J. T. Mathis, and J. M. Grebmeier. 2009. Ocean acidification at high latitudes: The bellweather. *Oceanography* 22:160-171.

Falkowski, P. G., R. T. Barber, and V. Smetacek. 1998. Biogeochemical controls and feedbacks on ocean primary production. *Science* 281:200-206.

Feder, H. M., S. C. Jewett, and A. Blanchard. 2005. Southeastern Chukchi Sea (Alaska) epibenthos. *Polar Biology* 28:402-421.

Fetterer, F., K. Knowles, W. Meier, and M. Savoie. 2016. Sea Ice Index, Version 2. National Snow and Ice Data Center, Boulder, CO.

Fonseca, D. B., B. Sainte-Marie, and F. Hazel. 2008. Longevity and change in shell condition of adult male snow crab *Chionoecetes opilio* inferred from dactyl wear and mark-recapture data. *Transactions of the American Fisheries Society* 137:1029-1043.

Frey, K. E., K. R. Arrigo, and W. J. Williams 2012. Primary Productivity and Nutrient Variability, *In Arctic Report Card 2012*. M. O. Jeffries, J. A. Richter-Menge, and J. E. Overland eds. Accessed online at http://www.arctic.noaa.gov/reportcard.

Frey, K. E., J. C. Comiso, L. W. Cooper, R. R. Gradinger, J. M. Grebmeier, and J.-É. Tremblay. 2015. Arctic Ocean Primary Productivity, *In Arctic Report Card 2015*. M. O. Jeffries, J. A. Richter-Menge, and J. E. Overland eds. Accessed online at http://www.arctic.noaa.gov/Report-Card.

Frey, K. E., D. K. Perovich, and B. Light. 2011. The spatial distribution of solar radiation under a melting Arctic sea ice cover. *Geophysical Research Letters* 38:L22501.

Fuhrmann, M. M., T. Pedersen, and E. M. Nilssen. 2017. Trophic niche of the invasive red king crab *Paralithodes camtschaticus* in a benthic food web. *Marine Ecology Progress Series* 565:113-129.

Fukuyama, A. K. and J. S. Oliver. 1985. Sea star and walrus predation on bivalves in Norton Sound, Bering Sea, Alaska. *Ophelia* 24:17-36.

Georgette, S. and H. Loon. 1993. Subsistence Use of Fish and Wildlife in Kotzebue, a Northwest Alaska Regional Center. Technical Paper No. 167. Alaska Department of Fish and Game, Juneau, AK.

Goddard, P., R. Lauth, and C. Armistead. 2014. Results of the 2012 Chukchi Sea Bottom Trawl Survey of Bottomfishes, Crabs, and Other Demersal Macrofauna. NOAA Technical Memorandum NMFS-AFSC-278. National Oceanic and Atmospheric Administration, Seattle, WA.

Gosselin, M., M. Levasseur, P. Wheeler, R. Horner, and B. Booth. 1997. New measurements of phytoplankton and ice algal production in the Arctic Ocean. *Deep-Sea Research Part II: Topical Studies in Oceanography* 44:1623-1644.

Grebmeier, J. M. 2012. Shifting patterns of life in the Pacific Arctic and sub-Arctic Seas. *Annual Review of Marine Science* 4:63-78.

Grebmeier, J. M., B. A. Bluhm, L. W. Cooper, S. L. Danielson, K. R. Arrigo, A. L. Blanchard, J. T. Clarke, R. H. Day, K. E. Frey, R. R. Gradinger, M. Kędra, B. Konar, K. J. Kuletz, S. H. Lee, J. R. Lovvorn, B. L. Norcross, and S. R. Okkonen. 2015a. Ecosystem characteristics and processes facilitating persistent macrobenthic biomass hotspots and associated benthivory in the Pacific Arctic. *Progress in Oceanography* 136:92-114.

Grebmeier, J. M. and L. W. Cooper. 2014a. PacMARS Benthic Infaunal Parameters. Version 1.0. UCAR/NCAR - Earth Observing Laboratory. Accessed online at https://doi.org/10.5065/D6H70CVR.

_____. 2014b. PacMARS Integrated Chlorophyll-a (1985-2012). Version 1.0. UCAR/NCAR - Earth Observing Laboratory. Accessed online at https://doi.org/10.5065/D6F47M47.

Grebmeier, J. M., L. W. Cooper, C. A. Ashjian, B. A. Bluhm, R. B. Campbell, K. E. Dunton, J. Moore, S. Okkonen, G. Sheffield, J. Trefry, and S. Y. Pasternak. 2015b. Pacific Marine Arctic Regional Synthesis (PacMARS) Final Report. North Pacific Research Board, Anchorage, AK.

Grebmeier, J. M., L. W. Cooper, H. M. Feder, and B. I. Sirenko. 2006a. Ecosystem dynamics of the Pacific-influenced northern Bering and Chukchi Seas in the Amerasian Arctic. *Progress in Oceanography* 71:331-361.

_____. 2014. Ecosystem dynamics of the Pacific-influenced northern Bering and Chukchi Seas in the Amerasian Arctic (updated sampling dataset). *Progress in Oceanography* 71:331-361.

Grebmeier, J. M., H. M. Feder, and C. P. McRoy. 1989. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. II. Benthic community structure. *Marine Ecology-Progress Series* 51:253-269.

Grebmeier, J. M. and H. R. Harvey. 2005. The western Arctic Shelf-Basin Interactions (SBI) project: An overview. *Deep-Sea Research Part II: Topical Studies in Oceanography* 52:3109-3115.

Grebmeier, J. M., C. P. McRoy, and H. M. Feder. 1988. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. I. Food-supply source and benthic biomass. *Marine Ecology-Progress Series* 48:57-67.

Grebmeier, J. M., J. E. Overland, S. E. Moore, E. V. Farley, E. C. Carmack, L. W. Cooper, K. E. Frey, J. H. Helle, F. A. McLaughlin, and S. L. McNutt. 2006b. A major ecosystem shift in the northern Bering Sea. *Science* 311:1461-1464.

Hardy, S. M., M. Lindgren, H. Konakanchi, and F. Huettmann. 2011. Predicting the distribution and ecological niche of unexploited snow crab (*Chionoecetes opilio*) populations in Alaskan waters: A first open-access ensemble model. *Integrative and Comparative Biology* 51:608-622.

Hébert, M., E. Wade, P. DeGrâce, J.-F. Landry, and M. Moriyasu. 2014. The 2013 Assessment of the Snow Crab (*Chionoecetes opilio*) Stock in the Southern Gulf of St. Lawrence (Areas 12, 19, 12E and 12F). Research Document 2014/084. DFO Canadian Science Advisory Secretariat, Ottawa, Canada.

Heifetz, J. 2002. Coral in Alaska: Distribution, abundance, and species associations. *Hydrobiologia* 471:19-28.

Heifetz, J., B. L. Wing, R. P. Stone, P. W. Malecha, and D. L. Courtney. 2005. Coral of the Aleutian Islands. *Fisheries Oceanography* 14:131-138.

Hill, V. and G. Cota. 2005. Spatial patterns of primary production on the shelf, slope and basin of the western Arctic in 2002. *Deep-Sea Research Part II: Topical Studies in Oceanography* 52:3344-3354.

Hoff, G. R. 2016. Results of the 2016 Eastern Bering Sea Upper Continental Slope Survey of Groundfish and Invertebrate Resources. NOAA Technical Memorandum NMFS-AFSC-339. National Oceanic and Atmospheric Administration, Seattle, WA.

Hoopes, D. and J. Karinen. 1972. Longevity and growth of tagged king crabs in the eastern Bering Sea. *Fishery Bulletin* 70:225-226.

Hopcroft, R., C. Ashjian, S. Smith, and K. Kosobokova. 2008. Zooplankton, *In Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research*. R. Hopcroft, B. Bluhm, R. Gradinger, T. E. Whitledge, T. Weingartner, B. Norcross, and A. Springer eds. University of Alaska Fairbanks, Institute of Marine Science, Fairbanks, AK.

Hopcroft, R. R., C. Clarke, R. J. Nelson, and K. A. Raskoff. 2005. Zooplankton communities of the Arctic's Canada Basin: The contribution by smaller taxa. *Polar Biology* 28:198-206.

Horner, R. and G. C. Schrader. 1982. Relative contributions of ice algae, phytoplankton, and benthic microalgae to primary production in nearshore regions of the Beaufort Sea. *Arctic* 35:485-503.

Hunt, G. L., Jr, P. Stabeno, G. Walters, E. Sinclair, R. D. Brodeur, J. M. Napp, and N. A. Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. *Deep Sea Research Part II: Topical Studies in Oceanography* 49:5821-5853.

Hunt, G. L., Jr, K. O. Coyle, L. B. Eisner, E. V. Farley, R. A. Heintz, F. Mueter, J. M. Napp, J. E. Overland, P. H. Ressler, S. Salo, and P. J. Stabeno. 2011. Climate impacts on eastern Bering Sea foodwebs: A synthesis of new data and an assessment of the Oscillating Control Hypothesis. *ICES Journal of Marine Science* 68:1230-1243.

Jadamec, L. S., W. E. Donaldson, and P. Cullenberg. 1999. Biological Field Techniques for *Chionoecetes* crabs. University of Alaska Sea Grant AK-SG-99-02, Fairbanks, AK.

Jewett, S. C., T. A. Dean, and D. R. Laur. 1996. Effect of the Exxon Valdez oil spill on the benthic invertebrates in an oxygen-deficient embayment in Prince William Sound, Alaska. *In* Proceedings of the Exxon Valdez Oil Spill Symposium. American Fisheries Society, Bethesda, MD.

Kawaguchi, S., H. Kurihara, R. King, L. Hale, T. Berli, J. P. Robinson, A. Ishida, M. Wakita, P. Virtue, S. Nicol, and A. Ishimatsu. 2010. Will krill fare well under Southern Ocean acidification? *Biology Letters* 7:228-291.

Kilada, R., J. B. Webb, K. W. McNeel, L. S. Slater, Q. Smith, and J. Ferguson. 2017. Preliminary assessment of a direct age-determination method for 3 commercially important crustaceans from Alaska. *Fishery Bulletin* 115:42-49.

Kim, S. L. and J. S. Oliver. 1989. Swarming benthic crustaceans in the Bering and Chukchi Seas and their relation to geographic patterns in gray whale feeding. *Canadian Journal of Zoology* 67:1531-1542.

Kon, T., M. Ono, and Y. Honma. 2010. Histological studies on the spent ovaries of aged snow crabs *Chionoecetes opilio* caught in the Sea of Japan. *Fisheries Science* 76:227-233.

Krembs, C., R. Gradinger, and M. Spindler. 2000. Implications of brine channel geometry and surface area for the interaction of sympagic organisms in Arctic sea ice. *Journal of Experimental Marine Biology and Ecology* 243:55-80.

Kruse, G. H., A. V. Tyler, B. Sainte-Marie, and D. Pengilly. 2007. A workshop on mechanisms affecting year-class strength formation in snow crabs (*Chionoecetes opilio*) in the eastern Bering Sea. *Alaska Fishery Research Bulletin* 12:277-290.

Lehnert, H. and R. P. Stone. 2014. Two new species of sponges (Porifera, Demospongiae) from the Aleutian Islands, Alaska. *Journal of the Marine Biological Association of the United Kingdom* 96:673-680.

Leu, E., C. Mundy, P. Assmy, K. Campbell, T. Gabrielsen, M. Gosselin, T. Juul-Pedersen, and R. Gradinger. 2015. Arctic spring awakening—steering principles behind the phenology of vernal ice algal blooms. *Progress in Oceanography* 139:151-170.

Livingston, P. A. 1989. Interannual trends in Pacific cod, *Gadus marcocephalus*, predation on three commercially important crab species in the eastern Bering Sea. *Fisheries Bulletin* 87:807-827.

Loeng, H., K. Brander, E. Carmack, S. Denisenko, K. Drinkwater, B. Hansen, K. Kovacs, P. Livingston, F. McLaughlin, and E. Sakshaug. 2005. Marine systems, *In Arctic Climate Impact Assessment*. C. Symon, L. Arris, and B. Heal eds., pp. 453-538. Cambridge University Press, New York, NY.

Logerwell, E., K. Rand, S. Parker-Stetter, J. Horne, T. Weingartner, and B. Bluhm. 2010. Beaufort Sea Marine Fish Monitoring 2008: Pilot Survey and Test of Hypotheses. BOEMRE 2010-048. Minerals Management Service, Anchorage, AK.

Loher, T., D. A. Armstrong, and B. G. Stevens. 2001. Growth of juvenile red king crab (*Paralithodes camtschaticus*) in Bristol Bay (Alaska) elucidated from field sampling and analysis of trawl survey data. *Fishery Bulletin* 99:572-587.

Long, W. C., K. M. Swiney, C. Harris, H. N. Page, and R. J. Foy. 2013. Effects of ocean acidification on juvenile red king crab (*Paralithodes camtschaticus*) and tanner crab (*Chionoecetes bairdi*) growth, condition, calcification, and survival. *PLoS ONE* 8:e60959.

Lovrich, G. A. and B. Sainte-Marie. 1997. Cannibalism in the snow crab, *Chionoecetes opilio* (O. Fabricius) (Brachyura: Majidae), and its potential importance to recruitment. *Journal of Experimental Marine Biology and Ecology* 211:225-245.

Malecha, P. W., R. P. Stone, and J. Heifetz. 2005. Living substrate in Alaska: Distribution, abundance, and species associations, *In Benthic Habitats and the Effects of Fishing*. P. W. Barnes and J. P. Thomas eds., pp. 289-299. American Fisheries Society Symposium 41, Bethesda, MD.

McCaughran, D. A. and G. C. Powell. 1977. Growth model for Alaska king crab (*Paralithodes camtschaticus*). *Journal of the Fisheries Research Board of Canada* 34:989-995.

McConnaughey, R. A. and K. R. Smith. 2000. Associations between flatfish abundance and surficial sediments in the eastern Bering Sea. *Canadian Journal of Fisheries and Aquatic Sciences* 57:2410-2419.

Merkouris, S. E., L. W. Seeb, and M. C. Murphy. 1998. Low levels of genetic diversity in highly exploited populations of Alaskan Tanner crabs, *Chionoecetes bairdi*, and Alaskan and Atlantic snow crabs, *C. opilio*. *Fishery Bulletin* 96:525-537.

Meyers, T. and T. Burton. 2009. *Hematodinium sp.* - Bitter crab disease of Tanner crabs, *In Diseases of Wild and Cultured Shellfish in Alaska*. pp. 84-89. Alaska Department of Fish and Game, Commercial Fisheries Division, Anchorage, AK.

Meyers, T., J. Morado, A. Sparks, G. Bishop, T. Pearson, D. Urban, and D. Jackson. 1996. Distribution of bitter crab syndrome in Tanner crabs (*Chionoecetes bairdi, C. opilio*) from the Gulf of Alaska and the Bering Sea. *Diseases of Aquatic Organisms* 26:221-227.

Morel, A. and D. Antoine. 2002. Small critters—Big effects. *Science* 296:1980-1982.

Moriarty, R. and T. D. O'Brien. 2013. Distribution of mesozooplankton biomass in the global ocean. *Earth System Science Data* 5:45-55.

Moriyasu, M. and C. Lanteigne. 1998. Embryo development and reproductive cycle in the snow crab, *Chionoecetes opilio* (Crustacea: Majidae), in the southern Gulf of St. Lawrence, Canada. *Canadian Journal of Zoology* 76:2040-2048.

Moriyasu, M. and P. Mallet. 1986. Molt stages of the snow crab *Chionoecetes opilio* by observation of morphogenesis of setae on the maxilla. *Journal of Crustacean Biology* 6:709-718.

Moss, J. H., M. F. Zaleski, and R. A. Heintz. 2016. Distribution, diet, and energetic condition of age-0 walleye pollock (*Gadus chalcogrammus*) and Pacific cod (*Gadus macrocephalus*) inhabiting the Gulf of Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 132:146-153.

Muller-Karger, F. E., R. Varela, R. Thunell, R. Luerssen, C. Hu, and J. J. Walsh. 2005. The importance of continental margins in the global carbon cycle. *Geophysical Research Letters* 32:L01602.

National Oceanic and Atmospheric Administration. 2012. COPEPOD: The Global Plankton Database. Annual Carbon Mass [Excel file]. National Oceanic and Atmospheric Administration. Accessed online at http://www.st.nmfs.noaa.gov/copepod/biomass/biomass-fields.html.

______. 2016a. AFSC/RACE: Alaska Groundfish Survey 1982-2015 for web. Alaska Fisheries Science Center Groundfish Assessment Program, Seattle, WA. Accessed online at http://www.afsc.noaa.gov/RACE/groundfish/survey_data/.

______. 2016b. Essential Fish Habitat (EFH) Mapper. GIS Shapefiles. National Oceanic and Atmospheric Administration, Seattle, WA. Accessed online at http://www.habitat.noaa.gov/protection/efh/efhmapper/index.html.

North Pacific Fishery Management Council. 2009. Fishery Management Plan for Fish Resources of the Arctic Management Area. North Pacific Fishery Management Council, Anchorage, AK.

______. 2010. Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage, AK.

______. 2011. Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage, AK.

______. 2015. Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage, AK.

______. 2016. Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage, AK.

Oceana. 2017a. Interpolated Benthic Biomass GIS File. Oceana, Juneau, AK.

______. 2017b. Interpolated Zooplankton GIS File. Oceana, Juneau, AK.

______. 2017c. Red King Crab GIS File. Oceana, Juneau, AK.

______. 2017d. Snow Crab GIS File. Oceana, Juneau, AK.

Oceana and Kawerak. 2014. Appendix: Oceana's quantitative procedure for identifying important ecological areas at higher levels of ecological complexity, *In Marine Life and Subsistence Use Data Synthesis*. Oceana and Kawerak eds., pp. 317-325, Juneau, AK.

Ohashi, R., A. Yamaguchi, K. Matsuno, R. Saito, N. Yamada, A. Iijima, N. Shiga, and I. Imai. 2013. Interannual changes in the zooplankton community structure on the southeastern Bering Sea shelf during summers of 1994–2009. *Deep Sea Research Part II: Topical Studies in Oceanography* 94:44-56.

Olson, M. B. and S. L. Strom. 2002. Phytoplankton growth, microzooplankton herbivory and community structure in the southeast Bering Sea: Insight into the formation and temporal persistence of an *Emiliania huxleyi* bloom. *Deep Sea Research Part II: Topical Studies in Oceanography* 49:5969-5990.

Orensanz, J., B. Ernst, D. A. Armstrong, P. Stabeno, and P. Livingston. 2004. Contraction of the geographic range of distribution of snow crab (*Chionoecetes opilio*) in the eastern Bering Sea: An environmental ratchet? *California Cooperative Oceanic Fisheries Investigations* 45:65-79.

Orensanz, J. M., E. Billy, and D. A. Armstrong. 2007. Variation of female size and stage at maturity in snow crab (*Chionoecetes opilio*) (Brachyura: Majidae) from the eastern Bering Sea. *Journal of Crustacean Biology* 27:576-591.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, and F. Joos. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437:681-686.

Otto, R. S. 1998. Assessment of the eastern Bering Sea snow crab, *Chionoecetes opilio*, stock under the terminal molting hypothesis, *In Canadian Special Publication of Fisheries and Aquatic Sciences 125: Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management*. G. S. Jamieson and A. Campbell eds., pp. 109-124. National Research Council of Canada, Ottawa, Canada.

Parada, C., D. A. Armstrong, B. Ernst, S. Hinckley, and J. M. Orensanz. 2010. Spatial dynamics of snow crab (*Chionoecetes opilio*) in the eastern Bering Sea—Putting together the pieces of the puzzle. *Bulletin of Marine Science* 86:413-437.

Patterson, B. 2015. Massive Toxic Algae Blooms May Prove a Sign of Climate Change to Come. *Scientific American*, August 11. Accessed online at https://www.scientificamerican.com/article/massive-toxic-algae-blooms-may-prove-a-sign-of-climate-change-to-come/.

Paul, A. J. 1984. Mating frequency and viability of stored sperm in the Tanner crab *Chionoecetes bairdi* (Decapoda, Majidae). *Journal of Crustacean Biology* 4:375-381.

Pirtle, J. L. and A. W. Stoner. 2010. Red king crab (*Paralithodes camtschaticus*) early post-settlement habitat choice: Structure, food, and ontogeny. *Journal of Experimental Marine Biology and Ecology* 393:130-137.

Pisareva, M. N., R. S. Pickart, K. Iken, E. A. Ershova, J. M. Grebmeier, L. W. Cooper, B. A. Bluhm, C. Nobre, R. R. Hopcroft, H. Hu, J. Wang, C. J. Ashjian, K. N. Kosobokova, and T. E. Whitledge. 2015. The relationship between patterns of benthic fauna and zooplankton in the Chukchi Sea and physical forcing. *Oceanography* 28:68-83.

Powell, G. C. 1967. Growth of King Crabs in the Vicinity of Kodiak Island, Alaska. Alaska Department of Fish and Game, Juneau, AK.

Powell, G. C., K. E. James, and C. L. Hurd. 1974. Ability of male king crab *Parallthodes camtschatica*, to mate repeatedly, Kodiak Alaska, 1973. *Fishery Bulletin* 72:17.

Punt, A. E., R. J. Foy, M. G. Dalton, W. C. Long, and K. M. Swiney. 2016. Effects of long-term exposure to ocean acidification conditions on future southern Tanner crab (*Chionoecetes bairdi*) fisheries management. *ICES Journal of Marine Science* 73:849-864.

Rand, K. M. and E. A. Logerwell. 2011. The first demersal trawl survey of benthic fish and invertebrates in the Beaufort Sea since the late 1970s. *Polar Biology* 34:475-488.

Raring, N. W., E. A. Laman, P. G. von Szalay, C. N. Rooper, and M. H. Martin. 2016. Data Report: 2012 Aleutian Islands Bottom Trawl Survey. NOAA Technical Memorandum NMFS-AFSC-332. National Oceanic and Atmospheric Administration, Seattle, WA.

Ravelo, A. M., B. Konar, and B. A. Bluhm. 2015. Spatial variability of epibenthic communities on the Alaska Beaufort Shelf. *Polar Biology* 38:1783-1804.

Raymond-Yakoubian, J., Y. Khokhlov, and A. Yarzutkina. 2014. Indigenous Knowledge and Use of Bering Strait Region Ocean Currents. Kawerak, Inc., Nome, AK.

Rooper, C. N., P. J. Etnoyer, K. L. Stierhoff, and J. V. Olson. 2016. Chapter 4: Effects of fishing gear on deep-sea corals and sponges in US waters, *In State of Deep-Sea Coral and Sponge Ecosystems of the United States*. T. F. Hourigan, P. J. Etnoyer, and S. D. Cairns eds., pp. 4-1–4-19. National Oceanic and Atmospheric Administration, Silver Spring, MD.

Rooper, C. N., M. E. Wilkins, C. S. Rose, and C. Coon. 2011. Modeling the impacts of bottom trawling and the subsequent recovery rates of sponges and corals in the Aleutian Islands, Alaska. *Continental Shelf Research* 31:1827-1834.

Sainte-Marie, B. and C. Carrière. 1995. Fertilization of the second clutch of eggs of snow crab, *Chionoecetes opilio*, from females mated once or twice after their molt to maturity. *Fishery Bulletin* 93:759-764.

Sainte-Marie, B., T. Gosselin, J. M. Sévigny, and N. Urbani. 2008. The snow crab mating system: Opportunity for natural and unnatural selection in a changing environment. *Bulletin of Marine Science* 83:131-161.

Schandelmeier, L. and V. Alexander. 1981. An analysis of the influence of ice on spring phytoplankton population structure in the southeast Bering Sea. *Limnology and Oceanography* 26:935-943.

Siddon, E. C., T. Kristiansen, F. J. Mueter, K. K. Holsman, R. A. Heintz, and E. V. Farley. 2014. Spatial match-mismatch between juvenile fish and prey provides a mechanism for recruitment variability across contrasting climate conditions in the eastern Bering Sea. *PLoS ONE* 8:e84526.

Sigler, M. F., F. J. Mueter, B. A. Bluhm, M. S. Busby, E. D. Cokelet, S. L. Danielson, A. De Robertis, L. B. Eisner, E. V. Farley, K. Iken, K. J. Kuletz, R. R. Lauth, E. A. Logerwell, and A. I. Pinchuk. 2016. Late Summer Open Water Zoogeography of the Northern Bering and Chukchi Seas. OCS Study BOEM 2011-AK-11-08 a/b. Bureau of Ocean Energy Management, Alaska OCS Region, Anchorage, AK.

Sigler, M. F., P. J. Stabeno, L. B. Eisner, J. M. Napp, and F. J. Mueter. 2014. Spring and fall phytoplankton blooms in a productive subarctic ecosystem, the eastern Bering Sea, during 1995–2011. *Deep Sea Research Part II: Topical Studies in Oceanography* 109:71-83.

Sirenko, B. I. and S. Y. Gagaev. 2007. Unusual abundance of macrobenthos and Pacific species invasions into the Chukchi Sea. *Russian Journal of Marine Biology* 33:355-364.

Smith, K. R., R. A. McConnaughey, and C. E. Armistead. 2011. Benthic Invertebrates of the Eastern Bering Sea: A Synopsis of the Life History and Ecology of Snails of the Genus *Neptunea*. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA.

Springer, A. M. and C. P. McRoy. 1993. The paradox of pelagic food webs in the northern Bering Sea—III: Patterns of primary production. *Continental Shelf Research* 13:575-599.

Springer, A. M., C. P. McRoy, and K. R. Turco. 1989. The paradox of pelagic food webs in the northern Bering Sea—II: Zooplankton communities. *Continental Shelf Research* 9:359-386.

Squires, H. J. and E. G. Dawe. 2003. Stomach contents of snow crab (*Chionoecetes opilio*, Decapoda, Brachyura) from the northeast Newfoundland shelf. *Journal of the Northwest Atlantic Fishery Science* 32:27-38.

Stabeno, P. J., N. B. Kachel, S. E. Moore, J. M. Napp, M. Sigler, A. Yamaguchi, and A. N. Zerbini. 2012. Comparison of warm and cold years on the southeastern Bering Sea shelf and some implications for the ecosystem. *Deep Sea Research Part II: Topical Studies in Oceanography* 65:31-45.

Stevens, B. G., J. A. Haaga, and W. E. Donaldson. 1994. Aggregative mating of tanner crabs, *Chionoecetes bairdi*. *Canadian Journal of Fisheries and Aquatic Sciences* 51:1273-1280.

Stevens, B. G. and J. Kittaka. 1998. Postlarval settling behavior, substrate preference, and time to metamorphosis for red king crab *Paralithodes camtschaticus*. *Marine Ecology Progress Series* 167:197-206.

Stockwell, D. 2008. Phytoplankton (Primary Production), *In Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research*. R. Hopcroft, B. Bluhm, R. Gradinger, T. Whitledge, T. Weingartner, B. Norcross, and A. Springer eds. Institute of Marine Sciences, University of Alaska, Fairbanks, AK.

Stone, R. P. 2006. Coral habitat in the Aleutian Islands of Alaska: Depth distribution, fine-scale species associations, and fisheries interactions. *Coral Reefs* 25:229-238.

______. 2014. The Ecology of Deep-Sea Coral and Sponge Habitats of the Central Aleutian Islands of Alaska. NOAA Professional Paper NMFS 16. National Oceanic and Atmospheric Administration, Seattle, WA.

Stone, R. P. and S. D. Cairns. 2017. Deep-sea coral taxa in the Alaska region: Depth and geographical distribution, *In The State of Deep-Sea Coral and Sponge Ecosystems of the United States: 2017. NOAA Technical Memorandum CRCP-3*. T. F. Hourigan, P. J. Etnoyer, and S. D. Cairns eds. National Oceanic and Atmospheric Administration, Silver Spring, MD.

Stone, R. P., H. Lehnert, and H. Resiwig. 2011. A Guide to the Deep-Water Sponges of the Aleutian Island Archipelago. NOAA Professional Paper NMFS 12. National Oceanic and Atmospheric Administration, Seattle, WA.

Stone, R. P., P. W. Malecha, and M. M. Masuda. 2017. A five-year, in situ growth study on shallow-water populations of the gorgonian octocoral *Calcigorgia spiculifera* in the Gulf of Alaska. *PLoS ONE* 12:e0169470.

Stone, R. P., C. E. O'Clair, and T. C. Shirley. 1992. Seasonal migration and distribution of female red king crabs in a Southeast Alaskan estuary. *Journal of Crustacean Biology* 12:546-560.

Stone, R. P. and C. N. Rooper. 2017. State of deep-sea coral and sponge ecosystems in the Alaska region, *In The State of Deep-Sea Coral and Sponge Ecosystems of the United States: 2017. NOAA Technical Memorandum CRCP-3*. T. F. Hourigan, P. J. Etnoyer, and S. D. Cairns eds., pp. 3-1–3-34. National Oceanic and Atmospheric Administration, Silver Spring, MD.

Stoner, A. W. 2009. Habitat-mediated survival of newly settled red king crab in the presence of a predatory fish: Role of habitat complexity and heterogeneity. *Journal of Experimental Marine Biology and Ecology* 382:54-60.

Stoner, A. W., M. L. Ottmar, and L. A. Copeman. 2010. Temperature effects on the molting, growth, and lipid composition of newly-settled red king crab. *Journal of Experimental Marine Biology and Ecology* 393:138-147.

Sundberg, K. A. and D. Clausen. 1977. Post-larval king crab (*Paralithodes camtschatica*) in Kachemak Bay, Lower Cook Inlet, Alaska, 1976, *In Environmental Studies of Kachemak Bay and Lower Cook Inlet. Vol 5: I-36*. L. L. Traskey, L. B. Flagg, and D. C. Burbank eds. Alaska Department of Fish and Game, Anchorage, AK.

Swiney, K. M., W. C. Long, G. L. Eckert, and G. H. Kruse. 2012. Red king crab, *Paralithodes camtschaticus*, size-fecundity relationship, and interannual and seasonal variability in fecundity. *Journal of Shellfish Research* 31:925-933.

Tremblay, J.-É., L. G. Anderson, P. Matrai, P. Coupel, S. Bélanger, C. Michel, and M. Reigstad. 2015. Global and regional drivers of nutrient supply, primary production and CO_2 drawdown in the changing Arctic Ocean. *Progress in Oceanography* 139:171-196.

Turnock, B. and L. Rugolo. 2011. Stock Assessment of Eastern Bering Sea Snow Crab (*Chionoecetes opilio*). National Marine Fisheries Service, Anchorage, AK.

Urban, D., D. Penguilly, L. Jadamec, and S. C. Byersdorfer. 2002. Testing carapace morphology characteristics for field identification of *Chionoecetes* hybrids, *In Crabs in Cold Water Regions: Biology, Management, and Economics*. A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley, and D. Woodby eds., pp. 97-113. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks, AK.

von Szalay, P. G. and N. W. Raring. 2016. Data Report: 2015 Gulf of Alaska Bottom Trawl Survey. NOAA Technical Memorandum NMFS-AFSC-325. National Oceanic and Atmospheric Administration, Seattle, WA.

Wang, J., G. F. Cota, and J. C. Comiso. 2005. Phytoplankton in the Beaufort and Chukchi Seas: Distribution, dynamics, and environmental forcing. *Deep Sea Research Part II: Topical Studies in Oceanography* 52:3355-3368.

Webb, J. B. and J. Bednarski. 2010. Variability in reproductive potential among exploited stocks of Tanner crab (*Chionoecetes bairdi*) in southeastern Alaska., *In Management of Expoited Crab Population Under Climate Change*. G. H. Kruse, G. L. Eckert, R. J. Foy, R. N. Lipcius, B. Sainte-Marie, D. L. Stram, and D. Woodby eds., pp. 295-317. Alaska Sea Grant College Program AK-SG-10-01, University of Alaska Fairbanks, Fairbanks, AK.

Webb, J. B., L. M. Slater, G. L. Eckert, and G. H. Kruse. 2016. The contribution of fecundity and embryo quality to reproductive potential of eastern Bering Sea snow crab (*Chionoecetes opilio*). *Canadian Journal of Fisheries and Aquatic Sciences* 73:1800-1814.

Webb, J. B., L. M. Stichert, Q. Smith, and K. McNeel. 2014. A Pilot Study Investigating the Applicability of a Novel Direct Aging Technique to Commercially Important Crustaceans in Alaska. Regional Operational Plan CF.5J.2014.02. Alaska Department of Fish and Game, Juneau, AK.

Westphal, M. J., G. L. Eckert, and S. L. Tamone. 2014. Comparison of first year growth among field, hatchery- and laboratory-raised juvenile red king crab, *Paralithodes camtschaticus* (Tilesius, 1815), in Alaska. *Journal of Crustacean Biology* 34:319-325.

Whitehouse, G. A. 2013. Preliminary Mass-Balance Food Web Model of the Eastern Chukchi Sea. NOAA Technical Memorandum NMFS-AFSC-262. National Oceanic and Atmospheric Administration, Seattle, WA.

Witherell, D. and C. Coon. 2002. Protecting Gorgonian corals off Alaska from fishing impacts. *In* Proceedings of the First International Symposium on Deep Sea Corals. Ecology Action Center, Halifax, Canada.

Yamamoto, T., T. Yamada, H. Fujimoto, and K. Hamasaki. 2014. Effects of temperature on snow crab (*Chionoecetes opilio*) larval survival and development under laboratory conditions. *Journal of Shellfish Research* 33:19-24.

Yang, M.-S., K. Dodd, R. Hibpshman, and A. Whitehorse. 2006. Food Habits of Groundfishes in the Gulf of Alaska in 1999 and 2001. NOAA Technical Memorandum NMFS-AFSC-164. National Oceanic and Atmospheric Administration, Seattle, WA.

Yeung, C. and R. A. McConnaughey. 2006. Community structure of eastern Bering Sea epibenthic invertebrates from summer bottom-trawl surveys 1982 to 2002. *Marine Ecology Progress Series* 318:47-63.

Zheng, J. and G. H. Kruse. 2006. Recruitment variation of eastern Bering Sea crabs: Climate-forcing or top-down effects? *Progress in Oceanography* 68:184-204.

Zheng, J., S. Siddeek, D. Pengilly, and D. Woodby. 2002. Overview of Recommended Harvest Strategy for Snow Crabs in the Eastern Bering Sea. Regional Information Report No. 5J02-03. Alaska Department of Fish and Game, Juneau, AK.

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FISHES

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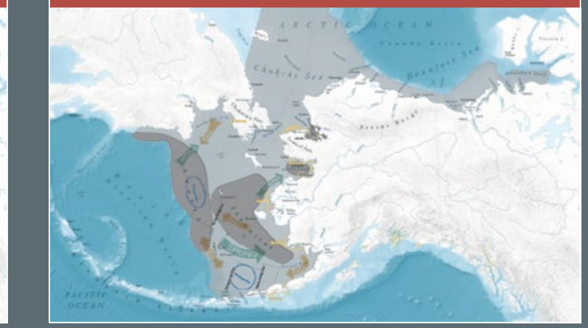
FISHES MAP INDEX

Osmerids

MAP 4.1.1 / PAGES 78–79

Pacific Herring



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Walleye Pollock

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North Pacific Cods

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Atka Mackerel

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Yellowfin Sole

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Forage Fish Assemblages

Marilyn Zaleski and Brianne Mecum

A forage fish assemblage is made up of small schooling fishes and is an important resource for the Bering Sea and Arctic marine ecosystems. Species composition differs depending on where the assemblage occurs. The forage fish assemblage in the Arctic is generally made up of Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*), Pacific herring (*Clupea pallasii*), capelin (*Mallotus villosus*), and eulachon (*Thaleichthys pacificus*), as well as rainbow smelt (*Osmerus mordax*), Pacific sand lance (*Ammodytes hexapterus*), and several species of sculpins (family *Cottidae*), and eelblennies (family *Stichaeidae*) (Logerwell et al. 2010, Thedinga et al. 2013, Goddard et al. 2014). The Bering Sea forage fish assemblage also includes Pacific herring, capelin, and eulachon, along with Pacific sand lance, lanternfishes, and other fish in the *Osmeridae* family (Sadorus and Palsson 2014).

Forage fish are a species-rich, diverse group. Table 4.1-1 includes some of the many forage fishes found in the North Pacific (Mecklenburg et al. 2002, Goddard et al. 2014, Johnson et al. 2015, North Pacific Fishery Management Council 2015a, Ormseth 2015). See the North Pacific Cods Summary for more information specific to Arctic and saffron cods.

Many forage fish have long, slender bodies with silver scales that enable them to blend together when schooling in large numbers. Herring, capelin, and sand lance are countershaded, so the top halves of their bodies are darker than their silver bellies (Johnson et al. 2015). Countershading is an adaptation that makes the fish difficult to see when looking down upon them (the dark color blends in with dark water below) as well as when looking up at them (silvery bellies blend in with the bright sky). Forage fish are therefore able to use countershading as a predator avoidance technique while schooling together.

Another forage fish group, the lanternfishes (family *Myctophidae*), relies on a different adaptation to camouflage themselves from prey beneath them: photophores (Moser and Ahlstrom 1972, Catul et al. 2011). These organs produce light, or bioluminescence, and are arranged on the bellies of lanternfishes in different patterns, depending upon the species (Moser and Ahlstrom 1972), so when predators look up from below, the photophores mimic the distant light from the surface of the water (Catul et al. 2011). Lanternfishes also make daily movements in the water column known as "diel vertical migration," where they stay at depth during the day and travel to the surface at night (Holton 1969, Catul et al. 2011).

Aside from using coloration as a protective adaptation, Pacific sand lance also bury themselves in the sand below the low tide line to avoid predators at night (Haynes et al. 2007). At these depths, they never risk exposure to dry sand. They prefer sediment with small particles as opposed to coarse gravel (Pinto et al. 1984, Haynes et al. 2007). They are relatively dormant and may stay buried through the winter months and appear in nearshore regions during the spring and summer (Robards et al. 1999).

DISTRIBUTION

Forage fishes include some of the world's most abundant fishes spanning large areas (Livingston 1993). Nearly all of the Aleutian Islands, eastern Bering Sea (EBS), and nearshore waters of the Chukchi and Beaufort Seas have forage fish assemblages. For example, herring are found in high numbers in Norton Sound and Kotzebue Sound where they come to spawn in spring, while staying offshore during their wintering season (Menard et al. 2015, Andrews et al. 2016). Herring were also found at several survey locations in the nearshore Chukchi Sea (Fechhelm et al. 1984, Goddard et al. 2014). Juvenile capelin also dominate the shallow, nearshore environment of the Chukchi Sea (Thedinga et al. 2013). The other osmerids range throughout the nearshore from the Gulf of Alaska (GOA) through the EBS and northward, but transition from predominately eulachon to rainbow smelt moving north past Unimak Pass (Logerwell et al. 2010, Goddard et al. 2014, National Oceanic and Atmospheric Administration 2016a).

TABLE 4.1-1. Common forage fishes found in the Bering Sea, the Chukchi Sea, and/or the Beaufort Sea.

Fish Family	Common Name	Species
Gadidae	Arctic cod	*Boreogadus saida*
	Saffron cod	*Eleginus gracilis*
Clupeidae	Pacific herring	*Clupea pallasii*
Osmeridae	Capelin	*Mallotus villosus*
	Eulachon	*Thaleichthys pacificus*
	Rainbow smelt	*Osmerus mordax*
Ammodytidae	Pacific sand lance	*Ammodytes hexapterus*
Myctophidae	Bigeye lanternfish	*Protomyctophum thompsoni*
	California headlightfish	*Diaphus theta*
	Northern lampfish	*Stenobrachius leucopsarus*
	Pinpoint lampfish	*Nannobrachium regale*
Stichaeidae	Snake prickleback	*Lumpenus sagitta*
	Daubed shanny	*Leptoclinus maculatus*
	Slender eelblenny	*Lumpenus fabricii*
	Stout eelblenny	*Anisarchus medius*
Pholidae	Crescent gunnel	*Pholis laeta*
Trichodontidae	Pacific sandfish	*Trichodon trichodon*
Bathylagidae	Northern smooth-tongue	*Leuroglossus schmidti*
Gonostomatidae	Black bristlemouth	*Cyclothone atraria*

Pacific sand lance along with several species of picklebacks, eelblennies, and gunnels populate the nearshore environment and the inner (0–165 ft [0–50 m] depths) and middle (165–330 ft [50–100 m] depths) domains of the EBS shelf. Norton Sound is dominated by picklebacks (family *Stichaeidae*), while Bristol Bay is a hotspot for sandfish (Logerwell et al. 2010, Goddard et al. 2014, National Oceanic and Atmospheric Administration 2016a). Pacific sand lance habitat includes sandy or bedrock bottoms with kelp and eelgrasss (Johnson et al. 2015). Pacific sand lance sometimes form mixed-species schools with Pacific herring and therefore share some distributional ranges (Hobson 1986, Haynes et al. 2007).

Other forage fishes live in deeper waters along the Aleutian Islands and the EBS shelf break. These include the bioluminescent lanternfishes (family *Myctophidae*) and the bristlemouths (family *Gonostomatidae*) (Logerwell et al. 2010, Goddard et al. 2014, National Oceanic and Atmospheric Administration 2016a), the latter of which is the most abundant vertebrate in the world (Irigoien et al. 2014).

LIFE CYCLE

Forage fish exhibit a wide variety of mating behaviors and reproductive strategies (see Table 4-2 for example). Herring spawn every year and the timing is affected, in part, by temperature and latitude as they mature later during colder temperatures and at higher latitudes (Hay 1985). They seasonally migrate from offshore overwintering areas along the outer domain of the EBS, north and south of the Pribilof Islands, to nearshore spawning habitats in the spring, with the migration pathway influenced by changes in the sea-ice extent (Tojo et al. 2007). Spawning habitat requirements for herring include a shallow area, like a bay or estuary, and vegetation to which their sticky eggs can adhere (Haegele and Schweigert 1985).

Capelin spawn yearly but experience very high mortality rates after spawning (Hamre 2002). Capelin prefer nearshore environments and their spawning Essential Fish Habitat (EFH) includes sand and cobble intertidal beaches (Hamre 2002, National Marine Fisheries Service 2005). As with herring, they use Norton Sound as a spawning location (Pahlke 1985) and, when not spawning, are found on the EBS shelf (National Marine Fisheries Service 2005).

Some forage fish species, such as eulachon and smelts, are anadromous, living and growing in the ocean but spawning in fresh water (Beacham et al. 2005). This adaptation extends their distribution into the freshwater basins and river systems of coastal Alaska. Eulachon, for example, spawn short distances upriver of their natal estuaries so that when their eggs hatch and are washed downstream, they are retained in protected estuarine environments (Beacham et al. 2005). Eulachon are "semelparous," meaning they only spawn once, so they experience 100% mortality after migrating to and spawning in freshwater streams (Clarke et al. 2007). Smelts are normally "iteroparous," able to spawn multiple times, although some forms are semelparous (Saint-Laurent et al. 2003).

TABLE 4.1-2. Life cycle characteristics of three forage fish species in Alaska waters.

	Pacific Herring *Clupea pallasii*	Capelin *Mallotus villosus*	Eulachon *Thaleichthys pacificus*
Spawning Locations	Shallow tidal areas with vegetation[1]	Sandy intertidal beaches[5, 6]	Sandy freshwater streams[9]
Spawn Timing	Summer[2]	May–August[5]	February–June[9]
Number of Eggs	11,000–134,000[3]	5,000–18,000[7]	20,000–40,000[10]
Age at Maturation	2–5 years[3]	2–6 years[6]	3–4 years[10, 11]
Lifespan	9–15 years[3]	2–6 years[8]	3–4 years[10, 11]
Maximum Length	18 inches (460 mm)[4]	10 inches (252 mm)[4]	7.8 inches (199 mm)[11]

Sources: [1]Haegele and Schweigert (1985); [2]Carlson (1980); [3]Lassuy and Moran (1989); [4]Mecklenburg et al. (2002); [5]National Marine Fisheries Service (2005); [6]Pahlke (1985); [7]Huse and Gjøsæter (1997); [8]Hamre (2002); [9]Beacham et al. (2005); [10]Hay and McCarter (2000); [11]Clarke et al. (2007).

ECOLOGICAL ROLE

The forage fish assemblage gets its name from its primary role of collectively linking lower and upper trophic levels. These fishes prey upon zooplankton, including energy-rich krill and copepods (Sturdevant 1996, Willette et al. 1997, Whitehouse 2013), then accumulate that energy, which is passed on to their predators (Watts and Draper 1986, Springer and Speckman 1997, Anthony et al. 2000, Bogstad and Gjøsæter 2001, Cherel et al. 2001, Iverson et al. 2002, Rose 2005). One example of this trophic link is Pacific herring passing the energy they gain from krill, copepods, and mysid shrimp (Fechhelm et al. 1984, Foy and Norcross 1998) to their fish, bird, and marine mammal predators (Livingston 1993, Sigler et al. 2009, Hop and Gjøsæter 2013). Herring, as well as capelin, play such an important role in the food web that spotted seals choose haulout sites based on where forage fishes spawn (Quakenbush 1988).

Mandy Lindeberg / NOAA Fisheries, Alaska Fisheries Science Center

A Pacific sand lance, *Ammodytes hexapterus*, peeking its head out of the sandy substrate. They can stay buried through the winter months.

4.1 FORAGE FISH ASSEMBLAGES

MAPS ON PAGES 78–81

MAPS ON PAGES 78–81

Seabirds also rely on forage fish assemblages. Murres and kittiwakes off the Aleutian Islands have diets full of Pacific sand lance and myctophids (Springer et al. 1996). Not every fish within the forage fish assemblage offers equal benefits for a particular predator. For example, the availability of Arctic cod over four-horned sculpin (*Myoxocephalus quadricornis*) plays an important role in Black Guillemot (*Cepphus grille*) survival (Divoky et al. 2015). Nevertheless, the diversity of species within the assemblage allows for a diversity of predators. Even polar bears (*Ursus maritimus*) have been observed eating estuarine forage fish (Dyck and Romberg 2007).

ECONOMIC IMPACT

Herring, capelin, and eulachon are all harvested for subsistence use in both the Bering Sea and the Arctic (Stephen R. Braund and Associates and Institute of Social and Economic Research 1993, Bacon et al. 2011, Thorsteinson and Love 2016). Herring roe is collected off of kelp and other types of seaweeds as well as hemlock branches (Sill 2015). Eulachon are harvested and smoked or used for their oil; they have such high oil content that they will burn like candles when lit on fire (Oceana 2011).

Pacific herring are managed by the State of Alaska, and some stocks are commercially harvested. The sac roe, food, and bait fishery targets around 20% of the estimated stock biomass (Russell 2016). Herring are also caught as bycatch in other federal groundfish fisheries, but because of their commercial and ecological importance they are managed as prohibited-species catch (PSC) (North Pacific Fishery Management Council 2015a). Three different herring savings areas have been established throughout the EBS in which trawl closures are implemented once PSC limits are reached (North Pacific Fishery Management Council 2016a).

CONSERVATION ISSUES

Because of the importance of forage fish to higher trophic level animals in food webs, one management concern involves leaving enough forage fish in the water to sustain their populations and feed their predators, rather than removing them from the marine ecosystem. For example, the Barents Sea harp seal (*Pagophilus groenlandicus*) population suffered a significant decline after a collapse of the capelin stock in the late 1980s (Sakshaug et al. 1994). Prior to the capelin collapse, harp seal stomach contents contained up to 90% capelin, while after the collapse capelin ranged between 0–6% of the seal diet composition (Nilssen et al. 2000). Capelin may be directly tied to the success of several predator populations in the Arctic (Tynan and DeMaster 1997).

Another example of the importance of forage fish in the ecosystem is the interaction between forage fishes, commercial fisheries, and northern fur seals (*Callorhinus ursinus*) (see Northern Fur Seal summary). Forage fish are designated as an ecosystem component species in the Fishery Management Plan (FMP) for groundfish of the Bering Sea and Aleutian Islands management area (Ormseth 2015); as such, there is no directed federal fishery allowed for forage fish and bycatch limits are set for each species with the exception of herring (managed as PSC, see Economic Impact section below) (Ormseth 2015).

Forage fish may be negatively affected by climate change. The Southern distinct population segment (DPS) of eulachon is a population that spans British Columbia south to California waters, and is separate from Alaska stocks, but is listed as threatened under the Endangered Species Act (ESA) (Gustafson 2016). The reasoning behind their poor status, likely due to recent poor oceanic conditions (Gustafson 2016), raises concerns regarding future climate change effects on Alaskan eulachon.

Another impact from climate change is the loss of sea ice as ocean temperatures rise. This leads to loss of ice-associated fish in the Arctic and shifts land-reliant predator diets to nearshore fishes (Divoky et al. 2015). As the Arctic continues to warm, and sea-ice extent decreases, predators will rely more and more on nearshore forage fish assemblages. In the Bering Sea, the winter sea ice extent and resulting summer cold pool strongly influence the spatial distribution of forage fish, particularly capelin (Andrews et al. 2016, Hollowed et al. 2012).

These shifts in changing diets for predators and changing stresses for fish (predation, warmer habitat) will affect the overall health of the marine food web.

MAPPING METHODS (MAPS 4.1.1–4.1.2)

Osmerids

Fishes from the *Osmeridae* family are comprised of capelin, eulachon, rainbow smelt, longfin smelt (*Spirinchus thaleichthys*), night smelt (*S. starksi*), surf smelt (*Hypomesus pretiosus*), and unidentified smelts (*Osmeridae*).

The relative abundance for osmerids was estimated by mapping datasets from bottom-trawl surveys which employed consistent methodologies and sampled waters within the US Exclusive Economic Zone (EEZ) of the EBS (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell 2008). Data points for capelin, eulachon, and smelt presence and absence were extracted, and each was mapped separately based on catch-per-unit-effort (CPUE) displaying kilograms per hectare. To delineate concentration areas, data points for each species were then classified into quartiles and general polygons were drawn around the top 25% for each species to obtain areas of higher concentration.

We then compared those trawl-survey catch areas for all three species to bycatch in Gulf of Alaska and Bering Sea groundfish fisheries (Alaska Fisheries Science Center 2016) to either corroborate concentration areas or expand them. Data points for each species were mapped by catch amount (kilograms) and binned using quartiles. General polygons were drawn around the top quartile for each species.

Finally, concentration-area polygons for each species, drawn from trawl-survey data, were then merged to concentration areas drawn from observer data. For capelin, this resulting concentration area was also merged to the known concentration areas in Bristol Bay and the northern part of Norton Sound, observations that were taken from National Oceanic and Atmospheric Administration (1988). We were unable to find other concentration-area data to combine with the resulting trawl-survey and observer data concentrations for eulachon and smelt so those were not expanded.

Smelt and eulachon spawning areas were obtained from the Alaska Department of Fish and Game's Anadromous Waters Catalog (Johnson et al. 2015).

The general distribution polygon for capelin is a broad delineation of this species range and was created by combining digitized distribution data from National Oceanic and Atmospheric Administration (1988) and Thorsteinson and Love (2016).

Spawning areas for capelin were interpreted from maps from Brown (2002) showing general, historical spawning areas as large circles extending offshore. To narrow their scope, those very general areas were mapped and then clipped to within 2 miles (3 km) of shore since capelin are known to move inshore to spawn in shallow areas on coarse sand and/or gravel beaches. We then merged those areas to spawning locations obtained from National Oceanic and Atmospheric Administration (1988).

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Pacific Herring

The general adult distribution area for Pacific herring is a compilation of previous data from National Oceanic and Atmospheric Administration (1988) and updated with new distribution data from Thorsteinson and Love (2016). The juvenile distribution area was obtained from National Oceanic and Atmospheric Administration (1988) but we were unable to update juvenile-specific distribution areas with new information.

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Major wintering grounds and pre- and post-spawning migration patterns in the Bering Sea and Bristol Bay were digitized from maps in Tojo et al. (2007).

Spawning areas include digitized data from Tojo et al. (2007), which documents historical spawning locations. Those areas were combined with spawning areas directly obtained from the Alaska Department of Fish and Game Most Environmentally Sensitive Areas (MESA) Project (Alaska Department of Fish and Game Habitat and Restoration Division 2001), which documents the most sensitive areas for a suite of marine species.

Herring Savings Areas were digitized from the most recent Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Islands Management Area (North Pacific Fishery Management Council 2016a). Herring Savings Areas are management areas that may be closed for certain time periods to commercial trawling if bycatch of Pacific herring exceeds 1% of the total biomass. These areas overlap important migration and overwintering areas and have been in place to reduce Pacific herring bycatch since 1991.

Data Quality

Trawl-survey data sampling was conducted within the US EEZ, therefore there is little to no coverage on the Russian side of the Bering Sea. The interpolation of the trawl-survey data estimates the distribution of osmerids during the summer months and may not represent the year-round distribution.

Bottom-trawl surveys in the Aleutian Islands were conducted every three years between 1983–2000 and then on even years between 2002–2016. Surveys on the Bering Sea slope were conducted on even years between 2002–2016 except for 2006 and 2014. Surveys of the EBS shelf were conducted from 1982–2016. Surveys of the northern Bering Sea occurred between 1982–2010. Gulf of Alaska surveys were conducted in 1984 and 1987; every 3 years over 1990–1999, and then on odd years from 2001–2015. Bottom-trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewers

- Ellen Yasumiishi
- Gordon Kruse

MAP DATA SOURCES

Pacific Herring Map

Distribution (Regular Use and Concentration): National Oceanic and Atmospheric Administration (1988); Thorsteinson and Love (2016)

Major Wintering Grounds: Tojo et al. (2007)

Pre- and Post-Spawning Migration: Tojo et al. (2007)

Spawning: Alaska Department of Fish and Game Habitat and Restoration Division (2001); Tojo et al. (2007)

Herring Savings Areas: North Pacific Fishery Management Council (2016a)

Osmerids Map

Relative Abundance (Concentration): Oceana (2017c) based on Alaska Fisheries Science Center (2016), Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), National Oceanic and Atmospheric Administration (1988), Raring et al. (2016), and von Szalay and Raring (2016)

Capelin Distribution: National Oceanic and Atmospheric Administration (1988); Thorsteinson and Love (2016)

Smelt and Eulachon Spawning: Johnson et al. (2015)

Capelin Spawning: Brown (2002); National Oceanic and Atmospheric Administration (1988)

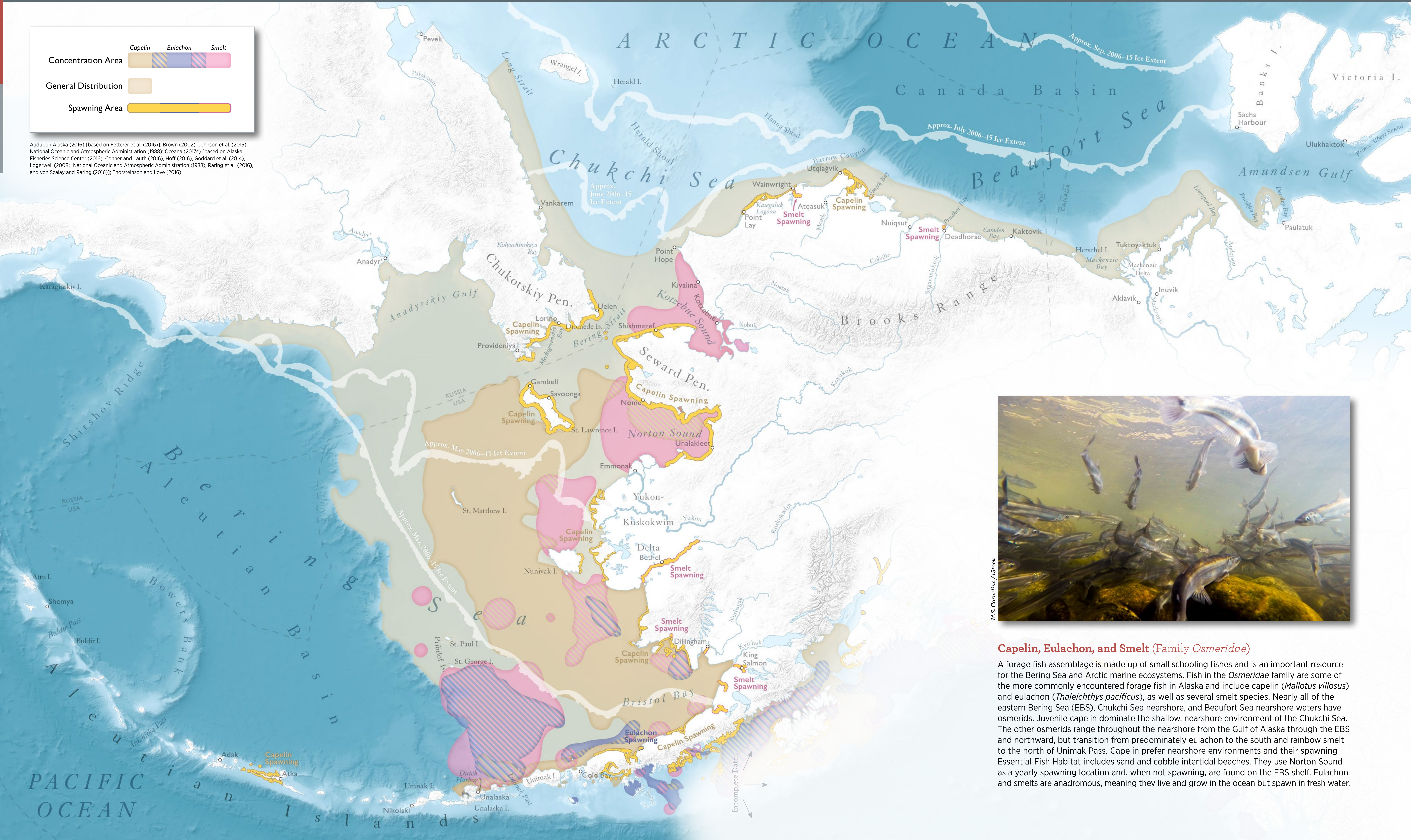
Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)

School of capelin.

G. Parsons / iStock

Osmerids

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman



Audubon Alaska (2016) [based on Fetterer et al. (2016)]; Brown (2002); Johnson et al. (2015); National Oceanic and Atmospheric Administration (1988); Oceana (2017c) [based on Alaska Fisheries Science Center (2016), Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), National Oceanic and Atmospheric Administration (1988), Raring et al. (2016), and von Szalay and Raring (2016)]; Thorsteinson and Love (2016)

M.S. Cornelius / iStock

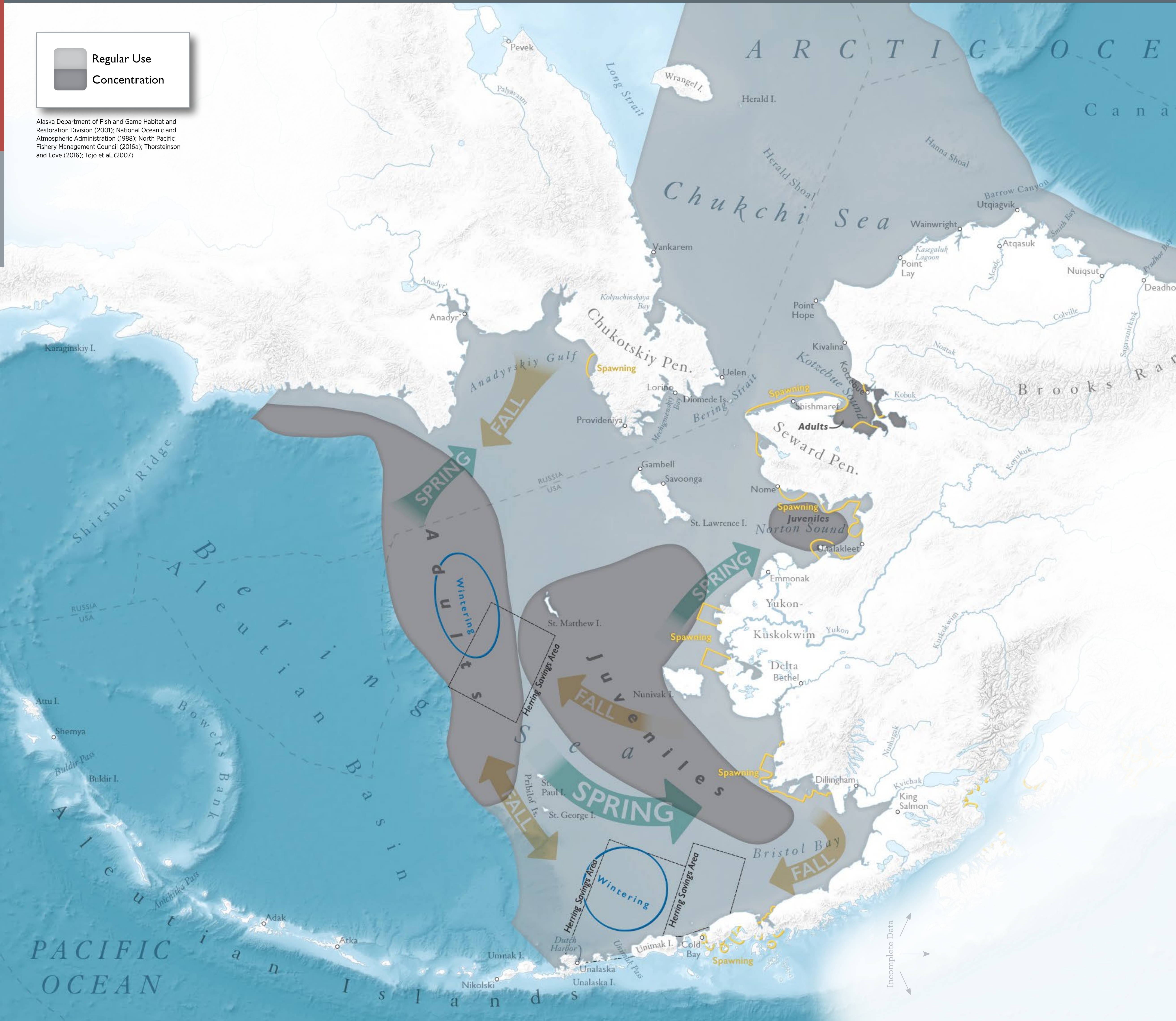
Capelin, Eulachon, and Smelt (Family *Osmeridae*)

A forage fish assemblage is made up of small schooling fishes and is an important resource for the Bering Sea and Arctic marine ecosystems. Fish in the *Osmeridae* family are some of the more commonly encountered forage fish in Alaska and include capelin (*Mallotus villosus*) and eulachon (*Thaleichthys pacificus*), as well as several smelt species. Nearly all of the eastern Bering Sea (EBS), Chukchi Sea nearshore, and Beaufort Sea nearshore waters have osmerids. Juvenile capelin dominate the shallow, nearshore environment of the Chukchi Sea. The other osmerids range throughout the nearshore from the Gulf of Alaska through the EBS and northward, but transition from predominately eulachon to the south and rainbow smelt to the north of Unimak Pass. Capelin prefer nearshore environments and their spawning Essential Fish Habitat includes sand and cobble intertidal beaches. They use Norton Sound as a yearly spawning location and, when not spawning, are found on the EBS shelf. Eulachon and smelts are anadromous, meaning they live and grow in the ocean but spawn in fresh water.

Pacific Herring

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA




R. Hibpshman

Pacific Herring *(Clupea pallasii)*

A forage fish assemblage is made up of small schooling fishes and is an important resource for the Bering Sea and Arctic marine ecosystems. Pacific herring are a forage fish found throughout the Bering Sea and the Arctic that are harvested both commercially and for subsistence. They are found in the Chukchi Sea nearshore and found in high numbers in Norton Sound and Kotzebue Sound where they come to spawn in spring. In the fall they head toward the middle and outer domains of the eastern Bering Sea shelf, staying offshore during their wintering season. Herring spawn every year and the timing is affected, in part, by temperature and latitude as they mature later in colder temperatures and at higher latitudes. Their spawning habitats (yellow outlines) are in shallow areas with vegetation to which their sticky eggs can adhere.

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Walleye Pollock

Gadus chalcogrammus

Jon Warrenchuk, Marilyn Zaleski, and Brianne Mecum

Walleye pollock (*Gadus chalcogrammus*) are the most abundant groundfish species in the Bering Sea (North Pacific Fishery Management Council 2016a) and an important link in the food web during all stages of their life cycle. Larval and juvenile pollock are preyed upon by other fishes and seabirds, while juvenile and adult pollock are major prey for marine mammals (Livingston 1993). Pollock also support the largest groundfish fishery in Alaska and is consistently one of the largest single-species fisheries in the world (Witherell and Armstrong 2015). Their meat is marketed for a wide variety of foods, from fish sticks to imitation crabmeat in sushi rolls.

Walleye pollock are considered to be a generalist species, able to occupy a range of marine habitats and utilize available prey sources (Bailey et al. 1999). Pollock are a relatively fast-growing fish (North Pacific Fishery Management Council 2015b, Laurel et al. 2016), and can grow up to 9 pounds (4 kg) (Hinckley 1987). They are also more adapted to warm waters compared to their cousin, the Pacific cod (*Gadus macrocephalus*) (see North Pacific Cods Summary), so may be more resilient to increased ocean temperatures (Laurel et al. 2016).

DISTRIBUTION

Pollock are ubiquitous in the North Pacific Ocean. They range from the coastal waters of the Pacific Northwest through the Gulf of Alaska and along the Aleutian Islands to the Sea of Okhotsk and Sea of Japan, and in the Bering Sea to the Chukchi Sea in the north (Mecklenburg et al. 2002). The largest concentrations of pollock are from the outer shelf and slope of the eastern Bering Sea (EBS), where these schooling fish occur in the mid-water or near the bottom (Mecklenburg et al. 2002). In the Bering Sea, pollock generally migrate to feed northward and shoreward as water temperatures warm in the spring and summer (Kotwicki et al. 2005).

A recent estimate of pollock biomass in the EBS is 11.3 million metric tons, which translates to an estimated population of 19.5 billion individual pollock over the age of 1 (North Pacific Fishery Management Council 2015a). However, the pollock population is smaller due to the effects of fishing; if the population were left unfished, there would be an estimated 31.3 billion pollock in the Bering Sea (North Pacific Fishery Management Council 2015a).

LIFE CYCLE

Pollock spawn in the late winter and early spring (Bailey et al. 1999). In the laboratory, walleye pollock have been observed to perform complex paired-mating behavior (Sakurai 1988). Males swim in circles, flaring their fins and shaking their body until a female is responsive and follows; they then mount ventrally, spawn, and disperse the eggs and sperm with rapid tail beats (Sakurai 1988). A female pollock can produce around 200,000 eggs each spawning season (Hinckley 1987). Consistent spawning areas of the Bering Sea include Unimak Pass, the southeastern Bering Sea outer shelf, and waters northwest of the Pribilof Islands (Wespestad et al. 2000).

Early Life History

Once hatched, pollock larvae are positively buoyant and can be swept up by ocean currents and transported toward nursery habitats (Hermann et al. 1996). Young-of-the-year (YOY) pollock face a biophysical gauntlet where they must survive by balancing larval transport, prey resources, predator avoidance, and habitat needs (Moss et al. 2016); YOY pollock utilize pelagic shelf habitats in the Bering Sea (Moss et al. 2009a, Hurst et al. 2012, Hurst et al. 2015). In those pelagic habitats, juvenile pollock have been observed hiding under jellyfish during the day (Brodeur 1998). This behavior may provide some refuge from other predators (Brodeur 1998). And just as temperature and sea-ice retreat affects what pollock eat (see Sea-Ice Habitat), YOY pollock occupy different areas in different temperature regimes. Cold years find pollock in the outer domain (330–660 foot [100–200 m] isobaths) of the Bering Sea while warm years find pollock distributed more in the middle domain (165–330 foot [50-100 m] isobaths) (Hollowed et al. 2012).

Age and Growth

Juvenile pollock are relatively fast growers. In habitats shared with their congener (same genus) Pacific cod, this is an important survival tactic, since they can grow faster than Pacific cod (Laurel et al. 2016) and reach sizes large enough to eat different prey. Pollock therefore outgrow the need to compete for the same food. However, their growth and productivity is closely tied to available food in their environment. If areas where pollock settle as juveniles do not match where their food is most productive, it can negatively affect their survival (Siddon et al. 2014).

Pollock begin maturing as early as two years of age, although that is a small proportion of the population. At age 4, more than 50% of the pollock population is mature and at 10 years of age, all pollock encountered are sexually mature (North Pacific Fishery Management Council 2016a). Age 4 is also when pollock typically are caught in the fishery; e.g., those born in 2008 were caught in the 2012 and 2013 EBS shelf fisheries as 4- and 5-year-olds (North Pacific Fishery Management Council 2016a). Although commercially harvested pollock may not live beyond age 5, walleye pollock can actually reach at least 28 years of age (Munk 2001).

ECOLOGICAL ROLE

Alaska pollock have a central role in the Bering Sea food web and are a key link between lower trophic levels and the seabirds and marine mammals at the top of the food chain. Juvenile pollock eat zooplankton like pteropods (sea snails) and copepod species (Siddon et al. 2014, Moss et al. 2016) while adults prey largely on krill (Brodeur et al. 2002, Ciannelli et al. 2004) and myctophids (Barbeaux et al. 2016). However, what they eat is largely dependent on what is available in the water column, and the EBS zooplankton assemblage is dependent on the timing of the winter sea-ice retreat. There is a spatial alignment of primary production, zooplankton and age-0 pollock in cold years and a mismatch in warm years (Coyle et al. 2011, Hunt et al. 2011, Sigler et al. 2016). Larger copepods and euphausiids are often more abundant in cold years with late ice retreat than in warm years with early ice retreat (Coyle et al. 2008). Young pollock consume these lipid-rich prey in cold years, better preparing them for surviving over their first winter (Coyle et al. 2011, Hunt et al. 2011, Sigler et al. 2016).

Pollock also cannibalize smaller, younger pollock, and this predation can regulate the population (Laevastu and Favorite 1988). Other fish, marine mammals, and seabirds also rely on pollock as an important food source (Livingston 1991, Livingston et al. 1993, Whitehouse 2013). It is estimated that marine mammals alone eat close to 300,000 metric tons of pollock in the EBS (Perez and McAlister 1993).

ECONOMIC IMPACT

Bering Sea pollock support one of the world's largest fisheries (Food and Agriculture Organization 1990). A large network of seafood companies, fishing vessels, factory trawlers, processors, wholesalers, and employees rely on pollock for revenue (North Pacific Fishery Management Council 2016a). Pollock are utilized for fillets, as headed and gutted whole fish, as surimi (ground paste used for imitation crab meat), and for the roe from pre-spawning females (North Pacific Fishery Management Council 2015a). Pollock catches in the Bering Sea average between 1 and 1.5 million metric tons each year (North Pacific Fishery Management Council 2015a); globally, pollock represents over 40% of whitefish production (North Pacific Fishery Management Council 2014). Approximately 120 fishing vessels, including 30 large factory trawlers, fish for pollock in the Bering Sea (North Pacific Fishery Management Council 2016a). Fishing occurs almost year-round; the A-season runs from January through mid-April with a focus on catching pre-spawning female pollock for their roe and B-season opens in June and ends at noon on November 1 (North Pacific Fishery Management Council 2015a).

CONSERVATION ISSUES

The Bering Sea pollock fishery has a reputation of being one of the best-managed fisheries in the world. This is largely due to strong laws that prevent overfishing and minimize bycatch, backed by an extensive (and expensive) infrastructure in Alaska for data collection, scientific assessment, in-season monitoring, and enforcement. This comprehensive data input means that the management system can be quick to respond to what is happening on the Bering Sea shelf in a given season. For example, in 2009–2010, following 2 years of declining pollock numbers, the catch limit for pollock in the Bering Sea was substantially decreased (North Pacific Fishery Management Council 2015a). Since then, the stock has increased and catch limits have been set above the long-term average (North Pacific Fishery Management Council 2015a).

While the EBS pollock stock has provided sustained industrial fishing opportunities for the last 40 years, other pollock stocks in the region have proven less resilient to fishing. In the "Donut Hole" of the North Pacific, a deep-water region outside of any country's jurisdiction, a large population of pollock was reported by Japanese scientists in the 1970s (Bailey 2011, Ianelli et al. 2016). Donut Hole pollock were subsequently thought to be connected to pollock spawning aggregations in the southeastern Aleutian Basin near Bogoslof Island (the Bogoslof population; Ianelli et al. (2016), T. Honkalehto (pers. comm.)). Collectively, this population was called the Aleutian Basin stock and an intense, high-seas international fishery developed for them in the mid-1980s (Bailey 2011, Ianelli et al. 2016). The fishery targeted winter spawning aggregations of pollock and removed substantial amounts of fish (almost 7 million metric tons in a period of 5 years) (Ianelli et al. 2016). By 1992, the Aleutian Basin pollock stock had collapsed, and international agreements prohibited further fishing (Bailey 2011). Despite low fishery removals since then, this population of pollock has still not recovered today (Bailey 2011). Another related population of pollock along the Aleutian Islands shelf also declined from peak abundance in the mid-1980s to relatively low levels in the 1990s after a short period of heavy fishing pressure and poor recruitment, and has remained at low abundance in recent years despite low fishery removals (Barbeaux et al. 2016).

A major concern surrounding the management of the pollock fishery is the competition with fish-eating marine predators, particularly Steller sea lions (*Eumetopias jubatus*) and northern fur seals (*Callorhinus ursinus*). (See Steller Sea Lion and Northern Fur Seal summaries in the Mammals Chapter). For endangered Steller sea lions, measures have been put into place to reduce possible interactions with fishing vessels and competition for resources, including area closures and seasonal fishery limits in Steller sea lion critical habitat (North Pacific Fishery Management Council 2015a).

Another conservation concern is the incidental catch of Chinook salmon (*Oncorhynchus tshawytscha*) and chum salmon (*O. keta*) by the Bering Sea pollock fishery. While bycatch represents less than 1% of the total Bering Sea pollock catch, even that small fraction can mean hundreds of thousands of Chinook and chum salmon are killed as bycatch (North Pacific Fishery Management Council 2015a).

Finally, the potential impacts of the pollock fishery on seafloor habitat and benthic communities are a concern. The fishery uses pelagic trawl gear to catch pollock, but in practice, the gear routinely drags along the seafloor when fishing near the bottom. Observers regularly record benthic invertebrates like crabs, snails, starfish, sea whips, and sponges in the catches (Ianelli et al. 2016).

MAPPING METHODS (MAP 4.2)

The relative abundance of walleye pollock was estimated by interpolating datasets from bottom-trawl surveys, which employed similar and consistent methodologies and sampled waters within the US Exclusive Economic Zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell 2008). Data points for walleye pollock presence and abundance were extracted and mapped based on catch-per-unit-effort (CPUE), displaying kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted (IDW) tool in ArcGIS version 10.5 based on CPUE values. A radius of the 12 nearest points was set as the search distance and interpolation was limited to the study area boundaries of the trawl surveys.

Walleye pollock spawning locations were created based on information from Bacheler et al. (2012), and Cianelli et al. (2012) and digitized from summary figures depicting modeled distribution of spawning patterns based on long-term egg and larvae collection.

The general distribution polygon is based on the Essential Fish Habitat (EFH) designation from (National Oceanic and Atmospheric Administration 2016b) for walleye pollock. This area is described as the general distribution for both late juveniles and mature adults, located in the lower and middle portion of the water column along the entire shelf (33–660 feet [-10–200 meters]) and slope (660–3,300 feet [200–1,000 meters]) throughout the Gulf of Alaska, Bering Sea, and Aleutian Islands.

Data Quality

The interpolation of the trawl-survey data estimates the distribution of walleye pollock during the summer months and may not represent the year-round distribution. The bottom-trawl surveys sample the pollock residing near the seafloor and may not be representative of pollock distribution throughout the water column. Data from acoustic surveys that estimate pollock abundance in the midwater component of the Bering Sea are not represented on the map. Additionally, pollock is a transboundary species but due to the study area sampled in bottom-trawl surveys, distribution in Russian waters is not represented on this map. Pollock are distributed across the Bering Sea shelf to Cape Navarin and southward along the Siberian coast (T. Honkalehto pers. comm.) but the bottom-trawl survey data only sampled waters within the US EEZ. Data for those areas are not yet published.

According to the source of the datasets (National Oceanic and Atmospheric Administration 2016b), bottom-trawl surveys in the Aleutian Islands were conducted every 3 years from 1983–2000 and on even years from 2002–2016. Surveys on the Bering Sea slope were conducted on even years from 2002–2016, except for 2006 and 2014. Surveys on the eastern Bering Sea shelf were conducted from 1982–2016. Surveys for the northern Bering Sea occurred in 1982, 1985, 1991, and 2010. Gulf of Alaska surveys were conducted in 1984 and 1987; every 3 years from 1990–1999, and on odd years from 2001–2015. Bottom-trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewer

- Taina Honkalehto

MAP DATA SOURCES

Relative Abundance: Oceana (2017e) based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)

Spawning: Cianelli et al. (2012); Bacheler et al. (2012)

Distribution: National Oceanic and Atmospheric Administration (2016b)

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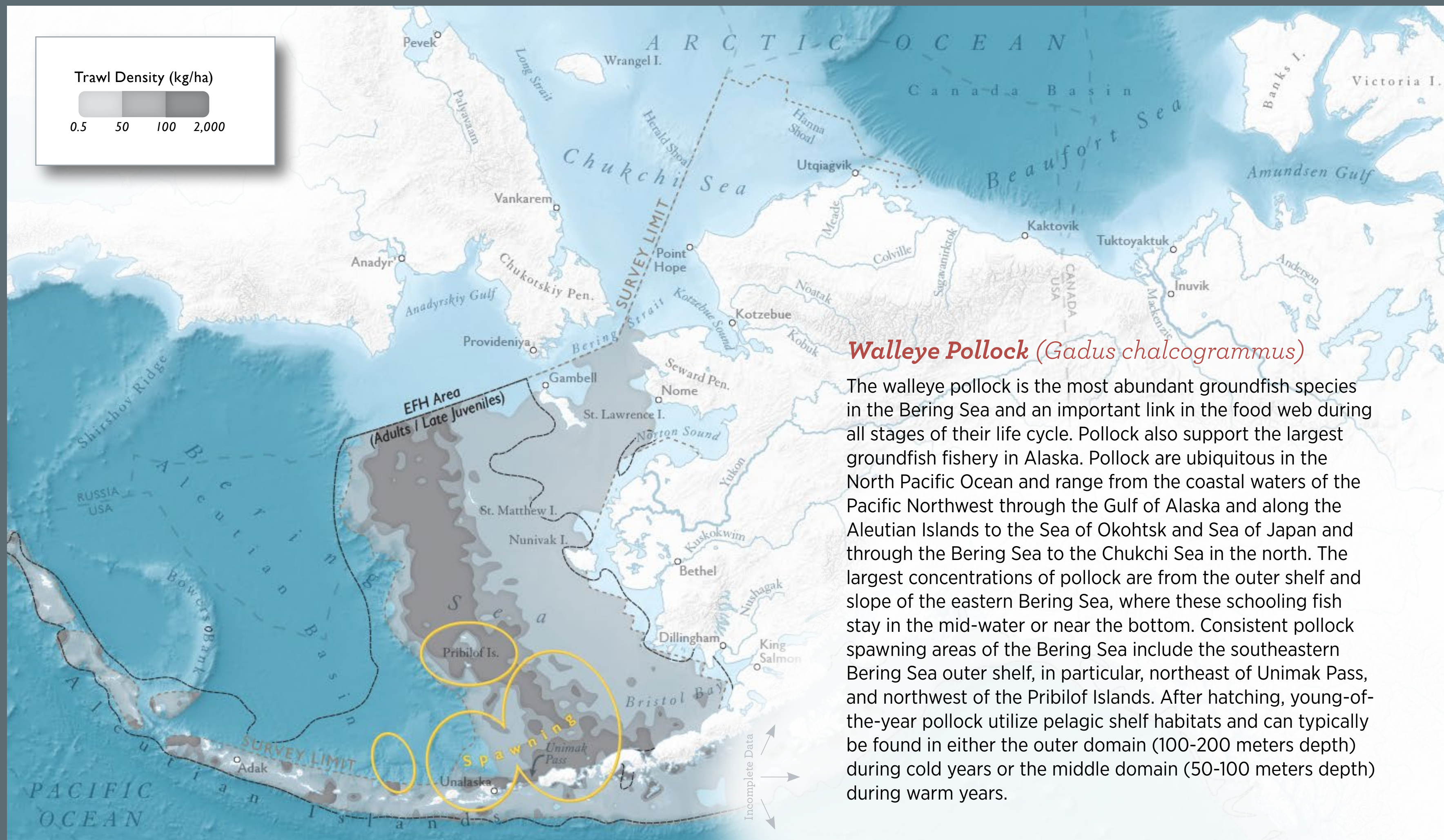
Walleye Pollock

OCEANA Audubon ALASKA



Walleye Pollock (Gadus chalcogrammus)

The walleye pollock is the most abundant groundfish species in the Bering Sea and an important link in the food web during all stages of their life cycle. Pollock also support the largest groundfish fishery in Alaska. Pollock are ubiquitous in the North Pacific Ocean and range from the coastal waters of the Pacific Northwest through the Gulf of Alaska and along the Aleutian Islands to the Sea of Okohtsk and Sea of Japan and through the Bering Sea to the Chukchi Sea in the north. The largest concentrations of pollock are from the outer shelf and slope of the eastern Bering Sea, where these schooling fish stay in the mid-water or near the bottom. Consistent pollock spawning areas of the Bering Sea include the southeastern Bering Sea outer shelf, in particular, northeast of Unimak Pass, and northwest of the Pribilof Islands. After hatching, young-of-the-year pollock utilize pelagic shelf habitats and can typically be found in either the outer domain (100-200 meters depth) during cold years or the middle domain (50-100 meters depth) during warm years.

Bacheler et al. (2012); Cianelli et al. (2012); National Oceanic and Atmospheric Administration (2016b); Oceana (2017e) [based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)]

Map Authors: Brianne Mecum and Jon Warrenchuk
Cartographer: Daniel P. Huffman

Alaska SeaLife Center

North Pacific Cods

Marilyn Zaleski and Brianne Mecum

Pacific Cod
Gadus macrocephalus

Arctic Cod
Boreogadus saida

Saffron Cod
Eleginus gracilis

Cods, also called gadids, are fishes in the family *Gadidae* and include the most well-known Atlantic cod (*Gadus morhua*) and Pacific cod (*G. macrocephalus*). Three dorsal fins set marine gadids apart from many other fish families, although their overall body size varies by species within the family (Mecklenburg et al. 2002). North Pacific gadids include walleye pollock (*G. chalcogrammus*) and a set of cods: Pacific cod, Arctic cod (*Boreogadus saida*), and saffron cod (*Eleginus gracilis*). All play important roles both ecologically and economically for Alaska fisheries. Pacific cod make up the second biggest fishery in the eastern Bering Sea (EBS) and Gulf of Alaska (GOA) (Witherell and Armstrong 2015). Arctic cod are the most important fish species in the Arctic ecosystem (Bradstreet et al. 1986, Mecklenburg et al. 2008). Combined with Arctic cod, saffron cod makes up a high proportion of the fish biomass in the Chukchi and Beaufort Seas (North Pacific Fishery Management Council 2009, Logerwell et al. 2015). Together, Arctic and saffron cods act as an essential link of energy from primary productivity to higher trophic levels in the Arctic food web (Lowry and Burns 1980, Craig et al. 1982).

Each of the North Pacific cods has a growth strategy suited for different temperature ranges, which affects where they live. Arctic cod are the smallest of these three cods, usually measuring less than 10 inches (25.4 cm) long (Mecklenburg et al. 2002). They are best suited for colder temperatures and thrive in waters 35–48 °F (2–9 °C) (Moulton and Tarbox 1987, Laurel et al. 2016). Arctic cod do not do well in warmer waters, but saffron cod are able to survive and grow, albeit slower, at higher temperatures (up to 68 °F or 20 °C) (Laurel et al. 2016). Saffron cod are a bit larger than Arctic cod, growing up to 2 feet (0.5 m) long (Mecklenburg et al. 2002), and their yellow fins visually set them apart from their cousins (Mecklenburg et al. 2002). Pacific cod are more generalists, maximizing their growth at temperatures between the ranges of Arctic cod and saffron cod (Laurel et al. 2016). Pacific cod are also the largest of the three species, growing up to 4 feet (1.5 m) long (Mecklenburg et al. 2002). They have a greater distribution and are potentially more adaptable to changing conditions, meaning they can live in a wider range of habitats.

DISTRIBUTION

Pacific cod have a broader range compared to Arctic and saffron cods. They are found throughout the North Pacific Ocean; in Alaska from Southeast Alaska and the Gulf of Alaska, along the Aleutian Islands, and across the coastal, inner, and outer domains of the EBS shelf (Mecklenburg et al. 2002, North Pacific Fishery Management Council 2015b). There are an estimated 980 million Pacific cod in the EBS alone (North Pacific Fishery Management Council 2015b). They have also been reported as far north as the Chukchi Sea (Mecklenburg et al. 2002), although that area is dominated by Arctic cod.

Arctic cod and saffron cod are the two most abundant gadids in the Chukchi Sea (North Pacific Fishery Management Council 2009, Thedinga et al. 2013, Goddard et al. 2014, Logerwell et al. 2015). The shallow, 0–165 foot (0–50 m) nearshore habitat of the Chukchi Sea is perfect for these fishes. Researchers estimate that 2.5 billion individual Arctic cod and over 260 million saffron cod live in the Chukchi Sea (Goddard et al. 2014). Arctic cod are abundant in the Beaufort Sea as well, although population surveys experienced high variations in catch across stations and seasons (Craig et al. 1982, Jarvela and Thorsteinson 1999). In contrast, saffron cod range as far south as the Gulf of Alaska, yet their presence in these waters is considered rare (see Mecklenburg et al. 2002).

TABLE 4.3-1. Life cycle characteristics of North Pacific cod species.

	Pacific Cod *Gadus macrocephalus*	Arctic Cod *Boreogadus saida*	Saffron Cod *Eleginus gracilis*
Spawning Habitat	Deep water[2]	Under sea ice[1]	Shallow water on sand/gravel[2]
Number of Eggs	1–2 million[2]	9,000–21,000[2]	29,000–124,000[2]
Mature Age	3 years[2]	3 years[1]	3 years[2]

Sources: [1]Craig et al. (1982); [2] Food and Agriculture Organization (1990)

LIFE CYCLE

The three North Pacific cods each have different spawning characteristics, but they all mature around three years of age (Table 4.3-1). Fecundity, or the number of eggs a female cod can make, is dependent upon the size of the female; therefore Pacific cod, being the largest of the gadids, is also the biggest egg producer. Pacific cod spawn in the late winter or early spring (Neidetcher et al. 2014). Arctic cod spawn under the ice in winter, making it difficult to identify spawning locations, although one known site is in Stefansson Sound northwest of Prudhoe Bay (Craig et al. 1982). Pacific cod spawn in deeper waters, but their larvae are positively buoyant so they float up near the surface and are pushed toward shallow nursery habitats by ocean currents (Rugen and Matarese 1988). Once there, they hide from predators in the eelgrass (*Zostera* spp.) (Laurel et al. 2007). Similarly, in saffron cod nurseries, the juveniles use eelgrass for protection (Laurel et al. 2007). These nursery habitats, as well as the right oceanic conditions and prey availability, are very important for survival (Moss et al. 2016).

As they grow, Pacific cod begin schooling, and at two years of age, shift habitat preferences to areas with rough, rocky bottoms (Ueda et al. 2006). They change locations within the Bering Sea throughout the year, moving deeper in the fall/winter and shallower in the spring/summer (Rand et al. 2014). They grow quickly, but unlike some fish that grow fast and mature early, Pacific cod can live up to 25 years (Munk 2001). Arctic cod are also fast-growing, early maturing fish, but likely have a shorter life span and may only live to the age of seven (Craig et al. 1982, Food and Agriculture Organization 1990). Saffron cod are similar, with less than 1% of the hundreds of thousands of eggs that are spawned surviving past 5 years (Food and Agriculture Organization 1990).

ECOLOGICAL ROLE

Pacific cod diets include snow crabs (*Chionoecetes opilio*) and Tanner crabs (*C. bairdi*), which make up over 20% of Pacific cod stomach contents (Livingston 1989). Pacific cod diets shift as they grow, from Chionoecetes crabs to larger red king crabs (*Paralithodes camtschaticus*) and fishes, including Pacific herring (*Clupea pallasii*), Atka mackerel (*Pleurogrammus monopterygius*), and arrowtooth flounder (*Atheresthes stomias*) (Livingston et al. 1993). Saffron cod feed on benthic invertebrates, such as shrimp and amphipods (Wolotira 1985, Coyle et al. 1997). Arctic cod eat zooplankton in high enough quantities to transfer up to 75% of zooplankton production to higher trophic levels in the Arctic food web (Copeman et al. 2016). Their primary prey items include copepods, amphipods, and mysid shrimp (Bradstreet and Cross 1982, Craig et al. 1982).

4.3
NORTH PACIFIC CODS
MAP ON PAGES 88–89

Pacific cod offer a large energy source to predators, such as Pacific halibut (*Hippoglossus stenolepis*) (Best and St-Pierre 1986), spotted seals (*Phoca larga*) (Whitehouse 2013), and Steller sea lions (*Eumetopias jubatus*) (Sinclair and Zeppelin 2002). Saffron cod are preyed upon by marine mammals (Lowry et al. 1980), making up a third of the diet for ringed seals (*Phoca hispida*) in the Chukchi Sea (Whitehouse 2013), and are also preyed upon by birds (Schmutz and Hobson 1998). Predators such as beluga whales (*Delphinapterus leucas*), narwhals (*Monodon monocerus*), ringed seals, and seabirds rely on Arctic cod for part, if not the majority, of their diets (Lowry and Burns 1980, Bradstreet and Cross 1982, Frost and Lowry 1984, Bluhm and Gradinger 2008). For example, Arctic cod used to comprise around 90% of the diets of Black Guillemot (*Cepphus grylle*), but that has decreased in recent years with changes in ice conditions (Divoky et al. 2015).

ECONOMIC IMPACT

The Pacific cod was the first commercially fished species in the EBS (Fredin 1985), beginning in the days of wooden schooners, and is now harvested using trawls, longlines, jigs, and pots (North Pacific Fishery Management Council 2015b). While more pollock are caught, the value of Pacific cod is greater (wholesale value per ton) than pollock as well as yellowfin sole (*Limanda aspera*) and Pacific ocean perch (*Sebastes alutus*) (North Pacific Fishery Management Council 2015a). They are sold for fillets and are an alternative for Atlantic cod in European markets (North Pacific Fishery Management Council 2015a).

Commercial fishing for Arctic cod and saffron cod is currently prohibited in US Arctic waters (North Pacific Fishery Management Council 2009). Arctic cod is harvested for subsistence through cracks in the ice or holes drilled by fishers, and in some communities, are harvested with poles during ice-free times (Bacon et al. 2011). Saffron cod are also taken for subsistence in coastal Alaska communities (Magdanz 2010).

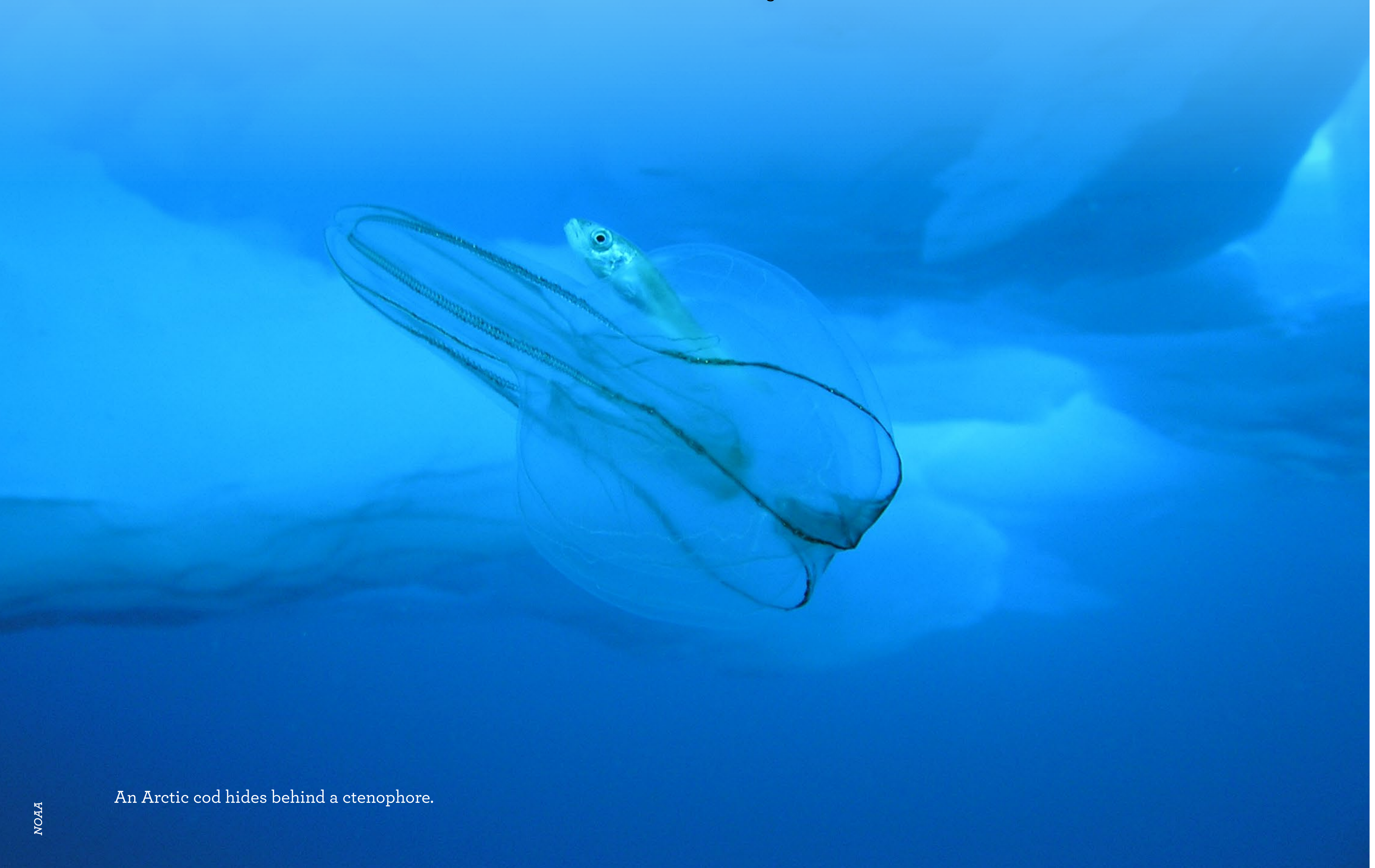
CONSERVATION ISSUES

Ocean temperatures are increasing, and North Pacific cods are already in habitats at the higher end of their temperature thresholds. Arctic cod, in particular, grow well in cold waters and play an important role in Arctic food webs (Bluhm and Gradinger 2008), by transferring energy efficiently from what they eat to what eats them (Harter et al. 2013). Any change in their ability to grow or shifts in their distribution will affect the whole ecosystem. For example, an animal most efficiently converts energy from what it eats within a certain temperature range, so with warmer ocean conditions, Arctic cod will become less and less efficient at transferring energy, and predators will therefore get less energy down the line (Laurel et al. 2016). Also, as temperatures increase, the four gadids may shift their established distributions to suit their metabolic needs, which could disrupt the balance of the North Pacific ecosystem (Bluhm and Gradinger 2008).

Arctic cod are a keystone species in the arctic marine food web and their critical role is justification for prohibiting a commercial fishery in the Arctic Management Area unless it would have minimal impacts on the stock (North Pacific Fishery Management Council 2009). Also, because of the close association of Arctic and saffron cod, it is estimated that 2.2 metric tons of Arctic cod bycatch would occur for every 1.1 metric ton of saffron cod harvested (North Pacific Fishery Management Council 2009), so while no commercial fishery is currently in place, a management concern will be capping bycatch limits and monitoring species catches closely if a fishery opens.

MAPPING METHODS (MAP 4.3)

The general-distribution polygon for Pacific cod is the Essential Fish Habitat (EFH) designation from National Oceanic and Atmospheric Administration (2016b). This distribution is described as located in pelagic waters along the entire Bering Sea shelf (0–660 feet [0–200 meters]) and upper (660–1,650) [200–500 m]) slope throughout the Bering Sea and Aleutian Islands, wherever there are soft substrates consisting of mud and sand.



An Arctic cod hides behind a ctenophore.

NOAA

4.3
NORTH PACIFIC CODS
MAP ON PAGES 88–89

Spawning areas for Pacific cod were digitized from Figure 5 in Neidetcher et al. (2014) showing concentrated spawning in the Bering Sea and Aleutian Islands from 2005–2007. During the course of the study, spawning concentrations were identified along the Aleutian Islands, north of Unimak Island, near the Pribilof Islands, and the Bering Sea shelf edge along the 660-foot (200-m) isobath. Observers identified the highest percent spawning (>35%) in 2005 in the western Aleutians at Attu Island, in the central Aleutians at Atka Island, and along the Bering Sea shelf north of Unimak Island, seaward of the Pribilof Islands and along the northern outer shelf. Spawning locations from this paper were shown as data points coded by daily percent. Percentages ranged from 15–35%, but in order to show just presence or absence, polygons were drawn around aggregated points in the figure. Therefore spawning polygons depict only presence of spawning, not magnitude of spawning.

The general distribution of saffron cod is a combination of three data sources, merged together. The first is the EFH area for adult and late juvenile saffron cod (National Oceanic and Atmospheric Administration 2016b), described as located in pelagic and epipelagic waters along the coastline, within nearshore bays, and under ice along the inner (0–165) [0 to 50 m]) shelf throughout Arctic waters and wherever there are substrates consisting of sand and gravel. The second is data from Smith (2010) and Audubon Alaska (2009) showing nearshore distribution in the US Beaufort Sea. The third is based on combined bottom trawl survey data for the Bering Sea (Conner and Lauth 2016, Hoff 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell 2008). Data points for saffron cod presence or absence were extracted and mapped based on catch-per-unit-effort (CPUE) displaying kilograms per hectare. A polygon was then drawn around all aggregated data points with a CPUE value above the average for the dataset.

Spatial data for saffron cod were not abundant. The main spawning area is from National Oceanic and Atmospheric Administration (1988), which documented spawning areas in Kotzebue Sound, nearshore areas of the Seward Peninsula, and Norton Sound areas.

The general distribution for Arctic cod is a combination of two datasets. The first was digitized from Thorsteinson and Love (2016). This study describes that Arctic cod are very abundant in the US Chukchi and Beaufort Seas. The second is based on combined bottom-trawl survey data for the Bering Sea (Conner and Lauth 2016, Hoff 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell 2008). Data points for Arctic cod presence or absence were extracted and mapped based on CPUE displaying kilograms per hectare. A polygon was then drawn around all aggregated data points with a CPUE value above the average for the dataset to indicate areas of either presence or absence.

Spatial information about Arctic cod spawning is limited. Arctic cod spawn under the ice in winter, making it difficult for scientists to identify spawning habitat and locations. One location was mapped based on text descriptions from Craig et al. (1982) where spawning Arctic cod were observed northwest of Prudhoe Bay, but other locations are unknown.

Data Quality

Because saffron cod and Arctic cod spawn under the ice in winter, information about specific spawning locations is limited. More information is needed, especially for Artic cod spawning locations in the Beaufort Sea. Saffron cod and Arctic cod distribution are both partially based on summer-trawl survey data and therefore may not be fully representative of the year-round distribution.

Bottom trawl surveys in the Bering Sea slope were conducted on even years from 2002–2016, except for 2006 and 2014. Surveys in the EBS shelf were conducted from 1982–2016. Surveys for the northern Bering Sea occurred from 1982–2010. Bottom-trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewer

- Elizabeth Logerwell

MAP DATA SOURCES

Pacific Cod Distribution: National Oceanic and Atmospheric Administration (2016b)

Pacific Cod Spawning: Neidetcher et al. (2014)

Saffron Cod Distribution: Audubon Alaska (2009); National Oceanic and Atmospheric Administration (2016b); Oceana (2017a) based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), and Logerwell (2008); Smith (2010)

Saffron Cod Spawning: National Oceanic and Atmospheric Administration (1988)

Arctic Cod Distribution: Oceana (2017a) based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), and Logerwell (2008); Thorsteinson and Love (2016)

Arctic Cod Spawning: Craig et al. (1982)

R. Hibpshman

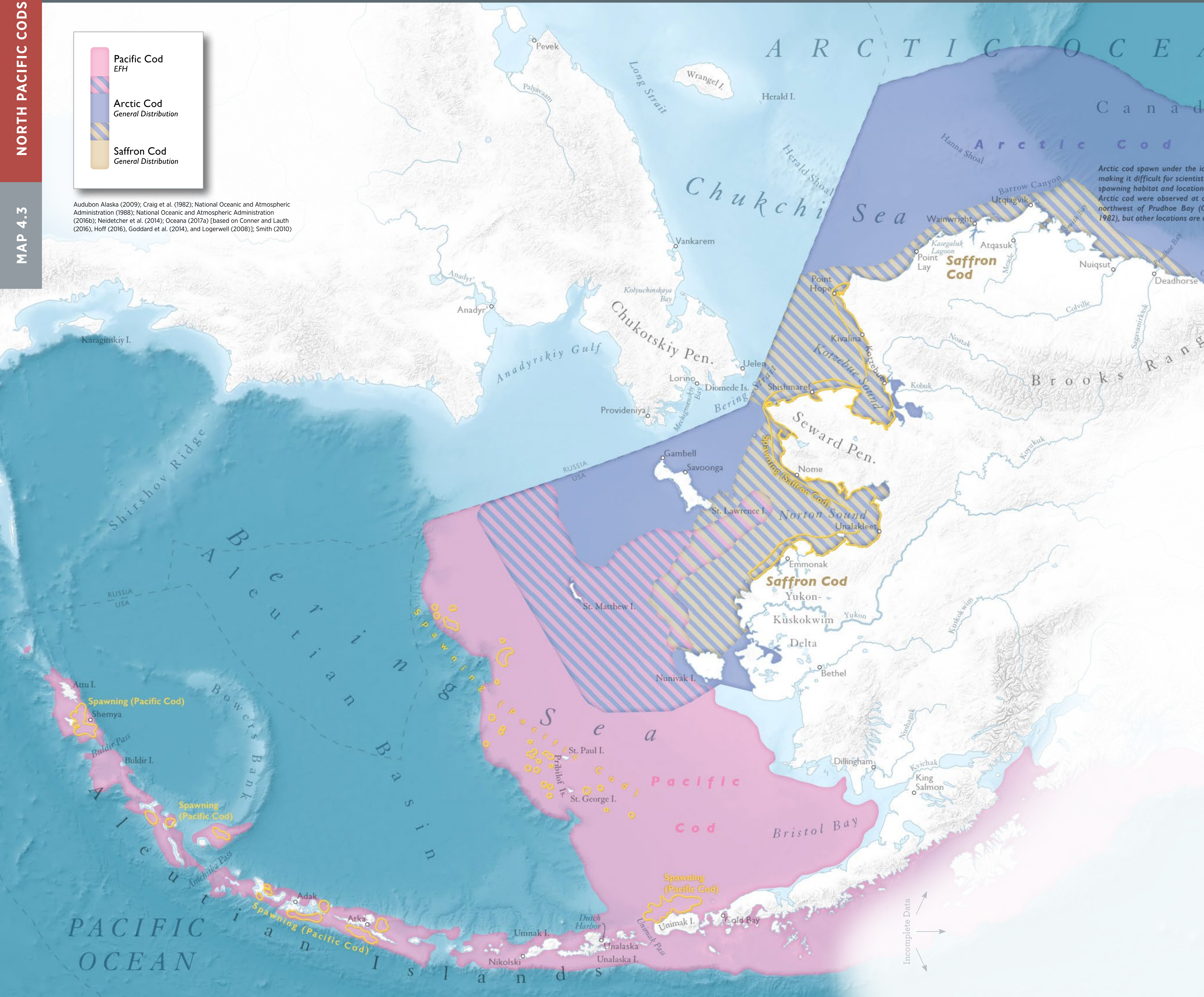
A Pacific cod has three dorsal fins, mottled coloration, thick body, and a long chin barbel.

Kitty Mecklenburg / NOAA

Juvenile gadids have more muted coloring, but they are still distinguishable between species based on their mouth shape, chin barbel size, and proportion of eye diameter to head depth.

North Pacific Cods

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman



Pacific Cod *Gadus macrocephalus*

Arctic Cod *Boreogadus saida*

Saffron Cod *Eleginus gracilis*

Cods, also called gadids, are fishes in the family *Gadidae* and include the most well-known members, Atlantic cod (*Gadus morhua*) and Pacific cod. North Pacific cods (Pacific cod, Arctic cod, and saffron cod) all play important roles both ecologically and economically for Alaska fisheries. Pacific cods make up the second biggest fishery in the eastern Bering Sea (EBS) and Gulf of Alaska (GOA). They have a broader distributional range compared to Arctic and saffron cods. They are found across the coastal, inner, and outer domains of the EBS shelf, along the Aleutian Islands, and throughout Southeast Alaska and the GOA. Pacific cod spawn in the deep water in the late winter and move to shallower habitats in the spring/summer.

Arctic cod are the most important fish species in the Arctic ecosystem. Arctic cod and saffron cod are the two most abundant fish species in the Chukchi Sea. Arctic cod are also abundant in the Beaufort Sea. In contrast, saffron cod range as far south as the Gulf of Alaska. They spawn nearshore on sand or gravel. Arctic cod spawning locations are difficult to identify because they spawn under the ice (see note above).

4.4 ATKA MACKEREL MAP ON PAGE 92

Atka Mackerel

Pleurogrammus monopterygius

Marilyn Zaleski, Jon Warrenchuk, and Brianne Mecum

Atka mackerel (*Pleurogrammus monopterygius*) are one of the most abundant marine fish in the Aleutian Islands. Atka mackerel have a complex life-history and very specific habitat requirements. Their range extends along the continental shelf from Southeast Alaska along the Aleutian Archipelago to Russia. Because of their high abundance, they play an important role in the Aleutians ecosystem as prey for marine fishes, seabirds, and marine mammals including the endangered Western stock of Steller sea lions (*Eumetopias jubatus*) (Merrick and Loughlin 1997, Yang 1998).

Atka mackerel are in the greenling family, *Hexagrammidae*, and are semi-pelagic schooling fish. Five lateral lines extend the full length of their bodies on either side (Mecklenburg et al. 2002), which help them sense water movement around them and give them a sense of where they are within schools or in relation to other objects in the water. Atka mackerel can display an assortment of color patterns that are associated with a variety of complex social behaviors (Lauth et al. 2010). Their coloration is generally bluish-green or gray but they become sexually dichromatic during the spawning season, when nest-guarding males become bright yellow with dark black vertical stripes (Lauth et al. 2010).

DISTRIBUTION

Widely distributed along the continental shelf from Russia across the Aleutian archipelago to the Alaska mainland and north along the Bering Sea shelf (North Pacific Fishery Management Council 2015b), Atka mackerel are one of the more prolific fish in the Aleutians in terms of biomass (Raring et al. 2016). This species is also found over the eastern Bering Sea (EBS) shelf, although in very low numbers, from 150 ft to beyond the shelf break at 650 ft (45–200 m) deep (Mecklenburg et al. 2002, National Oceanic and Atmospheric Administration 2016a). They spawn in areas with high relief rock substrates and strong water currents at bottom depths ranging from 100 to 475 ft (30–145 m) (Lauth et al. 2007b). Their Essential Fish Habitat (EFH) also includes sponges and corals, as they were primarily associated with these habitat-forming invertebrates when sampled during bottom-trawl surveys or observed with underwater cameras (Malecha et al. 2005, Stone 2006). Areas in the Aleutians closed to bottom trawling may be higher quality Atka mackerel habitat, especially those near well-mixed upwelling zones (Rand and Lowe 2011). Atka mackerel sampled inside trawl exclusion zones had fuller stomachs than those in areas open to bottom trawling, suggesting feeding is enhanced in areas of undisturbed habitat (Rand and Lowe 2011).

LIFE CYCLE

Atka mackerel establish nesting sites at specific locations on the seafloor, rather than broadcast-spawn eggs into the water column. In the Aleutian Islands, spawning begins in mid-to late summer and ends around mid-October (Lauth et al. 2007a). For male Atka mackerel, the reproductive cycle involves three phases of behavior: establishing a territory among males aggregated within a nesting site, courtship and spawning with females, and guarding and brooding eggs (Lauth et al. 2007a). Females can lay multiple batches of eggs, generally about 14 days apart, and each batch may contain 5,000 to 14,000 eggs (McDermott et al. 2007, McDermott et al. 2011). Their sticky eggs are generally laid in crevices found along rocky bottoms (Zolotov 1993). Males keep the nests clean by removing sea urchins, kelp, hydroids, sea stars, snails, and chitons, as well as guarding the nests against egg predation and cannibalism (Lauth et al. 2007a, Lauth et al. 2010). In contrast, schooling and non-nesting Atka mackerel exhibit a behavior known as "diel vertical migration," where they spend daylight hours swimming and feeding in the water column and at nighttime, stay close to or on the bottom (Nichol and Somerton 2002).

The eggs hatch between October and January, with most larvae hatching in November (Lauth et al. 2007a). After being fertilized and depending on water temperature, embryos take anywhere from 44 days (at 49.8 °F or 9.9 °C) to 100 days (at 39.0 °F or 3.9 °C) to develop and for larval Atka mackerel to hatch (Lauth and Blood 2007, Lauth et al. 2007b).

When larval Atka mackerel hatch, they are less than half-an-inch (around 10 mm) long (Kendall and Dunn 1985) but once they reach adulthood they can be up to almost 2 feet (600 mm) (Mecklenburg et al. 2002). Their growth is influenced by prey quality and has been observed to differ longitudinally in conjunction with varied diets: smaller-at-age Atka mackerel were found moving east to west with diets of copepods in the west compared to krill and fish in the east (Rand et al. 2010). Female Atka mackerel reach adulthood and begin producing eggs ready for spawning as early as three years old, although their fecundity is generally greater as they age and they produce more eggs as seven to ten year olds (McDermott et al. 2011). They can live as long as 15 years (Kimura et al. 2007).

ECOLOGICAL ROLE

Atka mackerel diets are high in krill (family *Euphausiidae*), a small, energy-rich crustacean, and they prey heavily on copepods (Yang 1998, Aydin et al. 2007, Rand et al. 2010). They also eat larval fish and are responsible for eating up to 410,000 metric tons of juvenile pollock (*Gadus chalcogrammus*) annually in the Aleutian Islands ecosystem (Yang 1998, Aydin et al. 2007). Their prey composition is largely dependent on where they are, rather than what they necessarily prefer, and this food availability directly affects Atka mackerel growth. In areas where Atka mackerel were able to eat more krill, they grew larger, while in areas where they ate less krill, they were smaller (Rand et al. 2010).

Atka mackerel play an important role in the food web. They transfer energy from small zooplankton and fishes up to larger predators (Logerwell and Schaufler 2005, Aydin et al. 2007) like Pacific cod (*Gadus macrocephalus*) and arrowtooth flounder (*Atheresthes stomias*), with Atka mackerel making up about 15% of Pacific cod diets in the Aleutians (Yang 1998, Aydin et al. 2007). Seabirds, such as the Thick-billed Murre (*Uria lomvia*), also prey heavily on juvenile Atka mackerel (Ogi 1980).

Marine mammals are another consumer of Atka mackerel (National Marine Fisheries Service 1995, Antonelis et al. 1997, Sinclair and Zeppelin 2002), comprising up to 65% of Steller sea lion diets (Merrick et al. 1997) and 73% of harbor seal (*Phoca vitulina*) diets in the Aleutians (Kenyon 1965). In one instance, a female harbor seal's stomach contained 72 freshly eaten Atka mackerel, suggesting that harbor seals selectively feed on this species (Kenyon 1965). Atka mackerel may also be a preferred prey of humpback whales (*Megaptera novaeangliae)* in the Aleutians: in the 1950s, a large percentage of humpback whales in that region had mackerel in their stomachs, and in some cases the stomachs were filled exclusively with these fish (Nemoto 1957).

ECONOMIC IMPACT

For thousands of years, Atka mackerel were an important food source for the Aleut people (Simenstad et al. 1978, Orchard 2001). Currently, factory trawlers remove around of 50,000 tons (45,000 metric tons) of Atka mackerel annually (average catch from 2011–2015) to sell to Japan, China, and Korea (Fissel et al. 2015). The Atka mackerel population was estimated to comprise 640,000 tons (580,000 metric tons) of fish 3 years and older (North Pacific Fishery Management Council 2015b). Atka mackerel between the ages of 2 to 11+ years old are caught by the commercial fishery and the majority of the catch is comprised of 3–5 year olds (North Pacific Fishery Management Council 2015b).

4.4 ATKA MACKEREL MAP ON PAGE 92

R. Hibpshman

Atka mackerels are known for their black and yellow striped pattern. However, this coloration is only displayed during spawning season by nest-guarding males.

CONSERVATION ISSUES

The effect of fishing on Atka mackerel benthic habitat is a conservation issue and management concern. The commercial fishery uses bottom-trawls with large-diameter roller gear to access the rough, hard-bottom seafloor of the Aleutians. This gear changes the seafloor habitat through direct contact and removes and damages deep-sea corals and sponges, which can take decades to recover after fishery-related removals (Rooper et al. 2011).

The Atka mackerel population in the Aleutians is affected by commercial fishing; their spawning biomass is estimated to be 46% of what it would be if the stock was unfished (North Pacific Fishery Management Council 2015b). The population of this species in the Gulf of Alaska was commercially extirpated after a short, intense fishery in the 1980s, and there has not been a directed fishery for them in that area since 1996 (Lowe 2015). Therefore, the Aleutian Atka mackerel population should be carefully managed.

Atka mackerel are a primary prey source for the Western stock of Steller sea lions, a population that has drastically declined since the 1960s. Some spatial and temporal fishery management measures have been implemented to reduce competition between commercial fisheries and sea lions for Atka mackerel prey (National Marine Fisheries Service 2010).

MAPPING METHODS (MAP 4.4)

The relative abundance of Atka mackerel was estimated by interpolating datasets from bottom-trawl surveys, which employed consistent methodologies and sampled waters within the US Exclusive Economic Zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell 2008). Data points for Atka mackerel presence or absence were extracted and mapped based on catch-per-unit-effort (CPUE) displaying kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted (IDW) tool in ArcGIS version 10.5 based on CPUE values, and interpolation was limited to the study area boundaries of the trawl surveys.

Nesting sites were created directly from site coordinates found in Appendix 1 from Lauth et al. (2007b). A radius of the 12 nearest points was set as the search distance.

EFH areas for Atka mackerel were obtained directly from National Oceanic and Atmospheric Administration (2016b). Areas for adult Atka mackerel EFH were displayed since these are considered the general distribution for this life stage. These areas are located wherever there are gravel and rock beds and kelp, along the inner (0 to 165-feet [0 to 50 m]), middle (165 to 330 feet [50 to 100 m]), and outer shelf (330 to 660 feet [100 to 200 m]) throughout the GOA and Bering Sea/Aleutian Islands (North Pacific Fishery Management Council 2016a).

Data Quality

Atka mackerel data are available throughout the US portions of the project area, although Atka mackerel are most highly concentrated around the Aleutian Islands and are less present further north, and as you move further offshore. Trawl-survey data sampling was conducted within the US EEZ, therefore there is little to no coverage on the Russian side of the Bering Sea. The interpolation of the trawl-survey data estimates the distribution of Atka mackerel during the summer months and may not represent the year-round distribution.

Bottom-trawl surveys in the Aleutian Islands were conducted every 3 years from 1983–2000, and on even years from 2002–2016. Surveys on the Bering Sea slope were conducted on even years from 2002–2016, except for 2006 and 2014. Surveys in the EBS shelf were conducted from 1982–2016. Surveys for the northern Bering Sea occurred from 1982–2010. Gulf of Alaska surveys were conducted in 1984 and 1987; every 3 years from 1990–1999, and on odd years from 2001–2015. Bottom trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewer

- Robert Lauth

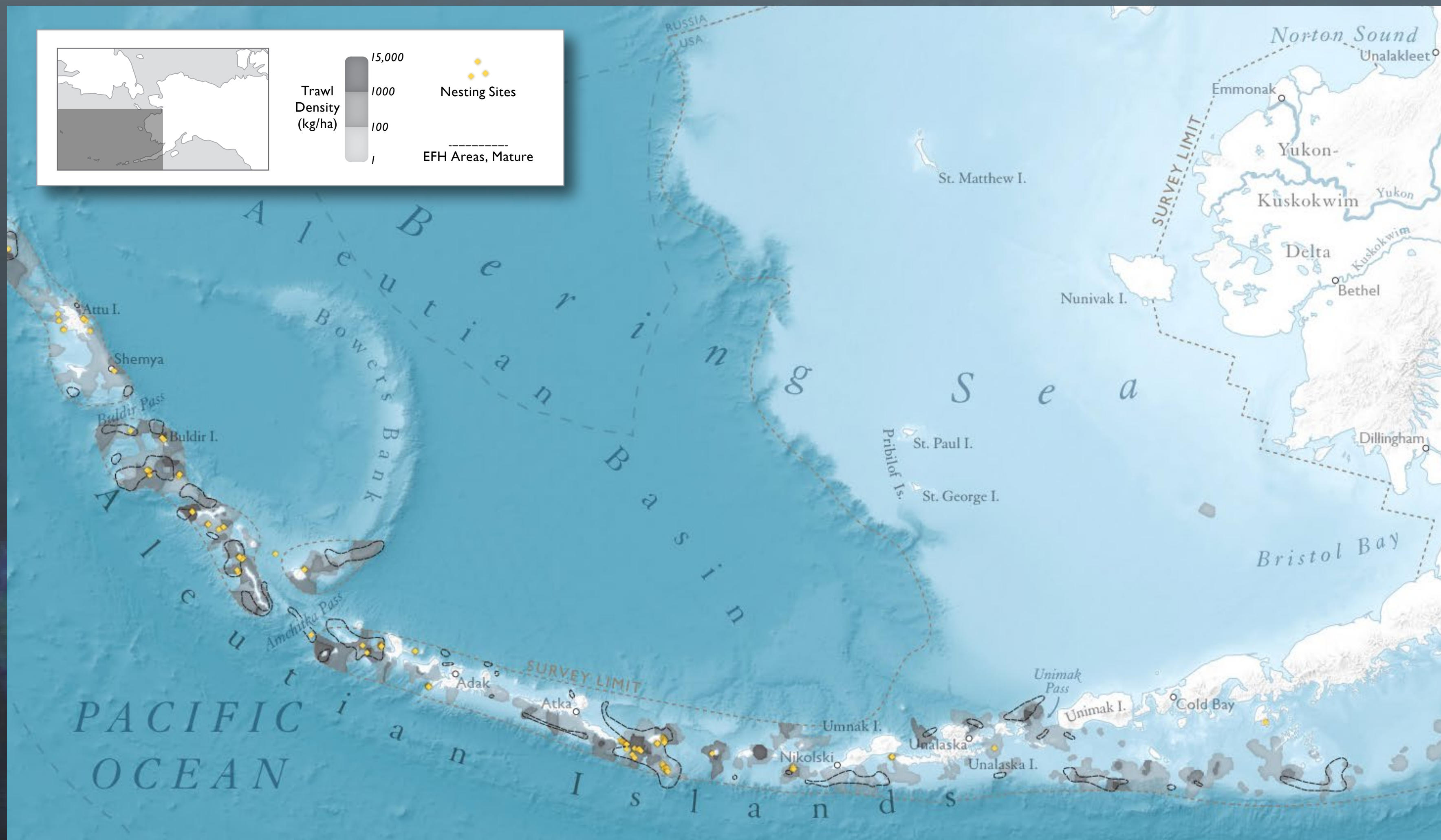
MAP DATA SOURCES

Relative Abundance: Oceana (2017b) based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)

Nesting Sites: Lauth et al. (2007b)

Essential Fish Habitat: National Oceanic and Atmospheric Administration (2016b)

Atka Mackerel



Lauth et al. (2007b); National Oceanic and Atmospheric Administration (2016b); Oceana (2017b) [based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)]

Map Authors: Brianne Mecum and Jon Warrenchuk
Cartographer: Daniel P. Huffman

Atka Mackerel
(*Pleurogrammus monopterygius*)

Atka mackerel are one of the more abundant marine fish in the Aleutian Islands. They are widely distributed along the Aleutian Archipelago from Russia to the Alaskan mainland, and to a smaller degree over the eastern Bering Sea shelf in the middle domain. Their Essential Fish Habitat includes sponges and corals, as they were primarily associated with these habitat-forming invertebrates when sampled during bottom-trawl surveys. They are nest spawners (yellow diamonds) with the males guarding the batches of fertilized eggs until hatching. Because of their high abundance, Atka mackerel play an important role in the Aleutian Island ecosystem as prey for marine fishes, seabirds, and marine mammals including the endangered Western stock of Steller sea lions (*Eumetopias jubatus*). Some spatial and temporal fishery management measures have been implemented to reduce competition for prey between commercial fisheries and the sea lions.

Bob Lauth / NOAA Fisheries

MAP ON PAGES 96–97

Yellowfin Sole

Limanda aspera

Jon Warrenchuk, Marilyn Zaleski, and Brianne Mecum

Yellowfin sole (*Limanda aspera*) are the most abundant flatfish and one of the most abundant fishes in the eastern Bering Sea (EBS). There are an estimated 16 billion individuals in the EBS (North Pacific Fishery Management Council 2015b). These benthic dwellers act as a transfer of energy between lower trophic benthic animals (see Benthic Biomass summary in the previous chapter) and upper trophic predators that rely on this ubiquitous species (Aydin et al. 2007).

Yellowfin sole are a "right-eyed" flatfish of the family *Pleuronectidae*, so-called because both of its eyes are on the right side of its body and, being a flatfish, the eyed side is always pointed up and the other is always pointed down. They are born with a symmetrical head like other fish, but the left eye migrates over to the right side in right-eyed flatfish as they metamorphose from larvae to juveniles (Ahlstrom et al. 1984). (See also Pacific Halibut Summary.) Yellowfin sole have yellow fins, hence their name, with a black line at the base separating the fins from the body (Mecklenburg et al. 2002) (see photo on page 95).

DISTRIBUTION

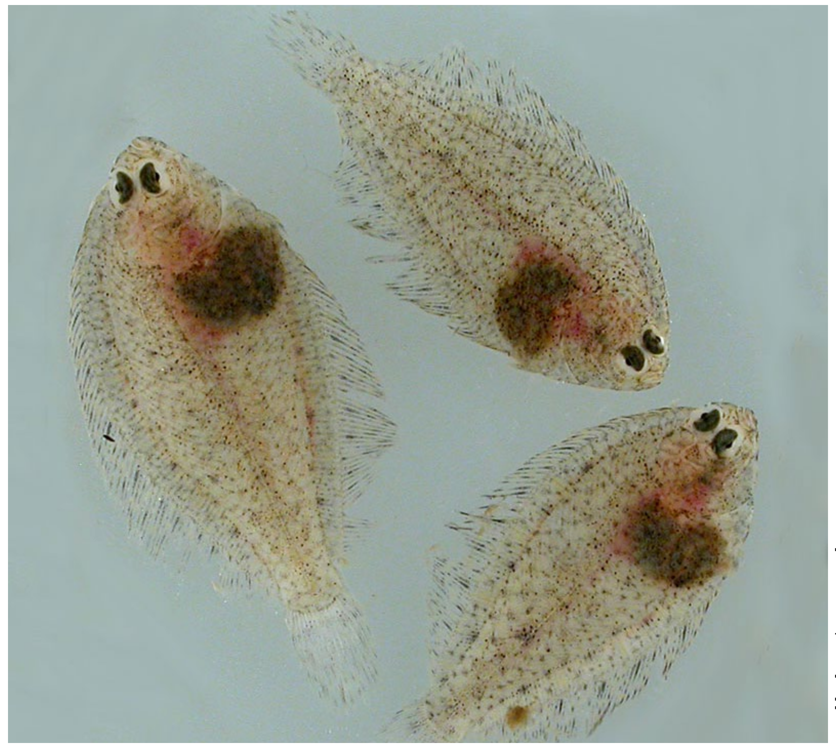
Yellowfin sole range along the continental shelf in waters generally less than 330 feet (100 m) deep from the Beaufort and Chukchi Seas up north to British Columbia in the south and along the Asian coast off South Korea (Wilderbuer et al. 1992). They occur in higher densities on sandy areas of the shelf (McConnaughey and Smith 2000) and are most common in the EBS shelf with an estimated population of 16 billion fish (Wilderbuer et al. 1992). Each year, yellowfin sole migrate from their wintering grounds near the deeper edge of the EBS shelf to their summer grounds in shallow waters less than 165 feet (50 m) deep for feeding and spawning (North Pacific Fishery Management Council 2015b).

LIFE CYCLE

Yellowfin sole are batch spawners, meaning within one year they may release several sets or batches of eggs instead of all at once. They begin producing their eggs in the spring and early summer, peaking around June (Paul et al. 1993), but some begin spawning as early as May and continue through August (Nichol and Acuna 2001). Females spawn in 8 to 11 batches, with the larger females producing more eggs; depending on her size, a female yellowfin sole can produce anywhere from 295,000 to 3 million eggs (Nichol and Acuna 2001). They spawn in the summer in the shallow waters of Bristol Bay and as far north as Nunivak Island (Fadeev 1970).

Larval yellowfin sole go through a transformation when their left eye shifts to the right side of their bodies (Ahlstrom et al. 1984). Newly hatched larvae are less than 0.25 inches long (2.2–2.8 mm) and only grow to about 0.4 inch (10 mm) before their metamorphosis (Ahlstrom et al. 1984). Once settled to the bottom, flatfish use estuaries and bays as nursery habitats (Norcross et al. 1996). Yellowfin sole will stay in these shallow, mixed sediment areas less than 130 feet (40 m) deep through their first or second year (Norcross et al. 1995, Norcross et al. 1996).

Yellowfin sole are relatively slow growing and long lived. While in their nursery habitats, they can grow from about 1 inch (3 cm) long to about 4.5 inches (11 cm) long within in the first year, and take 20 years to grow to about 13 inches (34 cm) long and a weight of 1 pound (450 g) (Norcross et al. 1996, Mecklenburg et al. 2002, North Pacific Fishery Management Council 2015b). Yellowfin sole can live up to 34 years (Munk 2001). Females grow slightly larger than males, and do not become reproductively mature until about nine years old (Fadeev 1970). They are caught by trawl fisheries generally after maturation, with an average age of 12 years for males and females in the 2014 fishery, (Norcross et al. 1996, Mecklenburg et al. 2002, North Pacific Fishery Management Council 2015b).


Mecklenburg / www.arcodiv.org

Juvenile yellowfin sole.

ECOLOGICAL ROLE

Yellowfin sole play a major role in the EBS food web (Aydin et al. 2007, Lee et al. 2010). On the central Bering Sea shelf, most of the primary production settles to the seafloor and feeds a large biomass of invertebrates that live on or in the seafloor sediments; yellowfin sole, in turn, feed on these invertebrates (Wilderbuer et al. 1992). They have a small mouth compared to other flatfishes, so they prey upon relatively small benthic invertebrates, such as polychaete worms, bivalves, amphipods, crangonid shrimp, brittlestars, and small crabs (Lang et al. 1995, Whitehouse 2013). As they grow, yellowfin sole shift their dominant prey selection from polychaete worms to echinoderms, including sand dollars, brittle stars, and sea cucumbers (Lang et al. 1995). Yellowfin sole are major prey items in the diets of other fishes, including Pacific cod (*Gadus macrocephalus*) and Pacific halibut (*Hippoglossus stenolepis*), and are also preyed upon by seabirds and marine mammals (Wilderbuer et al. 1992, Lee et al. 2010).

ECONOMIC IMPACT

In the 1950s, Russian and Japanese distant-water factory trawler fleets began targeting yellowfin sole in the EBS. Catches increased too quickly, taking almost 500,000 metric tons a year, and the yellowfin sole population became overfished by the 1960s (Bakkala 1993). Thereafter, the yellowfin sole population was allowed to slowly rebuild; today, US factory trawlers are permitted to catch 110,000–220,000 tons (100,000–200,000 metric tons) (North Pacific Fishery Management Council 2015b). The current directed fishery typically runs from winter through the fall and the Bering Sea/Aleutian Islands yellowfin sole are managed as a single stock (North Pacific Fishery Management Council 2015b).

CONSERVATION ISSUES

As with any commercially harvested species, a management concern for yellowfin sole is ensuring a healthy population of fish remains in the water to play their role in the marine ecosystem, as well as produce the next year class for subsequent fishing seasons. In comparing EBS biomass estimates from 1985 to 2016, yellowfin sole decreased by about 27% (North Pacific Fishery Management Council 2015b). Bycatch and habitat impacts from bottom trawling are also concerns for this and other groundfish fisheries (Dieter et al. 2003).

MAP ON PAGES 96–97

MAPPING METHODS (MAP 4.5)

The relative abundance of yellowfin sole was estimated by interpolating datasets from bottom-trawl surveys, which employed similar and consistent methodologies and sampled waters within the US Exclusive Economic Zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell 2008). Data points for yellowfin sole presence and absence were extracted and mapped based on catch-per-unit-effort (CPUE) displaying kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted (IDW) tool in the Spatial Analyst toolbar in ArcGIS version 10.5 based on CPUE values. A search radius of 12 points was set as the maximum distance and interpolation was limited to the study area boundaries of the trawl surveys.

Migration patterns, feeding, spawning, and over-wintering areas were digitized based on maps from Wilderbuer et al. (1992) depicting the seasonal migration patterns and distribution of yellowfin sole in the Bering Sea.

Data Quality

Yellowfin sole distribution within the waters of the US EEZ is well documented with over 30 years of data from the trawl-survey database. However, because surveys were only conducted within the US EEZ, we lack coverage outside of US waters. The interpolation of the trawl-survey data estimates the distribution of yellowfin sole during the summer months and may not represent the year-round distribution.

Bottom-trawl surveys in the Aleutian Islands were conducted every 3 years from 1983–2000 and on even years from 2002–2016. Surveys on the Bering Sea slope were conducted on even years from 2002–2016 except for 2006 and 2014. Surveys in the EBS shelf were conducted from 1982–2016. Surveys for the northern Bering Sea occurred from 1982–1993 and also in 2010. Gulf of Alaska surveys were conducted in 1984 and 1987; every 3 years from 1990–1999, and on odd years from 2001–2015. Bottom-trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewer

- Anonymous

MAP DATA SOURCES

Relative Abundance: Oceana (2017f) based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)

Feeding: Wilderbuer et al. (1992)

Spawning: Wilderbuer et al. (1992)

Wintering: Wilderbuer et al. (1992)

Migration: Wilderbuer et al. (1992)


R. Hibpshman

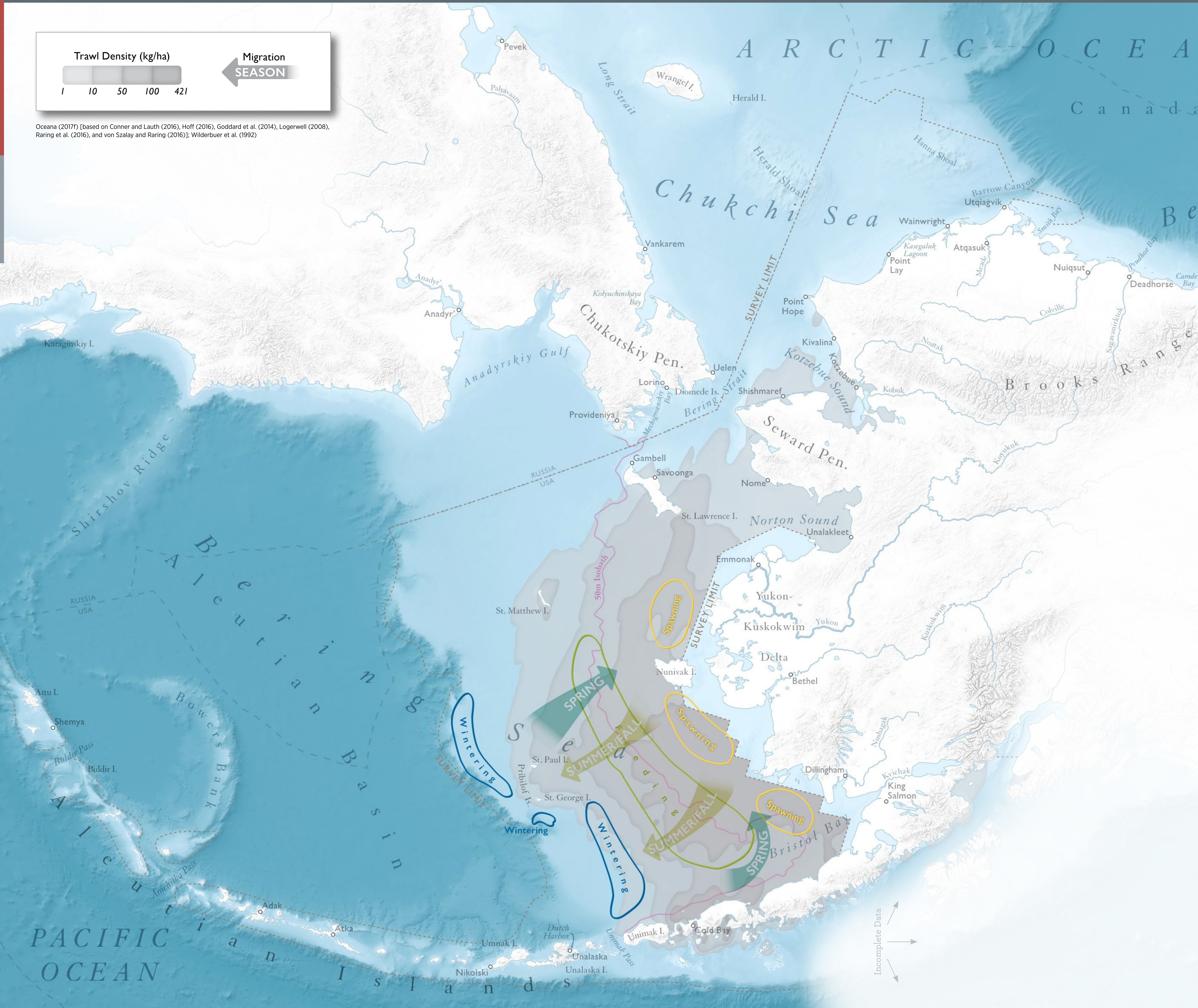
The yellowfin sole is an easily identified flatfish for its yellow dorsal, anal, and caudal fins, and the black lining at the base of its fins.

4.5 YELLOWFIN SOLE MAP 4.5

Yellowfin Sole

Map Authors: Brianne Mecum and Jon Warrenchuk
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA



Oceana (2017f) [based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)]; Wilderbuer et al. (1992)

NOAA Alaska Fisheries Science Center

Yellowfin Sole (*Limanda aspera*)

Yellowfin sole are the most abundant flatfish and one of the most abundant fishes in the eastern Bering Sea (EBS). There are an estimated 16 billion individuals in the EBS. Yellowfin sole range along the continental shelf in waters less than 330 ft (100 m) deep from the Beaufort and Chukchi Seas up north to British Columbia in the south and along the Asian coast off South Korea. They occur in higher densities on sandy areas of the shelf and are most common on the EBS shelf with an estimated population of 16 billion fish. Each year, yellowfin sole migrate from their wintering grounds near the deeper edge of the EBS shelf to their summer grounds in shallow waters less than 165 ft (50 m) deep for feeding and spawning. The current directed fishery manages the Bering Sea/Aleutian Islands yellowfin sole as a single stock.

MAP ON PAGE 100

Pacific Halibut

Hippoglossus stenolepis

Marilyn Zaleski and Brianne Mecum

Pacific halibut (*Hippoglossus stenolepsis*) is the largest teleost (ray-finned fish) in the North Pacific and as such is an important predator in the marine ecosystem as well as an important commercial species, where large fish yield large prices. The longest flatfish on record was a female Pacific halibut measuring in at 8.75 feet (2.67 m) (Mecklenburg et al. 2002).

Like the yellowfin sole (*Limanda aspera*), Pacific halibut are "right-eyed" flatfish in the *Pleuronectidae* family and have both eyes on the right side of their body (see Yellowfin Sole summary; Mecklenburg et al. [2002]). They are born with symmetrical faces as pelagic larvae, but by the time they grow to just over 0.5 inches (1.27 cm) their eyes shift and they transform into benthic-dwelling, asymmetrical juveniles (Ahlstrom et al. 1984). A small proportion of right-eyed flatfish have both eyes shift to the left side, but it is a rare and, for halibut, only occurs about once every 25,000 fish (Bell and St-Pierre 1970).

DISTRIBUTION

Pacific halibut have a far-reaching distribution from northern Japan and the northern Bering Sea south through the Gulf of Alaska (GOA) to California (Mecklenburg et al. 2002). They are abundant on the eastern Bering Sea (EBS) shelf generally less than 1,000 feet (300 m) deep, though they can be found as deep as 3,600 feet (1,100 m) (Mecklenburg et al. 2002).

Adult halibut migrate annually from shallow, summer feeding grounds to deeper areas to spawn from November to March (St-Pierre 1984, International Pacific Halibut Commission 2003, Valero and Webster 2012), a migration pattern that begins as juveniles (Best 1977). This movement pattern is motivated by temperature, with juvenile halibut following warmer water at the shelf edge in the winter and returning to the shelf flats after ice break-up in the spring (Best 1977). When they return to their summer feeding locations, some halibut show site-fidelity and return to the same feedings grounds (Loher 2008).

These migrations can span 750 miles (1,200 km) between spawning and feeding grounds, and the farther a halibut has to travel to spawn, the sooner it is likely to leave the summer feeding habitat (Loher and Seitz 2006). It is unknown if there is any migration from the GOA summer feeding grounds to EBS spawning locations, although it is unlikely that the GOA spawners migrate to and feed in the EBS (Seitz et al. 2007, Seitz et al. 2011).

LIFE CYCLE

Pacific halibut have a broad spawning season, beginning as early as late September and ending by March, although most spawning occurs between late-December and mid-January (St-Pierre 1984, Loher 2011). They spawn in both the GOA and the EBS and, because of currents, their larvae can be spread throughout and between both oceanic regions. Halibut spawned in the GOA can be transported into the EBS through Unimak Pass (St-Pierre 1989, Valero and Webster 2012). Samples of ichthyoplankton (larval fish) in Unimak Pass yielded postlarval halibut at "stages five through nine in their developmental progress, comparatively younger stages than those found in Shelikof Strait" (St-Pierre 1989). Spawning in the EBS occurs along the shelf edge from Unimak Pass northward to Pervenets/Middle Canyon and westward along the Aleutians to Attu Island (Best 1981, Seitz et al. 2011, Sohn 2016). However, it is unknown if the larval halibut produced in the EBS settle locally or are transferred northwestward toward the Asian coast (Best 1977, Vestfals et al. 2014, Wischniowski et al. 2015).

It takes about six to seven months for Pacific halibut to go from spawned egg to settled fish, with floating larval stages in between (St-Pierre 1989). In that time period, halibut undergo a metamorphosis with their left eye shifting to the right side of their heads. When they hatch, their eyes are symmetrical and they are about 0.4 inches long (11 mm), but by the time they have grown to about 0.8 inches (21 mm) they have both eyes on the same side (St-Pierre 1989).

R. Hibpshman

Pacific halibut can reach sizes over 400 pounds (180 kg).

MAP ON PAGE 100

Bristol Bay is the largest known nursery ground of Pacific halibut in the EBS (T. Loher pers. comm.), whether they are spawned in the EBS or arrive from the GOA via ocean currents (St-Pierre 1989). They prefer shallow water, less than 165 feet (< 50 m) deep for their nursery habitat with muddy or fine sands to easily bury themselves for predator avoidance (Stoner and Abookire 2002, Sohn 2016, Wilson et al. 2016). Aside from Bristol Bay, Pacific halibut settle around Nunivak Island, along the Alaska Peninsula, and around the Pribilof Islands that border the inner and middle shelves of the EBS (Best and Hardman 1982, Sohn 2016). They also prefer water near 39 °F (4° C) with a low isotherm of 36° F (2° C) defining their settlement range. Pacific Halibut are rarely found at temperatures below 32° F (0° C) (Best 1977).

Juvenile halibut tend to shoal, or loosely aggregate, with similar-sized/aged halibut, and they show an ontogenetic pattern of distribution (Best 1977). Age-1 halibut in the Bering Sea are found in shallow, nearshore habitats around the Alaska Peninsula and the Aleutian Islands, but by age 3 they have started to venture to deeper, offshore shelf habitats in Bristol Bay and toward Nunivak Island (Best 1977). Some tagging studies have shown juvenile movement from Bristol Bay to the GOA instead of to the EBS shelf (Best 1968, 1977; Skud 1977; Stewart et al. 2015).

As with most animals, growth of Pacific halibut is temperature dependent. For juvenile halibut, growth in colder water is slower than in warmer water, although cold-adapted juveniles can compensate for their slow growth once in warmer water conditions (Thomas et al. 2005). The reduced growth in cold years can slow juvenile halibut recruitment into the fishery by one year (Best 1977). Maturity varies by area, sex, and size of Pacific halibut. Females grow faster than males. Although there is some evidence to support density-dependence, meaning that halibut grow faster in less dense shoals (Clark and Hare 2002), more recent analyses indicate that low population density can also result in relatively slow growth (Stewart 2014). Other factors such as size-selective fishing can have a considerable effect on halibut size-at-age (Sullivan et al. 2016). This variation translates to a 12-year-old female being anywhere from 40 to 63 inches (100 to 160 cm) long (Sullivan et al. 2016) and weighing 29 to 128 pounds (13 to 58 kg) (International Pacific Halibut Commission 2003).

ECOLOGICAL ROLE

Fish as large as Pacific halibut require a substantial amount of food. In maintaining their energetic needs, they can directly affect their prey populations with the sheer volume of animals they eat (Best and St-Pierre 1986). Halibut are visual predators and they rely on both cues from prey as well as fellow halibut in their vicinity for success (Stoner and Ottmar 2004). Juvenile halibut prey upon small crustaceans, such as shrimp, small Tanner crabs (*Chionoecetes bairdi*) and snow crabs (*C. opilio*), and Pacific octopus (*Enteroctopus dofleini*); but as they grow, larger Tanner crabs, red squid (*Berryteuthis magister*), and fishes, including Pacific herring (*Clupea pallasii*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*G. chalcogrammus*), and Pacific sand lance (*Ammodytes hexapterus*) dominate their stomach contents (Best and St-Pierre 1986, Moukhametov et al. 2008).

Pacific halibut are prey for marine mammals but rarely for other fishes (Best and St-Pierre 1986). Halibut occasionally appear in Pacific sleeper shark (*Somniousus pacificus*) stomachs, including a 10-pound halibut dissected out of a 12-foot shark (Gotshall and Jow 1965). Steller sea lions (*Eumetopias jubatus*) and killer whales (*Orcinus orca*) have been found with halibut in their stomachs (Best and St-Pierre 1986, Merrick et al. 1997, John and Graeme 2006), but this large fish may be an apex predator in its own right.

ECONOMIC IMPACT

Pacific halibut drive commercial, subsistence, recreational, and charter fisheries throughout Alaska and are often a species of concern for how those fisheries divide such an important resource. Commercially, halibut fisheries are concentrated in the GOA but their catch and bycatch extend into the EBS (North Pacific Fishery Management Council 2016b). They represented a $132 million industry in 2015 (North Pacific Fishery Management Council 2016b), although there is an economic balancing act between this multi-use resource (Criddle 2004) and the portioning of catch limits as well as allowed bycatch, which are consistently debated through the Pacific Fisheries Management Council and North Pacific Fisheries Management Council.

CONSERVATION ISSUES

The allocation of the Pacific halibut catch between halibut users remains contentious. There is also concern for limiting halibut bycatch mortality in trawl and longline fisheries. The timing and physical techniques of returning incidentally caught halibut affect their discard mortality rates (Williams 2015). The current diminished average size of Pacific halibut and a declining "size at age" (expected size based on age of fish) are also important conservation concerns (Clarke and Hare 2002).

MAPPING METHODS (MAP 4.6)

The relative abundance of Pacific halibut was estimated by interpolating datasets from bottom-trawl surveys. These surveys employed similar and consistent methodologies and sampled waters within the US Exclusive Economic Zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay and Raring 2016), Chukchi Sea (Goddard et al. 2014), and Beaufort Sea (Logerwell 2008). Data points for Pacific halibut presence and absence were extracted and mapped based on catch-per-unit-effort (CPUE) displaying kilograms per hectare. To obtain continuous coverage across the study area, data points were interpolated using the Inverse Distance Weighted (IDW) tool in ArcGIS version 10.5 based on CPUE values. A radius of the 12 nearest points was set as the search distance and interpolation was limited to the study area boundaries of the trawl surveys.

Spawning areas for Pacific halibut were digitized from maps from St-Pierre (1984), who documented spawning locations from the Aleutian Islands to British Columbia. Nursery locations were drawn from Figure 3.1 in Sohn (2016), who documented settlement locations for age 0–1 Pacific halibut. General migration patterns in the Bering Sea were drawn based on text descriptions from Best (1977), a mark and recapture study assessing seasonal migrations.

Data Quality

Trawl-survey data sampling was conducted within the US EEZ, therefore there is little to no coverage on the Russian side of the Bering Sea, even though Pacific Halibut is obviously a transboundary species. Future studies may address the lack of survey data outside of US waters. Pacific halibut summer distribution is estimated through interpolation of trawl survey data, and may not represent year-round distribution.

Bottom-trawl surveys in the Aleutian Islands were conducted every 3 years from 1983–2000, and on even years from 2002–2016. Surveys on the Bering Sea slope were conducted on even years from 2002–2016, except for 2006 and 2014. Surveys in the EBS shelf were conducted from 1982–2016. Surveys for the northern Bering Sea occurred from 1982–2010. GOA surveys were conducted in 1984 and 1987; every 3 years from 1990–1999, and on odd years from 2001–2015. Bottom-trawl surveys in the Beaufort and Chukchi Seas occurred in 2008 and 2012, respectively. Data for the Beaufort and Chukchi Seas do not represent multi-year surveys or long-term trends like data for the Bering Sea.

Reviewer

- Timothy Loher

MAP DATA SOURCES

Relative Abundance: Oceana (2017d) based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)

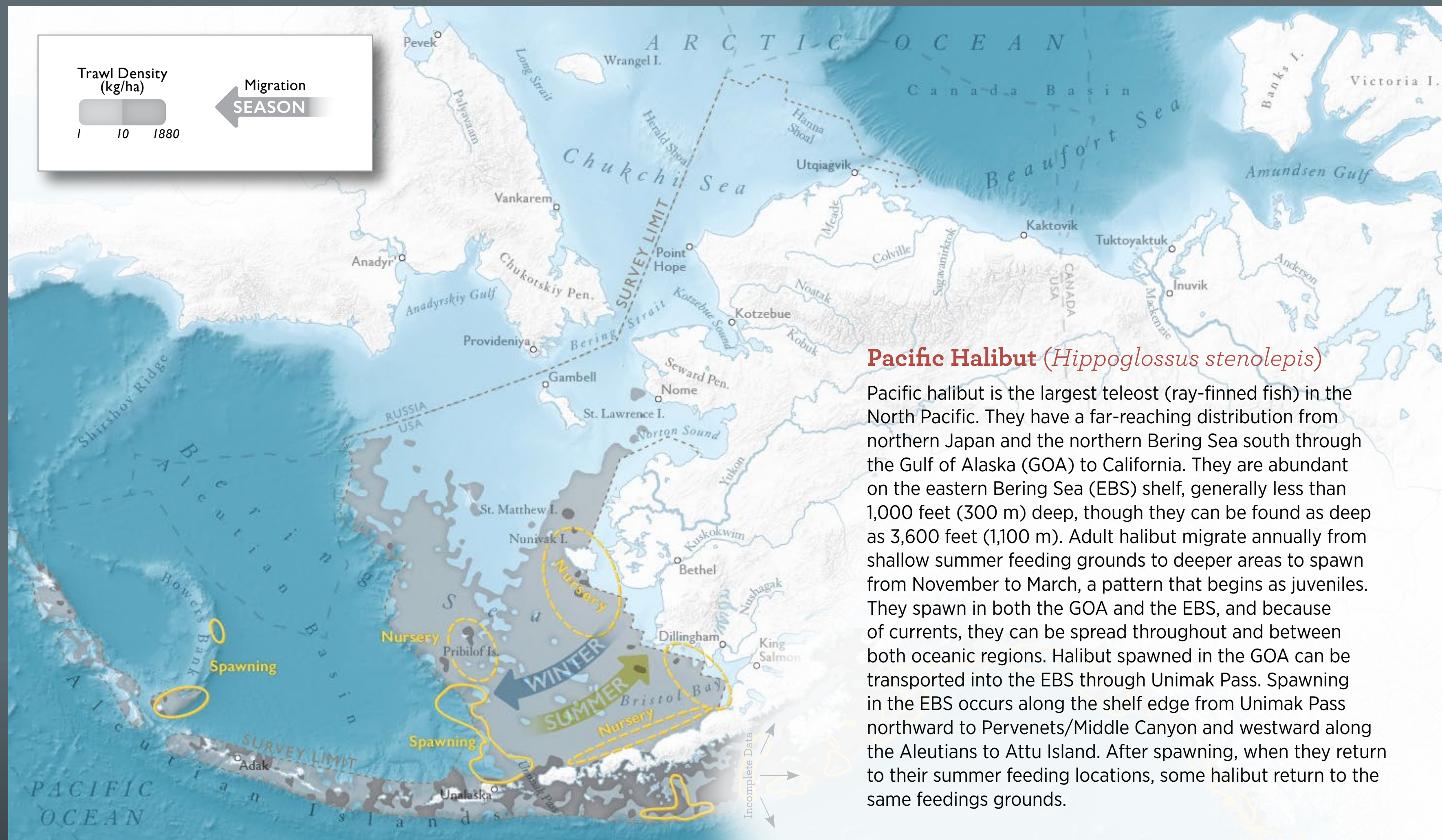
Spawning Areas: St-Pierre (1984)

Nursery Locations: Sohn (2016)

Migration: Best (1977)

Pacific Halibut

OCEANA Audubon ALASKA



Pacific Halibut *(Hippoglossus stenolepis)*

Pacific halibut is the largest teleost (ray-finned fish) in the North Pacific. They have a far-reaching distribution from northern Japan and the northern Bering Sea south through the Gulf of Alaska (GOA) to California. They are abundant on the eastern Bering Sea (EBS) shelf, generally less than 1,000 feet (300 m) deep, though they can be found as deep as 3,600 feet (1,100 m). Adult halibut migrate annually from shallow summer feeding grounds to deeper areas to spawn from November to March, a pattern that begins as juveniles. They spawn in both the GOA and the EBS, and because of currents, they can be spread throughout and between both oceanic regions. Halibut spawned in the GOA can be transported into the EBS through Unimak Pass. Spawning in the EBS occurs along the shelf edge from Unimak Pass northward to Pervenets/Middle Canyon and westward along the Aleutians to Attu Island. After spawning, when they return to their summer feeding locations, some halibut return to the same feedings grounds.

Best (1977); Oceana (2017d) [based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)]; Sohn (2016); St-Pierre (1984)

Map Authors: Brianne Mecum and Jon Warrenchuk
Cartographer: Daniel P. Huffman

An adult Pacific halibut.

iStock

Pacific Salmon

Marilyn Zaleski and Brianne Mecum

Chinook (King) Salmon	Sockeye (Red) Salmon	Coho (Silver) Salmon	Pink (Humpy) Salmon	Chum (Dog) Salmon
Oncorhynchus tshawytscha	*O. nerka*	*O. kisutch*	*O. gorbuscha*	*O. keta*

Five species of Pacific salmon inhabit the cold waters of the Bering, Chukchi, and Beaufort Seas: Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), and chum salmon (*O. keta*) (see Table 4.7-1). Each species has unique life history characteristics, but they are all anadromous fishes that move from fresh water to salt water and back to freshwater habitats during their life cycle. Salmon rely on ocean production for their success and survival; and, when they return to their natal freshwater environments are precious food resources for Alaska communities. A sixth Pacific salmon species, the masu or cherry salmon *O. masou*, is native to the eastern coast of Asia and is primarily found in the Sea of Japan and the Sea of Okhotsk, but is not discussed within this atlas as it is not found within the project area (Machidori and Kato 1984).

The ability for a fish to move between fresh water and the marine environment is physiologically taxing. In order for juvenile salmon to make the transition from freshwater streams to the ocean, they must undergo "smoltification," which involves changes in their coloration, morphology, physiology, osmoregulation, and behavior (Stefansson et al. 2008). Once they make the journey back to fresh water as adults, the transition is so energetically expensive that they stop feeding and focus exclusively on returning to streams to spawn (Groot and Margolis 1991). In doing so, they begin to decompose from the inside out and quickly die after spawning (Groot and Margolis 1991, Hendry and Berg 1999). The life-history trait of spawning only once is known as "semelparity" and distinguishes Pacific salmon from Atlantic salmon (*Salmo salar*), which are "iteroparous," and can spawn multiple times within their lifetime (Marschall et al. 1998).

Not all salmon follow an oceangoing lifestyle. Some sockeye salmon never go to sea; these freshwater-only sockeye salmon are known as "kokanees" (Alaska Department of Fish and Game 1994, Mecklenburg et al. 2002). Another semelparous and anadromous fish in this Atlas is the eulachon (*Thaleichthys pacificus*) (see the Forage Fish Assemblages Summary).

SPECIES DESCRIPTION

Pink salmon are the smallest of the five Pacific salmon (Kingsbury 1994), with very small scales compared to the other Pacific salmon species. When spawning, pink salmon develop distinct black spots on their backs and caudal fins, and change color from silver to splotchy brown or green along their sides above their white-to-light colored bellies. They also develop a large hump on their backs, inspiring another common name, humpy salmon.

Chinook, or king salmon, are the largest of the Pacific salmon, and a record 126-pound (57-kg) fish was caught in 1949 (Delaney 2008). Spawning Chinook salmon change from a silver coloration as well, although they may turn a reddish hue or darken to a deep grey as the black spots on their backs and caudal fins become more pronounced (Delaney 2008).

Chum salmon are the second largest of the Pacific species, and at sea they can be mistaken for coho or sockeye salmon (Buklis 2017). As chum salmon reach fresh water, they change from silver to patches of green and purple, inspiring a less common nickname, calico salmon (Buklis 2017). Chum salmon also develop large teeth on a hooked snout, earning them another name, dog salmon.

Sockeye and coho salmon also change color as they reach fresh water. Sockeye salmon change to the iconic red body and green head coloration, while coho salmon display dark backs and red-maroon sides when they spawn (Alaska Department of Fish and Game 1994, Elliot 2007).

DISTRIBUTION

Five species of Pacific salmon can be found in the Gulf of Alaska and the eastern and northern Bering Sea, and chum, pink, and king salmon are increasingly utilizing the Chukchi Sea (Craig and Haldorson 1986, Mecklenburg et al. 2002, Moss et al. 2009b). Chum salmon are the most widely distributed of the five species (Craig and Haldorson 1986). Like chum salmon, Chinook salmon range widely from California to the Bering Sea, returning to the coasts of both North America and Asia (Healey 1991, Delaney 2008). The major Alaska populations are from the Yukon-Kuskokwim River Delta (Delaney 2008), with some juvenile Chinook salmon migrating toward Norton Sound before heading offshore (Farley et al. 2005). Sockeye salmon dominate the offshore areas of the southern Bering Sea and Bristol Bay, with juveniles rarely found north of the northern Bering Sea (Farley et al. 2005). Juvenile coho salmon are found nearshore, adjacent to the Kuskoskwim River Delta (Farley et al. 2005).

With a changing climate, ranges of Pacific salmon have expanded. Pink and sockeye salmon have been found east of their known ranges in the Canadian Arctic (Babaluk et al. 2000) and Chinook salmon have recently been observed in both the Chukchi and Beaufort Seas (Logerwell et al. 2015). Normally, pink salmon are the most common Pacific salmon found north of the Bering Strait, followed by chum salmon, although they are uncommon east of Prudhoe Bay (Craig and Haldorson 1986, Babaluk et al. 2000, Farley et al. 2005). The river systems north of the Brooks Range host several other anadromous fishes: Dolly Varden (*Salvelinus malma*), Arctic char (*S. alpinus*), and whitefish species from the subfamily Coregoninae (Craig and Haldorson 1986, Schoen and Senner 2002, Logerwell et al. 2015).

LIFE CYCLE

Specific details of the freshwater and saltwater life cycles of Pacific salmon are well described in Groot and Margolis (1991). In general, they spawn in fresh water, where the eggs are fertilized in sediment and gravel nests called redds. After the eggs hatch, the fish stay hidden in their gravel nursery and survive off of their yolk sacs as alevins. Once their yolk sac is depleted, they are considered fry and at this point, they begin hunting for their food. Pacific salmon fry spend different amounts of time in freshwater streams, but the transition from fry to silvery smolt happens before they head to sea (Stefansson et al. 2008). The timing of their migration from stream to sea can affect their survival, and is stimulated by many variables, including environmental conditions, photoperiods, their size, stream-flow rates, and the number of fishes around them (Scheuerell et al. 2009).

Each species of Pacific salmon spends different amounts of time in the marine environment (Table 4.7-1) but all use the time at sea to grow and mature to adulthood. Once they are reproductively mature, they return to their natal stream where they spawn and die. For example, all pink salmon have a two-year life cycle, leaving fresh water in the spring and returning from the ocean during the late summer the following year (Heard 1991). Because of the fixed two-year cycle, pink salmon spawned on even years are reproductively isolated from those spawned on odd years and are essentially separate populations (Gharrett and Smoker 1993).

MAP ON PAGES 104–105

TABLE 4.7-1. Average size and age of the five main Pacific salmon species and their life cycle characteristics.

	Chinook *Oncorhynchus tshawytscha*	Sockeye *O. nerka*	Coho *O. kisutch*	Pink *O. gorbuscha*	Chum *O. keta*
Length	63 in (160 cm) [A]	34 in (86 cm) [F]	27 in (68 cm) [G]	25 in (64 cm)[H]	43 in (109 cm)[A]
Weight	30 lbs (13.5 kg) [A]	8 lbs (4 kg) [F]	10 lbs (4.5 kg) [G]	4 lbs (2 kg)[H]	13 lbs (6 kg)[J]
Age (Years Freshwater, Years Salt water)	0–2, 1–5 [A, B, C]	1–3, 1–4 [A, F]	1–4, 2–3 A	0, 2 [I]	0, 2–6 [A, J, K]
Spawn Timing	May–July [B, D]	Summer [F]	July–Nov. [G]	June–Oct. H	May – July and Sept.–Nov. [K]
# Eggs	7,400–13,400 [E]	2,000–4,500 [F]	2,400–4,500 [G]	1,500–2,000 [H]	2,400–3,100 [J]

Sources: (A) Mecklenberg et al. 2002; (B) Delaney (2008); (C) Healey (1980); (D) Healey (1991); (E) Skaugstad and McCracken (1991); (F) Alaska Department of Fish and Game (1994); (G) Elliot (2007); (H) Kingsbury (1994); (I) Heard (1991); (J) Buklis (2017); (K) Salo (1991)

Typically, salmon return to their natal streams at similar times during each year; however, the timing varies depending on the species and location. For example, Chinook salmon have been observed returning to freshwater streams from May through October, but their typical run peaks in June for higher-latitude populations (Healey 1991). Salmon find the river where they hatched by remembering the scent of their natal stream, having learned the specific chemical cues of their nursery habitat as juveniles before heading to sea (Dittman and Quinn 1996). Pacific salmon can migrate long distances up rivers if they have adequate access to spawning areas farther upstream. For instance, a monitored Chinook salmon traveled 2,389 miles (3,845 km) upstream (Delaney 2008).

ECOLOGICAL ROLE

Juvenile salmon begin eating once they change from alevins to fry. In general, salmon fry initially feed on small prey items such as lake fly larvae and pupae (Family *Chironomidae*), and small crustaceans from the genera *Daphnia* and *Corophium*, before moving up to larger insects, opossum shrimp (*Neomysis* sp.), larval fish, and other salmon fry (Healey 1991). Once they head out to sea, salmon smolts feed on zooplankton, including energy-rich krill, copepods, larvaceans, larval fishes, and larval decapod crustaceans (Moss et al. 2009b). As they grow, pteropods, or sea butterflies, become an important part of the pink salmon diet, in some cases making up over 60% of their stomach contents (Armstrong et al. 2005). The abundance of nutrient-rich prey in the marine environment allows salmon to build up over 90% of their body weight before returning to fresh water to spawn (Quinn 2005).

ECONOMIC IMPACT

Salmon are a vitally important food source for northern communities. Subsistence fishing for salmon has occurred for thousands of years and is integral for cultural and nutritional sustenance in the Arctic. In Alaska, 95% of rural households utilize fish for subsistence with over 100 pounds (45 kg) of salmon consumed per person on average (Fall et al. 2014). Salmon are used for subsistence trade and bartering, and fish are consumed on a daily basis in many communities (Bacon et al. 2011, Thorsteinson and Love 2016). In 2012, over 60,000 households in Alaska harvested salmon for subsistence and personal use (Fall et al. 2014).

Pacific salmon support major commercial fisheries. Salmon account for nearly a quarter of the ex-vessel value (price received by the fisherman at point of landing) of Alaska fisheries, earning $413 million in 2015 (North Pacific Fishery Management Council 2016b). These salmon fisheries employ more people than any other fishery, about 38,400 jobs, equalling about $1.96 billion in annual labor income (McDowell Group 2015). The sockeye salmon fishery in Bristol Bay is the world's largest salmon fishery (McDowell Group 2015) and its success, in part, is due to their diverse life history (variable years spent in freshwater and marine environments), and the availability of pristine freshwater habitats (seven different major watersheds in the area (Hilborn et al. 2003)). In some rural communities, particularly in Western Alaska, summer salmon harvests are often the only available source of income.

CONSERVATION ISSUES

The number of Pacific salmon returning each year to freshwater spawning grounds is difficult to predict. Managing commercial, personal-use, and subsistence harvests while allowing enough salmon to reach their spawning grounds is a challenging task. Allowing the harvest of too many salmon in a year when returns are not as strong as predicted is a concern, because the year-class of salmon produced may be depressed when they return as adults some two to five years later. Therefore, tracking information about the number of salmon spawning, the conditions of the nursery and ocean environments, the populations of potential predators and prey, and the interactions with other fisheries is important for managers to maximize what people are allowed to take while maintaining a sustainable fishery. In short, fisheries science is important for salmon management.

Chinook salmon have been facing declines throughout Alaska. Management of their dwindling stocks and understanding the causes behind poor returns is a concern. For example, the Yukon River once hosted hundreds of thousands of returning Chinook salmon, but now is seeing less than half of that, with returns below 100,000 (Carroll et al. 2016). The cause of these declines is unknown, although declining size-at-age (actual versus expected growth rate), which reduces female fecundity, is a possible culprit, as well as new diseases and impacts from climate change (Kocan et al. 2004, Jasper and Evenson 2006, Ronson 2016). Bycatch of Chinook salmon in the Bering Sea pollock fishery is also a continuing management concern (North Pacific Fishery Management Council 2015a).

Climate change is negatively affecting salmon populations as the oceans become more acidified. Ocean acidification hurts pteropods, a primary prey item for pink salmon (see above in Ecological Role), as well as other prey items with calcareous body parts (Orr et al. 2005, Fabry et al. 2009, Kawaguchi et al. 2010, Long et al. 2013).

Hatcheries that produce salmon are supplementing salmon populations for commercial harvest in order to protect, and not replace, the wild spawning stock (Stopha 2015). Recently, hatchery salmon accounted for 35% of Alaskan salmon production (Stopha 2015), so they are an important part of the salmon fishery economy. However, there are management concerns tied with hatchery salmon, including overwhelming the carrying capacity of the ocean for salmon and competition between hatchery and wild spawned fish for their shared resources. Asian hatchery salmon in the eastern Bering Sea ecosystem also introduce competition for resources (Weber and Fausch 2005, Ruggerone et al. 2012, Tatara and Berejikian 2012).

Atlantic salmon that escaped from salmon farms in British Columbia have been recovered as far away as the Bering Sea and pose a potential threat to wild Alaskan salmon stocks (Brodeur and Busby 1998). Concerns include not only competition for prey at sea, but also nursery habitats in streams; because they are iteroparous, a pair of Atlantic salmon can produce more offspring than a pair of any Pacific salmon species (Brodeur and Busby 1998).

MAP ON PAGES 104–105

Pollution from mining and industrial practices upstream is a concern for healthy salmon nurseries. Mining effluent has been shown to reduce fertilization success and increase post-hatch mortality of salmon fry (Stekoll et al. 2009). Exposure to copper damages salmon olfactory system, making them unable to smell and avoid dangers, including other pollutants and predators, as well as impairing their ability to imprint on their natal stream (Hansen et al. 1999). Pink salmon embryos exposed to crude oil had delayed development and were more susceptible to shock-induced mortality (Carls and Thedinga 2010). Increased olfactory damage, developmental delays, and juvenile mortality are of particular concern for salmon embryos in nursery habitats affected by proposed Chuitna and Pebble Mines in Alaska's Central Region and for possible oil spills from offshore oil drilling or oil transport.

MAPPING METHODS (MAP 4.7)

Pacific salmon ocean distribution was created by combining data for all five Pacific salmon species from multiple sources in order to obtain coverage throughout our entire study area. Arctic distribution is a compilation of the ranges of all five species from Thorsteinson and Love (2016). Maps from Augerot and Foley (2005) and data from State of the Salmon (2004) filled in missing distribution information for Russian waters, and remaining distribution information for the Bering Sea, Aleutian Islands, and Gulf of Alaska were obtained from National Oceanic and Atmospheric Administration (2016b).

Coastal staging areas were created based on the Alaska Department of Fish and Game's Anadromous Waters Catalog (Alaska Department of Fish and Game 2016). To create the coastal areas, all anadromous waters for Chinook salmon, sockeye salmon, coho salmon, pink salmon, and chum salmon were selected. A 3-mile (5-km) buffer was then drawn around all anadromous waters and the land was erased, resulting in 3-mile (5-km) buffers around the mouths of all anadromous waters. This same approach was used in the Bering Strait Marine Life and Subsistence Use Data Synthesis (Oceana and Kawerak 2014).

Salmon-bearing watersheds were created with data from the Atlas of Pacific Salmon (Augerot and Foley 2005) and updated with data from the Anadromous Waters Catalog (Alaska Department of Fish and Game 2016). The Atlas of Pacific Salmon identified nearly 2,000 watersheds used by one or more of the five species of Pacific salmon, however, many salmon-bearing Arctic rivers were not represented. Using the updated Anadromous Waters Catalog (Alaska Department of Fish and Game 2016), we selected all watersheds that contained known anadromous streams and then combined the two datasets. This resulted in 2,009 salmon-bearing watersheds in Alaska and Russia.

Migration information was digitized directly from Figure 6 in Farley et al. (2005), depicting the seaward migration routes for juvenile Chinook, sockeye, coho, pink, and chum salmon along the eastern Bering Sea shelf from August through October 2002.

Concentration areas are based on NOAA's Environmental Sensitivity Index (ESI) maps (National Oceanic and Atmospheric Administration 2011), which summarize the most at-risk coastal resources to identify particularly valuable and vulnerable biological resources. Areas for all five Pacific salmon were combined together and categorized as either concentration areas or high-concentration areas.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details (pages 23–24).

Data Quality

Salmon are easier to observe during the spawning phase of their life cycle, so information about behavior and distribution in fresh water is therefore more abundant than information from their ocean phase. However, we were able to piece together enough information to get a broad sense of ocean patterns. Because salmon have run, location, and species-specific behaviors, the scale of this map does not lend itself to an in-depth analysis of those intricacies. Smaller, region-specific maps would be required to investigate those complexities. In terms of data gaps, we were unable to find a complementary dataset to the Alaska Anadromous Waters Catalog for Russia or much information about ocean behavior or distribution of salmon on the Russian side of the Pacific.

Reviewer

- Edward Farley

MAP DATA SOURCES

Distribution: Augerot and Foley (2005); National Oceanic and Atmospheric Administration (2016b); State of the Salmon (2004); Thorsteinson and Love (2016)

Staging Areas: Alaska Department of Fish and Game (2016)

Salmon-Bearing Watersheds: Alaska Department of Fish and Game (2016); Augerot and Foley (2005)

Migration: Farley et al. (2005)

Concentration Areas: National Oceanic and Atmospheric Administration (2011)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)

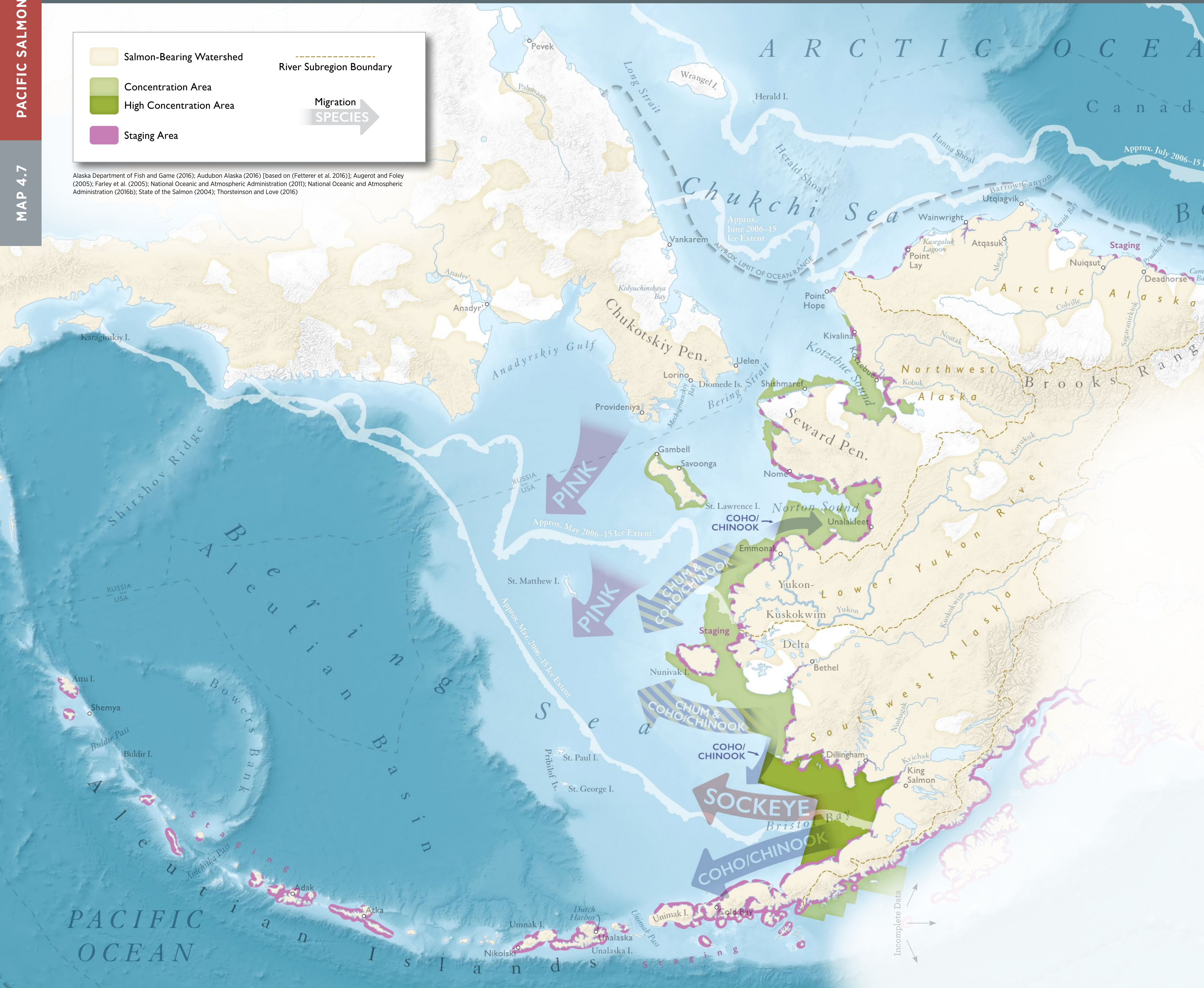
Pink salmon are also commonly known as "humpy" salmon due the the large hump they develop as they approach fresh water to spawn.

John Schoen

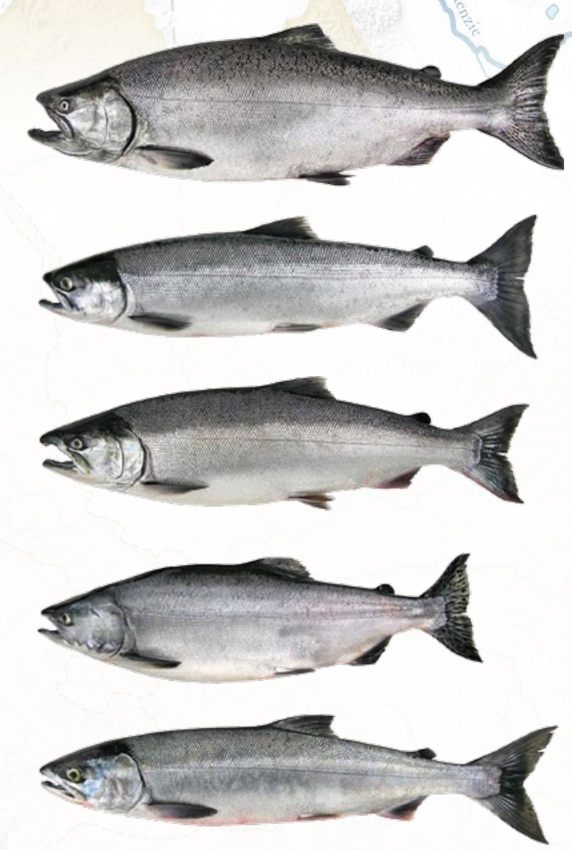
Pacific Salmon

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA



Alaska Department of Fish and Game (2016); Audubon Alaska (2016) [based on (Fetterer et al. 2016)]; Augerot and Foley (2005); Farley et al. (2005); National Oceanic and Atmospheric Administration (2011); National Oceanic and Atmospheric Administration (2016b); State of the Salmon (2004); Thorsteinson and Love (2016)



Chinook (King) Salmon
Oncorhynchus tshawytscha

Sockeye (Red) Salmon
O. nerka

Coho (Silver) Salmon
O. kisutch

Pink (Humpy) Salmon
O. gorbuscha

Chum (Dog) Salmon
O. keta

Alaska Department of Fish and Game

Pacific Salmon

Five species of Pacific salmon inhabit the cold waters of the Bering, Chukchi and Beaufort Seas: Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), and chum salmon (*O. keta*). Each species has unique life history characteristics but they are all anadromous fishes that move from fresh water to salt water and back to freshwater habitats during a normally completed life cycle. The arrows indicate general outmigration patterns of the Pacific salmon from their natal streams to their ocean habitats. The ocean range encompasses all five species of Pacific salmon, which can be found in the Gulf of Alaska and the eastern and northern Bering Sea, but chum and pink salmon are the only species regularly seen in the Arctic. Chum are the most widely distributed of the five species. Like chum salmon, Chinook range widely from California to the Bering Sea, returning to the coasts of both North America and Asia. The major Alaska populations are from the Yukon-Kuskokwim River Delta, with some juvenile Chinook migrating toward Norton Sound before heading offshore. Sockeye salmon dominate the offshore areas of the southern Bering Sea and Bristol Bay, with juveniles rarely found north of the northern Bering Sea. Juvenile cohos are found nearshore, adjacent to the Kuskoskwim River Delta.

REFERENCES

Ahlstrom, E. H., K. Amaoka, D. A. Hensley, H. G. Moser, and B. Y. Sumida. 1984. Pleuronectiformes: Development, *In Ontogeny and Systematics of Fishes: Based on an International Symposium Dedicated to the Memory of Elbert Halvor Ahlstrom*. pp. 640-670. American Society of Ichthyologists and Herpetologists, Lawrence, KS.

Alaska Department of Fish and Game. 1994. Sockeye Salmon. Alaska Department of Fish and Game, Juneau, AK.

______. 2016. Catalog of Waters Important for Spawning, Rearing or Migration of Anadromous Fishes. Alaska Department of Fish and Game, Juneau, AK.

Alaska Department of Fish and Game Habitat and Restoration Division. 2001. Oil Spill Contingency Planning: Most Environmentally Sensitive Areas (MESA) Along the Coast of Alaska, Volume I. Alaska Department of Fish and Game, Anchorage, AK.

Alaska Fisheries Science Center. 2016. AFSC/FMA: Web Map Observer Groundfish Data, Alaska, 1993-2015. Alaska Fisheries Science Center Fisheries Monitoring and Analysis Division, Seattle, WA. Accessed online at http://www.afsc.noaa.gov/FMA/spatial_data.htm.

Andrews, A. G., W. W. Strasburger, E. V. Farley, Jr, J. M. Murphy, and K. O. Coyle. 2016. Effects of warm and cold climate conditions on capelin (*Mallotus villosus*) and Pacific herring (*Clupea pallasii*) in the eastern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 134:235-246.

Anthony, J. A., D. D. Roby, and K. R. Turco. 2000. Lipid content and energy density of forage fishes from the northern Gulf of Alaska. *Journal of Experimental Marine Biology and Ecology* 248:53-78.

Antonelis, G. A., E. H. Sinclair, R. R. Ream, and B. W. Robson. 1997. Inter-island variation in the diet of female northern fur seals (*Callorhinus ursinus*) in the Bering Sea. *Journal of Zoology* 242:435-451.

Armstrong, J. L., J. L. Boldt, A. D. Cross, J. H. Moss, N. D. Davis, K. W. Myers, R. V. Walker, D. A. Beauchamp, and L. J. Haldorson. 2005. Distribution, size, and interannual, seasonal and diel food habits of northern Gulf of Alaska juvenile pink salmon, *Oncorhynchus gorbuscha*. *Deep Sea Research Part II: Topical Studies in Oceanography* 52:247-265.

Audubon Alaska. 2009. Saffron Cod GIS Feature Class. Audubon Alaska, Anchorage, AK.

______. 2016. Monthly Sea Ice Approximate 2006-2015 Medians GIS File. Audubon Alaska, Anchorage, AK.

Augerot, X. and D. N. Foley. 2005. *Atlas of Pacific Salmon: The First Map-Based Status Assessment of Salmon in the North Pacific*. University of California Press, Berkeley, CA.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A Comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands Large Marine Ecosystems Through Food Web Modeling. NOAA Technical Memorandum NMFS-AFSC-178. National Oceanic and Atmospheric Administration, Seattle, WA.

Babaluk, J. A., J. D. Reist, J. D. Johnson, and L. Johnson. 2000. First records of sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) from Banks Island and other records of Pacific salmon in Northwest Territories, Canada. *Arctic* 53:161-164.

Bacheler, N. M., L. Ciannelli, K. M. Bailey, and V. Bartolino. 2012. Do walleye pollock exhibit flexibility in where or when they spawn based on variability in water temperature? *Deep Sea Research Part II: Topical Studies in Oceanography* 65–70:208-216.

Bacon, J. J., T. R. Hepa, H. K. Brower, Jr., M. Pederson, T. P. Olemaun, J. C. George, and B. G. Corrigan. 2011. Estimates of Subsistence Harvest for Villages on the North Slope of Alaska, 1994-2003. North Slope Borough Department of Wildlife Management, Barrow, AK.

Bailey, K. M. 2011. An empty donut hole: The great collapse of a North American fishery. *Ecology and Society* 16:28.

Bailey, K. M., D. M. Powers, J. M. Quattro, G. Villa, A. Nishimura, J. J. Traynor, and G. Walters. 1999. Population ecology and structural dynamics of walleye pollock (*Theragra chalcogramma*), *In Dynamics of the Bering Sea*. T. R. Loughlin and K. Ohtani eds., pp. 581-614. Alaska Sea Grant AK-SG-99-03, Anchorage, AK.

Bakkala, R. G. 1993. Structure and Historical Changes in the Groundfish Complex of the Eastern Bering Sea. NOAA Technical Report NMFS 114. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA.

Barbeaux, S., J. Ianelli, and W. Paulson. 2016. Aleutian Islands walleye pollock SAFE, *In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions*. North Pacific Fishery Management Council, Anchorage, AK.

Beacham, T. D., D. E. Hay, and K. D. Le. 2005. Population structure and stock identification of eulachon (*Thaleichthys pacificus*), an anadromous smelt, in the Pacific Northwest. *Marine Biotechnology* 7:363-372.

Bell, F. H. and G. St-Pierre. 1970. The Pacific Halibut. Technical Report No. 6. International Pacific Halibut Commission, Seattle, WA.

Best, E. A. 1968. Studies of young halibut: Census of juveniles. *Western Fisheries* 75:38-41, 59-60.

______. 1977. Distribution and Abundance of Juvenile Halibut in the Southeastern Bering Sea. International Pacific Halibut Commission Scientific Report No. 62. International Pacific Halibut Commission, Seattle, WA.

______. 1981. Halibut ecology, *In The Bering Sea Shelf: Oceanography and Resources*. D. W. Hood and J. A. Calder eds., pp. 495-509. National Oceanic and Atmospheric Administration Office of Marine Pollution Assessment, University of Washington Press, Seattle, WA.

Best, E. A. and W. H. Hardman. 1982. Juvenile Halibut Surveys, 1973-1980. International Pacific Halibut Commission Technical Reports 20. International Pacific Halibut Commission, Seattle, WA.

Best, E. A. and G. St-Pierre. 1986. Pacific Halibut as Predator and Prey. International Pacific Halibut Commission Technical Report No. 21. International Pacific Halibut Commission, Seattle, WA.

Bluhm, B. A. and R. Gradinger. 2008. Regional variability in food availability for Arctic marine mammals. *Ecological Applications* 18:77–96.

Bogstad, B. and H. Gjøsæter. 2001. Predation by cod (*Gadus morhua*) on capelin (*Mallotus villosus*) in the Barents Sea: Implications for capelin stock assessment. *Fisheries Research* 53:197-209.

Bradstreet, M., K. Finley, A. Sekerak, W. B. Griffiths, C. Evans, M. Fabijan, and H. Stallard. 1986. Aspects of the Biology of Arctic cod (*Boreogadus saida*) in Arctic Marine Food Chains. Canadian Technical Report of Fisheries and Aquatic Sciences 1491. Department of Fisheries and Oceans, Winnipeg, Canada.

Bradstreet, M. S. W. and W. E. Cross. 1982. Trophic relationships at high Arctic ice edges. *Arctic* 35:1-12.

Brodeur, R. D. 1998. In situ observations of the association between juvenile fishes and scyphomedusae in the Bering Sea. *Marine Ecology Progress Series* 163:11-20.

Brodeur, R. D. and M. S. Busby. 1998. Occurrence of an Atlantic salmon *Salmo salar* in the Bering Sea. *Alaska Fishery Research Bulletin* 5:64-66.

Brodeur, R. D., M. T. Wilson, L. Ciannelli, M. Doyle, and J. M. Napp. 2002. Interannual and regional variability in distribution and ecology of juvenile pollock and their prey in frontal structures of the Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 49:6051-6067.

Brown, E. D. 2002. Life history, distribution, and size structure of Pacific capelin in Prince William Sound and the northern Gulf of Alaska. *ICES Journal of Marine Science* 59:983-996.

Buklis, L. S. 2017. Chum Salmon. Alaska Department of Fish and Game, Juneau, AK.

Carls, M. G. and J. F. Thedinga. 2010. Exposure of pink salmon embryos to dissolved polynuclear aromatic hydrocarbons delays development, prolonging vulnerability to mechanical damage. *Marine Environmental Research* 69:318-325.

Carlson, H. R. 1980. Seasonal distribution and environment of Pacific herring near Auke Bay, Lynn Canal, Southeastern Alaska. *Transactions of the American Fisheries Society* 109:71-78.

Carroll, H., J. Estensen, and F. Bue. 2016. 2016 Yukon River Salmon Fisheries Outlook. Alaska Department of Fish and Game and US Fish and Wildlife Service, Emmonak, AK.

Catul, V., M. Gauns, and P. K. Karuppasamy. 2011. A review on mesopelagic fishes belonging to family Myctophidae. *Reviews in Fish Biology and Fisheries* 21:339-354.

Cherel, Y., V. Ridoux, H. Weimerskirch, T. Tveraa, and O. Chastel. 2001. Capelin (*Mallotus villosus*) as an important food source for Northern Fulmars (*Fulmarus glacialis*) breeding at Bjørnøya (Bear Island), Barents Sea. *ICES Journal of Marine Science* 58:355-361.

Cianelli, L., N. M. Bacheler, and K. M. Bailey. 2012. Does Water Temperature Influence Pollock Spawning? Investigating "Boom" and "Bust" Years. BEST-BSIERP Bering Sea Project Summary Document. North Pacific Research Board and National Science Foundation.

Ciannelli, L., R. D. Brodeur, and J. M. Napp. 2004. Foraging impact on zooplankton by age-0 walleye pollock (*Theragra chalcogramma*) around a front in the southeast Bering Sea. *Marine Biology* 144:515-526.

Clark, W. G. and S. R. Hare. 2002. Effects of climate and stock size on recruitment and growth of Pacific halibut. *North American Journal of Fisheries Management* 22:852-862.

Clarke, A., A. Lewis, K. Telmer, and J. Shrimpton. 2007. Life history and age at maturity of an anadromous smelt, the eulachon *Thaleichthys pacificus* (Richardson). *Journal of Fish Biology* 71:1479-1493.

Conner, J. and R. R. Lauth. 2016. Results of the 2013 Eastern Bering Sea Continental Shelf Bottom Trawl Survey of Groundfish and Invertebrate Resources. NOAA Technical Memorandum NMFS-AFSC-331. National Oceanic and Atmospheric Administration, Seattle, WA.

Copeman, L. A., B. J. Laurel, K. M. Boswell, A. L. Sremba, K. Klinck, R. A. Heintz, J. J. Vollenweider, T. E. Helser, and M. L. Spencer. 2016. Ontogenetic and spatial variability in trophic biomarkers of juvenile saffron cod (*Eleginus gracilis*) from the Beaufort, Chukchi and Bering Seas. *Polar Biology* 39:1109-1126.

Coyle, K. O., L. B. Eisner, F. J. Mueter, A. I. Pinchuk, M. A. Janout, K. D. Cieciel, E. V. Farley, and A. G. Andrews. 2011. Climate change in the southeastern Bering Sea: Impacts on pollock stocks and implications for the oscillating control hypothesis. *Fisheries Oceanography* 20:139-156.

Coyle, K. O., J. A. Gillispie, R. L. Smith, and W. E. Barber. 1997. Food habits of four demersal Chukchi Sea fishes, *In Fish Ecology in Arctic North America Symposium*. J. B. Reynolds ed., pp. 310-318. American Fisheries Society Symposium 19, Bethesda, MD.

Coyle, K. O., A. I. Pinchuk, L. B. Eisner, and J. M. Napp. 2008. Zooplankton species composition, abundance and biomass on the eastern Bering Sea shelf during summer: The potential role of water-column stability and nutrients in structuring the zooplankton community. *Deep Sea Research Part II: Topical Studies in Oceanography* 55:1775-1791.

Craig, P. C., W. B. Griffiths, L. Haldorson, and H. McElderry. 1982. Ecological studies of Arctic cod (*Boreogadus-saida*) in Beaufort Sea coastal waters, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* 39:395-406.

Craig, P. C. and L. Haldorson. 1986. Pacific salmon in the North American Arctic. *Arctic* 39:2-7.

Criddle, K. R. 2004. Economic principles of sustainable multi-use fisheries management, with a case history economic model for Pacific halibut. *American Fisheries Society Symposium 43*:143-171.

Delaney, K. 2008. Chinook Salmon. Alaska Department of Fish and Game, Juneau, AK.

Dieter, B. E., D. A. Wion, and R. A. McConnaughey. 2003. Mobile Fishing Gear Effects on Benthic Habitats: A Bibliography (Second Edition). NOAA Technical Memorandum NMFS-AFSC-135. National Oceanic and Atmospheric Administration, Seattle, WA.

Dittman, A. and T. Quinn. 1996. Homing in Pacific salmon: Mechanisms and ecological basis. *The Journal of Experimental Biology* 199:83-91.

Divoky, G. J., P. M. Lukacs, and M. L. Druckenmiller. 2015. Effects of recent decreases in Arctic sea ice on an ice-associated marine bird. *Progress in Oceanography* 136:151-161.

Dyck, M. G. and S. Romberg. 2007. Observations of a wild polar bear (*Ursus maritimus*) successfully fishing Arctic charr (*Salvelinus alpinus*) and fourhorn sculpin (*Myoxocephalus quadricornis*). *Polar Biology* 30:1625-1628.

Elliot, S. 2007. Coho Salmon. Alaska Department of Fish and Game, Juneau, AK.

Fabry, V. J., J. B. McClintock, J. T. Mathis, and J. M. Grebmeier. 2009. Ocean acidification at high latitudes: The bellweather. *Oceanography* 22:160-171.

Fadeev, N. S. 1970. Fisheries and biological characteristics of the eastern Bering Sea yellowfin sole. *Proceedings of the All-Union Research Institute of Marine Fisheries and Oceanography (VNIRO)* 70:327-390.

Fall, J. A., L. B. Hutchinson-Scarbrough, B. Jones, M. A. Marchioni, J. T. Ream, T. Lemons, C. L. Brown, H. Ikuta, E. Mikow, S. Evans, and R. A. Grant. 2014. Alaska Subsistence and Personal Use Salmon Fisheries 2012 Annual Report. Alaska Department of Fish and Game, Division of Subsistence, Juneau, AK.

Farley, E. V., Jr, J. M. Murphey, B. W. Wing, J. H. Moss, and A. Middleton. 2005. Distribution, migration pathways, and size of Western Alaska juvenile salmon along the eastern Bering Sea shelf. *Alaska Fishery Research Bulletin* 11:15-26.

Fechhelm, R. G., P. C. Craig, J. S. Baker, and B. J. Gallaway. 1984. Fish Distribution and Use of Nearshore Waters in the Northeastern Chuckchi Sea. Outer Continental Shelf Environmental Assessment Program Final Report 32. National Oceanic and Atmospheric Administration, Anchorage, AK.

Fetterer, F., K. Knowles, W. Meier, and M. Savoie. 2016. Sea Ice Index, Version 2. National Snow and Ice Data Center, Boulder, CO.

Fissel, B. E., R. G. Felthoven, S. Kasperski, and C. O'Donnell. 2015. Decomposing productivity and efficiency changes in the Alaska head and gut factory trawl fleet. *Marine Policy* 62:337-346.

Food and Agriculture Organization. 1990. Gadiform fishes of the world (Order Gadiformes): An annotated and illustrated catalog of cods, hakes, grenadiers, and other gadiform fishes known to date. *FAO Fisheries Synopsis* 125.

Foy, R. J. and B. L. Norcross. 1998. Spatial and temporal differences in the diet of juvenile Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska, *In Exxon Valdez Oil Spill Restoration Project Annual Report: Juvenile Herring Growth and Habitats (Restoration Project 97320T)*. K. D. E. Stokesbury, E. D. Brown, R. J. Foy, J. Seitz, and B. L. Norcross eds. University of Alaska Fairbanks, Fairbanks, AK.

Fredin, R. A. 1985. Pacific Cod in the Eastern Bering Sea: A Synopsis. Northwest Alaska Fisheries Center Processed Report 85-05. Northwest Alaska Fisheries Center, Anchorage, AK.

Frost, K. J. and L. F. Lowry. 1984. Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea, *In The Alaskan Beaufort Sea Ecosystems and Environments*. P. W. Barnes, D. M. Schell, and E. Reimnitz eds. Academic Press, New York, NY.

Gharrett, A. and W. Smoker. 1993. Genetic components in life history traits contribute to population structure, *In Genetic Conservation of Salmonid Fishes.* J. G. Cloud and G. H. Thorgaard eds., pp. 197-202. Plenum Press, New York, NY.

Goddard, P., R. Lauth, and C. Armistead. 2014. Results of the 2012 Chukchi Sea Bottom Trawl Survey of Bottomfishes, Crabs, and Other Demersal Macrofauna. NOAA Technical Memorandum NMFS-AFSC-278. National Oceanic and Atmospheric Administration, Seattle, WA.

Gotshall, D. W. and T. Jow. 1965. Sleeper sharks (*Somniousus pacificus*) off Trinidad, California, with some life history notes. *California Fish and Game* 51:294-298.

Groot, C. and L. Margolis. 1991. *Pacific Salmon Life Histories*. University of British Columbia Press, Vancouver, Canada.

Gustafson, R. G. 2016. Status Review Update of Eulachon (*Thaleichthys pacificus*) Listed Under the Endangered Species Act: Southern Distinct Population Segment. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.

Haegele, C. W. and J. F. Schweigert. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. *Canadian Journal of Fisheries and Aquatic Sciences* 42:s39-s55.

Hamre, J. 2002. Capelin and Herring as Key Species for the Yield of Cod: Results from Multispecies Model Runs. Institute of Marine Research, Nordnes, Norway.

Hansen, J. A., J. D. Rose, R. A. Jenkins, K. G. Gerow, and H. L. Bergman. 1999. Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*) exposed to copper: Neurophysiological and histological effects on the olfactory system. *Environmental Toxicology and Chemistry* 18:1979-1991.

Harter, B. B., K. H. Elliott, G. J. Divoky, and G. K. Davoren. 2013. Arctic cod (*Boreogadus saida*) as prey: Fish length-energetics relationships in the Beaufort Sea and Hudson Bay. *Arctic* 66:191-196.

Hay, D. and P. McCarter. 2000. Status of the Eulachon *Thaleichthys pacificus* in Canada. Canadian Stock Assessment Secretariat, Ottawa, Canada.

Hay, D. E. 1985. Reproductive biology of Pacific herring (*Clupea harengus pallasi*). *Canadian Journal of Fisheries and Aquatic Sciences* 42:s111-s126.

Haynes, T. B., R. A. Ronconi, and A. E. Burger. 2007. Habitat use and behavior of the Pacific sand lance (*Ammodytes hexapterus*) in the shallow subtidal region of southwestern Vancouver Island. *Northwestern Naturalist* 88:155-167.

Healey, M. C. 1980. Utilization of the Nanaimo River Estuary by juvenile Chinook salmon, *Oncorhynchus tshawytscha*. *Fishery Bulletin* 77:653-668.

______. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*), *In Pacific salmon life histories*. C. Groot, and L. Margolis ed., pp. 313-393. University of British Columbia Press, Vancouver, Canada.

Heard, W. R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*), *In Pacific salmon life histories*. C. Groot and L. Margolis eds., pp. 119-230. University of British Columbia Press, Vancouver, Canada.

Hendry, A. P. and O. K. Berg. 1999. Secondary sexual characters, energy use, senescence, and the cost of reproduction in sockeye salmon. *Canadian Journal of Zoology* 77:1663-1675.

Hermann, A. J., W. C. Rugen, P. J. Stabeno, and N. A. Bond. 1996. Physical transport of young pollock larvae (*Theragra chalcogramma*) near Shelikof Strait as inferred from a hydrodynamic model. *Fisheries Oceanography* 5:58-70.

Hilborn, R., T. P. Quinn, D. E. Schindler, and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. *Proceedings of the National Academy of Sciences* 100:6564 - 6568.

Hinckley, S. 1987. The reproductive biology of walleye pollock, *Theragra chalcogramma*, in the Bering Sea, with reference to spawning stock structure. *Fishery Bulletin* 85:481-498.

Hobson, E. S. 1986. Predation on the Pacific sand lance, *Ammodytes hexapterus* (Pisces: Ammodytidae), during the transition between day and night in southeastern Alaska. *Copei* a1986:223-226.

Hoff, G. R. 2016. Results of the 2016 Eastern Bering Sea Upper Continental Slope Survey of Groundfish and Invertebrate Resources. NOAA Technical Memorandum NMFS-AFSC-339. National Oceanic and Atmospheric Administration, Seattle, WA.

Hollowed, A. B., S. J. Barbeaux, E. D. Cokelet, E. Farley, S. Kotwicki, P. H. Ressler, C. Spital, and C. D. Wilson. 2012. Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 65–70:230-250.

Holton, A. A. 1969. Feeding behavior of a vertically migrating lanternfish. *Pacific Science* 23:325-331.

Hop, H. and H. Gjøsæter. 2013. Polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) as key species in marine food webs of the Arctic and the Barents Sea. *Marine Biology Research* 9:878-894.

Hunt, G. L., Jr, K. O. Coyle, L. B. Eisner, E. V. Farley, R. A. Heintz, F. Mueter, J. M. Napp, J. E. Overland, P. H. Ressler, S. Salo, and P. J. Stabeno. 2011. Climate impacts on eastern Bering Sea foodwebs: A synthesis of new data and an assessment of the Oscillating Control Hypothesis. *ICES Journal of Marine Science* 68:1230-1243.

Hurst, T. P., D. W. Cooper, J. T. Duffy-Anderson, and E. V. Farley. 2015. Contrasting coastal and shelf nursery habitats of Pacific cod in the southeastern Bering Sea. *ICES Journal of Marine Science* 72:515-527.

Hurst, T. P., J. H. Moss, and J. A. Miller. 2012. Distributional patterns of 0-group Pacific cod (*Gadus macrocephalus*) in the eastern Bering Sea under variable recruitment and thermal conditions. *ICES Journal of Marine Science* 69:163-174.

Huse, G. and H. Gjøsæter. 1997. Fecundity of the Barents Sea capelin (*Mallotus villosus*). *Marine Biology* 130:309-313.

Ianelli, J. N., S. J. Barbeaux, and D. McKelvey. 2016. Assessment of walleye pollock in the Bogoslof Island region, *In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions for 2017*. pp. 301-310. North Pacific Fishery Management Council, Anchorage, AK.

International Pacific Halibut Commission. 2003. Halibut Length/Weight Chart (Imperial). International Pacific Halibut Commission, Seattle, WA.

Irigoien, X., T. A. Klevjer, A. Røstad, U. Martinez, G. Boyra, J. L. Acuña, A. Bode, F. Echevarria, J. I. Gonzalez-Gordillo, S. Hernandez-Leon, S. Agusti, D. L. Aksnes, C. M. Duarte, and S. Kaartvedt. 2014. Large mesopelagic fishes biomass and trophic efficiency in the open ocean. *Nature Communications* 5:3271.

Iverson, S. J., K. J. Frost, and S. Lang, L. C. 2002. Fat content and fatty acid composition of forage fish and invertebrates in Prince William Sound, Alaska: Factors contributing to among and within species variability. *Marine Ecology Progress Series* 241:161-181.

Jarvela, L. E. and L. K. Thorsteinson. 1999. The epipelagic fish community of Beaufort Sea coastal waters, Alaska. *Arctic* 52:80-94.

Jasper, J. R. and E. F. Evenson. 2006. Length-Girth, Length-Weight, and Fecundity of Yukon River Chinook Salmon *Oncorhynchus tshawytscha*. Fishery Data Series No. 06-70. Alaska Department of Fish and Game, Anchorage, AK.

John, K. B. F. and M. E. Graeme. 2006. Selective foraging by fish-eating killer whales *Orcinus orca* in British Columbia. *Marine Ecology Progress Series* 316:185-199.

Johnson, S. W., A. D. Neff, and M. R. Lindeberg. 2015. A Handy Field Guide to the Nearshore Marine Fishes of Alaska. NOAA Technical Memorandum NMFS-AFSC-293. National Oceanic and Atmospheric Administration, Seattle, WA.

Kawaguchi, S., H. Kurihara, R. King, L. Hale, T. Berli, J. P. Robinson, A. Ishida, M. Wakita, P. Virtue, S. Nicol, and A. Ishimatsu. 2010. Will krill fare well under Southern Ocean acidification? *Biology Letters* 7:228-291.

Kendall, A. W. and J. R. Dunn. 1985. Ichthyoplankton of the Continental Shelf Near Kodiak Island, Alaska. NOAA Technical Report NMFS 20. National Oceanic and Atmospheric Administration, Seattle, WA.

Kenyon, K. W. 1965. Food of harbour seals at Amchitka Island, Alaska. *Journal of Mammalogy* 46:103-104.

Kimura, D. K., D. M. Anderl, and B. J. Goetz. 2007. Seasonal marginal growth on otoliths of seven Alaska groundfish species support the existence of annual patterns. *Alaska Fishery Research Bulletin* 12:243-251.

Kingsbury, A. 1994. Pink Salmon. Alaska Department of Fish and Game, Juneau, AK.

Kocan, R., P. Hershberger, and J. Winton. 2004. Ichthyophoniasis: An emerging disease of Chinook salmon in the Yukon River. *Journal of Aquatic Animal Health* 16:58-72.

Kotwicki, S., T. W. Buckley, T. Honkalehto, and G. Walters. 2005. Variation in the distribution of walleye pollock (*Theragra chalcogramma*) with temperature and implications for seasonal migration. *Fishery Bulletin* 103:574-587.

Laevastu, T. and F. Favorite. 1988. *Fishing and Stock Fluctuation*. Fishing Books Ltd, Farnham, United Kingdom.

Lang, G. M., P. A. Livingston, and B. S. Miller. 1995. Food Habits of Three Congeneric Flatfishes: Yellowfin Sole (*Pleuronectes asper*), Rock Sole (*P. bilineatus*), and Alaska Plaice (*P. quadrituberculatus*) in the Eastern Bering Sea, *In Proceedings of the International Symposium on North Pacific Flatfish*. pp. 225-245. Alaska Sea Grant College Program AK-SG-95-04, Anchorage, AK.

Lassuy, D. R. and D. Moran. 1989. Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest): Pacific Herring. Oregon State University, Corvallis, OR.

Laurel, B. J., M. Spencer, P. Iseri, and L. A. Copeman. 2016. Temperature-dependent growth and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids. *Polar Biology* 39:1127-1135.

Laurel, B. J., A. W. Stoner, C. H. Ryer, T. P. Hurst, and A. A. Abookire. 2007. Comparative habitat associations in juvenile Pacific cod and other gadids using seines, baited cameras and laboratory techniques. *Journal of Experimental Marine Biology and Ecology* 351:42-55.

Lauth, R. R. and D. M. Blood. 2007. Description of embryonic development of Atka mackerel (*Pleurogrammus monpterygius*). *Fishery Bulletin* 105:571-576.

Lauth, R. R., J. Guthridge, D. Nichol, S. W. Mcentire, and N. Hillgruber. 2007a. Timing and duration of mating and brooding periods of Atka mackerel (*Pleurogrammus monopterygius*) in the North Pacific Ocean. *Fishery Bulletin* 105:560-570.

Lauth, R. R., J. L. Guthridge, D. W. Cooper, and S. W. McEntire. 2010. Behavioral ecology of color patterns in Atka mackerel. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*:399-411.

Lauth, R. R., S. W. McEntire, and H. H. Zenger, Jr. 2007b. Geographic distribution, depth range, and description of Atka mackerel *Pleurogrammus monopterygius* nesting habitat in Alaska. *Alaska Fishery Research Bulletin* 12:165-186.

Lee, S. I., K. Y. Aydin, P. D. Spencer, T. K. Wilderbuer, and C. I. Zhang. 2010. The role of flatfishes in the organization and structure of the eastern Bering Sea ecosystem. *Fisheries Science* 76:411-434.

Livingston, P. A. 1989. Interannual trends in Pacific cod, *Gadus marcocephalus*, predation on three commercially important crab species in the eastern Bering Sea. *Fisheries Bulletin* 87:807-827.

______. 1991. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1984–1986. NOAA Technical Memorandum, National Marine Fisheries Service, F/NWC-207. National Oceanic and Atmospheric Administration, Seattle, WA.

______. 1993. Importance of predation by groundfish, marine mammals and birds on walleye pollock *Theragra chalcogramma* and Pacific herring *Clupea pallasi* in the eastern Bering Sea. *Marine Ecology Progress Series* 102:205-215.

Livingston, P. A., A. Ward, G. M. Lang, and M.-S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. NOAA Technical Memorandum NMFS-AFSC-11. National Oceanic and Atmospheric Administration, Seattle, WA.

Logerwell, E., M. Busby, C. Carothers, S. Cotton, J. Duffy-Anderson, E. Farley, P. Goddard, R. Heintz, B. Holladay, J. Horne, S. Johnson, B. Lauth, L. Moulton, D. Neff, B. Norcross, S. Parker-Stetter, J. Seigle, and T. Sformo. 2015. Fish communities across a spectrum of habitats in the western Beaufort Sea and Chukchi Sea. *Progress in Oceanography* 136:115-132.

Logerwell, E., K. Rand, S. Parker-Stetter, J. Horne, T. Weingartner, and B. Bluhm. 2010. Beaufort Sea Marine Fish Monitoring 2008: Pilot Survey and Test of Hypotheses. BOEMRE 2010-048. Minerals Management Service, Anchorage, AK.

Logerwell, E. A. and L. E. Schaufler. 2005. New data on proximate composition and energy density of Steller sea lion (*Eumetopias jubatus*) prey fills seasonal and geographic gaps in existing information. *Aquatic Mammals* 31:62-82.

Logerwell, L. 2008. Cruise Report for the 2008 Beaufort Sea Survey. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA.

Loher, T. 2008. Homing and summer feeding site fidelity of Pacific halibut (*Hippoglossus stenolepis*) in the Gulf of Alaska, established using satellite-transmitting archival tags. *Fisheries Research* 92:63-69.

______. 2011. Analysis of match–mismatch between commercial fishing periods and spawning ecology of Pacific halibut (*Hippoglossus stenolepis*), based on winter surveys and behavioural data from electronic archival tags. *ICES Journal of Marine Science* 68:2240-2251.

Loher, T. and A. Seitz. 2006. Seasonal migration and environmental conditions of Pacific halibut *Hippoglossus stenolepis*, elucidated from pop-up archival transmitting (PAT) tags. *Marine Ecology Progress Series* 317:259-271.

Long, W. C., K. M. Swiney, C. Harris, H. N. Page, and R. J. Foy. 2013. Effects of ocean acidification on juvenile red king crab (*Paralithodes camtschaticus*) and tanner crab (*Chionoecetes bairdi*) growth, condition, calcification, and survival. *PLoS ONE* 8:e60959.

Lowe, S. A. 2015. Assessment of the Atka mackerel stock in the Gulf of Alaska, *In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska*. The Plan Team for the Groundfish Fisheries of the Gulf of Alaska ed., pp. 1465-1496. North Pacific Fishery Management Council, Anchorage, AK.

Lowry, L. F. and J. J. Burns. 1980. Foods utilized by bowhead whales near Barter Island, Alaska, Autumn 1979. *Marine Fisheries Review* 42:88-91.

Lowry, L. F., K. J. Frost, and J. J. Burns. 1980. Feeding of bearded seals in the Bering and Chukchi Seas and trophic interaction with Pacific walruses. *Arctic* 33:330-342.

Machidori, S. and F. Kato. 1984. Spawning populations and marine life of masu salmon *(Oncorhynchus masou)*. *International North Pacific Fisheries Comission Bulletin* 43:1-138.

Magdanz, J. S., N. S. Braem, B. C. Robbins, and D. S. Koster. 2010. . 2010. Subsistence Harvests in Northwest Alaska, Kivalina and Noatak, 2007. Technical Paper No. 354. Alaska Department of Fish and Game, Division of Subsistence, Kotzebue, AK.

Malecha, P. W., R. P. Stone, and J. Heifetz. 2005. Living substrate in Alaska: Distribution, abundance, and species associations, *In Benthic Habitats and the Effects of Fishing*. P. W. Barnes and J. P. Thomas eds., pp. 289-299. American Fisheries Society Symposium 41, Bethesda, MD.

Marschall, E. A., T. P. Quinn, D. A. Roff, J. A. Hutchings, N. B. Metcalfe, T. A. Bakke, R. L. Saunders, and N. L. Poff. 1998. A framework for understanding Atlantic salmon (*Salmo salar*) life history. *Canadian Journal of Fisheries and Aquatic Sciences* 55:48-58.

McConnaughey, R. A. and K. R. Smith. 2000. Associations between flatfish abundance and surficial sediments in the eastern Bering Sea. *Canadian Journal of Fisheries and Aquatic Sciences* 57:2410-2419.

McDermott, S. F., D. W. Cooper, J. L. Guthridge, I. B. Spies, M. F. Canino, P. Woods, and N. Hillgruber. 2011. Effects of maternal growth on fecundity and egg quality of wild and captive Atka mackerel. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 3:324-335.

McDowell Group. 2015. The Economic Value of Alaska's Seafood Industry. Alaska Seafood Marketing Institute and McDowell Group, Juneau, AK.

Mecklenburg, C. W., T. A. Mecklenburg, and L. K. Thorsteinson. 2002. *Fishes of Alaska*. American Fisheries Society, Bethesda, MD.

Mecklenburg, C. W., B. L. Norcross, B. A. Holladay, and T. A. Mecklenburg. 2008. Fishes, *In Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research*. R. Hopcroft, B. Bluhm, and R. Gradinger eds. Institute of Marine Sciences, University of Alaska Fairbanks, Fairbanks, AK.

Menard, J., J. Soong, S. Kent, L. Harlan, and J. Leon. 2015. 2014 Annual Management Report Norton Sound–Port Clarence Area and Arctic–Kotzebue. Fishery Management Report No. 15-39. Alaska Department of Fish and Game, Anchorage, AK.

Merrick, R. L., M. K. Chumbley, and G. V. Byrd. 1997. Diet diversity of Steller sea lions (*Eumetopias jubatus*) and their population decline in Alaska: A potential relationship. *Canadian Journal of Fisheries and Aquatic Sciences* 54:1342-1348.

Merrick, R. L. and T. R. Loughlin. 1997. Foraging behavior of adult female and young-of-the-year Steller sea lions in Alaskan waters. *Canadian Journal of Zoology* 75:776-786.

Moser, H. G. and E. H. Ahlstrom. 1972. Development of the lanternfish, *Scopelopsis multipunctatus* Brauer 1906, with a discussion of its phylogenetic position in the family Myctophidae and its role in a proposed mechanism for the evolution of photophore patterns in lanternfishes. *Fishery Bulletin* 70:541-564.

Moss, J. H., E. V. Farley, Jr, A. M. Feldmann, and J. N. Ianelli. 2009a. Spatial distribution, energetic status, and food habits of eastern Bering Sea age-0 walleye pollock. *Transactions of the American Fisheries Society* 138:497-505.

Moss, J. H., J. M. Murphy, E. V. Farley, Jr, L. B. Eisner, and A. G. Andrews. 2009b. Juvenile pink and chum salmon distribution, diet, and growth in the northern Bering and Chukchi Seas. *North Pacific Anadromous Fish Commission Bulletin* 5:191-196.

Moss, J. H., M. F. Zaleski, and R. A. Heintz. 2016. Distribution, diet, and energetic condition of age-0 walleye pollock (*Gadus chalcogrammus*) and Pacific cod (*Gadus macrocephalus*) inhabiting the Gulf of Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 132:146-153.

Moukhametov, I. N., A. M. Orlov, and B. M. Leaman. 2008. Diet of Pacific Halibut (*Hippoglossus stenolepis*) in the Northwestern Pacific Ocean. Technical Report No. 52. International Pacific Halibut Commission, Seattle, WA.

Moulton, L. L. and K. E. Tarbox. 1987. Analysis of Arctic cod movements in the Beaufort Sea nearshore region, 1978-79. *Arctic* 40:43-49.

Munk, K. M. 2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and considerations of age determination. *Alaska Fishery Research Bulletin* 8:12-21.

National Marine Fisheries Service. 1995. Status Review of the United States Steller Sea Lion (*Eumetopias jubatus*) Population. National Marine Mammal Laboratory, Alaska Fishery Science Center, National Marine Fisheries Service, Seattle, WA.

______. 2005. Final Environmental Impact Statement for Essential Fish Habitat Identification and Conservation in Alaska. National Marine Fisheries Service, Alaska Region, Anchorage, AK.

______. 2010. Authorization of the Bering Sea and Aleutian Islands and Gulf of Alaska Groundfish Fisheries, Section 7 Consultation - Final Biological Opinion, November, 2010.

National Oceanic and Atmospheric Administration. 1988. Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones: Strategic Assessment Data Atlas. National Oceanic and Atmospheric Administration, Rockville, MD.

______. 2011. Environmental Sensitivity Index including GIS Data and Maps (for the US Shorelines, including Alaska, Hawaii, and Puerto Rico). NOAA Office of Response and Restoration, Seattle, WA. Accessed online at http://response.restoration.noaa.gov/maps-and-spatial-data/download-esi-maps-and-gis-data.html.

______. 2016a. AFSC/RACE: Alaska Groundfish Survey 1982-2015 for web. Alaska Fisheries Science Center Groundfish Assessment Program, Seattle, WA. Accessed online at http://www.afsc.noaa.gov/RACE/groundfish/survey_data/.

______. 2016b. Essential Fish Habitat (EFH) Mapper. GIS Shapefiles. National Oceanic and Atmospheric Administration, Seattle, WA. Accessed online at http://www.habitat.noaa.gov/protection/efh/efhmapper/index.html.

Neidetcher, S. K., T. P. Hurst, L. Ciannelli, and E. A. Logerwell. 2014. Spawning phenology and geography of Aleutian Islands and eastern Bering Sea Pacific cod (*Gadus macrocephalus*). *Deep Sea Research Part II: Topical Studies in Oceanography* 109:204-214.

Nemoto, T. 1957. Foods of baleen whales in the northern Pacific. *Scientific Reports of the Whales Research Institute (Tokyo)* 12:33-89.

Nichol, D. G. and E. I. Acuna. 2001. Annual and batch fecundities of yellowfin sole, *Limanda aspera*, in the eastern Bering Sea. *Fishery Bulletin* 99:108-122.

Nichol, D. G. and D. A. Somerton. 2002. Diurnal vertical migration of the Atka mackerel *Pleurogrammus monopterygius* as shown by archival tags. *Marine Ecology Progress Series* 239:193-207.

Nilssen, K. T., O. P. Pedersen, L. P. Folkow, and T. Haug. 2000. Food consumption estimates of Barents Sea harp seals. *NAMMCO Scientific Publication* 2:9-27.

Norcross, B., B. Holladay, S. Dressel, and M. Frandsen. 1996. Recruitment of Juvenile Flatfishes in Alaska: Habitat Preferences near Kodiak Island, Volume 1: Final Study Report. OCS Study MMS 96-003. University of Alaska, Coastal Marine Institution, Fairbanks, AK.

Norcross, B. L., B. A. Holladay, and F. J. Müter. 1995. Nursery area characteristics of pleuronectids in coastal Alaska, USA. *Netherlands Journal of Sea Research* 34:161-175.

North Pacific Fishery Management Council. 2009. Fishery Management Plan for Fish Resources of the Arctic Management Area. North Pacific Fishery Management Council, Anchorage, AK.

______. 2014. Stock Assessment and Fishery Evaluation Report for the Groundfish Fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands Area: Economic Status of the Groundfish Fisheries Off Alaska, 2013. North Pacific Fishery Management Council, Anchorage, AK.

______. 2015a. Stock Assessment and Fishery Evaluation Report for the Groundfish Fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands Area: Economic Status of the Groundfish Fisheries Off Alaska, 2014. North Pacific Fishery Management Council, Anchorage, AK.

______. 2015b. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage, AK.

______. 2016a. Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Islands Management Area. North Pacific Fishery Management Council, Anchorage, AK.

______. 2016b. Stock Assessment and Fishery Evaluation Report for the Groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands Area: Economic Status of the Groundfish Fisheries Off Alaska, 2015. North Pacific Fishery Management Council, Anchorage, AK.

Oceana. 2011. A History of Hooligan: An Iconic and Threatened Fish. Oceana. Accessed online at http://usa.oceana.org/blog/history-hooligan-iconic-and-threatened-fish.

______. 2017a. Cod Distribution GIS Files. Oceana, Juneau, AK.

______. 2017b. Relative Abundance of Atka Mackerel GIS File. Oceana, Juneau, AK.

______. 2017c. Relative Abundance of Osmerids GIS File. Oceana, Juneau, AK.

______. 2017d. Relative Abundance of Pacific Halibut GIS File. Oceana, Juneau, AK.

______. 2017e. Relative Abundance of Walleye Pollock GIS File. Oceana, Juneau, AK.

______. 2017f. Relative Abundance of Yellowfin Sole GIS File. Oceana, Juneau, AK.

Oceana and Kawerak. 2014. Appendix: Oceana's quantitative procedure for identifying important ecological areas at higher levels of ecological complexity, *In Marine Life and Subsistence Use Data Synthesis*. Oceana and Kawerak eds., pp. 317-325, Juneau, AK.

Ogi, H. 1980. The pelagic feeding ecology of Thick-billed Murres in the North Pacific, March–June. *Bulletin of the Faculty of Fisheries Hokkaido University* 31:50-72.

Orchard, T. J. 2001. The Role of Selected Fish Species in Aleut Paleodiet. PhD thesis, University of Victoria.

Ormseth, O. A. 2015. Appendix: Status of forage species in the Bering Sea and Aleutian Islands region, *In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions*. The Plan Team for the Groundfish Fisheries of the Bering Sea and Aleutian Islands ed., pp. 1225-1270. North Pacific Fishery Management Council, Anchorage, AK.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, and F. Joos. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437:681-686.

Pahlke, K. A. 1985. Preliminary Studies of Capelin (*Mallotus villosus*) in Alaskan Waters. Informational Leaflet 250. Alaska Department of Fish and Game, Juneau, AK.

Paul, A. J., J. M. Paul, and R. L. Smith. 1993. The seasonal changes in somatic energy content of Gulf of Alaska yellowfin sole, *Pleuronectes asper*. *Journal of Fish Biology* 43:131-138.

Perez, M. A. and W. B. McAlister. 1993. Estimates of Food Consumption by Marine Mammals in the Eastern Bering Sea. NOAA Technical Memorandum NMFS-AFSC-14. National Oceanic and Atmospheric Administration, Seattle, WA.

Pinto, J. M., W. H. Pearson, and J. W. Anderson. 1984. Sediment preferences and oil contamination in the Pacific sand lance *Ammodytes hexapterus*. *Marine Biology* 83:193-204.

Quakenbush, L. T. 1988. Spotted seal, *Phoca largha*, *In Selected Marine Mammals of Alaska: Species Accounts with Research and Management Recommendations*. J. Lentfer ed. Marine Mammal Commission, Washington, DC.

Quinn, T. P. 2005. *The Behavior and Ecology of Pacific Salmon and Trout*. University of Washington Press, Seattle, WA.

Rand, K. M., D. A. Beauchamp, and S. A. Lowe. 2010. Longitudinal growth differences and the influence of diet quality on Atka mackerel of the Aleutian Islands, Alaska: Using a bioenergetics model to explore underlying mechanisms. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 2:362-374.

Rand, K. M. and S. A. Lowe. 2011. Defining essential fish habitat for Atka mackerel with respect to feeding within and adjacent to Aleutian Islands trawl exclusion zones. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 3:21-31.

Rand, K. M., P. Munro, S. K. Neidetcher, and D. G. Nichol. 2014. Observations of seasonal movement from a single tag release group of Pacific cod in the eastern Bering Sea. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 6:287-296.

Raring, N. W., E. A. Laman, P. G. von Szalay, C. N. Rooper, and M. H. Martin. 2016. Data Report: 2012 Aleutian Islands Bottom Trawl Survey. NOAA Technical Memorandum NMFS-AFSC-332. National Oceanic and Atmospheric Administration, Seattle, WA.

Robards, M. D., M. F. Willson, R. H. Armstrong, and J. F. Piatt. 1999. *Sand Lance: A Review of Biology and Predator Relations and Annotated Bibliography*. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Ronson, J. 2016. Conservation in the Age of Climate Change: The Case of the Disappearing Salmon. *Pacific Standard*, April 21.

Rooper, C. N., M. E. Wilkins, C. S. Rose, and C. Coon. 2011. Modeling the impacts of bottom trawling and the subsequent recovery rates of sponges and corals in the Aleutian Islands, Alaska. *Continental Shelf Research* 31:1827-1834.

Rose, G. A. 2005. Capelin (*Mallotus villosus*) distribution and climate: A sea "canary" for marine ecosystem change. *ICES Journal of Marine Science* 62:1524-1530.

Rugen, R. C. and A. C. Matarese. 1988. Spatial and Temporal Distribution and Relative Abundance of Pacific Cod (*Gadus macrocephalus*) Larvae in the Western Gulf of Alaska. Northwest and Alaska Fisheries Center Processed Report 88-18. National Marine Fisheries Service, Seattle, WA.

Ruggerone, G. T., B. A. Agler, and J. L. Nielsen. 2012. Evidence for competition at sea between Norton Sound chum salmon and Asian hatchery chum salmon. *Environmental Biology of Fishes* 94:149-163.

Russell, C. W. 2016. Alaska Peninsula - Aleutian Islands Management Area Food and Bait Herring Fishery Management Plans, 2016. Fishery Management Report No. 16-21. Alaska Department of Fish and Game, Anchorage, AK.

Sadorus, L. L. and W. A. Palsson. 2014. Results from the Gulf of Alaska NOAA Fisheries Service Bottom Trawl Survey in 2013. Report of Assessment and Research Activities. International Pacific Halibut Commission, Seattle, WA.

Saint-Laurent, R., M. Legault, and L. Bernatchez. 2003. Divergent selection maintains adaptive differentiation despite high gene flow between sympatric rainbow smelt ecotypes (*Osmerus mordax* Mitchill). *Molecular Ecology* 12:315-330.

Sakshaug, E., A. Bjørge, B. Gulliksen, H. Loeng, and F. Mehlum. 1994. Structure, biomass distribution, and energetics of the pelagic ecosystem in the Barents Sea: A synopsis. *Polar Biology* 14:405-411.

Sakurai, Y. 1988. Reproductive characteristics of walleye pollock with special reference to ovarian development, fecundity and spawning behavior. *In* Proceedings of the International Symposium on the Biology and Management of Walleye Pollock. Anchorage, AK.

Salo, E. O. 1991. Life history of chum salmon (*Oncorhynchus keta*), *In Pacific Salmon Life Histories*. C. Groot and L. Margolis eds. University of British Columbia Press, Vancouver, Canada.

Scheuerell, M. D., R. W. Zabel, and B. P. Sandford. 2009. Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon (*Oncorhynchus spp.*). *Journal of Applied Ecology* 46:983-990.

Schmutz, J. A. and K. A. Hobson. 1998. Geographic, temporal, and age-specific variation in diets of Glaucous Gulls in western Alaska. *Condor* 100:119-130.

Schoen, J. W. and S. E. Senner. 2002. Alaska's Western Arctic: A Summary and Synthesis of Resources. Audubon Alaska, Anchorage, AK.

Seitz, A. C., T. Loher, and J. L. Nielsen. 2007. Seasonal Movements and Environmental Conditions Experienced by Pacific Halibut in the Bering Sea, Examined by Pop-up Satellite Tags. Scientific Report No. 84. International Pacific Halibut Commission, Seattle, WA.

Seitz, A. C., T. Loher, B. L. Norcross, and J. L. Nielsen. 2011. Dispersal and behavior of Pacific halibut *Hippoglossus stenolepis* in the Bering Sea and Aleutian Islands region. *Aquatic Biology* 12:225-239.

Siddon, E. C., T. Kristiansen, F. J. Mueter, K. K. Holsman, R. A. Heintz, and E. V. Farley. 2014. Spatial match-mismatch between juvenile fish and prey provides a mechanism for recruitment variability across contrasting climate conditions in the eastern Bering Sea. *PLoS ONE* 8:e84526.

Sigler, M. F., F. J. Mueter, B. A. Bluhm, M. S. Busby, E. D. Cokelet, S. L. Danielson, A. De Robertis, L. B. Eisner, E. V. Farley, K. Iken, K. J. Kuletz, R. R. Lauth, E. A. Logerwell, and A. I. Pinchuk. 2016. Late Summer Open Water Zoogeography of the Northern Bering and Chukchi Seas. OCS Study BOEM 2011-AK-11-08 a/b. Bureau of Ocean Energy Management, Alaska OCS Region.

Sigler, M. F., D. J. Tollit, J. J. Vollenweider, J. F. Thedinga, D. J. Csepp, J. N. Womble, M. A. Wong, M. J. Rehberg, and A. W. Trites. 2009. Steller sea lion foraging response to seasonal changes in prey availability. *Marine Ecology Progress Series* 388:243-261.

Sill, L. 2015. Gathering Herring Eggs Subsistence Harvest a Sign of Spring. Alaska Fish and Wildlife News, Juneau, AK.

Simenstad, C. A., J. A. Estes, and K. W. Kenyon. 1978. Aleuts, sea otters, and alternate stable-state communities. *Science* 200:403-411.

Sinclair, E. H. and T. K. Zeppelin. 2002. Seasonal and spatial differences in diet in the Western stock of Steller sea lions (*Eumetopias jubatus*). *Journal of Mammalogy* 83:973-990.

Skaugstad, C. and B. McCracken. 1991. Fecundity of Chinook Salmon, Tanana River, Alaska. Fishery Data Series No. 91-8. Alaska Department of Fish and Game, Juneau, AK.

Skud, B. E. 1977. Drift, Migration, and Intermingling of Pacific Halibut Stocks. Scientific Report No. 63. International Pacific Halibut Commission, Seattle, WA.

Smith, M. A. 2010. *Arctic Marine Synthesis: Atlas of the Chukchi and Beaufort Seas*. Audubon Alaska and Oceana, Anchorage, AK.

Sohn, D. 2016. Distribution, Abundance, and Settlement of Slope-Spawning Flatfish During Early Life Stages in the Eastern Bering Sea. PhD thesis, Oregon State University, Corvallis, OR.

Springer, A. M., J. F. Piatt, and G. B. Van Vliet. 1996. Sea birds as proxies of marine habitats and food webs in the western Aleutian Arc. *Fisheries Oceanography* 5:45-55.

Springer, A. M. and S. G. Speckman. 1997. A forage fish is what? Summary of the symposium, *In Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems*. pp. 773-805. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks, Fairbanks, AK.

St-Pierre, G. 1984. Spawning Locations and Season for Pacific Halibut. Scientific Report No. 70. International Pacific Halibut Commission, Seattle, WA.

______. 1989. Recent Studies of Pacific Halibut Postlarvae in the Gulf of Alaska and Eastern Bering Sea. Scientific Report No. 73. International Pacific Halibut Commission, Seattle, WA.

State of the Salmon. 2004. State of the Salmon Database. GIS Shapefiles. Accessed online at http://www.stateofthesalmon.org/resources/sosdb.php.

Stefansson, S. O., B. T. Björnsson, L. O. E. Ebbesson, and S. D. McCormick. 2008. Smoltification, *In Fish Larval Physiology*. R. N. Finn and B. G. Kapoor eds., pp. 639-681. Science Publishers, Enfield, NH.

Stekoll, M. S., W. W. Smoker, B. J. Failor-Rounds, I. A. Wang, and V. J. Joyce. 2009. Response of the early developmental stages of hatchery reared salmonids to major ions in a simulated mine effluent. *Aquaculture* 298:172-181.

Stephen R. Braund and Associates and Institute of Social and Economic Research. 1993. North Slope Subsistence Study: Barrow 1987, 1988, and 1989. Minerals Management Service Report MMS 91-0086. Stephen R. Braund and Associates and Institute of Social and Economic Research, Anchorage, AK.

Stewart, I. J. 2014. Overview of Data Sources for the Pacific Halibut Stock Assessment and Related Analyses. Report of Assessment and Research Activities 2013. International Pacific Halibut Commission, Seattle, WA.

Stewart, I. J., B. M. Leaman, and S. J. D. Martell. 2015. Accounting For and Managing All Pacific Halibut Removals. Report of Assessment and Research Activities 2014. International Pacific Halibut Commission, Seattle, WA.

Stone, R. P. 2006. Coral habitat in the Aleutian Islands of Alaska: Depth distribution, fine-scale species associations, and fisheries interactions. *Coral Reefs* 25:229-238.

Stoner, A. W. and A. A. Abookire. 2002. Sediment preferences and size-specific distribution of young-of-the-year Pacific halibut in an Alaska nursery. *Journal of Fish Biology* 61:540-559.

Stoner, A. W. and M. L. Ottmar. 2004. Fish density and size alter Pacific halibut feeding: Implications for stock assessment. *Journal of Fish Biology* 64:1712-1724.

Stopha, M. 2015. Alaska Fisheries Enhancement Annual Report 2015. Regional Information Report No. 5J16-03. Alaska Department of Fish and Game, Juneau, AK.

Sturdevant, M. V. 1996. Appendix C. Diet overlap of forage fish species, *In APEX: Alaska Predator Ecosystem Experiment, Exxon Valdez Oil Spill Restoration Project Annual Report (Restoration Project 95163)*. D. C. Duffy ed. Alaska Natural Heritage Program, University of Alaska, Anchorage, AK.

Sullivan, J., S. Martell, and G. Kruse. 2016. Can fishing explain declines in size-at-age of Pacific halibut? *In Alaska Marine Science Symposium*. Anchorage, AK.

Tatara, C. P. and B. A. Berejikian. 2012. Mechanisms influencing competition between hatchery and wild juvenile anadromous Pacific salmonids in fresh water and their relative competitive abilities. *Environmental Biology of Fishes* 94:7-19.

Thedinga, J. F., S. W. Johnson, A. D. Neff, C. A. Hoffman, and J. M. Maselko. 2013. Nearshore fish assemblages of the northeastern Chukchi Sea, Alaska. *Arctic*: 66:257-268.

Thomas, P. H., L. S. Mara, M. S. Susan, and W. S. Allan. 2005. Compensatory growth, energy storage and behavior of juvenile Pacific halibut *Hippoglossus stenolepis* following thermally induced growth reduction. *Marine Ecology Progress Series* 293:233-240.

Thorsteinson, L. K. and M. S. Love. 2016. Alaska Arctic Marine Fish Ecology Catalog. US Geological Survey Scientific Investigations Report 2016-5038. US Geological Survey and Bureau of Ocean Energy Management Environmental Studies Program (OCS Study BOEM 2016-048), Reston, VA.

Tojo, N., G. H. Kruse, and F. C. Funk. 2007. Migration dynamics of Pacific herring (*Clupea pallasii*) and response to spring environmental variability in the southeastern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 54:2832-2848.

Tynan, C. T. and D. P. DeMaster. 1997. Observations and predictions of Arctic climatic change: Potential effects on marine mammals. *Arctic* 50:308-322.

Ueda, Y., Y. Narimatsu, T. Hattori, M. Ito, D. Kitagawa, N. Tomikawa, and T. Matsuishi. 2006. Fishing efficiency estimated based on the abundance from virtual population analysis and bottom-trawl surveys of Pacific cod *Gadus macrocephalus* in the waters off the Pacific coast of northern Honshu, Japan. *Nippon Suisan Gakkaishi* 72:201-209.

Valero, J. L. and R. A. Webster. 2012. Current Understanding of Pacific Halibut Migration Patterns. Report of Assessment and Research Activities 2011. International Pacific Halibut Commission, Seattle, WA.

Vestfals, C. D., L. Ciannelli, J. T. Duffy-Anderson, and C. Ladd. 2014. Effects of seasonal and interannual variability in along-shelf and cross-shelf transport on groundfish recruitment in the eastern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 109:190-203.

von Szalay, P. G. and N. W. Raring. 2016. Data Report: 2015 Gulf of Alaska Bottom Trawl Survey. NOAA Technical Memorandum NMFS-AFSC-325. National Oceanic and Atmospheric Administration, Seattle, WA.

Watts, P. D. and B. A. Draper. 1986. Note on the behavior of beluga whales feeding on capelin. *Arctic and Alpine Research* 18:439-439.

Weber, E. D. and K. D. Fausch. 2005. Competition between hatchery-reared and wild juvenile chinook salmon in enclosures in the Sacramento River, California. *Transactions of the American Fisheries Society* 134:44-58.

Wespestad, V. G., L. W. Fritz, W. J. Ingraham, and B. A. Megrey. 2000. On relationships between cannibalism, climate variability, physical transport, and recruitment success of Bering Sea walleye pollock (*Theragra chalcogramma*). *ICES Journal of Marine Science* 57:272-278.

Whitehouse, G. A. 2013. Preliminary Mass-Balance Food Web Model of the Eastern Chukchi Sea. NOAA Technical Memorandum NMFS-AFSC-262. National Oceanic and Atmospheric Administration, Seattle, WA.

Wilderbuer, T., K., G. E. Walters, and R. G. Bakkala. 1992. Yellowfin sole, *Pleuronectes asper*, of the eastern Bering Sea: Biological characteristics, history of exploitation, and management. *Marine Fisheries Review* 54:1-18.

Willette, M., M. Sturdevant, and S. Jewett. 1997. Prey resource partitioning among several species of forage fishes in Prince William Sound, Alaska, *In Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems*. pp. 11-29. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks, Fairbanks, AK.

Williams, G. H. 2015. Recommendations for Pacific Halibut Discard Mortality Rates in the 2016-2018 Groundfish Fisheries Off Alaska. Report of Assessment and Research Activities 2015. International Pacific Halibut Commission, Seattle, WA.

Wilson, M. T., K. L. Mier, and D. W. Cooper. 2016. Assessment of resource selection models to predict occurrence of five juvenile flatfish species (*Pleuronectidae*) over the continental shelf in the western Gulf of Alaska. *Journal of Sea Research* 111:54-64.

Wischniowski, S. G., C. R. Kastelle, T. Loher, and T. E. Helser. 2015. Incorporation of bomb-produced ^{14}C into fish otoliths: An example of basin-specific rates from the North Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences* 72:879-892.

Witherell, D. and J. Armstrong. 2015. Groundfish Species Profiles. North Pacific Fisheries Management Council, Anchorage, AK.

Wolotira, R. J. 1985. Saffron Cod (*Eleginus gracilis*) in Western Alaska : The Resource and its Potential. NOAA Technical Memorandum NMFS F/NWC-79. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA.

Yang, M.-S. 1998. The trophic role of Atka mackerel, *Pleurogrammus monopterygius*, in the Aleutian Islands area. *Fisheries Bulletin* 97:1047-1057.

Zolotov, O. G. 1993. Notes on the reproductive biology of *Pleurogrammus monopterygius* in Kamchatkan waters. *Journal of Ichthyology* 33:25-37.

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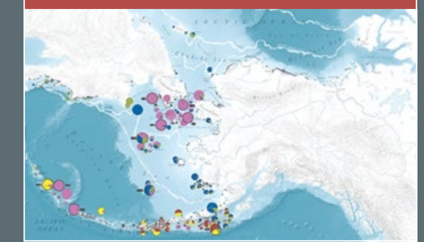
BIRDS

Milo Burcham

BIRDS MAP INDEX

Marine Bird Colonies



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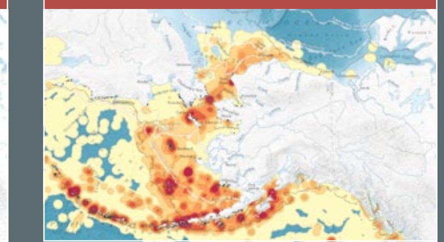

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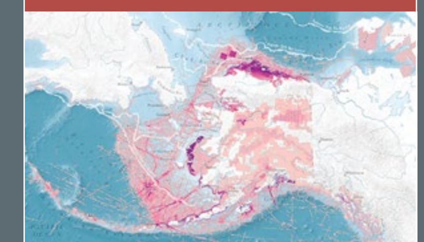

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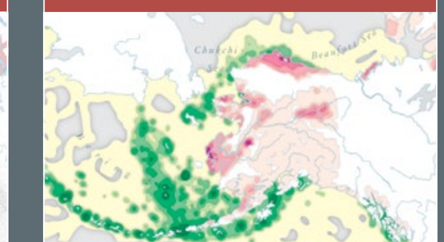

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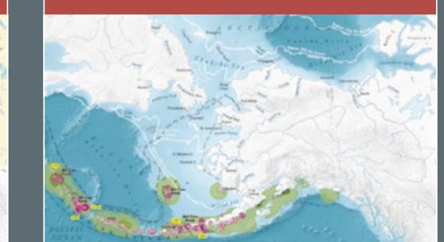

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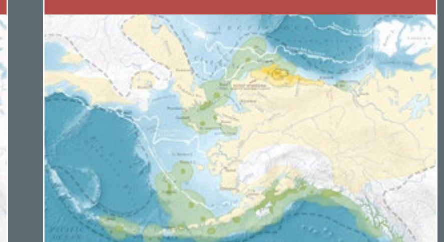

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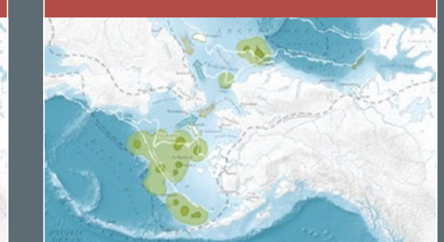

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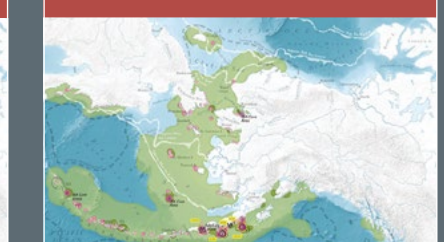

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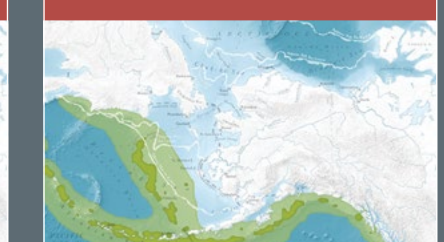

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Short-tailed / Sooty Shearwater

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Marine Bird Colonies

Melanie Smith

Marine birds sustain themselves by utilizing ocean resources during their annual cycle. The term "marine birds" refers to both seabirds and marine-associated waterbirds. Seabirds almost exclusively rely on the marine environment, with the exception of breeding terrestrially in colonies. Seabirds very rarely, if ever, venture inland or utilize fresh-water environments. Waterbirds are those that make use of either or both freshwater and saltwater environments and spend a much greater length of time on land throughout their annual cycle. Colonial-nesting waterbirds that often utilize marine resources include gulls, terns, and cormorants. Shorebirds are also considered marine waterbirds; in Alaska they do not nest colonially.

The dramatic, rocky coast of Alaska provides excellent habitat for colony-nesting birds: 865 colonies are mapped throughout the Bering, Chukchi, and Beaufort Seas, including parts of Russia and Arctic Canada, and provide nesting habitat for nearly 34 million birds. Different species prefer different nesting habitats, resulting in several species sharing the same area, but utilizing different niches. For example, Horned Puffins (*Fratercula corniculata*) nest in rock crevices in talus and between boulders below 300 feet (100 m), while their next closest relative, Tufted Puffins (*Fratercula cirrhata*), prefer earthen burrows high up along cliff edges and steep slopes covered with dense vegetation (Piatt and Kitaysky 2002a, b). Common and Thick-billed Murres (*Uria aalge* and *U. lomvia)* nest on ledges along cliff walls in very dense concentrations, with Thick-billed Murres selecting narrower ledges (Squibb and Hunt 1983, Gaston and Hipfner 2000, Ainley et al. 2002). Red-legged and Black-legged Kittiwakes (*Rissa brevirostris* and *R. tridactyla*) nest on ledges so small that often they face the cliff wall with their tails hanging over the edge, with Red-legged Kittiwakes more tolerant of nesting below overhangs (Byrd and Williams 1993a). Common Eiders (*Somateria mollissima*) are semi-colonial nesting sea ducks that select sites on the ground along sandy, low-lying barrier islands and spits amongst the cover of driftwood, rocks, or vegetation (Goudie et al. 2000).

DISTRIBUTION

The four most numerous categories of marine birds, from highest to lowest across the region, are auklets (16.1 million), murres (7.1 million), storm-petrels (4.4 million), and puffins (2.8 million). Ten species (including one group identified only to genus) total over one million birds across the project area. The most abundant species is the Least Auklet (*Aethia pusilla*), which nests in the largest colonies of any seabirds in this region, estimated at 7.8 million birds distributed across only 35 colonies. The next most abundant species in this region are: Crested Auklet (*A. cristatella*; 4.6 million), unidentified murres (*Uria* spp.; 2.9 million), Leach's Storm-Petrel (*Oceanodroma leucorhoa*; 2.3 million), Thick-billed Murre (2.2 million), Fork-tailed Storm-Petrel (*O. furcatea*; 2.2 million), Common Murre (2.0 million), Tufted Puffin (1.9 million), Black-legged Kittiwake (1.8 million), and Northern Fulmar (*Fulmarus glacialis*; 1.1 million).


Murre colony.

Roy W. Lowe / USFWS

Seven multi-species nesting colonies support over one million nesting birds. The largest nesting colony in the Bering, Chukchi, and Beaufort Seas is on Big Diomede Island, Russia, which is home to an approximated 5.1 million birds—primarily Least Auklets. The second-largest colony, and the largest in Alaska, is on Buldir Island where 3.5 million birds gather—primarily Leach's and Fork-tailed Storm-Petrels. St. George Island comes in at third with 2.1 million, half of which are Thick-billed Murres. In fourth place is Kiska Island (Sirius Point) with 1.8 million birds, mostly Least Auklets. Cape Yagnochymlo is the fifth largest colony, with 1.2 million birds, half of which are Crested Auklets. Ivekan Mountain on St. Lawrence Island comes in at sixth, with 1.2 million birds, of which two-thirds are Crested Auklets. Finally, the seventh-largest colony is on Hall Island with one million birds—a mix of Least Auklets, Thick-billed Murres, Northern Fulmars, and Crested Auklets.

Red-faced Cormorants (*Phalacrocorax urile*), Whiskered Auklets (*Aethia pygmaea*), and Red-legged Kittiwakes are endemic to the project area. All of their breeding colonies occur in the mapped region, with the exception of a small number of individuals that may breed along the adjacent margins of the area depicted. Tufted Puffins are present at the greatest number of colonies (398), followed by Horned Puffins (383), Pigeon Guillemots (*Cepphus columba*; 349), Pelagic Cormorants (*Phalacrocorax pelagicus*; 328), and Glaucous-winged Gulls (*Larus glaucescens;* 301). Table 5.1-1 shows the estimated abundance and number of colonies for marine birds in the region. (Note that the species abundances cited throughout this summary and on the associated map represent the best available count, but vary in degree of certainty and precision. They are best regarded as general estimates.)

LIFE CYCLE

Globally, about 13% of all bird species nest in colonies (Gill 1995), although when it comes to seabirds, about 98% of species breed colonially (Hamer et al. 2002). Seabirds are long-lived (20–60 years), balancing their late onset of breeding (up to 10 years) and generally low reproductive rates (often a single egg) with extended chick-rearing (up to 6 months) and high survival rates (Schreiber and Burger 2002). One popular illustration of the life history of seabirds comes from a monitoring site on Midway Atoll, where a Laysan Albatross (*Phoebastria immutabilis*) named Wisdom, the oldest known banded bird in the wild, continues to hatch a chick every year at 65+ years of age.

In the Bering, Chukchi, and Beaufort Seas, marine birds tend to migrate from March to May, and September to November, and lay eggs and rear chicks from May to August, with some notable differences between species/guilds. Auklets generally migrate to their breeding colonies in April and lay eggs in mid-May. Chicks hatch in late June and fledge by the end of August. From July through October they molt, and from August through October adults and juveniles leave the nesting colony to fly to their wintering areas (Byrd and Williams 1993b, Jones 1993, Jones et al. 2001, Bond et al. 2013).

Leach's Storm-Petrels, which winter farther south in sub-tropical and tropical waters, begin heading north earlier, in early March, arriving by late April. Eggs are laid in early June, hatching by mid-August. The young fledge late—by mid-October—when the adults and juveniles depart south, making it to wintering areas by late November (Huntington et al. 2013). In contrast, Fork-tailed Storm-Petrels tend to wander during winter months (November–March), arriving back at breeding colonies by mid-March. The early arrivals may lay eggs as soon as early April, but most do not lay until mid-May. In early August, chicks are hatched, then fledged by early November. These birds molt on their wintering grounds between November and February (Boersma and Silva 2001).

Typically, life cycles for Common Murres vary with the latitude of their breeding colony. These birds migrate to the Semidi Islands (just south of the Alaska Peninsula in the Gulf of Alaska) from mid-March to mid-May, with most arriving throughout April and early May. However, in the Chukchi Sea, Common Murres are migrating in mid-April to late May, with most arriving in the first half of May. At both sites, birds are laying eggs in June and early July and hatching chicks in July and August, although the Chukchi Sea birds tend to be a week or two behind the Semidi Island birds. September through mid-October (but as late as mid-November), the murres are migrating back to wintering grounds, where they finish out their annual molt by the end of November (Ainley et al. 2002).

The timing of spring molt and migration is speculative for Horned Puffins, but is believed to occur between early March and mid-June, with most birds molting in March and April and migrating in April and May. The majority of the birds lay eggs in late June through July, with hatching, rearing, and fledging taking place late July through mid-September. Both the fall molt (again, not well understood) and the migration happen in mid-September through November, and for some birds, as late as December. Horned Puffins are stationary during January and February on wintering grounds, then begin the cycle all over again. The annual cycle for Tufted Puffins is very similar to Horned Puffins, although the timing of migration, egg-laying, and chick-rearing tends to occur about two weeks earlier.

Diet

Colonial breeding is a survival strategy that helps species avoid predators. Seabirds do this by gathering in large, raucous groups, by locating their nests in hard-to-access cliffside areas, and by breeding synchronously so that predators are swamped with an overabundance of prey and can only take a limited number of eggs or chicks at any one time (Coulson 2002). One of the drawbacks of breeding among thousands of other individuals is the competition for food. Seabirds ameliorate this issue by selecting colonies near highly productive at-sea foraging hotspots, where ocean conditions tend to aggregate prey (such as are found in the highly productive Bering Sea ecosystem), and by regularly flying great distances (often over 30 miles [50 km]) from the colony to locate food. While many colonies are located near marine hotspots and heavily utilized foraging areas, others are located far from the nearest upwelling, requiring seabirds to travel. An example of this is the heavy use of the Bering Sea shelf break region by marine birds, especially surface-feeding birds, even though the nearest islands may be quite some distance away. Situated nearest to the shelf break, the Pribilof Islands, St. Matthew and Hall Islands, and St. Lawrence Island attract hundreds of thousands to millions of nesting seabirds.

Marine birds may be opportunistic surface-feeders (e.g., storm-petrels), or divers in pursuit of underwater prey (e.g., alcids), or in some cases bottom-feeders searching for bivalves on the ocean floor (e.g., eiders). Most colonial marine birds can be generalized into categories of planktivores (zooplankton-eaters) or piscivores (fish-eaters); however, many species utilize both types of food. Categorizing colonial birds into foraging guilds by combining foraging strategy (surface vs. diving) with primary forage type (planktivore vs. piscivore) reveals interesting patterns of habitat use (e.g. Wong et al. 2014). Surface-feeding colonial birds gather in the highest concentrations along areas influenced by upwelling from the Bering Sea shelf break, as well as along the Aleutian chain. Surface-feeding planktivores and piscivores form very similar concentration patterns, with the notable exception of the higher density of surface-feeding planktivores in the southern Chukchi Sea. Colonial diving birds have their highest concentrations on the Bering Sea shelf (especially near offshore islands), along the Aleutian chain, and in the Bering Strait. The distribution of diving piscivores is higher in the southeastern Bering Sea and northern Gulf of Alaska, while the diving planktivores have additional high-concentration areas in the Bering Strait and western Aleutians.

CONSERVATION ISSUES

Alaska bears a great responsibility for conserving seabird habitat as it is home to a significant proportion of the world's seabird abundance and diversity. The US, and particularly Alaska, supports the largest number of breeding seabird species of any nation, as well as the second-highest number of endemic breeding seabird species, and the third highest number of species of conservation concern (Croxall et al. 2012). Seabirds nesting at colonies can be severely impacted by natural disasters such as volcanic eruption (US Fish and Wildlife Service 2008c), and human-induced factors such as introduced species (e.g., eggs taken by foxes and rats on Aleutian Islands) (Byrd et al. 2005). Other disturbances at colonies may include hunting and the

TABLE 5.1-1. Species composition and estimated abundance for bird colonies in the project area.

	Composition	Abundance	# Colonies	% of Total Birds
< 20,000	Auklets: 3% Murres: 24% Puffins: 29% Storm-Petrels: 2% Other: 42%	1,282,886	731	4%
20,000–49,999	Auklets: 10% Murres: 31% Puffins: 28% Storm-Petrels: 6% Other: 25%	1,813,555	55	5%
50,000–99,999	Auklets: 21% Murres: 35% Puffins: 18% Storm-Petrels: 1% Other: 26%	1,696,155	23	5%
100,000–249,999	Auklets: 17% Murres: 43% Puffins: 13% Storm-Petrels: 8% Other: 19%	4,623,259	29	13%
250,000–499,999	Auklets: 35% Murres: 17% Puffins: 15% Storm-Petrels: 18% Other: 15%	4,103,467	12	12%
500,000+	Auklets: 65% Murres: 14% Puffins: 2% Storm-Petrels: 15% Other: 4%	20,754,236	15	61%
Total	Auklets: 47% Murres: 21% Puffins: 8% Storm-Petrels: 13% Other: 11%	34,273,558	865	100%

Table sources listed in Map Data Sources section.

collection of eggs by subsistence users, noise from aerial or vessel traffic, nearby development, or disruption by birdwatchers or other recreational visitors. In the ocean, colonial seabirds are exposed to a number of other stressors, among those underwater noise, shipping traffic (Humphries and Huettmann 2014), overfishing (Ainley et al. 1994, Cury et al. 2011), or climate-induced changes in forage productivity and availability (Meehan et al. 1998, Piatt et al. 2007, Koeppen et al. 2016). Other threats include fishing bycatch, ingestion of plastics (Causey and Padula 2015), and oil-and-gas activity and spills (O'Hara and Morandin 2010).

Although colonies with large bird populations are obvious conservation targets, others with only several hundred birds can also be a priority, depending upon the sensitivity of the species. Habitat for endemic species, those with low total abundance, few breeding colonies, and/or species of concern should be given special consideration. All colony sites depicted on this map should be protected from direct human disturbance and development, with the exception of allowable hunting and the gathering of eggs for subsistence. The Alaska Maritime National Wildlife Refuge currently owns and manages a majority of the colonies in Alaska. Conserving only 27 of the 865 colonies would protect three-quarters of all colonial nesting seabirds shown on this map—about 25 million individuals (see Table 5.1-1). Those sites, in particular, should receive the highest possible protection from harm.

MAPPING METHODS (MAPS 5.1.1–5.1.2d)

The North Pacific Seabird Data Portal (NPSDP) is part of the Seabird Information Network (SIN) (Seabird Information Network 2011). The NPSDP contains data depicting seabird colony locations, species, and populations across Alaska, as well as parts of eastern Russia and western Canada. These colonies range in size from a few individuals to several million birds. Surveyors recorded the abundance of each species present at each colony location by counting or estimating (or in some cases very roughly estimating) the number of individuals, nests, or pairs. The database reports the best estimate made for that colony based on one or more site visits. Smith et al. (2012) eliminated older (pre-1971), poor, or questionable records, and compiled a multi-species colony data layer from the SIN database.

In addition, Audubon Alaska updated colony data records for eight species. In Alaska, we added new information on Aleutian Terns (*Onychoprion aleuticus*), which represents the most recent or otherwise best estimate available for each colony location. This resulted in updated abundance estimates for some colonies, as well as the addition of new colony locations. Aleutian Tern colony data were provided by Seabird Information Network (2017) and the authors of Renner et al. (2015). Additional colony locations for Common Eiders, as well as one colony for Thick-billed Murres, were provided from unpublished nesting colony data collected by the Canadian Wildlife Service (2013). These data depicted nesting sites along the Canadian Beaufort coast—an

TABLE 5.1-2. Classification of foraging guilds for colonial nesting marine birds that regularly forage in the Bering, Chukchi, and Beaufort Seas.

Species	Surface	Diving[1]	Planktivorous	Piscivorous
Aleutian Tern	x		x	x
Arctic Tern	x			x
Black-legged Kittiwake	x		x	x
Fork-tailed Storm-Petrel	x		x	x
Glaucous Gull	x		x	x
Glaucous-winged Gull	x			x
Herring Gull	x		x	x
Ivory Gull	x		x	x
Leach's Storm-Petrel	x		x	x
Northern Fulmar	x		x	x
Red Phalarope	x		x	
Red-legged Kittiwake	x			x
Red-necked Phalarope	x		x	
Ross's Gull	x		x	x
Sabine's Gull	x		x	x
Unidentified Gull	x		x	x
Unidentified Kittiwake	x			x
Unidentified Phalarope	x		x	
Unidentified Storm-Petrel	x		x	x
Unidentified Tern	x			x
Ancient Murrelet		x	x	x
Black Guillemot		x		x
Cassin's Auklet		x	x	
Common Murre		x	x	x
Crested Auklet		x	x	
Double-crested Cormorant		x		x
Dovekie		x	x	
Horned Puffin		x		x
Least Auklet		x	x	
Parakeet Auklet		x	x	
Pelagic Cormorant		x		x
Pigeon Guillemot		x	x	x
Red-faced Cormorant		x		x
Short-tailed Shearwater		x	x	x
Sooty Shearwater		x	x	x
Thick-billed Murre		x	x	x
Tufted Puffin		x		x
Whiskered Auklet		x	x	
Unidentified Auklet		x	x	
Unidentified Cormorant		x		x
Unidentified Murre		x	x	x
Unidentified Puffin		x		x
Unidentified Shearwater		x	x	x

[1] The diving category included deep plungers such as shearwaters.

area not included in SIN. We also updated count data for Red-faced Cormorants in the Pribilof Islands based on Romano and Thomson (2016), and count data for larger Red-faced Cormorant colonies in the Aleutian Islands based on Alaska Maritime National Wildlife Refuge (2009), Byrd et al. (2001b), and Byrd and Williams (2004). Red-legged Kittiwake colony data were updated based on Byrd et al. (1997), Byrd et al. (2001a), Byrd et al. (2001b), Byrd et al. (2004), Thomson et al. (2014), and Williams (2017). Data for Crested, Least, and Parakeet Auklets were updated based on Artukhin et al. (2016), Konyukhov et al. (1998), and Vyatkin (2000).

Species were classified into foraging guilds (Table 5.1-2) based on diet information in the Birds of North America Online (Cornell Lab of Ornithology and American Ornithologists' Union 2016) and personal communication with George Hunt (University of Washington) and Brie Drummond (Alaska Maritime National Wildlife Refuge). Species that utilize both zooplankton and fish as primary food sources (depending on season, location, etc.) were added to both categories. We analyzed annual average density using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), with data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Survey data for summer and fall (June–November) were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We then ran a 31-mile (50-km) kernel density analysis to convert binned data into smoothed distribution data.

Data Quality

The colony data are available throughout the US and Russian portions of the project area, with the addition of some Canadian data, but data quality—survey dates and techniques—varies substantially among colonies. Very large colonies, such as those of auklets or storm-petrels, are the hardest to estimate and are likely to have the greatest uncertainty. As a result, species abundances presented on this and other maps in this chapter represent the best estimate available, but that estimate may be highly uncertain or imprecise.

The at-sea survey data used in the foraging guild maps have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. There is little to no survey coverage in the Canadian and Russian portions of the project area, potentially leaving major data gaps for these species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps.

Reviewer

- Robb Kaler

MAP DATA SOURCES

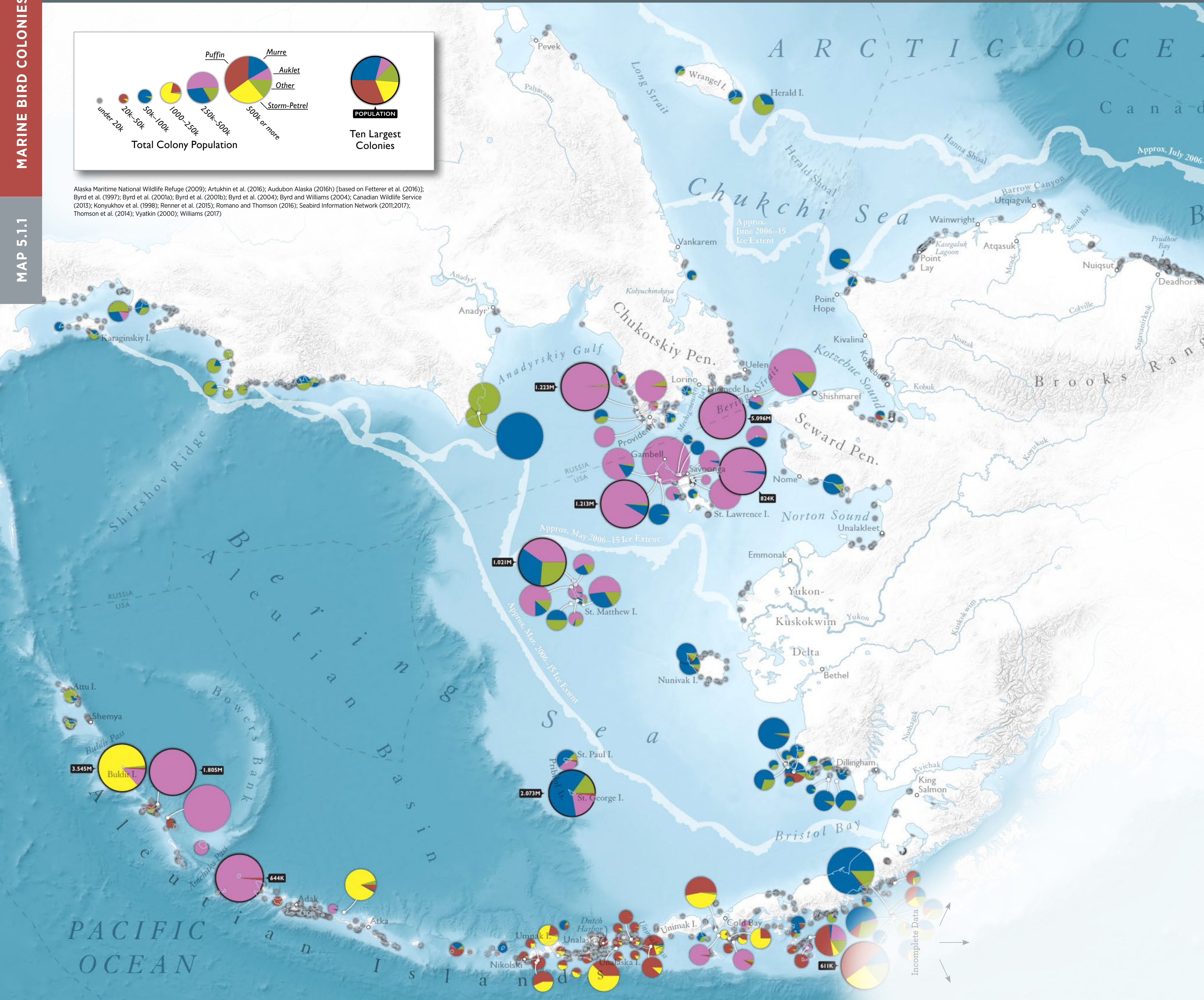
Marine Bird Colonies Map: Alaska Maritime National Wildlife Refuge (2009); Artukhin et al. (2016); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Byrd et al. (1997, 2001a, 2001b, 2004); Byrd and Williams (2004); Canadian Wildlife Service (2013); Konyukhov et al. (1998); Renner et al. (2015); Romano and Thomson (2016); Seabird Information Network (2011; 2017); Thomson et al. (2014); Vyatkin (2000); Williams (2017)

Foraging Guilds Maps: Audubon Alaska (2017e) based on Audubon Alaska (2016a)

Marine Bird Colonies

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Audubon ALASKA



Alaska Maritime National Wildlife Refuge (2009); Artukhin et al. (2016); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Byrd et al. (1997); Byrd et al. (2001a); Byrd et al. (2001b); Byrd et al. (2004); Byrd and Williams (2004); Canadian Wildlife Service (2013); Konyukhov et al. (1998); Renner et al. (2015); Romano and Thomson (2016); Seabird Information Network (2011;2017); Thomson et al. (2014); Vyatkin (2000); Williams (2017)

Gary Drew / USGS

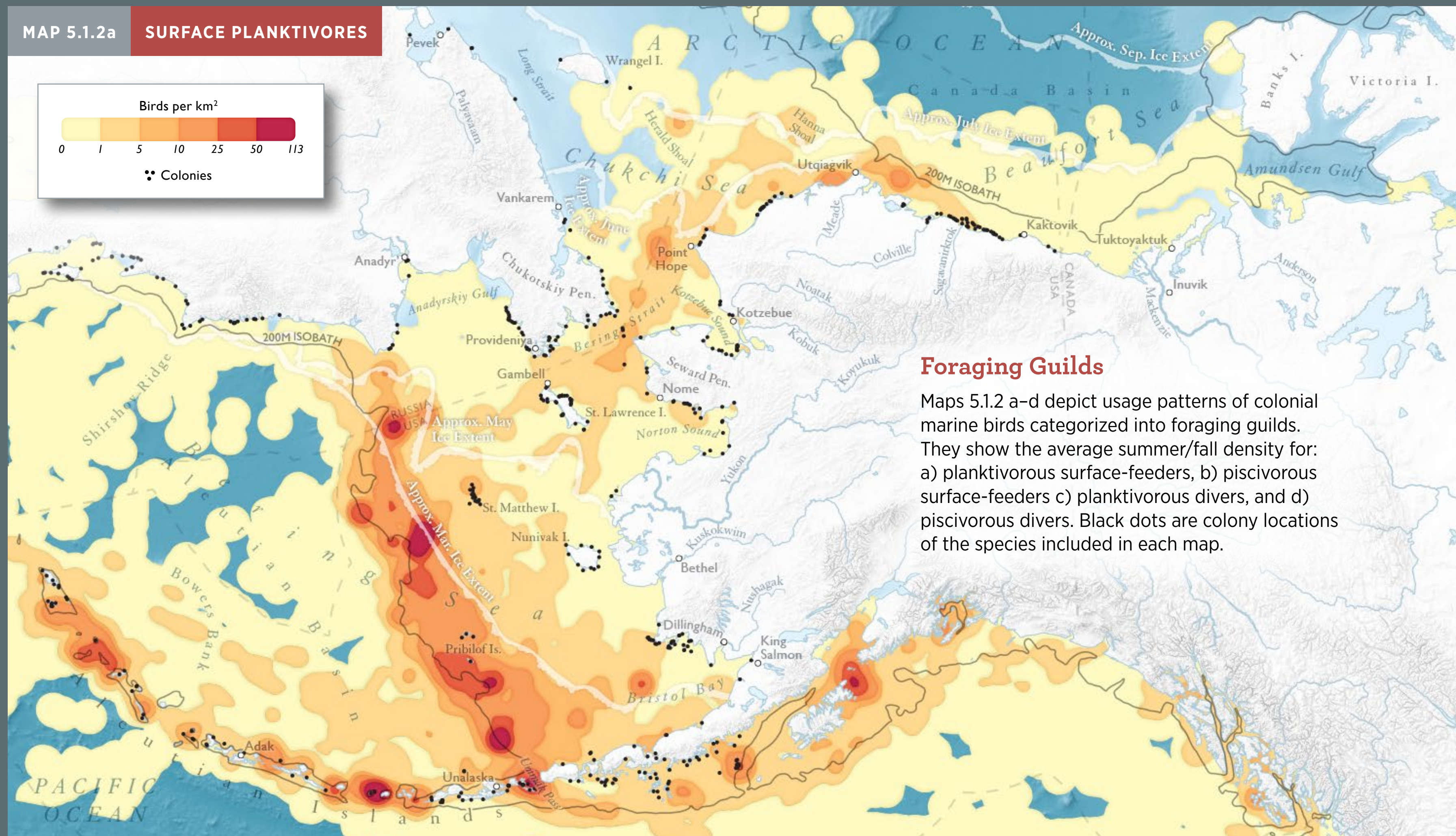
Marine Bird Colonies

Globally, about 13% of all bird species nest in colonies (Gill 1995), although when it comes to seabirds, about 98% of species breed colonially (Hamer et al. 2002). The term marine birds refers to both seabirds and marine-associated waterbirds. This region provides excellent habitat for colony-nesting marine birds: 865 colonies are mapped throughout the project area, providing nesting habitat for nearly 34 million birds. The four most numerous categories of birds, from highest to lowest across the region, are auklets (16.1 million), murres (7.1 million), storm-petrels (4.4 million), and puffins (2.8 million). Ten species (including one group identified only to genus) total over one million birds across the project area. The most abundant species is the Least Auklet (*Aethia pusilla*), which nests in the largest colonies of any seabirds in this region, estimated at 7.8 million birds distributed across only 35 colonies. The largest nesting colony in the project area is on Big Diomede Island, Russia, which is home to an approximated 5.1 million birds. The second-largest colony, and the largest in Alaska, is on Buldir Island where 3.5 million birds gather. Three-quarters of all colonial nesting birds, about 25 million individuals, nest in only 27 colonies.

Foraging Guilds

Map Author: Melanie Smith
Cartographer: Daniel P. Huffman

MAP 5.1.2a SURFACE PLANKTIVORES

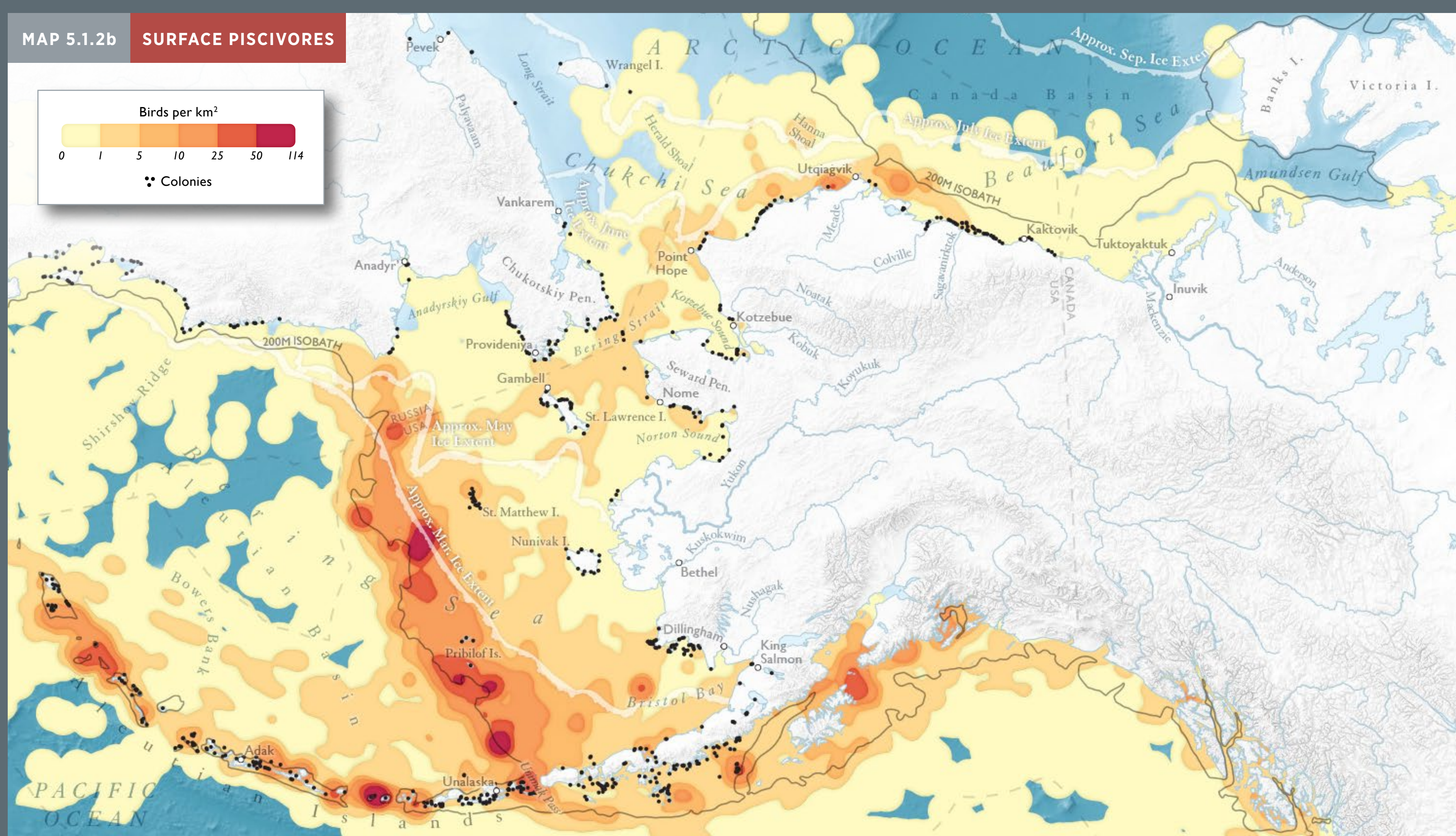


Foraging Guilds

Maps 5.1.2 a–d depict usage patterns of colonial marine birds categorized into foraging guilds. They show the average summer/fall density for: a) planktivorous surface-feeders, b) piscivorous surface-feeders c) planktivorous divers, and d) piscivorous divers. Black dots are colony locations of the species included in each map.

Audubon Alaska (2017e) based on Audubon Alaska (2016a)

MAP 5.1.2b SURFACE PISCIVORES

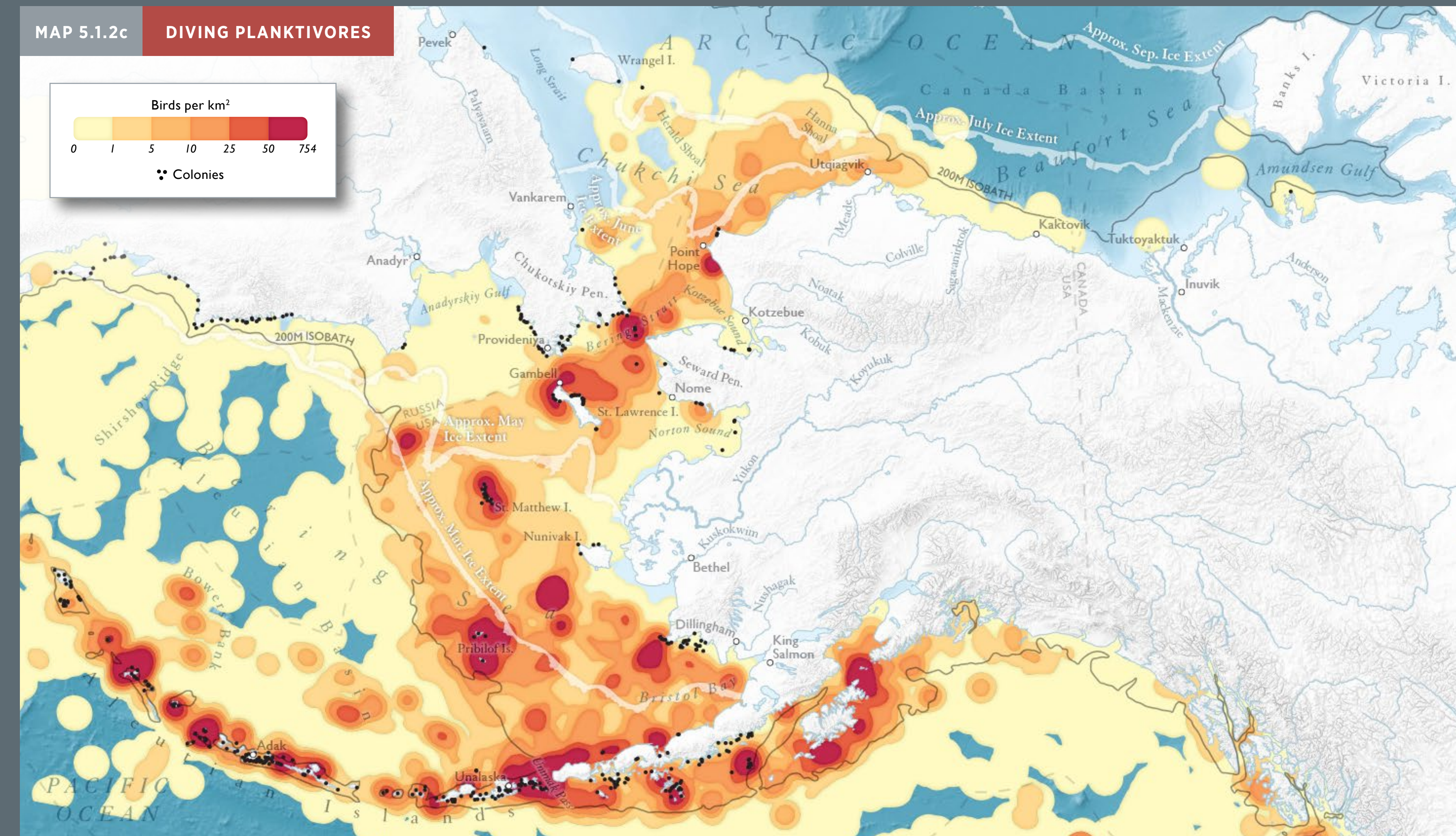


Audubon Alaska (2017e) based on Audubon Alaska (2016a)

NPPSD

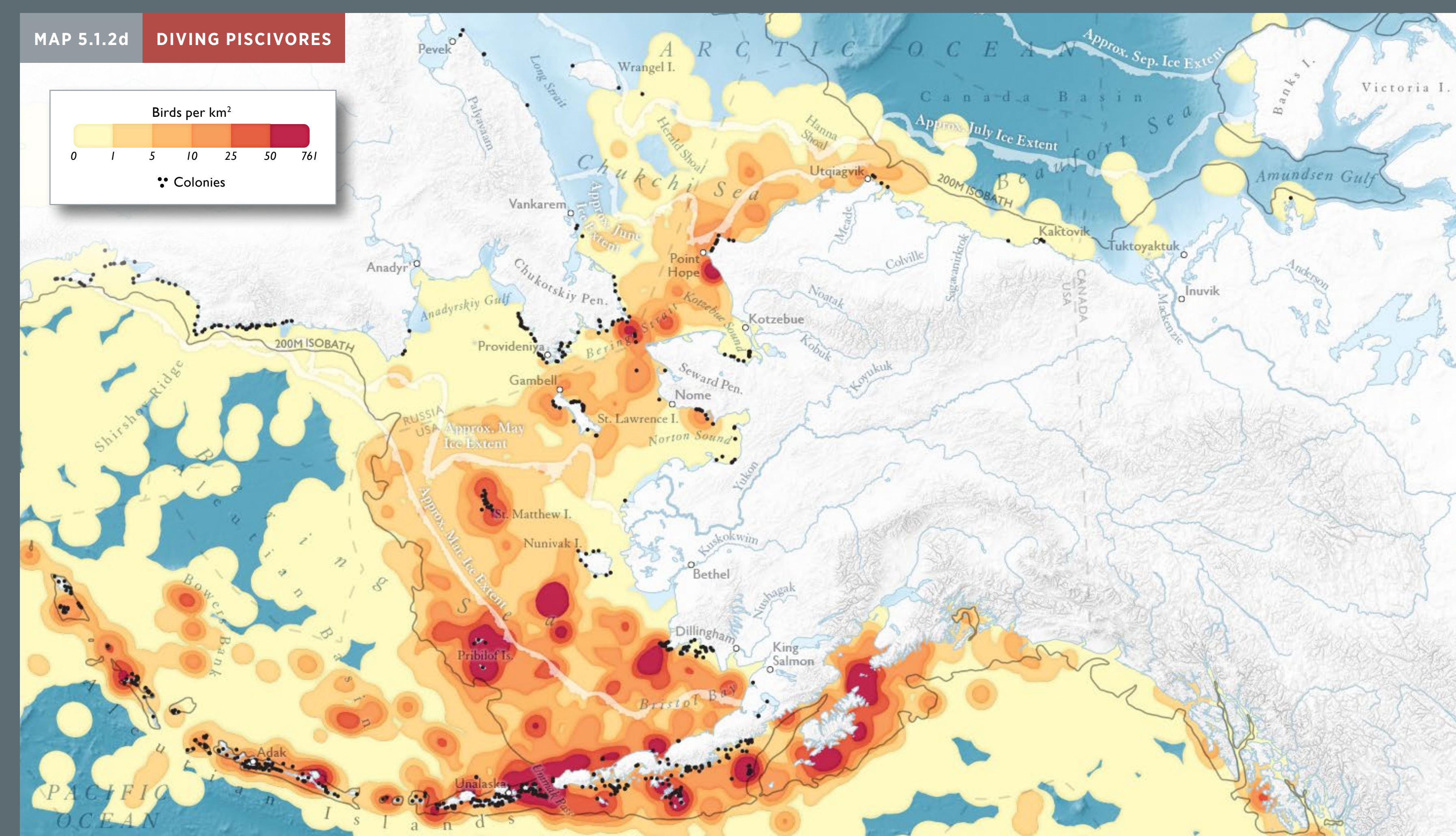
Audubon ALASKA

MAP 5.1.2c DIVING PLANKTIVORES



Audubon Alaska (2017e) based on Audubon Alaska (2016a)

MAP 5.1.2d DIVING PISCIVORES



Audubon Alaska (2017e) based on Audubon Alaska (2016a)

5.2
IMPORTANT BIRD AREAS
MAP ON PAGES 122–123

Important Bird Areas

Melanie Smith

Effective bird conservation requires the identification of areas used by populations for key life-history events including breeding, foraging, staging, molting, and migration. Important Bird Areas (IBAs) are based on an established program that identifies these essential habitats for birds (National Audubon Society 2012, BirdLife International 2017a). IBAs are designated using a set of scientific criteria that trigger the nomination of sites, which are reviewed by local and national committees of leading bird experts convened by Audubon and BirdLife International. The global network of more than 1,200 IBAs around the world continues to grow.

Marine IBAs are sites that are delineated from the surrounding seascape due to specific criteria. For an area to qualify as an IBA, it must support a high concentration of birds, provide habitat for a threatened or rare species, or provide habitat for a bird with a very limited or restricted range. In the US, sites are ranked as significant at the state, continental, or global level, based on the estimated population abundance. The majority of Alaska's IBAs are recognized at the global level for including 1% or more of the global population of seabirds (the A4ii criterion), or 1% or more of the North American population of waterbirds (waterfowl and shorebirds; the A4i criterion)—both of which qualify for global status. Audubon Alaska has identified 208 IBAs in the state, more than three-quarters of which are globally significant. Alaska has more globally significant IBAs than any other state, and almost half of all of the globally significant IBAs identified in the US.

DISTRIBUTION

Marine birds in Alaska (> 50 million) far outnumber the human population of the state (~740,000 in 2016), and marine bird densities across the Bering Sea are of global significance; the US Fish and Wildlife Service (2008b) estimates that seabird nesting along the Bering Sea coast accounts for 87% of the seabirds in the US. Accordingly, our project area includes many notable IBAs (Audubon Alaska 2014).

The Northern Alaska Peninsula Coastal IBA (see Map 5.2) has the largest number of recorded species, with 69. This IBA is globally significant for Black Scoter (*Melanitta americana*), Emperor Goose (*Chen canagica*), Glaucous-winged Gull, (*Larus glaucescens*) King Eider (*Somateria spectabilis*), Steller's Eider (*Polysticta stelleri*)), and White-winged Scoter (*Melanitta fusca*).

The Teshekpuk Lake Area IBA is especially significant for waterfowl and shorebirds, such as Red and Red-necked Phalaropes (*Phalaropus fulicarius* and *P. lobatus*), Northern Pintails (*Anas acuta*), Long-tailed Ducks (*Clangula hyemalis*), and Yellow-billed Loons (*Gavia adamsii*). It has the largest number of species triggering IBA status, at 31, and 15 of those are at the A4i level, indicating 1% or more of the North American population are present.

The greatest abundance of birds in any IBA is in Unimak and Akutan Passes, with an estimate of over 7 million birds, of which about 4.5 million are Short-tailed and Sooty Shearwaters (*Puffinus tenuirostris* and *P. griseus*), accompanied by hundreds of thousands of Black-legged Kittiwakes (*Rissa tridactyla*), Northern Fulmars (*Fulmarus glacialis*), Tufted Puffins (*Fratercula cirrhata*), Whiskered Auklets (*Aethia pygmaea*), and Crested Auklets (*A. cristatella*).

The Buldir Island Colony IBA is the single largest colony in Alaska, with 3.5 million birds, primarily nesting Leach's and Fork-tailed Storm-Petrels (*Oceanodroma leucorhoa* and *O. furcata*). However, the prize for the largest colony in the project area goes to Big Diomede Island, Russia. The Diomede Islands Colonies IBA (Big and Little Diomede Islands combined) is home to 5.1 million Least (*A. pusilla*), Crested, and Parakeet Auklets (*A. psittacula*) Auklets.

In addition, several other marine IBAs encompass over one million birds (Audubon Alaska 2014): Bering Sea Shelf Edge 166W55N (4.3 million); Semidi Islands Colonies (2.4 million); St. George Island Colony (2.1 million); Kiska Island Colonies (1.8 million); Southwest Cape Colonies (1.7 million); St. Matthew and Hall Islands Colonies (1.6 million); Savoonga Colonies (1.5 million); Kiska Island Marine (1.4 million); St. George Island Marine (1.3 million); Buldir & Near Islands Marine (1.1 million); and Fenimore Pass & Atka Island Marine (1.1 million).

LIFE CYCLE

Breeding areas, including places for courting, mating, nesting, and raising young, make up many of the IBAs identified throughout the Bering Sea, Arctic Ocean, and Interior. Several of the largest seabird congregation areas in the world are found at seabird colonies along cliffs and island shores in the Bering Sea. Many marine IBAs near the western Alaska coast are places that birds migrate through in spring, then molt, stage, and/or migrate through in the fall. Millions of birds stay in Alaska in the winter, most often concentrated in the southern Bering Sea and Aleutian Islands, or the northern Gulf of Alaska. Other IBAs often encompass foraging hotspots found at eddies, shelf breaks, and upwelling sites along the Bering Sea shelf, Bering Strait, Chukchi Sea, nearshore waters in the Beaufort Sea, and the Aleutian Islands.

CONSERVATION ISSUES

Ever-increasing human demands on marine resources have intensified the need to identify and conserve important ecosystem functions and habitat for birds. Globally, seabird numbers are thought to be in steep decline, down 70% since 1950 among the world's monitored populations, likely due to a combination of factors (Paleczny et al. 2015). Habitat loss (including impacts on marine forage resources) is a serious threat facing bird species around the world. In the marine realm, habitat can be lost to a number of stressors, such as underwater noise, shipping traffic (Humphries and Huettmann 2014), overfishing (Ainley et al. 1994, Cury et al. 2011), or climate-induced changes in forage productivity and availability (Meehan et al. 1998, Piatt et al. 2007, Koeppen et al. 2016). Other threats include natural disasters (US Fish and Wildlife Service 2008c), fishing bycatch (particularly relevant to the Short-tailed Albatross [*Phoebastria albatrus*]) (US Fish and Wildlife Service 2014a), ingestion of plastics (Causey and Padula 2015), oil-and-gas activity and spills (O'Hara and Morandin 2010), and introduced species (e.g. eggs taken by foxes and rats on Aleutian Islands) (Byrd et al. 2005).

Recognition of IBA status does not automatically impose any type of regulation or management guidelines. However, IBAs are often the focus of conservation efforts, and many of them have been subsequently protected under various conservation designations. In addition to providing a starting point for establishing legal protections, IBA information can be utilized in regional to global applications, such as environmental assessments, the design of best management practices, or broad-scale integrative spatial planning. Globally, thousands of IBAs and millions of acres of avian habitat have received recognition and better protection as a result of the IBA program. In the marine environment, IBAs make good candidates for Marine Protected Areas (MPAs) (Lascelles et al. 2012, Ronconi et al. 2012), because places where seabirds forage are often indicative of productivity hotspots for lower trophic organisms, fishes, and marine mammals (Piatt and Springer 2003, Piatt et al. 2007, Parsons et al. 2008, Suryan et al. 2012).

Audubon's Alaska IBA program is an initiative to address conservation issues through place-based assessments of threats and protections necessary for the long-term health of bird populations. The US, primarily Alaska, supports the largest number of breeding seabird species of any nation, as well as the second-highest number of endemic breeding species, and the third highest number of species of conservation concern (Croxall et al. 2012). Having a significant proportion of the

Aaron Lang / USFWS

In winter, the global population of over 350,000 Spectacled Eiders uses the perennial polynya south of St. Lawrence Island in the northern Bering Sea. Because of this level of aggregation, these birds are particularly vulnerable to disease, spills, or habitat degradation.

world's seabird abundance and diversity, Alaska bears a great responsibility for the stewardship of seabird habitat and conservation.

Three species of seabirds on the Endangered Species List are of particular concern: Short-tailed Albatross (endangered), Steller's Eider (threatened), and Spectacled Eider (*Somateria fischeri*; threatened), all of which use the Bering, Chukchi, and Beaufort Seas. Currently, there are no IBAs designated for Short-tailed Albatross. There are 20 globally significant IBAs for Steller's Eiders, 10 of which regularly have 1% or more of the North American population present. There are four globally significant IBAs for Spectacled Eider, which regularly have 1% or more of the North American population present.

Presently, several IBAs are within areas permanently withdrawn from offshore oil-and-gas development in Bristol Bay. Recently recommended by the US Coast Guard, shipping Areas to be Avoided would keep transiting vessels of 400 gross tons or more out of significant marine areas such as the St. Lawrence Island Polynya IBA, where the entire world's population of 350,000 Spectacled Eiders spends their winters. Many other colony IBAs are protected as part of the Alaska Maritime National Wildlife Refuge. IBAs are invaluable in the life histories of many species that live in the Bering, Chukchi, and Beaufort Seas, and should be regarded as having high conservation priority.

MAPPING METHODS (MAP 5.2)

Alaska's IBA network is a compilation of areas identified using at-sea surveys, colony data, and expert opinion. At-sea IBAs were established from an extensive database of at-sea survey data spanning 37 years, the North Pacific Pelagic Seabird Database, or NPPSD (US Geological Survey–Alaska Science Center 2015). Audubon Alaska developed a standardized and data-driven spatial method for identifying globally significant marine IBAs across Alaska, in a six-step process: 1) spatially binning data, and accounting for unequal survey effort; 2) filtering input data for persistence of species use; 3) analyzing data to produce data layers representing a gradient from low to high abundance; 4) drawing single-species core area boundaries around major concentrations based on abundance thresholds; 5) validating the results; and 6) combining overlapping boundaries into important areas for multiple species (Smith et al. 2014c).

Smith et al. (2012) identified globally significant colony IBAs by analyzing an extensive colony catalog put together by the US Fish and Wildlife Service (Seabird Information Network 2011). Spatial analysis was used to group nearby colonies in "metacolonies" (e.g. on adjoining cliffs or islets). Alaska's IBAs also include coastal and interior IBAs identified through GIS analysis of aerial survey data, employing similar methods to those described above using at-sea surveys (Smith et al. 2014b).

Finally, some IBAs were derived using boundaries drawn by experts to delineate areas of known high concentration. Expert opinion was used in areas where spatial data were insufficient to create GIS-derived boundaries. Together, these various IBA-identification methods make up the Alaska IBA network. IBAs from Canada and Russia were acquired from BirdLife International and delineated using similar methods with an emphasis on expert-derived IBAs.

Data Quality

The at-sea survey data used to identify IBAs in Alaska, the NPPSD, has variable coverage across the project area. Areas of Alaska vary greatly in survey coverage and effort, influencing identification of IBAs. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps. In Alaska, Smith et al. (2014c) developed methods that conservatively identified IBAs so that results minimized Type I errors (false positives), while recognizing that other areas of importance likely exist that were not identified. Therefore, areas not shown as IBAs on this map are not necessarily unimportant.

Reviewer

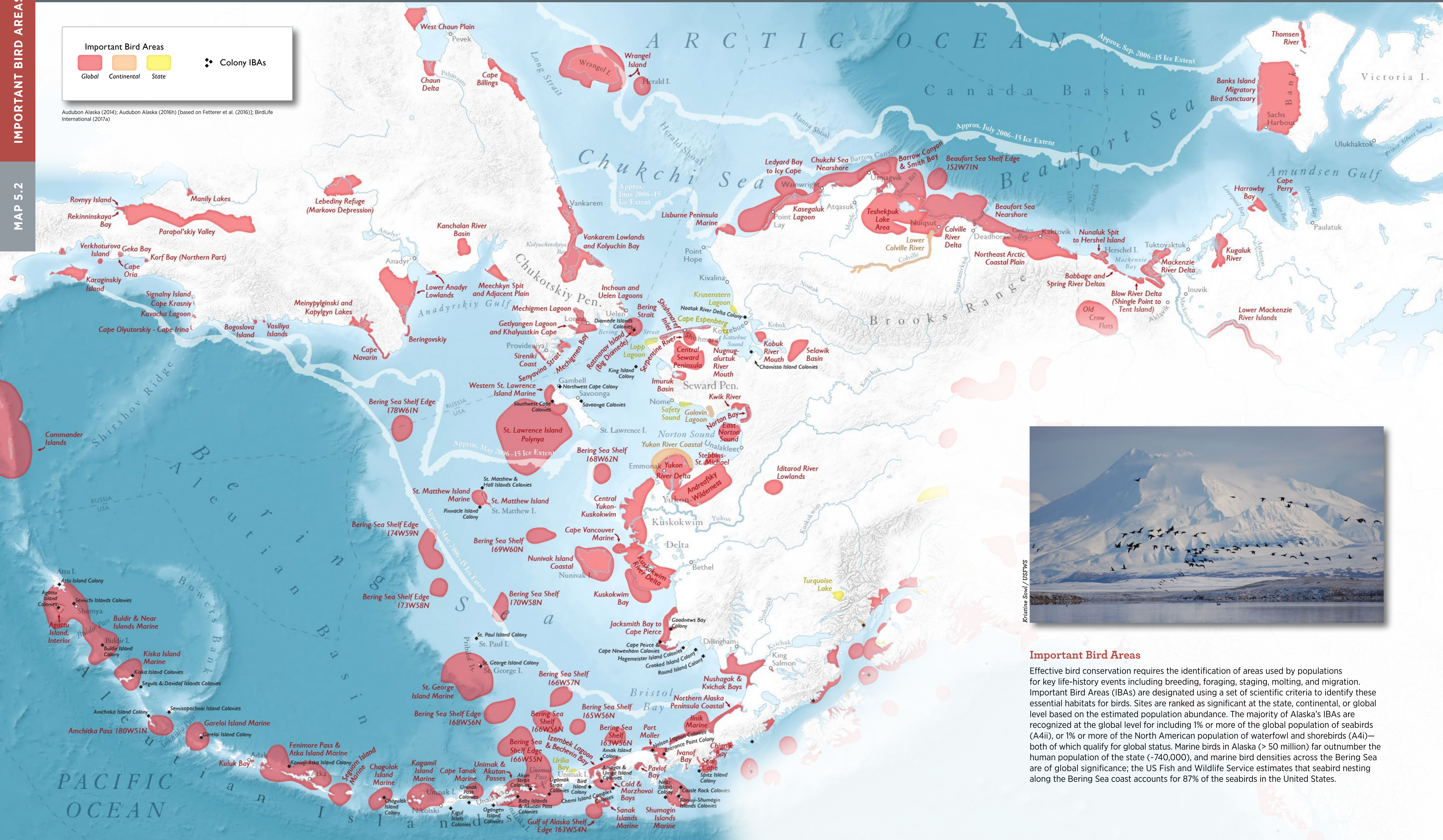
- Gary Drew

MAP DATA SOURCES

Important Bird Areas: Audubon Alaska (2014); BirdLife International (2017a)

Important Bird Areas

Map Author: Melanie Smith
Cartographer: Daniel P. Huffman



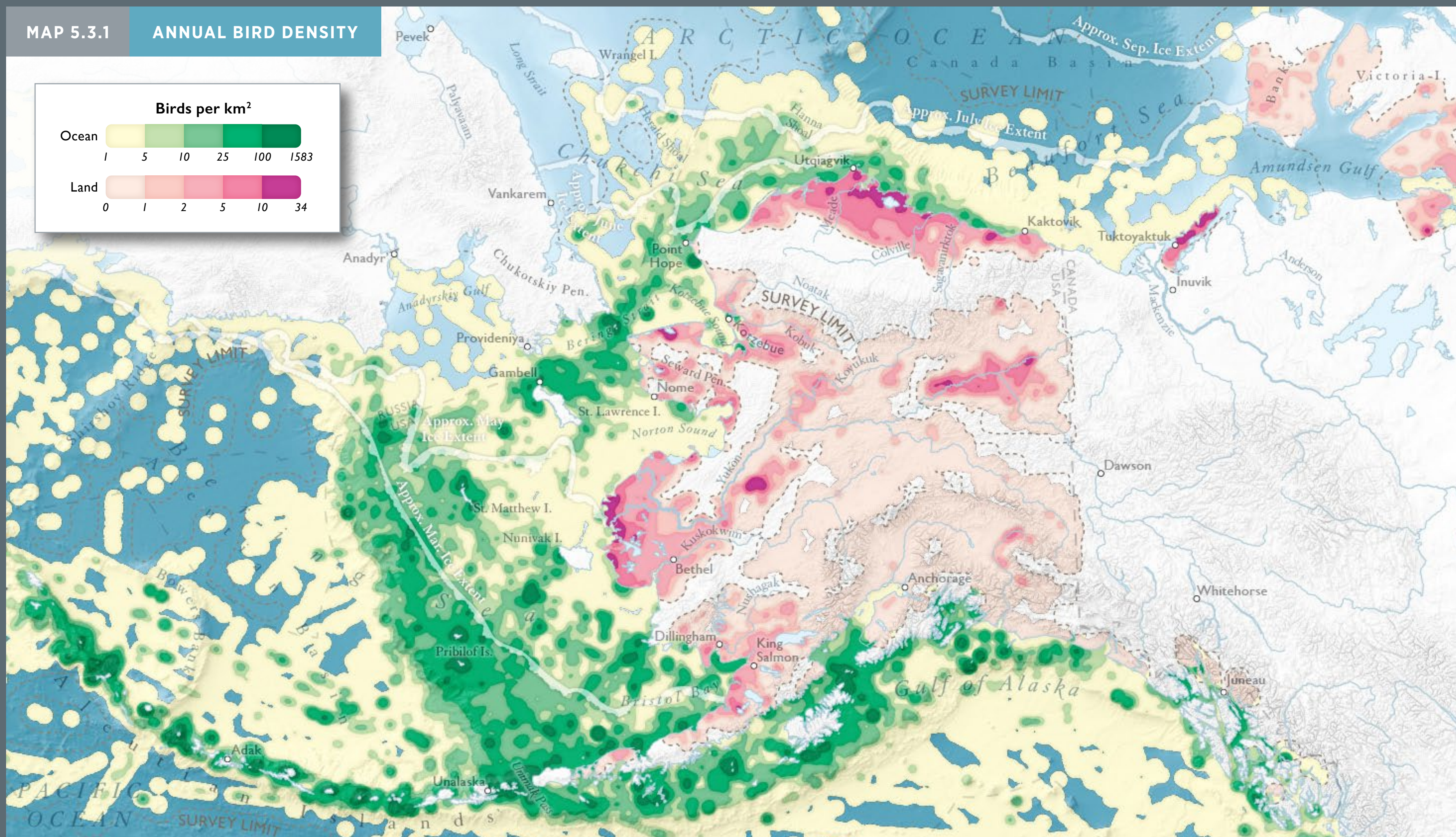
Kristine Sowl / USFWS

Important Bird Areas

Effective bird conservation requires the identification of areas used by populations for key life-history events including breeding, foraging, staging, molting, and migration. Important Bird Areas (IBAs) are designated using a set of scientific criteria to identify these essential habitats for birds. Sites are ranked as significant at the state, continental, or global level based on the estimated population abundance. The majority of Alaska's IBAs are recognized at the global level for including 1% or more of the global population of seabirds (A4ii), or 1% or more of the North American population of waterfowl and shorebirds (A4i)—both of which qualify for global status. Marine birds in Alaska (> 50 million) far outnumber the human population of the state (~740,000), and marine bird densities across the Bering Sea are of global significance; the US Fish and Wildlife Service estimates that seabird nesting along the Bering Sea coast accounts for 87% of the seabirds in the United States.

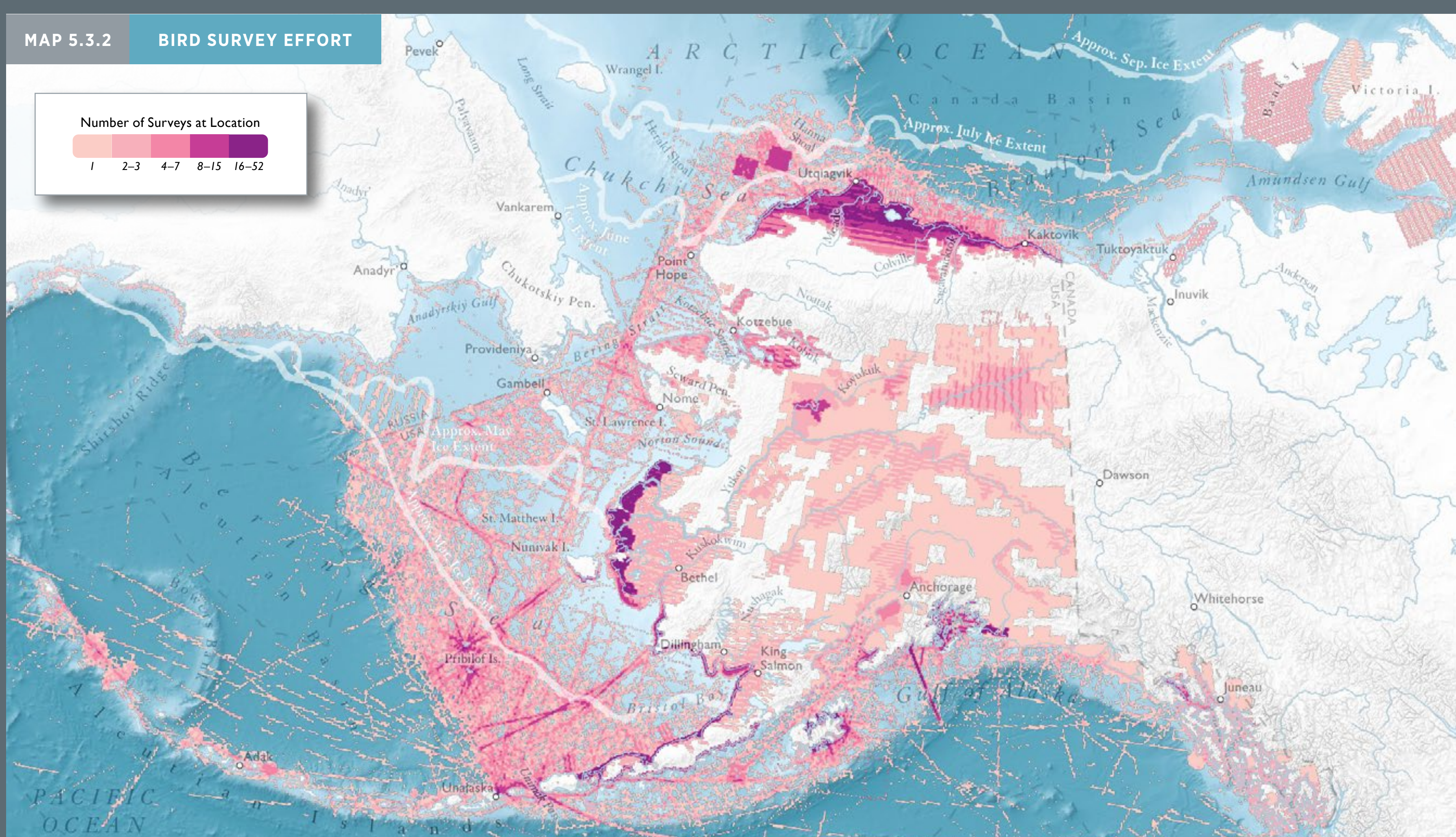
A Closer Look: Bird Density and Survey Effort

MAP 5.3.1 ANNUAL BIRD DENSITY



Map Authors: Melanie Smith, Erika Knight, and Benjamin Sullender
Cartographer: Daniel P. Huffman

MAP 5.3.2 BIRD SURVEY EFFORT



NPPSD Audubon ALASKA

Melanie Smith

MAPPING METHODS

Audubon Alaska collected the available bird survey databases for this region and compiled them into a single dataset called the Alaska Geospatial Bird Database (AGBD) in order to seamlessly analyze bird distribution and concentration (Audubon Alaska 2016a). The AGBD combines and integrates survey locations from available aerial and at-sea bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) compiled by the US Geological Survey (USGS). Surveys included in the AGBD were conducted between 1973 and 2014.

We processed each incoming dataset across a standard fishnet of 3.1-mile (5-km) bins, calculating average species density within each bin summarized by year and survey, and merged all results into a single dataset. We then dissolved that dataset to create a single value for each species in each bin representing the average density across all surveys and years, as well as the total average density of birds within each bin.

Bird survey effort (Audubon Alaska 2017a) was calculated by counting the number of surveys within each 3.1-mile (5-km) bin. Seasonal bird density was calculated using kernel density analysis with a 31-mile (50-km) search radius by breaking the species records out by season before dissolving and averaging density: winter (December–February), spring (March–May), summer (June–August), and fall (September–November). Annual bird density was calculated using kernel density analysis with a 15.5-mile (25-km) search radius based on the total average density of all species detected.

Data Quality

The AGBD survey data have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas delineated using this dataset may be biased toward US waters. Additionally, within Alaska, survey coverage and effort vary greatly, influencing overall accuracy of the resulting densities and mapped distribution patterns. Little to no survey coverage in the Canadian and Russian portions of the project area potentially result in major data gaps for total bird density and for species distributions depicted throughout this chapter.

MAP DATA SOURCES

These maps are based on the AGBD (Audubon Alaska 2016a). The AGBD is a compilation of many major survey efforts and compiled databases. The data included were:

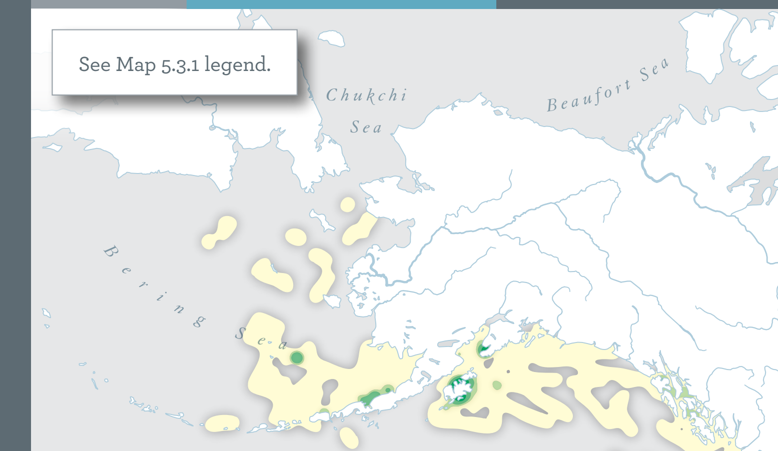
Manomet, Inc.: PRISM Shorebird (2002–2008)

NPS: Nearshore Survey (2006–2013), Wrangell Aerial Waterfowl Surveys (2007)

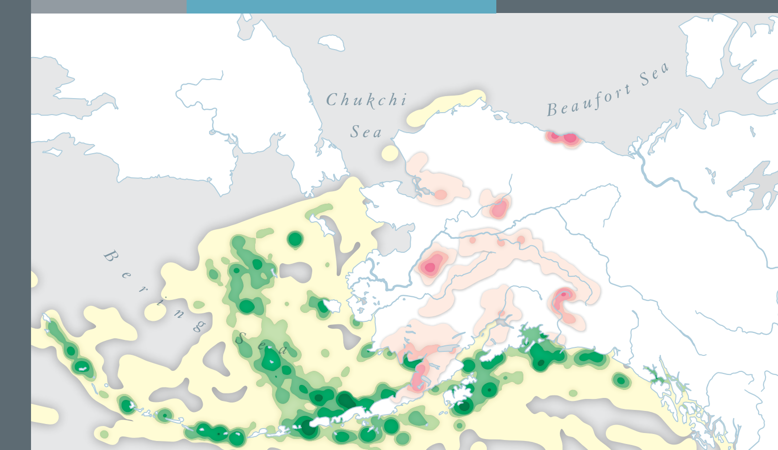
USGS: NPPSD v2

USFWS: Alaska Expanded (1989–2008), Arctic Coastal Plain (ACP) Breeding Pair (1992–2006), ACP Common Eider Shoreline Survey (1999–2009), ACP Waterbird (2007–2010), ACP Yellow-Billed Loon (2003–2004), Arctic Nearshore (1998–2003), Beaufort Nearshore (1999–2000), Beaufort Offshore (1999–2001), Black Scoter (2004–2008), Cook Inlet Steller's Eider (2004–2005), Copper River Dusky Canada Goose (1986–2009), Kodiak Steller's Eider (2001–2010), North Slope Eider (1992–2006), North Slope Shorebird Survey (2005–2007), PRISM Shorebird (2002–2008), Seward Peninsula Yellow-billed Loon (2005–2007), South-central Loon (2001–2003), Southeast Alaska (1997–2002), Southwest Alaska Emperor Goose (1999–2012), Southwest Alaska Steller's Eider (1997–2012), Teshekpuk Lake Goose Molting (1997–2006), Trumpeter Swan (2005), Central Arctic (2005–2011), At-Sea (2013–2014), Western Greater White-fronted Goose (1994–2008), Yukon Delta Goose Swan Crane (1985–2008), Yukon Delta Waterbird (1988–2008)

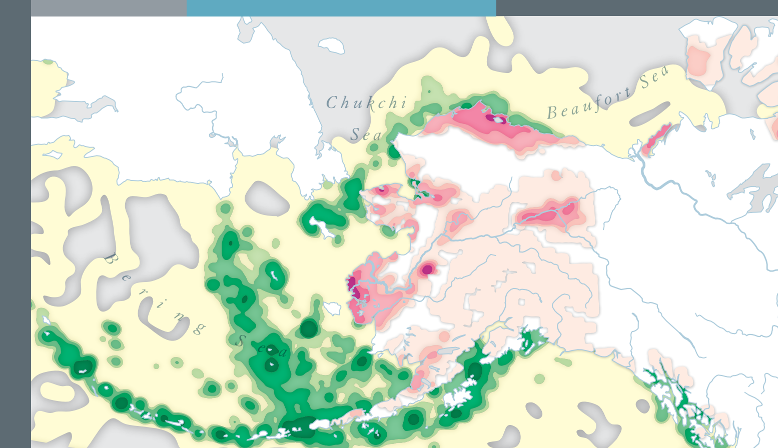
MAP 5.3.3a WINTER BIRD DENSITY



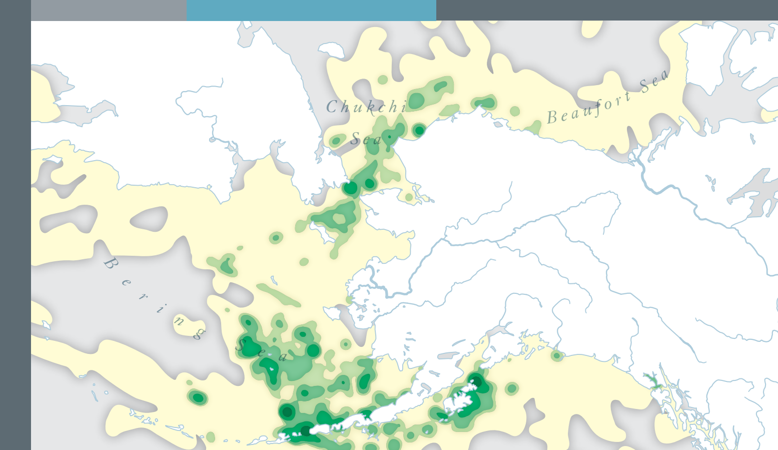
MAP 5.3.3b SPRING BIRD DENSITY



MAP 5.3.3c SUMMER BIRD DENSITY



MAP 5.3.3d FALL BIRD DENSITY



5.4
EIDERS
MAPS ON PAGES 132–139

Eiders

Max Goldman, Erika Knight, and Melanie Smith

King Eider
Somateria spectabilis

Spectacled Eider
S. fischeri

Common Eider
S. mollissima

Steller's Eider
Polysticta stelleri

Eiders are especially well-adapted to the Arctic climate, spending their entire lives within a few hundred miles of the sea-ice edge (Frimer 1994a, Oppel et al. 2011). These hardy Arctic and subarctic birds are among the northernmost nesters on the planet. The four eider species make up two distinct genera, *Somateria,* and *Polysticta,* within the sea ducks subfamily Meringae. As such, they spend the majority of their lives at sea, returning to shore only to breed (Johnsgard 1964, Lamothe 1973, Oppel et al. 2009a). Eiders are among the deepest diving of the more than 20 extant sea duck species, often reaching depths of more than 100 feet (30 m) while foraging for mollusks and crustaceans from the ocean floor. Differences mainly in size allow the four eider species to utilize similar habitats without directly competing for resources (Fox and Mitchell 1997, Merkel et al. 2007a, Merkel et al. 2007b). Because they feed on the ocean floor, they are generally found within 9 miles (15 km) of the shore, or where the shelf is not too deep to be accessible or productive (Oppel et al. 2009b, Oppel and Powell 2010b).

Eiders are deep divers, reaching depths of up to 165 feet (50 m) and averaging dives of 33–66 feet (10–20 m) (Frimer 1994b). They are covered in especially dense down, which contributes to their ability to withstand the brutal temperatures of the Arctic and subarctic. Male eiders have ornate plumage on their heads during breeding season, which they display to females with head-turning behavior, enticing them to copulate. Their webbed feet allow them to swim and dive extremely well, while the claws they have on each toe enable them to grip the icy substrate often present when they arrive at their breeding grounds (Bent 1925). While diving, eiders use their feet and wings to propel themselves forward. After each dive, they preen their feathers to promote drying and to redistribute the oil from their oil gland to protect their feathers from saturation in preparation for the next dive (Johnsgard 1964, Frimer 1994b).

DISTRIBUTION

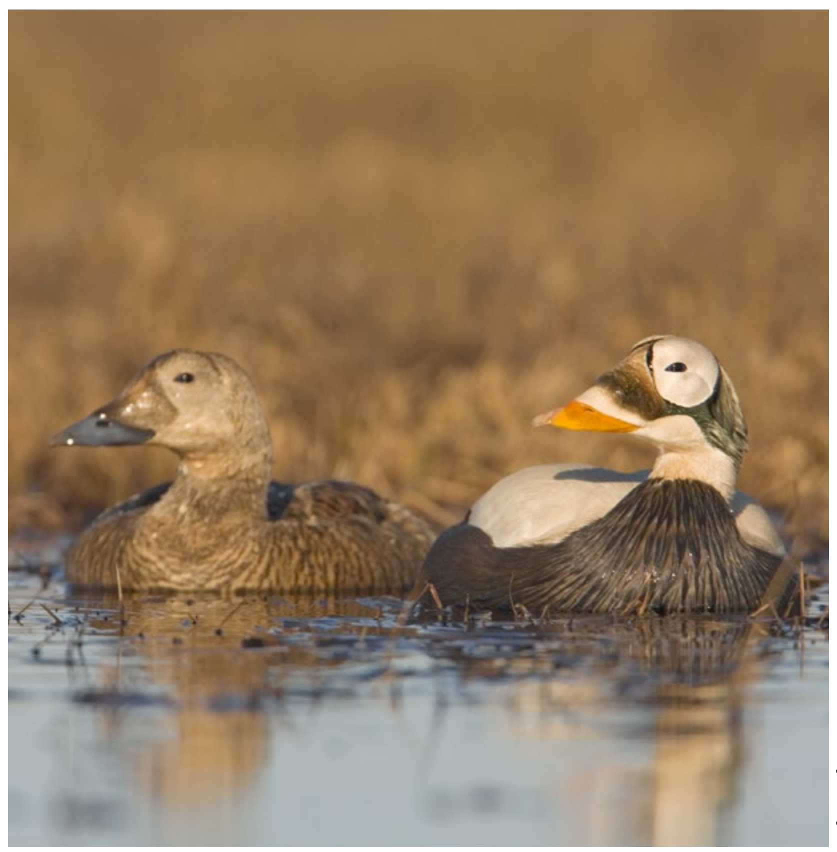
Eiders spend the vast majority of their time at sea. Males spend 11 months a year there, coming ashore only to breed. Females are on land for approximately three months for breeding, but spend the rest of the year in open water. When eiders migrate north during the spring, they often arrive before the thaw. They likely choose their nest sites based on which areas thaw and dry first. As sea ice marches south during the fall and winter, many eiders will follow the ice edge as it continues south, feeding at the productive ice margin. When the ice margin begins to retreat north in the spring, eiders again prepare to migrate to their breeding grounds.

Migration

In the spring, eiders of all species form flocks of 10,000–15,000, and up to 100,000, and migrate from staging and wintering areas to their breeding grounds. They are among the first birds to return to northern breeding grounds, flying at all hours and traveling thousands of miles north over sea ice at speeds of approximately 40 miles/hour (60 km/h) to get there (Phillips et al. 2006a, Phillips et al. 2006b, Oppel et al. 2008, Dickson 2012d, Dickson 2012c, Dickson 2012a). Soon after breeding, male eiders leave their mates and eggs for staging areas near breeding grounds to prepare for molt migration (Lamothe 1973, Cotter et al. 1997). They then depart in relatively small groups for molting areas further south. Females follow just after, or sometimes just before, the chicks fledge (Powell and Suydam 2012). The young often migrate on their own, as sea-ice formation forces them south (Frimer 1993). After molting, many eiders will over-winter in or near their molting areas, or until the advancing sea-ice edge forces them south (Oppel et al. 2008). Others will actively migrate to wintering areas. The fall migration takes place in small groups throughout the fall and early winter (Oppel et al. 2008, Dickson 2012d, Dickson 2012c).

Milo Burcham

King Eider male.



Milo Burcham

Spectacled Eider female and male.

5.4
EIDERS
MAPS ON PAGES 132–139

Wintering

Most Pacific-breeding eiders winter in the Bering Sea, seeking out the sea-ice margins of polynyas or the advancing ice edge. All of the approximately 70,000 Pacific-breeding Steller's Eiders (*Polysticta stelleri*) winter near the Alaska Peninsula, Kodiak Island, eastern Aleutian Islands, and lower Cook Inlet. While only 10% of Spectacled Eiders (*Somateria fischeri*) breed in Alaska, the entire population can be found wintering in a perennial polynya southwest of St. Lawrence Island. Eiders are often not sedentary during winter; some King Eiders (*S. spectabilis*) will travel up to 1,000 miles (1,600 km) among 3 or more wintering sites, while some eiders will remain at a single site throughout the winter months. Sea-ice concentration and food availability are the likely causes for winter movements (Oppel et al. 2008, Oppel and Powell 2009). As food availability fluctuates greatly throughout the winter, starvation becomes a grave and common threat to eiders when they begin their spring migration. In 1964, an estimated 10% (100,000 birds) of the global population of King Eiders died from exposure because of a lack of open water in staging areas in the Beaufort Sea due to a particularly harsh winter (Barry 1968). There are many other examples of mass starvation events, ice-fog related mass death, and records of large numbers of flightless, molting birds succumbing to exposure due to late season storms (Barry 1968, Myres 1958, Fournier and Hines 1994, Mallory et al. 2001).

Species Description

King Eider. The most conspicuous of the eiders, King Eiders are some of the northernmost breeding birds on the planet. They have a tendency to forage farther offshore, and in deeper water than the other eider species (Frimer 1995a, Bustnes and Lonne 1997, Fox and Mitchell 1997). King Eiders breed on the North Slope of Alaska, along the Beaufort Sea coast of Canada, and in coastal Northern Chukotka, Russia. They winter throughout the shallow waters of the Bering Sea shelf.

Spectacled Eider. Spectacled Eiders are the least colonial of the eiders, with many fewer nests per square mile than their cousins. They are listed as threatened under the Endangered Species Act (ESA). In Alaska, 5% of the global population of 363,000 Spectacled Eiders breed in coastal habitats along the Beaufort Sea and 5% of the population breed in the Yukon-Kuskokwim Delta, while the remaining 90% of the global population of this species breed on the northern coast of eastern Russia (D. Safine pers. comm.). They winter exclusively in the Bering Sea (Petersen et al. 1999).

Common Eider. The largest of the eider species, there are six to seven different subspecies of Common Eider (*Somateria mollissima*), each occupying a different geographic area of the Arctic (Mendall 1987). Common Eiders are distributed throughout high-northern latitudes, breeding in many regions of the Northern Hemisphere (Goudie et al 2000). In Alaska, Common Eiders are found in the Bering, Chukchi, and Beaufort Seas. In Canada, they breed terrestrially near Amundsen Gulf, and east into the Hudson Bay region and Nova Scotia. In Europe, Common Eiders breed along the Barents Sea, Baltic Sea, North Sea, and into France. They commonly winter in Iceland, Greenland, and Siberia and are found in the continental US as far south as Florida (Goudie et al 2000).

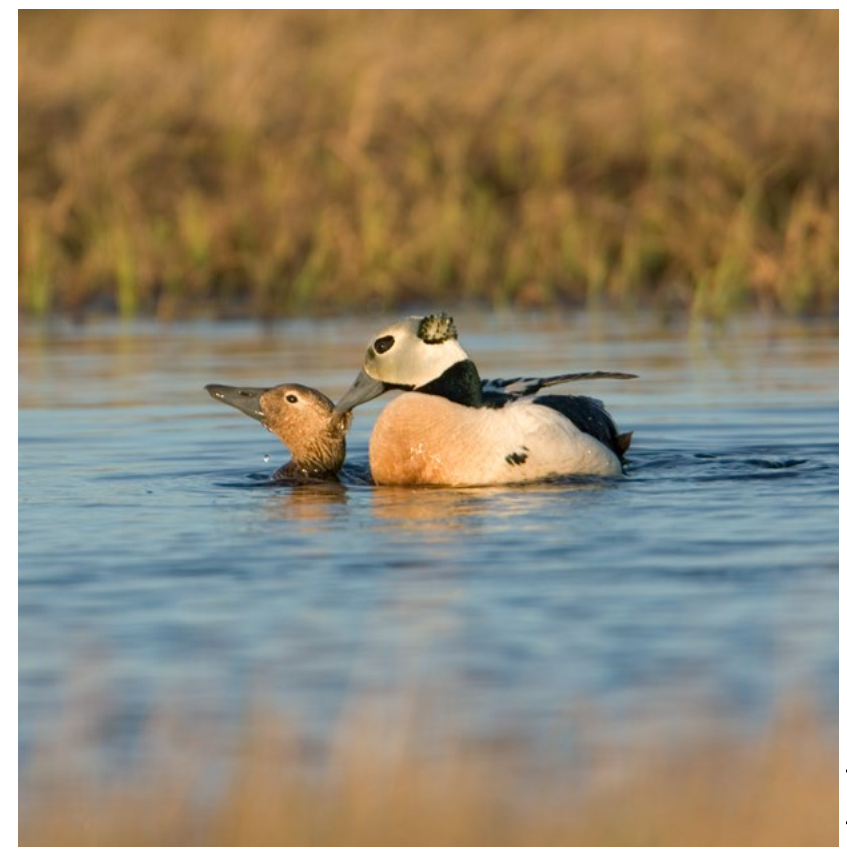
Steller's Eider. The smallest of the eider species, Steller's Eiders utilize freshwater tundra ponds during the breeding season. While the larger eider species are often found in deeper water during winter, Steller's Eiders occupy the shallow coastal waters throughout the Arctic and subarctic, rarely traveling south of Alaska waters (Fredrickson 2001). They are listed as threatened under the ESA and vulnerable on the International Union for the Conservation of Nature's (IUCN's) Redlist. Steller's Eiders are split into two populations: the Pacific-breeding population and the Atlantic-breeding population. Pacific-breeding Steller's Eiders most commonly breed on the northeastern coast of Russia, with less than 1% of the Pacific breeding population utilizing the North Slope of Alaska (D. Safine pers. comm.). They winter along the Alaska Peninsula and the Aleutian Islands, as well as along the eastern coast of the Anadyr Peninsula (Fredrickson 2001).

LIFE CYCLE

Pair bonds are formed on wintering grounds, or during spring migration (Johnsgard 1964, Lamothe 1973, Oppel and Powell 2010a). Males display to females in many ways, including head-turning to show off the ornate plumage possessed by the males of all four species, pushing (holding tip of bill close to water, chin held close to breast, head angled downward), cooing, and wing-flapping. Eider wing-flapping consists of a male facing a female, with body and head vertical, exposing the black V on its throat, and flapping twice (Johnsgard 1964). Eiders are often seasonally monogamous, although males may breed with more than one female in the same five-minute period (Lamothe 1973).

Dave Shaw

Common Eider male.



Milo Burcham

Steller's Eider female and male courtship.

5.4 EIDERS MAPS ON PAGES 132–139

Female eiders exhibit natal site fidelity, with 88% of King Eider females returning to within 15 miles (25 km) of their birth site the following year (Oppel and Powell 2010a). Nest sites are chosen as they become available, with island sites often the first to thaw and dry, followed by terrestrial sites near water (Cramp and Simmons 1977, Kondratyev 1992). The female eider chooses a location, accompanied by, but without influence from, her male counterpart. The female selects the site by probing with her bill. If the location is suitable, she settles in by moving side to side to depress the grass into a shallow bowl, which she further defines by removing vegetation (Lamothe 1973). After laying the third egg, she will begin to preen the down from her belly, adding it to the grasses that line the nest as an insulative layer. If the initial clutch fails or is predated, they may lay a second, but eiders are not known to have two successful clutches in a single season (Palmer 1976). Nest sites are often chosen in areas with an abundance of lemmings, likely to reduce predatory pressure from Arctic foxes (*Vulpes lagopus*).

Common Eiders utilize a semi-colonial breeding strategy, sometimes grouping together in the hundreds and thousands to breed. The natal-site fidelity present in all female eiders perpetuates an added benefit with Common Eiders, as their colonies are subsequently made up of closely related females, which may be the mechanism driving some of the Common Eider's uniquely cooperative behavior, such as egg-laying in nests of related individuals and communal chick-rearing, or creching (Anderson and Alisauskas 2001;2002, Ost et al. 2007).

Diet

Eiders are diving feeders, with each species hunting at different depths for prey of different sizes, likely due to the general size differences between the four species. Benthic invertebrates are the main food source for all eiders, consisting specifically of mollusks, crustaceans, echinoderms, and polychaete worms (Frimer 1995b;1997, Bustnes and Systad 2001, Lovvorn et al. 2003, Merkel et al. 2007a, Merkel et al. 2007b, Oppel et al. 2009c, Kristjansson et al. 2013). Some algae and marine vegetation are consumed as well as some fish and fish eggs. While in their breeding area, eiders are known to consume insects, including flies, midges, beetles, and larvae as well (Kistchinski and Flint 1974, Kondrat'ev 1992). The majority of food is eaten whole while submerged, with very few, larger items that require more manipulation consumed on the surface (Beauchamp et al. 1992, Bustnes and Lonne 1995).

CONSERVATION ISSUES

The Spectacled Eider and the Steller's Eider (US Fish and Wildlife Service 1997, 2001) are listed as threatened under the ESA due to substantial, unexplained decreases in population. Critical Habitat was proposed and accepted, but eider numbers continue to decline.

Since 2004, the IUCN Redlist has considered the Steller's Eider to be vulnerable because it is undergoing a rapid population reduction of 46% over 20 years (Larned et al. 2012), particularly in Alaska populations. In 2015, the IUCN deemed the Common Eider to be near threatened due to declines likely driven by overharvesting of aquatic resources, pollution, disturbance, and hunting.

Eiders are vulnerable to oil spills due to large flock sizes, distance from shore, and use of moderate-ice areas. A model of a possible oil spill on a primary staging area that would kill 1,000–5,000 breeding-age females showed that the population of King Eiders breeding in northern Alaska would decline to 1,500–3,500 females in 50 years (Bentzen and Powell 2012). Chronic oil contamination is also a serious problem in areas near international shipping lanes, such as the Aleutian Islands, the Bering Sea, the Bering Strait, and increasingly the Chukchi and Beaufort Seas.

Eiderdown is commonly used in quilts and bedding due to its insulative properties. Before eiders were given special protection under the Migratory Bird Treaty (1916, Article IV), eiderdown was collected through the indiscriminate killing of eiders. Today, eiderdown is still collected, but from nests of human-habituated eiders (female eiders line their nests with their down) and in much smaller quantities. Native subsistence hunters in Alaska and Canada harvest down, meat, and eggs from eiders.

Sport hunting of Common Eiders is becoming increasingly common, likely due to extremely liberal hunting regulations and an increase in restrictiveness over other waterfowl seasons. The impact of this increase is not well measured, but reported harvests of greater than 100,000 Common Eiders exceed sustainable levels of known breeding stocks by magnitudes of 5 to 10 (Reed and Erskine 1986).

TABLE 5.4-1. Eider life history characteristics and conservation status. Sources: Goudie et al. (2000), Fredrickson (2001), Petersen and Flint (2002), Powell and Suydam (2012), Warnock (2017).

	King Eider *Somateria spectabilis*	**Spectacled Eider** *S. fischeri*	**Common Eider** *S. mollissima*	**Steller's Eider** *Polysticta stelleri*
Body Size Mass Length Wingspan	**M** 2.5–4.5 pounds (200–2,100 g) **L** 19–28 inches (50–70 cm) **W** 34–40 inches (86–102 cm)	**M** 3–4 pounds (1,275–1,750 g) **L** 20 inches (53 cm) **W** 37 inches (95 cm)	**M** 3–6.5 pounds (1,300–3,040 g) **L** 19.5–28 inches (50–70 cm) **W** 31–43 inches (80–110 cm)	**M** 1.5–2 pounds (720–970 g) **L** 17–18 inches (43–46 cm) **W** 27 inches (69 cm)
Maximum Life Span (wild)	15 years	11 years	21 years	21 years
Clutch Size Range Average	**R** 1–16 eggs **A** 5 eggs	**R** 1–11 eggs **A** 4 eggs	**R** 1–14 eggs **A** 4 eggs	**R** 1–7 eggs **A** 4 eggs
Nest-Water Proximity	80% <100 feet (<30 m)	76% <3 feet (< 1 m)	Unknown	Avg. 10 feet (3 m)
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** No Status **IUCN:** Least Concern **WL:** Yellow List (Alaska NW Canada population)	**ESA:** Threatened **IUCN:** Least Concern **WL:** Red List	**ESA:** No Status **IUCN:** Near Threatened **WL:** Not Listed	**ESA:** Threatened **IUCN:** Vulnerable **WL:** Red List
Population Global Alaska	**G** 860,000 **A** 470,000	**G** 363,000 **A** 363,000	**G** 3.3–4 million **A** 170,000	**G** 117,500 **A** 82,000
Breeding Season Eggs Young	**E** June to late July **Y** July to late September	**E** Mid-March to mid-July **Y** Mid-June to early August	**E** June to late July **Y** July to October	**E** Early June to mid-July **Y** Early July to late August
Migration Spring Molt Fall	**S** April to late July **M** Early June to mid-September **F** Mid-October to mid-January	**S** Mid-April to mid-June **M** Mid-June to mid-September **F** Early Oct to mid-November	**S** Mid-March to June **M** Late June to late July **F** Mid-October to January	**S** Mid-April to early July **M** Late June to mid-October **F** Late July to December

5.4 EIDERS MAPS ON PAGES 132–139

TABLE 5.4-2. Data sources for eider maps (5.4.1–5.4.4), complied by layer.

	King Eider *Somateria spectabilis*	**Spectacled Eider** *S. fischeri*	**Common Eider** *S. mollissima*	**Steller's Eider** *Polysticta stelleri*
Range	• Audubon Alaska (2015) • Audubon Alaska (2016a) • BirdLife International (2017a) • Dickson et al. (1997) • eBird (2015) • National Oceanic and Atmospheric Administration (1988) • Powell and Suydam (2012) • Sea Duck Joint Venture (2016) • T. Bowman (pers. comm.)	• Audubon Alaska (2015) • Audubon Alaska (2016a) • BirdLife International (2017a) • D. Safine (pers. comm.) • eBird (2015) • Petersen et al. (1999) • Sea Duck Joint Venture (2016) • US Fish and Wildlife Service (2016b)	• Audubon Alaska (2015) • Audubon Alaska (2016a) • BirdLife International (2017a) • Dickson (2012b) • eBird (2015) • Petersen and Flint (2002) • Sea Duck Joint Venture (2016)	• Audubon Alaska (2015) • Audubon Alaska (2016a) • BirdLife International (2017a) • eBird (2015) • Martin et al. (2015) • Rosenberg et al. (2016) • Sea Duck Joint Venture (2016) • US Fish and Wildlife Service (2016b)
Breeding	• Audubon Alaska (2016b) based on > Audubon Alaska (2016a) > Dickson et al. (1997) > National Oceanic and Atmospheric Administration (1988) > Powell and Suydam (2012) > Sea Duck Joint Venture (2016) • Solovyeva and Kokhanova (2017) based on > Arkhipov et al. (2014) > Krechmar and Kondratyev (2006) > Solovyeva (2011)	• Audubon Alaska (2016b) based on Audubon Alaska (2016a) • Solovyeva and Kokhanova (2017) based on > Arkhipov et al. (2014) > Krechmar and Kondratyev (2006) > Solovyeva (2011)	• Audubon Alaska (2016b) based on Audubon Alaska (2016a) • BirdLife International (2017a) • Bollinger and Platte (2012) • Canadian Wildlife Service (2013) • D. Solovyeva (pers. comm.) • Sea Duck Joint Venture (2016) • Seabird Information Network (2011) • T. Bowman (pers. comm.) • US Fish and Wildlife Service (2008a)	• Arctic Landscape Conservation Cooperative (2012) • D. Safine (pers. comm.) • Sea Duck Joint Venture (2016) • Stehn and Platte (2009)
Wintering	• Dickson (2012a) • Oppel (2008) • Phillips et al. (2006b) • Sea Duck Joint Venture (2016) • T. Bowman and J. Fischer (pers. comm.)	• Audubon Alaska (2015) • Sexson et al. (2012)	• Dickson (2012b) • Petersen and Flint (2002) • Sea Duck Joint Venture (2016) • T. Bowman (pers. comm.) • T. Bowman and J. Fischer (pers. comm.) • US Fish and Wildlife Service (2008a)	• Kingsbery (2010) • Sea Duck Joint Venture (2016) • Sowls (1993)
Staging	• Audubon Alaska (2009b) • Dickson (2012c) • Oppel (2008) • Oppel et al. (2009a) • Phillips et al. (2007)	• Audubon Alaska (2015) • Sexson et al. (2012) • Sexson et al. (2016)	• Dickson (2012b) • Petersen and Flint (2002)	• D. Safine (pers. comm.) • Larned (2012) • Martin et al. (2015) • Rosenberg et al. (2016) • US Fish and Wildlife Service (2016a)
Molting	• Dickson (2012a) • National Oceanic and Atmospheric Administration (1988) • Oppel (2008) • Phillips et al. (2006b)	• Audubon Alaska (2015) • Sexson et al. (2012) • Sexson et al. (2016)	• D. Solovyeva (pers. comm.) • Dickson (2012b)	• D. Safine (pers. comm.) • US Fish and Wildlife Service (2016a)
Marine Regular Use	• Audubon Alaska (2017d) based on National Oceanic and Atmospheric Administration (1988)	• Audubon Alaska (2017d) based on > Audubon Alaska (2014) > BirdLife International (2017a)	• Audubon Alaska (2017d) based on National Oceanic and Atmospheric Administration (1988)	• Audubon Alaska (2017d) based on > Audubon Alaska (2014) > BirdLife International (2017a)
IBAs and IBA Core Areas	• Audubon Alaska (2014) • Audubon Alaska (2015) • BirdLife International (2017a)	• Audubon Alaska (2014) • Audubon Alaska (2015) • BirdLife International (2017a)	• Audubon Alaska (2014) • BirdLife International (2017a)	• Audubon Alaska (2014) • Audubon Alaska (2015) • BirdLife International (2017a)
Critical Habitat	Not applicable	• US Fish and Wildlife Service (2016b)	Not applicable	• US Fish and Wildlife Service (2016b)
Migration	• National Oceanic and Atmospheric Administration (1988) • Oppel et al. (2009a) • Powell and Suydam (2012)	• D. Solovyeva (pers. comm.) • Petersen et al. (1999) • Sexson et al. (2014)	• D. Solovyeva (pers. comm.) • Dickson (2012b) • National Oceanic and Atmospheric Administration (1988)	• Martin et al. (2015) • Rosenberg et al. (2016)

MAPPING METHODS (MAPS 5.4.1–5.4.4)

We categorized distribution and activity of eiders into four main categories of intensity: extent of range, regular use, concentration, and high concentration. Where possible, we analyzed survey data to draw boundaries and assess intensity of use. However, survey data alone did not provide adequate coverage of the project area. Therefore, the eider maps are a composite of both survey-derived polygons and polygons from other sources. Regular use and concentration areas are based on either a) isopleths resulting from spatial analysis, or b) information presented in reports and literature.

The mapped eider ranges were analyzed by Audubon Alaska (2016e) using species-specific observation points from eBird (2015) and Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), which combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). To assess range, we buffered all known occurrences of eiders, by species, using a 62-mile (100-km) radius, and merged polygons. Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. For each species of eider, the survey-derived range polygon was merged with the additional data listed in Table 5.4-2. Inconsistencies in the resulting polygons were manually edited and smoothed.

Breeding areas and breeding concentration areas were delineated by Audubon Alaska (2016b) based on multiple data sources. With the exception of Steller's Eiders, for which there were not enough observational data for analysis, breeding area data for mainland Alaska are based on Audubon Alaska's analysis of the AGBD (Audubon Alaska 2016a). From this database, those species-specific observation points recorded on land during the breeding season (as documented in Cornell Lab of Ornithology and American Ornithologists' Union (2016)) were processed using a kernel density analysis with a 15.5-mile (25-km) search radius. For eiders, the data generally encompass surveys conducted from the late 1980s to 2012. The 99% isopleth of the kernel density analysis was used to represent breeding regular use areas, and the 50% isopleth was used to represent breeding concentration areas. In Canada, Russia, and on St. Lawrence Island, survey data are spatially incomplete or unavailable; therefore, breeding areas in these regions are represented by merging available breeding polygons from several sources, as listed below. For Steller's Eiders, the breeding area is based on Sea Duck Joint Venture (2016) and Stehn and Platte (2009). The breeding concentration area is based on observations documented in Arctic Landscape Conservation Cooperative (2012) and Stehn and Platte (2009), with input from USFWS biologist David Safine.

For each species, wintering, molting, and staging data were composited from spatial data provided in several sources. In some cases, concentration information was available for wintering, staging, or molting. Data sources are listed together by activity, regardless of intensity (i.e. regular use or concentration), in Table 5.4-2. For more specific layer information, refer to the Map Data Sources section.

Areas of the ocean that are regularly used by each species but that cannot be assigned to a primary activity such as staging, molting, or wintering are shown as marine regular use. Marine regular use for King and Common Eiders is based on National Oceanic and Atmospheric Administration (1988) marine use areas, which were merged with a 6.2-mile (10-km) buffer of coastal areas within the species' range (Audubon Alaska 2017d). For Spectacled and Steller's Eiders, marine regular use is based on marine portions of Important Bird Areas (IBAs) in which activity-specific information is unknown.

High-concentration areas were represented using global IBAs. In Russia and Canada, we used IBA data from BirdLife International (2017a) while IBAs in Alaska were from Audubon Alaska (2014). Because IBA boundaries often encompass multiple species hotspots, in Alaska we also used available single-species IBA core areas (Audubon Alaska 2015) to show high concentration (see Smith et al. 2014c). IBA core areas do not exist for Common Eider.

Migration arrows were drawn by Audubon Alaska (2016d) based on several sources including satellite telemetry data, previously drawn migration arrows shown in National Oceanic and Atmospheric Administration (1988), and textual descriptions of migration.

The sea-ice data shown on these maps approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

Eider data exist across much of the project area. The observation data used to generate range polygons are generally available across the project area, although sparser in Russia and Canada than in Alaska. Many of the migration, wintering, staging, and molting areas are based on data from satellite telemetry studies. For all of these studies, individuals were tagged in Alaska and Canada only; we were unable to find telemetry data for eiders tagged in the Russian Far East.

As with telemetry data, the AGBD used to analyze breeding regular-use and breeding concentration areas is most robust in Alaska. However, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. There is little to no survey coverage across the Canadian and Russian portions of the project area, potentially leaving major data gaps in the mapped distribution and concentration of these species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps.

Reviewers

- Tim Bowman
- Julian Fischer
- David Safine

Common Eider female on nest.

USFWS

MAP DATA SOURCES

KING EIDER MAP

Extent of Range: Audubon Alaska (2016e) based on Audubon Alaska (2015), Audubon Alaska (2016a), Dickson et al. (1997), eBird (2015), National Oceanic and Atmospheric Administration (1988), Powell and Suydam (2012), Sea Duck Joint Venture (2016), and T. Bowman (pers. comm.)

Breeding: Audubon Alaska (2016b) based on Audubon Alaska (2016a), Dickson et al. (1997), National Oceanic and Atmospheric Administration (1988), Powell and Suydam (2012), and Sea Duck Joint Venture (2016); Solovyeva and Kokhanova (2017) based on Arkhipov et al. (2014), Krechmar and Kondratyev (2006), and Solovyeva (2011)

Breeding Concentration: Audubon Alaska (2016b) based on Audubon Alaska (2016a)

Wintering: Dickson (2012a); Kingsbery (2010); Oppel (2008); Phillips et al. (2006b); Sea Duck Joint Venture (2016); Sowls (1993); T. Bowman and J. Fischer (pers. comm.)

Staging: Audubon Alaska (2009b); Dickson (2012c); Oppel (2008); Oppel et al. (2009a); Phillips et al. (2007)

Molting: Dickson (2012a); National Oceanic and Atmospheric Administration (1988); Oppel (2008); Phillips et al. (2006b)

Marine Regular Use: Audubon Alaska (2017d) based on National Oceanic and Atmospheric Administration (1988)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Migration: Audubon Alaska (2016d) based on National Oceanic and Atmospheric Administration (1988), Oppel (2009), and Powell and Suydam (2012)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

SPECTACLED EIDER MAP

Extent of Range: Audubon Alaska (2017l) based on Audubon Alaska (2015), Audubon Alaska (2016a), BirdLife International (2017a), D. Safine (pers. comm.), eBird (2015), Petersen et al. (1999), Sea Duck Joint Venture (2016), and US Fish and Wildlife Service (2016b)

Breeding: Audubon Alaska (2017j) based on Audubon Alaska (2016a); Solovyeva and Kokhanova (2017) based on Arkhipov et al. (2014), Krechmar and Kondratyev (2006), and Solovyeva (2011)

Breeding Concentration: Audubon Alaska (2017j) based on Audubon Alaska (2016a)

Wintering: Audubon Alaska (2015); Sexson et al. (2012)

Wintering Concentration: Sexson et al. (2012)

Staging: Sexson et al. (2012); Sexson et al. (2016)

Staging Concentration: Audubon Alaska (2015); Sexson et al. (2016)

Molting: Sexson et al. (2012); Sexson et al. (2016)

Molting Concentration: Audubon Alaska (2015); Sexson et al. (2016)

Marine Regular Use: Audubon Alaska (2017d) based on Audubon Alaska (2014) and BirdLife International (2017a)

Critical Habitat: US Fish and Wildlife Service (2016b)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Migration: Audubon Alaska (2017k) based on Petersen et al. (1999) and Sexson et al. (2014); D. Solovyeva (pers. comm.)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

COMMON EIDER MAP

Extent of Range: Audubon Alaska (2017c) based on Audubon Alaska (2014), Audubon Alaska (2016a), BirdLife International (2017a), Dickson (2012b), eBird (2015), Petersen and Flint (2002), and Sea Duck Joint Venture (2016)

Breeding: Audubon Alaska (2017b) based on Audubon Alaska (2016a), Bollinger and Platte (2012), D. Solovyeva (pers. comm.), Sea Duck Joint Venture (2016), T. Bowman (pers. comm.), and US Fish and Wildlife Service (2008a)

Breeding Concentration: Audubon Alaska (2017b) based on Audubon Alaska (2016a), Bollinger and Platte (2012), Canadian Wildlife Service (2013), Seabird Information Network (2011), T. Bowman (pers. comm.), and US Fish and Wildlife Service (2008a)

Wintering: Dickson (2012b); Petersen and Flint (2002); Sea Duck Joint Venture (2016); T. Bowman (pers. comm.); T. Bowman and J. Fischer (pers. comm.); US Fish and Wildlife Service (2008a)

Wintering Concentration: Dickson (2012b); Petersen and Flint (2002)

Staging: Dickson (2012b); Petersen and Flint (2002)

Staging Concentration: Dickson (2012b)

Molting: D. Solovyeva (pers. comm.); Dickson (2012b)

Marine Regular Use: Audubon Alaska (2017d) based on National Oceanic and Atmospheric Administration (1988)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

Migration: D. Solovyeva (pers. comm.); Dickson (2012b); National Oceanic and Atmospheric Administration (1988)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

STELLER'S EIDER MAP

Extent of Range: Audubon Alaska (2016k) based on Audubon Alaska (2015), BirdLife International (2017a), eBird (2015), Martin et al. (2015), Rosenberg et al. (2016), Sea Duck Joint Venture (2016), US Fish and Wildlife Service (2016b), and US Geological Survey–Alaska Science Center (2015)

Breeding: D. Safine (pers. comm.); Sea Duck Joint Venture (2016); Stehn and Platte (2009)

Breeding Concentration: Audubon Alaska (2016i) based on Arctic Landscape Conservation Cooperative (2012) and D. Safine (pers. comm.)

Wintering: Kingsbery (2010); Sea Duck Joint Venture (2016); Sowls (1993)

Staging: D. Safine (pers. comm.); Larned (2012); Martin et al. (2015); Rosenberg et al. (2016); US Fish and Wildlife Service (2016a)

Molting: D. Safine (pers. comm.); US Fish and Wildlife Service (2016a)

Marine Regular Use: Audubon Alaska (2017d) based on Audubon Alaska (2014) and BirdLife International (2017a)

Critical Habitat: US Fish and Wildlife Service (2016b)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

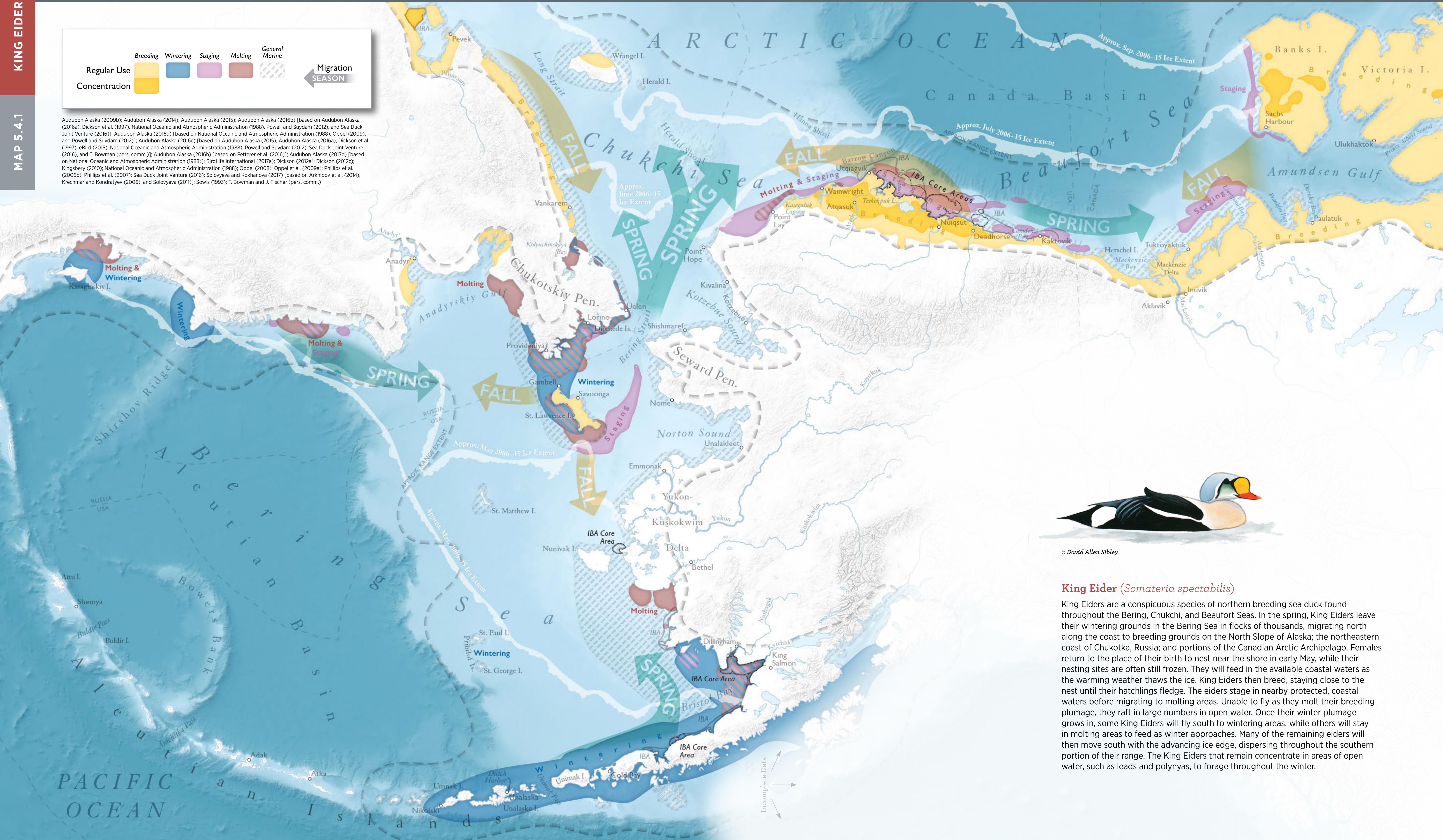
Migration: Audubon Alaska (2016j) based on Martin et al. (2015) and Rosenberg et al. (2016)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

King Eider

Map Authors: Erika Knight, Max Goldman, and Melanie Smith
Cartographer: Daniel P. Huffman

Audubon ALASKA



Audubon Alaska (2009b); Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016b) [based on Audubon Alaska (2016a), Dickson et al. (1997), National Oceanic and Atmospheric Administration (1988), Powell and Suydam (2012), and Sea Duck Joint Venture (2016)]; Audubon Alaska (2016d) [based on National Oceanic and Atmospheric Administration (1988), Oppel (2009), and Powell and Suydam (2012)]; Audubon Alaska (2016e) [based on Audubon Alaska (2015), Audubon Alaska (2016a), Dickson et al. (1997), eBird (2015), National Oceanic and Atmospheric Administration (1988), Powell and Suydam (2012), Sea Duck Joint Venture (2016), and T. Bowman (pers. comm.)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2017d) [based on National Oceanic and Atmospheric Administration (1988)]; BirdLife International (2017a); Dickson (2012a); Dickson (2012c); Kingsbery (2010); National Oceanic and Atmospheric Administration (1988); Oppel (2008); Oppel et al. (2009a); Phillips et al. (2006b); Phillips et al. (2007); Sea Duck Joint Venture (2016); Solovyeva and Kokhanova (2017) [based on Arkhipov et al. (2014), Krechmar and Kondratyev (2006), and Solovyeva (2011)]; Sowls (1993); T. Bowman and J. Fischer (pers. comm.)

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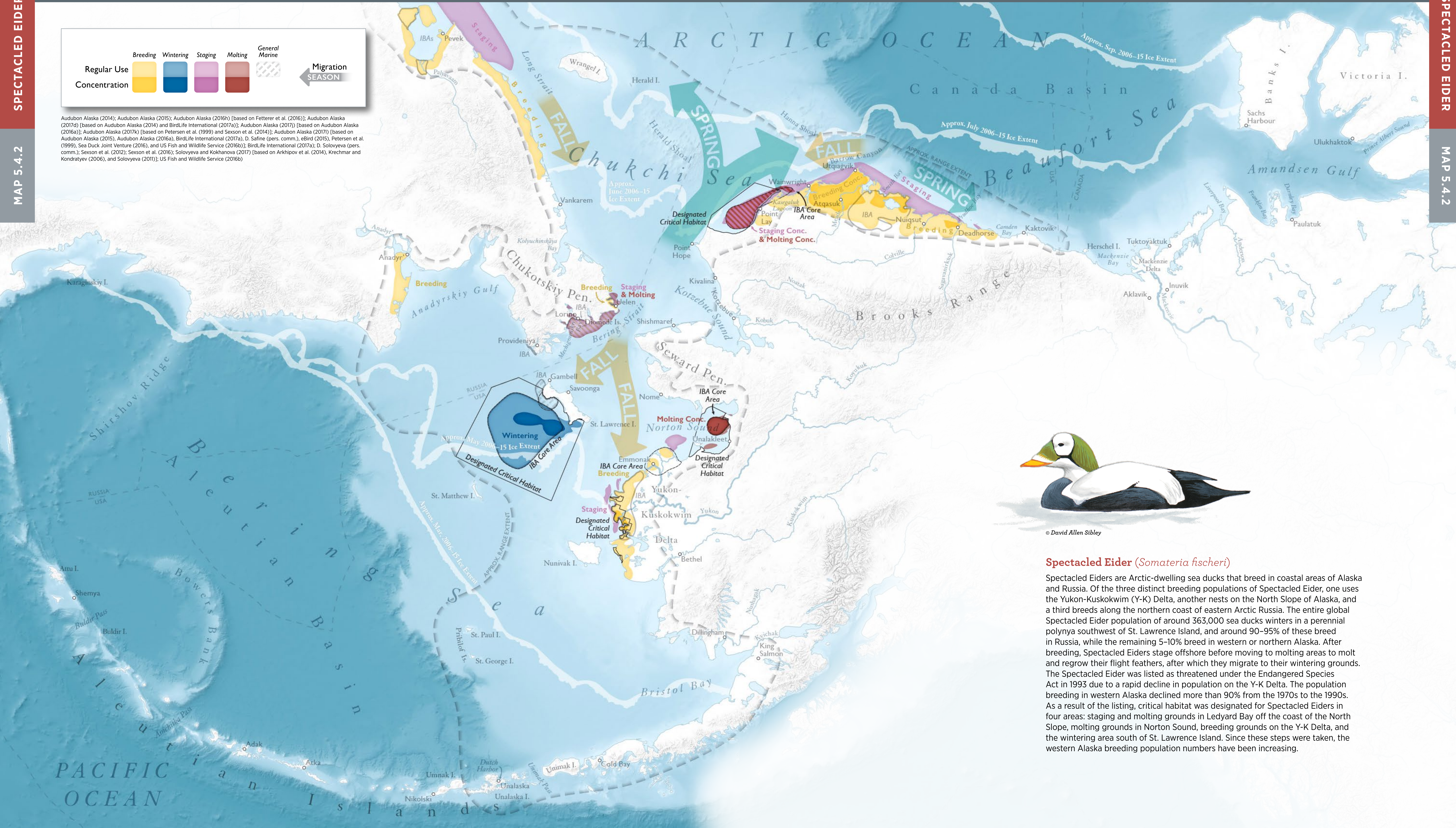
King Eider (*Somateria spectabilis*)

King Eiders are a conspicuous species of northern breeding sea duck found throughout the Bering, Chukchi, and Beaufort Seas. In the spring, King Eiders leave their wintering grounds in the Bering Sea in flocks of thousands, migrating north along the coast to breeding grounds on the North Slope of Alaska; the northeastern coast of Chukotka, Russia; and portions of the Canadian Arctic Archipelago. Females return to the place of their birth to nest near the shore in early May, while their nesting sites are often still frozen. They will feed in the available coastal waters as the warming weather thaws the ice. King Eiders then breed, staying close to the nest until their hatchlings fledge. The eiders stage in nearby protected, coastal waters before migrating to molting areas. Unable to fly as they molt their breeding plumage, they raft in large numbers in open water. Once their winter plumage grows in, some King Eiders will fly south to wintering areas, while others will stay in molting areas to feed as winter approaches. Many of the remaining eiders will then move south with the advancing ice edge, dispersing throughout the southern portion of their range. The King Eiders that remain concentrate in areas of open water, such as leads and polynyas, to forage throughout the winter.

Spectacled Eider

Map Authors: Melanie Smith, Erika Knight, and Max Goldman
Cartographer: Daniel P. Huffman

Audubon ALASKA



Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2017d) [based on Audubon Alaska (2014) and BirdLife International (2017a)]; Audubon Alaska (2017j) [based on Audubon Alaska (2016a)]; Audubon Alaska (2017k) [based on Petersen et al. (1999) and Sexson et al. (2014)]; Audubon Alaska (2017l) [based on Audubon Alaska (2015), Audubon Alaska (2016a), BirdLife International (2017a), D. Safine (pers. comm.), eBird (2015), Petersen et al. (1999), Sea Duck Joint Venture (2016), and US Fish and Wildlife Service (2016b)]; BirdLife International (2017a); D. Solovyeva (pers. comm.); Sexson et al. (2012); Sexson et al. (2016); Solovyeva and Kokhanova (2017) [based on Arkhipov et al. (2014), Krechmar and Kondratyev (2006), and Solovyeva (2011)]; US Fish and Wildlife Service (2016b)

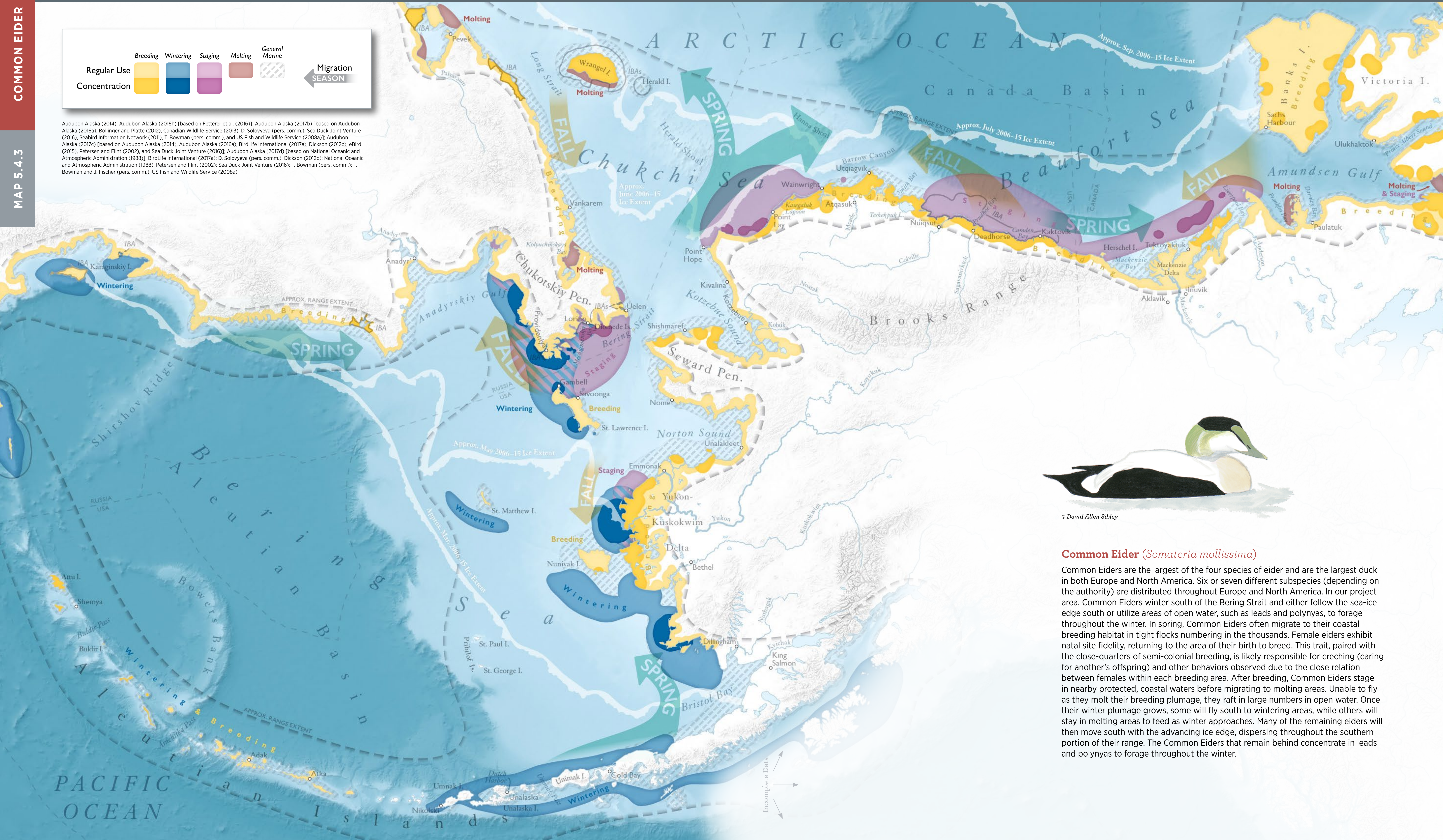
Spectacled Eider (*Somateria fischeri*)

Spectacled Eiders are Arctic-dwelling sea ducks that breed in coastal areas of Alaska and Russia. Of the three distinct breeding populations of Spectacled Eider, one uses the Yukon-Kuskokwim (Y-K) Delta, another nests on the North Slope of Alaska, and a third breeds along the northern coast of eastern Arctic Russia. The entire global Spectacled Eider population of around 363,000 sea ducks winters in a perennial polynya southwest of St. Lawrence Island, and around 90–95% of these breed in Russia, while the remaining 5–10% breed in western or northern Alaska. After breeding, Spectacled Eiders stage offshore before moving to molting areas to molt and regrow their flight feathers, after which they migrate to their wintering grounds. The Spectacled Eider was listed as threatened under the Endangered Species Act in 1993 due to a rapid decline in population on the Y-K Delta. The population breeding in western Alaska declined more than 90% from the 1970s to the 1990s. As a result of the listing, critical habitat was designated for Spectacled Eiders in four areas: staging and molting grounds in Ledyard Bay off the coast of the North Slope, molting grounds in Norton Sound, breeding grounds on the Y-K Delta, and the wintering area south of St. Lawrence Island. Since these steps were taken, the western Alaska breeding population numbers have been increasing.

Common Eider

Map Authors: Erika Knight, Max Goldman, and Melanie Smith
Cartographer: Daniel P. Huffman

Audubon ALASKA



Audubon Alaska (2014); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2017b) [based on Audubon Alaska (2016a), Bollinger and Platte (2012), Canadian Wildlife Service (2013), D. Solovyeva (pers. comm.), Sea Duck Joint Venture (2016), Seabird Information Network (2011), T. Bowman (pers. comm.), and US Fish and Wildlife Service (2008a)]; Audubon Alaska (2017c) [based on Audubon Alaska (2014), Audubon Alaska (2016a), BirdLife International (2017a), Dickson (2012b), eBird (2015), Petersen and Flint (2002), and Sea Duck Joint Venture (2016)]; Audubon Alaska (2017d) [based on National Oceanic and Atmospheric Administration (1988)]; BirdLife International (2017a); D. Solovyeva (pers. comm.); Dickson (2012b); National Oceanic and Atmospheric Administration (1988); Petersen and Flint (2002); Sea Duck Joint Venture (2016); T. Bowman (pers. comm.); T. Bowman and J. Fischer (pers. comm.); US Fish and Wildlife Service (2008a)

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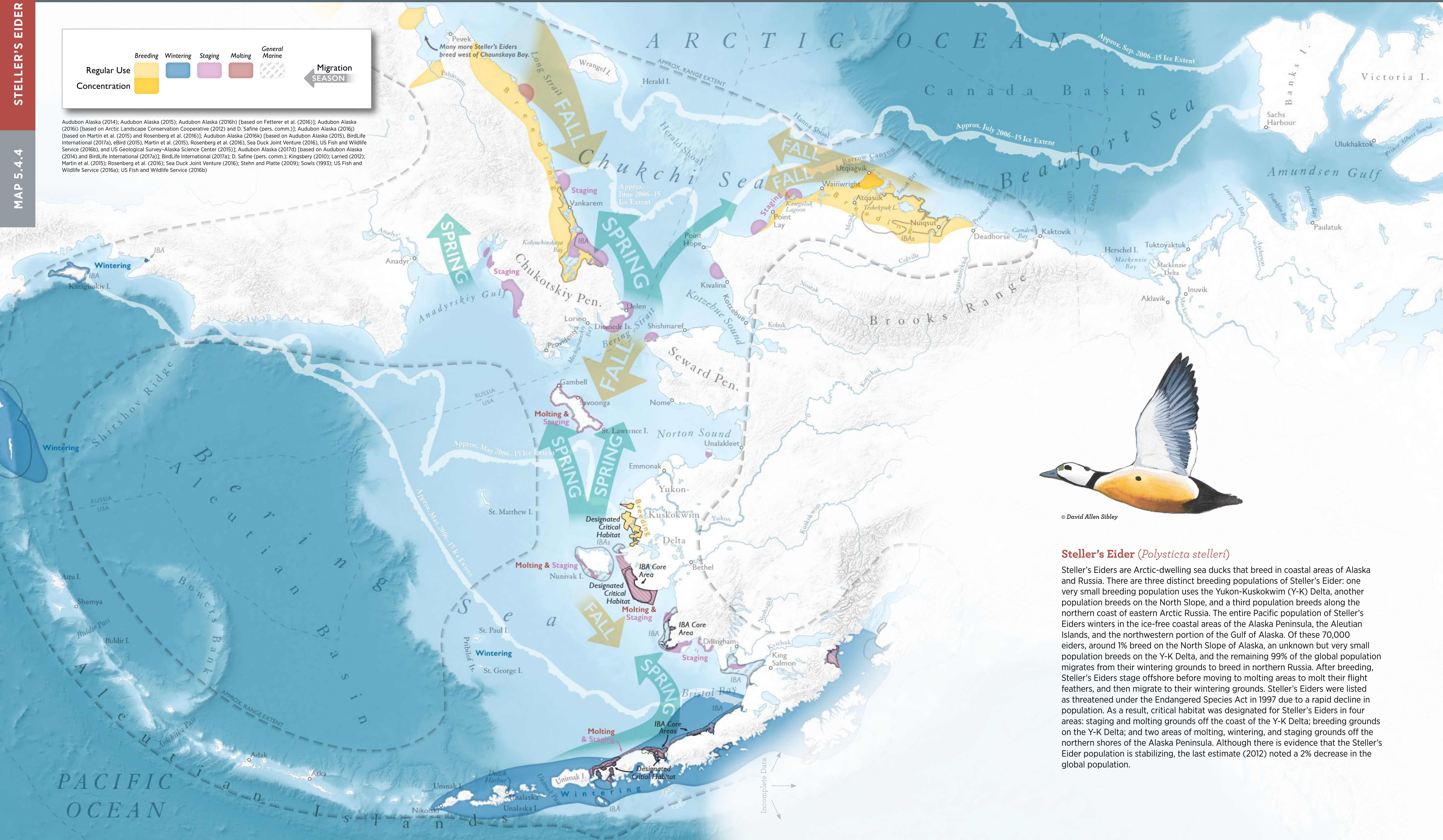
Common Eider (*Somateria mollissima*)

Common Eiders are the largest of the four species of eider and are the largest duck in both Europe and North America. Six or seven different subspecies (depending on the authority) are distributed throughout Europe and North America. In our project area, Common Eiders winter south of the Bering Strait and either follow the sea-ice edge south or utilize areas of open water, such as leads and polynyas, to forage throughout the winter. In spring, Common Eiders often migrate to their coastal breeding habitat in tight flocks numbering in the thousands. Female eiders exhibit natal site fidelity, returning to the area of their birth to breed. This trait, paired with the close-quarters of semi-colonial breeding, is likely responsible for creching (caring for another's offspring) and other behaviors observed due to the close relation between females within each breeding area. After breeding, Common Eiders stage in nearby protected, coastal waters before migrating to molting areas. Unable to fly as they molt their breeding plumage, they raft in large numbers in open water. Once their winter plumage grows, some will fly south to wintering areas, while others will stay in molting areas to feed as winter approaches. Many of the remaining eiders will then move south with the advancing ice edge, dispersing throughout the southern portion of their range. The Common Eiders that remain behind concentrate in leads and polynyas to forage throughout the winter.

Steller's Eider

Map Authors: Erika Knight, Max Goldman, and Melanie Smith
Cartographer: Daniel P. Huffman

Audubon ALASKA



Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2016i) [based on Arctic Landscape Conservation Cooperative (2012) and D. Safine (pers. comm.)]; Audubon Alaska (2016j) [based on Martin et al. (2015) and Rosenberg et al. (2016)]; Audubon Alaska (2016k) [based on Audubon Alaska (2015), BirdLife International (2017a), eBird (2015), Martin et al. (2015), Rosenberg et al. (2016), Sea Duck Joint Venture (2016), US Fish and Wildlife Service (2016b), and US Geological Survey–Alaska Science Center (2015)]; Audubon Alaska (2017d) [based on Audubon Alaska (2014) and BirdLife International (2017a)]; BirdLife International (2017a); D. Safine (pers. comm.); Kingsbery (2010); Larned (2012); Martin et al. (2015); Rosenberg et al. (2016); Sea Duck Joint Venture (2016); Stehn and Platte (2009); Sowls (1993); US Fish and Wildlife Service (2016a); US Fish and Wildlife Service (2016b)

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Steller's Eider (*Polysticta stelleri*)

Steller's Eiders are Arctic-dwelling sea ducks that breed in coastal areas of Alaska and Russia. There are three distinct breeding populations of Steller's Eider: one very small breeding population uses the Yukon-Kuskokwim (Y-K) Delta, another population breeds on the North Slope, and a third population breeds along the northern coast of eastern Arctic Russia. The entire Pacific population of Steller's Eiders winters in the ice-free coastal areas of the Alaska Peninsula, the Aleutian Islands, and the northwestern portion of the Gulf of Alaska. Of these 70,000 eiders, around 1% breed on the North Slope of Alaska, an unknown but very small population breeds on the Y-K Delta, and the remaining 99% of the global population migrates from their wintering grounds to breed in northern Russia. After breeding, Steller's Eiders stage offshore before moving to molting areas to molt their flight feathers, and then migrate to their wintering grounds. Steller's Eiders were listed as threatened under the Endangered Species Act in 1997 due to a rapid decline in population. As a result, critical habitat was designated for Steller's Eiders in four areas: staging and molting grounds off the coast of the Y-K Delta; breeding grounds on the Y-K Delta; and two areas of molting, wintering, and staging grounds off the northern shores of the Alaska Peninsula. Although there is evidence that the Steller's Eider population is stabilizing, the last estimate (2012) noted a 2% decrease in the global population.

5.5
LONG-TAILED DUCK
MAP ON PAGES 144–145

Long-tailed Duck

Clangula hyemalis

Max Goldman, Erika Knight, and Melanie Smith

Long-tailed Ducks (*Clangula hyemalis*) are distinct Arctic sea ducks with smallish bodies and eponymous slim, elongated tail feathers. Once commonly referred to in North America as Oldsquaw, Long-tailed Ducks breed in tundra and taiga regions of far-northern latitudes.

Small for a sea duck, this plump, black-and-gray duck is in a near constant state of plumage change, with three molts per annum, instead of the much more common two molts each year (Salomonsen 1949). The namesake elongated tail feathers are displayed by males year-round. During winter, the Long-tailed Duck's head is white, with a gray patch around the eye and a black patch extending down the neck to its black back and rump. In summer, as breeding season approaches, the male's head turns from white to black, but the gray eyepatch remains. As the summer turns to fall, its head and neck turn white, and its breast and flanks turn gray (Palmer 1976, Payne et al. 2015). Females undergo three molts also, though they are more nuanced than the male's. Male Long-tailed Ducks are slightly larger than females, although there is substantial overlap between the two sexes. While Long-tailed Ducks are distinct, when silhouetted they are sometimes confused with Northern Pintails due to the accentuated tail-feathers each species possesses. However, the erratic flight pattern of the Long-tailed Duck is unique.

These ducks are highly vocal, with a distinctive, nasal call that carries widely. The call of the Long-tailed Duck can be heard throughout the treeless areas where these ducks spend their lives. Males are the most common caller, using their vocality during courtship, although they will also call during the winter (Palmer 1976, Robertson and Savard 2002).

DISTRIBUTION

Long-tailed Ducks are an Arctic- and subarctic-breeding species with a Holarctic distribution. They typically nest at low densities in tundra and taiga habitats, with higher densities sometimes seen on islands (Robertson and Savard 2002). Sea ice and its accompanying features are integral components of Long-tailed Duck ecology (Gilchrist and Robertson 2000).

Wintering

These small, hardy ducks will remain at the northern extent of their range until ice necessitates a move further south to their wintering grounds. They spend the winter on both coasts of North America and on the Great Lakes, sometimes using other large freshwater bodies throughout the continent. In other parts of their range, Long-tailed Ducks spend the winter in southwestern Greenland and throughout most of Iceland (Scott and Rose 1996), as well as ice-free coastal areas of the North and Baltic Seas such as Denmark, Germany, Poland, Finland, Sweden, and Norway (Mathiasson 1970, Laursen 1989). In the North Pacific and Arctic Oceans, Long-tailed Ducks congregate during winter in coastal or protected waters of the Bering Sea, and south as far as the Sea of Okhotsk near Hokkaido, Japan (Dement'ev 1966, Kistchinski 1973, Brazil and Yabuuchi 1991).

Migration

Long-tailed Ducks often gather at distinct, traditional, coastal areas in the thousands before beginning the journey north (Palmer 1976, Woodby and Divoky 1982, Veit and Petersen 1993). As with other Arctic sea ducks, many Long-tailed Ducks begin their northward migration in late winter, while the sea-ice margin is still near its maximum annual extent (Bergman 1974, Campbell et al. 2007a). Most migrate north along offshore leads from their temperate and subarctic wintering grounds in spring, preferring not to stray from open water and food sources (Johnson 1985, Ader and Kespaik 1996).

As they migrate along coastal areas, they can often be identified by their distinct, erratic flight patterns (Palmer 1976). They generally travel in small groups, flying close to the water's surface. Some birds are known to take an overland route in years of especially heavy ice coverage, even crossing the Brooks Range on the way to their coastal breeding habitat (Richardson and Johnson 1981, Woodby and Divoky 1982, Johnson et al. 2005). Upon arrival, flocks of Long-tailed Ducks will congregate in leads or polynyas as they wait for their inland breeding habitat to thaw (McLaren and Alliston 1985).

After breeding, male Long-tailed Ducks migrate to molting areas in small groups beginning in late June, and juveniles and some females join them in July (Johnson and Richardson 1982, Johnson 1985, Petersen et al. 2003). Molting groups of 30,000–40,000 individuals are found in protected coastal waters along the Beaufort and Chukchi coasts and the Chukotka and Seward Peninsulas, although smaller molting groups are likely present throughout the Arctic, including some that molt on breeding areas (e.g. females with broods) (Howell et al. 2003, Flint et al. 2004, Derksen 2015, Payne et al. 2015, Viain and Guillemette 2016). After molting, many Long-tailed Ducks spend September and early October staging in the Canadian Beaufort Sea before migrating to wintering areas in October to December (Ader and Kespaik 1996, Campbell et al. 2007a, Bartzen et al. 2017).

LIFE CYCLE

Long-tailed Ducks do not reach sexual maturity until their third year (Robertson and Savard 2002). Females exhibit a high rate of natal site fidelity, returning year after year to the breeding area of their birth, regardless of success (Alison 1975b, Robertson and Savard 2002). Long-tailed Duck females choose a nest site and begin nest-building after the first egg is laid (Alison 1975b). Females lay six to eight eggs and line the nest with grasses, sedges, heathers, willow leaves, and a sparse amount of down (Drury 1961, Alison 1975b). Eggs hatch after three to four weeks of incubation, and ducklings are able to feed immediately. As early as a single day after hatching, ducklings are led to open water by their mothers (Alison 1975b). While they are poor divers at first, they learn quickly and must be taken to new ponds regularly as food resources become depleted (Alison 1976, Pehrsson and Nystrom 1988). While many large sea ducks require eight weeks or more to fledge, Long-tailed Ducks can take flight after only six weeks (Alison 1975a, Alison 1976).

TABLE 5.5-1. Long-tailed Duck life history characteristics and conservation status. Sources: Robertson and Savard (2002), Warnock (2017).

	Long-tailed Duck *Clangula hyemalis*
Body Size	
Mass	**M** 1–2.5 pounds (500–1,100 g)
Length	**L** 15–19 inches (40–50 cm)
Wingspan	**W** 70–95 inches (190–240 cm)
Maximum Life Span (wild)	Unknown
Clutch Size	
Range	**R** 6–8 eggs
Average	**A** 7 eggs
Conservation Status	
Endangered Species Act	**ESA:** Not Listed
IUCN Red List	**IUCN:** Vulnerable
Audubon AK WatchList	**WL:** Not Listed
Population	
Global	**G** 6,500,000
Alaska	**A** 200,000
Breeding Season	
Eggs	**E** Late May–Early July
Young	**Y** Early July–Late August
Migration	
Spring	**S** Early April to Late May
Molt	**M** Late June to August
Fall	**F** Late October to Late December

5.5
LONG-TAILED DUCK
MAP ON PAGES 144–145

The Long-tailed Duck undergoes three distinct molts per year. The male Long-tailed Duck (shown here in winter plumage) has two distinct, elongated tail feathers, for which the species is named.

Milo Burcham

Diet

Long-tailed Ducks are likely the most adept divers of all sea ducks, regularly gathering food at depths of 15–50 feet (5–15 m), and as deep as 230 feet (70 m) (Schorger 1947;1951, Bustnes and Systad 2001). They feed primarily on epibenthic prey found among the rocks and kelp along the ocean floor, consuming their prey underwater unless the food item is especially large (Peterson and Ellarson 1977, White et al. 2009). On breeding grounds, Long-tailed Ducks eat larval and adult aquatic insects, crustaceans, small fishes, fish roe, and vegetable matter (Cottam 1939, Pehrsson and Nystrom 1988, Sellin 1990). When wintering on salt water, they tend to eat epibenthic amphipods, mysids, bivalves, gastropods, and isopods (Cottam 1939, Johnson 1984, Sanger and Jones 1984) and abundant herring eggs when available. On freshwater wintering grounds, they tend to feed more heavily on amphipods, fish, oligochaete worms, and mollusks (Peterson and Ellarson 1977, Rofritz 1977).

CONSERVATION ISSUES

There is evidence of a decline in the worldwide population of Long-tailed Ducks, but regional trends vary (Schamber et al. 2009, Bellebaum et al. 2014, Bowman 2015). The International Union for the Conservation of Nature (IUCN) lists the worldwide population of Long-tailed Ducks as vulnerable. In North America, they are protected by the Migratory Bird Treaty Act of 1918, but legally hunted for both sport and subsistence. In North America, the Long-tailed Duck population apparently declined substantially from the 1970s to the 1990s, but has since stabilized, although the species is poorly monitored (Robertson and Savard 2002). Elsewhere, these ducks are one of the species protected by the Agreement on the Conservation of African-Eurasian Migratory Waterbirds. In 2008, the US Fish and Wildlife Service (USFWS) rejected an Endangered Species Act petition to list them as endangered. They are not listed on Audubon Alaska's WatchList.

Long-tailed Ducks are responding to increased and persistent threats with declines in numbers in many parts of their circumpolar range, although actual causes of decline are difficult to ascertain. Flint et al. (2012) provided evidence suggesting that changes in abundance of some sea duck species, including Long-tailed Ducks, were strongly influenced by changes in the oceanic environment, although multiple causes are likely responsible. While lead shot has been a consistent source of contamination, it was outlawed in the US in 1998, Canada in 1999, and again briefly in the US in 2016, although the ban was lifted by the US Department of the Interior in March of 2017. Waterfowl and other birds are known to ingest lead shot (Pattee and Hennes 1983, Schummer et al. 2011). In Alaska, especially high lead-exposure levels in nesting female Long-tailed Ducks has been proposed as a cause of nest declines of more than 20% in the Yukon-Kuskokwim Delta population (Flint et al. 1997, Schamber et al. 2009).

Long-tailed Duck mortality due to gill-net entanglement has historically been a common occurrence and substantial source of mortality throughout their global range (Scott 1938, Ellarson 1956, Zydelis et al. 2009). Changes in fisheries management in the US and Canada have abated much of the local concern, although international fisheries in

MAP ON PAGES 144–145

much of the Long-tailed Duck's range have not adopted safer practices, and bycatch is possibly still an important source of mortality in the Baltic Sea (Žydelis et al. 2013).

MAPPING METHODS (MAP 5.5)

We categorized Long-tailed Duck distribution and activity into three main categories of intensity: extent of range, regular use, and concentration. Where possible, we analyzed survey data to draw boundaries and assess intensity of use. However, survey data alone did not provide adequate coverage of the project area. Therefore, the Long-tailed Duck map is a composite of both survey-derived polygons and polygons from other sources. Regular-use and concentration areas are based on either a) isopleths resulting from spatial analysis, or b) information presented in reports and literature.

The mapped Long-tailed Duck range was analyzed by Audubon Alaska (2016g) using observation points from eBird (2015) and Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a). The AGBD combines and integrates point locations from available bird surveys conducted by the USFWS, the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). To assess range, we buffered all known occurrences of Long-tailed Ducks using a 62-mile (100-km) radius, and merged polygons. Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. The survey-derived range polygon was merged with Long-tailed Duck data from Audubon Alaska (2015), Bartzen et al. (2017), BirdLife International (2017a), Sea Duck Joint Venture (2016), Petersen et al. (2003), and Portenko (1972). Inconsistencies in the resulting polygons were manually edited and smoothed.

Breeding regular-use and concentration areas were delineated by Audubon Alaska (2017f) by merging and smoothing breeding data from BirdLife International (2017a), personal communication with USFWS biologist Marc Romano, National Oceanic and Atmospheric Administration (1988), Dickson et al. (1997), Portenko (1972), Sea Duck Joint Venture (2016), and Audubon Alaska's analysis of the AGBD (Audubon Alaska 2016a). For our analysis, Long-tailed Duck observation points recorded on land during the breeding season (May–September, as documented in Cornell Lab of Ornithology and American Ornithologists' Union (2016)) were processed using a kernel density analysis with a 15.5-mile (25-km) search radius. For Long-tailed Duck, the data encompass surveys conducted from 1988 to 2013. The 99% isopleth of this analysis was incorporated into the merged breeding regular-use polygon. Breeding concentration areas were represented by the 50% isopleth from the kernel density analysis.

Wintering areas were compiled by Audubon Alaska based on wintering information provided in Bartzen et al. (2017), Kingsbery (2010), Sea Duck Joint Venture (2016), and Sowls (1993).

Staging areas were compiled by Audubon Alaska based on staging information provided in Bartzen et al. (2017) and Petersen et al. (2003).

Molting areas were compiled by Audubon Alaska based on molting information provided in National Oceanic and Atmospheric Administration (1988), National Oceanic and Atmospheric Administration (2005), Portenko (1972), and Dickson and Gilchrist (2002). In addition, we delineated molting areas along the North Slope coast of Alaska based on aerial survey data recorded in Fischer et al. (2002) and Lysne et al. (2004), and in personal communication with Paul Flint, whose research on Long-tailed Duck molting areas is documented in Flint et al. (2016).

Areas of the ocean that are regularly used by Long-tailed Ducks but that cannot be assigned to a primary activity such as staging, molting, or wintering are shown based on National Oceanic and Atmospheric Administration (1988), merged with a 6.2-mile (10-km) buffer of the coastal areas within the species' range.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, IBAs for Long-tailed Ducks are based on data from BirdLife International (2017a), while IBAs in Alaska are from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also show single-species IBA core areas to indicate high concentrations specific to Long-tailed Ducks (see Smith et al. 2014c).

Migration arrows were published in Bartzen et al. (2017).

The sea-ice data shown on this map approximate median monthly sea ice extent. The monthly sea-ice lines were based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

Various forms of Long-tailed Duck data exist across much of the project area. The observation data used to generate range polygons are available across the project area, although they are sparser in Russia and Canada than in Alaska. Molting data are also sparser in Russia. Migration, wintering, and staging data are largely based on one satellite telemetry study of 57 Long-tailed Ducks tagged in the western Canadian Arctic (Bartzen et al. 2017), although the wintering and staging areas incorporate data from additional publications as well.

As with telemetry data, the AGBD used to analyze breeding regular-use and breeding concentration areas is most robust in Alaska. However, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting map. There is little to no survey coverage in the Canadian and Russian portions of the project area, potentially leaving major data gaps in the mapped distribution and concentration of this species. Refer to Map 5.3.1 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps.

Reviewers

- Tim Bowman
- Julian Fischer

MAP DATA SOURCES

Extent of Range: Audubon Alaska (2016g) based on Audubon Alaska (2015), Audubon Alaska (2016a), Bartzen et al. (2017), BirdLife International (2017a), eBird (2015), Petersen et al. (2003), Portenko (1972), and Sea Duck Joint Venture (2016)

Breeding: Audubon Alaska (2017f) based on Audubon Alaska (2016a) and Sea Duck Joint Venture (2016); BirdLife International (2017a); Dickson et al. (1997); M. Romano (pers. comm.); National Oceanic and Atmospheric Administration (1988); Portenko (1972)

Breeding Concentration: Audubon Alaska (2017f) based on Audubon Alaska (2016a)

Wintering: Bartzen et al. (2017); Kingsbery (2010); Sea Duck Joint Venture (2016); Sowls (1993)

Staging: Bartzen et al. (2017); Petersen et al. (2003)

Molting: Audubon Alaska (2016f) based on Fischer et al. (2002), Lysne et al. (2004) and P. Flint (pers. comm.); Dickson and Gilchrist (2002); National Oceanic and Atmospheric Administration (1988); National Oceanic and Atmospheric Administration (2005); Portenko (1972)

Marine Regular Use: Audubon Alaska (2017g) based on National Oceanic and Atmospheric Administration (1988)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Migration: Bartzen et al. (2017)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

MAP ON PAGES 144–145

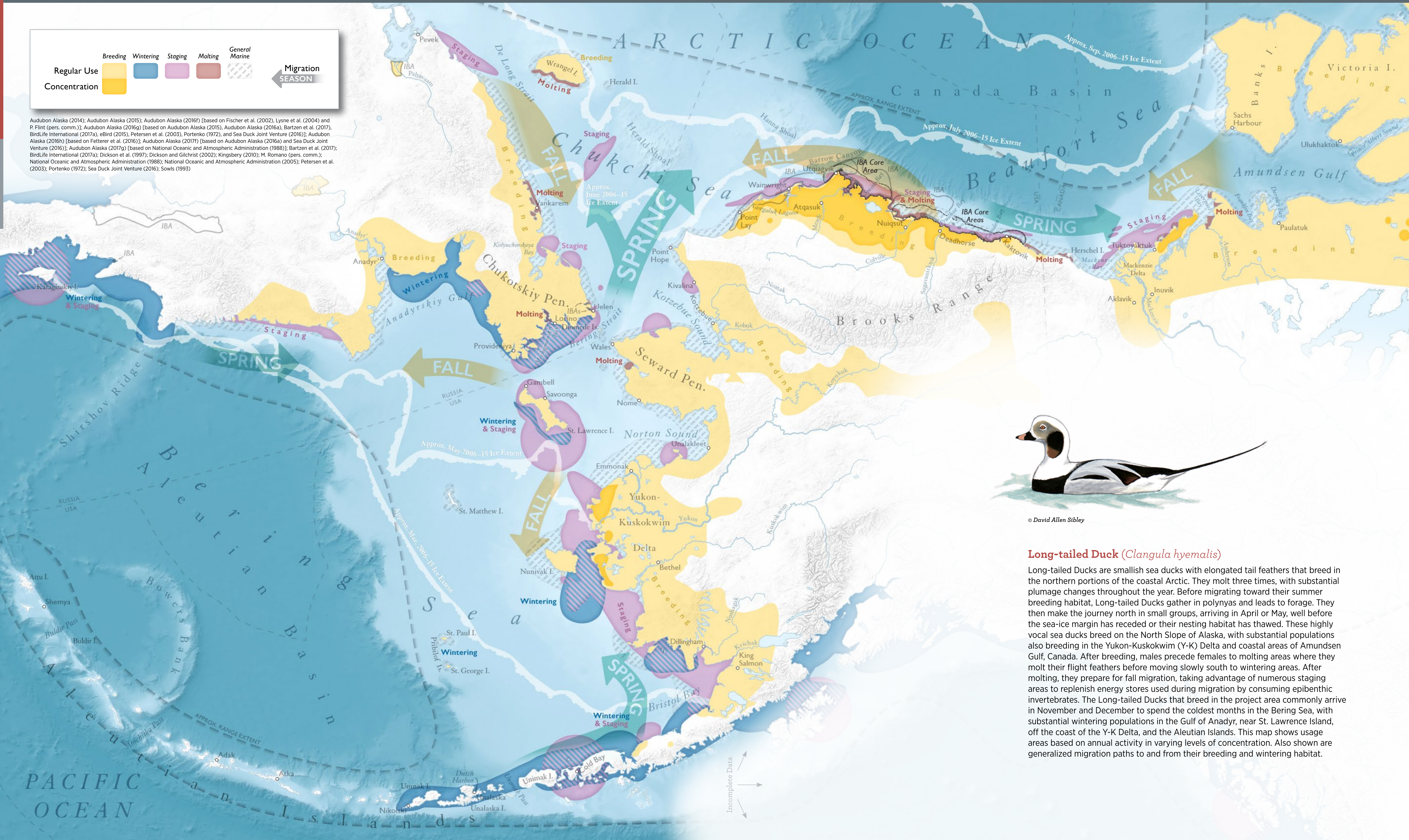
Long-tailed Duck nests are composed of grasses and leaves, and lined with down. Females incubate six to eight eggs for nearly a month before their ducklings hatch. These precocious ducklings leave the nest to feed with their parents within a day of hatching, and fledge when only a month and a half old. A female Long-tailed Duck is pictured on a downy nest.

Milo Burcham

Long-tailed Duck

Map Authors: Erika Knight, Max Goldman, and Melanie Smith
Cartographer: Daniel P. Huffman

Audubon ALASKA



Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016f) [based on Fischer et al. (2002), Lysne et al. (2004) and P. Flint (pers. comm.)]; Audubon Alaska (2016g) [based on Audubon Alaska (2015), Audubon Alaska (2016a), Bartzen et al. (2017), BirdLife International (2017a), eBird (2015), Petersen et al. (2003), Portenko (1972), and Sea Duck Joint Venture (2016)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2017f) [based on Audubon Alaska (2016a) and Sea Duck Joint Venture (2016)]; Audubon Alaska (2017g) [based on National Oceanic and Atmospheric Administration (1988)]; Bartzen et al. (2017); BirdLife International (2017a); Dickson et al. (1997); Dickson and Gilchrist (2002); Kingsbery (2010); M. Romano (pers. comm.); National Oceanic and Atmospheric Administration (1988); National Oceanic and Atmospheric Administration (2005); Petersen et al. (2003); Portenko (1972); Sea Duck Joint Venture (2016); Sowls (1993)

Long-tailed Duck (*Clangula hyemalis*)

Long-tailed Ducks are smallish sea ducks with elongated tail feathers that breed in the northern portions of the coastal Arctic. They molt three times, with substantial plumage changes throughout the year. Before migrating toward their summer breeding habitat, Long-tailed Ducks gather in polynyas and leads to forage. They then make the journey north in small groups, arriving in April or May, well before the sea-ice margin has receded or their nesting habitat has thawed. These highly vocal sea ducks breed on the North Slope of Alaska, with substantial populations also breeding in the Yukon-Kuskokwim (Y-K) Delta and coastal areas of Amundsen Gulf, Canada. After breeding, males precede females to molting areas where they molt their flight feathers before moving slowly south to wintering areas. After molting, they prepare for fall migration, taking advantage of numerous staging areas to replenish energy stores used during migration by consuming epibenthic invertebrates. The Long-tailed Ducks that breed in the project area commonly arrive in November and December to spend the coldest months in the Bering Sea, with substantial wintering populations in the Gulf of Anadyr, near St. Lawrence Island, off the coast of the Y-K Delta, and the Aleutian Islands. This map shows usage areas based on annual activity in varying levels of concentration. Also shown are generalized migration paths to and from their breeding and wintering habitat.

Loons

Max Goldman, Erika Knight, and Melanie Smith

Yellow-billed Loon

Gavia adamsii

Red-throated Loon

G. stellata

The Yellow-billed Loon (*Gavia adamsii*) and the Red-throated Loon (*G. stellata*) are migratory diving birds that nest in the lakes of northern North America and Eurasia. These subarctic and Arctic species hunt fish in nearshore marine habitats or large, clear, freshwater lakes. A close relative of the Common Loon (*G. immer*), the Yellow-billed Loon is distinct because of its namesake yellow bill and its northerly range, although the two species are often mistaken for each other (Phillips 1990). This confusion stems not only from their physical appearance but also from obvious similarities in behavior and call, which has likely resulted in incorrect estimates of population size and range for the Yellow-billed Loon in the past (North 1994). As a result, there are very few long-term data regarding this species, and the only monitored population is the Alaska—Arctic Coastal Plain (Alaska—ACP) breeding population, which is often used as an indicator of the species as a whole (Schmutz and Rizzolo 2012, US Fish and Wildlife Service 2014b, J. Schmutz 2017). The Red-throated Loon is distinctly smaller than the five other extant loons (*Gavia* spp.) and is rarely mistaken for any other species, although winter plumage of the Red-throated Loon and the Pacific Loon are similar.

Red-throated and Yellow-billed Loons are distinguished from each other by a number of characteristics. The Red-throated Loon is substantially smaller and slighter, with finer features and unique markings, such as a dark, brownish-red throat patch, and pale-gray head and neck. They lack the distinctive black back markings of other loons in breeding plumage and can be as little as one-third the size of the much bulkier Yellow-billed Loon. The slender neck and fine, pointed, upturned bill of the Red-throated Loon give it a quintessential loon profile.

Among the largest of the five extant species of loon, the Yellow-billed Loon is very similar in appearance to its similarly sized sister taxon, the Common Loon (Evers et al. 2010). In breeding plumage, both species have black heads and black backs spotted with white. Each has a "necklace" of white stripes as well, although the number of stripes differs between species, with the Yellow-billed Loon having more than 12 and the Common Loon having fewer than 12 stripes (North 1994). The differences in their bills give the clearest way to identify the two species. The Yellow-billed Loon's yellow- to ivory-colored bill is often held in an uptilted position, while the Common Loon holds its bluish-black bill closer to parallel with the water (Binford and Remsen 1974, Burn and Mather 1974, Evers et al. 2010).

Yellow-billed Loons, Red-throated Loons, and their cousins are well-suited to foraging under water. Their streamlined shape allows them to efficiently move through their aquatic habitat to pursue prey. They propel themselves with their feet, keeping their wings pinned closely to their bodies. Their aptness in water does not translate to land, however, as they often have difficulty walking, and are only able to initiate flight from water (US Fish and Wildlife Service 2014b). When they take to the air, loons fly with their necks outstretched and their feet trailing behind (Andres 1993).

Milo Burcham

Red-throated Loon adult in breeding plumage.

TABLE 5.6-1. Loon life-history characteristics and conservation status. Sources: North (1994), Barr et al. (2000), Warnock (2017).

	Yellow-billed Loon *Gavia adamsii*	Red-throated Loon *G. stellata*
Body Size Mass Length	**M** 10–13 pounds (4.5–6 kg) **L** 30–36 inches (75–90 cm)	**M** 3–5 pounds (1.5–2.5 kg) **L** 20–27 inches (50–70 cm)
Maximum Life Span (wild)	Unknown	Unknown
Clutch Size Range	1–2 eggs	1–2 eggs
Nest-Water Proximity	<6.5 feet (<2 m)	<6.5 feet (<2 m)
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Not Warranted **IUCN:** Near Threatened **WL:** Red List	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Red List
Population Global Alaska	**G** 24,000 **A** 3,500	**G** 400,000 **A** 15,000
Breeding Season Eggs Young	**E** May to August **Y** Mid-July to October	**E** May to August **Y** Mid-July to October
Migration Spring Fall	**S** April to July **F** Mid-August to November	**S** April to July **F** Mid-August to November

DISTRIBUTION

The Yellow-billed Loon and Red-throated Loon are the rarest and the most widely distributed of the five extant loons, respectively.

Migration

Starting in April, Yellow-billed and Red-throated Loons migrate from wintering grounds to breeding grounds, and return after breeding each fall, usually arriving at wintering areas by mid-November (North 1994, Barr et al. 2000). They mainly utilize coastal marine resources when migrating, although some western Canada breeding Yellow-billed Loons follow an overland migration route from Southeast Alaska, likely foraging in large lakes along the way (Schmutz 2017). Traveling singly or in pairs, Arctic-breeding loons congregate in leads and polynyas near their breeding territory before beginning the nesting process (Barr et al. 2000, Mallory and Fontaine 2004). After breeding, males, females, and juveniles will migrate independently to wintering grounds beginning in early September. Failed breeders may leave as early as July (North 1994, Barr et al. 2000). Juvenile loons are known to stay in wintering areas until sexually mature, will not migrate to breeding areas until the age of three, and are not likely to successfully breed until they are six (Evers et al. 2010).

Wintering

The wintering range of Yellow-billed Loons includes coastal waters of the Aleutians through Southeast Alaska, south to Puget Sound; the Pacific Coast of Asia from the Sea of Okhotsk to the Yellow Sea; the Barents Sea to the Norwegian coast; and likely the British coast. Red-throated Loons winter in the Aleutian Islands, Southeast Alaska, Asia and Russia, but their winter range also extends along the east coast of the US, the western US south to Baja, Mexico, and portions of coastal Europe including Scandinavia, the UK, Portugal, Spain, and Italy, among others (Gibson and Byrd 2007, Strann and Østnes 2007, US Fish and Wildlife Service 2014b, Gibson et al. 2015). They prefer sheltered marine coastal areas with moderately shallow water, presumably for prey selection.

LIFE CYCLE

Yellow-billed and Red-throated Loons generally form pair bonds once they arrive at their breeding territory in June. Loons are monogamous each breeding season, although death or eviction from their territory will immediately prompt a new pair bond to form. Yellow-billed and Red-throated Loons are especially territorial, evicting any other loons and diving ducks from their territory, which is comprised of 1–2 lakes ranging in size from 30 to more than 250 acres (13–100 ha). They avoid lakes that are associated with rivers and have fluctuating seasonal water levels (North and Ryan 1986, 1989).

After the bond has been established and their territory has been defended, the pair will begin building a nest or improving on a previous year's nest (Davis 1972, Dickson 1993, Eberl and Picman 1993, US Fish and Wildlife Service 2014b). Loon nests are most often located on islands or peninsulas within 3 feet (1 m) of the water's edge (North 1994). They are simple nests, comprised of a depression in shoreline vegetation, peat, or mud that is intermittently reinforced with grass and moss throughout habitation (North and Ryan 1989, Barr et al. 2000).

Nest building is immediately followed by the laying of usually two, 3.5-inch (9-cm) long, brownish, elliptical eggs. The pair divides the task of incubation, splitting time between sitting on eggs and foraging for themselves and their mate. About 28 days later, the eggs will hatch. Chicks leave the nest with their parents soon after hatching, moving between natal and brood-rearing lakes until fledging at about ten weeks (North 1994, Earnst et al. 2005, Earnst et al. 2006). Survival rates from hatching to fledging are approximately 50%, with late ice melt contributing to especially low chick survival in some years (US Fish and Wildlife Service 2014b).

Diet

Loons pursue prey underwater, and often under ice, by propelling themselves forward with their rear-facing feet to catch a variety of small fishes, such as ninespine sticklebacks (*Pungitius pungitius*), least cisco (*Coregonus sardinella*), Alaska blackfish (*Dallia pectoralis*), and slimy sculpin (*Cottus cognatus*) (US Fish and Wildlife Service 2014b, Haynes et al. 2015). In wintering ranges, they will consume a more varied diet, including fishes, crustaceans, and worms (Bailey 1922, Cottam 1939, North 1994, Barr et al. 2000, US Fish and Wildlife Service 2014b).

CONSERVATION ISSUES

Loons are protected in the US by the Migratory Bird Treaty Act of 1918, and the Agreement on the Conservation of African-Eurasian Waterbirds. The Yellow-billed Loon was designated as a candidate for listing under the Endangered Species Act (ESA) in March of 2009, after a petition to the US Fish and Wildlife Service (USFWS) to list them as an endangered or threatened species was received in April of 2004. After publishing a 12-month finding in the Federal Register in 2007, USFWS concluded that listing the Yellow-billed Loon as an endangered or threatened species under the ESA was "warranted, but precluded by higher listing priorities," and was thereby added to the list of species annually reviewed by USFWS. In 2010, the International Union for the Conservation of Nature (IUCN) classified the Yellow-billed Loon as near-threatened due to "a moderately rapid population decline owing to unsustainable subsistence harvest" (IUCN 2016). In October of 2014, after further study into the population status within Alaska, the USFWS found that listing the Yellow-billed Loon was not warranted.

The Red-throated Loon is not listed by the ESA, and is considered a species of least concern by the IUCN (BirdLife International 2016a), although conservative estimates show that the Alaska population likely dropped by over 50% (Groves et al. 1996). Audubon Alaska includes both species on the Red List of its WatchList, indicating that each species is experiencing declines (Warnock 2017).

Human activity and climate change are the most pressing management concerns regarding Yellow-billed Loons. In the Yellow Sea portion of their wintering range, intertidal reclamation for industrial and agriculture development has resulted in the destruction of as much as 60% of the area's tidal wetlands over the last half-century

MAPS ON PAGES 150–153

Bob Wick / Bureau of Land Management

Yellow-billed Loons, among the largest of the loon species, breed on the banks of freshwater ponds in the far northern portions of Alaska in the US, the Chukotka Peninsula in Russia, and the Canadian Arctic.

(Murray et al. 2014). Red-throated Loons have been especially hard hit by this habitat loss and the resulting concentration of environmental toxins, such as polychlorinated biphenyl (PCB), as they rely on shallow waters to feed during the winter (Schmutz et al. 2009). As with many Arctic-breeding species, infrastructure development and spill potential related to hydrocarbon extraction pose imminent threats. Oil and gas exploration is prevalent in the breeding and nearshore marine regular-use and concentration areas for both the Yellow-billed and Red-throated Loons in Alaska (Bart et al. 2013). Oil spills, infrastructure, vehicle and aircraft disturbance, lake pollution, and increased predation are issues that may affect them. Additionally, the sustained warming of the Arctic, and sea-level rise due to global climate change threatens to inundate their Arctic coastal tundra breeding habitats with fresh water, destroying the saline sensitive environment that sustains adult loons and their young through the breeding season (Schoen et al. 2013). Subsistence harvest of loons continues but is not considered to be a serious threat, as take numbers are low, and unlikely to impact populations (Naves and Zeller 2017). These concerns, along with commercial fishing bycatch and the potential for an increase in novel pathogens as the climate becomes more temperate, pose the most pressing threats to the survival of the Yellow-billed and Red-throated Loons in the Arctic (Groves et al. 1996, Agler et al. 1999, Hodges et al. 2002).

MAPPING METHODS (MAPS 5.6.1–5.6.2)

For the loon maps, we categorized distribution and activity into four main categories of intensity: extent of range, regular use, and concentration. Where possible, we analyzed survey data to draw boundaries and assess intensity of use. However, survey data alone did not provide adequate coverage of the project area. Therefore, the loon maps are a composite of both survey-derived polygons and polygons from other sources. Regular-use and concentration areas are based on either a) boundaries based on spatial analysis, or b) information presented in reports and literature.

The mapped range extents for each species were analyzed by Audubon Alaska (2016m) using observation points from eBird (2015), Schmutz (2017), Arctic Landscape Conservation Cooperative (2013) (for Yellow-billed Loons only), and Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). To assess range, we buffered all known occurrences of each species using a 62-mile (100-km) radius, and merged polygons. Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. For Yellow-billed Loons, the survey-derived range polygon was merged with range data from Alaska Department of Fish and Game (2016). Inconsistencies in the resulting polygons were manually edited and smoothed.

For Yellow-billed Loons, breeding regular-use and concentration areas were delineated by Audubon Alaska (2017m) by merging and smoothing breeding data from US Fish and Wildlife Service (2014b), Audubon Alaska (2009d), and Audubon Alaska's analysis of the AGBD (Audubon Alaska 2016a). For our analysis, Yellow-billed Loon observation points recorded on land during the breeding season (as documented in Cornell Lab of Ornithology and American Ornithologists' Union (2016)) were processed using a kernel density analysis with a 15.5-mile (25-km) search radius. The data encompass surveys conducted from 1992 to 2011. The 99% isopleth of this analysis was incorporated into the merged breeding regular-use polygon. Breeding concentration areas were represented by the 50% isopleth from the kernel density analysis.

For Red-throated Loons, breeding regular-use and concentration areas were compiled by Audubon Alaska (2009c) based on data from several sources, including Portenko (1972), Flint et al. (1984), Walker and Smith (2014), and Drew and Piatt (2005). The breeding regular-use area also incorporated data from Cornell Lab of Ornithology and American Ornithologists' Union (2016).

MAPS ON PAGES 150–153

To delineate general marine regular-use areas, we used a combination of telemetry data (Schmutz 2017) and at-sea surveys (Audubon Alaska 2016a). To delineate areas from telemetry data, location classes with the highest spatial certainty were utilized (LC 0–3), and we removed points that intersected land. To discriminate points where loons were stopped on the water or moving slowly through an area (i.e. not migrating), we selected only locations with a movement rate of 3.1 miles (5 km) per hour or less. Next, we converted points to a raster grid with a 3.1-mile (5-km) cell size, counting the number of unique individuals occurring in each bin. We then converted raster cells back to points resulting in one point at the centroid of each bin. To remove spatial outliers, we ran a nearest neighbor analysis to identify points within 31 miles (50 km) of another occurrence, from either the telemetry or at-sea survey data. Next we ran a 78-mile (125-km) kernel density analysis, and calculated the 99% isopleth. We then reverse-buffered the isopleth line to trim back toward the buffered point locations. Next, we analyzed the at-sea survey data using nearly the same process: removed points on land, utilized locations within 31 miles (50 km) of each other, averaged reported densities across 3.1-mile (5-km) cells, ran a 78-mile (125-km) kernel density analysis, calculated the 99% isopleth, and trimmed the result. Due to many overlaps and inconsistencies between the results of the telemetry and at-sea analyses, GIS analysis alone was not a sufficient delineator—the final boundaries were hand-drawn to incorporate the results of the two analyses while referring back to the original point data, including the timing and density of birds reported. After that, we ran a 31-mile (50-km) kernel density analysis for each of the datasets (telemetry and at-sea) using the same methods as used for the previous (marine regular-use) analyses. We then delineated the areas with a density of 1 or more standard deviations above the mean regional density. The resulting polygons were classified into regular-use staging or regular-use wintering based on timing of use and geographic location. Areas with density of 3 or more standard deviations above the mean density were mapped as staging and wintering concentration areas.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, IBAs are shown based on data from BirdLife International (2017a) while IBAs in Alaska are from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also show single-species IBA core areas to indicate high concentrations specific to each species (see Smith et al. 2014c).

Migration arrows were drawn by Audubon Alaska (2016d) based on satellite telemetry data from Schmutz (2017).

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

By combining telemetry, at-sea, and aerial surveys, data for Yellow-billed and Red-throated Loons exist across much of the project area, although data are sparser in Russia and Canada than in Alaska. Migration and wintering data are based on one satellite telemetry study (Schmutz 2017) in which over 50 birds of each species were tagged in Alaska between 2000 and 2010.

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Arctic Canada. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Areas of little to no survey coverage in the Canadian and Russian portions of the project area potentially resulted in data gaps for these species, although telemetry data were used to fill gaps in many locations. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps.

Reviewer

- Joel Schmutz

MAP DATA SOURCES

YELLOW-BILLED LOON MAP

Extent of Range: Audubon Alaska (2016m) based on Alaska Department of Fish and Game (2016), Arctic Landscape Conservation Cooperative (2013), Audubon Alaska (2016a), eBird (2015), and Schmutz (2017)

Breeding: Audubon Alaska (2017m) based on Audubon Alaska (2009d), Audubon Alaska (2016a), and US Fish and Wildlife Service (2014b)

Breeding Concentration: Audubon Alaska (2017m) based on Audubon Alaska (2016a)

Wintering: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017)

Wintering Concentration: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017)

Staging: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017)

Staging Concentration: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017); BirdLife International (2017a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Migration: Audubon Alaska (2016l) based on Schmutz (2017)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

RED-THROATED LOON MAP

Extent of Range: Audubon Alaska (2016m) based on Audubon Alaska (2016a), eBird (2015), and Schmutz (2017)

Breeding: Audubon Alaska (2009c) based on Flint et al. (1984), Portenko (1972), US Geological Survey–Alaska Science Center (2015), and Walker and Smith (2014); Cornell Lab of Ornithology and American Ornithologists' Union (2016); Portenko (1972)

Breeding Concentration: Audubon Alaska (2009c) based on Flint et al. (1984), Portenko (1972), US Geological Survey–Alaska Science Center (2015), and Walker and Smith (2014)

Wintering: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017)

Wintering Concentration: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017)

Staging: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017)

Staging Concentration: Audubon Alaska (2016n) based on Audubon Alaska (2016a) and Schmutz (2017)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

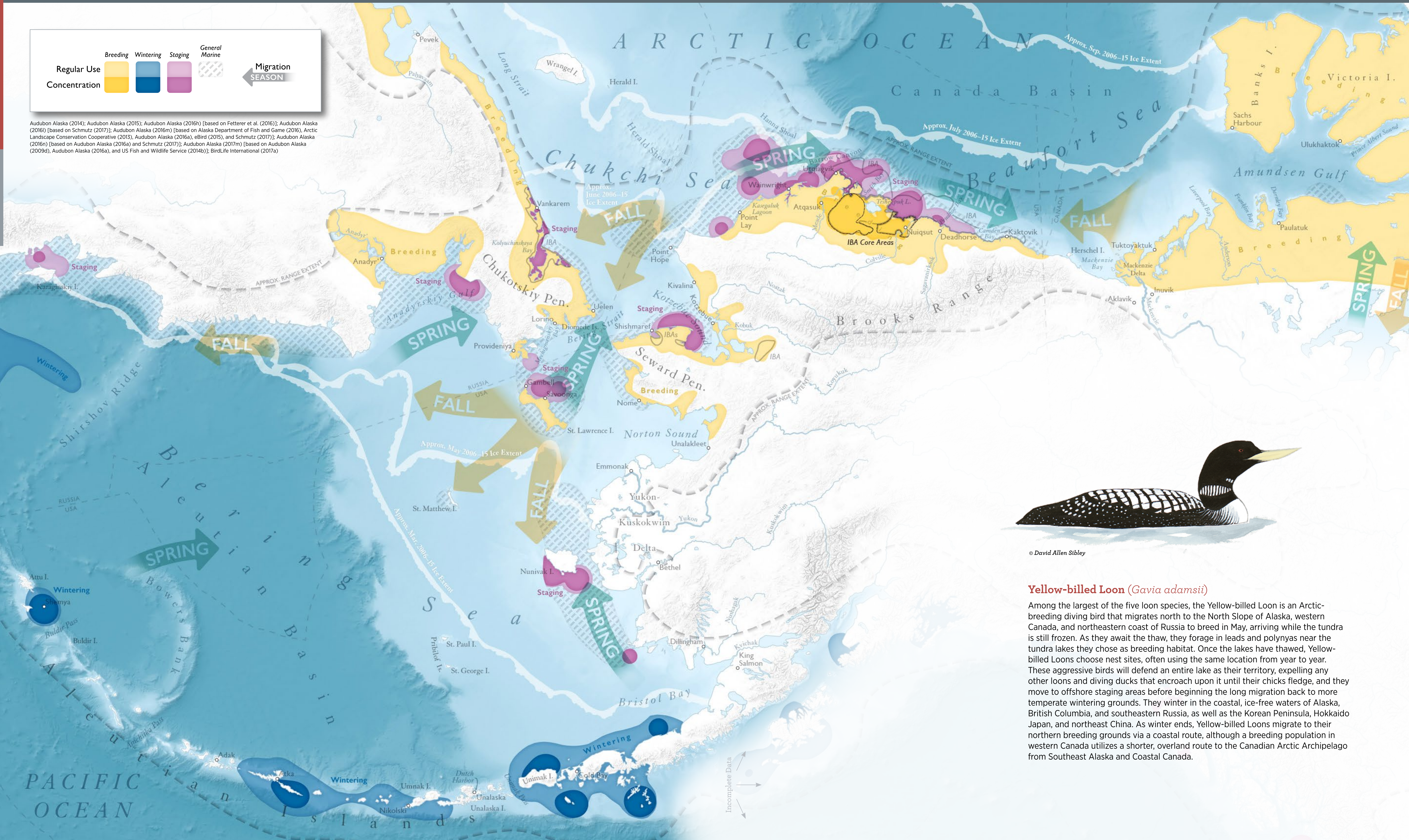
Migration: Audubon Alaska (2016l) based on Schmutz (2017)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Yellow-billed Loon

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Audubon ALASKA



Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2016l) [based on Schmutz (2017)]; Audubon Alaska (2016m) [based on Alaska Department of Fish and Game (2016), Arctic Landscape Conservation Cooperative (2013), Audubon Alaska (2016a), eBird (2015), and Schmutz (2017)]; Audubon Alaska (2016n) [based on Audubon Alaska (2016a) and Schmutz (2017)]; Audubon Alaska (2017m) [based on Audubon Alaska (2009d), Audubon Alaska (2016a), and US Fish and Wildlife Service (2014b)]; BirdLife International (2017a)

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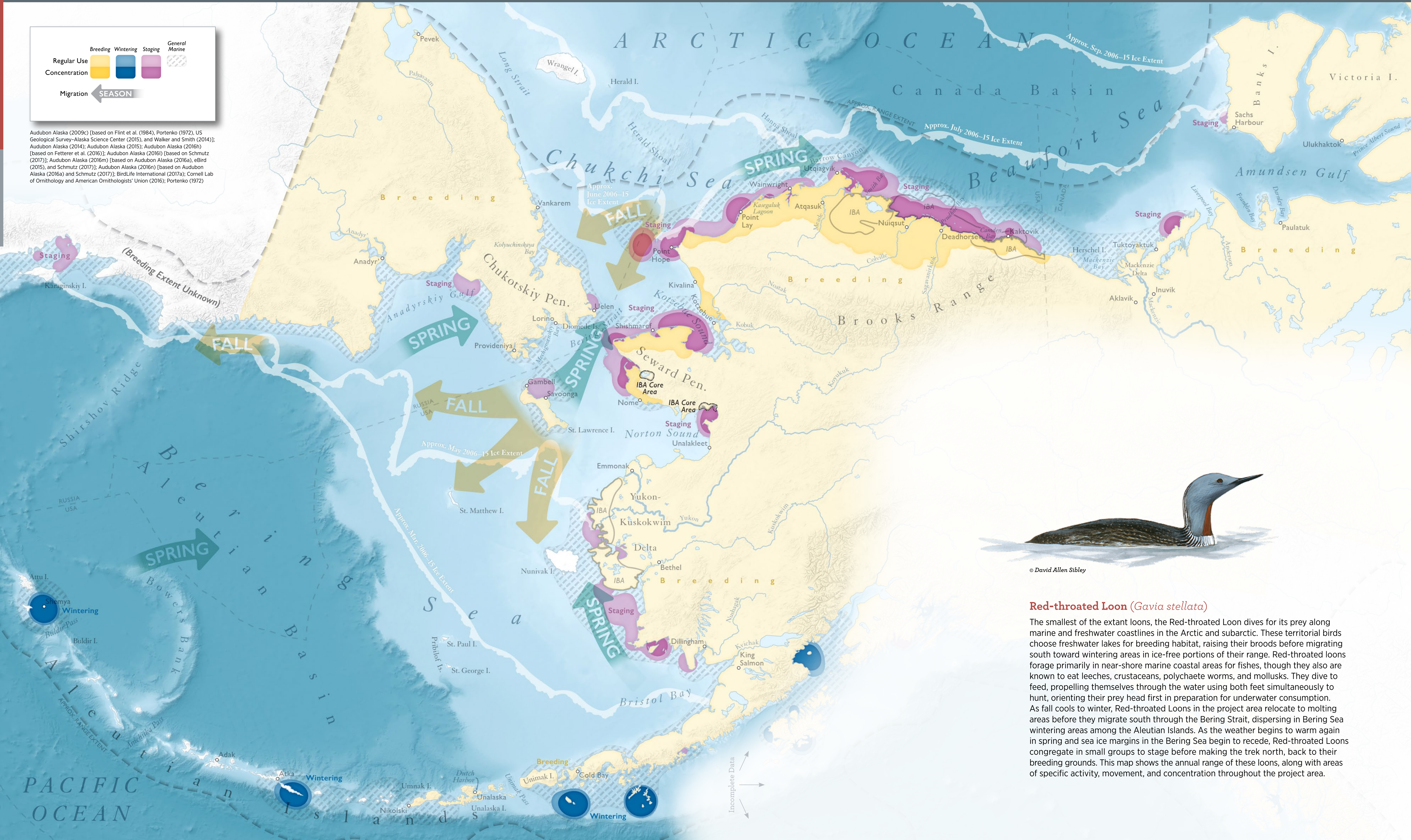
Yellow-billed Loon *(Gavia adamsii)*

Among the largest of the five loon species, the Yellow-billed Loon is an Arctic-breeding diving bird that migrates north to the North Slope of Alaska, western Canada, and northeastern coast of Russia to breed in May, arriving while the tundra is still frozen. As they await the thaw, they forage in leads and polynyas near the tundra lakes they chose as breeding habitat. Once the lakes have thawed, Yellow-billed Loons choose nest sites, often using the same location from year to year. These aggressive birds will defend an entire lake as their territory, expelling any other loons and diving ducks that encroach upon it until their chicks fledge, and they move to offshore staging areas before beginning the long migration back to more temperate wintering grounds. They winter in the coastal, ice-free waters of Alaska, British Columbia, and southeastern Russia, as well as the Korean Peninsula, Hokkaido Japan, and northeast China. As winter ends, Yellow-billed Loons migrate to their northern breeding grounds via a coastal route, although a breeding population in western Canada utilizes a shorter, overland route to the Canadian Arctic Archipelago from Southeast Alaska and Coastal Canada.

Red-throated Loon

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Audubon ALASKA



Audubon Alaska (2009c) [based on Flint et al. (1984), Portenko (1972), US Geological Survey–Alaska Science Center (2015), and Walker and Smith (2014)]; Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2016l) [based on Schmutz (2017)]; Audubon Alaska (2016m) [based on Audubon Alaska (2016a), eBird (2015), and Schmutz (2017)]; Audubon Alaska (2016n) [based on Audubon Alaska (2016a) and Schmutz (2017)]; BirdLife International (2017a); Cornell Lab of Ornithology and American Ornithologists' Union (2016); Portenko (1972)

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Red-throated Loon (*Gavia stellata*)

The smallest of the extant loons, the Red-throated Loon dives for its prey along marine and freshwater coastlines in the Arctic and subarctic. These territorial birds choose freshwater lakes for breeding habitat, raising their broods before migrating south toward wintering areas in ice-free portions of their range. Red-throated loons forage primarily in near-shore marine coastal areas for fishes, though they also are known to eat leeches, crustaceans, polychaete worms, and mollusks. They dive to feed, propelling themselves through the water using both feet simultaneously to hunt, orienting their prey head first in preparation for underwater consumption. As fall cools to winter, Red-throated Loons in the project area relocate to molting areas before they migrate south through the Bering Strait, dispersing in Bering Sea wintering areas among the Aleutian Islands. As the weather begins to warm again in spring and sea ice margins in the Bering Sea begin to recede, Red-throated Loons congregate in small groups to stage before making the trek north, back to their breeding grounds. This map shows the annual range of these loons, along with areas of specific activity, movement, and concentration throughout the project area.

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Red-faced Cormorant

Phalacrocorax urile

Max Goldman, Erika Knight, and Melanie Smith

Among the least known and understood species in the Northern Hemisphere, the Red-faced Cormorant (*Phalacrocorax urile*) is a medium to large, colonial-nesting seabird that utilizes coastal waters, islands, and continental shelves in the North Pacific. They are similar in both appearance and range to the Pelagic Cormorant (*P. pelagicus*). Red-faced Cormorants are exclusively marine, spending their entire lives in, above, or within a few feet of the water.

As their name suggests, Red-faced Cormorants are distinguished by the red facial skin that is prominent in breeding adults. It is often paired with a yellowish bill and a pale-blue gape. Also, while in breeding plumage, adult birds display a single crest of feathers on their crown, or sometimes double crests on their crown and nape, and a conspicuous white patch on their flank (Causey 2002). They are, in general, approximately 25% larger than Pelagic Cormorants. Male and female Red-faced Cormorants exhibit dimorphism in size alone, with identical plumage through all stages of life (Causey 2002). They have a well-developed uropygial gland, which they use to oil their wet feathers by first rubbing it with their bill, and then preening their feathers, in order to reduce saturation in subsequent dives.

DISTRIBUTION

The range of the Red-faced Cormorant extends, in a latitudinally narrow band, from the Kenai Peninsula west through the Aleutian Islands and the Commander Islands to the Kuril Islands, the Kamchatka Peninsula, and Northern Japan. They rarely range south of the Aleutians or the Alaska Peninsula; some colonies are found north into Bristol Bay and the Pribilof Islands (Gabrielson and Lincoln 1959, Siegel-Causey and Litvinenko 1993).

Migration and Wintering

Red-faced Cormorants are not migratory—instead, they may disperse within nearshore areas of their year-round range after breeding. In years of heavy sea-ice coverage in the Bering Sea, their northern winter range extent will be constrained by the ice (Siegel-Causey and Litvinenko 1993). High levels of winter mortality are regularly recorded based on carcasses uncovered by melting snow (Causey 2002).

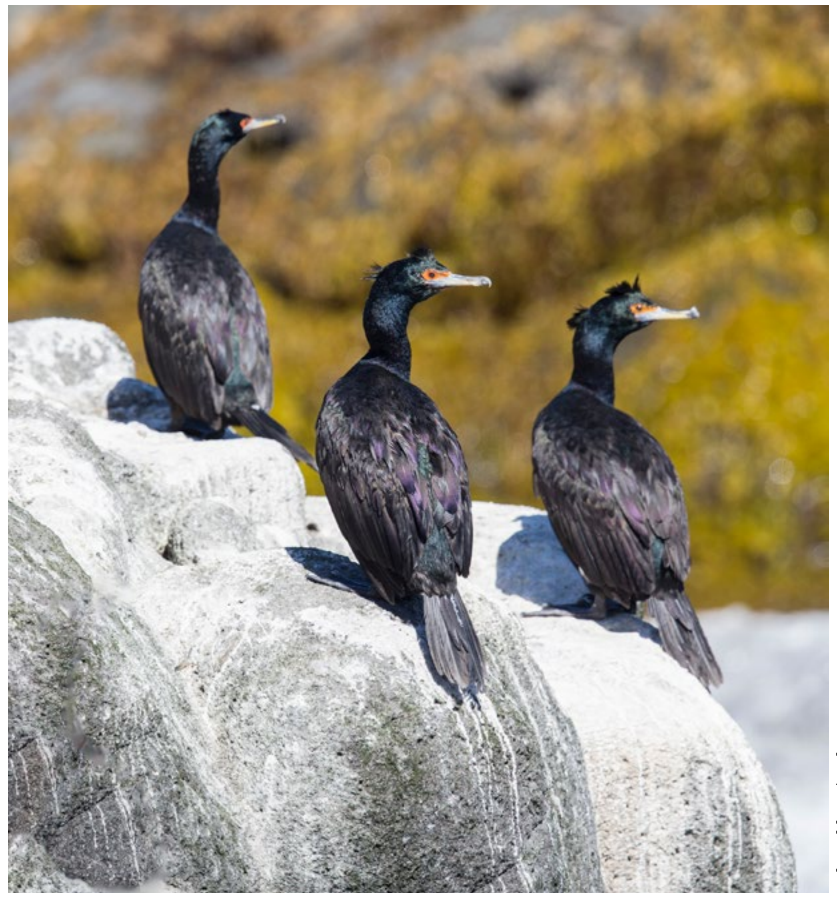
LIFE CYCLE

Pair bonding begins in early May, and by mid-May, breeding birds have found a mate, and the males have initiated the process of building a trial nest to strengthen their bond, in a location that the male will often use year after year. The trial nest is rarely used for incubation (Wright et al. 2013).

Red-faced Cormorants nest in relatively small colonies, generally consisting of less than 50 nests (Siegel-Causey 1988). Most of their nests are found in the steep, rocky cliffs of the islands in the southern Bering Sea. In Alaska, they often nest among cliff-nesting seabirds, such as puffins, murres, and kittiwakes. Red-faced Cormorants are among the first to arrive at the nesting site and defend their preferred locations (the least accessible portion of the seaside cliffs) from other incoming nesters (Nysewander 1983b).

Although male Red-faced Cormorants initiate nest-building as a component of pair bonding, both sexes participate in nest construction by gathering mainly grasses, seaweeds, sticks, and guano to create a 14–15 inch (40–50 cm) wide nest; the size of the nest is often constrained by the available surface on the cliff-faces they prefer (Bent 1922).

Once the nest is completed, Red-faced Cormorants will lay 2–4 greenish to pale-blue eggs, each 2–2.5 inches (6–6.5 cm) long and covered in chalky white deposits. The female cormorant lays an egg every two days (Wehle 1978, Hunt et al. 1981, Nysewander 1983b, Wright et al. 2013). Both parents will incubate the eggs until hatching,



Bob Waldrop / RedPoint Images

Red-faced Cormorants tend to nest in relatively small colonies (less than 50 nests) on steep, rocky, island cliffs in the southern Bering Sea.

usually after 31–34 days. The clutch will never be left alone, as there are often egg-eating predatory birds and Arctic foxes (*Vulpes lagopus*) in the vicinity of the nesting sites (Hunt et al. 1981, Nysewander 1983b, Wright et al. 2013).

Chicks hatch featherless, with their eyes closed. Red-faced Cormorant parents share the brooding duties, never leaving the nestlings alone for the first four weeks of life (Palmer 1962, Palmer 1976). As is the case with many seabirds, the survival rate of the brood is approximately 50%, and they are not known to produce a second clutch even when the first is completely lost (Hunt et al. 1981, Wright et al. 2013). After 40–50 days, the chicks will fledge, but will continue to accompany their parents for food for several weeks (Robertson 1971, Wright et al. 2013).

Diet

Red-faced Cormorants subsist on fishes that live on the ocean floor, such as smelt, sand lances, flounder, and sculpin, as well as some bottom-dwelling macroinvertebrates, including amphipods, euphausiids, decapods, polychaete worms, and pelagic mollusks (Palmer 1962, Hunt et al. 1981). They generally hunt in inshore areas with rocky bottoms, pursuing their prey by diving from the water's surface, propelling themselves with their feet, and swallowing their prey underwater, except when it is large or difficult to swallow (Hoffman et al. 1981, Causey 2002).

CONSERVATION ISSUES

The Red-faced Cormorant is not protected under the Endangered Species Act (ESA) and is listed as a species of least concern by the International Union for the Conservation of Nature (IUCN). However, substantial declines in population have been noted, and the US Fish and Wildlife Service (USFWS) considers Red-faced Cormorants a species of conservation concern (BirdLife International 2012). While data on population size are not strong as very little research has been done specific to these birds, the perceived declines could be substantial for an endemic species with a limited range. The Red-faced Cormorant is listed as declining in Audubon Alaska's 2017 WatchList (Warnock 2017).

According to the Alaska Seabird Information Series (2006), there are many steps that should be taken in order to restore the Red-faced Cormorant to an Alaska population of 50,000 individuals. A comprehensive monitoring program should be established to identify and survey populations at key index locations, and to measure changes in mortality, nesting, and reproductive success. Prey availability should also be monitored, including continued research into the commercially viable fishes upon which Red-faced Cormorants rely. Human disturbance is a constant concern, with the repercussions of fuel spills and fisheries infringement at the forefront of this issue.

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TABLE 5.7-1. Red-faced Cormorant characteristics and conservation status. Sources: Causey (2002), Warnock (2017).

	Red-faced Cormorant *Phalacrocorax urile*
Body Size Mass Length Wingspan	 **M** 4–5.5 pounds (1,850–2,400 g) **L** 30–39 inches (75–100 cm) **W** Unknown
Maximum Life Span (wild)	Unknown
Clutch Size Range Average	 **R** 2–4 eggs **A** 2.5 eggs
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	 **ESA:** Not Listed **IUCN:** Least Concern **WL:** Red List
Population Global Alaska	 **G** 200,000 **A** 20,000
Breeding Season Eggs Hatch Fledge	 **E** Late May **H** June **F** Late July to Early August

MAPPING METHODS (MAP 5.7)

We categorized distribution into four main categories of intensity: extent of range, regular use, concentration, and high concentration. The extent of range was drawn by buffering all known occurrences of Red-faced Cormorant using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), and the Seabird Information Network (2011). The AGBD combines and integrates point locations from available bird surveys conducted by the USFWS, the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. Red-faced Cormorant observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

Because of the relative lack of survey data in Russia, concentration areas in Russia are often not known or depicted. Where there were gaps in survey coverage, we buffered species' colony locations, using a buffer radius equal to the species' average maximum foraging distance (12.4 miles [20 km] (Cornell Lab of Ornithology and American Ornithologists' Union 2016)). These two types of boundaries were combined to represent regular use across the project area.

High concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, we used IBA data from BirdLife International (2017a) while IBAs in Alaska are from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also used single-species IBA core areas (Audubon Alaska 2015) to show high concentration for Red-faced Cormorants (see Smith et al. 2014c).

Red-faced Cormorant colony data were downloaded from the Seabird Information Network (2011). The colony count data for the Pribilof Islands were updated based on Romano and Thomson (2016), and count data for larger colonies in the Aleutian Islands were updated based on Alaska Maritime National Wildlife Refuge (2009), Byrd et al. (2001b), and Byrd and Williams (2004). This map represents the most recent or otherwise best estimate available for each colony location (see Smith et al. 2012). On the map, the size of each colony point represents the percent of the total population present at that colony. Total population was the sum of the abundance of the species across all colonies within the project area.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of this map. The colony data are available throughout the US and Russia portions of the project area, but data quality—survey dates and techniques—varies greatly among colonies. Colony sizes should be interpreted as estimates rather than precise counts.

Reviewer

- Marc Romano

MAP DATA SOURCES

Extent of Range: Audubon Alaska (2016e) based on Audubon Alaska (2016a), eBird (2015), Romano and Thomson (2016), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Alaska Maritime National Wildlife Refuge (2009), Audubon Alaska (2016a), Byrd et al. (2001b), Byrd and Williams (2004), Romano and Thomson (2016), and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

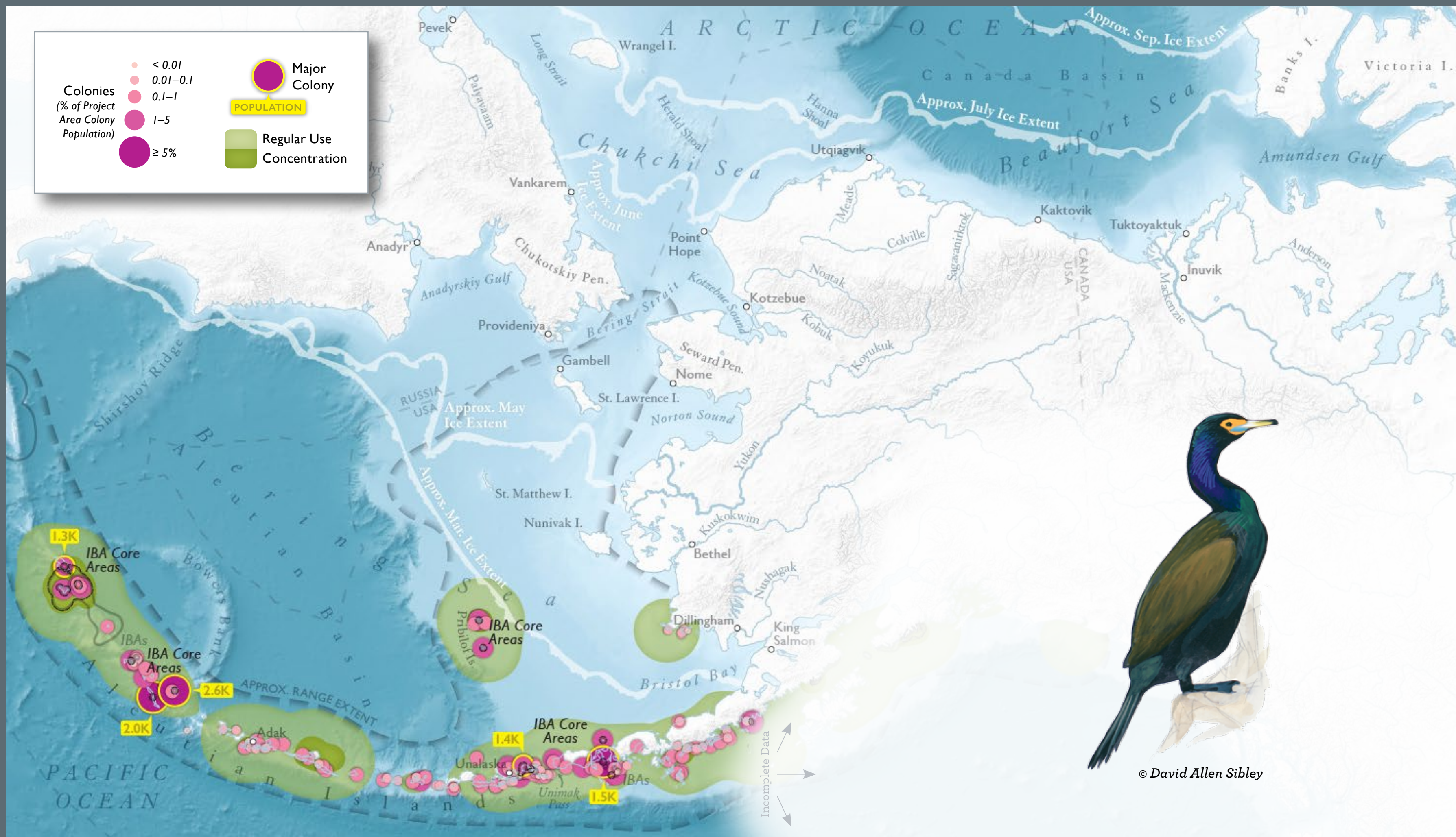
IBA Core Areas: Audubon Alaska (2015)

Colonies: Alaska Maritime National Wildlife Refuge (2009); Byrd et al. (2001b); Byrd and Williams (2004); Romano and Thomson (2016); Seabird Information Network (2011)

Sea Ice Extent: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Red-faced Cormorant

Audubon ALASKA



Alaska Maritime National Wildlife Refuge (2009); Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Alaska Maritime National Wildlife Refuge (2009), Audubon Alaska (2016a), Byrd et al. (2001b), Byrd and Williams (2004), Romano and Thomson (2016), and Seabird Information Network (2011)]; Audubon Alaska (2016e) [based on Audubon Alaska (2016a), eBird (2015), Romano and Thomson (2016), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Byrd et al. (2001b); Byrd and Williams (2004); Romano and Thomson (2016); Seabird Information Network (2011)

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Red-faced Cormorant (*Phalacrocorax urile*)

Red-faced Cormorants are cliff-nesting, colonial-breeding seabirds found in the Aleutian Islands in the southern Bering Sea. They nest among Pelagic Cormorants (*P. pelagicus*), Horned and Tufted Puffins (*Fratercula corniculata, F. cirrhata*), Thick-billed and Common Murres (*Uria lomvia, U. aalge*), and Red-legged and Black-legged Kittiwakes (*Rissa brevirostris, R. tridactyla*), selecting the least accessible seaside cliffs as nesting habitat. They are often the first to arrive during breeding season, and aggressively defend their nest sites from other nesting birds. While some colonies may be home to nearly 3,000 birds, the majority of colonies are much smaller, often containing 50 or fewer nests.

Each year, breeding Red-faced Cormorants lay two to four eggs each, of which half the chicks will survive. The others fall victim to starvation or predation by other birds and Arctic foxes. Historically, Red-faced Cormorant numbers have been difficult to ascertain, as this species has been (and often still is) regularly confused with its closely related cousin, the much more prolific and gregarious Pelagic Cormorant. When breeding season is over and cooler weather moves in, Red-faced Cormorants take to the sea, foraging in the nearshore areas surrounding the Aleutians and the western coast of Alaska, sometimes making it as far north as the Bering Strait. Sea-ice extent generally constrains winter movements of Red-faced Cormorants, and exposure and starvation are likely culprits of winter mortality.

Robin Corcoran / USFWS

Phalaropes

Nils Warnock, Erika Knight, and Melanie Smith

Red-necked Phalarope

Phalaropus lobatus

Red Phalarope

P. fulicarius

While technically these shorebirds belong to the family *Scolopacidae*, Red-necked and Red Phalaropes (*Phalaropus lobatus* and *P. fulicarius*) act more like seabirds, spending 9–11 months of the year on open waters (Tracy et al. 2002, Warnock et al. 2002). Both species breed in Alaska, with Red Phalaropes being a coastal breeder from Western Alaska north and eastward into Canada, while Red-necked Phalaropes breed at both coastal and interior sites throughout much of Alaska (Rubega et al. 2000, Tracy et al. 2002, Armstrong 2015). Another phalarope, Wilson's Phalarope (*P. tricolor*) is a rare local breeder in interior Alaska, infrequently seen in the marine realm (Armstrong 2015). Hereafter, phalarope refers to Red-necked and Red Phalaropes unless otherwise stated. Phalaropes are known for their characteristic spinning motion while feeding in water, a technique that generates a micro water vortex that spins their invertebrate prey to the surface (Obst et al. 1996, Prakash et al. 2008). In the marine realm, phalaropes are denizens of areas where different types of marine waters come together (upwelling areas, drift lines, thermal gradients, ice edges, etc.) and concentrate food, making it more accessible (Briggs et al. 1984, Brown and Gaskin 1988, Tyler et al. 1993, Wahl et al. 1993, Warnock et al. 2002). Whalers of the past called Red Phalaropes "bowhead birds" because of their propensity to be found with feeding bowhead whales (*Balaena mysticetus*) (Nelson 1983). Unlike the majority of sexually dimorphic shorebirds, the larger and most colorful breeding phalaropes are female, with role reversals attributed to their sometimes polyandrous lifestyle, in which females mate with more than one male (Emlen and Oring 1977).

In contrast to other shorebirds, phalaropes are uniquely adapted for life at sea. Phalaropes appear to have more feathers in the breast and belly region than most shorebirds, which gives them extra waterproofing and added buoyancy on the water (Warnock et al. 2002). They possess laterally flattened legs with lobed toes, allowing them to readily swim and spin in the water in search of food (Obst et al. 1996). Their feeding mode is also adapted to life around water, using the surface tension of water to rapidly transport tiny invertebrate prey items in small water droplets between their mandibles to the back of the jaw to be swallowed (Rubega and Obst 1993, Rubega 1997).

DISTRIBUTION

In the late 1880s in the Arctic Ocean, Nelson (1883) noted that Red Phalaropes were often found along the edge of the ice pack feeding on invertebrates (Orr et al. 1982, Johnson and Herter 1989). Red Phalaropes are known to feed on ice-associated amphipods, *Apherusa glacialis* (Divoky 1984, Tracy et al. 2002).

Direct evidence of where phalaropes from Alaska spend their non-breeding season is lacking. It is likely that these birds spend the non-breeding season off the western coast of South America, after migrating south along the Pacific Flyway (Nisbet and Veit 2015). In South America, both species are common in non-breeding months in the productive Peru Current System (a.k.a. the Humboldt Current) offshore of Peru and Northern Chile, where Red Phalaropes, in particular, are found in less-stratified water near the shelf break (Rubega et al. 2000, Tracy et al. 2002, Spear and Ainley 2008).

Milo Burcham

Spending the majority of their lives at sea, phalaropes are highly pelagic shorebirds, unique in many ways. An example is the plumage difference between male and female phalaropes. While most sexually dimorphic avian pairs consist of a more distinctly plumed male, female phalarope plumage is brighter and more colorful than their smaller male counterparts. Pictured is a female Red Phalarope in breeding plumage.

5.8 PHALAROPES MAPS ON PAGE 160

TABLE 5.8-1. Phalarope life history characteristics and conservation status. Sources: Rubega et al. (2000), Tracy et al. (2002), Warnock (2017).

	Red-necked Phalarope *Phalaropus lobatus*	Red Phalarope *P. fulicarius*
Body Size		
Mass	**M** 0.7–1.7 ounces (20–48 g)	**M** M 1.3–2.7 ounces (37–77 g)
Length	**L** 7–7.4 inches (18–19 cm)	**L** 7.9–8.7 inches (20–22 cm)
Wingspan	**W** 12.2–13.4 inches (31–34 cm)	**W** 14.6–15.7 inches (37–40 cm)
Maximum Life Span (wild)	10+	6+
Clutch Size		
Range	**R** 1–6 eggs	**R** 1–6 eggs
Average	**A** 4 eggs	**A** 4 eggs
Nest-Water Proximity	< 330 feet (< 100 m) from water	< 330 feet (< 100 m) from water
Conservation Status		
Endangered Species Act	**ESA:** Not Listed	**ESA:** Not Listed
IUCN Red List	**IUCN:** Least Concern	**IUCN:** Least Concern
Audubon AK WatchList	**WL:** Not Listed	**WL:** Not Listed
Population		
Global	**G** 4,050,000	**G** 2,165,000
Alaska	**A** 1,250,000	**A** 590,000
Breeding Season		
Eggs	**E** June to July	**E** June to July
Young	**Y** June to August	**Y** June to August
Migration		
Spring	**S** April to May	**S** May to June
Molt	**M** October to March	**M** August to September
Fall	**F** July to October	**F** July to November

Migration
Direct evidence (via tagging studies) of migration routes used by either species is lacking for Alaska breeding phalaropes. The only tracking study of either species is based on the 13,700-mile (22,000- km) movement of one geolocator-tagged Red-necked Phalarope tracked from breeding grounds in Scotland across the Gulf of Mexico to non-breeding grounds between the Galapagos Islands and the South American coast in the Pacific Ocean (Smith et al. 2014a).

In Alaska, phalaropes appear to head to coastal lagoons and marine waters after breeding (Gabrielson and Lincoln 1959, Johnson and Herter 1989, Kessel 1989). Red Phalaropes typically become strictly pelagic after breeding, and migrate and feed farther offshore than Red-necked Phalaropes (Johnson and Herter 1989). During their fall migration, Red-necked Phalaropes follow coastal, pelagic, and interior routes, staging in the west at places such as Lake Abert, OR; Mono Lake, CA; and Great Salt Lake, UT (Rubega et al. 2000, Oring et al. 2013). Smith et al. (2014b) identified four pelagic areas in Alaska with predictable, globally important numbers with at least 1% of the global population of Red Phalaropes. These include a region in the Beaufort Sea 11 miles (18 km) offshore encompassing parts of Barrow Canyon and Smith Bay; a region (152°W 71°N) 42 miles (68 km) from land along the Beaufort–Chukchi Seas shelf edge; a marine region between Seguam and Amlia islands in the Aleutian chain; and a region (178°W 61°N) over 125 miles (200 km) from land in the eastern Bering Sea along the shelf edge. Red-necked Phalaropes do not typically concentrate in large numbers offshore in Alaska waters during migration, although large passages of these birds have been observed at inshore areas such as the Wrangell Narrows in Southeast Alaska during fall and spring migration (Gabrielson and Lincoln 1959, also N. Warnock, pers. obs.).

Species Description
Red-necked Phalarope. Red-necked Phalaropes are circumpolar breeders in subarctic and Arctic regions. In Alaska, breeding birds have been found in coastal areas from the Copper River Delta north through the Alaska Peninsula and parts of the Aleutians to the North Slope into Canada. Interior Alaska breeding birds mainly occur across a swath of the central part of the state along the Yukon River (Cramp et al. 1983, Rubega et al. 2000).

Red Phalarope. Like Red-necked Phalaropes, Red Phalaropes are circumpolar breeders in subarctic and Arctic regions, but generally breed farther north and are more coastal than Red-necked Phalaropes. In Alaska, breeding birds have been found in coastal areas from Bristol Bay to St. Lawrence Island to the North Slope into Canada (Cramp et al. 1983, Tracy et al. 2002).

LIFE CYCLE
Phalaropes typically breed in moist to wet tundra areas and around other wetlands in subarctic and Arctic regions (Kessel 1989, Piersma et al. 1996, Rubega et al. 2000, Tracy et al. 2002). Pair bonding appears to occur either shortly before arrival, or on the breeding grounds (Rubega et al. 2000, Tracy et al. 2002). Both species are known for their polyandrous mating systems, yet the third phalarope species, Wilson's Phalaropes, are more typically monogamous. The percentage of polyandrous Red Phalaropes ranges from 36 to 50% (Tracy et al. (2002) and references therein), while for Red-necked Phalaropes, the range is from 0 to 14% (Rubega et al. (2000) and references therein). Males incubate the typical four-egg clutches and rear the chicks.

Diet
Phalaropes commonly feed on terrestrial and marine invertebrates (Rubega et al. 2000, Tracy et al. 2002). At breeding sites, phalarope diets are often dominated by crane flies (*Tipulidae*), mosquitos, and midges (*Chironomidae*). In the marine environment, phalaropes frequently rely on amphipods and copepods (Rubega et al. 2000, Tracy et al. 2002). Red-necked Phalaropes at interior saline lakes predominately eat brine flies (*Ephydra hians*), and to a much lesser degree, brine shrimp (*Artemia salina*) (Rubega et al. 2000).

CONSERVATION ISSUES
Phalaropes are protected under the US Migratory Bird Treaty Act of 1918, but neither phalarope has any other special protected status in the US. The International Union for Conservation of Nature (IUCN) lists both phalaropes as species of least concern (BirdLife International 2016c), although Red-necked and possibly Red Phalarope populations have undergone declines (Rubega et al. 2000, Tracy et al. 2002, Andres et al. 2012). Both populations seem especially vulnerable to declines in their prey on South American non-breeding grounds caused by El Niño–Southern Oscillation (ENSO) events (Nisbet and Veit 2015). Declines in breeding phalaropes on the North Slope of Alaska in the early to mid-1980s were attributed to the massive ENSO event of 1982–83 (Troy 1996). Phalaropes have also been identified as vulnerable to being caught as bycatch in gill nets at sea (Žydelis et al. 2013, BirdLife International 2016c).

MAPPING METHODS MAPS (5.8.1–5.8.2)
We categorized distribution into four main categories of intensity: extent of range, regular use, concentration, and high concentration. Where possible, we analyzed survey data to draw boundaries and assess intensity of use. However, survey data alone did not provide adequate coverage of the project area. Therefore, the phalarope maps are a composite of both survey-derived polygons and polygons from other sources. Regular-use and concentration areas are based on either a) boundaries resulting from spatial analysis, or b) information presented in reports and literature.

The extent of range was drawn by buffering all known occurrences of each species using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a) and eBird (2015). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. For each species, observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. The survey-derived range polygon for each species was merged with range data from Cornell Lab of Ornithology and American Ornithologists' Union (2016), BirdLife International (2017c), BirdLife International (2017a), Audubon Alaska (2015) and/or National Oceanic and Atmospheric Administration (1988). Inconsistencies in the resulting polygons were manually edited and smoothed.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-miles (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, we used IBA data from BirdLife International (2017a) while IBAs in Alaska were from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska, we also show single-species IBA core areas (Audubon Alaska 2015) to indicate high concentrations specific to Red Phalaropes (see Smith et al. 2014c). For Red-necked Phalaropes, no single-species IBA core areas are known in the project area.

Breeding habitat suitability data on the Arctic Coastal Plain are displayed. These data were modeled by Saalfeld et al. (2013b) based on data from 767 plots surveyed as part of PRISM. For Red Phalarope, breeding and breeding-concentration areas from National Oceanic and Atmospheric Administration (1988) are shown in addition to the modeled data. For Red-necked Phalarope, breeding areas from Cornell Lab of Ornithology and American Ornithologists' Union (2016) and BirdLife International (2017c) are shown in addition to the modeled data.

The migration data shown for Red Phalarope are from National Oceanic and Atmospheric Administration (1988).

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines were based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality
The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. There is little to no survey coverage in the Canadian and Russian portions of the project area, potentially leaving major data gaps for these species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps.

Reviewer
- Dan Ruthrauff

MAP DATA SOURCES

RED-NECKED PHALAROPE MAP

Extent of Range: Audubon Alaska (2017h) based on Audubon Alaska (2016a), BirdLife International (2017c), Cornell Lab of Ornithology and American Ornithologists' Union (2016), eBird (2015), and Northwest Territories (2017)

Regular Use: Audubon Alaska (2017i) based on Audubon Alaska (2016a)

Concentration: Audubon Alaska (2017i) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

Breeding Habitat Suitability: Saalfeld et al. (2013b; 2013a)

Breeding Area: BirdLife International (2017c); Cornell Lab of Ornithology and American Ornithologists' Union (2016)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

RED PHALAROPE MAP

Extent of Range: Audubon Alaska (2017h) based on Audubon Alaska (2015), Audubon Alaska (2016a), BirdLife International (2017a), Cornell Lab of Ornithology and American Ornithologists' Union (2016), eBird (2015), and National Oceanic and Atmospheric Administration (1988)

Regular Use: Audubon Alaska (2017i) based on Audubon Alaska (2016a)

Concentration: Audubon Alaska (2017i) based on Audubon Alaska (2015) and Audubon Alaska (2016a)

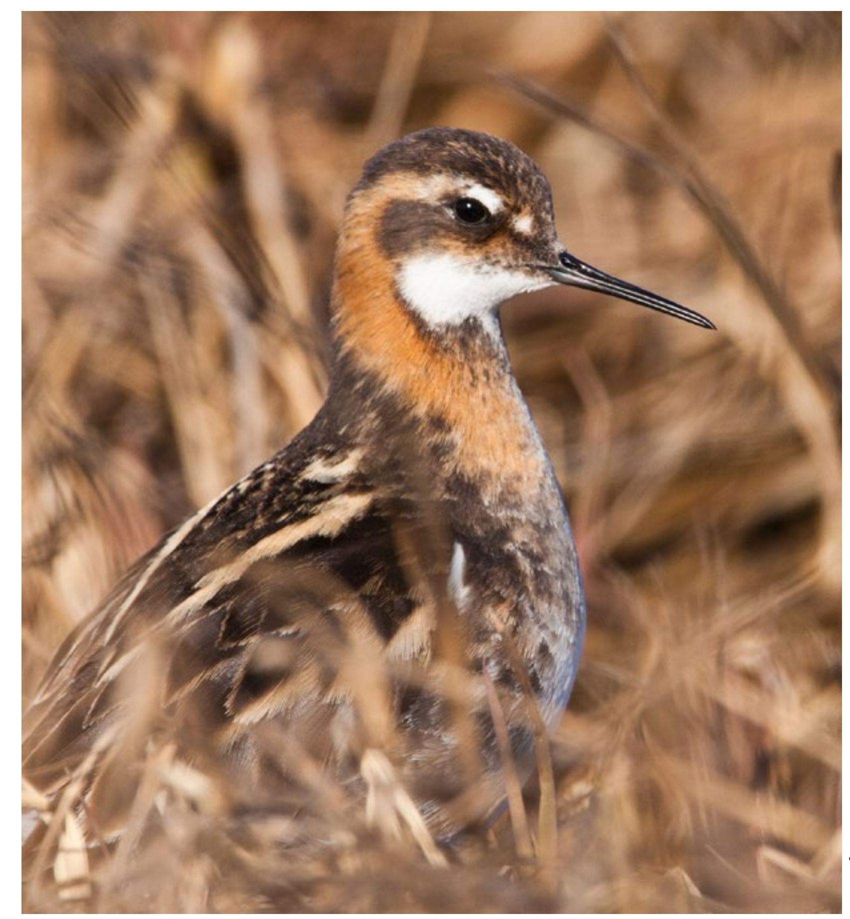
IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Breeding Habitat Suitability: Saalfeld et al. (2013b; 2013a)

Migration: National Oceanic and Atmospheric Administration (1988)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)



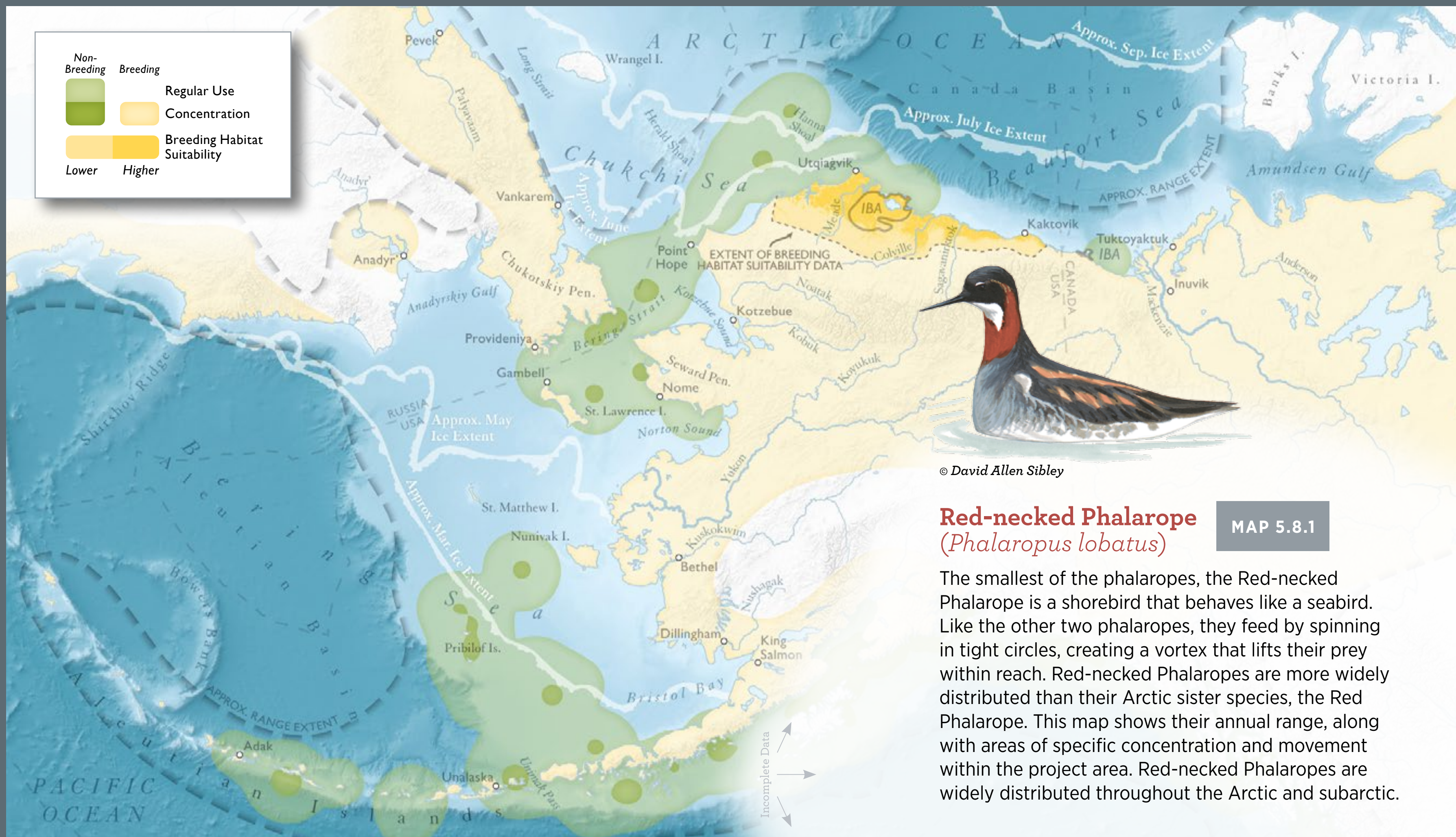
Dave Shaw

Red-necked Phalarope.

5.8 PHALAROPES MAPS ON PAGE 160

Phalaropes

Audubon ALASKA



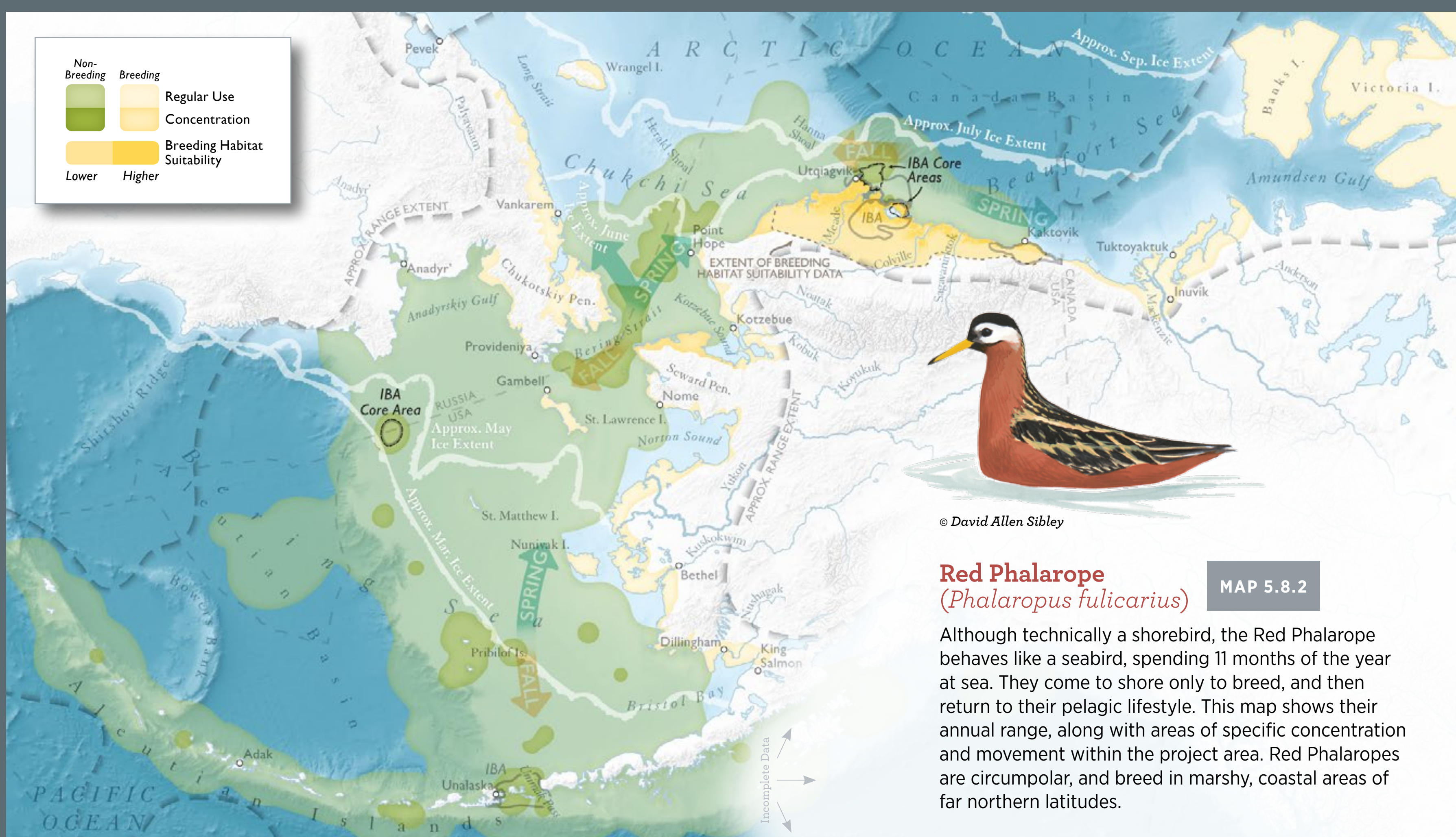
Red-necked Phalarope
(Phalaropus lobatus)

MAP 5.8.1

The smallest of the phalaropes, the Red-necked Phalarope is a shorebird that behaves like a seabird. Like the other two phalaropes, they feed by spinning in tight circles, creating a vortex that lifts their prey within reach. Red-necked Phalaropes are more widely distributed than their Arctic sister species, the Red Phalarope. This map shows their annual range, along with areas of specific concentration and movement within the project area. Red-necked Phalaropes are widely distributed throughout the Arctic and subarctic.

Audubon Alaska (2014); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2017h) [based on Audubon Alaska (2016a), BirdLife International (2017c), Cornell Lab of Ornithology and American Ornithologists' Union (2016), eBird (2015), and Northwest Territories (2017)]; Audubon Alaska (2017i) [based on Audubon Alaska (2016a)]; BirdLife International (2017a); BirdLife International (2017c); Cornell Lab of Ornithology and American Ornithologists' Union (2016); Saalfeld et al. (2013b;2013a)

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman



Red Phalarope
(Phalaropus fulicarius)

MAP 5.8.2

Although technically a shorebird, the Red Phalarope behaves like a seabird, spending 11 months of the year at sea. They come to shore only to breed, and then return to their pelagic lifestyle. This map shows their annual range, along with areas of specific concentration and movement within the project area. Red Phalaropes are circumpolar, and breed in marshy, coastal areas of far northern latitudes.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Audubon Alaska (2017h) [based on Audubon Alaska (2015), Audubon Alaska (2016a), BirdLife International (2017a), Cornell Lab of Ornithology and American Ornithologists' Union (2016), eBird (2015), and National Oceanic and Atmospheric Administration (1988)]; Audubon Alaska (2017i) [based on Audubon Alaska (2015) and Audubon Alaska (2016a)]; BirdLife International (2017a); National Oceanic and Atmospheric Administration (1988); Saalfeld et al. (2013b;2013a)

MAP ON PAGE 163

Aleutian Tern

Onychoprion aleuticus

Nils Warnock, Erika Knight, and Melanie Smith

Overall, this is a rather mysterious bird whose wintering distribution and population dynamics are poorly understood. The type specimen and egg were collected by Ferdinand Bischoff as part of an expedition led by the Smithsonian Institution and the Chicago Academy of Sciences in June of 1868 on Kodiak Island (Gabrielson and Lincoln 1959), and the species was described by Spencer Baird in 1869 (Dixey et al. 1981). Aleutian Terns (*Onychoprion aleuticus*) are now known to have a breeding distribution in eastern Russia and in coastal Alaska; populations in Alaska at least appear to be in steep decline, or individuals from known breeding colonies are redistributing (Renner et al. 2015). Compared to its cousin, the Arctic Tern (*Sterna paradisaea*), a bird with which it often nests and feeds (Holtan 1980), Aleutian Terns are relatively non-aggressive (Baird et al. 1983).

Like most terns, the Aleutian Tern is adapted to life in the air and water (Gochfeld and Burger 1996). They have long, pointed wings, relatively small, streamlined bodies, and small legs and feet that are awkward for serious walking or swimming (Gochfeld and Burger 1996, North 2013). They are strong fliers and generally feed by hovering and snatching prey from the water surface or by plunge-diving (Gochfeld and Burger 1996, North 2013).

Milo Burcham

Aleutian Tern adult in breeding plumage.

DISTRIBUTION

Aleutian Terns are not known to associate with sea ice. In the southeastern Bering Sea, Aleutian Tern densities were slightly higher in years with early spring ice retreat and they foraged in shallower waters in those years (Renner et al. 2016).

Migration

Migration routes of Aleutian Terns are still largely unknown, although limited tracking and presence/absence data offer clues (Pyare et al. 2013, Renner et al. 2015). Based on eBird records (eBird 2017), after the breeding season ends in August, terns begin to decline quickly in Alaska, with a few sightings in September. Sites offshore from South Korea and Taiwan have August records. In September, Aleutian Terns are seen offshore from Taiwan down into Southeast Asia including the Philippines, Indonesia, and Malaysia (see also Hill and Bishop (1999), Poole et al. (2011)). However, based on eBird records, sightings of Aleutian Terns in much of Southeast Asia begin to decline and mostly disappear by January through February. It is not clear if this is because of a lack of observations during this period or that the terns move on to other unknown areas. Understanding the migration and wintering areas will allow for more specific conservation actions. Spring migration appears to begin in March stretching into April with records of Aleutian Terns from the western coast of the Malaysian Peninsula across Southeast Asia to Taiwan. By May, Aleutian Terns appear to mostly be gone from Southeast Asia (but see Lee (1992)) and are recorded along the coast from Hong Kong north to Russian and Alaska (Hill and Bishop 1999).

Wintering

The non-breeding distribution of Aleutian Terns is still poorly understood. At least part of their wintering season is spent in Southeast Asia (see discussion below, Hill and Bishop (1999), Poole et al. (2011), North (2013), Pyare et al. (2013), and Goldstein et al. (in review)). In *Onychoprion* terns in general, pre-alternate molt occurs on the non-breeding grounds (Howell 2010). It has been noted that Aleutian Terns are unusual among these terns in that they drop four to five inner primaries at once, suggesting that they molt in non-breeding areas with rich food resources (Howell 2010, North 2013).

LIFE CYCLE

Arrival of Aleutian Terns to the breeding grounds occurs from April to June, depending on location and latitude (North 2013). They nest on the ground in relatively small colonies, sometimes with Arctic Terns, and they tend to nest along the coastline strips between intertidal flats and more vegetated uplands (Holtan 1980, Baird et al. 1983, Kessel 1989, North 2013). Colonies are more dense on islands with no predators (Baird et al. 1983). Occasionally they nest at more interior sites in bogs and other wetlands. It is speculated that by nesting with more aggressive Arctic Terns, Aleutian Terns gain predator protection (Baird et al. 1983). While Aleutian Terns are some of the last seabirds to arrive on their breeding grounds, they are among the first to lay eggs (end of May into June), fledge chicks (mid-July through August), and then leave the breeding grounds (Baird et al. 1983).

Diet

Like many terns, this species appears to mainly feed on small fishes and crustaceans such as euphausiids (Holtan 1980, Kessel 1989, Gochfeld and Burger 1996, North 2013). On the Alaska Peninsula, in the Kodiak Archipelago, breeding Aleutian Terns fed mainly on capelin (*Mallotus villosus*), sculpins (*Enophrys bison*), and sand lance (*Ammodytes hexapterus*), as well as other small fishes and occasionally euphausiids (Baird et al. 1983). On the Copper River Delta, Alaska, three-spined stickleback (*Gasterosteus aculeatus*) was commonly eaten as well as salmon smolt (Holtan 1980).

CONSERVATION ISSUES

Aleutian Terns are protected under the US Migratory Bird Treaty Act of 1918, but they do not have any other special protection status. Aleutian Terns were recently added to Audubon Alaska's Red WatchList because of apparent steep declines in Alaska (Warnock 2017). Renner et al. (2015) calculated a 93% decline in Aleutian Tern numbers at known breeding colonies over the past three decades, but it remains uncertain if this reflects a redistribution of birds (perhaps to Russia where up to 80% of the global population may nest) or an actual decline.

In the Aleutians Islands Aleutian Terns were preyed upon by Peregrine Falcons, and levels of the pesticide dichlorodiphenyldichloroethylene (DDE) in one tern was higher than average levels found in resident birds (White et al. 1973). Likewise, mercury levels have been found to be of concern in the stickleback, a fish species consumed by Aleutian Terns (Kenney et al. 2012); but overall, contaminant loads and links in Aleutian Terns are poorly understood and studied. Introduced predators may be a problem for these ground nesters and they do not nest in any numbers in areas where foxes occur (Bailey and Kaiser 1993). Disturbance of tern colonies by subsistence egg collectors

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TABLE 5.9-1. Aleutian Tern life history characteristics and conservation status. Sources: North (2013), Warnock (2017).

	Aleutian Tern *Onychoprion aleuticus*
Body Size Mass Length Wingspan	**M** 3–5 ounces (83–140 g) **L** 12.5–13.4 inches (32–34 cm) **W** 29.5–31.5 inches (75–8.0 cm)
Maximum Life Span (wild)	Unknown
Clutch Size Range Average	**R** 1–3 eggs **A** 2 eggs
Nest-Water Proximity	Mostly coastal near water (within 2 miles [3 km]), but occasionally farther inland
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Not Listed **IUCN:** Least Concern (but see discussion above) **WL:** Red List
Population Global Alaska	**G** 31,000 **G** 5,500
Breeding Season Eggs Young	**E** June to July **Y** June to August
Migration Spring Fall	**S** April to May **F** August to September

can be detrimental (Renner et al. 2015). On a larger scale, factors like sea temperature impacting the availability and abundance of prey of Aleutian Terns, and factors potentially impacting terns on their poorly understood wintering grounds, may present significant management issues for which actions are still unidentified (Renner et al. 2015).

MAPPING METHODS (MAP 5.9)

We categorized distribution into four main categories of intensity: extent of range, regular use, concentration, and high concentration. The extent of range was drawn by buffering all known occurrences of Aleutian Terns using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), Renner et al. (2015), and Seabird Information Network (2017). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. Aleutian Tern observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

Because of the relative lack of survey data in Russia, concentration areas in Russia are often not known or depicted. Where there were gaps in survey coverage, such as in Russia, we buffered species' colony locations, using a buffer radius equal to the species' average maximum foraging distance. Because consistent information regarding the average maximum foraging distance for Aleutian Terns was not available, the average maximum foraging radius for Arctic Terns (12 miles [19 km] (Lascelles 2008)) was used. These two types of boundaries were combined to represent regular use across the project area.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Alaska, we used IBA data from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also show single-species IBA core areas (Audubon Alaska 2015) to indicate high concentrations specific to Aleutian Terns (see Smith et al. 2014c). In Russia and Canada, we accessed IBA data from BirdLife International (2017a); however, no Russian or Canadian Aleutian Tern IBAs are present within the map area.

Aleutian Tern colony data were provided by Seabird Information Network (2017) and the authors of Renner et al. (2015). This map represents the most recent or otherwise best estimate available for each colony location (see Smith et al. 2012). On the map, the size of each colony point represents the percent of the total population present at that colony. Total population was the sum of the abundance of the species across all colonies within the project area.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. Aleutian Terns do not use Canadian waters in our project area. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist but fewer Aleutian Terns nest). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting map. There is little to no survey coverage in the Canadian and Russian portions of the project area, potentially leaving major data gaps for this species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of this map. The colony data are available throughout the US and Russian portions of the project area, but data quality—survey dates and techniques—varies greatly among colonies. Colony sizes should be interpreted as estimates rather than precise counts.

Reviewers

- Pat Baird
- Robin Corcoran
- Michael Goldstein
- Susan Oehlers

MAP DATA SOURCES

Extent of Range: Audubon Alaska (2016e) based on Audubon Alaska (2016a), eBird (2015), Renner et al. (2015), and Seabird Information Network (2017)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Renner et al. (2015), and Seabird Information Network (2017)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014)

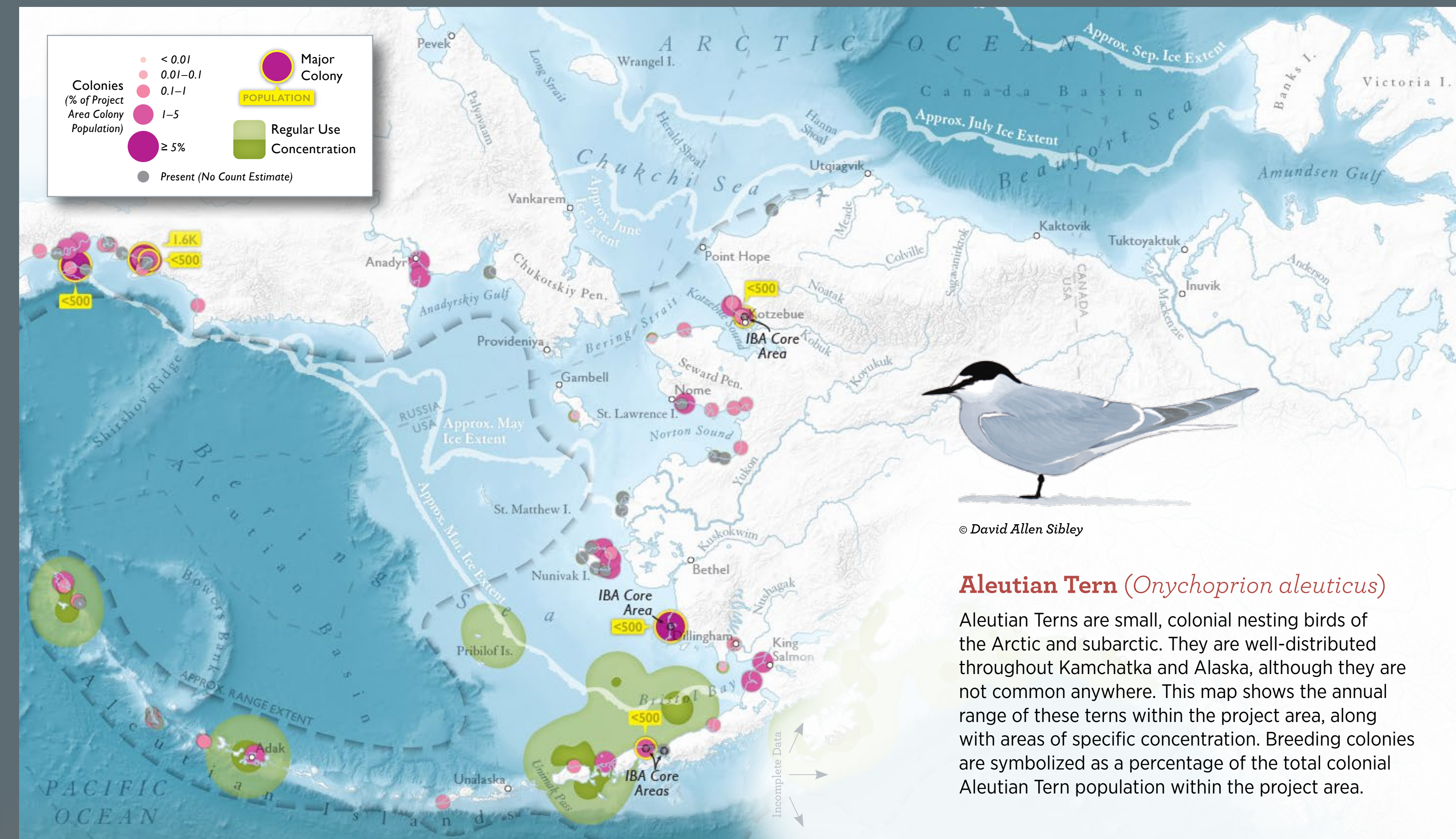
IBA Core Areas: Audubon Alaska (2015)

Colonies: Renner et al. (2015); Seabird Information Network (2017)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Aleutian Tern

Audubon ALASKA



Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2016a)]; Audubon Alaska (2016e) [based on Audubon Alaska (2016a), eBird (2015), Renner et al. (2015), and Seabird Information Network (2017)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Renner et al. (2015); Seabird Information Network (2017)

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Adult Aleutian Tern on a nest.

Mike Denega

MAPS ON PAGE 167

Kittiwakes

Max Goldman, Erika Knight, and Melanie Smith

Red-legged Kittiwake

Rissa brevirostris

Black-legged Kittiwake

R. tridactyla

Kittiwakes are small, pelagic gulls belonging to the genus *Rissa*. Both species, the well-studied Black-legged Kittiwake (*Rissa tridactyla*) and the lesser-studied Red-legged Kittiwake (*R. brevirostris*), are distributed in the far northern latitudes of the Arctic and subarctic. The Black-legged Kittiwake boasts a circumpolar distribution in the northern hemisphere, while the Red-legged Kittiwake is less abundant and breeds exclusively in the Bering Sea. The attention given to Black-legged Kittiwakes is likely a result of their relative abundance and the ease of observing their breeding habits in the portions of their range that overlap human population centers, such as northern Europe. Researchers and managers rely upon kittiwake breeding success as an indicator of ecosystem health. Breeding kittiwakes are particularly tolerant of anthropogenic disturbance, and are considered the "white rats" of the seabird world (Hatch et al. 2009).

Kittiwakes are small gulls with forked tails and mostly white plumage, accented by a gray back (darker in the Red-legged Kittiwake) and black-tipped wings. A kittiwake's bill is relatively small, thin, and greenish-yellow in color. The Black-legged Kittiwake has a longer, more pointed bill than its congeneric sister species. Differences in bills and profiles, as well as the namesake differences in leg color, are evident field marks to differentiate between species (Kaufman 1989). The legs of Red-legged Kittiwakes are scarlet red and distinct, although some Black-legged Kittiwakes are known to have a reddish tint to their black legs (Grant 2010). Their short legs and dexterous claws are well suited for nesting on the tenuous substrate of coastal cliffs, yet these same features encumber their ability to walk with agility. They are excellent fliers and can hover on the wing, easily making difficult maneuvers in and out of their precarious nests. The eyes of Red-legged Kittiwakes are larger than those of Black-legged Kittiwakes, a trait that allows Red-legged Kittiwakes to see well in low-light situations, and regularly feed at night (Storer 1987).

Kittiwakes only vocalize in rudimentary ways, using a few simple calls to recognize individuals, warn the colony of danger, and announce themselves when arriving to or leaving the nest (Firsova 1978, Wooller 1978). The calls of Red-legged Kittiwakes are higher in pitch than those of Black-legged Kittiwakes (Firsova 1978).

DISTRIBUTION

Advancing winter sea ice in the Bering Sea displaces kittiwakes that breed in the far north so they are sometimes found at the ice edge. While some kittiwakes (especially Black-legged Kittiwakes) spend the winter south of the Aleutian Islands in the Gulf of Alaska (Kessel and Gibson 1978, Everett et al. 1990), most of the kittiwakes that breed in the Pribilof Islands and the western Aleutians seem to prefer to winter in the western portion of their range (McKnight et al. 2011, Orben et al. 2015a, Orben et al. 2015c), see Figure 5.10-1.

Migration

Not fully migratory, many birds can be found in the vicinity of the breeding colony well into winter if sea ice permits, although the well studied Red-legged Kittiwakes of the Pribilofs are highly migratory (Orben 2017). The majority of kittiwakes do travel away from the breeding colony, generally departing in September and slowly heading west or south to molt and feed in warmer waters through the cold northern winter (Forsell and Gould 1981). They arrive in their wintering areas in late fall or winter (Briggs et al. 1987). In spring, kittiwakes return to their breeding grounds. Unlike other seabirds that move as a flock, kittiwakes migrate in small groups until they congregate in large numbers at the breeding colony. Most Red-legged Kittiwakes likely stay in the Bering Sea to spend the coldest months foraging on the continental shelf, sea-ice margin, and open ocean as daily conditions dictate (Orben et al. 2015a). Many are still found near their breeding colonies at the sea-ice margin (Shuntov 1963, Kessel and Gibson 1978, Everett et al. 1990). Black-legged Kittiwakes also prefer cold, ice-free waters far from shore (Brown 1986) and only low numbers are found in the ice-free portions of the Bering Sea in winter. Most prefer the productive waters of the western subarctic gyre as well as the Gulf of Alaska; and waters off the coasts of British Columbia, Canada; and the western US all the way to Baja, Mexico (Harrington 1975, Gould et al. 1982, Morgan et al. 1991).

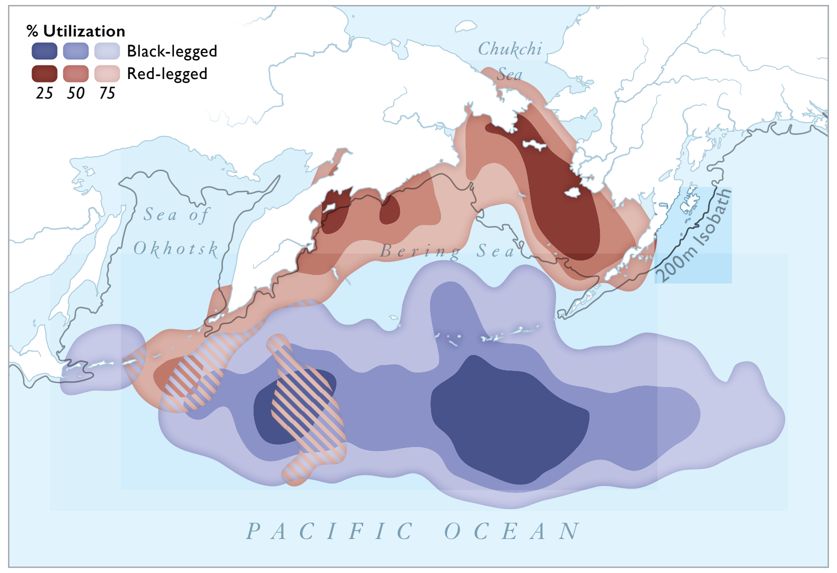


FIGURE 5.10-1. At-sea utilization distributions (UDs) for Red-legged Kittiwakes (n = 17) and Black-legged Kittiwakes (n = 34) in the subarctic North Pacific from October 15, 2010 to February 27, 2011. Adapted from Orben et al. 2015a. Adapted from Orben et al. (2015a).

Species Description

Red-legged Kittiwake. The Red-legged Kittiwake breeds on a very small number of islands in the southern Bering Sea, the Aleutian Islands, and the Commander Islands in Russia. The islands supporting Red-legged Kittiwake colonies include the Pribilofs; Bogoslof and Fire Islands; Buldir Island; and Bering, Cooper, and Arri Kamen Islands in the Commanders (Stejneger 1885, Preble and McAtee 1923, Kenyon and Phillips 1965, Byrd and Tobish 1978, Firsova 1978). They range from the Gulf of Alaska north through the Bering Sea to the Chukchi Sea, west as far as mainland Chukotka, south as far as Japan, and east to Prince William Sound.

Black-legged Kittiwake. Black-legged Kittiwakes are circumpolar in coastal areas of the Arctic and subarctic. In Alaska, they nest as far north as Cape Lisburne and as far south as Boussole Head near Glacier Bay, with the largest portion of the population breeding in the Gulf of Alaska (Fairchild et al. 2007, Seabird Information Network 2017). Pacific breeding birds travel as far west as the Kolyma River Delta in Russia and are known to utilize Wrangel Island south to the Sea of Okhotsk (Kondratyev et al. 2000). In eastern North America, two areas are widely used by Black-legged Kittiwakes: the Canadian High Arctic and the Gulf of St. Lawrence.

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TABLE 5.10-1. Kittiwake life history characteristics and conservation status. Sources: Byrd and Williams (1993), Hatch et al. (2009), Warnock (2017)

	Red-legged Kittiwake *Rissa brevirostris*	Black-legged Kittiwake *R. tridactyla*
Body Size Mass Length	**M** 10.4–17.2 ounces (296–489 g) **L** 13.8–15.4 inches (35–39 cm)	**M** 11.1–20.5 ounces (316–580 g) **L** 14.9–16.4 inches (38–41 cm)
Maximum Life Span (wild)	Unknown	Avg. 13 years
Clutch Size Range Average	**R** 1–3 eggs **A** 2 eggs	**R** 1–3 eggs **A** 2 eggs
Nest-Water Proximity	Coastal cliff nester	Coastal cliff nester
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Not Listed **IUCN:** Vulnerable **WL:** Red List	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Red List
Population Global Alaska	**G** 306,000 **A** 209,000	**G** 17,500,000 **A** 1,322,000
Breeding Season Eggs Young	**E** June to mid-August **Y** Mid-July to mid-September	**E** May to July **Y** June to August
Migration Spring Fall	**S** April **F** September	**S** March to May **F** September to December


Milo Burcham

Red-legged Kittiwake.


Milo Burcham

Black-legged Kittiwake.

LIFE CYCLE

Kittiwakes form large, dense, noisy colonies upon coastal cliffs, often within 25 miles (40 km) of productive feeding grounds (Biderman and Drury 1978, Hunt et al. 1981, Springer 1991). Red-legged Kittiwakes are known to travel great distances for food; in the Pribilofs they travel up to 60 miles (200 km) to forage (Kokubun et al. 2015).

Kittiwakes prefer nest sites on near-vertical faces up to 1,000 feet (300 m) high, often among murres or other cliff-nesting seabirds (Hickey and Craighead 1977, Hunt et al. 1981). Many form pairs once they have arrived at their breeding grounds in late April or early May, although experienced birds often arrive already paired (Nysewander 1983a, Byrd and Williams 1993a). Kittiwakes are often the first birds to arrive at their breeding colony and use this time to gradually construct their nests out of mud and plants before they begin laying their eggs in June, with both members of the pair constructing the nest (Byrd and Williams 1993a). In June, the female lays a single egg, rarely laying a second (Hunt et al. 1981, Johnson and Baker 1985, Lloyd 1985, Byrd 1989). Both parents participate in incubation and foraging during the approximately four weeks between laying and hatching (Hunt et al. 1981). After hatching, the young stay in the nest for the first two weeks before venturing out to explore the area directly surrounding the nest. They fledge after about five weeks and will return to the nest for food for several weeks (Hunt et al. 1981).

Diet

Kittiwakes feed within the top few feet of the ocean surface (Hunt et al. 1981, Hatch et al. 1993). They are especially buoyant, and are not well adapted to diving, so they forage by pursuit-plunging or dipping after their prey, seeking small fish and marine invertebrates such as sand lance (*Ammodytidae* spp.), capelin (*Mallotus villosus*), Pacific herring (*Clupea pallasii*), Arctic cod (*Arctogadus glacialis*), saffron cod (*Eleginus gracilis*), lanternfishes (*Myctophidae*), northern lampfish (*Stenobrachius leucopsarus*), walleye pollock (*Theragra chalcogramma*), squid (cephalopods), amphipods, and euphausiids (Schneider and Hunt 1984, Bradstreet 1985, Dragoo 1991).

Red-legged and Black-legged Kittiwakes feed both diurnally and nocturnally, but the Red-legged Kittiwake is better adapted to nocturnal feeding, with larger eyes that more easily gather the scarce light available during low-light feeding sessions (Storer 1987). Kittiwakes often forage at nutrient-rich upwelling sites over the continental shelf, where their prey concentrates. They are also known to utilize pelagic waters in areas where the shelf is especially narrow (Hunt et al. 1981, Schneider and Hunt 1984), such as at Buldir Island in Alaska, where they forage over pelagic waters near the colony (Schneider and Hunt 1984). Both species of kittiwake are often seen foraging over large schools of fish among larger gulls, murres, terns, cormorants, and puffins.

CONSERVATION ISSUES

Though Black-legged Kittiwakes have large populations across their circumpolar range they have faced recent declines in Alaska (Goyert et al. 2017). Red-legged Kittiwakes experienced substantial declines in the 1970s and 1980s, leading to an International Union for Conservation of Nature (IUCN) listing of vulnerable in 1994, continuing through their most recent evaluation in 2015 (Renner et al. 2012, International Union for the Conservation of Nature 2014). Red-legged Kittiwakes were designated as a candidate for listing as threatened or endangered under the Endangered Species Act in 1994, though more research was deemed necessary to complete the listing. The species is listed in the Red Book of Russia. The decline at their largest colony on St. George Island in the Pribilofs has stabilized, although their numbers still fluctuate in other portions of their range. These declines may be due to commercial fisheries depleting the forage fish on which kittiwakes rely (Renner et al. 2012). Red-legged and Black-legged Kittiwakes are on the Red List of Audubon Alaska's 2017 WatchList, indicating declines in their population (Warnock 2017).

Climate change appears to be a major contributiong factor to the substantial declines both species of kittiwake continue to experience (Goyert et al. 2017). Kittiwakes are susceptible to many pressures, both natural and anthropogenic. Anthropogenic disturbance is a common concern regarding colonial breeding seabirds, although kittiwakes seem to be affected less by this disturbance than other colonial nesters. The main predator of kittiwake adults, chicks, and eggs is the Arctic fox (*Vulpes lagopus*). Other predators include Glaucous-winged Gulls (*Larus glaucescens*), Glaucous Gulls (*L. hyperboreus*), Common Ravens (*Corvus corax*), Bald Eagles (*Haliaeetus leucocephalus*), and Peregrine Falcons (*Falco peregrinus*) (Nysewander 1983a, Fadely et al. 1989, Suryan et al. 2006a). The Alaska Maritime National Wildlife Refuge conducts an introduced-fox eradication program, which has been successful thus far (Ebbert and Byrd 2002).

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As with many species of seabird, the dependence of kittiwakes on abundant prey brings them into regular contact with commercial fisheries, although their surface-feeding habits do not regularly cause them to be caught in gill nets (Ainley et al. 1981). Commercial fisheries have likely depleted forage fish stocks utilized by kittiwakes, but more data are needed to confirm this theory (Springer 1992, Hatch et al. 1993).

Contact with oil rarely resulted in death for kittiwakes impacted by the *Exxon Valdez* oil spill of 1989 (Piatt et al. 1990a, Piatt et al. 1990b). While long-term effects of oiling events on kittiwakes are unknown, biomagnification and ingestion during preening are likely to have detrimental effects on exposed birds.

The commercial harvest of kittiwake eggs has had past adverse effects on the size and distribution of colonies, and likely caused substantial declines in kittiwake recruitment in colonies of Red-legged Kittiwakes in the Pribilofs in the 1970s (Hunt et al. 1981). In Greenland, hunting and egging continued into the 21st century but has since been forbidden (Nyeland 2004, Merkel and Barry 2008).

MAPPING METHODS (MAPS 5.10.1–5.10.2)

We categorized distribution into four main categories of intensity: extent of range, regular use, concentration, and high concentration. The kittiwake extents of range were drawn by buffering all known occurrences of each species using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), and the Seabird Information Network (2011). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. For each species, observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed. The Red-legged Kittiwake range was extended into Anadyrskiy Gulf, where survey data are limited, based on personal communication with Rachael Orben.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

Because of the relative lack of survey data in Russia, concentration areas in Russia are often not known or depicted. Where there were gaps in survey coverage, such as in Russia, we buffered species' colony locations, using a buffer radius equal to the species' average maximum foraging distance (44 miles [71 km] for Black-legged Kittiwakes (Lascelles 2008) and 75 miles [120 km] for Red-legged Kittiwakes (Cornell Lab of Ornithology and American Ornithologists' Union 2016)). These two types of boundaries were combined to represent regular use across the project area.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, we used IBA data from BirdLife International (2017a) while IBAs in Alaska are from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also show single-species IBA core areas (Audubon Alaska 2015) to indicate high concentrations for each species (see Smith et al. 2014c).

Kittiwake colony data were downloaded from the Seabird Information Network (2011). The colony count data for Red-legged Kittiwakes were updated based on Byrd et al. (1997), Byrd et al. (2001a), Byrd et al. (2001b), Byrd et al. (2004), Thomson et al. (2014), and Williams (2017). This map represents the most recent or otherwise best estimate available for each colony location (see Smith et al. 2012). On the map, the size of each colony point represents the percent of the total population present at that colony. Total population was the sum of the abundance of the species across all colonies within the project area.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines were based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. Kittiwakes generally do not use the areas of Canadian waters in our project area. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps. The colony data are available throughout the US and Russian portions of the project area, but data quality—survey dates and techniques—varies greatly among colonies. Colony sizes should be interpreted as estimates rather than precise counts.

Reviewers

- Rachael Orben
- Marc Romano

MAP DATA SOURCES

RED-LEGGED KITTIWAKE MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), R. Orben (pers. comm.), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Byrd et al. (1997), Byrd et al. (2001a), Byrd et al. (2001b), Byrd et al. (2004), Seabird Information Network (2011), Thomson et al. (2014), and Williams (2017)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2015) and Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Byrd et al. (1997); Byrd et al. (2001a, b); Byrd et al. (2004); Seabird Information Network (2011); Thomson et al. (2014); Williams (2017)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

BLACK-LEGGED KITTIWAKE MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a) and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2015) and Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

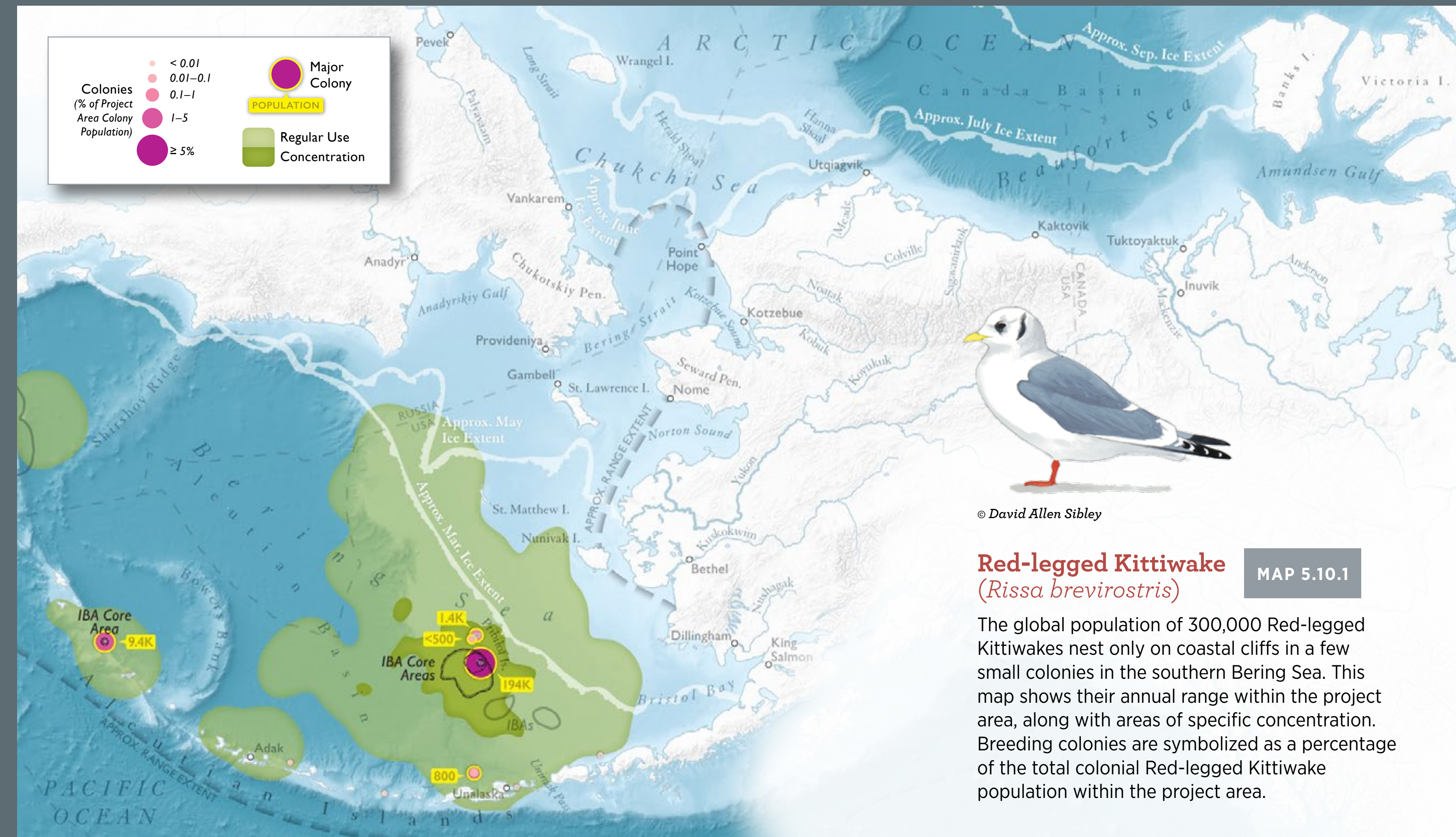
IBA Core Areas: Audubon Alaska (2015)

Colonies: Seabird Information Network (2011)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Kittiwakes

Audubon ALASKA

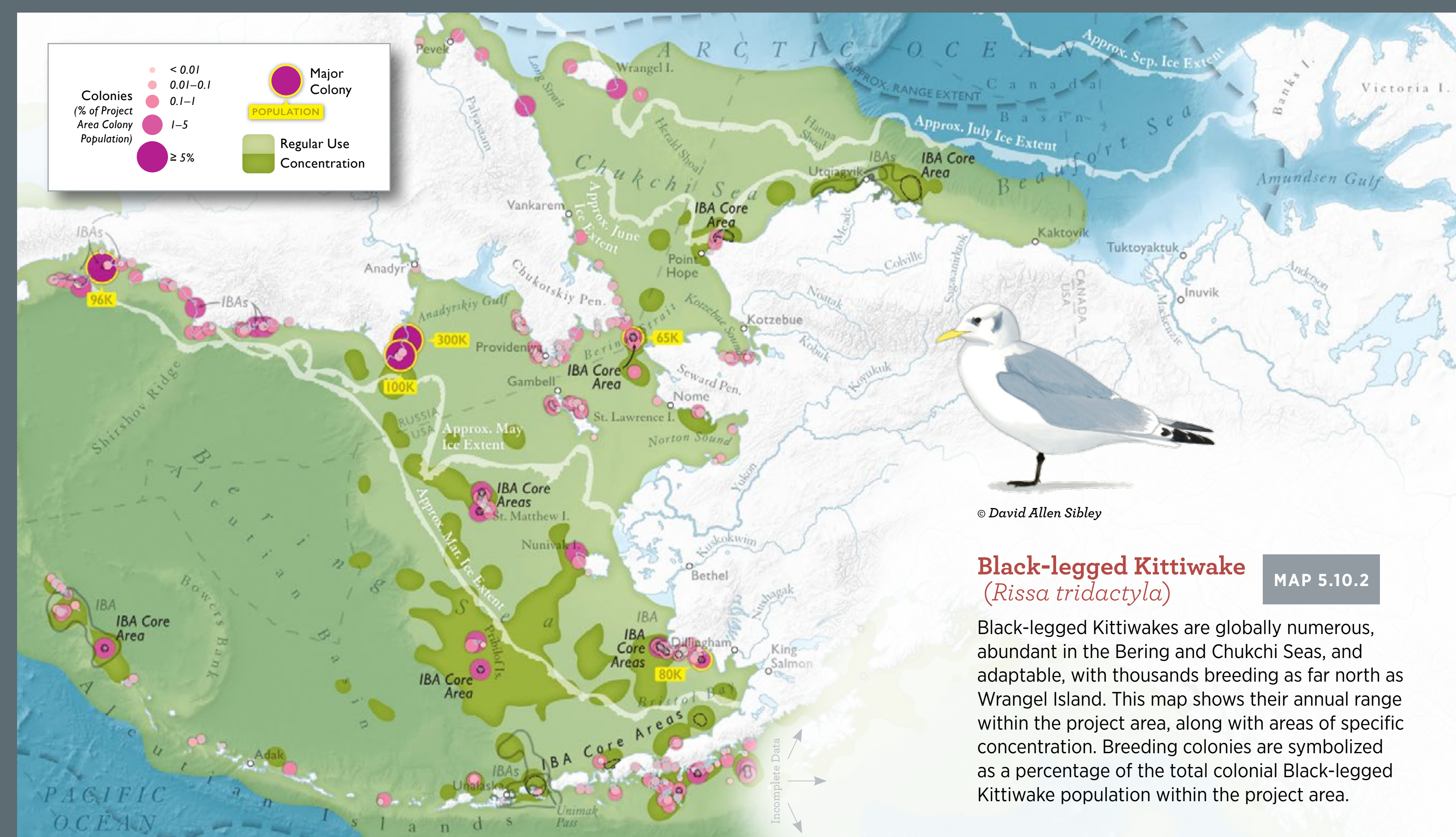


Red-legged Kittiwake *(Rissa brevirostris)* MAP 5.10.1

The global population of 300,000 Red-legged Kittiwakes nest only on coastal cliffs in a few small colonies in the southern Bering Sea. This map shows their annual range within the project area, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Red-legged Kittiwake population within the project area.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2015), Audubon Alaska (2016a), Byrd et al. (1997), Byrd et al. (2001a), Byrd et al. (2001b), Byrd et al. (2004), eBird (2015), R. Orben (pers. comm.), Seabird Information Network (2011), Thomson et al. (2014), and Williams (2017)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Byrd et al. (1997); Byrd et al. (2001a); Byrd et al. (2001b); Byrd et al. (2004); Seabird Information Network (2011); Thomson et al. (2014); Williams (2017)

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman



Black-legged Kittiwake *(Rissa tridactyla)* MAP 5.10.2

Black-legged Kittiwakes are globally numerous, abundant in the Bering and Chukchi Seas, and adaptable, with thousands breeding as far north as Wrangel Island. This map shows their annual range within the project area, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Black-legged Kittiwake population within the project area.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2015), Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Seabird Information Network (2011)

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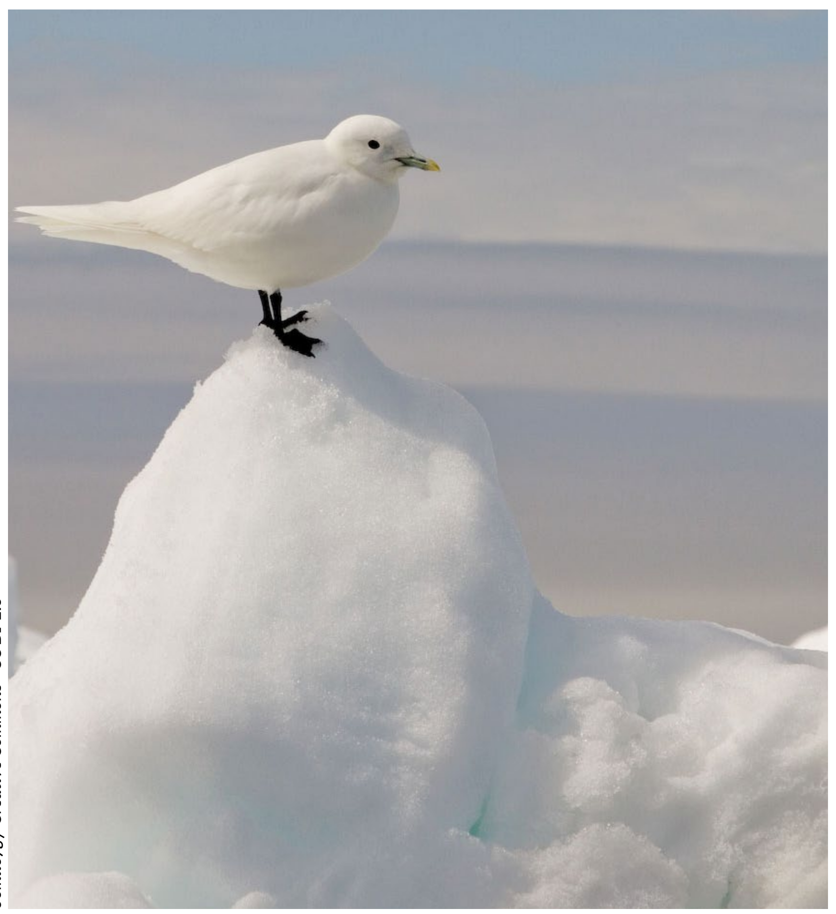
Ivory Gull

Pagophila eburnea

Nils Warnock, Erika Knight, and Melanie Smith

As its genus name implies (*Pagophilia* means "a preference for ice"), the Ivory Gull (*Pagophila eburnea*) is a species that is almost exclusively dependent on sea ice throughout its annual cycle (Cramp et al. 1983, Mallory et al. 2008). During the non-breeding season, these birds move tens of thousands of miles along the ice-edge (Gilg et al. 2010, Spencer et al. 2014a). This medium-sized gull is, in adult plumage, strikingly white with short, black legs and a small, orange-tipped, yellowish-green to greenish-blue bill. Uncommon to rare in Alaskan waters, the Ivory Gull is mainly pelagic and stays near ice, but occasionally shows up at interior sites (Gabrielson and Lincoln 1959, Divoky 1976, eBird 2017). This species is easy to miss, however, because of the extremely remote areas it inhabits. In Alaska's Arctic waters, only single, or as many as tens of birds are seen at a time. These birds may come from the Russian breeding colonies of about 4,000 birds from around Severnaya Zemliya to the west, and possibly from smaller Canadian colonies to the east (Volkov and De Korte 1996, Gilg et al. 2010, I. Stenhouse pers. comm.). While trend data are sparse, the global population is thought to be in decline (Robertson et al. 2007, Gilg et al. 2009, Environment Canada 2014, BirdLife International 2016b).

Little is known about the physical adaptations of Ivory Gulls, but Gabrielsen and Mehlum (1989) found that the resting metabolic rate of the Ivory Gull was about 200% higher than predicted for a relatively small seabird. This may allow Ivory Gulls to increase heat production when stressed by the cold, although this is based on measurements from a single bird. The mean body temperature of this bird was 104.5° F (40.3° C). Ivory Gulls possess short, stout tarsi (Cramp et al. 1983) with strong, claw-like feet, perhaps for gripping on ice (Howell and Dunn 2007).



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The Ivory Gull prefers especially remote, icy areas in the circumpolar Northern Hemisphere. Named for their distinct, all-white adult plumage, the Ivory Gull's inaccessible habitat has contributed to the mystery of this species.

DISTRIBUTION

While Ivory Gulls have been spotted as far south as southern California (Mallory et al. 2008), most observations of this ghost-like gull are within sight of Arctic sea ice. Depending upon the location, they associate on the ice with walrus (*Odobenus rosmarus divergens*), ice seals, and polar bears (*Ursus maritimus*), and at sea with kittiwakes, Red Phalaropes (*Phalaropus fulicarius*), and Sabine's Gulls (*Xema sabini*) (Divoky 1976, Cramp et al. 1983). Satellite-tagged, post-breeding Ivory Gulls from the northeast Atlantic generally followed the northern-most edge of sea ice off Canada, Greenland, and Russia during their non-breeding season, although some birds use glacier fronts in open-water areas (Gilg et al. 2010). Likewise, tagged Ivory Gulls from Seymour Island in Arctic Canada showed a strong affinity for edge regions of sea ice and dense pack ice (average of 50% concentration) (Spencer et al. 2014a).

Post-breeding migration has been described as "bi-directional trans-polar migration" (Gilg et al. 2010), with birds heading in both easterly and westerly directions to wintering grounds along ice edges. Ivory Gulls travel an average 4–6 miles (6–10 km) per hour, with highest travel rates during November (Gilg et al. 2010, Spencer et al. 2014a). Like many migratory seabirds, fall migration is more prolonged in Ivory Gulls than their spring migration (Gilg et al. 2010, Spencer et al. 2014a).

Migration

Based on the movements of satellite-tagged individuals, major wintering areas of Ivory Gulls appear to be in the Bering Sea, southeast Greenland, and the Davis Strait/Labrador Sea, with most birds arriving at these wintering areas in November and December (Gilg et al. 2010, Spencer et al. 2014a). Although sample sizes are small, up to 25% of birds that winter in the Bering Sea come from colonies in Franz Joseph Land in Russia, 20% from Svalbard, and 11% from Greenland (Gilg et al. 2010). Genetically, Ivory Gulls collected near Utqiaġvik (formerly Barrow) during the non-breeding season are largely differentiated from breeding birds from Norway, Greenland, and Canada, also suggesting a Russian connection for these birds (Royston and Carr 2016).

LIFE CYCLE

Ivory Gulls nest in Arctic Canada, Greenland, Norway (Svalbard), and Russia at some of the highest latitudes and remotest sites of any bird in the world (Cramp et al. 1983, Volkov and De Korte 1996, Krajick 2003, Mallory et al. 2008). Typically, small nesting colonies (tens to thousands of birds) are found on steep rock cliffs and gravel plateaus 6–31 miles (10–50 km) from the water in places with few predators (particularly Arctic fox [*Volpes lagopus*]) (Robertson et al. 2007, Mallory et al. 2008, Gilg et al. 2009). They will also nest in flat, bare areas near the sea (Cramp et al. 1983, Volkov and De Korte 1996). Rarely, small colonies have been found on floating, gravel, and rock-covered islands in the ice (Boertmann et al. 2010). Ivory Gulls nest on the ground, usually laying two eggs.

Diet

The diet of Ivory Gulls consists mostly of invertebrates and fishes, although the species is omnivorous and highly opportunistic, depending upon location and season (Mallory et al. 2008). In certain seasons and areas, birds are known to feed on placentas and feces of marine mammals, as well as on scraps of kills made by polar bears (Divoky 1976, Gjertz and Lydersen 1986). In Alaska's Chukchi Sea, southwest of Utqiaġvik (formerly Barrow), 13 Ivory Gulls were collected in the month of October and 92% of them had Arctic cod (*Boreogadus saida*) in their stomachs, while 23% had ingested plant material (Divoky 1976). In the Bering Sea, walleye pollock (*Theragra chalcogramma*) are an important prey for Ivory Gulls (Divoky 1981, Mallory et al. 2008)

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CONSERVATION ISSUES

In Canada, the Ivory Gull is listed as endangered under the Species at Risk Act, and a recovery strategy is in place (Environment Canada 2014). It is also listed as a Category 3 (Rare) species in the Red Data Book of the Russian Federation and designated as near threatened on the IUCN Red List of Threatened Species (BirdLife International 2016b). The Conservation of Arctic Flora and Fauna (CAFF)'s Circumpolar Seabird Group has also developed an international conservation strategy (Gilchrist et al. 2008). Since 2010, Audubon Alaska has included the Ivory Gull on its Red List, indicating that the species is declining (Warnock 2017).

Ivory Gulls appear to be declining and thus are of significant management concern (Gilg et al. 2009, Environment Canada 2014). For a species that relies so heavily on sea ice throughout its annual cycle, perhaps the major long-term challenge for Ivory Gulls is the rapid decline of Arctic sea ice due to changing climatic conditions, including rising temperatures (Serreze et al. 2007). The mechanism(s) for how this impacts Ivory Gull populations is unclear; although some suggest changing winter habitat conditions are of particular concern (Krajick 2003). During the breeding season, unusual rainstorm events have caused significant breeding failure with close to 100% chick mortality at Ivory Gull colonies in Greenland (Yannic et al. 2014). Subsistence hunting in Greenland has been documented to be a significant source of mortality for adult Ivory Gulls, but hunting appears to be declining (Stenhouse et al. 2004). Additionally, high loads of environmental contaminants have been measured in these Arctic gulls (Braune et al. 2006, Braune et al. 2007, Verreault et al. 2010). Using feather samples from adult birds collected in Arctic Canada, methylmercury was found to have increased significantly over the past 130 years (Bond et al. 2015). At Seymore Island in Canada, eggs of Ivory Gulls had elevated levels of mercury, in some cases high enough to have negative impacts on reproductive success (Braune et al. 2006).

MAPPING METHODS (MAP 5.11)

We categorized distribution into three main categories of intensity: extent of range, regular use, and concentration. The extent of range was drawn by buffering all known occurrences of Ivory Gulls using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), Spencer et al. (2015), and Gilg et al. (2016). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. Ivory Gull observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). Data from Portenko (1972), indicating regular use of the shorelines around St. Lawrence and Wrangel Islands, is also shown as regular use. For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

Migration arrows were digitized by Audubon Alaska (2009a) based on migration information provided in Mallory et al. (2008).

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

TABLE 5.11-1. Ivory Gull life history characteristics and conservation status. Sources: Mallory et al. (2008), Warnock (2017).

	Ivory Gull *Pagophila eburnea*
Body Size Mass Length Wingspan	**M** 1–1.5 pounds (465–617 g) **L** 15.7–16.9 inches (40–43 cm) **W** 42.5–47.2 inches (108–120 cm)
Maximum Life Span (wild)	20+ years
Clutch Size Range Average	**R** 1–3 eggs **A** 2.2 eggs
Nest-Water Proximity	9–14 miles (15–22 km) inland (in North America)
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Not Listed **IUCN:** Near Threatened **WL:** Red List
Population Global Alaska	**G** 19,500 **A** 1,000
Breeding Season Eggs Young	**E** June to August **Y** July to September
Migration Spring Molt Fall	**S** March to May **M** March to July **F** September to November

Data Quality

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years Survey data is most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. There is little to no survey coverage in the Canadian and Russian portions of the project area, potentially leaving major data gaps for this species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of this map.

Reviewer

- Iain Stenhouse

MAP DATA SOURCES

Extent of Range: Audubon Alaska (2016e) based on Audubon Alaska (2016a), eBird (2015), Gilg et al. (2016), and Spencer et al. (2014a, b)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a); Portenko (1972)

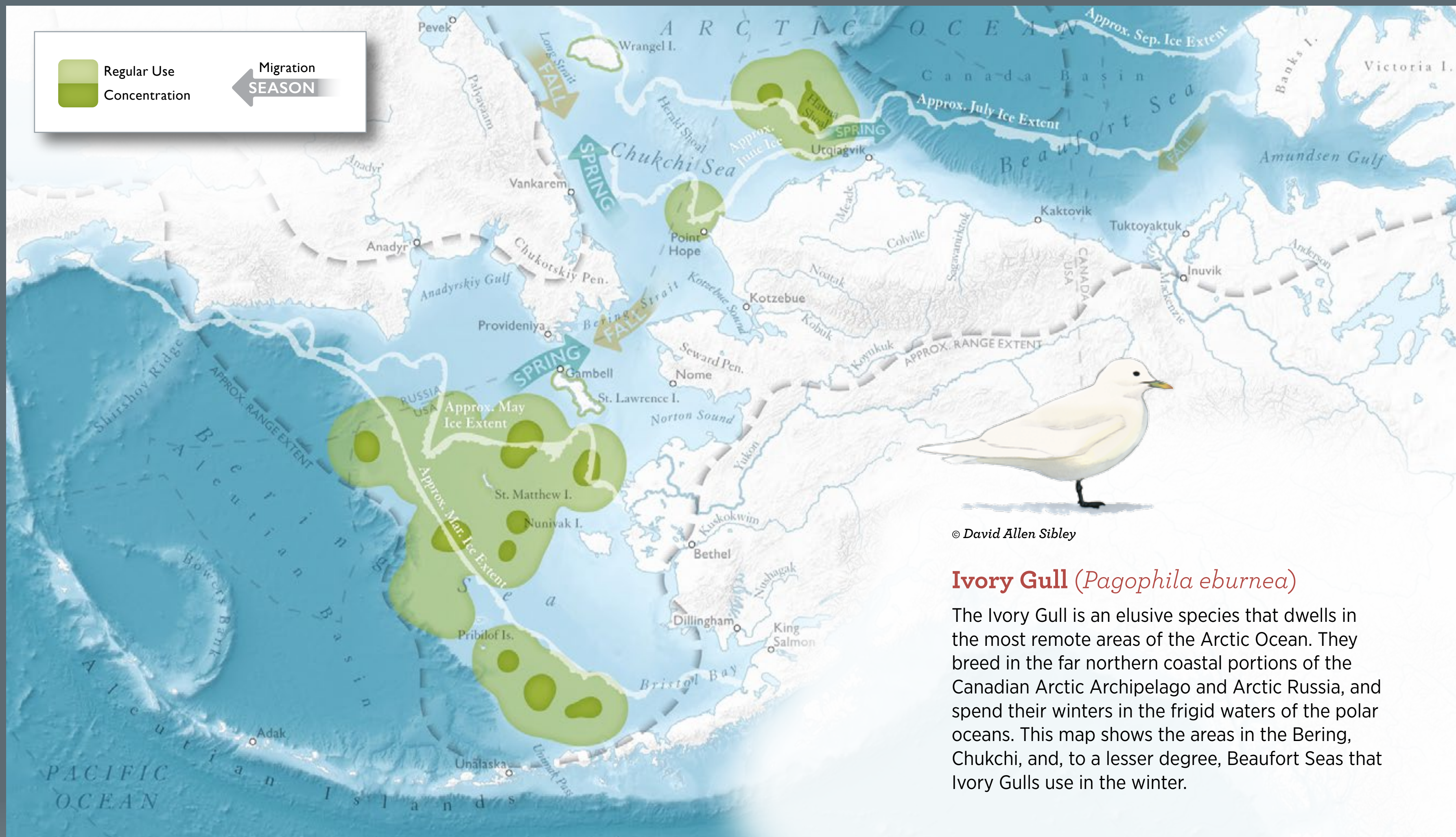
Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

Migration: Audubon Alaska (2009a) based on Mallory et al. (2008)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Ivory Gull

Audubon ALASKA



Ivory Gull (*Pagophila eburnea*)

The Ivory Gull is an elusive species that dwells in the most remote areas of the Arctic Ocean. They breed in the far northern coastal portions of the Canadian Arctic Archipelago and Arctic Russia, and spend their winters in the frigid waters of the polar oceans. This map shows the areas in the Bering, Chukchi, and, to a lesser degree, Beaufort Seas that Ivory Gulls use in the winter.

Audubon Alaska (2009a) [based on Mallory et al. (2008)]; Audubon Alaska (2016c) [based on Audubon Alaska (2016a)]; Audubon Alaska (2016e) [based on Audubon Alaska (2016a), eBird (2015), Gilg et al. (2016), Spencer et al. (2014a;2014b)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; Portenko (1972)

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Ivory Gull.

Gerrit Vyn

Murres

Max Goldman, Erika Knight, and Melanie Smith

Common Murre

Uria aalge

Thick-billed Murre

U. lomvia

The largest and most well-studied birds in the auk family (*Alcidae*), the two congeneric species of murre, the Common Murre (*Uria aalge*) and Thick-billed Murre (*U. lomvia*), are among the most abundant seabirds in the Northern Hemisphere. They are found in cooler, continental shelf waters of the Arctic and subarctic in North America, Europe, and eastern Asia (Gaston and Hipfner 2000, Wong et al. 2014). A pursuit-diving colonial nester, murres live their entire lives on or very near the ocean, coming ashore only to breed. Common and Thick-billed Murres are very difficult to tell apart at a distance or in low light; and the fact that they often nest in the same areas in colonies numbering in the millions only serves to exacerbate the problem, resulting in many records of unidentified murre species. Raptors, such as the Bald Eagle (*Haliaeetus leucocephalus*), Gyrfalcon (*Falco rusticolus*), and Rough-legged Hawk (*Buteo lagopus*), and mammals, such as the red fox (*Vulpes vulpes*), Arctic fox (*Vulpes lagopus*), and polar bear (*Ursus maritimus*), are the most common natural predators of adult murres, while foxes, corvids, and gulls are common predators of eggs and young (Ainley et al. 2002).

Common and Thick-billed Murres have dark brown or black heads, necks, upper wings, and backs and have white underparts. They use their short tails for propping themselves up when perched on the rocky cliffs on which they breed (Ainley et al. 2002). Both species have long, tapered black bills. The bill of the Common Murre is finer than that of the Thick-billed Murre, which has a noticeable decurve at the tip of the culmen, compared to the subtle taper of the Common Murre's bill. The most distinctive field mark is a diagnostic white line on the bill of the Thick-billed Murre, though this is difficult to observe from a distance. There are also minor differences in plumage between the two murres as well. The Common Murre shows a curved, upside-down "U" on its upper chest at the margin between black and white feathers, while the Thick-billed Murre has a sharper, inverted "V" where black feathers meet white feathers on its chest (Ainley et al. 2002).

Murres have very short wings and a relatively large and heavy body, resulting in the highest wing-load of extant flighted birds (Croll et al. 1991). This high wing-load makes takeoff very difficult, and murres require an especially fast wing beat and flight speed to stay airborne (Croll et al. 1991). They are, however, well-suited for swimming and diving, regularly reaching depths of over 330 feet (100 meters) and dive durations of over 4 minutes (Piatt and Nettleship 1985). The depth and duration of their dives indicate that they employ an unknown mechanism to avoid lung collapse and decompression sickness upon returning to the surface (Piatt and Nettleship 1985).

Murres are known to communicate with a broad variety of sounds (Gaston and Hipfner 2000). Communication is constant and critical within the murres' breeding colonies to help this highly aggressive species maintain order. Murres most commonly communicate as a form of individual recognition between mates and neighbors, so breeding colonies are very noisy. After leaving the colony, murres vocalize to locate each other after dives of over two minutes in foggy and often stormy seas that may separate parent and chick (Gaston and Hipfner 2000, Ainley et al. 2002).

DISTRIBUTION

Thick-billed and Common Murres are true seabirds, spending all of their lives at sea in waters that remain below 46° F (8° C), except during the breeding season, when they leave the water for cliffs for 6–10 weeks. In the Bering Sea, murres often move south with the sea-ice margin and begin to move north again as soon as the sea ice recedes. During the winter, forage-fish assemblages can be highly variable, and mortality is often high, as birds without proper fat stores starve in the snow and ice of the far north (Gaston and Hipfner 2000, Ainley et al. 2002, Orben et al. 2015b).

Migration

The first few weeks of migration for fathers and chicks is strictly in the water, until around six weeks after hatching, when chicks are able to fly (Gaston and Hipfner 2000, Ainley et al. 2002). Arctic-breeding murres in high latitudes move south ahead of the advance of the sea-ice margin through the Chukchi and Bering Seas toward molting areas in the southern Bering Sea. While spring migration is not well understood, movements are likely timed with the northward retreat of the winter sea ice in the Bering Sea (Gaston and Hipfner 2000, Ainley et al. 2002).

Wintering

Both male and female murres migrate to molting areas in the fall after breeding, becoming flightless for one to two months. The Common Murre winter range extends farther south than that of the Thick-billed Murre (Gaston and Hipfner 2000, Ainley et al. 2002). Murres are often found near shore, using open water inlets and coves as feeding refugia during the winter months. The Pacific breeding populations of murres utilize Bristol Bay, the Aleutian Islands, and the continental shelf waters south of the sea-ice margin as wintering grounds (Divoky 1979, Gould et al. 1982, Harrison 1982, Brown 1986, Shuntov 1993). Male and female murres often winter in different areas, returning to the same locations each year (Hatch et al. 2000).

Species Description

Common Murre. Common Murres breed in Arctic and subarctic waters. In the Pacific, they breed on coastal cliffs from 72 to 33°N, specifically Wrangel Island in the northern Beaufort Sea, south through the Bering Strait, St. Lawrence Island, the Pribilofs, Bristol Bay, and the Aleutian Islands, along the shores of the Gulf of Alaska, and south to Monterey, California, including the Farallon Islands (Carter et al. 2001, Ainley et al. 2002). In the Atlantic, they breed in coastal areas from 56 to 43°N, including the southern tip of Greenland, south to Labrador Island and Quebec, Newfoundland, and Nova Scotia in the Bay of Fundy (Nettleship 1980, Cairns et al. 1986, Lock et al. 1994). Their winter range includes offshore portions of the same general area, except where sea ice encroaches.

Thick-billed Murres. Thick-billed Murres utilize similar areas as Common Murres, but with some distinct differences. While Common Murres range as far south as California to breed, Thick-billed Murres do not go farther south than the coast of British Columbia, Canada, staying instead between 72 and 50°N in the Pacific (Campbell et al. 2007b). They also breed farther north in the Atlantic than do Common Murres (between 82 and 46°N), using the cliffs on the coast of Prince Leopold Island, Baffin Island, and Greenland, as well as Labrador, Newfoundland, and Nova Scotia (Nettleship 1980, Cairns et al. 1986). There are breeding populations of Thick-billed Murres that do not interact with Common Murres in northern Hudson Bay and Hudson Strait, and on the Beaufort Sea coast of Canada in the Northwest Territories, near Amundsen Gulf (Johnson and Ward 1985, Gaston and Hipfner 2000).

LIFE CYCLE

Highly social, Common and Thick-billed Murres breed nearly shoulder to shoulder with other murres in colonies often composed of hundreds of thousands of breeding birds. They do not build nests, and instead lay their eggs on the rocky substrate of the island cliff ledges, slopes, and flat surfaces of their breeding habitat (Stephensen and Irons 2003). By breeding in high numbers and high density, they are somewhat protected from large gulls (*Larus* spp.) that attempt to take chicks or steal food brought to chicks (Spear 1993). Murres lay their single, especially hard egg in a highly synchronous manner, with 90% of all eggs in a given colony laid within 15 days of each other (Murphy and Schauer 1996). The long, pointed shape of the egg is an adaptation that keeps it

TABLE 5.12-1. Murre life history characteristics and conservation status. Sources: Gaston and Hipfner (2000), Ainley et al. (2002), Warnock (2017).

	Common Murre *Uria aalge*	Thick-billed Murre *U. lomvia*
Body Size Mass Length Wingspan	**M** 1.8–2.5 pounds (800–1,125 g) **L** 15–17 inches (38–43 cm) **W** 25–28 inches (64–71 cm)	**M** 1.75–3.3 pounds (795–1480 g) **L** 13.7–18.9 inches (35–48 cm) **W** 25–30 inches (64–75 cm)
Maximum Life Span (wild)	26 years	29 years
Clutch Size Range Average	**R** 1 egg **A** 1 egg	**R** 1 egg **A** 1 egg
Nest-Water Proximity	Coastal cliff nester	Coastal cliff nester
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Not Listed	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Not Listed
Population Global Alaska	**G** 18 million **A** 2.8 million	**G** 22 million **A** 2.2 million
Breeding Season Eggs Young	**E** Early June to August **Y** Mid-July to mid-September	**E** Late May to late June **Y** Late June to late July
Migration Spring Molt Fall	**S** April to June **M** Early September to mid-December **F** August to mid-November	**S** March to May **M** Late August to mid-December **F** July to mid-September

from rolling off the cliffside nest, as it instead rolls in a tight circle. Both sexes share equally in incubating the egg (Wanless and Harris 1986, Verspoor et al. 1987). If an egg is lost early in the breeding season, pairs will reclutch, producing another single egg.

Adults share foraging responsibilities as well, and must seek abundant, energy-rich prey within 37–43 miles (60–70 km) of breeding ledges, as chicks are fed a single fish several times a day (Gaston and Hipfner 2000). Chicks leave the nest with their fathers well before they are capable of flight, at only three or four weeks old. This event is also highly synchronous, with large groups of male murres leading their young chicks to the cliff's edge, jumping into the water, then calling for the chicks to join them in the water (Roelke and Hunt 1978). If the chick becomes separated from its father, it is immediately surrounded by other murres until reunited through a duet of calls between the chick and parent. Back together, chicks then begin their first migration, swimming with their fathers until they are able to fly (Roelke and Hunt 1978). The female stays at the nest site for up to two weeks after her mate and chick have left, before flying south with non-breeding subadults (Gaston and Hipfner 2000).

Diet

Pursuit-diving seabirds, murres use their short, powerful wings for propulsion and capture prey in their bills. Unlike puffins, they generally catch a single fish at a time, repositioning the prey for swallowing headfirst while they are still under water (Sanford and Harris 1967, Swennen and Duiven 1977, Raikow et al. 1988). Although they are commonly found hunting by themselves, murres also forage cooperatively in flocks that often consist of thousands of seabirds of many species, such as shearwaters, cormorants, gulls, jaegers, kittiwakes, and other alcids. They are also often joined by marine mammals, including whales and dolphins foraging for fishes and invertebrates, such as Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*), pollock (*Pollachius* spp.), sand lance (*Ammodytes* spp.), capelin (*Mallotus villosus*), herring (*Clupea* spp.), euphausiids, large copepods, and squid. They feed mostly in the epibenthic and demersal zones, on or just above the ocean floor. The high energetic requirements of their northern-latitude habitat, poor insulation, and high wing-loading require murres to consume 10–30% of their body mass each day (Johnson and West 1975, Swennen and Duiven 1977).

CONSERVATION ISSUES

While the Common and Thick-billed Murres are protected by the Migratory Bird Treaty Act of 1918, they have no other protections, owing to large, relatively stable populations throughout their global range. They are not listed on Audubon Alaska's WatchList, but Common Murre population numbers have declined in the southeast Bering Sea (Goyert et al. 2017). However, murres are susceptible to many pressures, both natural and anthropogenic. Eggs and chicks are commonly eaten by foxes. In 1976, two red foxes on Shaiak Island in the Aleutians in Alaska caused the loss of nearly all of the eggs of 25,000 breeding pairs of murres due to their own predation and that of large gulls, which preyed on the unprotected eggs after the foxes flushed the murres from their nests (Petersen 1982, Bailey 1993).

As with many species of seabirds, the murres' dependence on abundant prey brings them into regular contact with commercial fisheries. Murres are commonly caught in gill nets throughout their global range (Ainley et al. 1981). Commercial fisheries have also likely depleted forage fish stocks utilized by murres, but few data have been gathered to support this theory (Duffy and Schneider 1994, Gaston and Hipfner 2000).

Murres are regularly susceptible to high mortality due to oil spills (Piatt et al. 1990a). Contact with oil often results in hypothermia and malnutrition due to a loss of the insulative properties of their feathers (Seip et al. 1991). During preening, they also ingest oil, which has longer-term effects (Wiens et al. 1984).

Anthropogenic disturbance is a common concern regarding colonial breeding seabirds. Murres are especially sensitive to human intrusions, such as low-flying aircraft, loud or close watercraft, and the close approach by people on foot or in non-motorized watercraft (Chardine and Mendenhall 1998).

The commercial harvest of murre eggs was responsible for precipitous declines in local breeding populations near the end of the 19th century, but those efforts have ceased under the Migratory Bird Treaty Act of 1918 and other protections. The subsistence harvest of murre eggs is not widespread, and only three communities are known to regularly collect Common or Thick-billed Murre eggs: Pond Inlet in Nunavut and Ivujivik in Quebec in Canada, and Cape Thompson in Alaska in the US. Little is known about the subsistence value of murres to Japanese or Russian communities.

Starvation is a common cause of murre mortality, and dead murres are sometimes found in very large numbers. As recently as the winter of 2015–16, Common Murres in Alaska suffered a large mortality event of ~500,000 birds, likely caused by a combination of climate factors, such as atypically warm weather patterns and water temperatures leading to diminished forage-fish assemblages (Cavole et al. 2016). The competition for insufficient food resources caused the Common Murre population to travel great distances, even to inland locations in search of food. Suffering diminished body condition, many starved. As the climate becomes increasingly variable, mass die-offs will likely become more common (Sydeman et al. 2016).

MAPPING METHODS (MAPS 5.12.1–5.12.3)

Due to the difficulty of identifying murres in many field conditions, much of the data used in these maps are identified only as "unidentified murre" rather than to species level. In order to present information for murres as completely as possible, we have made three maps: one specific to Common Murres, one specific to Thick-billed Murres, and one that incorporates all data regarding murres (Total Murres).

We categorized distribution into four main categories of intensity: extent of range, regular use, concentration, and high concentration. The extent of range was drawn by buffering all known occurrences of Common Murres, Thick-Billed Murres, or Total Murres using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), the Seabird Information Network (2011), and Canadian Wildlife Service (2013). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. For each species and for Total Murres, observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed. The Thick-billed Murre range was extended throughout the western Bering Sea, where survey data are limited, based on Orben et al. (2015b).

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

Because of the relative lack of survey data in Russia, concentration areas in Russia are often not known or depicted. Where there were gaps in survey coverage, such as in Russia, we buffered species' colony locations, using a buffer radius equal to the species' average maximum foraging distance (42 miles [68 km] for Common Murres and 66 miles [106 km] for Thick-billed Murres (Lascelles 2008)); for colonies not identified to the species level, the average of Common Murre and Thick-billed Murre foraging radii (54 miles [87 km]) was used). These two types of boundaries were combined to represent regular use across the project area.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, we used IBA data from BirdLife International (2017a) while IBAs in Alaska are from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also show single-species IBA core areas (Audubon Alaska 2015) to indicate high concentrations for each species (see Smith et al. 2014c).

Murre colony data were downloaded from the Seabird Information Network (2011) and supplemented with data provided by the Canadian Wildlife Service (Canadian Wildlife Service 2013). These maps represent the most recent or otherwise best estimate available for each colony location (see Smith et al. 2012). On the map, the size of each colony point represents the percent of the total population present at that colony. Total population was the sum of the abundance of the species across all colonies within the project area.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

The Common Murre and Thick-billed Murre maps represent only those areas where murres could be identified to the species level; there are areas not shown on each species-specific map where murres are present, but it is unknown which (or if both) species uses these areas. The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. There is little to no survey coverage in the Canadian and Russian portions of the project area, potentially leaving major data gaps for these species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps. For example, the Common Murre map indicates that there is a colony of approximately 500,000 Common Murres at Cape Navarin; therefore, it seems likely that the species concentrates in marine waters near this colony. However, our concentration analysis did not show a concentration area in this vicinity, perhaps because survey data are limited here. The colony data are available throughout the US and Russian portions of the project area, but data quality—survey dates and techniques—varies greatly between colonies. Colony sizes should be interpreted as estimates rather than precise counts.

Reviewer
- Rachael Orben

MAP DATA SOURCES

COMMON MURRE MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Canadian Wildlife Service (2013); Seabird Information Network (2011)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

THICK-BILLED MURRE MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), eBird (2015), Orben et al. (2015b), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Canadian Wildlife Service (2013); Seabird Information Network (2011)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

TOTAL MURRES MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

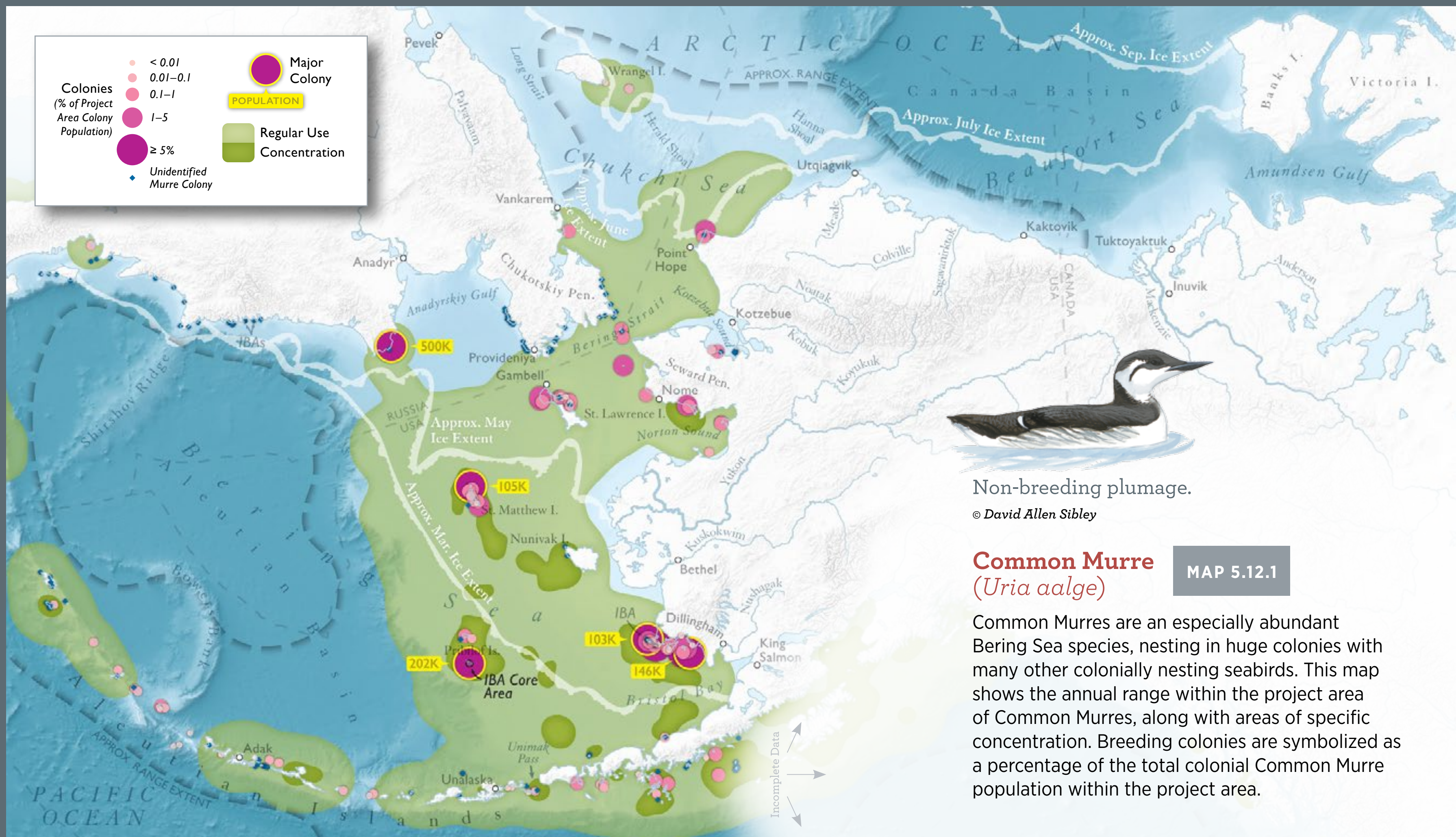
Colonies: Canadian Wildlife Service (2013); Seabird Information Network (2011)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Murres

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Audubon ALASKA



Non-breeding plumage.

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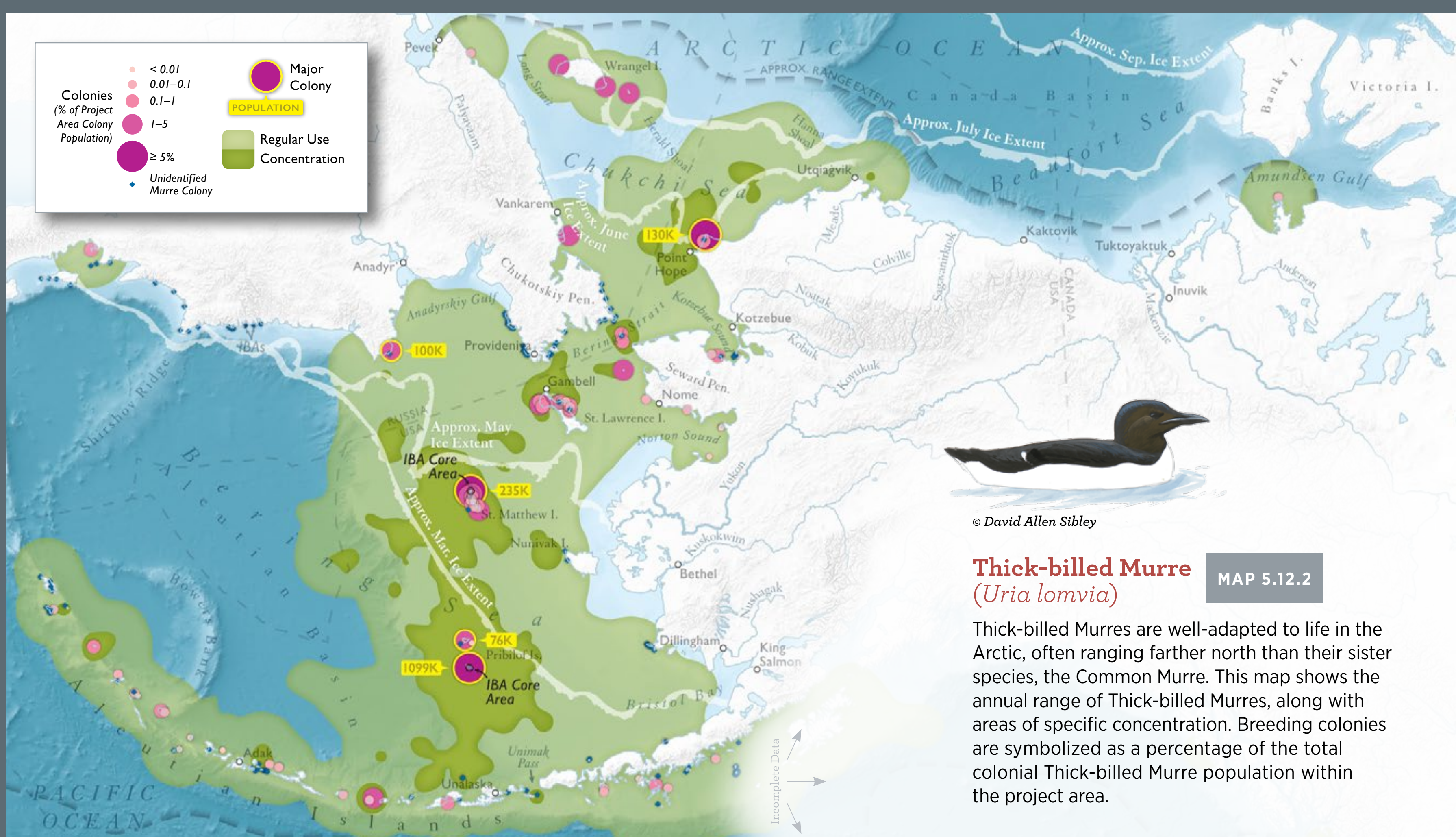
Common Murre (*Uria aalge*)

MAP 5.12.1

Common Murres are an especially abundant Bering Sea species, nesting in huge colonies with many other colonially nesting seabirds. This map shows the annual range within the project area of Common Murres, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Common Murre population within the project area.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), eBird (2015), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Canadian Wildlife Service (2013); Seabird Information Network (2011)



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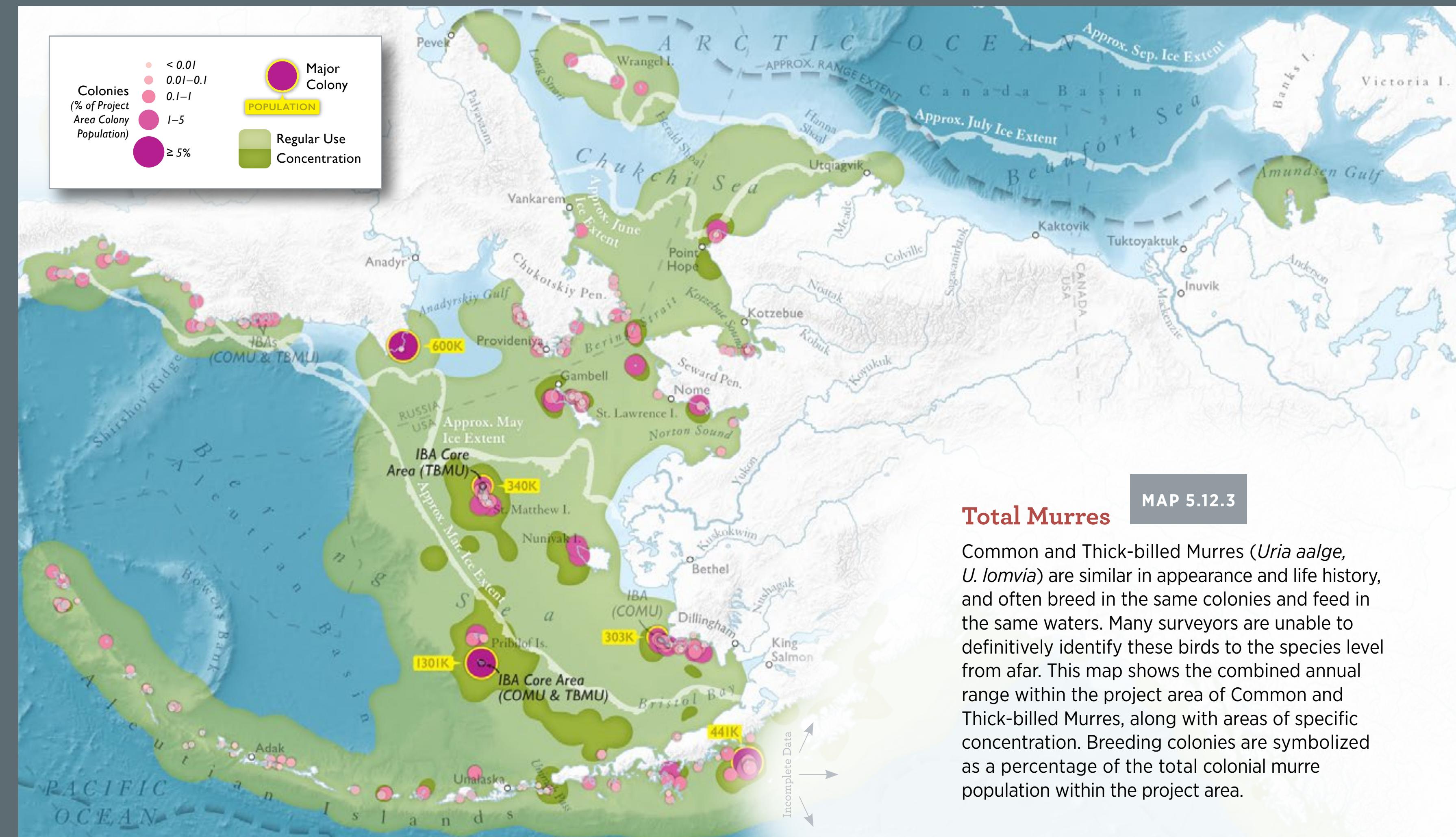
Thick-billed Murre (*Uria lomvia*)

MAP 5.12.2

Thick-billed Murres are well-adapted to life in the Arctic, often ranging farther north than their sister species, the Common Murre. This map shows the annual range of Thick-billed Murres, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Thick-billed Murre population within the project area.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), eBird (2015), Orben et al. (2015b), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Canadian Wildlife Service (2013); Seabird Information Network (2011)



Total Murres

MAP 5.12.3

Common and Thick-billed Murres (*Uria aalge, U. lomvia*) are similar in appearance and life history, and often breed in the same colonies and feed in the same waters. Many surveyors are unable to definitively identify these birds to the species level from afar. This map shows the combined annual range within the project area of Common and Thick-billed Murres, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial murre population within the project area.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2016a), Canadian Wildlife Service (2013), eBird (2015), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Canadian Wildlife Service (2013); Seabird Information Network (2011)

Common and Thick-billed Murres at a shared, cliff-side breeding colony. Note the distinguishing white line along the length of Thick-billed Murre's bill in the upper right portion of the photograph.

Milo Burcham

5.13 PUFFINS MAPS ON PAGE 179

Puffins

Max Goldman, Erika Knight, and Melanie Smith

Horned Puffin

Fratercula corniculata

Tufted Puffin

F. cirrhata

Among the most iconic and well-known species of the Arctic, Horned (*Fratercula corniculata*) and Tufted (*F. cirrhata*) Puffins are ornate, diving seabirds that nest colonially among the numerous coastal cliffs of the Arctic and Subarctic. Closely related to (and in the case of the Horned Puffin, closely resembling) the Atlantic Puffin (*F. arctica*), they are adapted to a plethora of climatic regimes, utilizing the frigid and often ice-covered waters of the Chukchi Sea down to the subtropical currents of the central North Pacific Ocean (Gaston and Jones 1998).

While Horned and Tufted Puffins share many physical traits and adaptations, they are visually distinguishable due to substantial phenotypic differentiation. Adult Tufted Puffins are covered in brownish-black plumage, with a large, white face-mask; a large, grooved, orange bill; and long, golden head-plumes that curve down the neck (Piatt and Kitaysky 2002a, b). Their legs and feet are bright yellowish to almost red, and their short neck becomes shorter during flight when they retract it into their shoulders (Gaston and Jones 1998). In contrast, Horned Puffins have a tall, narrow, deeply curved, bright-yellow bill, with a reddish tip and grooves along its edges for holding fish (Bésdard 1969). They have distinct facial patches: an orange patch at the gape, and a fleshy, black protrusion above their orange eye that earns them their name. The Horned Puffin's legs are also bright yellowish to almost red, and their necks are similarly short. However, they are especially distinct from their Pacific-dwelling congener in flight, as they have a clearly visible white breast which, when paired with their white face and black crown, makes the black band around their necks look like a broad necklace (Gaston and Jones 1998, Piatt and Kitaysky 2002a).

Puffins are excellent swimmers, and regularly dive 180 feet (60 m) or more to capture prey (Bédard 1969). They use their wings to propel themselves through the water. This marine aptitude comes at a cost, however, and puffins are not exceptional fliers. They require a long stretch of water surface to take off, and their rapid wingbeats propel them on an especially direct flight path, without much opportunity for maneuvering (Gaston and Jones 1998). After foraging, they are often too laden to successfully take flight, and instead will dive to evade disturbance. They walk upright, traversing tenuous substrate with ease by clinging to the surface with their large claws. Puffins are not particularly vocal, although they regularly communicate with calls and growls during the breeding season, both on the water and at the colony (Seneviratne et al. 2009, Klenova and Kolesnikova 2013).

DISTRIBUTION

Horned and Tufted Puffins are found in the northern latitudes of the Pacific and Arctic Oceans. After the summer breeding season in the Bering Sea, they are displaced by the advancing winter sea-ice margin. While most appear to seek out the deep, oceanic waters of the central North Pacific at the onset of winter, some are found near the ice edge, preferring passes among the ice-free Aleutian Islands (Gabrielson and Lincoln 1959, Gould and Piatt 1993).

Migration

As is the case with other alcids, puffins are not completely migratory, with many individuals staying near their breeding colonies unless forced to relocate due to sea-ice advance, as happens in both the Bering Sea and the Sea of Okhotsk (Hatch et al. 2000). Most puffins disperse from their breeding habitat by late October, possibly as far south as the Channel Islands in California, although they generally stay far from land at this time and prefer foraging in the open ocean (Ainley et al. 1990, Wahl et al. 1993). After accompanying their parents to the southern wintering areas, juveniles may stay for one or two years as they mature, before returning to the breeding grounds to attempt, but

Horned Puffin taking flight.

Terri Stinnett Photography

TABLE 5.13-1. Puffin life history characteristics and conservation status. Sources: Piatt and Kitaysky (2002a, b), Warnock (2017).

	Horned Puffin *Fratercula corniculata*	Tufted Puffin *F. cirrhata*
Body Size Mass / Length / Wingspan	**M** 1–1.4 pounds (483–648 g) **L** 8–15 inches (20–38 cm)	**M** 1.1–2.2 pounds (520–1000 g) **L** 14–16 inches (35–40 cm)
Maximum Life Span (wild)	20 years	Unknown
Clutch Size Range / Average	**R** 1 egg **A** 1 egg	**R** 1 egg **A** 1 egg
Nest-Water Proximity	Coastal cliff nester	Coastal cliff nester
Conservation Status Endangered Species Act / IUCN Red List / Audubon AK WatchList	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Red List	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Red List
Population Global / Alaska	**G** 1,200,000 **A** 921,000	**G** 3,500,000 **A** 2,280,000
Breeding Season Eggs / Young	**E** June to mid August **Y** Mid-July to October	**E** May to mid-August **Y** Mid-June to early October
Migration Spring / Molt / Fall	**S** March to mid-June **F** September to December	**S** Mid-February to mid-May **F** September to December

usually fail, to breed (Baird et al. 1983, Gould and Piatt 1993). In the spring, once the weather has begun to warm and the day is sufficiently long (usually near the beginning of April), adults begin to return to their breeding area in flocks (Wehle 1980, Harding 2001).

Species Description

Horned Puffin. Horned Puffins are distributed throughout the North Pacific Ocean, from the subtropical gyre, at approximately 35°N, to the Beaufort Sea. They breed along the coastline and on offshore islands from British Columbia through the Gulf of Alaska, the Aleutians, and the Bering and Chukchi Seas, as far north as Wrangel Island (Wehle 1980). In the western portion of their range, Horned Puffins breed on the Kuril Islands and along the coast of the Sea of Okhotsk (Konyukhov et al. 1998, Golubova 2002). They winter over a broad area of the pelagic North Pacific. About 77% of the world population of Horned Puffins is found in Alaska (Piatt and Kitaysky 2002a).

Tufted Puffins. Similarly, Tufted Puffins are also found from as far south as subtropical Pacific waters off the coast of California, at about 35°N, to the Beaufort Sea (Gould and Piatt 1993). About 65% of the global population of Tufted Puffins is found in the state of Alaska (Piatt and Kitaysky 2002b). The largest colonies are concentrated in the Aleutian Islands and along the Alaska Peninsula in the southern Bering Sea, although they are found to breed on islands throughout the Sea of Okhotsk, the Bering Sea, the Chukchi Sea, and as far north as Cape Lisburne (Golubova 2002).

LIFE CYCLE

In the Bering and Chukchi Seas, resources do not become available until the sea ice has receded and the newly available sunlight catalyzes productivity in the waters beneath. Puffins begin to occupy their steep, cliffside breeding colonies in early May (Hatch and Hatch 1983, Harding 2001). Mates arrive in pairs, or begin forming pairs immediately after arrival at the breeding grounds, and have occupied nesting habitat within one week (Sealy 1973; Wehle 1976, 1980; Harding 2001). These pairs are likely monogamous within each season. They excavate burrows with their claws and bills in the rocky soil on steep slopes well above the shoreline, then line their nests with nearby grasses, feathers, fishing line, or algae. Horned Puffins are more likely to use a crevice to nest than are Tufted Puffins, although both are known to dig burrows (Piatt and Kitaysky 2002a, b). The presence of foxes and other mammalian predators will catalyze a move to crevices or caves or more inaccessible habitat. The male puffin will defend the female at the nest and on the water with aggressive movements and chasing behavior. Within three to four weeks of mating, a single egg is laid, and parents take turns incubating it with their featherless brood patches. Chicks begin to hatch throughout the colony after five or six weeks of incubation, and parents will brood their newly hatched chick for another week after hatching (Harding 2001; Piatt and Kitaysky 2002a, b). As with many colonial-breeding seabirds, their reproductive progression is highly synchronized. Most breeding puffins depart the colony within two to three weeks, once chicks are fledged (Elphick and Hunt 1993, Morrison et al. 2009).

Diet

While wintering in the southern portion of their range, puffins dive to pursue squid, euphausiids, and pelagic fishes in the open ocean—traits that are more similar to other pelagic birds than to other alcids (Baird et al. 1983, Byrd et al. 1993, Piatt and Kitaysky 2002a). The adult puffin diet is made up of mostly soft-bodied organisms, although they predominately feed fish to their young, foraging in bays and along the continental shelf within a broad 60-mile (100-km) range for schooling fishes, such as anchovy (*Engraulis mordax*), capelin (*Mallotus villosus*), lanternfish (especially *Myctophidae*), juvenile pollock (*Theragra chalcogramma*), rockfish (*Sebastes* spp.), greenling (*Hexagrammidae*), and sand lance (*Ammodytes* spp.) (Piatt et al. 1992, Piatt and Kitaysky 2002a, b, Piatt and Springer 2003, Piatt et al. 2006, Golubova and Nazarkin 2009, Sydeman et al. 2016). They capture their prey by diving and propelling themselves through the water with their wings (Bédard 1969). Puffins eat their prey under water, unless they are foraging for their young, in which case they orient their prey perpendicular to their bills, which can hold up to 20 fish at once, a unique quality among seabirds (Bédard 1969). While their maximum dive depth likely reaches over 300 feet (100 m), they usually forage in water less than 200 feet (60 m) deep (Piatt and Nettleship 1985). Puffins are known to forage in relatively low densities and are also commonly found among other species of seabird, foraging in mixed-species flocks of 10–20 individuals (Wehle 1976, Piatt et al. 1992).

CONSERVATION ISSUES

Horned and Tufted Puffins are both protected by the Migratory Bird Treaty Act of 1918. Horned and Tufted Puffins are also both on the Red List of Audubon Alaska's WatchList, owing to declines in recent years, especially in the southeast Bering Sea region (Dragoo et al. 2016, Goyert et al. 2017). Tufted Puffin declines are not as significant or widespread as those suffered by the Horned Puffin (Sydeman et al. 2016).

Puffins are susceptible to predation, and some other birds prey on adults during the breeding season, including Bald Eagles (*Haliaeetus leucocephalus*), Steller's Sea-Eagles (*H. pelagicus*), and Peregrine Falcons (*Falco peregrinus*). Chicks and eggs are at risk as well, with gulls and Common Ravens (*Corvus corax*) the likely culprits. Foxes are especially detrimental to seabird colonies, as they kill and store prey, and are known to decimate colonies when they gain access (Bailey 1993). Brown bears (*Ursus arctos*) destroy nesting burrows and habitat in search of eggs and chicks on the Alaska Peninsula, and in 1992 and 1993, almost 100% of nestlings on Ugaiushak Island and nearby Central Island were eaten by brown bears (Springer et al. 1999, Piatt and Kitaysky 2002a, b). Norway rats (*Rattus norvegicus*) and ground squirrels (*Spermophilus undulatus*) were intentionally or accidentally introduced to many seabird colonies in Alaska during the 1800s and early 1900s, causing precipitous declines in seabird recruitment levels. Affected seabirds rebounded rapidly after rat-eradication efforts (Croll et al. 2016).

MAPS ON PAGE 179

Anthropogenic disturbance is a concern. Investigator and harvester disturbance during hatching or incubation may have led to desertion in the past (Amaral 1977, Wehle 1980). Subsistence harvest of adults and eggs is a common cultural pursuit among most coastal communities in the Bering Strait region of Alaska, although the impact is not likely to affect puffin population sizes (Fall et al. 2003).

As is the case with many seabirds, Horned and Tufted Puffins are especially susceptible to impacts from oil spills. Nearly 600 dead birds were recovered after the *Exxon Valdez* spill in 1989, although estimates of puffin mortality as a result of that spill were likely more than 20,000 birds (Piatt et al. 1990a, b; Glickson et al. 2014).

Bycatch in gill nets is a common and widespread problem. Changes in fishing regulations have abated the issue somewhat. From the 1950s to 1990s, hundreds of thousands of puffins were drowned in the gill nets of offshore fisheries (Ainley et al. 1981; Piatt and Kitaysky 2002a, b). The banning of high driftnet fishing in the late 1980s lowered mortality to less than 1,000 birds per year, although Russian and Japanese fleets still employ those banned methods, likely resulting in high puffin and other seabird mortality (DeGange et al. 1993, Artyukhin and Burkanov 2000, Gjerdrum et al. 2003, Žydelis et al. 2013).

MAPPING METHODS (MAPS 5.13.1–5.13.2)

We categorized distribution into four main categories of intensity: extent of range, regular use, concentration, and high concentration. The Horned Puffin and Tufted Puffin extents of range were drawn by buffering all known occurrences of each species using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), and the Seabird Information Network (2011). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. For each species, observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

Because of the relative lack of survey data in Russia, concentration areas in Russia are often not known or depicted. Where there were gaps in survey coverage, such as in Russia, we buffered species' colony locations, using a buffer radius equal to the species' average maximum foraging distance (58 miles [94 km] for Horned Puffin; 62 miles [100 km] for Tufted Puffin (Lascelles 2008)). These two types of boundaries were combined to represent regular use across the project area.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, we used IBA data from BirdLife International (2017a) while IBAs in Alaska are from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also show single-species IBA core areas (Audubon Alaska 2015) to indicate high concentrations for each species (see Smith et al. 2014c).

Puffin colony data were downloaded from the Seabird Information Network (2011). This map represents the most recent or otherwise best estimate available for each colony location (see Smith et al. 2012). On the map, the size of each colony point represents the percent of the total population present at that colony. Total population was the sum of the abundance of the species across all colonies within the project area.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines were based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. Puffins generally do not use the areas of Canadian waters in our project area. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. There is little to no survey coverage in the Canadian and Russian portions of the project area, potentially leaving major data gaps for these species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps.

The colony data are available throughout the US and Russian portions of the project area, but data quality—survey dates and techniques—varies greatly between colonies. Colony sizes should be interpreted as estimates rather than precise counts.

Reviewers

- Nora Rojek
- Liz Labunski

MAP DATA SOURCES

HORNED PUFFIN MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a) and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Seabird Information Network (2011)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

TUFTED PUFFIN MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a) and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

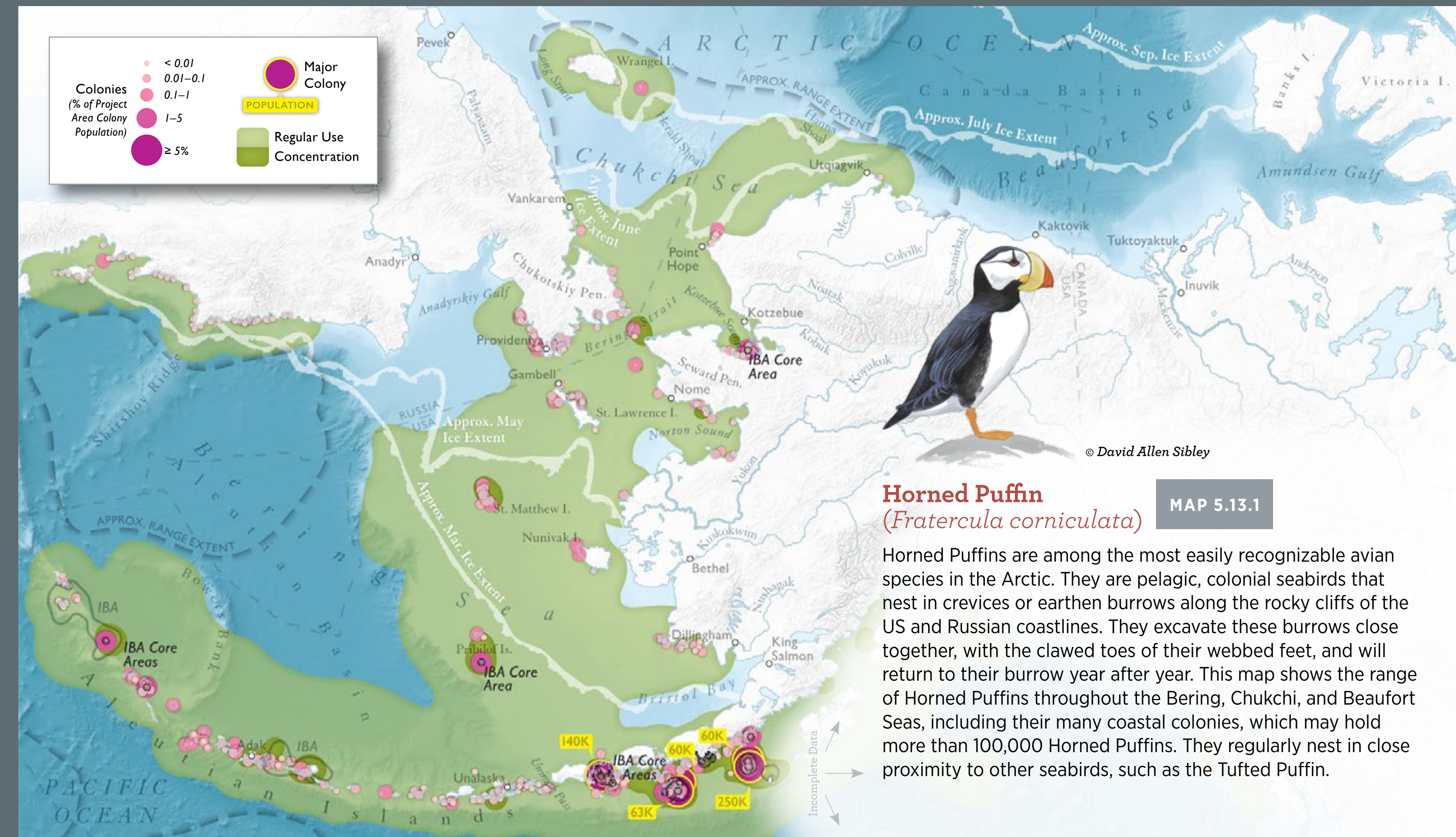
IBA Core Areas: Audubon Alaska (2015)

Colonies: Seabird Information Network (2011)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Puffins

Audubon ALASKA



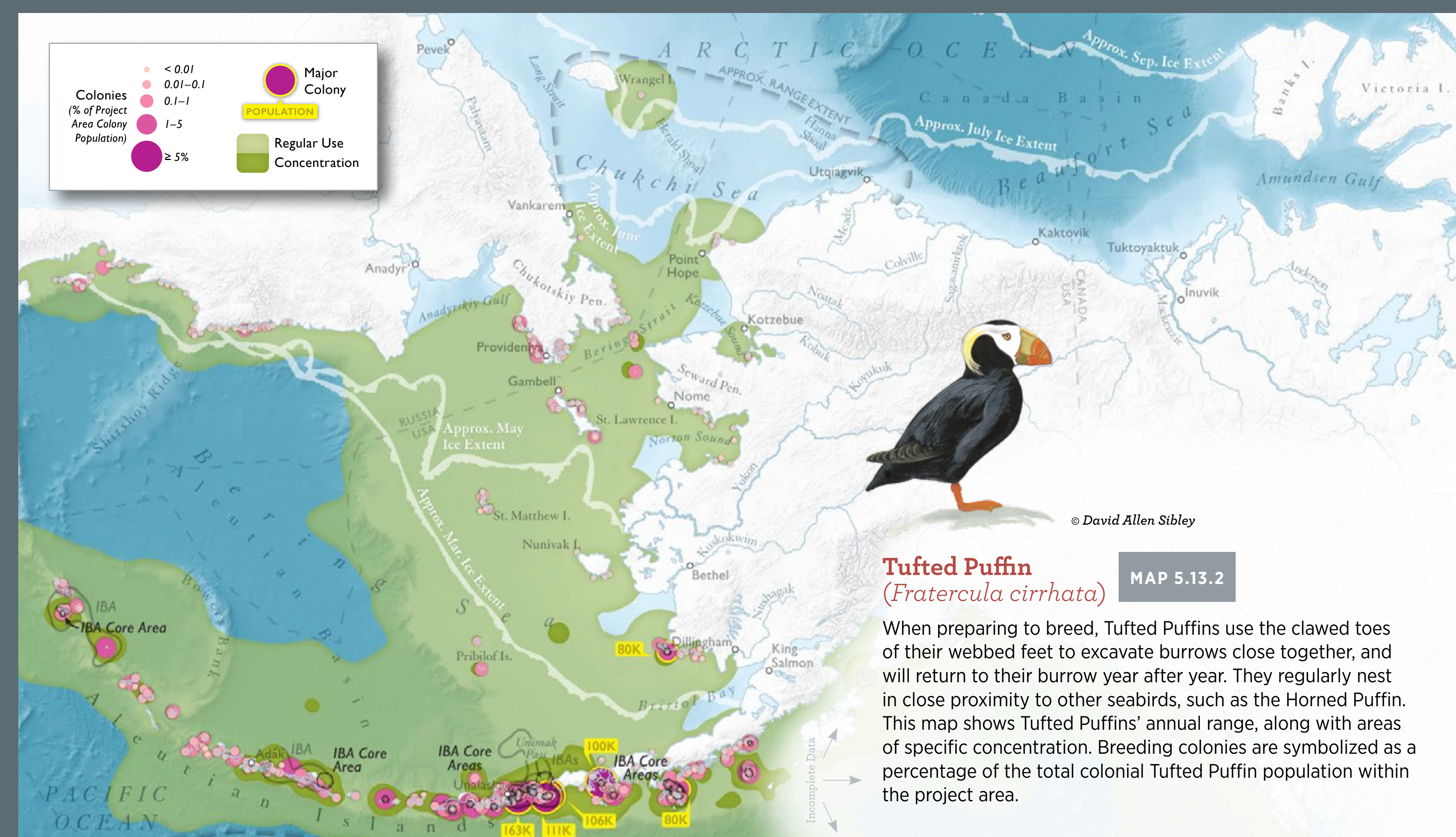
Horned Puffin

(Fratercula corniculata) MAP 5.13.1

Horned Puffins are among the most easily recognizable avian species in the Arctic. They are pelagic, colonial seabirds that nest in crevices or earthen burrows along the rocky cliffs of the US and Russian coastlines. They excavate these burrows close together, with the clawed toes of their webbed feet, and will return to their burrow year after year. This map shows the range of Horned Puffins throughout the Bering, Chukchi, and Beaufort Seas, including their many coastal colonies, which may hold more than 100,000 Horned Puffins. They regularly nest in close proximity to other seabirds, such as the Tufted Puffin.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Seabird Information Network (2011)

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman



Tufted Puffin

(Fratercula cirrhata) MAP 5.13.2

When preparing to breed, Tufted Puffins use the clawed toes of their webbed feet to excavate burrows close together, and will return to their burrow year after year. They regularly nest in close proximity to other seabirds, such as the Horned Puffin. This map shows Tufted Puffins' annual range, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Tufted Puffin population within the project area.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Seabird Information Network (2011)

Auklets

Susan Culliney, Erika Knight, and Melanie Smith

Parakeet Auklet
Aethia psittacula

Crested Auklet
A. cristatella

Whiskered Auklet
A. pygmaea

Least Auklet
A. pusilla

Auklets are part of the Alcid family, which also includes murres, puffins, guillemots, and murrelets. Among the six species of auklets, the four *Aethia* species are the most closely related and have ranges in the Bering Sea and Arctic Ocean: Parakeet Auklet (*Aethia psittacula*), Crested Auklet (*A. cristatella*), Whiskered Auklet (*A. pygmaea*), and Least Auklet (*A. pusilla*). Of these four, Crested and Whiskered are most closely related, sharing traits such as a pungent citrus-like odor, forehead crests, and similar vocalizations (Jones 1993, Douglas et al. 2004). There are two other auklet species in Alaska: Cassin's Auklet (*Ptychoramphus aleuticus*) is in the same tribe as the *Aethia* species but only has limited breeding ranges in Alaska waters, while Rhinoceros Auklets (*Cerorhinca monocerata*) are actually more closely related to puffins. The remainder of this summary will, therefore, focus on the four closely related *Aethia* species that occupy the Bering, Chukchi, and (to a lesser degree) Beaufort Seas.

Auklets are enigmatic seabirds. They are characterized by elaborate facial feather ornamentation and complex courtship duets and dances, yet their showiness is contrasted by their mystery. Most of the data on auklets come from breeding colonies that congregate on rocky islands and coastlines. However, these are pelagic birds, only coming on land to breed, and quickly returning to their marine habitat following the nesting season. Fledging chicks leap from their natal cliffs and eagerly take to the sea. Much of the data on foraging behavior, migratory movements, and wintering range, therefore, remain poorly known or unknown, yet are critical to conservation of these species.

Males and females appear identical, differentiated primarily by size. Auklets are characterized by generally dark plumages, contrasted with striking white eyes, generally red bills, and conspicuous ornamental facial plumes, which vary by species. The Least Auklet has a knob on its bill and numerous bristly facial plumes that cluster around its auriculars and forehead. The Whiskered Auklet has two bright white facial streaks that form a handsome pattern along with the thin black plumes that curl up and over its bill. The Parakeet Auklet is relatively drab with a single prominent white facial streak extending from just behind its eye to the back of its head. The Crested Auklet is overall very dark, with a white streak extending from its eye toward the back of its head, and a prominent black puff of feathers curling over and beyond its bill.

These elaborate facial patterns and plumes in both sexes are probably the result of sexual selection. Birds with more prominent facial decoration are preferred by both sexes (Jones and Montgomerie 1992, Jones 1993). The particularly protruding feather plumes in Crested and Whiskered Auklets have also been proposed as a sensory adaptation, for navigating tight crevices in dark nesting burrows (Seneviratne and Jones 2008).

DISTRIBUTION

Counting auklets can be difficult and typically relies on estimating colony sizes, but biologists estimate there are about 16.5 million auklets nesting in this region (Seabird Information Network 2011). Even though they are present in the millions in these Arctic seas, they are not sea-ice inhabitants. Auklets shift their distribution during the winter, probably to avoid the advancing ice edge and to seek out winter foraging opportunities.

Migration

Auklet migration is poorly understood, but some movement must occur between terrestrial nesting sites and the species' pelagic lives during winter. Soon after their nesting duties are complete, auklets return to the sea. Jones et al. (2001) posit Parakeet Auklets move southward after the nesting season, where they remain dispersed over winter, and then return north. Recent tagging data appear to confirm this, with Parakeet Auklets moving from clusters around breeding colonies into more open waters of the eastern Bering Sea and North Pacific (Schacter and Robbins 2016). The tracking study also found Crested Auklets following a similar pattern away from breeding colonies during the winter, moving into concentrations in the Sea of Okhotsk, nestled between Japan and Russia, some time spent around Aleutian Islands, and into the Bering Strait and Chukchi Sea (Schacter and Robbins 2016). Whiskered Auklets, by contrast, may linger for a time on breeding islands, perhaps due to their wintering range remaining so close their nesting islands (Zubakin and Konyukhov 2001). Recent tracking data add confirmation, finding Whiskered Auklets remaining generally near their colony year-found (Schacter and Robbins 2016).

Wintering

In winter, the pelagic nature of auklets makes their non-breeding habits difficult to study. After leaving the colony in the fall, their movements in the Arctic Ocean are probably initially dictated by the extent of sea ice. The winter range of Parakeet Auklets is better documented than the others: in the early fall, Parakeet Auklets may roam as far north as Utqiaġvik (formerly Barrow), but overall the species quickly moves down into the Northern Pacific, and may go as far south as waters far offshore from Washington, Oregon, and California (Manning and MacPherson 1952, Gould and Piatt 1993, Rottenborn and Morlan 2000, Jones et al. 2001). Whiskered Auklets, by contrast, stay near breeding colonies in waters remaining free of ice (Troy and Bradstreet 1991, Byrd and Williams 1993b).

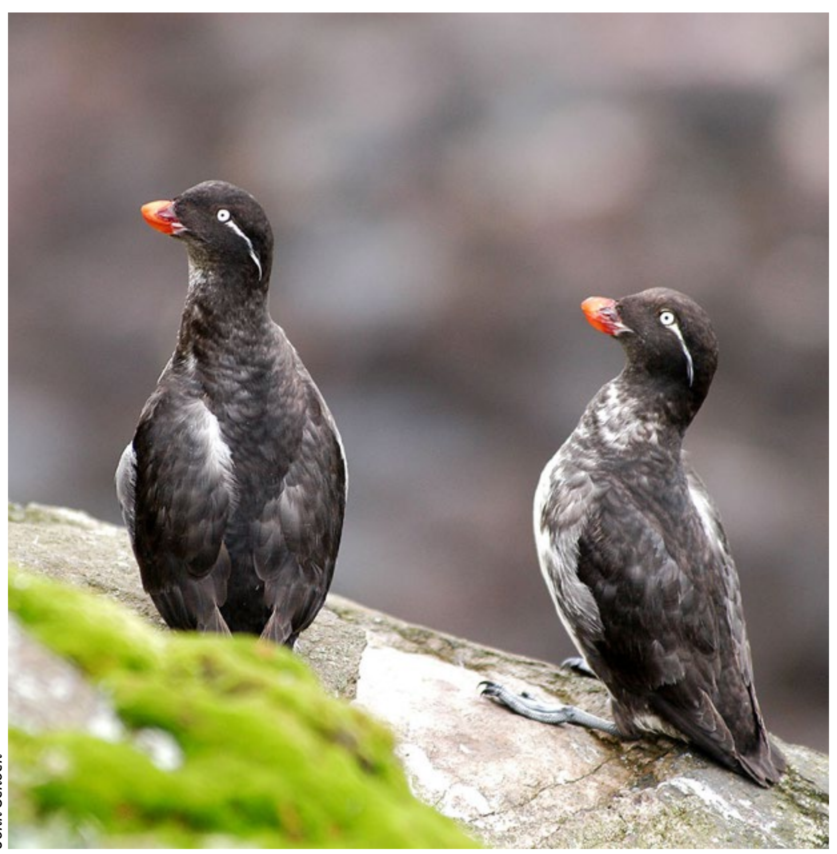
Species Description

Parakeet Auklet. The second largest of the four species considered here, the Parakeet Auklet is more "mild-mannered" and less colonial than other auklets. Compared to other auklet species, Parakeet Auklets have a small population size—500,000 to 1 million nesting across the region (Pollom et al. 2017). This species is the most widely dispersed of the auklets included in this summary. Breeding occurs on islands and rocky mainland coastlines in the Bering Sea, along the Aleutian chain, and in parts of Southeast Alaska (Jones et al. 2001). Presumably from the nearest colonies in the Bering Strait, birds regularly forage as far north as Barrow Canyon, with localized hotspots identified in Hope Basin and the Hanna Shoal region (Kuletz et al. 2015). However, Parakeet Auklets probably vacate the Chukchi and Bering Seas when sea ice forms and they migrate to points south, where they are regularly seen far offshore from Washington, Oregon, and California. Vagrants have even been found in the northwestern Hawaiian Islands.

Crested Auklet. Larger and more aggressive than the others, the Crested Auklet is also much more gregarious, congregating in colonies during the breeding season that can reach nearly a million pairs, and remaining in dense flocks even during the winter (Jones 1993). In total, an estimated 4.6 million Crested Auklets nest here—they are the second most abundant species in this region (Seabird Information Network 2011). They breed on rocky islands and rocky mainland coastlines in the Aleutian chain, the Alaska Peninsula, and as far north as the Bering Strait, including points in Russia (Jones 1993). Following the nesting season, they are found in high densities in the Chukchi Sea, especially the Hanna Shoal region, where they most likely undergo their wing molt in September (Kuletz et al. 2015). Many of these birds may be coming from southern colonies, migrating northward after chick-rearing (Kuletz et al. 2015). After sea ice moves in, their wintering range clusters to the north and south of the Aleutian chain.

Whiskered Auklet. Secretive and nocturnal in its comings and goings from nest sites (Knudtson and Byrd 1982), the Whiskered Auklet is a less colonial species than its counterparts. Whiskered Auklets are endemic to this region with a total global population of only about 120,000 (Warnock 2017). They have a limited breeding range on select islands in the Aleutian chain, rarely wandering north of the Pribilof Islands (Byrd and Williams 1993b). Their winter range is not much different; they spend winter in waters near their breeding islands, as sea ice allows. Unlike other auklets, some Whiskered Auklet individuals continue to visit nesting habitat and nesting chambers during the wintering season (Zubakin and Konyukhov 2001).

Least Auklet. The smallest member of the Alcid family, the tiny Least Auklet is about the size of a chunky American Robin (*Turdus migratorius*) (Bond et al. 2013). This auklet species exhibits strong colonial and flocking tendencies and may be particularly susceptible to introduced rats, which killed large numbers of Least Auklets in some years on one island in the Aleutian chain (Major et al. 2006). Least Auklets are the most abundant and most densely packed species in this region, with nearly 8 million individuals present in only 35 breeding colonies



John Schoen

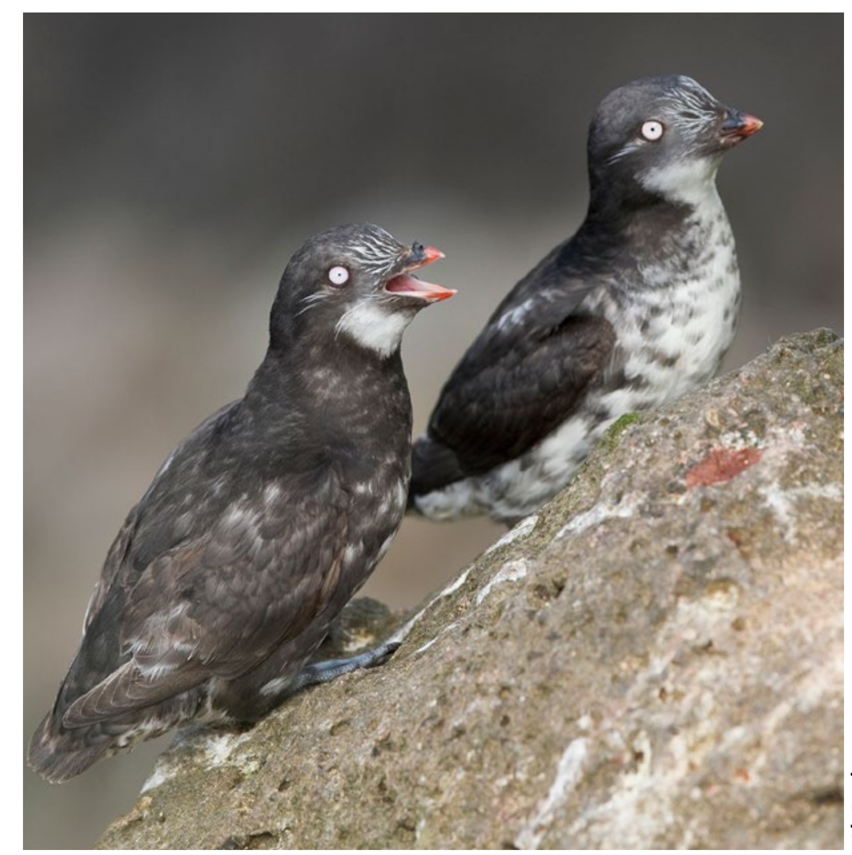
Parakeet Auklets.

Milo Burcham

Crested Auklet.

Nature Picture Library / Alamy Stock Photo

Whiskered Auklet.



Milo Burcham

Least Auklets.

MAPS ON PAGES 186–187

TABLE 5.14-1. Auklet life history characteristics and conservation status. Sources: Byrd and Williams (1993b), Jones (1993), Jones et al. (2001), Bond et al. (2013), Warnock (2017).

	Parakeet Auklet *Aethia psittacula*	**Crested Auklet** *A. cristatella*	**Whiskered Auklet** *A. pygmaea*	**Least Auklet** *A. pusilla*
Body Size Mass Length	**M** 8–12 ounces (230–350 g) **L** 9–10 inches (23–26 cm)	**M** 7–11 ounces (200–325 g) **L** 7–8 inches (18–20 cm)	**M** 3–5 ounces (90–150 g) **L** 6–7 inches (17–19 cm)	**M** 2–3 ounces (60–90 g) **L** 4–5 inches (12–14 cm)
Maximum Life Span (wild)	Unknown	8 years	Unknown	4.5 years
Clutch Size Range Average	**R** 1 egg **A** 1 egg	**R** 1 egg **A** 1 egg	**R** 1 egg **A** 1 egg	**R** 1 egg **A** 1 egg
Nest-Water Proximity	<650–800 feet (200–250 m) above sea level	Colonial cliff nester	Colonial cliff nester	Colonial cliff nester
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Not Listed	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Not Listed	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Yellow List	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Not Listed
Population Global Alaska	**G** 1.2 million **A** 1 million	**G** 8.2 million **A** 2 million	**G** 121,000 **A** 116,000	**G** 30 million **A** 9 million
Breeding Season Eggs Young	**E** Mid-May to July **Y** Mid-June to mid-September	**E** May to July **Y** Late June to early September	**E** May to mid-June **Y** June to early September	**E** May to mid-July **Y** Mid-June to early September
Migration Spring Molt Fall	**S** March to May **M** June to November **F** Mid-August to November	**S** Late March to mid-May **M** June to October **F** August to October	**S** April to May **M** June to October **F** Late July to early September	**S** March to June **M** June to October **F** Mid-July to November

(Seabird Information Network 2011). They breed on rocky coastlines and islets in the Bering Sea and along the Aleutian chain. The largest colony in the project area, Big Diomede Island, Russia, is home to 2 million Least Auklets (Seabird Information Network 2011). From this and other nesting colonies, these birds range into the Chukchi and Beaufort Seas during summer and fall with localized hotspots identified in the Hope Basin and Hanna Shoal in summer and fall (Kuletz et al. 2015). In the winter, some birds remain near breeding sites as sea ice allows, but others may head south into the North Pacific (Sydeman et al. 2010, Bond et al. 2013).

LIFE CYCLE

Auklets are colonial breeders. Crested and Least are more vocal and gregarious than Whiskered and Parakeet. Colonies regularly include mixed *Aethia* and other seabird species. Where *Aethia* species overlap, there can be some competition for nest sites, with Crested and Parakeet both dominant over Whiskered, and with all three usually displacing the relatively tiny Least Auklet (Knudtson and Byrd 1982). However, the variation in sizes between these species also allows for niche differentiation into a range of nest cavity sizes.

Auklets do not build a nest, but instead lay their single egg per season directly on the substrate, in rocky cavities on talus slopes and rocky cliffs, with varying levels of bare and vegetated microterrain (Byrd et al. 1993, Byrd and Williams 1993b, Hipfner and Byrd 1993, Jones 1993, Jones et al. 2001, Bond et al. 2013). The size of the cavity chamber and entrance vary by species size. Colonies of Crested Auklets occur on both islands and mainland coastlines of Alaska and Russia; Parakeet and Least Auklets occur on islands in Alaska and also along certain mainland coastlines in Russia. Whiskered Auklets are limited to islands (Seabird Information Network 2011).

All four of these auklet species exhibit conspicuous visual and vocal displays at nesting colonies, using a variety of chirps, whinnies, and cackles, as well as courtship dance moves (Byrd and Williams 1993b, Jones 1993, Jones et al. 2001, Bond et al. 2013). Particularly large colonies can create a tremendously loud roar (Bond et al. 2013) that can be heard from some distance. Auklet pairs primarily display on land, while copulation takes place on the water (Jones et al. 2001, Bond et al. 2013).

Both Crested and Whiskered Auklets have an unusual citrus-like smell, which is thought to act as a parasite repellant and mate attractant (Beier and Wartzok 1979, Douglas et al. 2001, Douglas et al. 2004, Douglas 2008). During courtship, Crested Auklet pairs anoint each other with this scent, thus transferring ectoparasite repellent between partners (Douglas 2008). Birds that smell more strongly, and therefore have more scent to share, are more sexually attractive to potential partners (Jones 1993, Douglas et al. 2004).

Prior to fledging, chicks will exit their nest chamber to practice flapping and strengthen their new wing muscles; the whirring of thousands of chick wings in a dense Crested Auklet colony has been notably audible to some researchers (Jones 1993). Chicks leaving nests apparently fly directly out to sea and move offshore to begin immediately fending for themselves; those that fall short in the initial flight are susceptible to predation (Jones et al. 2001, Bond et al. 2013).

Diet

Auklets are agile divers that forage on the open ocean, using their wings to propel themselves underwater in pursuit of prey. Crested, Whiskered, and Least Auklets forage on marine zooplankton, with *Neocalanus* copepods and euphausiids being common prey (Bédard 1969, Piatt et al. 1990c, Troy and Bradstreet 1991, Byrd and Williams 1993b, Jones 1993, Bond et al. 2013). The Parakeet Auklet's special conical bill is thought to be adapted to feeding on zooplankton and crustaceans, and even small fishes that cluster around jellyfish tentacles (Jones et al. 2001). However, in using this foraging tactic, Parakeet Auklets are also apparently susceptible to ingesting plastic particles that cluster around jellyfish and mimic prey items (Jones et al. 2001). Auklet diets during the non-breeding season are not well studied.

Auklet foraging focuses on areas where water currents bring prey items into greater concentration, and the four species appear somewhat differentiated in their foraging microhabitats. Parakeet Auklets feed in turbulent tidal areas (Hunt et al. 1993, Hunt et al. 1998). Whiskered Auklets favor well-mixed waters (Haney 1991), where currents converge near islands (Byrd and Gibson 1980). Least and Crested Auklets forage in deeper waters that are stratified, where upwelling brings prey to the surface (Haney 1991, Hunt et al. 1993, Jones 1993, Bond et al. 2013), but Crested Auklets probably seek deeper concentrations of prey (Jones 1993).

MAPS ON PAGES 186–187

Parakeet Auklet in flight.

Milo Burcham

CONSERVATION ISSUES

These auklets are all species of least concern under the International Union for the Conservation of Nature (IUCN) Red List and are not listed under the US Endangered Species Act because of its restricted distribution and reliance on Alaska waters, Whiskered Auklets are on Audubon Alaska's Yellow List, indicating a vulnerable population (Warnock 2017). As migratory birds, auklets are protected in the US by the broad-sweeping Migratory Bird Treaty Act of 1918, which gains its impact through several international treaties between the US and Canada, Russia, and Japan. The remote breeding islands and isolated coastlines favored by auklet breeding colonies afford a de facto measure of protection for these species. The Alaska Maritime National Wildlife Refuge covers much of the auklet breeding range in the US.

The amount of time these birds spend far at sea, coupled with their remote island breeding habitat, means these species are well removed from most direct human impacts. Limited subsistence take of birds and eggs continues to take place today (Jones 1993, Jones et al. 2001, Bond et al. 2013), but with no known impact on populations. Most negative impacts from humans are instead indirect in nature.

Auklets are prey to large falcons, owls, Common Ravens (*Corvus corax*), gull species, and Arctic foxes (*Vulpes lagopus*), with Whiskered Auklets probably particularly vulnerable due to their terrestrial presence during the winter (Williams et al. 2003). Parakeet, Crested, and Least Auklets have even been found in the stomachs of fish such as Pacific halibut (*Hippoglossus stenolepis*) and cod. Where these predators are found naturally, auklet populations can persist (Jones et al. 2001). But introductions of predators to islands where they did not normally occur can devastate or even extirpate the local auklet populations (Murie 1959, Bailey 1993, Bailey and Kaiser 1993, Jones 1993). However, different auklet populations may be able to withstand some introduced predation pressure (Bond et al. 2013). Unlike foxes and avian predators, rats can access nesting chambers within rocky crevices. Introduced Norway rats (*Rattus norvegicus*) killed large numbers of Least Auklets on Kiska Island (Bond et al. 2013). By far, the accidental introduction of Norway rats by humans may represent the biggest threat to breeding auklet populations (Jones 1993, Bond et al. 2013).

Human marine activity can also cause harm to auklets. For instance, the lights of fishing vessels can be fatally attractive (Dick and Donaldson 1978, Byrd and Williams 1993b, Jones 1993, Bond et al. 2013); bright lights of one vessel attracted 6,000 Crested Auklets to the boat, with a high mortality rate (Dick and Donaldson 1978). Auklets also comprise a significant percentage of the drowned seabird bycatch in offshore gillnets and driftnets (DeGange and Day 1991). Commercial fishing may also have trophic impacts, but the exact effects are uncertain (Bond et al. 2013).

Marine pollution is another threat. Oil spills may represent an acute threat to Crested and Whiskered Auklets, due to the dense flocking behavior exhibited by these species (Byrd and Williams 1993b, Jones 1993). Auklets were among those birds oiled and killed by the 1989 *Exxon Valdez* oil spill (Jones et al. 2001). Parakeet Auklets are also susceptible to plastic pollution, as their particular foraging tactic seeks small prey among jellyfish tentacles and may confuse small plastic pieces for prey (Robards et al. 1995, Jones et al. 2001). However, Parakeet Auklet chicks do not appear to be at risk of plastic ingestion, probably because adults feed chicks undigested prey items rather than regurgitated meals (Bond et al. 2010). The long-term population impacts of plastics on auklets are not well understood.

Both climate change and natural variation in breeding and marine habitat could have an impact on auklet populations. Foraging niches, dependent on water columns and currents, could make these species vulnerable to climate change, which may cause dramatic shifts in marine hydrography and productivity (Jones et al. 2002, Bond et al. 2010, Wolf et al. 2010). Populations also appear strongly tied to terrestrial breeding habitat. Auklets' coastal rocky habitat may decline as vegetation takes over talus slopes (Roby and Brink 1986), but erosion and volcanic activity can also create new habitat (Sowls et al. 1978), perhaps setting a basic equilibrium (Jones et al. 2001), although continued conservation of auklets may require ensuring fresh habitat does consistently exist (Stephensen and Irons 2003).

MAPPING METHODS (MAPS 5.14.1–5.14.4)

We categorized distribution into four main categories of intensity: extent of range, regular use, concentration, and high concentration. The extents of range for auklets were drawn by buffering all known occurrences of each species using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), and the Seabird Information Network (2011). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. For each species, observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

Because of the relative lack of survey data in Russia, concentration areas in Russia are often not known or depicted. Where there were gaps in survey coverage, such as in Russia, we buffered species' colony locations, using a buffer radius equal to the species' average maximum foraging distance (58 miles [94 km] for Crested Auklets and 44 miles [71 km] for Least Auklets (Lascelles 2008)); information regarding the average maximum foraging distance for Parakeet Auklets and Whiskered Auklets was not available, so the average of the foraging radii for Crested Auklets and Least Auklets (51 miles [82 km]) was used. These two types of boundaries were combined to represent regular use across the project area.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Russia and Canada, we used IBA data from BirdLife International (2017a) while IBAs in Alaska are from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, in Alaska we also show single-species IBA core areas (Audubon Alaska 2015) to indicate high concentrations for each species (see Smith et al. 2014c).

Auklet colony data were downloaded from the Seabird Information Network (2011) and, where such information was known, updated based on publications by Artukhin et al. (2016), Konyukhov et al. (1998), or Vyatkin (2000). These maps represent the most recent or otherwise best estimate available for each colony location (see Smith et al. 2012). On the map, the size of each colony point represents the percent of the total population present at that colony. Total population was the sum of the abundance of the species across all colonies within the project area.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines were based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. Auklets generally do not use the areas of Canadian waters in our project area. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting maps. There is little to no survey coverage in the Russian portion of the project area, potentially leaving major data gaps for these species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of these maps.

The colony data are available throughout the US and Russian portions of the project area, but data quality—survey dates and techniques—varies greatly between colonies. Colony sizes should be interpreted as estimates rather than precise counts. Note that just over 4,000 Whiskered Auklets are accounted for in the breeding colony catalog (Seabird Information Network 2011), out of a total estimated population of approximately 120,000 birds. Therefore, the largest breeding colonies shown may not be the largest that exist for that species.

Reviewer

- Heather Renner

MAP DATA SOURCES

PARAKEET AUKLET MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Seabird Information Network (2011), and Vyatkin (2000)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2015) and Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Seabird Information Network (2011); Vyatkin (2000)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

CRESTED AUKLET MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Artukhin et al. (2016), Audubon Alaska (2016a), Konyukhov et al. (1998), Seabird Information Network (2011), and Vyatkin (2000)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2015) and Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Artukhin et al. (2016); Konyukhov et al. (1998); Seabird Information Network (2011); Vyatkin (2000)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

WHISKERED AUKLET MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a) and Seabird Information Network (2011)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2015) and Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Seabird Information Network (2011)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

LEAST AUKLET MAP

Extent of Range: Audubon Alaska (2016c) based on Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)

Regular Use: Audubon Alaska (2016c) based on Artukhin et al. (2016), Audubon Alaska (2016a), Konyukhov et al. (1998), Seabird Information Network (2011), and Vyatkin (2000)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2015) and Audubon Alaska (2016a)

IBAs: Audubon Alaska (2014); BirdLife International (2017a)

IBA Core Areas: Audubon Alaska (2015)

Colonies: Artukhin et al. (2016); Konyukhov et al. (1998); Seabird Information Network (2011); Vyatkin (2000)

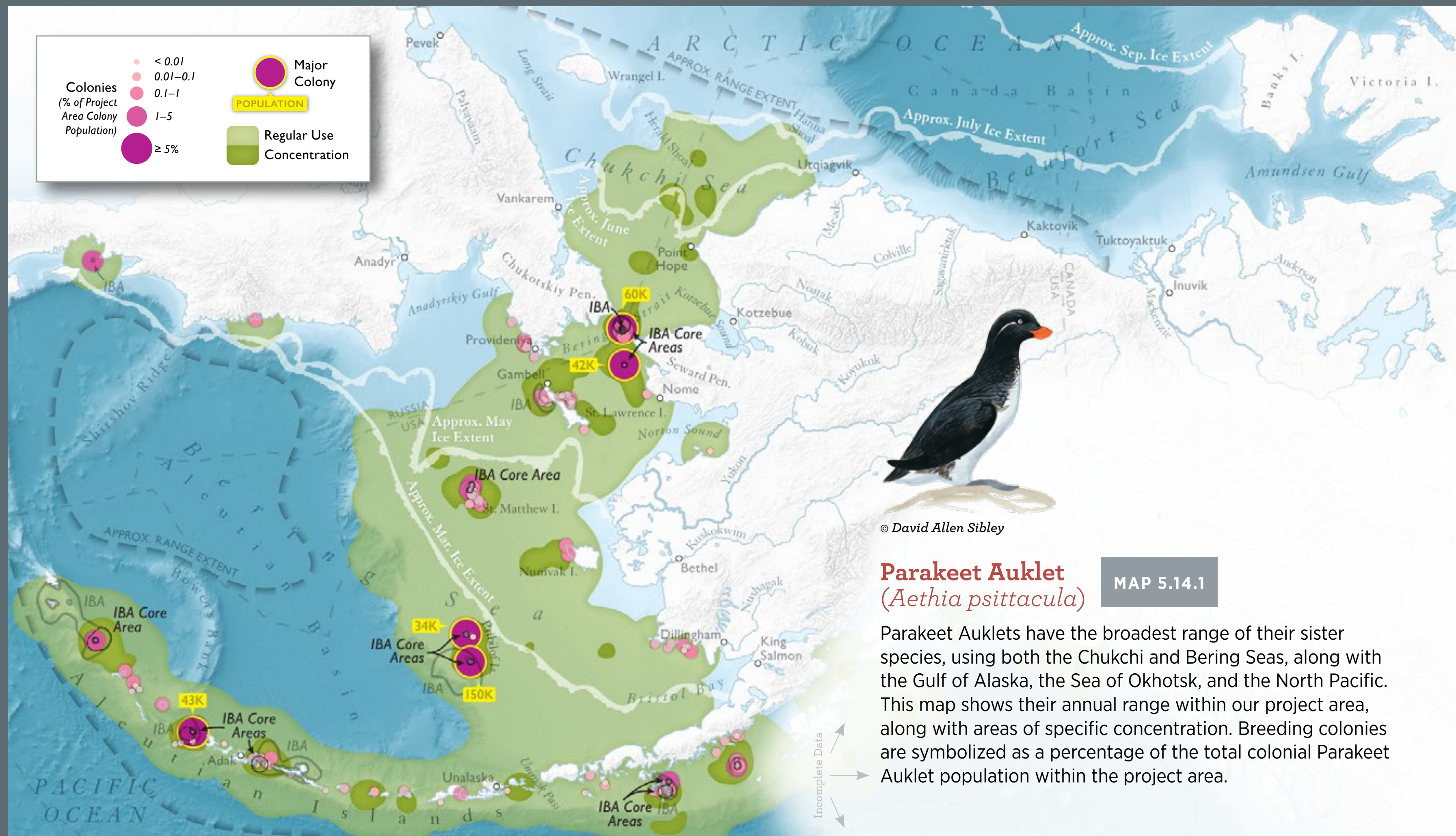
Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Auklets, like other Alcids, use their large, webbed feet to propel themselves through the water. When perched on land, they rest on their tarsi instead of on their toes (metatarsi) like other perching birds. Pictured is a perched Crested Auklet.

Milo Burcham

Auklets

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman



Parakeet Auklet
(Aethia psittacula)

MAP 5.14.1

Parakeet Auklets have the broadest range of their sister species, using both the Chukchi and Bering Seas, along with the Gulf of Alaska, the Sea of Okhotsk, and the North Pacific. This map shows their annual range within our project area, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Parakeet Auklet population within the project area.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2015), Audubon Alaska (2016a), eBird (2015), Seabird Information Network (2011), and Vyatkin (2000)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Seabird Information Network (2011); Vyatkin (2000)

Whiskered Auklet
(Aethia pygmaea)

MAP 5.14.3

The Whiskered Auklet is endemic to the far-southern Bering Sea, occurring nowhere in the world other than the Kuril, Commander, and Aleutian Islands. This map shows the annual range of the Whiskered Auklet within our project area, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Whiskered Auklet population within the project area.

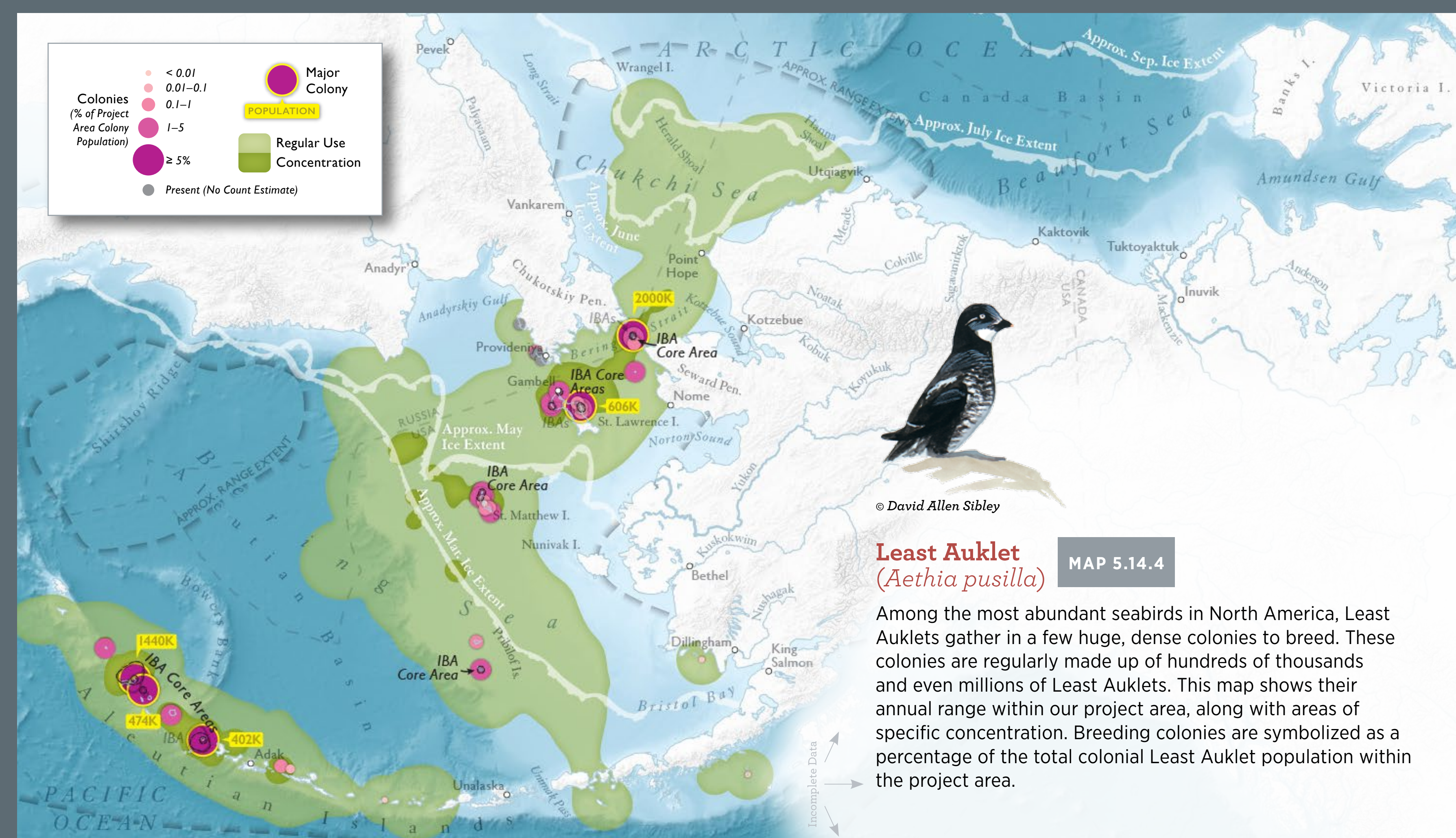
Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2015), Audubon Alaska (2016a), eBird (2015), and Seabird Information Network (2011)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Seabird Information Network (2011)

Crested Auklet
(Aethia cristatella)

MAP 5.14.2

Crested Auklets are colonial-nesting seabirds of the Bering Sea. They engage in intricate and elaborate courtship in their colonies, among hundreds of thousands of other auklet pairs. This map shows their range within our project area, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Crested Auklet population within the project area.

Artukhin et al. (2016); Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Artukhin et al. (2016), Audubon Alaska (2015), Audubon Alaska (2016a), eBird (2015), Konyukhov et al. (1998), Seabird Information Network (2011), and Vyatkin (2000)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Konyukhov et al. (1998); Seabird Information Network (2011); Vyatkin (2000)



Least Auklet
(Aethia pusilla)

MAP 5.14.4

Among the most abundant seabirds in North America, Least Auklets gather in a few huge, dense colonies to breed. These colonies are regularly made up of hundreds of thousands and even millions of Least Auklets. They gather in these annual range within our project area, along with areas of specific concentration. Breeding colonies are symbolized as a percentage of the total colonial Least Auklet population within the project area.

Artukhin et al. (2016); Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Artukhin et al. (2016), Audubon Alaska (2015), Audubon Alaska (2016a), eBird (2015), Konyukhov et al. (1998), Seabird Information Network (2011), and Vyatkin (2000)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; BirdLife International (2017a); Konyukhov et al. (1998); Seabird Information Network (2011); Vyatkin (2000)

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Short-tailed Albatross

Phoebastria albatrus

Nils Warnock, Erika Knight, and Melanie Smith

As ponderous on land as they are graceful in the air, Short-tailed Albatrosses (*Phoebastria albatrus*) are regular visitors to Alaska waters. In the late 1800s, global populations were estimated to be in the hundreds of thousands to millions (Hasegawa and DeGange 1982), and these global wind travelers were reportedly seen and eaten regularly by local communities in the Bering Sea region (Nelson et al. 1887, Gabrielson and Lincoln 1959, Murie 1959, Yesner and Aigner 1976). However, plumage hunters decimated the breeding colonies in Japan at the turn of the century (Hasegawa and DeGange 1982), and by the 1950s, ornithologists in Alaska were suggesting that the birds were nearly extinct or extinct (Gabrielson and Lincoln 1959, Murie 1959). While still numerically rare, populations are climbing back from the precipitously low number of 50–60 birds (Kuro-o et al. 2010). Since the early 2000s, sightings have been increasing in Alaska, with a population today of nearly 500 birds (Kuletz et al. 2014). Aside from their breeding grounds, few other regions are as important to Short-tailed Albatrosses as the upwelling waters on either side of the Aleutian chain and Alaska Peninsula (Piatt et al. 2006, Suryan et al. 2007).

Like all albatrosses, the Short-tailed Albatross is adapted to life on the wing at sea, with long, slender wings, relatively light bodies, and ability to dynamically soar (Suryan et al. 2008, Sachs et al. 2013). Medium in size and body mass, Short-tailed Albatrosses have especially high wing-loading relative to other albatrosses that may limit their use of the Central Pacific and other open-ocean areas of low wind speed and productivity in favor of more productive coastal upwelling systems (Suryan et al. 2008).

DISTRIBUTION

For seabirds like albatrosses that have a long maturation period and a long breeding season (Weimerskirch 1992, Finkelstein et al. 2010), migration and wintering periods often overlap (Croxall et al. 2005). The non-breeding period for adult Short-tailed Albatrosses may only last for three to four months. Some Short-tailed Albatrosses may not reproduce until they are six years old, spending those years away from the breeding grounds on the open water; some of these non-breeding birds will return to the breeding colony (especially birds four years and older) for periods of time (Hasegawa and DeGange 1982, McDermond and Morgan 1993). Likewise, around 20% of adult birds forgo breeding in any given year (US Fish and Wildlife Service 2008c, Finkelstein et al. 2010, R. Suryan pers. comm.). Short-tailed Albatrosses are not typically known to associate with sea ice, although Murie (1959) cites an early Alaskan explorer who noted that St. Lawrence communities often caught very fat albatross on the sea ice near the island.

LIFE CYCLE

Short-tailed Albatrosses are monogamous with about an eight-month breeding cycle (US Fish and Wildlife Service 2008c). Like all albatrosses, the age of first breeding is quite delayed, and for Short-tailed Albatrosses, the average is six years (Finkelstein et al. 2010). This species breeds on islands in Japan, although in recent years, at least one pair has successfully bred on Midway Atoll (VanderWerf 2012). In Japan, about 80% of all Short-tailed Albatrosses flock to the largest colony on Torishima Island in the Izu Islands, with smaller numbers in the Senkaku Islands (VanderWerf 2012). Birds begin arriving at breeding colonies in early October, and successful breeders and fledglings leave the islands in late May to June (Hasegawa and DeGange 1982, McDermond and Morgan 1993).

Migration

Post-breeding dispersal to non-breeding areas is rapid (McDermond and Morgan 1993, R. Suryan pers. comm.). For birds that move away from the breeding colonies in Japan, the most common destination is Alaska, along continental shelf margins and areas of upwelling in passes among the Aleutian Islands (Piatt et al. 2006, Kuletz et al. 2014). Distribution patterns for different ages and sexes of Short-tailed Albatross are distinct but overlap at times, with post-breeding female adult birds staying longer in Japanese and Russian waters than males. Juveniles and subadults are more likely to occur along the continental shelf off western North America, and rarely as far south as Mexico (Suryan et al. 2007, US Fish and Wildlife Service 2008c, VanderWerf 2012). There are few records of this species north of St. Lawrence Island (US Fish and Wildlife Service 2008c), although they have been documented in the Chukchi Sea (Day et al. 2013). Movements and concentration areas away from the breeding colonies are generally focused on where food, especially squid, is concentrated and accessible (Kuletz et al. 2014).

Diet

In general, albatrosses snatch fish, fish eggs, squid, and occasionally crustaceans ranging in length from <0.1 to 40 inches (0.1 to 100 cm) from the top water layer (Cherel and Klages 1998, US Fish and Wildlife Service 2008c). They closely associate with commercial fishing fleets, where the birds grab fish and offal produced by these fishing activities (Melvin et al. 2001, Dietrich and Melvin 2007, Suryan et al. 2007, US Fish and Wildlife Service 2008c).

Short-tailed Albatrosses have long, slender wings and light bodies which are well-suited for life on the wing.

John Schoen

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TABLE 5.15-1. Short-tailed Albatross life history characteristics and conservation status. Sources: Suryan et al. (2007), US Fish and Wildlife Service (2008c), Warnock (2017).

	Short-tailed Albatross *Phoebastria albatrus*
Body Size Mass Length Wingspan	**M** 9.5–18.7 pounds (4.3–8.5 kg) **L** 37 inches (94 cm) **W** 90 inches (228 cm)
Maximum Life Span (wild)	45+ years
Clutch Size Range Average	**R** 1 egg **A** 1 egg
Nest-Water Proximity	Nests on ocean islands
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Endangered **IUCN:** Vulnerable **WL:** Red List
Population Global Alaska	**G** 4,350 **A** 500
Breeding Season Eggs Young	**E** October to December **Y** January to June
Migration Spring Molt Fall	**S** May to June **M** June to September **F** September to October

CONSERVATION ISSUES

Since July 31, 2000, the Short-tailed Albatross has been federally listed as endangered in the US under the Endangered Species Act and is currently (2014) under a five-year review. Since 2008, there is also a joint US/Japan Recovery Plan and Team (US Fish and Wildlife Service 2008c). In Canada, the species is covered under the Migratory Bird Convention Act and is listed as threatened (Committee on the Status of Endangered Wildlife in Canada (COSEWIC) 2013). The Short-tailed Albatross is also a protected species under the 13-country Agreement on the Conservation of Albatrosses and Petrels (ACAP). While the US is an observer nation under ACAP, it is currently not a ratified member (Agreement on the Conservation of Albatrosses and Petrels 2009). The Short-tailed Albatross is on the Red List of Audubon Alaska's WatchList because of its depressed population status (Warnock 2017).

With the majority of the global population of Short-tailed Albatrosses thought to be nesting on Torishima Island (note that the Senkaku Islands breeding population has not been surveyed since 2002), anything that negatively affects that island's ecosystem is of management concern. One major concern is the island's active volcano, which in the past decade has erupted three times (1902, 1939, and 2002), causing loss of breeding habitat due to lava flows in some years (Hasegawa and DeGange 1982, Finkelstein et al. 2010). As a consequence, translocation efforts to other islands have been undertaken with some success (Deguchi et al. 2012, Deguchi et al. 2014). For many albatross species, ingestion of plastics is a problem, and 7 of the 11 Short-tailed Albatross chicks examined in one study had eaten plastic (McDermond and Morgan 1993, H. Hasegawa pers. comm.). In Alaska's waters, a significant management concern has been the bycatch of Short-tailed Albatross by certain commercial fisheries, particularly longline fisheries (Gilman 2003), although the US recovery plan notes only 17 cases of this species taken by commercial fishing activities since 1988 (US Fish and Wildlife Service 2014a). For an extensive list of management concerns, see US Fish and Wildlife Service (2008c) and Phillips et al. (2016).

MAPPING METHODS (MAP 5.15)

We categorized distribution into three main categories of intensity: extent of range, regular use, and concentration. The extent of range was drawn by buffering all known occurrences of Short-tailed Albatross using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a), eBird (2015), and data downloaded from Ocean Biographic Information System-Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) (Geernaert 2004, Halpin et al. 2009, Geernaert 2012, Hyrenbach et al. 2013), and satellite telemetry data (Suryan et al. 2006b, Suryan et al. 2007, Suryan et al. 2008, Suryan and Fischer 2010, Deguchi et al. 2014). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. Short-tailed Albatross observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed.

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km), which was then merged with a 50% core area delineated by O'Connor (2013) from satellite telemetry data described in Suryan et al. (2006b), Suryan et al. (2007), Suryan et al. (2008), Suryan and Fischer (2010), and Deguchi et al. (2014). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. Short-tailed Albatrosses do not use Canadian waters. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting map. There is little to no survey coverage in the Russian portions of the project area, potentially leaving major data gaps for this species. Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of this map. The range and regular-use polygons are based in part on this mostly US observation data, but also incorporate satellite telemetry data from a study of more than 50 birds tagged in Japan.

Reviewer

- Robert Suryan

MAP DATA SOURCES

Extent of Range: Audubon Alaska (2016e) based on Audubon Alaska (2016a), Deguchi et al. (2014), eBird (2015), Geernaert (2004, 2012), Hyrenbach et al. (2013), Suryan et al. (2006b, 2007, 2008), and Suryan and Fischer (2010)

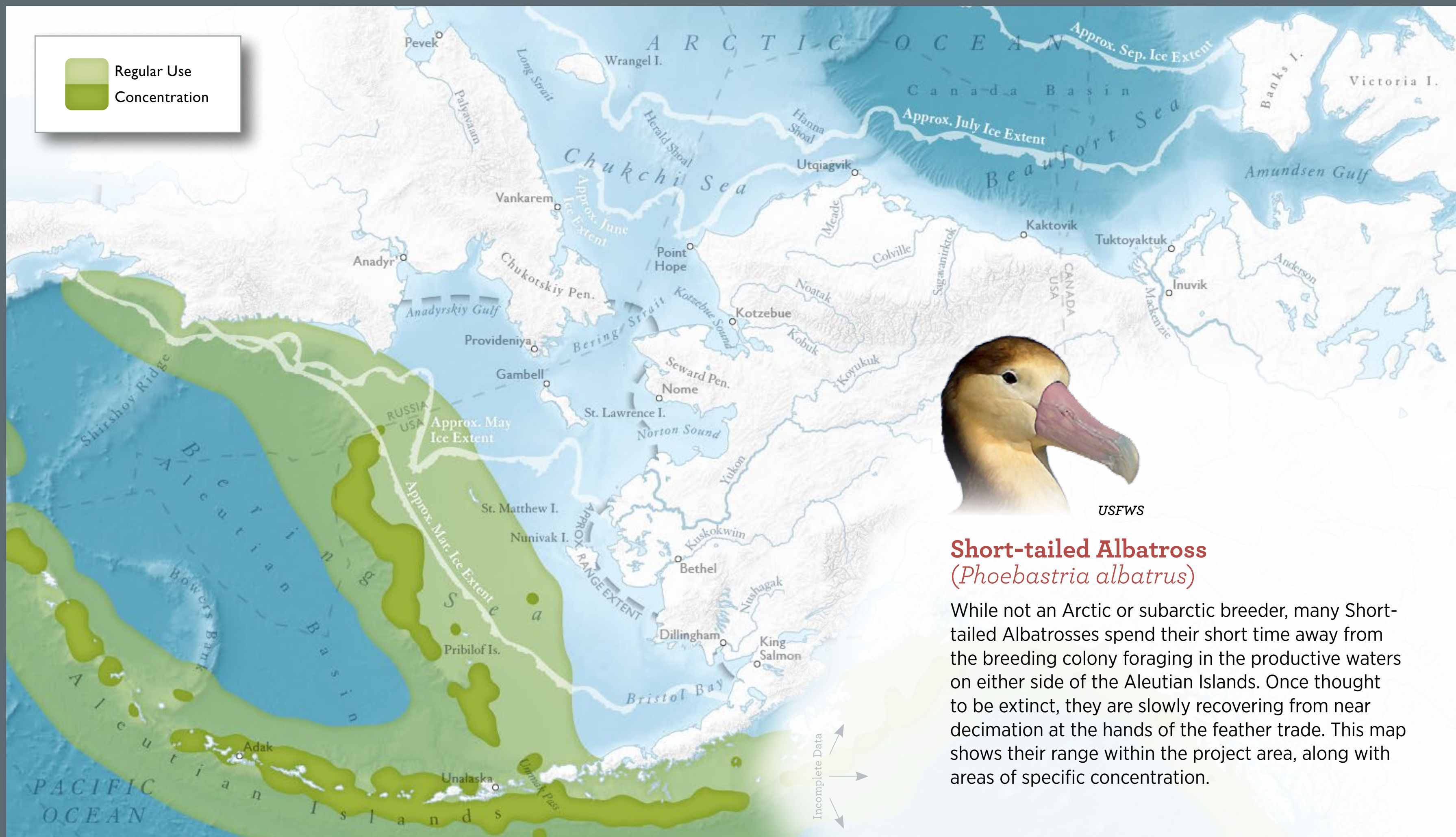
Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a); O'Connor (2013)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a), Geernaert (2004, 2012), and Hyrenbach et al. (2013)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Short-tailed Albatross

Audubon ALASKA



Short-tailed Albatross
(Phoebastria albatrus)

While not an Arctic or subarctic breeder, many Short-tailed Albatrosses spend their short time away from the breeding colony foraging in the productive waters on either side of the Aleutian Islands. Once thought to be extinct, they are slowly recovering from near decimation at the hands of the feather trade. This map shows their range within the project area, along with areas of specific concentration.

Audubon Alaska (2016c) [based on Audubon Alaska (2016a), Geernaert (2004), Geernaert (2012), and Hyrenbach et al. (2013)]; Audubon Alaska (2016e) [based on Audubon Alaska (2016a), Deguchi et al. (2014), eBird (2015), Geernaert (2004), Geernaert (2012), Hyrenbach et al. (2013), Suryan et al. (2006b), Suryan et al. (2007), Suryan et al. (2008), and Suryan and Fischer (2010)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]; O'Connor (2013)

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Robin Corcoran/USFWS

Breeding Short-tailed Albatrosses spend at least eight months of the year at their breeding colony: pairing, laying, incubating, hatching, rearing, fledging, and caring for a single chick. Non-breeders will stay at sea or come to the breeding colony for a shorter period of time before returning to the open ocean that they are well adapted to utilize. Juvenile birds (pictured) take 10–12 years to reach sexual maturity.

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Shearwaters

Nils Warnock, Max Goldman, Erika Knight, and Melanie Smith

Short-tailed Shearwater
Ardenna tenuirostris

Sooty Shearwater
A. griseus

Formerly of the *Puffinus* genus, Short-tailed (*Ardenna tenuirostris*) and Sooty (*A. griseus*) Shearwaters belong to the family of birds known as *Procellariidae* that includes petrels and fulmars. Combined, Short-tailed and Sooty Shearwaters make up one of the most abundant pelagic bird taxa in North Pacific waters (Schneider and Shuntov 1993, Shuntov 2000). They also travel some of the farthest distances of any bird that comes to Alaska, averaging 36,000–40,000 miles (59,000–64,000 km) per year (Shaffer et al. 2006, Carey et al. 2014). Both shearwater species arrive in Alaska in late April and early May and leave about 150 days later, from mid-September to early October, as they head to their breeding colonies in the Southern Hemisphere (Shaffer et al. 2006, Carey et al. 2014). These global ocean movements allow Sooty and Short-tailed Shearwaters to breed in the Southern Hemisphere when primary productivity is higher than in the Northern Hemisphere, then move to North Pacific waters when primary productivity surpasses productivity in the southern latitudes—a strategy that has been described as "the pursuit of an endless summer" (Shaffer et al. 2006, Carey et al. 2014).

Like albatross and other procellariids, shearwaters are adapted to a life at sea with their long, slender wings and relatively light bodies. In flight, especially when wind speeds are low, both species move along using a series of stiff wingbeats followed by a period of gliding. Aiding procellariids in their ability to find patchy food on the open ocean is a typically large olfactory bulb, which allows them to smell prey and even their nests on their breeding colonies from far away (e.g. Bonadonna et al. (2001), Nevitt et al. (2004)). To catch food, Sooty Shearwaters dive up to 230 feet (70 m) under water, and have been shown to have higher red blood cell counts and hematocrit values compared to other petrel species that do not dive as deep in pursuit of prey (Dunphy et al. 2015).

DISTRIBUTION

Most non-breeding Short-tailed Shearwaters are found in North Pacific waters off of Japan, Russia, and Alaska, from 40°N to over 70°N up in the Chukchi Sea (Minami et al. 1995, Gall et al. 2013, Carey et al. 2014, Yamamoto et al. 2015). In Alaska, the most abundant shearwater in the Bering Sea is the Short-tailed (Schneider and Shuntov 1993). Almost all of this species' individuals breed in large colonies on the Furneaux Group of islands off of southeastern Australia (Carey et al. 2014).

Sooty Shearwaters flock to the same North Pacific waters off of Japan, Russia, and western North America, although between 30°N and 60°N (Minami et al. 1995, Shaffer et al. 2006). Sooty Shearwaters breed in large island colonies off of New Zealand and to a lesser degree in Australia, Chile, and the Falkland Islands (BirdLife International 2017b). Birds from the Falkland Islands travel north and spend the non-breeding season in the North Atlantic Ocean (Hedd et al. 2012).

Migration
While Short-tailed and Sooty Shearwaters from breeding grounds in the Pacific Ocean share an epic migration strategy of moving between the Northern and Southern Hemispheres, how they do it differs. Short-tailed Shearwaters follow a triangular/circular migration route, moving northwest across the Pacific Ocean to coastal waters off Japan and across to Alaska and then back down the central Pacific to their breeding grounds (Carey et al. 2014) (see Figure 5.16-1). New Zealand-breeding Sooty Shearwaters tend to embark on a figure-eight migration, where the birds head northeast to east (as far east as the coast of South America) after which birds head northwest toward Japan or north along the western coast of North America to Alaska before coming back down through the Central Pacific to the breeding gounds (Shaffer et al. 2006).

For adult Short-tailed Shearwaters, average northward migration is rapid, with birds moving about 500 (±75) miles/day (840 [±125] km/day) begininning in mid-April, crossing the equator on 26 April, reaching non-breeding grounds on 2 May (±6 days), with a total transit time of about two weeks (Carey et al. 2014). For the reverse southward migration, the average adult Short-tailed leaves the nonbreeding grounds on 26 September (±7 days), crosses the equator on 7 October and arrives back to the breeding colonies on 13 October (± 6 days), moving 430 miles/day (700 km/day) (Carey et al. 2014).

Rick Hibpshman

Short-tailed Shearwater.

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Sooty Shearwater.

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TABLE 5.16-1. Shearwater life history characteristics and conservation status. Sources: Shaffer et al. (2006), Carey et al. (2014), Warnock (2017).

	Short-tailed Shearwater *Ardenna tenuirostris*	Sooty Shearwater *A. grisea*
Body Size Mass Length Wingspan	**M** 19 ounces (550 g) **L** 16.5 inches (42 cm) **W** 36–39 inches (91–99 cm)	**M** 23–33.5 ounces (650–950 g) **L** 15.5–18 inches (40–46 cm) **W** 37–43 inches (94–110 cm)
Maximum Life Span (wild)	40 years	34 years
Clutch Size Range Average	**R** 1 egg **A** 1 egg	**R** 1 egg **A** 1 egg
Nest-Water Proximity	Nest on islands	Nest on islands
Conservation Status Endangered Species Act IUCN Red List Audubon AK WatchList	**ESA:** Not Listed **IUCN:** Least Concern **WL:** Not Listed	**ESA:** Not Listed **IUCN:** Near Threatened **WL:** Not Listed
Population Global Alaska	**G** 23 million **A** >3.4 million	**G** 20 million **A** >1 million
Breeding Season Eggs Young	**E** November–December **Y** January–April	**E** Late November to early December **Y** January to April
Migration Spring Molt Fall	**S** April to early May **M** May to early September (wing) **F** Late September to mid-October	**S** April to early May **M** May to August (wing) **F** Late September to mid-October

New Zealand-breeding Sooty Shearwaters also leave their breeding grounds in early April, on average traveling 325–575 miles/day (550–900 km/day) (depending on prevailing winds) and arriving at North Pacific non-breeding grounds on 4 May (± 13 days) (Shaffer et al. 2006). Reversing direction, Sooty Shearwaters leave northern waters in mid-to late September, cross the equator on average on 7 October (± 5 days), and cover 525 (± 80) miles/day (840 [± 135] km/day), before arriving to the breeding grounds in mid-October (Shaffer et al. 2006).

Wintering
The term "wintering" is a misnomer for these shearwaters since they are Southern Hemisphere breeders that come to the Northern Hemisphere during their "summer" period, hence "non-breeding" is a more apt description. Based on tracking studies of both shearwaters, there are three main non-breeding areas, all in highly productive waters: 1) the California Current region (for Sooty Shearwaters); 2) Alaska waters, especially waters around the Gulf of Alaska (mostly Sooty Shearwaters), the Aleutian Islands, and the southern Bering Sea; and 3) the region where the Kuroshio and Oyashio Currents pass Japan and Russia's Kamchatka Peninsula (Shaffer et al. 2006, Carey et al. 2014). In the Bering Sea, Short-tailed Shearwaters move north later in the non-breeding season in response to changing sea temperature and changing distributions of krill, a major prey item (Yamamoto et al. 2015).

LIFE CYCLE
Both shearwater species nest on the ground surface and in burrows to escape predation (Warham and Wilson 1982); they lay only one egg and once the chick hatches, parents share feeding duties. Short-tailed Shearwaters are intermittent breeders, where on average, 14% of birds are not present at their breeding colony in any given year (Bradley et al. 2000). Perhaps as an adaptation to reduce foraging competition around breeding colonies with huge numbers of birds, these shearwaters will go on extended foraging trips for weeks over 930 miles (1,500 km) from the colony (Weimerskirch 1998, Klomp and Schultz 2000). In both species, adults depart from breeding colonies in March and April, before fledged chicks leave the colonies (Warham and Wilson 1982, Carey et al. 2014). In late March and early April, adult Short-tailed Shearwaters move from breeding colonies south to cold, productive waters along the Antarctic Polar Front and the northwest Ross Sea, where they feed and fatten until mid-April (Carey et al. 2014).

Diet
Major food items for both species include squid, fishes, and various crustaceans (e.g. Schneider and Shuntov (1993), Minami et al. (1995), Weimerskirch and Cherel (1998). In a diet comparison of the two species from the western North Pacific, Sooty Shearwaters ate more fish and squid while Short-tailed Shearwaters fed more at the lower zooplankton level (Minami et al. 1995). In the Bering Sea, euphausiids are a major prey item for Short-tailed Shearwaters (Murie 1959, Schneider and Shuntov 1993, Hunt et al. 1996).

At sea, both species surface-feed and plunge-dive in large flocks numbering in the tens of thousands of birds (Howell et al. 2012, N. Warnock pers. obs.). In the Central Pacific Ocean, Sooty Shearwaters were commonly observed plunge-diving for prey that was being chased by tuna, and eating squid (Spear and Ainley 1999). While chasing food underwater, shearwaters will flap their wings in pursuit (Howell 2010), and Sooty Shearwaters can dive almost to 230 feet (70 m) (average depth is 46 [± 36] feet [14 ± 11 m]); (Shaffer et al. 2006).

CONSERVATION ISSUES
In the US, Sooty and Short-tailed Shearwaters are protected under the US Migratory Bird Treaty Act of 1918, but neither shearwater has any other special protection status. Globally, large-scale changing ocean conditions, especially related to warming water temperatures and the negative impacts on the prey of shearwaters, have caused declines in shearwater populations (Veit et al. 1997, Baduini et al. 2001). More regionally, large-scale pelagic driftnet fishing efforts in the North Pacific, particularly for salmon and squid, negatively affected wintering concentrations of Sooty and particularly Short-tailed Shearwaters, killing thousands to hundreds of thousands of birds per year until this fishery was banned in most regions in the 1980s (DeGange et al. 1993, Uhlmann 2003). Other fisheries, including gillnetting, longlining, and trawling, are known to incidentally take shearwaters but to a lesser extent (Uhlmann 2003). On the breeding grounds, the chicks of both shearwater species have been and continue to be harvested by local subsistence communities (Moller and Kitson 2008); in the Titi Islands of New Zealand an estimated 360,000 Sooty Shearwater chicks (aka "muttonbirds") are harvested each year (ranging from 320,000 to 400,000 birds) (Newman et al. 2009).

MAPPING METHODS (MAP 5.17)
Due to the difficulty of identifying shearwaters in many field conditions, much of the data used in these maps are identified only as "shearwater" rather than specifically as Sooty or Short-tailed Shearwater. The shearwaters map combines all available data regarding shearwaters in this region, whether recorded to the species or genus level.

We categorized distribution into three main categories of intensity: extent of range, regular use, and concentration. The extent of range was drawn by buffering all known occurrences of shearwaters using data from Audubon's Alaska Geospatial Bird Database (AGBD) (Audubon Alaska 2016a) and eBird (2015). The AGBD combines and integrates point locations from available bird surveys conducted by the US Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Program for Regional and International Shorebird Monitoring (PRISM), as well as data from the North Pacific Pelagic Seabird Database (NPPSD) (US Geological Survey–Alaska Science Center 2015). Individual spatial outliers were removed if the observation was not within 62 miles (100 km) of another observation. Shearwater observations from these data sources were then buffered with a 62-mile (100-km) radius and merged. In some cases, inconsistencies were manually edited and smoothed.

MAP ON PAGE 194

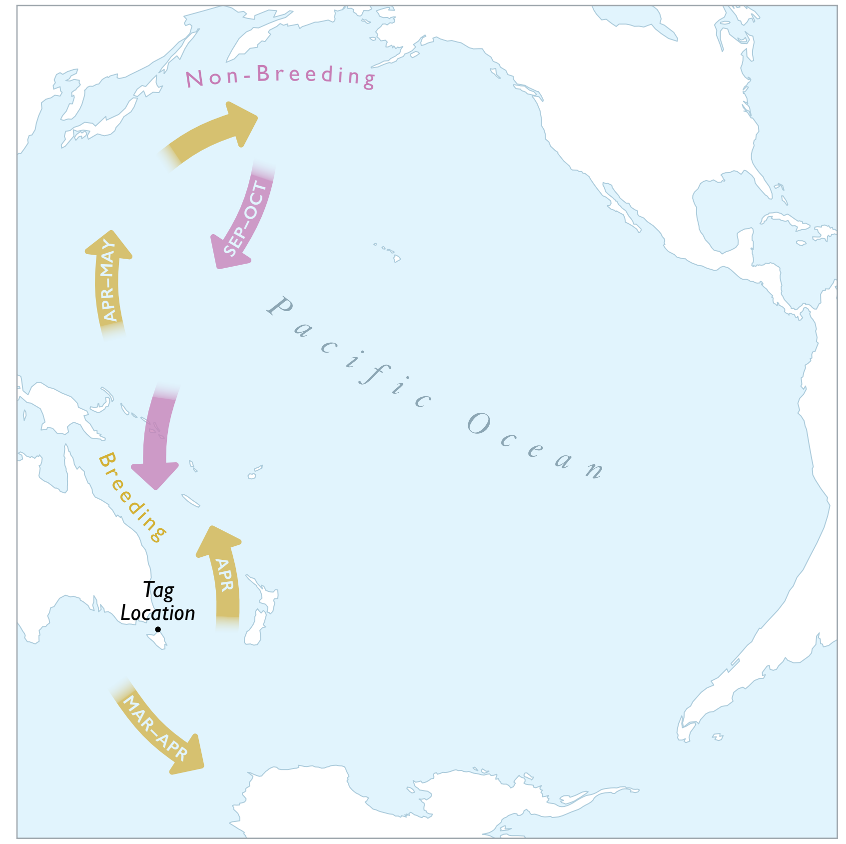


FIGURE 5.16-1. **Short-tailed Shearwater migration:** From Australian breeding grounds (tagging location), Short-tailed Shearwaters head south to stage off the coast of Antarctica before migrating north to Japanese and Alaskan waters, where they spend the Austral winter (Boreal summer). They then return across the Pacific Ocean to breed during the Austral summer (Boreal winter). Source: Carey et al. (2014).

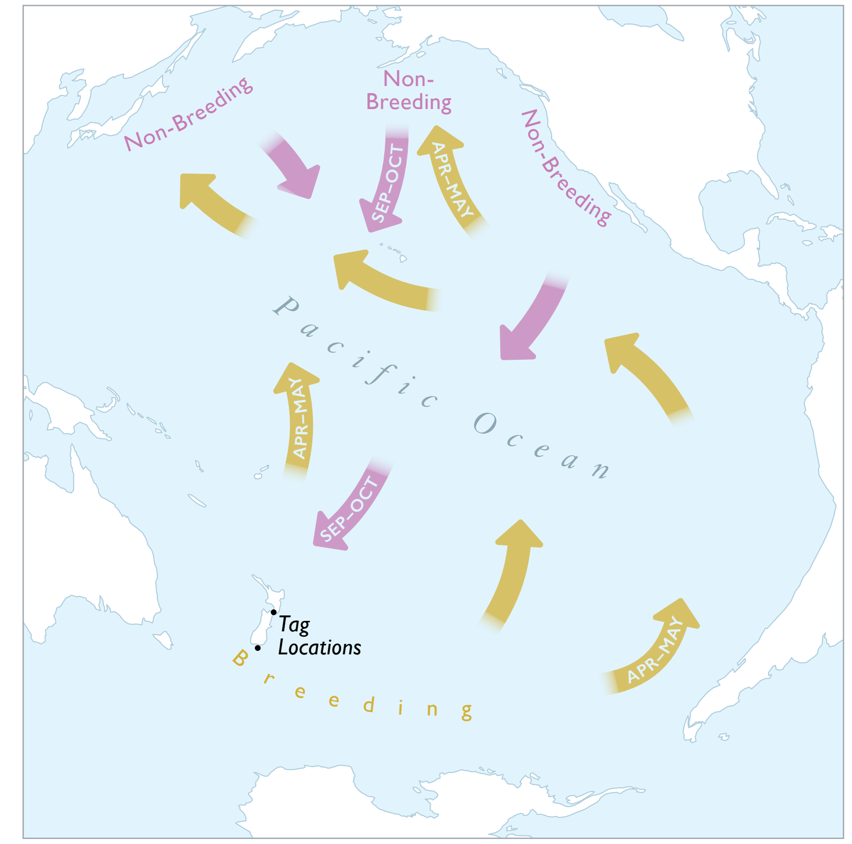


FIGURE 5.16-2. **Sooty Shearwater migration:** From New Zealand breeding grounds (tagging location), Sooty Shearwaters travel northeast or east towards South America before heading north to Alaska or northwest towards Japan for the Austral winter (Boreal summer). They complete their "figure 8" migration by crossing the Pacific to return to their breeding grounds for the Austral summer (Boreal winter). Source: Shaffer et al. (2006).

To determine regular-use and concentration areas, survey data were averaged across 3.1-mile (5-km) bins representing species density summarized by year and survey. We ran kernel density analyses to convert binned data into smoothed distribution data, then selected areas of repeated occurrence. In Alaska, the regular-use areas represent the 99% isopleth from a kernel density raster, using a search radius of 78 miles (125 km). For the concentration areas, we ran a 31-mile (50-km) kernel density analysis, then delineated density values that are 1 or more standard deviations above the project area mean density.

High-concentration areas were represented using global Important Bird Areas (IBAs). In Alaska, we used IBA data from Audubon Alaska (2014). Because IBA boundaries often encompass multiple-species hotspots, we also showed single-species IBA core areas (Audubon Alaska 2015) to indicate high concentrations specific to Sooty Shearwaters and Short-tailed Shearwaters (see Smith et al. 2014c). No IBAs for shearwaters are present in the Russian and Canadian portions of the project area (BirdLife International 2017a).

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016h) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality
The at-sea survey data used in the analysis have variable coverage across the project area, with greater effort in the US, lower effort in Russia, and lowest effort in Canada. Shearwaters generally do not use the Canadian waters in our project area. The primary data source for at-sea observation data, the NPPSD, includes data from more than 350,000 transects designed to survey birds at sea, conducted over 37 years. Survey data are most robust in Alaska, and therefore distribution and concentration areas may be biased toward US waters (where more data exist). Additionally, areas of Alaska vary greatly in survey coverage and effort, influencing overall accuracy of the resulting map. There is little to no survey coverage in the Russian portions of the project area, potentially leaving major data gaps for this species. However, while data for the Russian portion of the map is limited, kernel density analyses of tracking data for both Sooty and Short-tailed Shearwaters indicate that these species' use of the Russian Bering Sea is much less than their use of waters in Alaska's Bering Sea (Carey et al. 2014, Thompson et al. 2015). Refer to Map 5.3.2 of Bird Survey Effort in this chapter for more insight into the relative accuracy of this map.

Reviewer
• Martin Renner

MAP DATA SOURCES
Extent of Range: Audubon Alaska (2016e) based on Audubon Alaska (2016a) and eBird (2015)

Regular Use: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

Concentration: Audubon Alaska (2016c) based on Audubon Alaska (2016a)

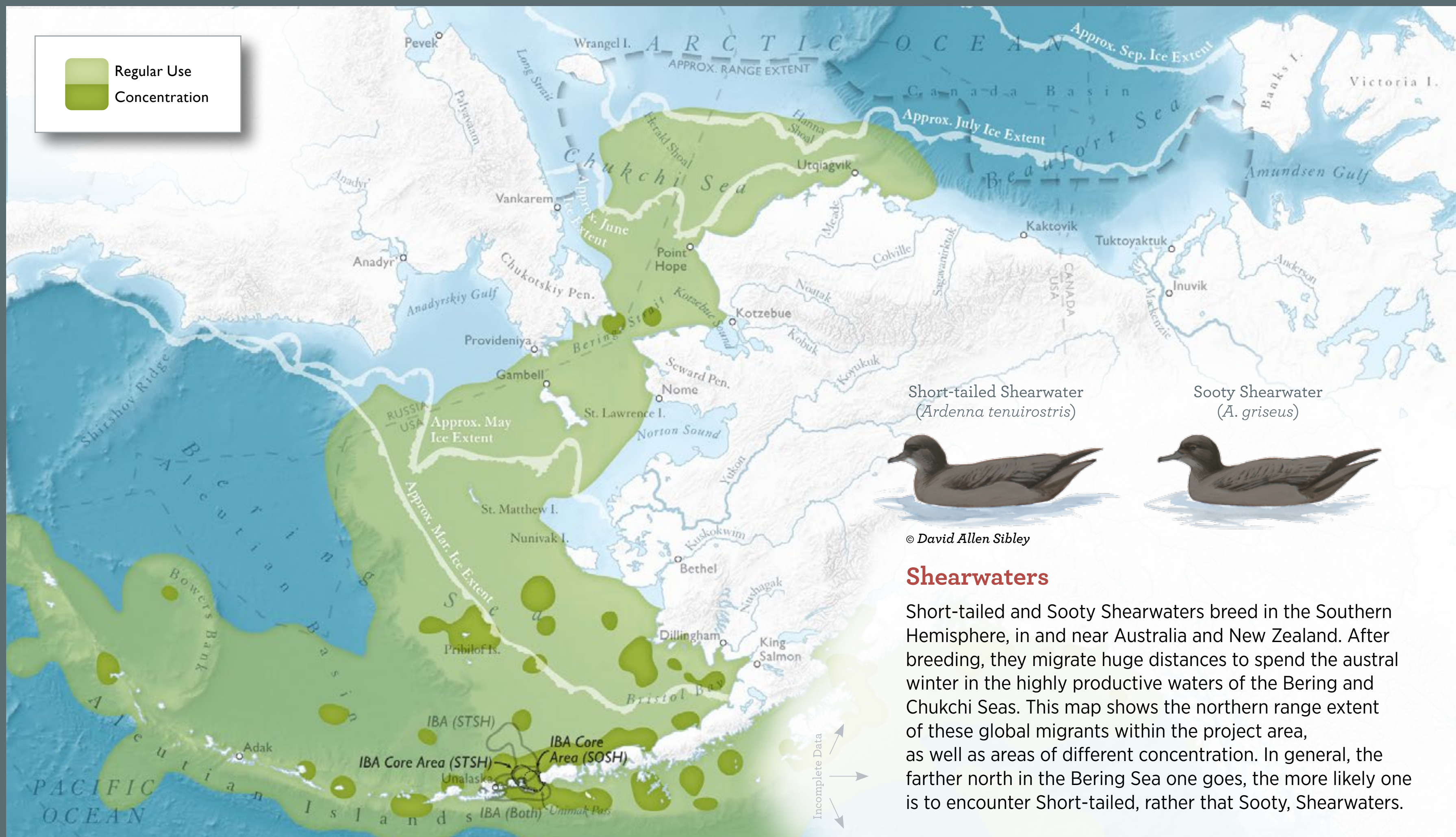
IBAs: Audubon Alaska (2014)

IBA Core Areas: Audubon Alaska (2015)

Sea Ice: Audubon Alaska (2016h) based on Fetterer et al. (2016)

Shearwaters

Audubon ALASKA



Shearwaters

Short-tailed and Sooty Shearwaters breed in the Southern Hemisphere, in and near Australia and New Zealand. After breeding, they migrate huge distances to spend the austral winter in the highly productive waters of the Bering and Chukchi Seas. This map shows the northern range extent of these global migrants within the project area, as well as areas of different concentration. In general, the farther north in the Bering Sea one goes, the more likely one is to encounter Short-tailed, rather that Sooty, Shearwaters.

Audubon Alaska (2014); Audubon Alaska (2015); Audubon Alaska (2016c) [based on Audubon Alaska (2016a)]; Audubon Alaska (2016e) [based on Audubon Alaska (2016a) and eBird (2015)]; Audubon Alaska (2016h) [based on Fetterer et al. (2016)]

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

During the Austral winter (summer in the Northern Hemisphere), Short-tailed and Sooty Shearwaters descend upon the Bering Sea in staggering numbers, becoming the most abundant seabird in the Arctic as soon as they arrive. They gather in massive groups, along with other seabirds such as kittiwakes, puffins, fulmars, and auklets. Shearwaters breed in the Southern Hemisphere during the Austral summer (winter in the Northern Hemisphere), and migrate thousands of miles during their non-breeding season to take advantage of the huge blooms of productivity in the far north during the ice-free months.

REFERENCES

Ader, A. and J. Kespaik. 1996. Seasonal migration dynamics of the Long-tailed Duck (*Clangula hyemalis*), the Common Scoter (*Melanitta nigra*), and the Velvet Scoter (*Melanitta fusca*) in Estonia. *Gibier Faune Sauvage* 13:1297–1385.

Agler, B. A., S. J. Kendall, D. B. Irons, and S. P. Klosiewski. 1999. Declines in marine bird populations in Prince William Sound, Alaska coincident with a climatic regime shift. *Waterbirds* 22:98–103.

Agreement on the Conservation of Albatrosses and Petrels. 2009. ACAP Species Assessment: Short-tailed Albatross *Phoebastria albatrus*. Accessed online 20 March 2017 at http://www.acap.aq.

Ainley, D. G., A. R. DeGange, L. L. Jones, and R. J. Beach. 1981. Mortality of seabirds in high-seas salmon gillnets. *Fishery Bulletin* 79:800–806.

Ainley, D. G., S. H. Morrell, and R. J. Boekelheide. 1990. Rhinoceros Auklet and Tufted Puffin, *In Seabirds of the Farallon Islands*. D. G. Ainley and R. J. Boekelheide eds., pp. 339–348. Stanford University Press, Stanford, CA.

Ainley, D. G., D. N. Nettleship, H. R. Carter, and A. E. Storey. 2002. Common Murre (*Uria aalge*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/commur/introduction.

Ainley, D. G., W. J. Sydeman, S. A. Hatch, and U. W. Wilson. 1994. Seabird population trends along the west coast of North America: Causes and the extent of regional concordance. *Studies in Avian Biology* 15:119–133.

Alaska Department of Fish and Game. 2016. Species Range Maps. Alaska Department of Fish and Game, Juneau, AK.

Alaska Maritime National Wildlife Refuge. 2009. Unpublished data regarding seabird colonies on Attu Island. Alaska Maritime National Wildlife Refuge, Homer, AK.

Alison, R. 1975a. Capturing and marking Oldsquaws. *Bird-Banding* 46:248–250.

Alison, R. M. 1975b. Breeding biology and behavior of the Oldsquaw (*Clangula hyemalis* L.). *Ornithological Monographs* 18:1–52.

Alison, R. M. 1976. Oldsquaw brood behavior. *Bird-Banding* 47:210–213.

Amaral, M. J. 1977. A Comparative Breeding Biology of the Tufted and Horned Puffin in the Barren Islands, Alaska. MS thesis, University of Washington, Seattle, WA.

Anderson, V. R. and R. T. Alisauskas. 2001. Egg size, body size, locomotion, and feeding performance in captive King Eider ducklings. *Condor* 103:195–199.

______. 2002. Composition and growth of King Eider ducklings in relation to egg size. *Auk* 119:62–70.

Andres, B. A. 1993. Foraging flights of Pacific, *Gavia pacifica*, and Red-throated, *G. stellata*, Loons on Alaska coastal-plain. *Canadian Field-Naturalist* 107:238–240.

Andres, B. A., P. A. Smith, R. G. Morrison, C. L. Gratto-Trevor, S. C. Brown, and C. A. Friis. 2012. Population estimates of North American shorebirds, 2012. *Wader Study Group Bulletin* 119:178–194.

Arctic Landscape Conservation Cooperative. 2012. Threatened Eider Geodatabase for Northern Alaska, 2012 Edition. Arctic Landscape Conservation Cooperative, Anchorage and Fairbanks, AK.

______. 2013. Yellow-billed Loon Geodatabase, 2013 Edition. Arctic Landscape Conservation Cooperative, Anchorage and Fairbanks, AK.

Arkhipov, V. Y., T. Noah, S. Koschkar, and F. A. Kondrashov. 2014. Birds of Cape Schmidt and its surroundings. *Russian Ornithological Journal* 25:3771–3797.

Armstrong, R. H. 2015. *Guide to the Birds of Alaska*. 6th edition. Alaska Northwest Books, Portland, OR.

Artukhin, Y. B., A. V. Andreev, Y. N. Gerasimov, N. B. Konyukhov, P. S. Vyatkin, I. M. Tiunov, Y. V. Shibaev, A. V. Kondratyev, E. G. Lobkov, V. V. Pronkevich, V. B. Zykov, F. V. Kazanskiy, Z. V. Revyakina, E. E. Syroechkovskiy, A. M. Trukhin, N. N. Yakushev, and V. E. Kirichenko. 2016. *Marine Important Bird Areas of the Russian Far East*. BirdsRussia, Moscow, Russia.

Artyukhin, Y. B. and V. N. Burkanov. 2000. Incidental mortality of seabirds in the drift net salmon fishery by Japanese vessels in the Russian exclusive economic zone, 1993–1997, *In Seabirds of the Russian Far East*. A. V. Kondratyev, N. M. Litvinenko, and G. W. Kaiser eds., pp. 105–116. Canadian Wildlife Service Special Publication, Ottawa, Canada.

Audubon Alaska. 2009a. Ivory Gull Migration GIS File. Audubon Alaska, Anchorage, AK.

______. 2009b. King Eider Concentration GIS File. Audubon Alaska, Anchorage, AK.

______. 2009c. Red-throated Loon GIS File. Audubon Alaska, Anchorage, AK.

______. 2009d. Yellow-billed Loon GIS File. Audubon Alaska, Anchorage, AK.

______. 2014. Important Bird Areas of Alaska, v3. Audubon Alaska, Anchorage, AK. Accessed online at http://databasin.org/datasets/f9e442345fb54ae28cf72f249d2c23a9.

______. 2015. Single Species Core Areas (Basis for Identifying Important Bird Areas). Audubon Alaska, Anchorage, AK.

______. 2016a. Alaska Geospatial Bird Database v2. Audubon Alaska, Anchorage, AK.

______. 2016b. King Eider Breeding and Breeding Concentration in Alaska and Canada GIS File. Audubon Alaska, Anchorage, AK.

______. 2016c. King Eider Breeding in Russia GIS File. Audubon Alaska, Anchorage, AK.

______. 2016d. King Eider Migration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016e. King Eider Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016f. Long-tailed Duck Molting GIS File. Audubon Alaska, Anchorage, AK.

______. 2016g. Long-tailed Duck Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016h. Monthly Sea Ice Approximate 2006–2015 Medians GIS File. Audubon Alaska, Anchorage, AK.

______. 2016i. Steller's Eider Breeding Concentration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016j. Steller's Eider Migration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016k. Steller's Eider Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016l. Yellow-billed Loon and Red-throated Loon Migration GIS Files. Audubon Alaska, Anchorage, AK.

______. 2016m. Yellow-billed Loon and Red-throated Loon Range GIS Files. Audubon Alaska, Anchorage, AK.

______. 2016n. Yellow-billed Loon and Red-throated Loon Wintering GIS Files. Audubon Alaska, Anchorage, AK.

______. 2017a. Bird Survey Effort GIS File. Audubon Alaska, Anchorage, AK.

______. 2017b. Common Eider Breeding GIS File. Audubon Alaska, Anchorage, AK.

______. 2017c. Common Eider Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2017d. Eider Marine Regular Use GIS Files. Audubon Alaska, Anchorage, AK.

______. 2017e. Foraging Guilds GIS File. Audubon Alaska, Anchorage, AK.

______. 2017f. Long-tailed Duck Breeding and Breeding Concentration GIS File. Audubon Alaska, Anchorage, AK.

______. 2017g. Long-tailed Duck Marine Regular Use GIS File. Audubon Alaska, Anchorage, AK.

______. 2017h. Phalarope Range GIS Files. Audubon Alaska, Anchorage, AK.

______. 2017i. Phalarope Regular Use and Concentration GIS Files. Audubon Alaska, Anchorage, AK.

______. 2017j. Spectacled Eider Breeding and Breeding Concentration GIS Files. Audubon Alaska, Anchorage, AK.

______. 2017k. Spectacled Eider Migration GIS File. Audubon Alaska, Anchorage, AK.

______. 2017l. Spectacled Eider Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2017m. Yellow-billed Loon and Red-throated Loon Breeding and Breeding Concentration GIS Files. Audubon Alaska, Anchorage, AK.

Baduini, C. L., K. D. Hyrenbach, K. O. Coyle, A. Pinchuk, V. Mendenhall, and G. L. Hunt. 2001. Mass mortality of Short-tailed Shearwaters in the south-eastern Bering Sea during summer 1997. *Fisheries Oceanography* 10:117–130.

Bailey, A. M. 1922. Notes on the Yellow-billed Loon. *Condor* 24:204–205.

Bailey, E. P. 1993. Introduction of Foxes to Alaskan Islands—History, Effects on Avifauna, and Eradication. Resource Publication 193. US Fish and Wildlife Service, Washington, DC.

Bailey, E. P. and G. W. Kaiser. 1993. Impacts of introduced predators on nesting seabirds in the northeast Pacific, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 218–226. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Baird, P. A., P. J. Gould, C. J. Lensink, and G. A. Sanger. 1983. The Breeding Biology and Feeding Ecology of Marine Birds in the Gulf of Alaska. US Fish and Wildlife Service, Denver Wildlife Research Center, Migratory Bird Project, Denver, CO.

Barr, J. F., C. Eberl, and J. W. McIntyre. 2000. Red-throated Loon (*Gavia stellata*), *In The Birds of North America*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/retloo/introduction.

Barry, T. W. 1968. Observations on natural mortality and native use of eider ducks along the Beaufort Sea coast. *Canadian Field-Naturalist* 82:140–144.

Bart, J., R. M. Platte, B. Andres, S. Brown, J. A. Johnson, and W. Larned. 2013. Importance of the National Petroleum Reserve—Alaska for Aquatic Birds. *Conservation Biology* 27:1304–1312.

Bartzen, B. A., D. L. Dickson, and T. D. Bowman. 2017. Migration characteristics of Long-tailed Ducks (*Clangula hyemalis*) from the western Canadian Arctic. *Polar Biology* 40:1–15.

Beauchamp, G., M. Guillemette, and R. Ydenberg. 1992. Prey selection while diving by Common Eiders, *Somateria mollissima*. *Animal Behaviour* 44:417–426.

Bédard, J. 1969. Adaptive radiation in Alcidae. *Ibis* 111:189–198.

Beier, J. C. and D. Wartzok. 1979. Mating behaviour of captive spotted seals (*Phoca largha*). *Animal Behaviour* 27:772–781.

Bellebaum, J., J. Kube, A. Schulz, H. Skov, and H. Wendeln. 2014. Decline of Long-tailed Duck *Clangula hyemalis* numbers in the Pomeranian Bay revealed by two different survey methods. *Ornis Fennica* 91:129–137.

Bent, A. C. 1922. *Life Histories of North American Petrels and Pelicans and their Allies, Order Turbinares and Order Steganopodes*. US National Museum, US Government Printing Office, Washington, DC.

______. 1925. *Life Histories of North American Wild Fowl*. US National Museum, US Government Printing Office, Washington, DC.

Bentzen, R. L. and A. N. Powell. 2012. Population dynamics of King Eiders breeding in Northern Alaska. *Journal of Wildlife Management* 76:1011–1020.

Bergman, G. 1974. The spring migration of the Long-Tailed Duck and the Common Scoter in western Finland. *Ornis Fennica* 51:129–145.

Biderman, J. O. and W. H. Drury. 1978. Ecological Studies in the Northern Bering Sea: Studies of Seabirds in the Bering Strait. Environmental Assessment of the Alaska Continental Shelf, Annual Report of Principal Investigators. US Department of Commerce, Environmental Assessment Program, Boulder, CO.

Binford, L. C. and J. V. Remsen, Jr. 1974. Identification of the Yellow-billed Loon (*Gavia adamsii*). *Western Birds* 5:111–126.

BirdLife International. 2012. Data Zone. BirdLife International, Cambridge, United Kingdom. Accessed online 1 July 2012 at http://www.birdlife.org/datazone/home.

______. 2016a. *Gavia stellata*. Birdlife International, Cambridge, United Kingdom. Accessed online at http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22697829A86220430.en.

______. 2016b. *Pagophila eburnea*. BirdLife International, Cambridge, United Kingdom. Accessed online at http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22694473A90111998.en.

______. 2016c. *Phalaropus fulicarius*. BirdLife International, Cambridge, United Kingdom. Accessed online at http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22693494A86675091.en.

______. 2017a. Important Bird Areas (IBAs). BirdLife International, Cambridge, United Kingdom. Accessed online 24 March 2017 at http://www.birdlife.org/datazone/site.

______. 2017b. Species Factsheet: *Ardenna griseus*. Birdlife International, Cambridge, United Kingdom. Accessed online 15 Mar 2017 at http://www.birdlife.org.

______. 2017c. Species Factsheet: *Phalaropus lobatus*. Birdlife International, Cambridge, United Kingdom. Accessed online 15 Mar 2017 at http://www.birdlife.org.

Boersma, D. and M. C. Silva. 2001. Fork-tailed Storm-Petrel (*Oceanodroma furcata*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/fcspet/introduction.

Boertmann, D., K. Olsen, and O. Gilg. 2010. Ivory Gulls breeding on ice. *Polar Record* 46:86–88.

Bollinger, K. S. and R. M. Platte. 2012. Aerial Population Surveys of Common Eiders and Other Waterbirds During the Breeding Season, Northwestern Alaska, 2006–2009. US Fish and Wildlife Service, Fairbanks, AK.

Bonadonna, F., J. Spaggiari, and H. Weimerskirch. 2001. Could osmotaxis explain the ability of Blue Petrels to return to their burrows at night? *Journal of Experimental Biology* 204:1485–1489.

Bond, A. L., K. A. Hobson, and B. A. Branfireun. 2015. Rapidly increasing methyl mercury in endangered Ivory Gull (*Pagophila eburnea*) feathers over a 130 year record. *Proceedings of the Royal Society of London B: Biological Sciences* 282:20150032.

Bond, A. L., I. L. Jones, S. S. Seneviratne, and S. B. Muzaffar. 2013. Least Auklet (*Aethia pusilla*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/leauk/introduction.

Bond, A. L., I. L. Jones, J. C. Williams, and G. V. Byrd. 2010. Auklet (Charadriiformes: Alcidae, *Aethia* spp.) chick meals from the Aleutian Islands, Alaska have a very low incidence of plastic marine debris. *Marine Pollution Bulletin* 60:1346–1349.

Bowman, T. D., E. D. Silverman, S. G. Gilliland, and J. B. Leirness. 2015. Status and trends of North American sea ducks: Reinforcing the need for better monitoring, *In Studies in Avian Biology*. J.-P. L. Savard, D. V. Derksen, D. Esler, and J. M. Eadie eds. CRC Press, Boca Raton, FL.

Bradley, J. S., R. D. Wooller, and I. J. Skira. 2000. Intermittent breeding in the Short-tailed Shearwater *Puffinus tenuirostris*. *Journal of Animal Ecology* 69:639–650.

Bradstreet, M. S. W. 1985. Feeding studies, *In Population Estimation, Productivity, and Food Habits of Nesting Seabirds at Cape Pierce and the Pribilof Islands, Bering Sea, Alaska*. S. R. Johnson ed., pp. 257–306. LGL Ecological Research Associates, Inc. for Minerals Management Service, Anchorage, AK.

Braune, B. M., M. L. Mallory, and H. G. Gilchrist. 2006. Elevated mercury levels in a declining population of Ivory Gulls in the Canadian Arctic. *Marine Pollution Bulletin* 52:978–982.

Braune, B. M., M. L. Mallory, H. G. Gilchrist, R. J. Letcher, and K. G. Drouillard. 2007. Levels and trends of organochlorines and brominated flame retardants in Ivory Gull eggs from the Canadian Arctic, 1976 to 2004. *Science of the Total Environment* 378:403–417.

Brazil, M. and M. Yabuuchi. 1991. *The Birds of Japan*. Smithsonian Institution Press, Washington, DC.

Briggs, K. T., K. F. Dettman, D. B. Lewis, and W. B. Tyler. 1984. Phalarope feeding in relation to autumn upwelling off California, *In Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships*. D. N. Nettleship, G. A. Sanger, and P. F. Springer eds., pp. 51–63. Canadian Wildlife Service, Ottawa, Canada.

Briggs, K. T., W. M. B. Tyler, D. B. Lewis, and D. R. Carlson. 1987. Bird communities at sea off California: 1975 to 1983. *Studies in Avian Biology* 11:1–74.

Brown, R. G. 1986. *Revised Atlas of Eastern Canadian Seabirds*. Volume 1. Canadian Wildlife Service, Ottawa, Canada.

Brown, R. G. B. and D. E. Gaskin. 1988. The pelagic ecology of the Grey and Red-necked Phalaropes *Phalaropus fulicarius* and *P. lobatus* in the Bay of Fundy, eastern Canada. *Ibis* 130:234–250.

Burn, D. M. and J. R. Mather. 1974. The White-Billed Diver in Britain. *British Birds* 67:257–296.

Bustnes, J. O. and O. J. Lonne. 1995. Sea ducks as predators on sea urchins in a northern kelp forest, *In Ecology of Fjords and Coastal Waters*. H. R. Skjoldal, C. Hopkins, K. E. Erikstad, and H. P. Leinas eds., pp. 599–608. Elsevier Science, Amsterdam, Netherlands.

______. 1997. Habitat partitioning among sympatric wintering Common Eiders *Somateria mollissima* and King Eiders *Somateria spectabilis*. *Ibis* 139:549–554.

Bustnes, J. O. and G. H. Systad. 2001. Comparative feeding ecology of Steller's Eider and Long-tailed Ducks in winter. *Waterbirds* 24:407–412.

Byrd, G. V. 1989. Seabirds in the Pribilof Islands, Alaska: Trends and Monitoring Methods. MS thesis, University of Idaho, Moscow, ID.

Byrd, G. V. and D. D. Gibson. 1980. Distribution and population status of Whiskered Auklet in the Aleutian Islands, Alaska. *Western Birds* 11:135–140.

Byrd, G. V., E. C. Murphy, G. W. Kaiser, A. Y. Kondratyev, and Y. V. Shibaev. 1993. Status and ecology of offshore fish-feeding alcids (murres and puffins) in the North Pacific, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 176–186. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Byrd, G. V. and T. Tobish. 1978. Wind-caused mortality in a kittiwake colony at Buldir Island, Alaska. *Murrelet* 59:37.

Byrd, G. V. and J. C. Williams. 1993a. Red-legged Kittiwake (*Rissa brevirostris*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/relkit/introduction/.

______. 1993b. Whiskered Auklet (*Aethia pygmaea*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/whiauk/introduction/.

Byrd, G. V., J. C. Williams, Y. B. Artyukhin, and P. S. Vyatkin. 1997. Trends in populations of Red-legged Kittiwake *Rissa brevirostris*, a Bering Sea endemic. *Bird Conservation International* 7:167–180.

Byrd, G. V., J. C. Williams, and H. M. Renner. 2004. Ledge-Nesting Seabirds at Chagulak Island in 2004. Report AMNWR 04/21. US Fish and Wildlife Service, Homer, AK.

Byrd, V., D. Kildaw, and C. Lascink. 2001a. Seabird Monitoring Results form Bogoslof Island, Alaska in 2000. Report AMNWR 01/02. US Fish and Wildlife Service, Homer, AK.

Byrd, V. and J. Williams. 2004. Cormorant Surveys in the Near Island Group, Aleutian Islands, Alaska, in July 2003 with Notes on Other Species. Report AMNWR 03/13. US Fish and Wildlife Service, Homer, AK.

Byrd, V., J. Williams, D. Roseneau, and A. Kettle. 2001b. Wildlife Surveys at Amak Island, Alaska, in June 2001. Report AMNWR 01/03. US Fish and Wildlife Service, Homer, AK.

Byrd, V. G., H. M. Renner, and M. Renner. 2005. Distribution patterns and population trends of breeding seabirds in the Aleutian Islands. *Fisheries Oceanography* 14:139–159.

Cairns, D. K., R. D. Elliot, W. Threlfall, and W. A. Montevecchi. 1986. Researcher's guide to Newfoundland seabird colonies. *Memorial University of Newfoundland Occasional Paper in Biology* 10:1–50.

Campbell, W., N. K. Dawe, I. McTaggart-Cowan, J. M. Cooper, G. W. Kaiser, and M. C. E. McNall. 2007a. *Birds of British Columbia*. Volume 2: Nonpasserines-Diurnal Birds of Prey through Woodpeckers. University of British Columbia Press, British Columbia, Canada.

______. 2007b. *Birds of British Columbia*. Volume 1: Nonpasserines-Introduction, Loons through Waterfowl. University of British Columbia Press, British Columbia, Canada.

Canadian Wildlife Service. 2013. Unpublished nesting colony data for Northwest Territories and Yukon. Canadian Wildlife Service, Ottawa, Canada.

Carey, M. J., R. A. Phillips, J. R. D. Silk, and S. A. Shaffer. 2014. Trans-equatorial migration of Short-tailed Shearwaters revealed by geolocators. *Emu* 114:352–359.

Carter, H. R., U. W. Wilson, R. W. Lowe, M. S. Rodway, D. A. Manuwal, J. E. Takekawa, and J. L. Yee. 2001. Population trends of the Common Murre (*Uria aalge californica*), *In Biology and Conservation of the Common Murre in California, Oregon, Washington, and British Columbia. Volume 1: Natural History and Population Trends*. D. A. Manuwal, H. R. Carter, T. S. Zimmerman, and D. L. Orthmeyer eds., pp. 33–132. US Geological Survey Information and Technology Report USGS/BRD/ITR-2000-0012, Washington, DC.

Causey, D. 2002. Red-faced Cormorant (*Phalacrocorax urile*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/refcor/introduction.

Causey, D. and V. Padula. 2015. Phthalates in western Aleutian Island seabirds. *AccessScience*. https://doi.org/10.1036/1097-8542.YB150685.

Cavole, L. M., A. M. Demko, R. E. Diner, A. Giddings, I. Koester, C. M. Pagniello, M.-L. Paulsen, A. Ramirez-Valdez, S. M. Schwenck, and N. K. Yen. 2016. Biological impacts of the 2013–2015 warm-water anomaly in the northeast Pacific: Winners, losers, and the future. *Oceanography* 29:273–285.

Chardine, J. and V. Mendenhall. 1998. Human Disturbance at Arctic Seabird Colonies. Conservation of Arctic Flora and Fauna (CAFF) Technical Report No. 2. CAFF Circumpolar Seabird Working Group, Akureyri, Iceland.

Cherel, Y. and N. Klages. 1998. A review of the food of albatrosses, *In Albatross Biology and Conservation*. G. Robertson and R. Gales eds., pp. 113–136. Surrey Beatty & Sons, Chipping Norton, United Kingdom.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2013. COSEWIC Assessment and Status Report on the Short-tailed Albatross *Phoebastria albatrus* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Canada.

Cornell Lab of Ornithology and American Ornithologists' Union. 2016. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at http://bna.birds.cornell.edu/bna.

Cottam, C. 1939. Food habits of North American diving ducks. *US Department of Agriculture Technical Bulletin* 643:1–139.

Cotter, R. C., D. L. Dickson, and C. J. Gratto. 1997. Breeding biology of the King Eider in the western Canadian Arctic, *In King and Common Eiders of the Western Canadian Arctic*. D. L. Dickson ed., pp. 51–57. Canadian Wildlife Service Occasional Paper No. 94, Edmonton, Canada.

Coulson, J. C. 2002. Colonial breeding in seabirds, *In Biology of Marine Birds*. E. A. Schreiber and J. Burger eds. CRC Press, Boca Raton, FL.

Cramp, S. and K. Simmons. 1977. *Birds of the Western Palearctic: Handbook of the Birds of Europe, the Middle East and North Africa*. Volume 9. Oxford University Press, Oxford, United Kingdom.

Cramp, S., K. L. E. Simmons, D. C. Brooks, N. J. Collar, E. Dunn, R. Gillmor, P. A. D. Hollom, R. J. Hudson, E. M. Nicholson, M. A. Ogilvie, and P. J. S. Olney. 1983. *Handbook of the Birds of Europe, the Middle East and North Africa: The birds of the Western Palearctic*. Volume 3: Waders to Gulls. Oxford University Press, Oxford, United Kingdom.

Croll, D. A., A. J. Gaston, and D. G. Noble. 1991. Adaptive loss of mass in Thick-billed Murres. *Condor* 93:496–502.

Croll, D. A., K. M. Newton, M. McKown, N. Holmes, J. C. Williams, H. S. Young, S. Buckelew, C. A. Wolf, G. Howald, and M. F. Bock. 2016. Passive recovery of an island bird community after rodent eradication. *Biological Invasions* 18:703–715.

Croxall, J. P., S. H. M. Butchart, B. Lascelles, A. J. Stattersfield, B. Sullivan, A. Symes, and P. Taylor. 2012. Seabird conservation status, threats, and priority actions: A global assessment. *Bird Conservation International* 22:1–34.

Croxall, J. P., J. R. D. Silk, R. A. Phillips, V. Afanasyev, and D. R. Briggs. 2005. Global circumnavigations: Tracking year-round ranges of nonbreeding albatrosses. *Science* 307:249–250.

Cury, P. M., I. L. Boyd, S. Bonhommeau, T. Anker-Nilssen, R. J. Crawford, R. W. Furness, J. A. Mills, E. J. Murphy, H. Österblom, M. Paleczny, J. F. Piatt, J. P. Roux, L. Shannon, and W. J. Sydeman. 2011. Global seabird response to forage fish depletion—one-third for the birds. *Science* 334:1703–1706.

Davis, R. A. 1972. A Comparative Study of the Use of Habitat by Arctic Loons and Red-throated Loons. PhD thesis, University of Western Ontario, London, United Kingdom.

Day, R. H., T. J. Weingartner, R. R. Hopcroft, L. A. M. Aerts, A. L. Blanchard, A. E. Gall, B. J. Gallaway, D. E. Hannay, B. A. Holladay, J. T. Mathis, B. L. Norcross, J. M. Questel, and S. S. Wisdom. 2013. The offshore northeastern Chukchi Sea, Alaska: A complex high-latitude ecosystem. *Continental Shelf Research* 67:147–165.

DeGange, A. R. and R. H. Day. 1991. Mortality of seabirds in the Japanese land-based gillnet fishery for salmon. *Condor* 93:251–258.

DeGange, A. R., R. H. Day, J. E. Takekawa, and V. M. Mendenhall. 1993. Losses of seabirds in gill nets in the North Pacific, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 204–211. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Deguchi, T., J. Jacobs, T. Harada, L. Perriman, Y. Watanabe, F. Sato, N. Nakamura, K. Ozaki, and G. Balogh. 2012. Translocation and hand-rearing techniques for establishing a colony of threatened albatross. *Bird Conservation International* 22:66–81.

Deguchi, T., R. M. Suryan, K. Ozaki, J. F. Jacobs, F. Sato, N. Nakamura, and G. R. Balogh. 2014. Translocation and hand-rearing of the Short-tailed Albatross *Phoebastria albatrus*: Early indicators of success for species conservation and island restoration. *Oryx* 48:195–203.

Dement'ev, G. P. 1966. *Birds of the Soviet Union (Ptitsy Sovetskogo Soyuza)*. Volume 1. Israel Program for Scientific Translations, Jerusalem, Israel.

Denlinger, L. M. 2006. Alaska Seabird Information Series. US Fish and Wildlife Service, Migratory Bird Management, Nongame Program, Anchorage, AK. Accessed online at http://alaska.fws.gov/mbsp/mbm/seabirds/species.htm.

Derksen, D. V., M. R. Petersen, and J.-P. L. Savard. 2015. Habitats of North American sea ducks, *In Studies in Avian Biology*. J.-P. L. Savard, D. V. Derksen, D. Esler, and J. M. Eadie eds. CRC Press, Boca Raton, FL.

Dick, M. H. and W. Donaldson. 1978. Fishing vessel endangered by Crested Auklet landings. *Condor* 80:235–236.

Dickson, D. L. 1993. Breeding biology of Red-throated Loons in the Canadian Beaufort Sea region. *Arctic* 46:1–7.

______. 2012a. Movement of King Eiders from Breeding Grounds on Banks Island, NWT, to Moulting and Wintering Areas. Technical Report Series No. 516. Canadian Wildlife Service, Edmonton, Canada.

______. 2012b. Seasonal Movement of Common Eiders Breeding in Arctic Canada. Technical Report Series No. 521. Canadian Wildlife Service, Edmonton, Canada.

______. 2012c. Seasonal Movement of King Eiders Breeding in Western Arctic Canada and Northern Alaska. Technical Report Series No. 520. Canadian Wildlife Service, Edmonton, Canada.

______. 2012d. Seasonal Movement of Pacific Common Eiders Breeding in Arctic Canada. Technical Report 521. Canadian Wildlife Service, Edmonton, Canada.

Dickson, D. L., R. C. Cotter, J. E. Hines, and M. F. Kay. 1997. Distribution and abundance of King Eiders in the western Canadian Arctic, *In King and Common Eiders of the Western Canadian Arctic. Canadian Wildlife Service Occasional Paper No. 94*. D. L. Dickson ed., pp. 29–39. Canadian Wildlife Service, Ottawa, Canada.

Dickson, D. L. and H. G. Gilchrist. 2002. Status of marine birds of the southeastern Beaufort Sea. *Arctic* 55:46–58.

Dietrich, K. S. and E. F. Melvin. 2007. Alaska Trawl Fisheries: Potential Interactions with North Pacific Albatrosses. Report WSG-TR 07-01. Washington Sea Grant, Seattle, WA.

Divoky, G. J. 1976. The pelagic feeding habits of Ivory and Ross' Gulls. *Condor* 78:85–90.

______. 1979. Sea ice as a factor in seabird distribution and ecology in the Beaufort, Chukchi, and Bering Seas, *In Conservation of Marine Birds of Northern North America. Wildlife Research Report No. 11*. J. C. Bartonek and D. N. Nettleship eds. US Fish and Wildlife Service, Washington, DC.

______. 1981. Birds and the ice-edge ecosystem in the Bering Sea, *In The Eastern Bering Sea Shelf: Oceanography and Resources. Section VI: Marine Birds*. G. L. Hunt, Jr ed., pp. 799–956. National Oceanic and Atmospheric Administration, Seattle, WA.

______. 1984. The Pelagic and Nearshore Birds of the Alaskan Beaufort Sea. Outer Continental Shelf Environmental Assessment Program Final Report 23. National Oceanic and Atmospheric Administration, Anchorage, AK.

Dixey, A. E., A. Ferguson, R. Heywood, and A. R. Taylor. 1981. Aleutian Tern: New to the western Palearctic. *British Birds* 74:411–416.

Douglas, H., T. Jones, and W. Conner. 2001. Heteropteran chemical repellents identified in the citrus odor of a seabird (Crested Auklet: *Aethia cristatella*): Evolutionary convergence in chemical ecology. *Naturwissenschaften* 88:330–332.

Douglas, H. D. 2008. Prenuptial perfume: Alloanointing in the social rituals of the Crested Auklet (*Aethia cristatella*) and the transfer of arthropod deterrents. *Naturwissenschaften* 95:45–53.

Douglas, H. D., J. E. Co, T. H. Jones, and W. E. Conner. 2004. Interspecific differences in *Aethia* spp. auklet odorants and evidence for chemical defense against ectoparasites. *Journal of Chemical Ecology* 30:1921–1935.

Dragoo, D. E. 1991. Food Habits and Productivity of Kittiwakes and Murres at St. George Island, Alaska. MS thesis, University of Alaska, Fairbanks, AK.

Dragoo, D. E., H. M. Renner, and R. S. A. Kaler. 2016. Breeding Status and Population Trends of Seabirds in Alaska, 2015. Report AMNWR 2016/03. US Fish and Wildlife Service, Homer, AK.

Drew, G. S. and J. F. Piatt. 2005. North Pacific Pelagic Seabird Database (NPPSD) v1. US Geological Survey, Anchorage, AK.

Drury, W. H. 1961. Observations on some breeding water birds on Bylot Island. *Canadian Field-Naturalist* 75:84–101.

Duffy, D. C. and D. C. Schneider. 1994. Seabird-fishery interactions: A manager's guide. *BirdLife Conservation Series* 1:26–38.

Dunphy, B. J., G. A. Taylor, T. J. Landers, R. L. Sagar, B. L. Chilvers, L. Ranjard, and M. J. Rayner. 2015. Comparative seabird diving physiology: First measures of haematological parameters and oxygen stores in three New Zealand Procellariiformes. *Marine Ecology Progress Series* 523:187–198.

Earnst, S. L., R. Platte, and L. Bond. 2006. A landscape-scale model of Yellow-billed Loon (*Gavia adamsii*) habitat preferences in northern Alaska. *Hydrobiologia* 567:227–236.

Earnst, S. L., R. A. Stehn, R. M. Platte, W. W. Larned, and E. J. Mallek. 2005. Population size and trend of Yellow-billed Loons in northern Alaska. *Condor* 107:289–304.

Ebbert, S. E. and G. V. Byrd. 2002. Eradications of invasive species to restore natural biological diversity on Alaska Maritime National Wildlife Refuge, *In Turning the Tide: The Eradication of Invasive Species*. C. R. Veitch and M. N. Clout eds., pp. 102–109. IUCN Invasive Species Specialist Group, Gland, Switzerland and Cambridge, United Kingdom.

Eberl, C. and J. Picman. 1993. Effect of nest-site location on reproductive success of Red-throated Loons (*Gavia stellata*). *Auk* 110:436–444.

eBird. 2015. eBird: An Online Database of Bird Distribution and Abundance. eBird, Ithaca, NY. Accessed online 21 Sept 2015 at http://www.ebird.org.

______. 2017. eBird: An Online Database of Bird Distribution and Abundance. eBird, Ithaca, NY. Accessed online March 2017 at http://www.ebird.org.

Ellarson, R. 1956. A Study of the Old-Squaw duck on Lake Michigan. PhD thesis, University of Wisconsin, Madison, WI.

Elphick, C. S. and G. L. Hunt. 1993. Variations in the distributions of marine birds with water mass in the northern Bering Sea. *Condor* 95:33–44.

Emlen, S. T. and L. W. Oring. 1977. Ecology, sexual selection, and the evolution of mating systems. *Science* 197:215–223.

Environment Canada. 2014. Recovery Strategy for the Ivory Gull (*Pagophila eburnea*) in Canada. Species at Risk Recovery Strategy Series. Environment Canada, Ottawa, Canada.

Everett, W. T., M. L. Ward, and J. J. Brueggeman. 1990. Birds observed in the central Bering Sea pack ice in February and March 1983. *Le Gerfaut* 79:159–166.

Evers, D. C., J. D. Paruk, J. W. Mcintyre, and J. F. Barr. 2010. Common Loon (*Gavia immer*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/comloo/introduction.

Fadely, B. S., J. F. Piatt, S. A. Hatch, and D. G. Roseneau. 1989. Populations, Productivity, and Feeding Habits of Seabirds at Cape Thompson, Alaska. US Department of Interior, Minerals Management Service, Anchorage, AK.

Fairchild, L., C. Mischler, and H. Renner. 2007. Biological Monitoring on Chowiet Island in 2006: Summary Appendices. US Fish and Wildlife Service, Homer, AK.

Fall, J. A., C. L. Brown, D. Caylor, S. Georgette, T. Krauthoefer, and A. W. Paige. 2003. Alaska Subsistence Fisheries 2002. Annual Report 315. Alaska Department of Fish and Game, Juneau, AK.

Fetterer, F., K. Knowles, W. Meier, and M. Savoie. 2016. Sea Ice Index, Version 2. National Snow and Ice Data Center, Boulder, CO.

Finkelstein, M., S. Wolf, M. Goldman, D. Doak, P. Sievert, G. Balogh, and H. Hasegawa. 2010. The anatomy of a (potential) disaster: Volcanoes, behavior, and population viability of the Short-tailed Albatross (*Phoebastria albatrus*). *Biological Conservation* 143:321–331.

Firsova, L. V. 1978. Breeding biology of the Red-legged Kittiwake, *Rissa brevirostris* (Bruch), and the Common Kittiwake, *Rissa tridactyla* (Linnaeus), on the Commander Islands, *In Systematics and Biology of Rare and Little-Studied Birds*. pp. 36–45. Zoological Institute, Academy of Sciences USSR, Leningrad, USSR.

Fischer, J. B., T. J. Tiplady, and W. W. Larned. 2002. Monitoring Beaufort Sea Waterfowl and Marine Birds: Aerial Survey Component. OCS Study MMS 2002-002. US Fish and Wildlife Service, Division of Migratory Bird Management, Anchorage, AK.

Flint, P. L., D. L. Lacroix, J. A. Reed, and R. B. Lanctot. 2004. Movements of flightless Long-tailed Ducks during wing molt. *Waterbirds* 27:35–40.

Flint, P. L., M. R. Petersen, and J. B. Grand. 1997. Exposure of Spectacled Eiders and other diving ducks to lead in western Alaska. *Canadian Journal of Zoology* 75:439–443.

Flint, P. L., J. A. Reed, D. L. Lacroix, and R. B. Lanctot. 2016. Habitat use and foraging patterns of molting male Long-tailed Ducks in lagoons of the central Beaufort Sea, Alaska. *Arctic* 69:19–28.

Flint, P. L., J. L. Schamber, K. A. Trust, A. K. Miles, J. D. Henderson, and B. W. Wilson. 2012. Chronic hydrocarbon exposure of harlequin ducks in areas affected by the Selendang Ayu oil spill at Unalaska Island, Alaska. *Environmental Toxicology and Chemistry* 31:2828–2831.

Flint, V., R. Bohme, Y. Kostin, and A. Kuznetsov. 1984. *A Field Guide to the Birds of the USSR*. Princeton University Press, Princeton, NJ.

Forsell, D. J. and P. J. Gould. 1981. Distribution and Abundance of Marine Birds and Mammals in the Kodiak Area of Alaska. US Fish and Wildlife Service, Washington, DC.

Fournier, M. A. and J. E. Hines. 1994. Effects of starvation on muscle and organ mass of King Eiders *Somateria spectabilis* and the ecological and management implications. *Wildfowl* 45:188–197.

Fox, A. D. and C. Mitchell. 1997. Rafting behaviour and predator disturbance to Steller Eiders *Polysticta stelleri* in northern Norway. *Journal fuer Ornithologie* 138:103–109.

Fredrickson, L. H. 2001. Steller's Eider (*Polysticta Stelleri*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/steeid/introduction.

Frimer, O. 1993. Occurrence and distribution of King Eiders *Somateria spectabilis* and Common Eiders *S. mollissima* at Disko, West Greenland. *Polar Research* 12:111–116.

______. 1994a. Autumn arrival and moult in King Eiders (*Somateria spectabilis*) at Disko, West Greenland. *Arctic* 47:137–141.

______. 1994b. The behaviour of moulting King Eiders *Somateria spectabilis*. *Wildfowl* 45:176–187.

______. 1995a. Adaptations by the King Eider *Somateria spectabilis* to its moulting habitat: Review of a study at Disko, West Greenland. *Dansk Ornitologisk Forenings Tidsskrift* 89:135–142.

______. 1995b. Comparative behaviour of sympatric moulting populations of Common Eider *Somateria mollissima* and King Eider *S. spectabilis* in central West Greenland. *Wildfowl* 46:129–139.

______. 1997. Diet of moulting King Eiders *Somateria spectabilis* at Disko Island, West Greenland. *Ornis Fennica* 74:187–194.

Gabrielsen, G. W. and F. Mehlum. 1989. Thermoregulation and energetics of Arctic seabirds, *In Physiology of Cold Adaptation in Birds*. C. Bech and R. E. Reinertsen eds., pp. 137–145. Springer, New York, NY.

Gabrielson, I. N. and F. C. Lincoln. 1959. *The Birds of Alaska*. Stackpole Company and Wildlife Management Institute, Mechanicsville, PA and Washington, DC.

Gall, A. E., R. H. Day, and T. J. Weingartner. 2013. Structure and variability of the marine-bird community in the northeastern Chukchi Sea. *Continental Shelf Research* 67:96–115.

Gaston, A. J. and J. M. Hipfner. 2000. Thick-billed Murre (*Uria lomvia*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/thbmur/introduction/.

Gaston, A. J. and I. L. Jones. 1998. *The Auks: Alcidae*. Oxford University Press, Oxford, United Kingdom and New York, NY.

Geernaert, T. 2004. IPHC Opportunistic Albatross Observations 1998–2002. OBIS-SEAMAP, Duke University. Accessed online at http://seamap.env.duke.edu/dataset/104.

______. 2012. IPHC Seabird Survey 2002–2011. OBIS-SEAMAP, Duke University. Accessed online at http://seamap.env.duke.edu/dataset/828.

Gibson, D. D. and G. V. Byrd. 2007. *Birds of the Aleutian Islands, Alaska*. Nuttall Ornthological Club and American Ornithologists' Union, Cambridge, MA and Washington, DC.

Gibson, D. D., L. H. DeCicco, R. E. Gill, Jr, S. C. Heinl, A. J. Lang, T. G. Tobish, Jr, and J. J. Withrow. 2015. Checklist of Alaska Birds. 21st edition. University of Alaska Museum, Fairbanks, AK.

Gilchrist, G., H. Strøm, M. V. Gavrilo, and A. Mosbech. 2008. International Ivory Gull conservation strategy and action plan. CAFF Technical Report No. 18. Conservation of Arctic Flora and Fauna International Secretariat, Circumpolar Seabird Group, Akureyri, Iceland.

Gilchrist, H. G. and G. J. Robertson. 2000. Observations of marine birds and mammals wintering at polynyas and ice edges in the Belcher Islands, Nunavut, Canada. *Arctic* 53:61–68.

Gilg, O., D. Boertmann, F. Merkel, A. Aebischer, and B. Sabard. 2009. Status of the endangered Ivory Gull, *Pagophila eburnea*, in Greenland. *Polar Biology* 32:1275–1286.

Gilg, O., L. Istomina, G. Heygster, H. Strøm, M. V. Gavrilo, M. L. Mallory, G. Gilchrist, A. Aebischer, B. Sabard, M. Huntemann, A. Mosbech, and G. Yannic. 2016. Living on the edge of a shrinking habitat: The Ivory Gull, *Pagophila eburnea*, an endangered sea-ice specialist. *Biology Letters* 12:20160277.

Gilg, O., H. Strøm, A. Aebischer, M. V. Gavrilo, A. E. Volkov, C. Miljeteig, and B. Sabard. 2010. Post-breeding movements of northeast Atlantic Ivory Gull *Pagophila eburnea* populations. *Journal of Avian Biology* 41:532–542.

Gill, F. B. 1995. *Ornithology*. 2nd edition. Macmillan, New York, NY.

Gilman, E. 2003. Marine matters: Seabird mortality in North Pacific longline fisheries. *Endangered Species Update* 20:36.

Gjerdrum, C., A. M. J. Vallée, C. C. St. Clair, D. F. Bertram, J. L. Ryder, and G. S. Blackburn. 2003. Tufted Puffin reproduction reveals ocean climate variability. *Proceedings of the National Academy of Sciences* 100:9377–9382.

Gjertz, I. and C. Lydersen. 1986. Polar bear predation on ringed seals in the fast-ice of Hornsund, Svalbard. *Polar Research* 4:65–68.

Glickson, D., M. Grabowski, T. Coolbaugh, D. Dickins, R. Glenn, K. Lee, W. L. Majors, M. Myers, B. Norcross, M. Reed, B. Salerno, R. Suydam, J. Tiedje, M. L. Timmermans, and P. Wadhams. 2014. *Responding to Oil Spills in the US Arctic Marine Environment*. National Academies Press, Washington, DC.

Gochfeld, M. and J. Burger. 1996. Family sternidae (terns), *In Handbook of the Birds of the World*. J. del Hoyo, A. Elliott, and J. Sargatal eds., pp. 624–667. Lynx Edicions, Barcelona, Spain.

Golubova, E. Y. 2002. The state of food resources and reproductive success of Tufted and Horned Puffins in the Northern Sea of Okhotsk. *Russian Journal of Ecology* 33:356–365.

Golubova, E. Y. and M. V. Nazarkin. 2009. Feeding ecology of the Tufted Puffin (*Lunda cirrhata*) and the Horned Puffin (*Fratercula corniculata*) in the northern Sea of Okhotsk. *Russian Journal of Marine Biology* 35:593–608.

Goudie, R. I., G. J. Robertson, and A. Reed. 2000. Common Eider (*Somateria mollissima*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/comeid/introduction.

Gould, P. J., D. J. Forsell, and C. J. Lensink. 1982. Pelagic Distribution and Abundance of Seabirds in the Gulf of Alaska and Eastern Bering Sea. US Fish and Wildlife Service, Washington, DC.

Gould, P. J. and J. F. Piatt. 1993. Seabirds of the central North Pacific, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 27–38. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Goyert, H. F., E. O. Garton, B. A. Drummond, and H. M. Renner. 2017. Density dependence and changes in the carrying capacity of Alaskan seabird populations. *Biological Conservation* 209:178–187.

Grant, P. J. 2010. *Gulls: A Guide to Identification*. 2nd edition. A&C Black, London, United Kingdom.

Groves, D. J., B. Conant, R. J. King, J. I. Hodges, and J. G. King. 1996. Status and trends of loon populations summering in Alaska, 1971–1993. *Condor* 98:189–195.

Halpin, P. N., A. J. Read, E. Fujioka, B. D. Best, B. Donnelly, L. J. Hazen, C. Kot, K. Urian, E. LaBrecque, A. Dimatteo, J. Cleary, C. Good, L. B. Crowder, and K. D. Hyrenbach. 2009. OBIS-SEAMAP: The world data center for marine mammal, sea bird, and sea turtle distributions. *Oceanography* 22:104–115.

Hamer, K. C., E. Schreiber, and J. Burger. 2002. Breeding biology, life histories, and life history-environment interactions in seabirds, *In Biology of Marine Birds*. E. A. Schreiber and J. Burger eds., pp. 217–261. CRC Press, Boca Raton, FL.

Haney, J. C. 1991. Influence of pycnocline topography and water-column structure on marine distributions of alcids (Aves: Alcidae) in Anadyr Strait, northern Bering Sea, Alaska. *Marine Biology* 110:419–435.

Harding, A. M. A. 2001. The Breeding Ecology of Horned Puffins, *Fratercula corniculata*, in Alaska. MA thesis, University of Durham, Durham, United Kingdom.

Harrington, B. A. 1975. Pelagic gulls in winter off southern California. *Condor* 77:346–350.

Harrison, C. S. 1982. Spring distribution of marine birds in the Gulf of Alaska, USA. *Condor* 84:245–254.

Hasegawa, H. and A. R. DeGange. 1982. The Short-tailed Albatross, *Diomedea albatrus*, its status, distribution and natural history. *American Birds* 36:806–814.

Hatch, S. A., G. V. Byrd, D. B. Irons, and G. L. Hunt, Jr. 1993. Status and ecology of kittiwakes (*Rissa tridactyla* and *R. brevirostris*) in the North Pacific, *In The Status, Ecology and Conservation of Marine Birds in the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 140–153. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Hatch, S. A. and M. A. Hatch. 1983. Populations and habitat use of marine birds in the Semidi Islands, Alaska. *Murrelet* 64:39–46.

Hatch, S. A., P. M. Meyers, D. M. Mulcahy, and D. C. Douglas. 2000. Seasonal movements and pelagic habitat use of murres and puffins determined by satellite telemetry. *Condor* 102:145–154.

Hatch, S. A., G. J. Robertson, and P. H. Baird. 2009. Black-legged Kittiwake (*Rissa tridactyla*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/commur/introduction.

Haynes, T. B., J. A. Schmutz, J. F. Bromaghin, S. J. Iverson, V. M. Padula, and A. E. Rosenberger. 2015. Diet of Yellow-billed Loons (*Gavia adamsii*) in Arctic lakes during the nesting season inferred from fatty acid analysis. *Polar Biology* 38:1239–1247.

Hedd, A., W. Montevecchi, H. Otley, R. Phillips, and D. Fifield. 2012. Trans-equatorial migration and habitat use by Sooty Shearwaters *Puffinus griseus* from the South Atlantic during the nonbreeding season. *Marine Ecology Progress Series* 449:277–290.

Hickey, J. J. and F. L. Craighead. 1977. A census of the seabirds of the Pribilof Islands, *In Environmental Assessments of the Alaskan Continental Shelf, Annual Report 2*. pp. 96–195. Outer Continental Shelf Environmental Assessment Program, Boulder, CO.

Hill, N. P. and K. D. Bishop. 1999. Possible winter quarters of the Aleutian Tern? *Wilson Journal of Ornithology* 111:559–560.

Hipfner, J. M. and G. V. Byrd. 1993. Breeding biology of the Parakeet Auklet compared to other crevice-nesting species at Buldir Island, Alaska. *Colonial Waterbirds* 16:128–138.

Hodges, J. I., D. J. Groves, and B. P. Conant. 2002. Distribution and Abundance of Waterbirds Near Shore in Southeast Alaska, 1997–2002. US Fish and Wildlife Service, Juneau, AK.

Hoffman, W., D. Heinemann, and J. A. Wiens. 1981. The ecology of seabird feeding flocks in Alaska. *Auk* 98:437–456.

Holtan, L. H. 1980. Nesting Habitat and Ecology of Aleutian Terns on the Copper River Delta, Alaska. US Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Howell, M. D., J. B. Grand, and P. L. Flint. 2003. Body molt of male Long-tailed Ducks in the near-shore waters of the North Slope, Alaska. *The Wilson Bulletin* 115:170–175.

Howell, S. N. G. 2010. *Molt in North American Birds*. Houghton Mifflin Harcourt, Boston, MA.

Howell, S. N. G., J. B. Patteson, and D. Shearwater. 2012. *Petrels, Albatrosses, and Storm-Petrels of North America: A Photographic Guide*. Princeton University Press, Princeton, NJ.

Humphries, G. R. and F. Huettmann. 2014. Putting models to a good use: A rapid assessment of Arctic seabird biodiversity indicates potential conflicts with shipping lanes and human activity. *Diversity and Distributions* 20:1–13.

Hunt, G. L., Jr, K. O. Coyle, S. Hoffman, M. B. Decker, and E. N. Flint. 1996. Foraging ecology of Short-tailed Shearwaters near the Pribilof Islands, Bering Sea. *Marine Ecology Progress Series* 141:1–11.

Hunt, G. L., Jr, P. J. Gould, D. J. Forsell, and H. Peterson, Jr. 1981. Pelagic distribution of marine birds in the eastern Bering Sea, *In The Eastern Bering Sea Shelf: Oceanography and Resources*. D. W. Hood and J. A. Calder eds., pp. 689–718. National Oceanic and Atmospheric Administration, Seattle, WA.

Hunt, G. L., Jr, N. M. Harrison, and J. F. Piatt. 1993. Foraging ecology as related to the distribution of planktivorous auklets in the Bering Sea, *In The Status, Ecology and Conservation of Marine Birds in the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 18–26. Canadian Wildlife Service, Victoria, British Columbia. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Hunt, G. L., Jr, R. W. Russell, K. O. Coyle, and T. Weingartner. 1998. Comparative foraging ecology of planktivorous auklets in relation to ocean physics and prey availability. *Marine Ecology Progress Series* 167:241–259.

Huntington, C. E., R. G. Butler, and R. Mauck. 2013. Leach's Storm-Petrel (*Oceanodroma leucorhoa*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/lcspet/introduction.

Hyrenbach, D., J. Piatt, G. Balogh, and G. Drew. 2013. NPPSD Short-tailed Albatross Sightings. OBIS-SEAMAP. Accessed online at http://seamap.env.duke.edu/dataset/311.

International Union for the Conservation of Nature. 2014. Red List of Threatened Species. Accessed online at http://www.iucnredlist.org.

Johnsgard, P. A. 1964. Comparative behavior and relationships of the eiders. *Condor* 66:113–129.

Johnson, S. R. 1984. Prey Selection by Oldsquaws (*Clangula hyemalis L.*) in a Beaufort Sea Lagoon, Alaska. LGL Limited, Edmonton, Canada.

______. 1985. Adaptations of the Long-tailed Duck (*Clangula hyemalis L.*) during the period of molt in Arctic Alaska. *Proceedings of the International Ornithological Congress* 18:530–540.

Johnson, S. R. and J. S. Baker. 1985. Population Estimation, Productivity, and Food Habits of Nesting Seabirds at Cape Pierce and the Pribilof Islands, Bering Sea, Alaska. US Minerals Management Service, Anchorage, AK.

Johnson, S. R. and D. R. Herter. 1989. *The Birds of the Beaufort Sea*. BP Exploration, Inc., Anchorage, AK.

Johnson, S. R., L. E. Noel, W. J. Gazey, and V. C. Hawkes. 2005. Aerial monitoring of marine waterfowl in the Alaskan Beaufort Sea. *Environmental Monitoring and Assessment* 108:1–43.

Johnson, S. R. and W. J. Richardson. 1982. Water bird migration near the Yukon and Alaskan coast of the Beaufort Sea 2. Molt migration of sea ducks in summer. *Arctic* 35:291–301.

Johnson, S. R. and J. G. Ward. 1985. Observations of Thick-billed Murres (*Uria lomvia*) and other seabirds at Cape Parry, Amundsen Gulf, NWT. *Arctic* 38:112–115.

Johnson, S. R. and G. C. West. 1975. Growth and development of heat regulation in nestlings, and metabolism of adult Common and Thick-billed Murres. *Ornis Scandinavica* 6:109–115.

Jones, I. L. 1993. Crested Auklet (*Aethia cristatella*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/creauk/introduction/.

Jones, I. L., F. M. Hunter, and G. J. Robertson. 2002. Annual adult survival of Least Auklets (Aves, Alcidae) varies with large-scale climatic conditions of the North Pacific Ocean. *Oecologia* 133:38–44.

Jones, I. L., N. B. Konyukhov, J. C. Williams, and G. V. Byrd. 2001. Parakeet Auklet (*Aethia psittacula*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/parauk/introduction.

Jones, I. L. and R. Montgomerie. 1992. Least Auklet ornaments: Do they function as quality indicators? *Behavioral Ecology and Sociobiology* 30:43–52.

Kaufman, K. 1989. Black-legged Kittiwake and Red-legged Kittiwake. *American Birds* 43:3–7.

Kenney, L. A., F. A. von Hippel, J. J. Willacker, and T. M. O'Hara. 2012. Mercury concentrations of a resident freshwater forage fish at Adak Island, Aleutian Archipelago, Alaska. *Environmental Toxicology and Chemistry* 31:2647–2652.

Kenyon, K. W. and R. E. Phillips. 1965. Birds from the Pribilof Islands and vicinity. *Auk* 82:624–635.

Kessel, B. 1989. *Birds of the Seward Peninsula, Alaska: Their Biogeography, Seasonality, and Natural History*. University of Alaska Press, Fairbanks, AK.

Kessel, B. and D. D. Gibson. 1978. Status and distribution of Alaska birds. *Studies in Avian Biology* 1:1–100.

Kingsbery, R. 2010. Winter Seabird Monitoring at St. George Island, Alaska in 2008–2009. US Fish and Wildlife Service, Homer, AK.

Kistchinski, A. A. 1973. Waterfowl in north-east Asia. *Wildfowl* 24:88–102.

Kistchinski, A. A. and V. E. Flint. 1974. On the biology of the Spectacled Eider. *Wildfowl* 25:5–15.

Klenova, A. V. and Y. A. Kolesnikova. 2013. Evidence for a non-gradual pattern of call development in auks (Alcidae, Charadriiformes). *Journal of Ornithology* 154:705–716.

Klomp, N. I. and M. A. Schultz. 2000. Short-tailed Shearwaters breeding in Australia forage in Antarctic waters. *Marine Ecology Progress Series* 194:307–310.

Knudtson, E. P. and G. V. Byrd. 1982. Breeding biology of Crested, Least, and Whiskered Auklets on Buldir Island, Alaska. *Condor* 84:197–202.

Koeppen, W., K. Kuletz, A. Poe, H. Renner, M. Smith, T. Van Pelt, N. Walker, and J. Williams. 2016. Chapter 6: Exploring vulnerabilities of seabirds using projected changes in climate in the Aleutian Islands and Bering Sea, *In The Aleutian-Bering Climate Vulnerability Assessment. Draft Final Report.* A. Poe, T. Van Pelt, and J. Littell eds., pp. 101–119. Aleutian and Bering Sea Islands Landscape Conservation Cooperative, Anchorage, AK.

Kokubun, N., T. Yamamoto, D. M. Kikuchi, A. Kitaysky, and A. Takahashi. 2015. Nocturnal foraging by Red-legged Kittiwakes, a surface feeding seabird that relies on deep water prey during reproduction. *PLoS ONE* 10:e0138850.

Kondratyev, A. V. 1992. Feeding niche partitioning by three coexistent diving duck species in the same habitat during brood-rearing period. *Zoologicheskii Zhurnal* 71:89–101.

Kondratyev, A. Y., P. S. Vyatkin, and Y. V. Shibaev. 2000. Conservation and protection of seabirds and their habitat, *In Seabirds of the Russian Far East*. A. V. Kondratyev, N. M. Litvinenko, and G. W. Kaiser eds., pp. 117–129. Canadian Wildlife Service Special Publication, Ottawa, Canada.

Konyukhov, N., L. Bogoslovskaya, B. Zvonov, and T. Van Pelt. 1998. Seabirds of the Chukotka Peninsula, Russia. *Arctic* 51:315–329.

Krajick, K. 2003. In search of the Ivory Gull. *Science* 301:1840–1841.

Krechmar, A. V. and A. V. Kondratyev. 2006. *Waterfowl Birds of North-East Asia*. Russian Academy of Sciences Far East Branch, North-East Scientific Center, Institute of Biological Problems of the North, Magadan, Russia.

Kristjansson, T. O., J. E. Jonsson, and J. Svavarsson. 2013. Spring diet of Common Eiders (*Somateria mollissima*) in Breiafjrur, West Iceland, indicates non-bivalve preferences. *Polar Biology* 36:51–59.

Kuletz, K. J., M. C. Ferguson, B. Hurley, A. E. Gall, E. A. Labunski, and T. C. Morgan. 2015. Seasonal spatial patterns in seabird and marine mammal distribution in the Pacific Arctic: Identifying biologically important pelagic areas. *Progress in Oceanography* 136:175–200.

Kuletz, K. J., M. Renner, E. A. Labunski, and G. L. Hunt. 2014. Changes in the distribution and abundance of albatrosses in the eastern Bering Sea: 1975–2010. *Deep Sea Research Part II: Topical Studies in Oceanography* 109:282–292.

Kuro-o, M., H. Yonekawa, S. Saito, M. Eda, H. Higuchi, H. Koike, and H. Hasegawa. 2010. Unexpectedly high genetic diversity of mtDNA control region through severe bottleneck in vulnerable albatross *Phoebastria albatrus*. *Conservation Genetics* 11:127–137.

Lamothe, P. 1973. Biology of King Eider (*Somateria spectabilis*) in a Fresh Water Breeding Area on Bathurst Island, NWT. MS thesis, University of Alberta, Edmonton, Canada.

Larned, W., K. Bollinger, and R. Stehn. 2012. Late Winter Population and Distribution of Spectacled Eiders (*Somateria fischeri*) in the Bering Sea, 2009 and 2010. Unpublished report. US Fish and Wildlife Service, Anchorage, AK.

Larned, W. W. 2012. Steller's Eider Spring Migration Surveys, Southwest Alaska. US Fish and Wildlife Service, Anchorage, AK.

Lascelles, B. 2008. The BirdLife Seabird Foraging Database: Guidelines and Examples of its Use. BirdLife International, Cambridge, United Kingdom.

Lascelles, B. G., G. M. Langham, R. A. Ronconi, and J. B. Reid. 2012. From hotspots to site protection: Identifying marine protected areas for seabirds around the globe. *Biological Conservation* 156:5–14.

Laursen, K. 1989. Estimates of sea duck winter populations of the western Palearctic. *Danish Review of Game Biology* 13:2–20.

Lee, D. S. 1992. Specimen records of Aleutian Terns from the Philippines. *Condor* 94:276–279.

Lloyd, D. S. 1985. Breeding Performance of Kittiwakes and Murres in Relation to Oceanographic and Meteorologic Conditions Across the Shelf of the Southeastern Bering Sea. MS thesis, University of Alaska, Fairbanks, AK.

Lock, A. R., R. G. B. Brown, and S. H. Gerriets. 1994. Gazetteer of Marine Birds in Atlantic Canada: An Atlas of Sea Bird Vulnerability to Oil Pollution. Canadian Wildlife Service, Environment Canada.

Lovvorn, J. R., S. E. Richman, J. M. Grebmeier, and L. W. Cooper. 2003. Diet and body condition of Spectacled Eiders wintering in pack ice of the Bering Sea. *Polar Biology* 26:259–267.

Lysne, L. A., E. J. Mallek, and C. P. Dau. 2004. Nearshore Surveys of Alaska's Arctic Coast, 1999–2003. US Fish and Wildlife Service, Migratory Bird Management Waterfowl Branch, Fairbanks, AK.

Major, H. L., I. L. Jones, G. V. Byrd, J. C. Williams, and C. Handel. 2006. Assessing the effects of introduced Norway rats (*Rattus norvegicus*) on survival and productivity of Least Auklets (*Aethia pusilla*). *Auk* 123:681–694.

Mallory, M. L. and A. J. Fontaine. 2004. Key Marine Habitat Sites for Migratory Birds in Nunavut and the Northwest Territories. Occasional Paper No. 109. Canadian Wildlife Service, Ottawa, Canada.

Mallory, M. L., H. G. Gilchrist, S. E. Jamieson, G. J. Robertson, and D. G. Campbell. 2001. Unusual migration mortality of King Eiders in central Baffin Island. *Waterbirds* 24:453–456.

Mallory, M. L., I. J. Stenhouse, G. Gilchrist, G. Robertson, J. C. Haney, and S. D. MacDonald. 2008. Ivory Gull (*Pagophila eburnea*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/ivogul/introduction.

Manning, T. H. and A. H. MacPherson. 1952. Birds of the east James Bay coast between Long Point and Cape Jones. *Canadian Field-Naturalist* 66:1–35.

Martin, P. D., D. C. Douglas, and T. Obritschkewitsch. 2015. Distribution and movements of Steller's Eiders in the non-breeding period. *Condor* 117:341–353.

Mathiasson, S. 1970. Numbers and distribution of Long-Tailed wintering Ducks in northern Europe. *British Birds* 63:414–424.

McDermond, D. K. and K. Morgan. 1993. Status and conservation of North Pacific albatrosses, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 70–81. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

McKnight, A., D. Irons, A. Allyn, K. Sullivan, and R. M. Suryan. 2011. Winter dispersal and activity patterns of post-breeding Black-legged Kittiwakes *Rissa tridactyla* from Prince William Sound, Alaska. *Marine Ecology Progress Series* 442:241–253.

McLaren, M. A. and W. G. Alliston. 1985. Effects of snow and ice on waterfowl distribution in the central Canadian Arctic islands. *Arctic* 38:43–52.

Meehan, R., V. Byrd, G. J. Divoky, and J. F. Piatt. 1998. Implications of Climate Change for Alaska's Seabirds. University of Alaska Fairbanks, Fairbanks, AK.

Melvin, E. F., J. K. Parrish, K. S. Dietrich, and O. S. Hamel. 2001. Solutions to Seabird Bycatch in Alaska's Demersal Longline Fisheries. Report WSG-AS 01-01. Washington Sea Grant, Seattle, WA.

Mendall, H. L. 1987. Identification of eastern races of the Common Eider, *In Eider Ducks in Canada*. A. Reed ed., pp. 82–88. Canadian Wildlife Service Report Series No. 47, Ste-Foy, Canada.

Merkel, F. and T. Barry. 2008. Seabird Harvest in the Arctic. CAFF Technical Report No. 16. Conservation of Arctic Flora and Fauna International Secretariat, Circumpolar Seabird Group (CBird), Akureyri, Iceland.

Merkel, F. R., S. E. Jamieson, K. Falk, and A. Mosbech. 2007a. The diet of Common Eiders wintering in Nuuk, southwest Greenland. *Polar Biology* 30:227–234.

Merkel, F. R., A. Mosbech, S. E. Jamieson, and K. Falk. 2007b. The diet of King Eiders wintering in Nuuk, southwest Greenland, with reference to sympatric wintering Common Eiders. *Polar Biology* 30:1593–1597.

Minami, H., M. Minagawa, and H. Ogi. 1995. Changes in stable carbon and nitrogen isotope ratios in Sooty and Short-tailed Shearwaters during their northward migration. *Condor* 97:565–574.

Moller, H. and J. C. Kitson. 2008. Looking after your ground: Resource management practice by Rakiura Maori titi harvesters. *Papers and Proceedings of the Royal Society of Tasmania* 142:161–176.

Morgan, K. H., K. Vermeer, and R. W. McKelvey. 1991. *Atlas of Pelagic Birds of Western Canada*. Canadian Wildlife Service, Ottawa, Canada.

Morrison, K., J. M. Hipfner, C. Gjerdrum, and D. Green. 2009. Wing length and mass at fledging predict local juvenile survival and age at first return in Tufted Puffins. *Condor* 111:433–441.

Murie, O. J. 1959. Fauna of the Aleutian Islands and Alaska Peninsula. *North American Fauna* 61:1–364.

Murphy, E. C. and J. H. Schauer. 1996. Synchrony in egg-laying and reproductive success of neighboring Common Murres, *Uria aalge*. *Behavioral Ecology and Sociobiology* 39:245–258.

Murray, N. J., R. S. Clemens, S. R. Phinn, H. P. Possingham, and R. A. Fuller. 2014. Tracking the rapid loss of tidal wetlands in the Yellow Sea. *Frontiers in Ecology and the Environment* 12:267–272.

Myres, M. T. 1958. Preliminary Studies of the Behavior, Migration and Distributional Ecology of Eider Ducks in Northern Alaska, 1958. Interim progress report to the Arctic Institute of North America. McGill University, Montreal, Canada.

National Audubon Society. 2012. Important Bird Areas Program: A Global Currency for Bird Conservation. National Audubon Society, New York, NY. Accessed online 15 Jan 2012 at http://web4.audubon.org/bird/iba/index.html.

National Oceanic and Atmospheric Administration. 1988. Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones: Strategic Assessment Data Atlas. National Oceanic and Atmospheric Administration, Rockville, MD.

______. 2005. Environmental Sensitivity Index, Version 3.0. National Oceanic and Atmospheric Administration Office of Response and Restoration, Seattle, WA. Accessed online at http://response.restoration.noaa.gov/maps-and-spatial-data/download-esi-maps-and-gis-data.html#Alaska.

Naves, L. C. and T. K. Zeller. 2017. Subsistence harvest of Yellow-Billed Loons in Alaska: Challenges in harvest assessment of a species of conservation concern. *Journal of Fish and Wildlife Management* 8:114–124.

Nelson, C. H. 1983. Eye color changes in Barrow's Goldeneye and Common Goldeneye ducklings. *The Wilson Bulletin* 95:482–488.

Nelson, E. W. 1883. *Birds of Bering Sea and the Arctic Ocean*. US Government Printing Office, Washington, DC.

Nelson, E. W., F. W. True, T. H. Bean, and W. H. Edwards. 1887. *Report Upon Natural History Collections Made in Alaska: Between the Years 1877 and 1881*. US Government Printing Office, Washington, DC.

Nettleship, D. N. 1980. A Guide to the Major Seabird Colonies of Eastern Canada: Identity, Distribution, and Abundance. Unpublished report. Canadian Wildlife Service, Ottawa, Canada.

Nevitt, G., K. Reid, and P. Trathan. 2004. Testing olfactory foraging strategies in an Antarctic seabird assemblage. *Journal of Experimental Biology* 207:3537–3544.

Newman, J., D. Scott, C. Bragg, S. Mckechnie, H. Moller, and D. Fletcher. 2009. Estimating regional population size and annual harvest intensity of the Sooty Shearwater in New Zealand. *New Zealand Journal of Zoology* 36:307–323.

Nisbet, I. and R. R. Veit. 2015. An explanation for the population crash of Red-necked Phalaropes (*Phalaropus lobatus*) staging in the Bay of Fundy in the 1980s. *Marine Ornithology* 43:119–121.

North, M. R. 1994. Yellow-billed Loon (*Gavia adamsii*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/yebloo/introduction.

______. 2013. Aleutian Tern (*Onychoprion aleuticus*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/aleter1/introduction.

North, M. R. and M. R. Ryan. 1986. Yellow-billed Loon Populations on the Colville River Delta, Arctic Alaska. Supplemental Project Report. US Fish and Wildlife Service, Anchorage, AK.

______. 1989. Characteristics of lakes and nest sites used by Yellow-Billed Loons in Arctic Alaska. *Journal of Field Ornithology* 60:296–304.

Northwest Territories. 2017. Species at Risk: Red-necked Phalarope. Accessed online 15 Mar 2017 at http://www.nwtspeciesatrisk.ca/species/red-necked-phalarope-0.

Nyeland, J. 2004. Apparent trends in the Black-legged Kittiwake in Greenland. *Waterbirds* 27:342–349.

Nysewander, D. R. 1983a. Black-legged Kittiwake (*Rissa tridactyla*), *In The Breeding Biology and Feeding Ecology of Marine Birds in the Gulf of Alaska*. P. A. Baird and P. J. Gould eds., pp. 295–348. Outer Continental Shelf Environmental Assessment Program Final Report 45. National Oceanic and Atmospheric Administration, Anchorage, AK.

______. 1983b. Cormorants (*Phalacrocorax* spp.), *In The Breeding Biology and Feeding Ecology of Marine Birds in the Gulf of Alaska*. P. A. Baird and P. J. Gould eds., pp. 207–236. Outer Continental Shelf Environmental Assessment Program Final Report 45. National Oceanic and Atmospheric Administration, Anchorage, AK.

O'Connor, A. J. 2013. Distributions and Fishery Associations of Immature Short-tailed Albatrosses (*Phoebastria albatrus*) in the North Pacific. MS thesis, Oregon State University, Corvallis, OR.

O'Hara, P. D. and L. A. Morandin. 2010. Effects of sheens associated with offshore oil and gas development on the feather microstructure of pelagic seabirds. *Marine Pollution Bulletin* 60:672–678.

Obst, B. S., W. M. Hamner, and P. P. Hamner. 1996. Kinematics of phalarope spinning. *Nature* 384:121.

Oppel, S. 2008. King Eider Migration and Seasonal Interactions at the Individual Level. PhD thesis, University of Alaska Fairbanks, Fairbanks, AK.

______. 2009. Satellite Telemetry of King Eiders from Northern Alaska, 2002–2009. OBIS-SeaMap. Accessed online at http://seamap.env.duke.edu/.

Oppel, S., D. L. Dickson, and A. N. Powell. 2009a. International importance of the eastern Chukchi Sea as a staging area for migrating King Eiders. *Polar Biology* 32:775–783.

Oppel, S. and A. N. Powell. 2009. Does winter region affect spring arrival time and body mass of King Eiders in northern Alaska? *Polar Biology* 32:1203–1209.

______. 2010a. Age-specific survival estimates of King Eiders derived from satellite telemetry. *Condor* 112:323–330.

______. 2010b. Carbon isotope turnover in blood as a measure of arrival time in migratory birds using isotopically distinct environments. *Journal of Ornithology* 151:123–131.

Oppel, S., A. N. Powell, and M. G. Butler. 2011. King Eider foraging effort during the pre-breeding period in Alaska. *Condor* 113:52–60.

Oppel, S., A. N. Powell, and D. L. Dickson. 2008. Timing and distance of King Eider migration and winter movements. *Condor* 110:296–305.

______. 2009b. Using an algorithmic model to reveal individually variable movement decisions in a wintering sea duck. *Journal of Animal Ecology* 78:524–531.

Oppel, S., A. N. Powell, and D. M. O'Brien. 2009c. Using eggshell membranes as a non-invasive tool to investigate the source of nutrients in avian eggs. *Journal of Ornithology* 150:109–115.

Orben, R. 2017. Unpublished data from Red-legged Kittiwake pre-lay and incubation tracking study. Oregon State University, Newport, OR.

Orben, R. A., D. B. Irons, R. Paredes, D. D. Roby, R. A. Phillips, and S. A. Shaffer. 2015a. North or south? Niche separation of endemic Red-legged Kittiwakes and sympatric Black-legged Kittiwakes during their non-breeding migrations. *Journal of Biogeography* 42:401–412.

Orben, R. A., R. Paredes, D. D. Roby, D. B. Irons, and S. A. Shaffer. 2015b. Body size affects individual winter foraging strategies of Thick-billed Murres in the Bering Sea. *Journal of Animal Ecology* 84:1589–1599.

______. 2015c. Wintering North Pacific Black-legged Kittiwakes balance spatial flexibility and consistency. *Movement Ecology* 3:36.

Oring, L. W., L. Neel, and K. E. Oring. 2013. US Shorebird Conservation Plan: Intermountain West Regional Shorebird Plan. US Shorebird Conservation Partnership.

Orr, C. D., R. M. P. Ward, N. A. Williams, and R. G. B. Brown. 1982. Migration patterns of Red and Northern Phalaropes in southwest Davis Strait and in the northern Labrador Sea. *The Wilson Bulletin* 94:303–312.

Ost, M., C. W. Clark, M. Kilpi, and R. Ydenberg. 2007. Parental effort and reproductive skew in coalitions of brood rearing female Common Eiders. *American Naturalist* 169:73–86.

Paleczny, M., E. Hammill, V. Karpouzi, and D. Pauly. 2015. Population trend of the world's monitored seabirds, 1950–2010. *PLoS ONE* 10:1–11.

Palmer, R. S. 1962. *Handbook of North American Birds*. Volume 1: Loons through Flamingos. Yale University Press, New Haven, CT.

______. 1976. *Handbook of North American Birds*. Volume 1–3. Yale University Press, New Haven, CT.

Parsons, M., I. Mitchell, A. Butler, N. Ratcliffe, M. Frederiksen, S. Foster, and J. B. Reid. 2008. Seabirds as indicators of the marine environment. *ICES Journal of Marine Science* 65:1520–1526.

Pattee, O. H. and S. K. Hennes. 1983. Bald eagles and waterfowl: The lead shot connection. *Transactions of the North American Wildlife and Natural Resources Conference* 48:230–237.

Payne, A. M., M. L. Schummer, and S. A. Petrie. 2015. Patterns of molt in Long-tailed Ducks (*Clangula hyemalis*) during autumn and winter in the Great Lakes Region, Canada. *Waterbirds* 38:195–200.

Pehrsson, O. and K. G. K. Nystrom. 1988. Growth and movements of Oldsquaw ducklings in relation to food. *Journal of Wildlife Management* 52:185–191.

Petersen, M. R. 1982. Predation on seabirds by red foxes at Shaiak Island, Alaska. *Canadian Field-Naturalist* 96:41–45.

Petersen, M. R. and P. L. Flint. 2002. Population structure of Pacific Common Eiders breeding in Alaska. *Condor* 104:780–787.

Petersen, M. R., W. W. Larned, and D. C. Douglas. 1999. At-sea distribution of Spectacled Eiders: A 120-year-old mystery resolved. *Auk* 116:1009–1020.

Petersen, M. R., B. J. McCaffery, and P. L. Flint. 2003. Post-breeding distribution of Long-tailed Ducks *Clangula hyemalis* from the Yukon-Kuskokwim Delta, Alaska. *Wildfowl* 54:103–113.

Peterson, S. R. and R. S. Ellarson. 1977. Food habits of Oldsquaws wintering on Lake Michigan, Michigan, USA. *The Wilson Bulletin* 89:81–91.

Phillips, A. R. 1990. Identification and southward limits, in America, of *Gavia adamsii*, the Yellow-billed Loon. *Western Birds* 21:17–24.

Phillips, L. M., S. Oppel, and A. N. Powell. 2006a. Movements of the King Eider during the non-breeding period revealed by satellite telemetry. *Journal of Ornithology* 147:118–119.

Phillips, L. M., A. N. Powell, and E. A. Rexstad. 2006b. Large-scale movements and habitat characteristics of King Eiders throughout the nonbreeding period. *Condor* 108:887–900.

Phillips, L. M., A. N. Powell, E. J. Taylor, and E. A. Rexstad. 2007. Use of the Beaufort Sea by King Eiders breeding on the North Slope of Alaska. *Journal of Wildlife Management* 71:1892–1898.

Phillips, R. A., R. Gales, G. B. Baker, M. C. Double, M. Favero, F. Quintana, M. L. Tasker, H. Weimerskirch, M. Uhart, and A. Wolfaardt. 2016. The conservation status and priorities for albatrosses and large petrels. *Biological Conservation* 201:169–183.

Piatt, J. F., H. R. Carter, and D. N. Nettleship. 1990a. Effects of oil pollution on marine bird populations, *In The Effects of Oil on Wildlife: Research, Rehabilitation, and General Concerns. Proceedings from: The Oil Symposium*. Herndon, VA.

Piatt, J. F. and A. S. Kitaysky. 2002a. Horned Puffin (*Fratercula corniculata*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/horpuf/introduction/.

______. 2002b. Tufted Puffin (*Fratercula cirrhata*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/tufpuf/introduction.

Piatt, J. F., C. J. Lensink, W. Butler, M. Kendziorek, and D. R. Nysewander. 1990b. Immediate impact of the 'Exxon Valdez' oil spill on marine birds. *Auk* 107:387–397.

Piatt, J. F. and D. N. Nettleship. 1985. Diving depths of four alcids. *Auk* 102:293–297.

Piatt, J. F., A. Pinchuk, A. Kitayski, A. M. Springer, and S. A. Hatch. 1992. Foraging Distribution and Feeding Ecology of Seabirds at the Diomede Islands, Bering Strait. US Fish and Wildlife Service Final Report. OCS Study MMS 92-0041. Minerals Management Service, Anchorage, AK.

Piatt, J. F., B. D. Roberts, W. W. Lidster, J. L. Wells, and S. A. Hatch. 1990c. Effects of human disturbance on breeding Least and Crested Auklets at St. Lawrence Island, Alaska. *Auk* 107:342–350.

Piatt, J. F. and A. M. Springer. 2003. Advection, pelagic food webs, and the biogeography of seabirds in Beringia. *Marine Ornithology* 31:141–154.

Piatt, J. F., W. J. Sydeman, and F. Wiese. 2007. Introduction: A modern role for seabirds as indicators. *Marine Ecology Progress Series* 352:199–204.

Piatt, J. F., J. Wetzel, K. Bell, A. R. DeGange, G. R. Balogh, G. S. Drew, T. Geernaert, C. Ladd, and G. V. Byrd. 2006. Predictable hotspots and foraging habitat of the endangered Short-tailed Albatross (*Phoebastria albatrus*) in the North Pacific: Implications for conservation. *Deep Sea Research Part II: Topical Studies in Oceanography* 53:387–398.

Piersma, T., J. van Gils, and P. Wiersma. 1996. Family Scolopacidae (sandpipers, snipes and phalaropes), *In Handbook of the Birds of the World. Volume 3*. J. del Hoyo, A. Elliott, and J. Sargatal eds., pp. 444–533. Lynx Edicions, Barcelona, Spain.

Pollom, E. L., J. P. Gorey, and L. Slater. 2017. Biological Monitoring at Chowiet Island, Alaska in 2016. AMNWR 2017/04. US Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge, Homer, AK.

Poole, C., N. Brickle, and D. Bakewell. 2011. South-East Asia's final frontier? *Birding ASIA* 16:26–31.

Portenko, L. A. 1972. Birds of the Chukchi Peninsula and Wrangel Island. Volume I. Akademiya Nauk SSSR, Leningrad, USSR.

Powell, A. N. and R. S. Suydam. 2012. King Eider (*Somateria spectabilis*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/kineid/introduction.

Prakash, M., D. Quéré, and J. W. Bush. 2008. Surface tension transport of prey by feeding shorebirds: The capillary ratchet. *Science* 320:931–934.

Preble, E. A. and W. L. McAtee. 1923. A biological survey of the Pribilof Islands, Alaska. *North American Fauna* 46.

Pyare, S., M. I. Goldstein, D. Duffy, S. Oehlers, N. Catterson, and J. Frederick. 2013. Aleutian Tern (*Onychoprion aleuticus*) Research in Alaska: Survey Methodology, Migration, and Statewide Coordination. Final Report to the Alaska Department of Fish and Game. Alaska Department of Fish and Game, Juneau, AK.

Raikow, R. J., L. Bicanovsky, and A. H. Bledsoe. 1988. Forelimb joint mobility and the evolution of wing-propelled diving in birds. *Auk* 105:446–451.

Reed, A. and A. J. Erskine. 1986. Populations of the Common Eider in eastern North America: Their size and status, *In Eider Ducks in Canada*. A. Reed ed., pp. 156–162. Canadian Wildlife Service Report Series No. 47, Ste-Foy, Canada.

Renner, H. M., F. Mueter, B. A. Drummond, J. A. Warzybok, and E. H. Sinclair. 2012. Patterns of change in diets of two piscivorous seabird species during 35 years in the Pribilof Islands. *Deep Sea Research Part II: Topical Studies in Oceanography* 65:273–291.

Renner, H. M., M. D. Romano, M. Renner, S. Pyare, M. I. Goldstein, and Y. Arthukin. 2015. Assessing the breeding distribution and population trends of the Aleutian Tern *Onychoprion aleuticus*. *Marine Ornithology* 43:179–187.

Renner, M., S. Salo, L. B. Eisner, P. H. Ressler, C. Ladd, K. J. Kuletz, J. A. Santora, J. F. Piatt, G. S. Drew, and G. L. Hunt, Jr. 2016. Timing of ice retreat alters seabird abundances and distributions in the southeast Bering Sea. *Biology Letters* 12:20160276.

Richardson, W. J. and S. R. Johnson. 1981. Water bird migration near the Yukon and Alaskan coast of the Beaufort Sea: 1. Timing, routes and numbers in spring. *Arctic* 34:108–121.

Robards, M. D., J. F. Piatt, and K. D. Wohl. 1995. Increasing frequency of plastic particles ingested by seabirds in the subarctic North Pacific. *Marine Pollution Bulletin* 30:151–157.

Robertson, G., H. G. Gilchrist, and M. L. Mallory. 2007. Colony dynamics and persistence of Ivory Gull breeding in Canada. *Avian Conservation and Ecology* 2:8.

Robertson, G. J. and J. L. Savard. 2002. Long-tailed Duck (*Clangula hyemalis*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/lotduc/introduction.

Robertson, I. 1971. Influence of Brood-size on Reproductive Success of Two Species of Cormorant, *Phalacrocorax auritus* & *P. pelagicus*, and Its Relation to the Problem of Clutch-size. MS thesis, University of British Columbia, Vancouver, Canada.

Roby, D. D. and K. L. Brink. 1986. Decline of breeding Least Auklets on St. George Island, Alaska. *Journal of Field Ornithology* 57:57–59.

Roelke, M. and G. Hunt. 1978. Cliff attendance, foraging patterns and post-fledging behaviour of known-sex adult Thick-billed Murres (*Uria lomvia*). *Pacific Seabird Group* 5:81.

Rofritz, D. J. 1977. Oligochaetes as a winter food source for the Old Squaw. *Journal of Wildlife Management* 41:590–591.

Romano, M. D. and G. Thomson. 2016. Cormorant Surveys in the Pribilof Islands, Alaska, 2015. US Fish and Wildlife Service, Homer, AK.

Ronconi, R. A., B. G. Lascelles, G. M. Langham, J. B. Reid, and D. Oro. 2012. The role of seabirds in marine protected area identification, delineation, and monitoring: Introduction and synthesis. *Biological Conservation* 156:1–4.

Rosenberg, D. H., M. J. Petrula, D. Zwiefelhofer, T. Hollmen, D. D. Hill, and J. Schamber. 2016. Seasonal Movements and Distribution of Pacific Steller's Eiders (*Polysticta stelleri*). Alaska Department of Fish and Game, Juneau, AK.

Rottenborn, S. and J. Morlan. 2000. Report of the California Bird Records Committee: 1997 records. *Western Birds* 31:1–37.

Royston, S. R. and S. M. Carr. 2016. Conservation genetics of high-arctic gull species at risk: I. Diversity in the mtDNA control region of circumpolar populations of the endangered Ivory Gull (*Pagophila eburnea*). *Mitochondrial DNA Part A* 27:3995–3999.

Rubega, M. A. 1997. Surface tension prey transport in shorebirds: How widespread is it? *Ibis* 139:488–493.

Rubega, M. A. and B. S. Obst. 1993. Surface-tension feeding in phalaropes: Discovery of a novel feeding mechanism. *Auk* 110:169–178.

Rubega, M. A., D. Schamel, and D. M. Tracy. 2000. Red-necked Phalarope (*Phalaropus lobatus*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab or Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/renpha/introduction.

Saalfeld, S. T., R. B. Lanctot, S. C. Brown, D. T. Saalfeld, J. A. Johnson, B. A. Andres, and J. R. Bart. 2013a. Data from: Predicting breeding shorebird distributions on the Arctic Coastal Plain of Alaska. Arctic Landscape Conservation Cooperative, Fairbanks and Anchorage, AK. Accessed online at http://arcticlcc.org/projects/biological/modeling-shorebird-distribution-on-the-north-slope/.

______. 2013b. Predicting breeding shorebird distributions on the Arctic Coastal Plain of Alaska. *Ecosphere* 4:16.

Sachs, G., J. Traugott, A. Nesterova, and F. Bonadonna. 2013. Experimental verification of dynamic soaring in albatrosses. *Journal of Experimental Biology* 216:4222–4232.

Salomonsen, F. 1949. Some notes on the molt of the Long-tailed Duck (*Clangula hyemalis*). *Avicultural Magazine* 55:59–62.

Sanford, R. C. and S. W. Harris. 1967. Feeding behavior and food-consumption rates of a captive California Murre. *Condor* 69:298–302.

Sanger, G. A. and R. D. Jones, Jr. 1984. Winter feeding ecology and trophic relationships of Oldsquaws and White-winged Scoters on Kachemak Bay, Alaska, *In Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships: Proceedings of the Pacific Seabird Group Symposium, Seattle, WA*. D. N. Nettleship, G. A. Sanger, and P. F. Springer eds., pp. 20–28. Canadian Wildlife Service, Dartmouth, Canada.

Schacter, C. R. and K. F. Robbins. 2016. A comparison of winter distributions of *Aethia* auklets derived from tracking data and ship-based surveys, *In Pacific Seabird Group Annual Meeting*. 10–13 February 2016, Oahu, HI.

Schamber, J. L., P. L. Flint, J. B. Grand, H. M. Wilson, and J. A. Morse. 2009. Population dynamics of Long-tailed Ducks breeding on the Yukon-Kuskokwim Delta, Alaska. *Arctic* 62:190–200.

Schmutz, J. A. 2017. Unpublished Yellow-billed and Red-throated Loon satellite telemetry data collected from 2000 to 2010. US Geological Survey, Anchorage, AK.

Schmutz, J. A. and D. J. Rizzolo. 2012. Monitoring Marine Birds of Concern in the Eastern Chukchi Nearshore Area (Loons). US Geological Survey and Bureau of Ocean Energy Management, Anchorage, AK.

Schmutz, J. A., K. A. Trust, and A. C. Matz. 2009. Red-throated Loons (*Gavia stellata*) breeding in Alaska, USA, are exposed to PCBs while on their Asian wintering grounds. *Environmental Pollution* 157:2386–2393.

Schneider, D. and G. L. Hunt, Jr. 1984. A comparison of seabird diets and foraging distribution around the Pribilof Islands, Alaska, *In Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships: Proceedings of the Pacific Seabird Group Symposium, Seattle, WA*. D. N. Nettleship, G. A. Sanger, and P. F. Springer eds., pp. 86–95. Canadian Wildlife Service, Environment Canada, Ottawa, Canada.

Schneider, D. C. and V. P. Shuntov. 1993. The trophic organization of the marine bird community in the Bering Sea. *Reviews in Fisheries Science* 1:311–335.

Schoen, S. K., M. L. Kissling, N. R. Hatch, C. S. Shanley, and S. W. Stephensen. 2013. Marine birds of Yakutat Bay, Alaska: Evaluating summer distribution, abundance and threats at sea. *Marine Ornithology* 41:55–61.

Schorger, A. W. 1947. The deep diving of the loon and Old-squaw and its mechanism. *The Wilson Bulletin* 59:151–159.

______. 1951. Deep diving of the Old-squaw. *The Wilson Bulletin* 63:112–112.

Schreiber, E. A. and J. Burger. 2002. Seabirds in the marine environment, *In Biology of Marine Birds*. E. A. Schreiber and J. Burger eds., pp. 1–15. CRC Press, Boca Raton, FL.

Schummer, M. L., I. Fife, S. A. Petrie, and S. S. Badzinski. 2011. Artifact ingestion in sea ducks wintering at northeastern Lake Ontario. *Waterbirds* 34:51–58.

Scott, D. A. and P. M. Rose. 1996. *Atlas of Anatidae Populations in Africa and Western Eurasia*. Volume 41. Wetlands International, Wageningen, Netherlands.

Scott, W. E. 1938. Old-squaws taken in gill-nets. *Auk* 55:668–668.

Sea Duck Joint Venture. 2016. Meet the Sea Ducks. Sea Duck Joint Venture, Anchorage, AK. Accessed online at http://seaduckjv.org/meet-the-sea-ducks/.

Seabird Information Network. 2011. North Pacific Seabird Data Portal. Accessed online at http://axiom.seabirds.net/maps/north-pacific-seabirds/.

______. 2017. North Pacific Seabird Data Portal. Accessed online at http://axiom.seabirds.net/maps/north-pacific-seabirds/.

Sealy, S. G. 1973. Breeding biology of the Horned Puffin on St. Lawrence Island, Bering Sea, with zoogeographical notes on the North Pacific puffins. *Pacific Science* 27:99–119.

Seip, K. L., E. Sandersen, F. Mehlum, and J. Ryssdal. 1991. Damages to seabirds from oil spills: Comparing simulation results and vulnerability indexes. *Ecological Modelling* 53:39–60.

Sellin, D. 1990. Fish spawn as food of birds. *Vogelwelt* 111:217–223.

Seneviratne, S., I. Jones, and E. Miller. 2009. Vocal repertoires of auklets (Alcidae: Aethiini): Structural organization and categorization. *Wilson Journal of Ornithology* 121:568–584.

Seneviratne, S. S. and I. L. Jones. 2008. Mechanosensory function for facial ornamentation in the Whiskered Auklet, a crevice-dwelling seabird. *Behavioral Ecology* 19:784–790.

Serreze, M. C., M. M. Holland, and J. Stroeve. 2007. Perspectives on the Arctic's shrinking sea-ice cover. *Science* 315:1533–1536.

Sexson, M. G., J. M. Pearce, and M. R. Petersen. 2014. Spatiotemporal Distribution and Migratory Patterns of Spectacled Eiders. Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, AK.

Sexson, M. G., M. R. Petersen, G. A. Breed, and A. N. Powell. 2016. Shifts in the distribution of molting Spectacled Eiders (*Somateria fischeri*) indicate ecosystem change in the Arctic. *Condor* 118:463–476.

Sexson, M. G., M. R. Petersen, and A. N. Powell. 2012. Spatiotemporal distribution of Spectacled Eiders throughout the annual cycle, *In 15th Alaska Bird Conference*. Anchorage, AK.

Shaffer, S. A., Y. Tremblay, H. Weimerskirch, D. Scott, D. R. Thompson, P. M. Sagar, H. Moller, G. A. Taylor, D. G. Foley, B. A. Block, and D. P. Costa. 2006. Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. *Proceedings of the National Academy of Sciences* 103:12799–12802.

Shuntov, V. P. 1963. Summer distribution of kittiwakes in the Bering Sea. *Ornitologiya* 6:325–330.

______. 1993. Biological and physical determinants of marine bird distribution in the Bering Sea, *In The Status, Ecology and Conservation of Marine Birds in the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 10–17. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

______. 2000. Seabird distribution in the marine domain, *In Seabirds of the Russian Far East*. A. V. Kondratyev, N. M. Litvinenko, and G. W. Kaiser eds., pp. 83–104. Canadian Wildlife Service Special Publication, Ottawa, Canada.

Siegel-Causey, D. 1988. Phylogeny of the Phalacrocoracidae. *Condor* 90:885–905.

Siegel-Causey, D. and N. M. Litvinenko. 1993. Status, ecology, and conservation of shags and cormorants of the temperate North Pacific, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 122–130. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Smith, M., M. Bolton, D. J. Okill, R. W. Summers, P. Ellis, F. Liechti, and J. D. Wilson. 2014a. Geolocator tagging reveals Pacific migration of Red-necked Phalarope *Phalaropus lobatus* breeding in Scotland. *Ibis* 156:870–873.

Smith, M. A., N. J. Walker, C. M. Free, M. J. Kirchhoff, G. S. Drew, N. Warnock, and I. J. Stenhouse. 2014b. Identifying marine Important Bird Areas using at-sea survey data. *Biological Conservation* 172:180–189.

Smith, M. A., N. J. Walker, C. M. Free, M. J. Kirchhoff, N. Warnock, A. Weinstein, T. Distler, and I. J. Stenhouse. 2012. Marine Important Bird Areas in Alaska: Identifying Globally Significant Sites Using Colony and At-sea Survey Data. Audubon Alaska, Anchorage, AK.

Smith, M. A., N. J. Walker, I. J. Stenhouse, C. M. Free, M. J. Kirchhoff, O. Romanenko, S. Senner, N. Warnock, and V. Mendenhall. 2014c. A new map of Important Bird Areas in Alaska, *In 16th Alaska Bird Conference*. Juneau, AK.

Solovyeva, D. V. 2011. King Eider (*Somateria spectabilis*), *In Field Guide of Waterfowl of Russia*. E. E. Syroechkovsky ed., pp. 140–142. Working Group on Waterfowl of Northern Eurasia, Institute for Nature Conservation, Zoological Museum, Moscow State University, Moscow, Russia.

Solovyeva, D. V. and V. Kokhanova. 2017. King Eider Breeding Area in Russia. Institute of Biological Problems of the North, Magadan, Russia.

Sowls, A. L. 1993. Trip Report: Winter Wildlife Surveys, St. Paul Island, Alaska, 8–12 March 1993. US Fish and Wildlife Service, Homer, AK.

Sowls, A. L., S. A. Hatch, and C. J. Len-Sink. 1978. Catalog of Alaskan Seabird Colonies. Report FWS/OBS 78/78. US Fish and Wildlife Service.

Spear, L. B. 1993. Dynamics and effect of Western Gulls feeding in a colony of guillemots and Brandt's Cormorants. *Journal of Animal Ecology* 62:399–414.

Spear, L. B. and D. G. Ainley. 1999. Migration routes of Sooty Shearwaters in the Pacific Ocean. *Condor* 101:205–218.

______. 2008. The seabird community of the Peru Current, 1980–1995, with comparisons to other eastern boundary currents. *Marine Ornithology* 36:125–144.

Spencer, N. C., H. G. Gilchrist, and M. L. Mallory. 2014a. Annual movement patterns of endangered Ivory Gulls: The importance of sea ice. *PLoS ONE* 9:e115231.

______. 2014b. Data from: Annual movement patterns of endangered Ivory Gulls: The importance of sea ice. Dryad Data Repository.

Springer, A. M. 1991. Seabird distribution as related to food webs and the environment: Examples from the North Pacific Ocean. *Studies of High Latitude Seabirds* 1:39–48.

______. 1992. A review: Walleye pollock in the North Pacific—how much difference do they really make? *Fisheries Oceanography* 1:80–96.

Springer, A. M., J. F. Piatt, V. P. Shuntov, G. B. Van Vliet, V. L. Vladimirov, A. E. Kuzin, and A. S. Perlov. 1999. Marine birds and mammals of the Pacific subarctic gyres. *Progress in Oceanography* 43:443–487.

Squibb, R. C. and G. L. Hunt. 1983. A comparison of nesting-ledges used by seabirds on St. George Island. *Ecology* 64:727–734.

Stehn, R. and R. Platte. 2009. Steller's Eider Distribution, Abundance, and Trend on the Arctic Coastal Plain, Alaska, 1989–2008. US Fish and Wildlife Service, Anchorage, AK.

Stejneger, L. H. 1885. Results of Ornithological Explorations in the Commander Islands and in Kamtschatka. US Government Printing Office, Washington, DC.

Stenhouse, I. J., G. J. Robertson, and H. G. Gilchrist. 2004. Recoveries and survival rate of Ivory Gulls banded in Nunavut, Canada, 1971–1999. *Waterbirds* 27:486–492.

Stephensen, S. W. and D. B. Irons. 2003. Comparison of colonial breeding seabirds in the eastern Bering Sea and the Gulf of Alaska. *Marine Ornithology* 31:167–173.

Storer, R. W. 1987. The possible significance of large eyes in the Red-Legged Kittiwake. *Condor* 89:192–194.

Strann, K. B. and J. E. Østnes. 2007. Numbers and Distribution of Wintering Yellow-billed and Common Loons in Norway. Unpublished report. Norwegian Institute for Nature Research and Zoologisk Institute, Tromsø and Dragvoll, Norway.

Suryan, R. M., D. J. Anderson, S. A. Shaffer, D. D. Roby, Y. Tremblay, D. P. Costa, P. R. Sievert, F. Sato, K. Ozaki, G. R. Balogh, and N. Nakamura. 2008. Wind, waves, and wing loading: Morphological specialization may limit range expansion of endangered albatrosses. *PLoS ONE* 3:e4016.

Suryan, R. M., K. S. Dietrich, E. F. Melvin, G. R. Balogh, F. Sato, and K. Ozaki. 2007. Migratory routes of Short-tailed Albatrosses: Use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. *Biological Conservation* 137:450–460.

Suryan, R. M. and K. N. Fischer. 2010. Stable isotope analysis and satellite tracking reveal interspecific resource partitioning of nonbreeding albatrosses off Alaska. *Canadian Journal of Zoology* 88:299–305.

Suryan, R. M., D. B. Irons, E. D. Brown, P. G. R. Jodice, and D. D. Roby. 2006a. Site-specific effects on productivity of an upper trophic-level marine predator: Bottom-up, top-down, and mismatch effects on reproduction in a colonial seabird. *Progress in Oceanography* 68:303–328.

Suryan, R. M., J. A. Santora, and W. J. Sydeman. 2012. New approach for using remotely sensed chlorophyll a to identify seabird hotspots. *Marine Ecology Progress Series* 451:213–225.

Suryan, R. M., F. Sato, G. R. Balogh, K. D. Hyrenbach, P. R. Sievert, and K. Ozaki. 2006b. Foraging destinations and marine habitat use of Short-tailed Albatrosses: A multi-scale approach using first-passage time analysis. *Deep Sea Research Part II: Topical Studies in Oceanography* 53:370–386.

Swennen, C. and P. Duiven. 1977. Size of food objects of three fish-eating seabird species: *Uria aalge*, *Alca torda*, and *Fratercula arctica* (Aves, Alcidae). *Netherlands Journal of Sea Research* 11:92–98.

Sydeman, W. J., J. F. Piatt, S. A. Thompson, M. García-Reyes, S. A. Hatch, M. L. Arimitsu, L. Slater, J. C. Williams, N. A. Rojek, and S. G. Zador. 2016. Puffins reveal contrasting relationships between forage fish and ocean climate in the North Pacific. *Fisheries Oceanography* 26:379–395.

Sydeman, W. J., S. A. Thompson, J. A. Santora, M. F. Henry, K. H. Morgan, and S. D. Batten. 2010. Macro-ecology of plankton–seabird associations in the North Pacific Ocean. *Journal of Plankton Research* 32:1697–1713.

Thompson, D. R., L. G. Torres, G. A. Taylor, M. J. Rayner, P. M. Sagar, S. A. Shaffer, R. A. Phillips, and S. J. Bury. 2015. Stable isotope values delineate the non-breeding distributions of Sooty Shearwaters *Puffinus griseus* in the North Pacific Ocean. *Marine Ecology Progress Series* 521:277–282.

Thomson, G., B. A. Drummond, and M. D. Romano. 2014. Biological Monitoring at St. Paul Island, Alaska in 2014. Report AMNWR 2014/12. US Fish and Wildlife Service, Homer, AK.

Tracy, D. M., D. L. Schamel, and J. Dale. 2002. Red Phalarope (*Phalaropus fulicarius*), *In The Birds of North America Online*. P. G. Rodewald ed. Cornell Lab of Ornithology, Ithaca, NY. Accessed online at https://birdsna.org/Species-Account/bna/species/redpha1/introduction.

Troy, D. M. 1996. Population dynamics of breeding shorebirds in Arctic Alaska. *International Wader Studies* 8:15–27.

Troy, D. M. and M. S. W. Bradstreet. 1991. Marine bird abundance and habitat use, *In Marine Birds and Mammals of the Unimak Pass Area: Abundance, Habitat Use and Vulnerability*. Final Report to Mineral Management Service Contract# MMS14-35-001-30564. pp. 5-1 to 5-70. LGL Alaska Research Associates, Inc., Anchorage, AK.

Tyler, W. B., K. T. Briggs, D. B. Lewis, and R. G. Ford. 1993. Seabird distribution and abundance in relation to oceanographic processes in the California Current system, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 48–60. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Uhlmann, S. 2003. Fisheries Bycatch Mortalities of Sooty Shearwaters (*Puffinus griseus*) and Short-tailed Shearwaters (*P. tenuirostris*). DOC Science Internal Series 92. Department of Conservation, Wellington, New Zealand.

US Fish and Wildlife Service. 1997. Endangered and threatened wildlife and plants; Proposed rule to list Spectacled Eider as threatened and notice of 12-month finding for a petition to list two Alaskan eiders as endangered. *Federal Register* 57:19852–19856.

______. 2001. Endangered and threatened wildlife and plants; Final determination of critical habitat for the Spectacled Eider. *Federal Register* 66:9146–9185.

______. 2008a. Action Plan for Pacific Common Eider. Unpublished report. US Fish and Wildlife Service, Anchorage, AK.

______. 2008b. Seabirds Overview. US Fish and Wildlife Service, Anchorage, AK. Accessed online 15 July 2013 at http://alaska.fws.gov/mbsp/mbm/seabirds/seabirds.htm.

______. 2008c. Short-tailed Albatross Recovery Plan. US Fish and Wildlife Service, Anchorage, AK.

______. 2014a. Short-tailed Albatross (*Phoebastria albatrus*) 5-year Review: Summary and Evaluation. US Fish and Wildlife Service, Anchorage, AK.

______. 2014b. Species Status Assessment Report: Yellow-billed Loon (*Gavia adamsii*). US Fish and Wildlife Service, Fairbanks, AK.

______. 2016a. Anchorage Fish and Wildlife Field Office Endangered Species Consultation. US Fish and Wildlife Service, Anchorage, AK. Accessed online 20 September 2016 at https://www.fws.gov/alaska/fisheries/fieldoffice/anchorage/endangered/consultation.htm.

______. 2016b. FWS Critical Habitat for Threatened and Endangered Species. US Fish and Wildlife Service. Accessed online at http://ecos.fws.gov/crithab/.

US Geological Survey—Alaska Science Center. 2015. North Pacific Pelagic Seabird Database (NPPSD) Version 2.0 US Geological Survey, Anchorage, AK.

VanderWerf, E. A. 2012. Hawaiian Bird Conservation Action Plan. Pacific Rim Conservation, Honolulu, HI.

Veit, R., J. McGowan, D. Ainley, T. Wahl, and P. Pyle. 1997. Apex marine predator declines ninety percent in association with changing oceanic climate. *Global Change Biology* 3:23–28.

Veit, R. R. and W. R. Petersen. 1993. *Birds of Massachusetts*. Massachusetts Audubon Society, Lincoln, MA.

Verreault, J., G. W. Gabrielsen, and J. O. Bustnes. 2010. The Svalbard Glaucous Gull as bioindicator species in the European Arctic: Insight from 35 years of contaminants research. *Reviews of Environmental Contamination and Toxicology* 205:77–116.

Verspoor, E., T. Birkhead, and D. N. Nettleship. 1987. Incubation and brooding shift duration in the Common Murre, *Uria aalge*. *Canadian Journal of Zoology* 65:247–252.

Viain, A. and M. Guillemette. 2016. Does water temperature affect the timing and duration of remigial moult in sea ducks? An experimental approach. *PLoS ONE* 11:e0155253.

Volkov, A. E. and J. De Korte. 1996. Distribution and numbers of breeding Ivory Gulls *Pagophila eburnea* in Severnaja Zemlja, Russian Arctic. *Polar Research* 15:11–21.

Vyatkin, P. S. 2000. Кадастр гнездовий колониальных морских птиц Корякского нагорья и восточного побережья Камчатки (Nest cadaster of colonial seabirds of the coasts of Koryak Highland and eastern Kamchatka), *In* Биология и охрана птиц Камчатки, Том *2 (The Biology and Conservation of the Birds of Kamchatka, Volume 2)*. Y. B. Artukhin and Y. N. Gerasimov eds., pp. 7–15. Russian Academy of Sciences, Far East Branch, Kamchatka Institute of Ecology, Moscow, Russia.

Wahl, T. R., K. H. Morgan, and K. Vermeer. 1993. Seabird distribution off British Columbia and Washington, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 39–47. Canadian Wildlife Service, Victoria, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Walker, N. J. and M. A. Smith. 2014. Alaska Waterbird Database v1. Audubon Alaska, Anchorage, AK.

Wanless, S. and M. Harris. 1986. Time spent at the colony by male and female guillemots *Uria aalge* and razorbills *Alca torda*. *Bird Study* 33:168–176.

Warham, J. and G. J. Wilson. 1982. The size of Sooty Shearwater population at the Snares Islands, New Zealand. *Notornis* 29:23–30.

Warnock, N. 2017. The Alaska WatchList 2017. Audubon Alaska, Anchorage, AK.

Warnock, N., C. Elphick, and M. A. Rubega. 2002. Shorebirds in the marine environment, *In Biology of Marine Birds*. E. A. Schreiber and J. Burger eds., pp. 581–615. CRC Press, Boca Raton, FL.

Wehle, D. H. S. 1976. Summer Food and Feeding Ecology of Tufted and Horned Puffins on Buldir Island, Alaska, 1975. MS thesis, University of Alaska, Fairbanks, AK.

______. 1978. Studies of marine birds on Ugaiushak Island, *In Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the Year Ending March 1978*. pp. 208–312. National Oceanic and Atmospheric Administration, Boulder, CO.

______. 1980. The Breeding Biology of the Puffins: Tufted Puffin (*Lunda cirrhata*), Horned Puffin (*Fratercula corniculata*), Common Puffin (*F. arctica*), and Rhinoceros Auklet (*Cerorhinca monocerata*). PhD thesis, University of Alaska, Fairbanks, AK.

Weimerskirch, H. 1992. Reproductive effort in long-lived birds: Age-specific patterns of condition, reproduction and survival in the Wandering Albatross. *Oikos* 64:464–473.

______. 1998. How can a pelagic seabird provision its chick when relying on a distant food resource? Cyclic attendance at the colony, foraging decision and body condition in Sooty Shearwaters. *Journal of Animal Ecology* 67:99–109.

Weimerskirch, H. and Y. Cherel. 1998. Feeding ecology of Short-tailed Shearwaters: Breeding in Tasmania and foraging in the Antarctic? *Marine Ecology Progress Series* 167:261–274.

White, C. M., W. B. Emison, and F. S. L. Williamson. 1973. DDE in a resident Aleutian Island peregrine population. *Condor* 75:306–311.

White, T. P., R. R. Veit, and M. C. Perry. 2009. Feeding ecology of Long-tailed Ducks *Clangula hyemalis* wintering on the Nantucket Shoals. *Waterbirds* 32:293–299.

Wiens, J. A., R. G. Ford, and D. Heinemann. 1984. Information needs and priorities for assessing the sensitivity of marine birds to oil spills. *Biological Conservation* 28:21–49.

Williams, J. 2017. Unpublished data regarding Red-legged Kittiwake colony count for Koniuji Island. Provided by Alaska Maritime National Wildlife Refuge staff, Homer, AK.

Williams, J. C., G. V. Byrd, and N. B. Konyukhov. 2003. Whiskered Auklets *Aethia pygmaea*, foxes, humans and how to right a wrong. *Marine Ornithology* 31:175–180.

Wolf, S. G., M. A. Snyder, W. J. Sydeman, D. F. Doak, and D. A. Croll. 2010. Predicting population consequences of ocean climate change for an ecosystem sentinel, the seabird Cassin's Auklet. *Global Change Biology* 16:1923–1935.

Wong, S. N. P., C. Gjerdrum, K. H. Morgan, and M. L. Mallory. 2014. Hotspots in cold seas: The composition, distribution, and abundance of marine birds in the North American Arctic. *Journal of Geophysical Research: Oceans* 119:1691–1705.

Woodby, D. A. and G. J. Divoky. 1982. Spring migration of eiders and other waterbirds at Point Barrow, Alaska *Arctic* 35:403–410.

Wooller, R. D. 1978. Individual vocal recognition in the kittiwake gull, *Rissa tridactyla* (L.). *Ethology* 48:68–86.

Wright, S. K., G. V. Byrd, H. M. Renner, and A. L. Sowls. 2013. Breeding ecology of Red-faced Cormorants in the Pribilof Islands, Alaska. *Journal of Field Ornithology* 84:49–57.

Yamamoto, T., K. Hoshina, B. Nishizawa, C. E. Meathrel, R. A. Phillips, and Y. Watanuki. 2015. Annual and seasonal movements of migrating Short-tailed Shearwaters reflect environmental variation in sub-Arctic and Arctic waters. *Marine Biology* 162:413–424.

Yannic, G., A. Aebischer, B. Sabard, and O. Gilg. 2014. Complete breeding failures in Ivory Gull following unusual rainy storms in North Greenland. *Polar Research* 33:22749.

Yesner, D. R. and J. S. Aigner. 1976. Comparative biomass estimates and prehistoric cultural ecology of the southwest Umnak region, Aleutian Islands. *Arctic Anthropology* 13:91–112.

Zubakin, V. A. and N. B. Konyukhov. 2001. Breeding biology of the Whiskered Auklet (*Aethia pygmaea*): Postnesting period. *Biology Bulletin* 28:31–39.

Zydelis, R., J. Bellebaum, H. Osterblom, M. Vetemaa, B. Schirmeister, A. Stipniece, M. Dagys, M. van Eerden, and S. Garthe. 2009. Bycatch in gillnet fisheries—an overlooked threat to waterbird populations. *Biological Conservation* 142:1269–1281.

Žydelis, R., C. Small, and G. French. 2013. The incidental catch of seabirds in gillnet fisheries: A global review. *Biological Conservation* 162:76–88.

Milo Burcham

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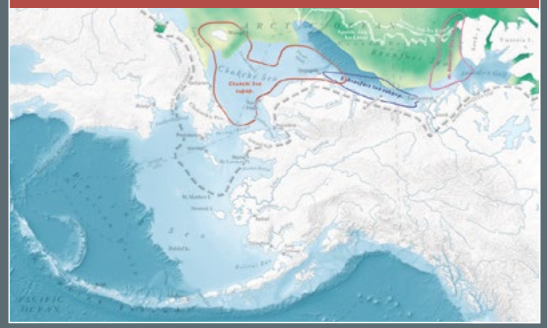
MAMMALS

Terri Stinnett Photography

MAMMALS MAP INDEX

Polar Bear



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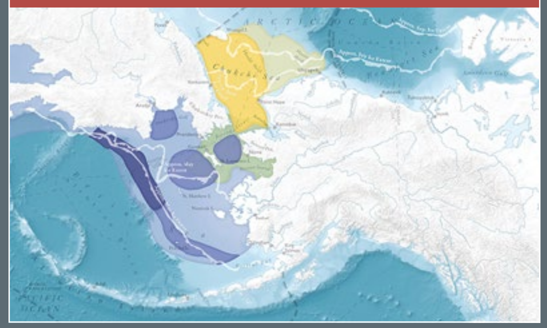

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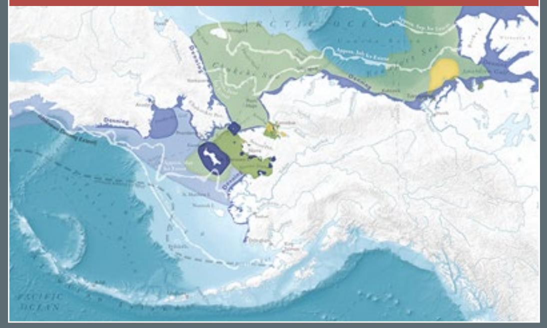

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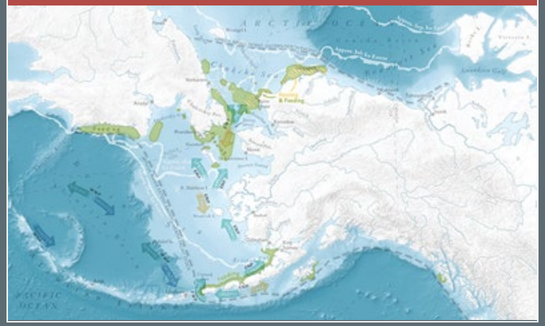

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Polar Bear

Ursus maritimus

Max Goldman, Erika Knight, and Melanie Smith

One of the most recognizable species on the planet, polar bears (*Ursus maritimus*) are among the largest of the eight extant bear species, along with the American brown bear (*U. arctos*), a closely related cousin (Wozencraft 2005). Even the word Arctic is Greek for "of the bear." Polar bears are an ice-obligate species; they rely heavily on sea ice for travel, resting, breeding, and denning and have evolved to thrive on food resources (mainly seals) that utilize drifting pack ice (Moore and Huntington 2008). They are regarded as marine mammals by the US Marine Mammal Protection Act because of this reliance. Polar bears are relatively long-lived, reaching sexual maturity at an advanced age. They are characterized by substantial maternal investment in cub rearing and small litter sizes (Amstrup et al. 1986, Derocher and Stirling 1998). Although polar bears genetically diverged from brown bears relatively recently (from 150,000 to 500,000 years ago), they have developed distinct adaptations suited to their Arctic range (Ray 1971, Liu et al. 2014, Welch et al. 2014).

ADAPTATIONS

The polar bear is exceedingly well adapted to utilize the opportunities available in the Arctic. Their dense, white to yellowish fur is distinct and well suited to the snow-covered ice on which these bears evolved. Under their dense fur is black skin (evident in the color of their noses), which serves to absorb the sunlight that penetrates their hollow hair shafts and warms their bodies. Relative to the American brown bear, polar bears exhibit a longer skull and snout, as well as an elongated overall body structure (Stirling et al. 1977, Ramsay and Stirling 1988). The ears and tail of the polar bear are especially and predictably small, owing likely to adaptations related to thermoregulation (Allen 1877). Their large feet are covered in papillae, small bumps that improve traction on ice and snow. Their large feet also help to distribute their weight over ice and improve propulsion when swimming (Durner et al. 2011, Pagano et al. 2012, US Fish and Wildlife Service 2016). The pronounced curvature of their short claws makes escape by prey unlikely once captured. Specialized dentition, including incisors and long, sharp canines for catching and holding prey and carnassials (modified molars) for shearing meat and breaking bone, is due to an almost entirely carnivorous diet. Polar bears are sexually dimorphic, with boars weighing between 800 and 1,600 pounds (360 and 730 kg), twice the size of sows who generally weigh between 350 and 600 pounds (160 and 270 kg). Pregnant females weigh up to 1,100 pounds (500 kg) (US Fish and Wildlife Service 2016).

DISTRIBUTION

Polar bears are found in five Arctic nations, or "range states" including Greenland (Denmark), Canada, the US, Russia, and Norway. The circumpolar population of 26,000 polar bears is are divided into 19 subpopulations in 4 ecoregions (Amstrup et al. 2008, Regehr et al. 2016) (Figure 6.1-1). The ecoregions are "based on the spatial and temporal dynamics of sea ice" (US Fish and Wildlife Service 2016) and polar bear life history (Amstrup et al. 2008). These four ecoregions are:

- **Archipelago Ice Ecoregion**, characterized by year-round sea ice, providing consistent habitat for seals and polar bears.
- **Polar Basin Convergent Ice Ecoregion**, characterized by ice that formed in other parts of the Arctic converging on shore, creating hunting habitat for polar bears within this ecoregion.
- **Polar Basin Divergent Ice Ecoregion**, characterized by winter advance of sea ice across the continental shelf beneath the Chukchi, Beaufort, and Bering Seas and retreat of the ice margin north of the Chukchi shelf break in summer (US Fish and Wildlife Service 2016).
- **Seasonal Ice Ecoregion**, characterized by ice presence for much of the year, and complete ice absence throughout the rest of the year. This habitat is at the southernmost extent of polar bear habitat.

The Polar Basin Convergent and Archipelago Sea Ice Regions may well be the last strongholds for Polar Basin Divergent bears, as they are forced to seek out more suitable habitat. Since the sea ice they now rely upon is seasonal and highly variable, and they are not well-accustomed to utilizing terrestrial habitat for long periods, the Polar Basin Divergent bears are likely the most vulnerable to climate change (Atwood et al. 2015a, b).

Population Dynamics

The 19 subpopulation units developed by the International Union for Conservation of Nature's (IUCN) Polar Bear Specialist Group (PBSG) were established based on a combination of genetic information and practical considerations of range state managers, and effectively serve as management units for research, monitoring and reporting on polar bears. According to the PBSG (2017), bear numbers are stable in 6 of the 19 units (32%); declining in 3 units (16%); increasing in 1 unit (5%); and deemed data deficient in 9 units (47%).

Two of the three subpopulations that use the Chukchi and Beaufort Seas, the Chukchi Sea subpopulation (CS) and the Southern Beaufort Sea subpopulation (SBS), are considered to be part of the Polar Basin Divergent ice ecoregion (Amstrup et al. 2008, Regehr et al. 2016). They spend the vast majority of their time offshore hunting seals on sea ice, except when denning or when the lack of available sea ice necessitates coming ashore. The Northern Beaufort Sea subpopulation (NBS) is considered Polar Basin Convergent. The smaller, and less well-known Viscount Melville Sound polar bears (VM) are found at the extreme northeastern extent of the project area in the Archipelago Ecoregion, and are not featured here, due to the fact that they do not specifically use the Bering, Chukchi, or Beaufort Seas, and there is very little research regarding this subpopulation (Amstrup et al. 2008, Regehr et al. 2016).

While previous efforts that estimated the Chukchi Sea subpopulation at approximately 2,000 bears had been accepted by the PBSG (Belikov

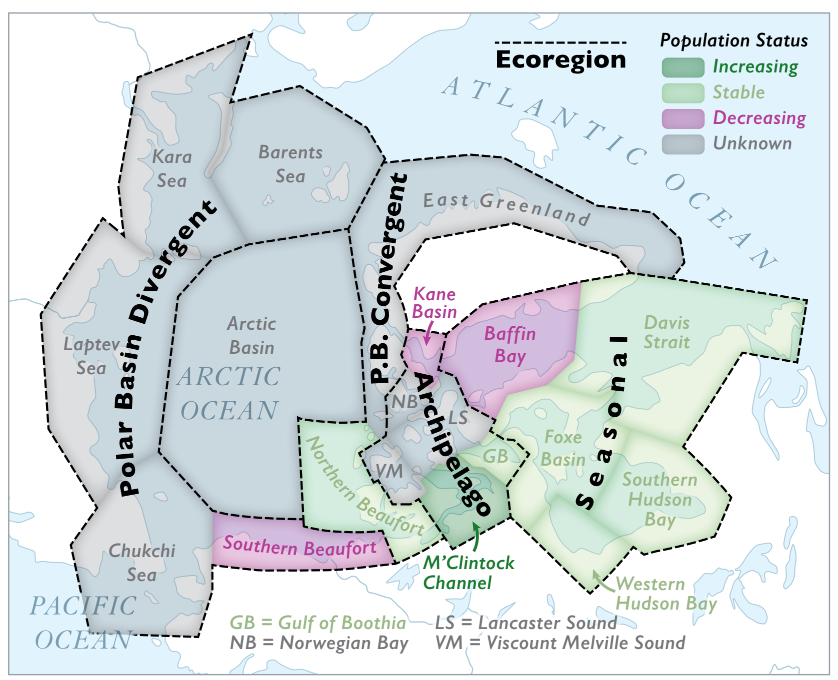

FIGURE 6.1-1. Throughout their circumpolar range, there are 19 subpopulations of polar bear within four distinct ice ecoregions. Each ice ecoregion is characterized by slight, but important, differences in sea-ice habitat. All-white region over inland Greenland has no known polar bears. Figure adapted from Aars et al. (2006), Amstrup et al. (2008), Obbard et al. (2010), Polar Bear Specialist Group (2015), Regehr et al. (2016), Schliebe et al. (2006), and Wiig et al. (2015).

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FIGURE 6.1-2. The US-Russia Bilateral Agreement (2000) and the Inuvialuit-Inupiat Polar Bear Management Agreement (1988, 2000, and 2011) were signed to manage conservation and safeguard cultural access to polar bear for Native peoples of Chukotka and Alaska, and Canada and Alaska, respectively.

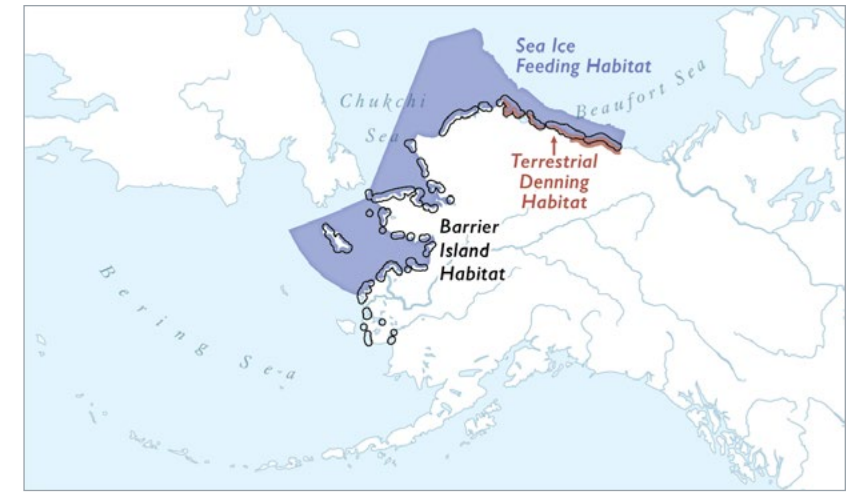

FIGURE 6.1-3. Critical habitat for polar bears, including designations of sea ice feeding, denning, and barrier island habitat. Barrier island habitat includes coastal barrier islands and spits along Alaska's coast as well as a no-disturbance zone that extends 1 mile from these features. Barrier island habitat is buffered for visual clarity—to highlight the areas within which the barrier island critical habitat is located—and extends beyond the official designation. Critical habitat for polar bears was designated by the US Fish and Wildlife Service effective 2011, but the critical habitat final rule was vacated and remanded in 2013 by an order issued by the US District Court for the District of Alaska. In 2016, the 9th Circuit Court Panel reversed the District Court's judgment and the original designation has therefore been reinstated.

1992, Aars et al. 2006) they have since deemed them data deficient and decided a population designation of "unknown" was more appropriate. The Southern Beaufort Sea (SBS) polar bear population was estimated at approximately 1,700 bears from 1978–83 (Amstrup et al. 1986), 1500 in the early 2000s (Regehr et al. 2006), and 900 by 2010 (Bromaghin et al 2015). Rode et al. (2014) suggest that the recent declines in polar bear population where due to changes in sea ice availability.

Sea-Ice Habitat

During winter and into spring, polar bears seek out the highly dynamic boundary between sea ice and water to hunt seals that are using ice holes for breathing or are hauling out after feeding in the highly productive waters at the sea-ice edge. Polar bears very rarely pursue seals on open land or in the water, preferring instead to use leads (systems of stress-induced fissures in sea ice that allow access to open water) (Weeks 2010), and polynyas, (wind or warm-water, upwelling-induced, ice-free areas) (Stringer and Groves 1991). Leads and polynyas play a crucial role in Arctic ecology, creating a zone of productivity and access in a vast seascape. These are important feeding areas for seals, which in turn attract polar bears. Once spring arrives, nearshore leads continue to be integral to polar bear feeding, as do landfast ice zones—ice that is fastened to the coastline or sea floor (Weeks 2010). Landfast and pack ice are crucial habitat components for ringed seals (*Phoca hispida*), as they build their birthing lairs here, under the snow. As newborn polar bear cubs emerge between February and mid-April (Stirling et al. 1988), this food source is critical to the survivability of polar bears (Freitas et al. 2012).

When sea ice recedes in summer, sunlight catalyzes algal blooms that form the basis of highly productive waters found at the ice edge throughout the Arctic (see Biological Setting chapter). Primary production and zooplankton blooms attract pelagic fish and contribute to seafloor food availability. As sea ice recedes, polar bears decide to either follow the productive but tenuous sea ice north, farther and farther away from the coastline and into the less productive waters over the polar basin, or come ashore, where it is very difficult to acquire the calories needed to offset energetic costs associated with terrestrial foraging (Derocher et al. 2004, Whiteman et al. 2015). Once sea-ice concentration drops below a certain threshold, polar bears have been documented to quickly abandon sea ice for land, where their preferred prey (see Diet subsection) are almost entirely absent (Stirling et al. 1999, Cherry et al. 2013).

LIFE CYCLE

Polar bears rely on sea ice as courting and mating habitat. They breed in the spring, generally ending by June (Schliebe et al. 2006, US Fish and Wildlife Service 2016). Males will follow a female as she makes her way to fertile seal-hunting habitat. Eventually, the males in pursuit will engage in intense fighting amongst themselves, often resulting in serious injury (Ramsay and Stirling 1988, Stirling et al. 1988, Derocher and Stirling 1990). The victor will then mate with the female for many days. After fertilization, the egg remains dormant for months as the newly impregnated female consumes large amounts of calories, often nearly doubling her body weight (Rosing-Asvid 2006). The delaying of implantation, and subsequently of birth, is likely dependent upon food availability and timed to coincide with seal pupping. Some females will forgo reproduction in years when food and suitable denning habitat are particularly scarce (Ramsay and Stirling 1988).

Denning

In fall or early winter pregnant polar bears will seek out a location in which to build maternity dens. The CS and SBS subpopulations historically built their maternity dens on the ice. However, denning is now most often terrestrial and constructed in a snowdrift or palsa (an elevated feature of permafrost) when snowfall is not sufficient (Rode et al. 2015a, Olson et al. 2017). The den consists of a narrow entrance tunnel, and one or more chambers. Polar bears reuse the same denning areas from year to year (Ramsay and Stirling 1990).

In the CS subpopulation, the most important denning area is Wrangel Island, Russia. Up to 200 pregnant female bears descend upon Wrangel Island each fall to give birth (Garner et al. 1990, Garner et al. 1994, Rode et al. 2015a). CS polar bears also breed on the northeastern coast of the Chukotka Peninsula, Russia (Stishov 1991) (Ovsyanikov 2005, Ovsyanikov and Menyushina 2008, Ovsyanikov 2009).

For the SBS subpopulation, denning on fast ice is much more prevalent; up to 37% of SBS females den on ice, compared to 5–10% of CS females (Fischbach et al. 2007, Rode et al. 2015a, Olson et al. 2017). Core areas along the coastline, riverbanks, barrier islands, and coastal bluffs of the North Slope of Alaska and the northern coast of Canada are also important denning sites for SBS bears (Durner et al. 2004, Durner et al. 2006).

Pregnant polar bears enter into a state of dormancy when denning (Stirling et al. 1988). Their heart rate slows dramatically but they do not technically hibernate, as their body temperature does not decrease. Polar bear young are born in an altricial state from November to February, requiring constant care. Twinning is by far the most common birth pattern, but litters of one, three, and rarely four have been observed (Stirling et al. 1988). In March or April, the bears will break out of the den, and the family group will emerge (Stirling et al. 1988). Depending on when the ice floe break-up occurs, female polar bears may not have

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1900 — **Lacey Act** prohibits trade in wildlife, fish, and plants that have been illegally taken, possessed, transported, or sold.

1965 — **IUCN** lists polar bears as Believed to be Threatened–Requires Watching.

October 1972 — **Marine Mammal Protection Act** enacted; Polar bears listed as protected.

March 1973 — **Convention on International Trade in Endangered Species (CITES)** formed to ensure that international trade in wild animals and plants does not threaten their survival.

November 1973 — **Agreement on the Conservation of Polar Bears** signed by Norway, Denmark (Greenland), Canada, the Soviet Union, and the US.

September 1978 — **Pelly Amendment to The Fisherman's Protective Act** authorized embargo against any country undermining endangered or threatened species.

1982 — **IUCN** lists polar bears as vulnerable.

January 1988 — **Inuvialuit-Inupiat Polar Bear Management Agreement** in the Southern Beaufort Sea limits subsistence harvest.

October 2000 — **Bilateral Agreement** between the US and the Russian Federation on the Conservation and Management of the Alaska-Chukotka Polar Bear Population

May 2008 — **Memorandum of Understanding** between Environment Canada and the US Department of the Interior for the conservation and management of shared polar bear populations.

May 2008 — **Endangered Species Act** lists polar bears as threatened, specifically because of threat to habitat due to climate

December 2008 — **Critical Habitat Designation Final Rule** published by the US Department of the Interior, designating more than 180,000 mi^2 of Alaskan and adjacent territorial and US waters.

February 2016 — **Polar Bear Critical Habitat** affirmed in a District Court decision previously vacated in Alaska Oil and Gas Association v. Jewel, Ninth Circuit Court of Appeals. The US Supreme Court declined to hear the case.

December 2016 — **The US Polar Bear Conservation Management Plan** finalized describing the mechanisms for the recovery of the polar bear.

FIGURE 6.1-4. The legal landscape continues to influence human-polar bear interaction in Alaska but has evolved since the turn of the 20th century. The graphic shows some important and impactful legislative highlights.

Specifically adapted to the frigid conditions in the Arctic, polar bears are the most carnivorous of the eight living species of bear, with little to no vegetative food found in most polar bear diets.

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eaten for eight months, despite expending large amounts of energy birthing and nourishing their offspring (Watts and Hansen 1987).

Diet

The polar bear diet consists mainly of ringed and bearded seals (*Erignathus barbatus*), the bodies of which are 34–76% fat (Stirling and McEwan 1975). Consumption of seal meat, organs, and bone provide a complete set of trace elements, vitamins, and minerals (Derocher 2012). Individuals have been documented to consume up to 70% lipids (Best 1985, Cherry et al. 2011). When on land, bears have been observed consuming more than 60 terrestrial food resources, such as berries, bird eggs, birds, fishes, small mammals, scavenged ungulates, and lichens (Derocher 2012, Iles et al. 2013, Iverson et al. 2014). Subsistence carcass dumps or bonepiles of harvested whales are becoming increasingly important food sources for seasonally terrestrial polar bears (see Conservation Issues). Energy-expenditure modeling (Pritchard and Robbins 1990, Hilderbrand et al. 1999), isotopic analysis (Hobson et al. 2009, McKinney et al. 2009), availability analyses (Wallenius 1999, Rode et al. 2006a), and comparative studies on captive brown bears (Rode et al. 2006b, Rode et al. 2010) strongly indicate that lipid-poor terrestrial foods are calorically insufficient to sustain entire subpopulations over the long term (Rode et al. 2015a), but may occasionally supplement the diets of individual bears and sub-adults (Welch et al. 1997).

CONSERVATION ISSUES

Due to their tenuous habitat and previously unregulated commercial harvest, legislative protections have been necessary to ensure the survival of the polar bear. They are a protected species under the Marine Mammal Protection Act (MMPA) of 1972 along with cetaceans (whales, dolphins, porpoises), pinnipeds (seals, sea lions), and the marine mustelid (sea otter). MMPA protection does not prohibit traditional subsistence harvest by Alaska Native hunters. Since 2008, polar bears in the US Arctic have been listed as a threatened species under the Endangered Species Act (ESA) of 1973, primarily on the basis of future threat of sea-ice habitat decline. As a result of the observed and projected loss of sea-ice habitat due to global climate change, the polar bear is listed as vulnerable on the IUCN Red List of Threatened Species.

The most pressing concern regarding polar bears is sea-ice decline due to Arctic warming and the resulting habitat loss (US Fish and Wildlife Service 2008, 2015). Without stabilization of annual available sea-ice habitat, the CS and SBS populations will likely need to migrate to other, more stable ecoregions (Polar Basin Convergent, Archipelago), or risk severe reduction in numbers (Durner et al. 2009, Durner et al. 2011, Pagano et al. 2012, Atwood et al. 2015a, Ware et al. 2017).

Subsistence harvesting is a time-honored tradition—one that is protected by the MMPA. However, as the population of polar bears declines, so must the take of polar bears. Through agreements such as the Inuvialuit-Inupiat Agreement of 1988 (revised 2011) and the US-Russia Bilateral Agreement of 1988 (revised 2000), Native communities have expressed openness to regulating subsistence harvest to sustainable levels. However, implementation has proven difficult. Polar bear take also happens due to defense-of-life removals, which occur where the habitats for bears and humans overlap.

The discarded bowhead whale carcasses (bonepiles) left by Native subsistence hunting in Alaska, Canada, and Russia are a controversial food source for many CS and SBS bears (Rogers et al. 2015). While the availability of this food source is no doubt welcome to many struggling CS and SBS bears, there are accompanying concerns that warrant consideration. As polar bears increasingly rely on human settlements and activities for food, so too will human-bear interaction increase, potentially resulting in injury or death to humans or polar bears. With the aggregation of an otherwise solitary species, the threats of disease transmission and impact of an oil spill at a population level increase. In order to address some of these concerns, US Fish and Wildlife Service, in cooperation with Native organizations, has plans to remove or disperse bonepiles to reduce bear concentrations (i.e., minimize the risk of harmful impacts from disease transmission, oil spills) (US Fish and Wildlife Service 2016).

As oil-and-gas activity increases in the Arctic, the likelihood of a spill also increases. A large Arctic oil spill without proper prevention and response measures could heavily impact polar bear populations. Also, an increase in shipping, especially along the Northern Sea Route north of Russia, has been noted. It is unclear what impact this might have on CS and SBS bears.

MAPPING METHODS (MAPS 6.1a–6.1d)

Polar bear data are mapped on four seasonal maps, each of which shows polar bear marine habitat selection for the following seasons, as defined by Durner et al. (2009):

Winter: December through May;
Spring: June through July;
Summer: August through September, and;
Fall: October through November.

This analysis was completed by Audubon Alaska (2014) based on seasonal models presented in Durner et al. (2009). On the advice of George Durner, our team mapped polar bear sea-ice habitat selection by applying the seasonal resource selection coefficients presented in Durner et al. (2009) to the most recent five years of available sea-ice data (average sea-ice concentration data acquired as 15.5-mile (25 km) monthly grids from the National Snow and Ice Data Center (2014) for each month from October 2008 through September 2013). The models were run for each of the 60 months; then monthly results were grouped by season, averaged into the four seasonal layers representing mean habitat selection value, and clipped to the maximum extent of sea-ice extent (15% ice concentration or greater) for each season over the 5-year period.

The mapped polar bear range was aggregated by Audubon Alaska based on information provided in several sources: Amstrup et al. (2005), Bromaghin et al. (2015), Durner et al. (2010), Kochnev et al. (2003), National Oceanic and Atmospheric Administration (1988), Rode et al. (2015a, b), US Fish and Wildlife Service (1995), and Community Conservation Plans developed for six communities in the Inuvialuit Settlement Region of Canada (Aklavik, Inuvik, Olokhaktomiut, Paulatuk, Sachs Harbour, and Tuktoyaktuk) in 2008 (Community of Aklavik et al. 2008, Community of Inuvik et al. 2008, Community of Olokhaktomiut et al. 2008, Community of Paulatuk et al. 2008, Community of Sachs Harbour et al. 2008, Community of Tuktoyaktuk et al. 2008).

Annual subpopulation core areas were analyzed by Amstrup et al. (2005), based on positions of radio-collared female polar bears captured over 18 years in coastal areas of the Chukchi and Beaufort Seas near northern Alaska and northwestern Canada.

Denning information is shown on the fall and winter maps, when denning occurs. Denning range data were aggregated by Audubon Alaska based on several sources including Durner et al. (2010), Fischbach et al. (2007), National Oceanic and Atmospheric Administration (1988), Olson et al. (2017), Rode et al. (2015a), US Fish and Wildlife Service (1995), and Community Conservation Plans for the Inuvialuit Settlement Region. The denning concentration area was delineated in National Oceanic and Atmospheric Administration (1988). More recent studies of den locations along the Beaufort Sea coast indicate that there has been a major shift in the distribution of dens in this region, with more now occurring on land than on sea ice; these studies further support the National Oceanic and Atmospheric Administration (1988) identification of the Beaufort coast as an important denning area.

Bonepiles, a food source for some polar bears during the spring and/or fall whaling seasons, are indicated in Dutton et al. (2011) and Schliebe et al. (2008) and are shown on the applicable spring and fall maps. As of 2012, the bonepile at Barrow is no longer in use (T. Atwood pers. comm.).

Sea-ice data on this map include polynyas and approximate median monthly sea-ice extent. The polynya data were compiled from Carmack and MacDonald (2002), Stringer and Groves (1991), and an analysis of the average 1993–1994 extent of recurring leads in the Beaufort and Chukchi Seas conducted by Audubon Alaska (2009a) and based on data in Eicken et al. (2005). The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016).

Data Quality

Data quality is variable across the map. There is an extensive history of radio and satellite tracking of polar bears, especially in Amundsen Gulf, along Alaska's Beaufort Sea coast and along Alaska's Chukchi Sea coast. Habitat utilization information and data layers for these regions exist from previous studies, for example Amstrup et al. (2006), Durner et al. (2009). US Fish and Wildlife Service and US Geological Survey are also conducting new satellite tracking studies on bears along the Chukchi and Beaufort coasts of Alaska (e.g. http://alaska.usgs.gov/science/biology/polar_bears/tracking.html). Such studies are directly applicable to adult females, but not males, as male polar bears do not retain collars because their necks are bigger than their heads. Russian areas of the map are lacking information from telemetry or mark-recapture studies altogether.

Reviewers

- Todd Atwood
- Ryan Wilson

MAP DATA SOURCES

Marine Habitat Selection (Seasonal): Audubon Alaska (2014) based on Durner et al. (2009)

Extent of Range: Audubon Alaska (2016l) based on Amstrup et al. (2005), Bromaghin et al. (2015), Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Kochnev et al. (2003), National Oceanic and Atmospheric Administration (1988), Rode et al. (2015a, b), and US Fish and Wildlife Service (1995)

Subpopulation Core Areas (Annual): Amstrup et al. (2005)

Denning Range: Audubon Alaska (2016k) based on Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Fischbach et al. (2007), National Oceanic and Atmospheric Administration (1988), Olson et al. (2017), Rode et al. (2015a), and US Fish and Wildlife Service (1995)

Denning Concentration: Fischbach et al. (2007); National Oceanic and Atmospheric Administration (1988); Olson et al. (2017)

Bonepile Locations: Dutton et al. (2011); Schliebe et al. (2008); T. Atwood (pers. comm.)

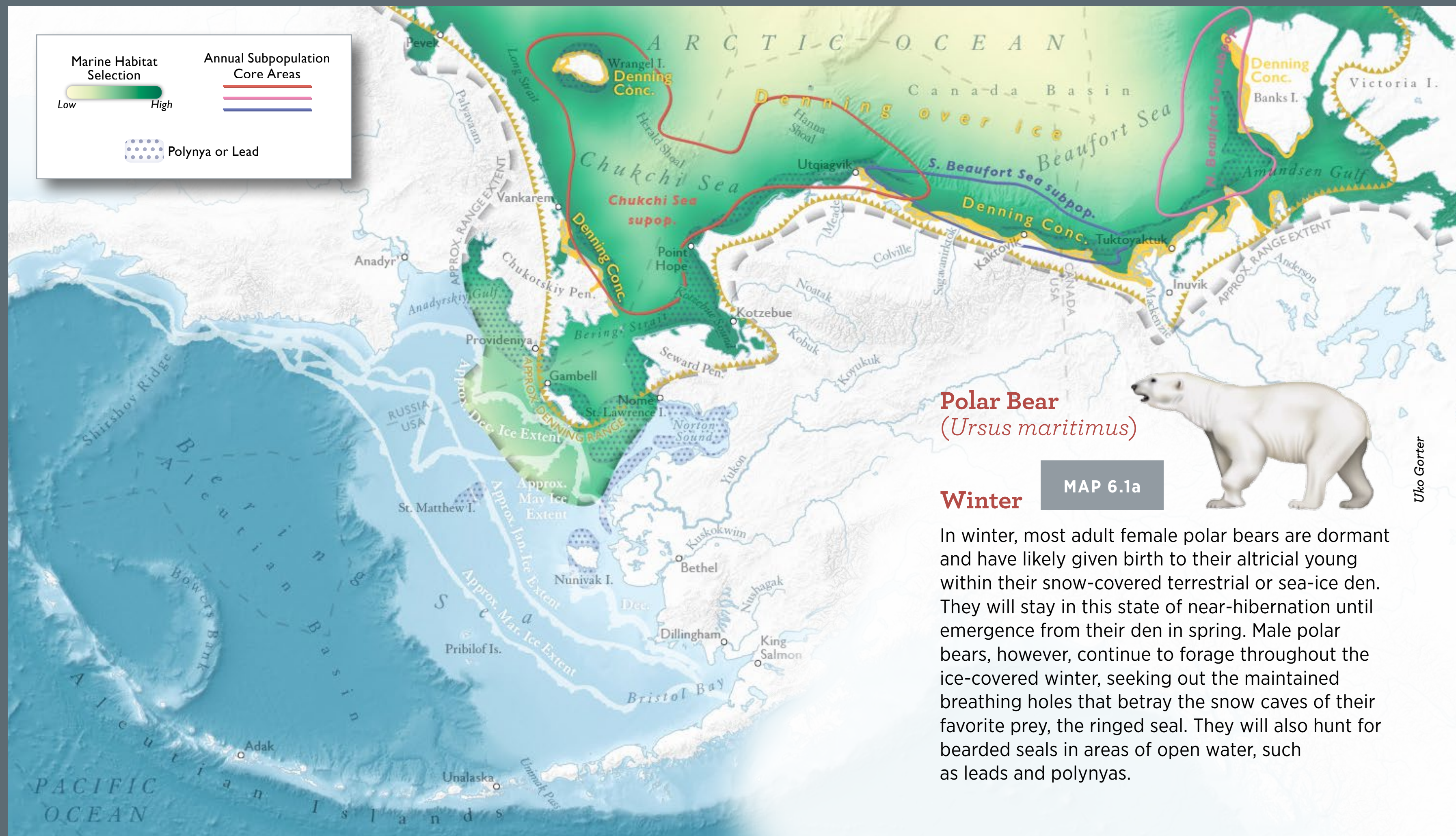
Polynyas: Audubon Alaska (2009a) based on Eicken et al. (2005); Carmack and MacDonald (2002); Stringer and Groves (1991)

Sea Ice Extent: Audubon Alaska (2016j) based on Fetterer et al. (2016)

MAPS ON PAGES 212–213

Polar Bear

Map Authors: Melanie Smith, Erika Knight, and Max Goldman
Cartographer: Daniel P. Huffman



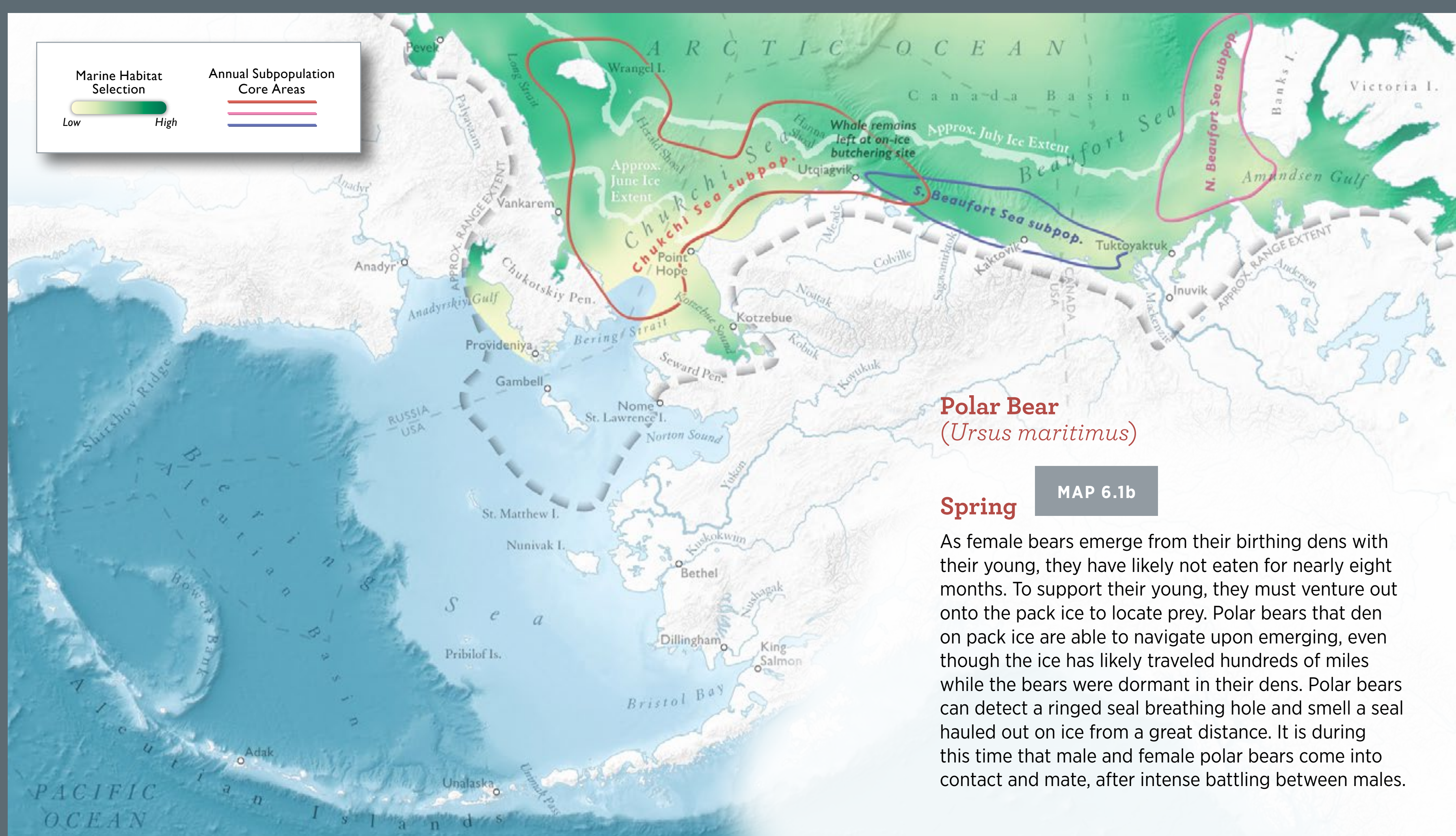
Polar Bear
(Ursus maritimus)

MAP 6.1a

Winter

In winter, most adult female polar bears are dormant and have likely given birth to their altricial young within their snow-covered terrestrial or sea-ice den. They will stay in this state of near-hibernation until emergence from their den in spring. Male polar bears, however, continue to forage throughout the ice-covered winter, seeking out the maintained breathing holes that betray the snow caves of their favorite prey, the ringed seal. They will also hunt for bearded seals in areas of open water, such as leads and polynyas.

Amstrup et al. (2005); Audubon Alaska (2009a) [based on Eicken et al. (2005); Carmack and MacDonald (2002)]; Audubon Alaska (2014) [based on Durner et al. (2009)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2016k) [based on Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Fischbach et al. (2007), National Oceanic and Atmospheric Administration (1988), Olson et al. (2017), Rode et al. (2015a), and US Fish and Wildlife Service (1995)]; Audubon Alaska (2016l) [based on Amstrup et al. (2005), Bromaghin et al. (2015), Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Kochnev et al. (2003), National Oceanic and Atmospheric Administration (1988), Rode et al. (2015a, b), and US Fish and Wildlife Service (1995)]; Dutton et al. (2011); Fischbach et al. (2007); National Oceanic and Atmospheric Administration (1988); Olson et al. (2017); Schliebe et al. (2008); Stringer and Groves (1991); T. Atwood (pers. comm.)



Polar Bear
(Ursus maritimus)

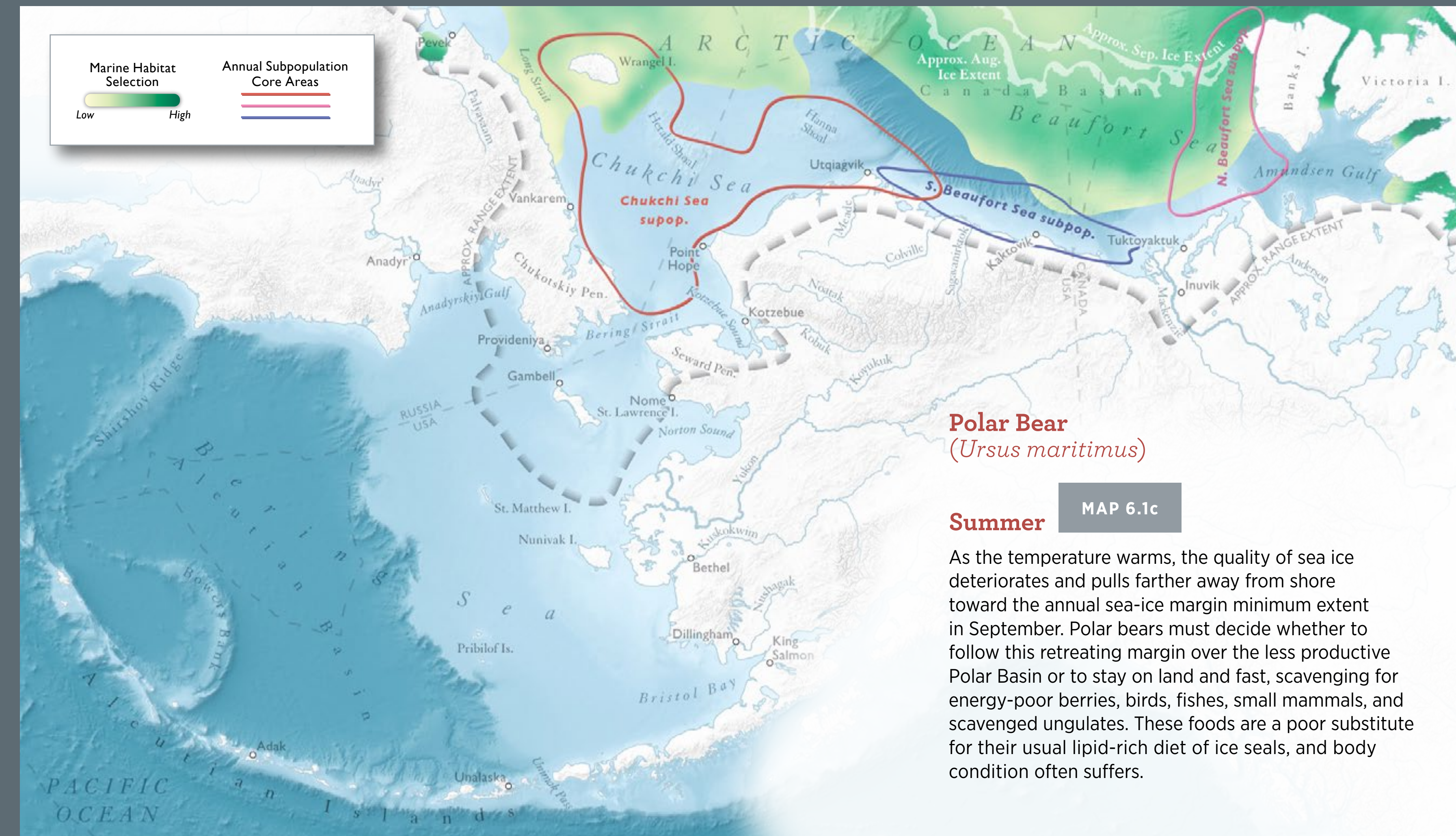
MAP 6.1b

Spring

As female bears emerge from their birthing dens with their young, they have likely not eaten for nearly eight months. To support their young, they must venture out onto the pack ice to locate prey. Polar bears that den on pack ice are able to navigate upon emerging, even though the ice has likely traveled hundreds of miles while the bears were dormant in their dens. Polar bears can detect a ringed seal breathing hole and smell a seal hauled out on ice from a great distance. It is during this time that male and female polar bears come into contact and mate, after intense battling between males.

Amstrup et al. (2005); Audubon Alaska (2009a) [based on Eicken et al. (2005); Carmack and MacDonald (2002)]; Audubon Alaska (2014) [based on Durner et al. (2009)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2016k) [based on Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Fischbach et al. (2007), National Oceanic and Atmospheric Administration (1988), Olson et al. (2017), Rode et al. (2015a), and US Fish and Wildlife Service (1995)]; Audubon Alaska (2016l) [based on Amstrup et al. (2005), Bromaghin et al. (2015), Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Kochnev et al. (2003), National Oceanic and Atmospheric Administration (1988), Rode et al. (2015a, b), and US Fish and Wildlife Service (1995)]; Dutton et al. (2011); Fischbach et al. (2007); National Oceanic and Atmospheric Administration (1988); Olson et al. (2017); Schliebe et al. (2008); Stringer and Groves (1991); T. Atwood (pers. comm.)

Audubon ALASKA



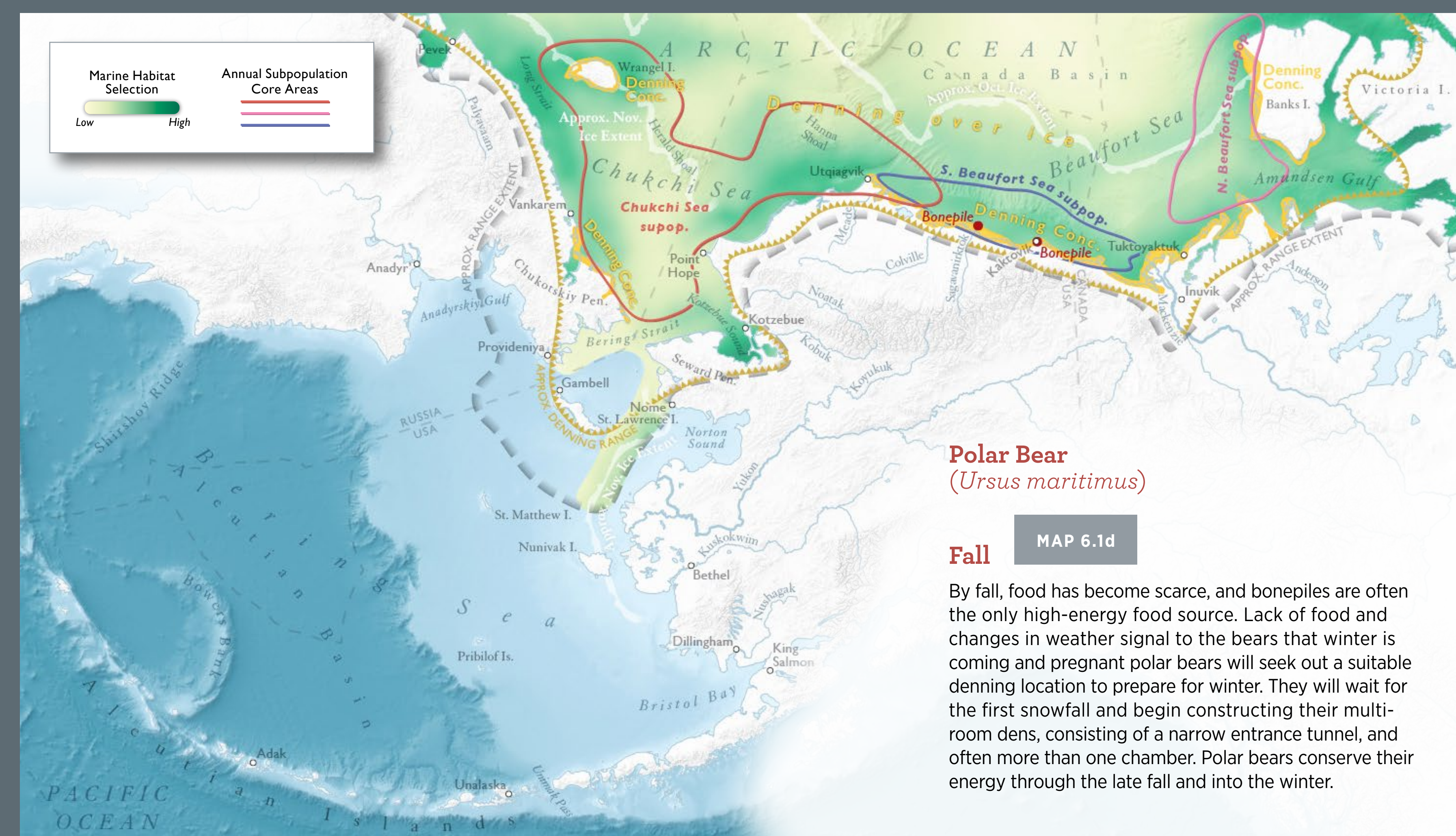
Polar Bear
(Ursus maritimus)

MAP 6.1c

Summer

As the temperature warms, the quality of sea ice deteriorates and pulls farther away from shore toward the annual sea-ice margin minimum extent in September. Polar bears must decide whether to follow this retreating margin over the less productive Polar Basin or to stay on land and fast, scavenging for energy-poor berries, birds, fishes, small mammals, and scavenged ungulates. These foods are a poor substitute for their usual lipid-rich diet of ice seals, and body condition often suffers.

Amstrup et al. (2005); Audubon Alaska (2009a) [based on Eicken et al. (2005); Carmack and MacDonald (2002)]; Audubon Alaska (2014) [based on Durner et al. (2009)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2016k) [based on Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Fischbach et al. (2007), National Oceanic and Atmospheric Administration (1988), Olson et al. (2017), Rode et al. (2015a), and US Fish and Wildlife Service (1995)]; Audubon Alaska (2016l) [based on Amstrup et al. (2005), Bromaghin et al. (2015), Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Kochnev et al. (2003), National Oceanic and Atmospheric Administration (1988), Rode et al. (2015a, b), and US Fish and Wildlife Service (1995)]; Dutton et al. (2011); Fischbach et al. (2007); National Oceanic and Atmospheric Administration (1988); Olson et al. (2017); Schliebe et al. (2008); Stringer and Groves (1991); T. Atwood (pers. comm.)



Polar Bear
(Ursus maritimus)

MAP 6.1d

Fall

By fall, food has become scarce, and bonepiles are often the only high-energy food source. Lack of food and changes in weather signal to the bears that winter is coming and pregnant polar bears will seek out a suitable denning location to prepare for winter. They will wait for the first snowfall and begin constructing their multi-room dens, consisting of a narrow entrance tunnel, and often more than one chamber. Polar bears conserve their energy through the late fall and into the winter.

Amstrup et al. (2005); Audubon Alaska (2009a) [based on Eicken et al. (2005); Carmack and MacDonald (2002)]; Audubon Alaska (2014) [based on Durner et al. (2009)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2016k) [based on Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Fischbach et al. (2007), National Oceanic and Atmospheric Administration (1988), Olson et al. (2017), Rode et al. (2015a), and US Fish and Wildlife Service (1995)]; Audubon Alaska (2016l) [based on Amstrup et al. (2005), Bromaghin et al. (2015), Community of Aklavik et al. (2008), Community of Inuvik et al. (2008), Community of Olokhaktomiut et al. (2008), Community of Paulatuk et al. (2008), Community of Sachs Harbour et al. (2008), Community of Tuktoyaktuk et al. (2008), Durner et al. (2010), Kochnev et al. (2003), National Oceanic and Atmospheric Administration (1988), Rode et al. (2015a, b), and US Fish and Wildlife Service (1995)]; Dutton et al. (2011); Fischbach et al. (2007); National Oceanic and Atmospheric Administration (1988); Olson et al. (2017); Schliebe et al. (2008); Stringer and Groves (1991); T. Atwood (pers. comm.)

MAPS ON PAGES 220–223

Pacific Walrus

Odobenus rosmarus divergens

Max Goldman and Erika Knight

The walrus (*Odobenus rosmarus*) is the largest of all pagophilic (strong preference for ice) pinnipeds and is the only extant representative of the family *Odobenidae*, which evolved in the North Pacific Ocean over 50 million years ago in the late Miocene and early Pliocene (Kohno 2006, Harington 2008). They dispersed throughout the Arctic Ocean and North Atlantic between 10,000 and 2.5 million years ago (Harington and Beard 1991, Dyke et al. 1999, Harington 2008).

Two subspecies of walruses are recognized: the Atlantic (*O. r. rosmarus*) and Pacific (*O. r. divergens*) (Fay 1982, Wozencraft 2005). A third subspecies, the Laptev (*O. r. laptevi*) is sometimes recognized. They are morphologically similar to the Pacific walrus, and generally considered to be the same subspecies. The Atlantic walrus is substantially smaller and has shorter tusks (Fay 1982).

Walruses are social and gregarious animals. They travel together in groups, hauling out to rest on ice or land in dense groups. Walruses are known to pack together in close physical contact with each other, likely for warmth and to protect their young from predators, such as the polar bear (*Ursus maritimus*) (Fay 1985). The young will often lie on top of adult walruses in groups that can range in size from a few individuals to several thousand animals (Gilbert 1999, Kastelein 2009, Jefferson et al. 2011). When disturbed, stampedes from a haulout can result in injuries and mortalities due to trampling. Calves and young animals are particularly vulnerable to trampling injuries and death.

The Pacific walrus is geographically isolated and ecologically distinct from other walrus populations in the Arctic. Pacific walruses primarily feed on mollusks and marine worms across vast offshore areas of the shallow continental shelf waters of the northern Bering and Chukchi Seas (Fay 1982). The species generally occurs in waters less than 328 feet (100 m) deep, feeding in areas of soft sediments with productive benthic resources, and moving with the ever-changing, extremely productive sea-ice edge. The Pacific walrus tends to occupy first-year ice, favoring areas with broken pack ice, leads, and polynyas (US Fish and Wildlife Service 2002, 2014).

TABLE 6.2-1. Estimates of Pacific walrus population size, 1975–2006.

Year	Population size *	Reference
1975	214,687	Udevitz et al. (2001)
1980	250,000–290,000	Johnson et al. (1982), Fedoseev (1984)
1985	242,366	Udevitz et al. (2001)
1990	201,039	Gilbert et al. (1992)
2006	129,000 (55,000–507,000)	Speckman et al. (2010)

*Due to differences in methods, comparisons of estimates across years (population trends) are subject to several caveats and are not reliable. The 2006 survey was the only one that allowed for a measure of precision (95% confidence interval) (Taylor and Udevitz 2015)

The Pacific walrus population was estimated at over 200,000 animals in both 1985 and 1990 (Gilbert 1989, 1992). However, characteristics of walrus behavior and difficulties associated with conducting surveys resulted in unreliable estimates (Gilbert 1999). Due to these challenges, the current population size is unknown (US Fish and Wildlife Service 2002, 2014). As recently as 1960, the Pacific walrus population was estimated at less than 100,000 individuals due to commercial harvest (Fay 1982).

Historical commercial harvest records indicate that Pacific walruses were hunted along the southern coast of Russia in the Sea of Okhotsk, Unimak Pass, and the Shumigan Islands of Alaska beginning during the 17th century (Elliott 1882). Harvest continued until a moratorium was imposed on commercial walrus harvests in 1972 in the US. Commercial harvests in Russia ended in 1990. Walruses have long been, and continue to be, a subsistence food for Native communities in the Arctic.

Ryan Kingsbery / USGS

MAPS ON PAGES 220–223

Brad Benter / USFWS

Walruses utilize ice floes as platforms for resting and for breeding, with groups of females hauling out together on ice floes as groups of males compete for their attention.

ADAPTATIONS

The word "walrus" began as the Danish word *hvalros*, meaning "sea horse." Walruses use broken annual pack ice as a platform for resting between benthic foraging trips, birthing, and nursing (US Fish and Wildlife Service 2002, Simpkins et al. 2003, Laidre et al. 2008, Minerals Management Service 2010).

They are sexually dimorphic with adult males weighing up to 4,400 pounds (2,000 kg) and measuring 7–12 feet (2.1–3.6 m) long (most between 1,800 and 3,700 pounds [820 and 1680 kg]). Females can weigh up to 2,400 pounds (1,100 kg), generally weighing around 1,800 pounds (820 kg), or two-thirds of a male's size (Fay 1982). Adult walruses annually molt their short, brown pelage during the summer months (Fay 1982). Walruses spend nearly two-thirds of their time in water (Fay 1982). They are capable of diving to depths of more than 820 feet (250 m) (Born et al. 2005). Male walruses regularly forage for extended periods, even up to six days, without hauling out to rest by inflating a pouch on their necks with air, allowing them to rest at the surface (Fay 1960, Jay et al. 2011).

Tusks

Walrus tusks are used as offensive and defensive weapons (Kastelein and Gerrits 1990, Kastelein 2009). Adult male walruses use their tusks to display to other males, establishing dominance during mating (Fay et al. 1984). Both male and female walruses use their tusks to establish and defend positions on land or ice haulouts (Fay 1982). Walruses also use their tusks to anchor themselves to ice floes when resting in the water during inclement weather (Fay 1982, Kastelein 2009). The generic name *Odobenus* (tooth walker) is based on observations of walruses using their tusks to pull themselves out of the water. They may also use their tusks to assist in climbing steep slopes.

Surrounding the tusks is a mat of stiff whiskers called mystacial vibrissae. The vibrissae are an extremely sensitive organ, supplied by blood and nerves, and are used by walruses to locate prey while foraging. They are often worn down to lengths much shorter than their full length of 12 inches (30 cm) (Kastelein et al. 1990, Kastelein and Gerrits 1990).

DISTRIBUTION

In winter, the entire Pacific walrus population concentrates in the Bering Sea to breed, where sea-ice conditions are most favorable for them (US Fish and Wildlife Service 2002). While the exact areas in which walruses congregate in winter to breed vary according to the location and extent of annual sea-ice margins, they are generally found near St. Lawrence Island, Nunivak Island, and in the Gulf of Anadyr (Fay 1982, Mymrin et al. 1990, Burn et al. 2009, Speckman et al. 2011).

In spring, sea ice in the Bering Sea begins to retreat northward, and female and juvenile Pacific walruses move with it, through the Bering Strait and into the productive waters over the continental shelf in the Chukchi Sea. In summer, they concentrate mainly in the northwestern and northeastern Chukchi Sea, along the edge of the ice (Fay 1982, Jay et al. 2012a). Adult male walruses will stay behind as the females and young move north, opting instead to spend the warmer months feeding near the coastal haulouts in the Gulf of Anadyr and Bristol Bay.

In September, when the annual sea-ice margin is at its minimum extent and recedes out over deep, Arctic basin waters, walruses congregate in large numbers at terrestrial haulouts on Wrangel Island, along the northern coast of the Chukotka Peninsula, and increasingly along the Chukchi coast in Alaska, especially near Point Lay (Fay 1982, Belikov et al. 1996, Kochnev 2004, Kavry et al. 2008, Huntington et al. 2012, National Oceanic and Atmospheric Administration 2014). In late September and October, walruses that spent the summer in the Chukchi Sea typically begin moving south in advance of the developing sea ice. Large herds of southbound migrants often congregate for short times to rest at coastal haulout sites in the southern Chukchi Sea along the Russian coast (Fay and Kelly 1980).

Sea-Ice Habitat

Pacific walruses use ice floes to breed, calve, haul out to rest, and as refugia from predators such as killer whales (Fay 1982, Simpkins et al. 2003). Haulouts are an integral component of walrus energy management, allowing them to rest between foraging bouts. Because sea ice is a critical component of their habitat, females and juveniles follow the ice margins as they advance and retreat throughout the year, staying near the ideal thickness and coverage for feeding and hauling out. Walruses prefer ice floes, leads, polynyas, and areas with thinner ice in which they can easily create breathing holes. Conversely, they avoid areas with high concentrations of thick and consolidated pack ice, such as in the Chukchi Sea in winter (Burns et al. 1981, Fay 1982).

LIFE CYCLE

Pacific walruses are identified and managed as a single panmictic (unstructured, random-mating) population (US Fish and Wildlife Service 2014). They ensure their social standing through a series of confrontations decided by body size, tusk size, and aggressiveness. As the individuals that compose a group are constantly changing, they must continually reaffirm their social status with each new group, or group member (Fay 1982).

Leks

Pacific walruses mate primarily in January and February in the Bering Sea. Leks (gatherings of males for the purpose of competing for the attention of nearby females) are formed in the water alongside groups of females hauled out on sea ice. The competition to mate includes vocalizations and visual displays among the dominant males. Subdominant males keep to the edges of the gathering and do not display. When appropriate, a single female will join a male in the water to copulate (Fay et al. 1984). During this time, adult males forage very little (Fay 1982, Fay et al. 1984, Sjare and Stirling 1996, North Atlantic Marine Mammal Commission 2004, Ray et al. 2006)

Calving

Most calving occurs in April–June (following a 15- to 16-month pregnancy), and mothers give birth, care for, and nurse their newborn calves on the ice (Fay 1985). Walrus calves remain with their mothers for at least two years (Fay 1982). Walruses experience much lower rates of mortality among calves than other pinniped species (Fay et al. 1989, Chivers 1999). Calves nurse exclusively into their second year when they are gradually weaned and taught to forage (Fay 1982, Fisher and Stewart 1997). Calves can nurse while in the water after about 14 days.

Diet

Walruses consume a broad diet consisting mostly of benthic invertebrates, such as clams, small crustaceans, snails, and polychaete worms, although fishes and other vertebrates are also occasionally reported including marine birds and seals (Fay 1982, Bowen and Siniff 1999, Dehn et al. 2007, Sheffield and Grebmeier 2009). Walruses require approximately 60–180 pounds (25–70 kg) of food per day and utilize over 100 taxa as potential sources, although clams typically make up over 90% of stomach contents (Fay 1982).

Walruses root with their muzzles in the bottom sediment of waters 300 feet (100 m) deep or less and use their whiskers to locate prey items (Fay and Burns 1988, Kovacs and Lydersen 2008). They use their fore-flippers, noses, and jets of water to extract prey buried up to 12 inches (30 cm) deep (Fay 1982, Levermann et al. 2003, Kastelein 2009). Walruses typically swallow invertebrates without shells in their entirety (Fay 1982). They remove the soft parts of mollusks from their shells by suction and discard the shells (Fay 1982). The foraging behavior of walruses can have a major impact on benthic communities in the Bering and Chukchi Seas, as walrus bioturbation disturbs benthic substrates and impacts benthic structure, nutrient flux, and benthic species composition (Klaus et al. 1990, Ray et al. 2006).

CONSERVATION ISSUES

In 2008, the US Fish and Wildlife Service received a petition filed by the Center for Biological Diversity to list the Pacific walrus under the Endangered Species Act (ESA), citing global warming as a primary concern. As the climate in the Arctic continues to warm and summer sea-ice margins retreat further from the continental shelf, walruses have begun to haulout on land, sometimes prompting longer foraging trips, increasing the likelihood for anthropogenic disturbance, and attracting predators (Tynan and DeMaster 1997, Kelly 2001, Jay and Fischbach 2008, Laidre et al. 2008, Moore and Huntington 2008). In 2011, the US Fish and Wildlife Service found that listing walruses under the ESA was warranted but precluded by higher priority listing actions. That finding resulted in walruses being added to the list of candidate species. A


Bill Hickey / USFWS

Pacific walruses are highly social animals, with intricate herd and subherd social structures and status hierarchies.

final determination of their status under the ESA is due in 2017. Pacific walruses are also protected from take and harassment by the Marine Mammal Protection Act (MMPA) of 1972. Harassment is defined very broadly by the MMPA, and includes any alteration of an animal's behavior.

Many factors determine the health and potential risks affecting the Pacific walrus population. Global climate change continues to severely deplete the sea-ice habitat Pacific walruses use for some important behaviors (Jay et al. 2011), leaving an uncertain future for this species. Increasingly, walruses are utilizing land-based haulouts in late summer when Chukchi Sea ice has receded away from the continental shelf. This puts walruses in the position of potentially depleting nearshore forage resources or making long, foraging trips to areas such as Hanna Shoal (Jay et al. 2012a, Jay et al. 2012b). Other potential stressors, such as impacts to prey species, calf/juvenile mortality, and disease/parasitism/predation rates are also likely to be influenced by environmental changes associated with a warming climate driven by greenhouse gas emissions. An increase in summer shipping due to decreasing sea ice may affect walruses through ship strikes, noise, or spills of freight or fuel. Anthropogenic disturbance at land-based haulouts has resulted in the trampling deaths of thousands of walruses (Jay and Fischbach 2008, Fischbach et al. 2009), but management and protection programs have reduced this threat.

Finally, the Pacific walrus is harvested by Alaskan and Russian Native communities. Harvest levels have been declining since 1990, and the lowest levels on record in the US have occurred in 2013–2016. According to US Fish and Wildlife Service, a total average harvest of 3,960 animals occurred during 2010–2014. Currently, the harvest in Alaska is co-managed by US Fish and Wildlife Service and the Alaska Eskimo Walrus Commission.

Walrus migration information, provided by the Savoonga Tribal Council

Savoonga walrus experts have provided a description of three observed walrus migrations, below. These descriptions include the St. Lawrence Island Yupik terms for the migrations and the characteristics of the migrations, such as timing and relation to ice conditions.

Qavreq
The qavreq migration takes place in spring. It consists of concentrations of walruses headed west. Walrus move in this direction because there is usually thicker ice to the west of St. Lawrence Island in the spring. Bull walrus prefer that ice and can swim against strong currents to it. The walrus have some way of knowing that thicker ice is out there.

Anleghaq
The anleghaq migration takes place in late summer. This is when walruses start to come south in late summer to wait on the ice pack, or where there is food for them. This migration begins in late August and continues until winter sets in.

Ayughaayak
The ayughaayak migration no longer happens because of changed ice conditions near St. Lawrence Island. This migration took place in the spring. Walruses would concentrate on the ice between Gambell and Savoonga in mid to late June. This was a concentration of mainly male walruses.

MAPPING METHODS (MAPS 6.2a–6.2b)

Walrus data are shown on two seasonal maps: one for winter and spring, the other for summer and fall. The maps show the seasonal distribution of walruses throughout the project area, with distribution data categorized into four intensities: extent of range, regular use, concentration, and high concentration.

Walrus range data were digitized from US Fish and Wildlife Service (2014) for both the winter/spring and summer/fall timeframes. The US Fish and Wildlife Service (2014) summer/fall range data were merged with additional range data provided in Audubon Alaska and Oceana (2016), Fischbach et al. (2016), Jay et al. (2012a), and National Oceanic and Atmospheric Administration (1988) by Audubon Alaska (2016o).

The summer/fall regular-use areas in the Chukchi Sea represent the 95% monthly occupancy contours analyzed by Jay et al. (2012a), which were merged across all months (June–November) by Audubon Alaska. In the Bering Sea, summer/fall regular use is shown in US Fish and Wildlife Service (2014). This regular-use area was extended toward St. Matthew Island based on data from a February 2017 workshop with Bering Strait region traditional knowledge experts who reviewed Audubon Alaska's draft walrus maps (Audubon Alaska et al. 2017). The winter/spring regular-use area was combined from Audubon Alaska et al. (2017), Fay and Fedoseev (1984), National Oceanic and Atmospheric Administration (1988), and US Fish and Wildlife Service (2014) by Audubon Alaska (2017d).

Summer/fall concentration areas are shown based on data from three primary sources: Audubon Alaska and Oceana (2016), Jay et al. (2012a), and Oceana and Kawerak (2014). The summer/fall concentration areas from Jay et al. (2012a) represent the merged 50% monthly feeding contours June–November and are labeled as feeding areas. The Audubon Alaska and Oceana (2016) data represent 50% contours (July–October) of data from 2000 through 2014 from the Aerial Survey of Arctic Marine Mammals (ASAMM) (National Oceanic and Atmospheric Administration 2015a). The ASAMM data (formerly Bowhead Whale Aerial Survey Project [BWASP]) were analyzed in consultation with Megan Ferguson and Janet Clarke. Aerial survey methods, data, and metadata for the ASAMM database are available at: http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php. The Audubon Alaska and Oceana analysis used only on-transect data where there were more than 62 miles (100 km) of survey effort in a 12.4-mile x 12.4-mile (20-km by 20-km) grid cell. An observation rate (i.e. relative density) was calculated in each grid cell by dividing the observed number of animals over all years by the measure of total transect length over all years. This observation rate was converted into point data with one point per grid cell (at the centroid), and a kernel density function was run with an anisotropic kernel density function with a 24.8-mile (40-km) north-south search radius and a 49.6-mile (80 km) east-west search radius to smooth the data. The summer/fall concentration areas from Oceana and Kawerak (2014) represent merged concentration polygons specific to the summer and fall seasons; some of these polygons were based on data from National Oceanic and Atmospheric Administration (1988). These polygons were reviewed and modified by Bering Strait region traditional knowledge experts at the February 2017 workshop (Audubon Alaska et al. 2017), and represent areas where people reported regularly seeing groups of walruses in above-average densities.

Similarly, much of the mapped winter/spring concentration data were provided by Kawerak, Inc. (Oceana and Kawerak 2014) as winter- and spring-specific polygons. We merged these season-specific data and the merged polygons were updated based on traditional knowledge from the February Audubon Alaska et al. (2017) workshop. Outside the Bering Strait region, these data were supplemented with data from Fay (1982), Krupnik and Ray (2007), and National Oceanic and Atmospheric Administration (1988). The Krupnik and Ray (2007) and National Oceanic and Atmospheric Administration (1988) winter/spring concentration polygons represent areas where walruses congregate to breed.

The winter/spring and summer/fall high-concentration areas from Oceana and Kawerak (2014), updated based on Audubon Alaska et al. (2017), represent places where walruses were observed in higher densities than in concentration areas, in a particular spot by the dozens, or in a general broad area by the hundreds to thousands. The winter/spring high-concentration area near St. Lawrence Island was identified by Oceana and Kawerak (2014) and Audubon Alaska et al. (2017) as a breeding area and is labeled as such. A winter/spring high concentration area from Noongwook et al. (2007) is incorporated within the Oceana and Kawerak (2014) data. The summer/fall high-concentration areas also incorporate 20% monthly feeding contours

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(June–November) from Jay et al. (2012a) and 25% contours (July–October) from Audubon Alaska and Oceana (2016).

The Walrus Islands State Game Sanctuary boundary was produced by Alaska Department of Fish and Game (2016a). The Hanna Shoal Walrus Use Area boundary was provided by US Fish and Wildlife Service (2013).

Haulouts shown on the maps were provided from two sources: 1) Kawerak's 2013 Ice Seal and Walrus Project (Kawerak 2013), and 2) a database compiled by the US Geological Survey in cooperation with the Russian Academy of Sciences and Chukot-TINRO (Fischbach et al. 2016). The latter database incorporates recorded haulout locations from a variety of sources including published reports, state records, and local and traditional knowledge.

Movement information was drawn by Audubon Alaska based on walrus tracking animations from US Geological Survey (US Geological Survey 2016) and personal communication with US Geological Survey biologist Tony Fischbach.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality
Walrus range, regularly occurring areas, and haulout location information is generally consistent across the project area. Data quality of concentration, high concentration, and activity data varies among regions.

The mapped summer/fall concentration and high-concentration areas from Jay et al. (2012a) and Audubon Alaska and Oceana (2016) were generated from analyses of satellite telemetry data and aerial survey data, respectively. The Jay et al. (2012a) data were generated through a utilization distribution analysis of walrus satellite telemetry data collected from 2008 to 2011 and are specific to female walruses tagged in the Bering Strait, on the north coast of Chukotka, and the northwest coast of Alaska. The Audubon Alaska and Oceana (2016) data, meanwhile, are based only on those animals that were visible from the air at the time of the survey. The Oceana and Kawerak (2014) winter/spring and summer/fall concentration and high-concentration areas were generated through interviews with traditional ecological knowledge experts from nine Bering Strait indigenous communities, and were reviewed and updated by Bering Strait region traditional knowledge experts at the February 2017 workshop (Audubon Alaska et al. 2017). The western biological science and traditional ecological knowledge data were thus collected using different methodologies, and the types of information and concepts embodied in the visual representations of "concentrations" are not necessarily the same. Information regarding concentration and high-concentration areas is lacking across the remainder of the map area.

Feeding and breeding high-concentration areas are labeled where this information is known. This labeling is not intended to indicate that these are the only portions of the project area where these activities occur; additional feeding and breeding high-concentration areas may be present in regions where such information was not available as of our publication date.

Reviewers
- Bering Strait Traditional Knowledge-Holder Map Review Workshop participants
- Jim MacCracken
- Jonathan Snyder

MAP DATA SOURCES

SUMMER/FALL MAP

Extent (Summer/Fall): Audubon Alaska (2016o) based on Audubon Alaska and Oceana (2016), Audubon Alaska et al. (2017), Fischbach et al. (2016), Jay et al. (2012a), National Oceanic and Atmospheric Administration (1988), Oceana and Kawerak (2014), and US Fish and Wildlife Service (2014)

Extent (Winter/Spring): Audubon Alaska (2016p) based on National Oceanic and Atmospheric Administration (1988) and US Fish and Wildlife Service (2014)

Regular Use (Summer/Fall): Audubon Alaska et al. (2017); Jay et al. (2012a); US Fish and Wildlife Service (2014)

Concentration (Summer/Fall): Audubon Alaska et al. (2017); Audubon Alaska and Oceana (2016); Jay et al. (2012a); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014)

High Concentration (Summer/Fall): Audubon Alaska et al. (2017); Audubon Alaska and Oceana (2016); Jay et al. (2012a); Oceana and Kawerak (2014)

Feeding: Jay et al. (2012a)

Walrus Islands State Game Sanctuary: Alaska Department of Fish and Game (2016a)

Hanna Shoal Walrus Use Area: US Fish and Wildlife Service (2013)

Haulouts: Fischbach et al. (2016); Kawerak (2013)

Movement & Feeding Corridors: A. Fischbach (pers. comm.); US Geological Survey (2016)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

WINTER/SPRING MAP

Extent (Winter/Spring): Audubon Alaska (2016p) based on National Oceanic and Atmospheric Administration (1988) and US Fish and Wildlife Service (2014)

Extent (Summer/Fall): Audubon Alaska (2016o) based on Audubon Alaska and Oceana (2016), Audubon Alaska et al. (2017), Fischbach et al. (2016), Jay et al. (2012a), National Oceanic and Atmospheric Administration (1988), Oceana and Kawerak (2014), and US Fish and Wildlife Service (2014)

Regular Use (Winter/Spring): Audubon Alaska (2017d) based on Audubon Alaska et al. (2017), Fay and Fedoseev (1984), National Oceanic and Atmospheric Administration (1988), and US Fish and Wildlife Service (2014); Audubon Alaska et al. (2017); US Fish and Wildlife Service (2014)

Concentration (Winter/Spring): Audubon Alaska et al. (2017); Fay (1982); Krupnik and Ray (2007); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014)

High Concentration (Winter/Spring): Audubon Alaska et al. (2017); Noongwook et al. (2007); Oceana and Kawerak (2014)

Breeding: Audubon Alaska et al. (2017); Krupnik and Ray (2007); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014); US Fish and Wildlife Service (2014)

Walrus Islands State Game Sanctuary: Alaska Department of Fish and Game (2016a)

Haulouts: Fischbach et al. (2016); Kawerak (2013)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

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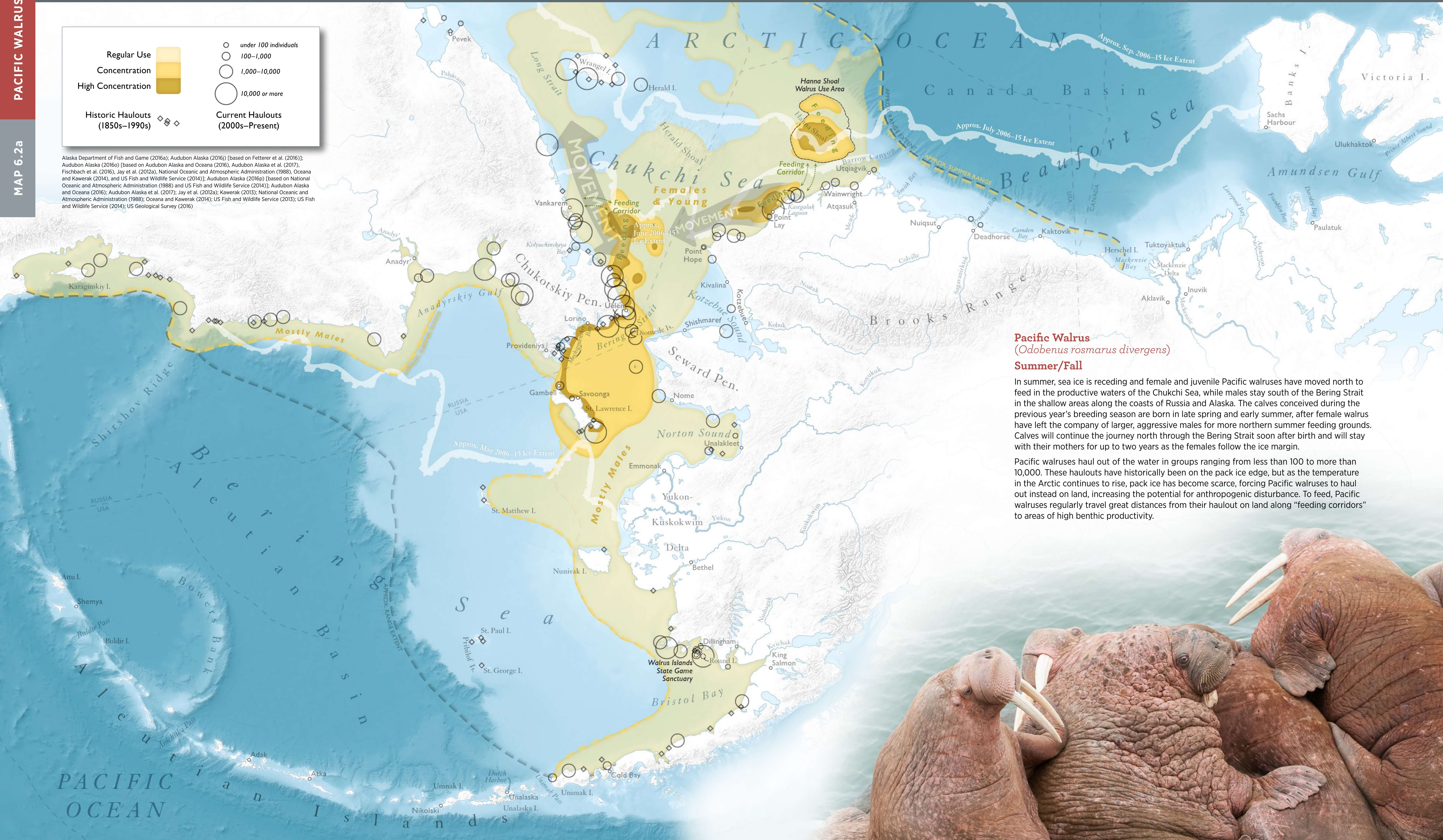
Pacific walruses haul out in groups often numbering more than 10,000 individuals. As temperatures throughout their range continue to rise, altering sea ice conditions, they are forced to use terrestrial haulouts in areas where they have historically used sea ice. With this proximity to land comes an increase in human-caused disturbance.

Terri Stinnett Photography

Pacific Walrus: Summer/Fall

Map Authors: Erika Knight, Melanie Smith, and Max Goldman
Cartographer: Daniel P. Huffman

KAWERAK, INC. OCEANA Audubon ALASKA



Alaska Department of Fish and Game (2016a); Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2016o) [based on Audubon Alaska and Oceana (2016), Audubon Alaska et al. (2017), Fischbach et al. (2016), Jay et al. (2012a), National Oceanic and Atmospheric Administration (1988), Oceana and Kawerak (2014), and US Fish and Wildlife Service (2014)]; Audubon Alaska (2016p) [based on National Oceanic and Atmospheric Administration (1988) and US Fish and Wildlife Service (2014)]; Audubon Alaska and Oceana (2016); Audubon Alaska et al. (2017); Jay et al. (2012a); Kawerak (2013); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014); US Fish and Wildlife Service (2013); US Fish and Wildlife Service (2014); US Geological Survey (2016)

Pacific Walrus
(Odobenus rosmarus divergens)

Summer/Fall

In summer, sea ice is receding and female and juvenile Pacific walruses have moved north to feed in the productive waters of the Chukchi Sea, while males stay south of the Bering Strait in the shallow areas along the coasts of Russia and Alaska. The calves conceived during the previous year's breeding season are born in late spring and early summer, after female walrus have left the company of larger, aggressive males for more northern summer feeding grounds. Calves will continue the journey north through the Bering Strait soon after birth and will stay with their mothers for up to two years as the females follow the ice margin.

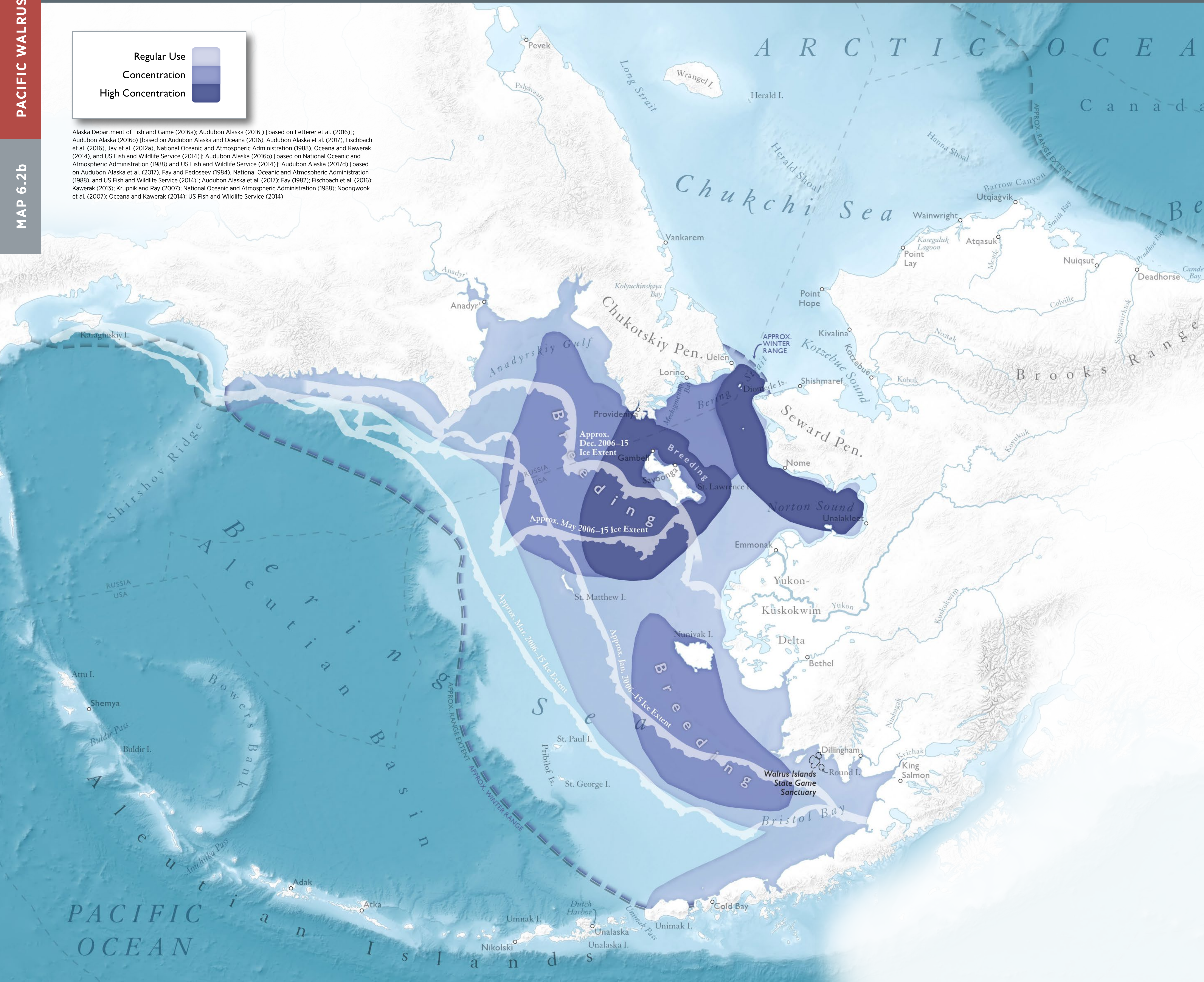
Pacific walruses haul out of the water in groups ranging from less than 100 to more than 10,000. These haulouts have historically been on the pack ice edge, but as the temperature in the Arctic continues to rise, pack ice has become scarce, forcing Pacific walruses to haul out instead on land, increasing the potential for anthropogenic disturbance. To feed, Pacific walruses regularly travel great distances from their haulout on land along "feeding corridors" to areas of high benthic productivity.

Terri Stinnett Photography

Pacific Walrus: Winter/Spring

Map Authors: Erika Knight, Melanie Smith, and Max Goldman
Cartographer: Daniel P. Huffman

KAWERAK, INC. OCEANA Audubon ALASKA



Alaska Department of Fish and Game (2016a); Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2016o) [based on Audubon Alaska and Oceana (2016), Audubon Alaska et al. (2017), Fischbach et al. (2016), Jay et al. (2012a), National Oceanic and Atmospheric Administration (1988), Oceana and Kawerak (2014), and US Fish and Wildlife Service (2014)]; Audubon Alaska (2016p) [based on National Oceanic and Atmospheric Administration (1988) and US Fish and Wildlife Service (2014)]; Audubon Alaska (2017d) [based on Audubon Alaska et al. (2017), Fay and Fedoseev (1984), National Oceanic and Atmospheric Administration (1988), and US Fish and Wildlife Service (2014)]; Audubon Alaska et al. (2017); Fay (1982); Fischbach et al. (2016); Kawerak (2013); Krupnik and Ray (2007); National Oceanic and Atmospheric Administration (1988); Noongwook et al. (2007); Oceana and Kawerak (2014); US Fish and Wildlife Service (2014)

Kim Shelden / NOAA

Pacific Walrus

(Odobenus rosmarus divergens)

Winter/Spring

This map shows the distribution of the Pacific walrus throughout the Bering Sea during the winter and spring seasons. As temperatures begin to cool in fall and early winter and ice margins begin to push southward, female and juvenile walruses also move south, reuniting with male walruses to breed and overwinter in the Bering Sea. During January and February, breeding bull walruses will follow groups of females as they haul out on large ice flows, their preferred breeding habitat.

Pacific walruses haul out of the water in groups ranging from less than 100 to more than 10,000. They tend to congregate around areas of thin ice, and are closely associated with polynyas and leads. In the winter and spring, these haulouts are usually on nearshore pack ice along the coast. Walruses use haulouts to rest after strenuous foraging bouts, to evade predation, and to breed. Throughout the rest of the winter, walruses are pushed farther south as the pack ice margin continues to march toward its maximum extent. Calving happens after 15 or 16 months of pregnancy, in April, May, or June.

Ice Seals

Benjamin Sullender and Erika Knight

Bearded Seal *Erignathus barbatus* | **Ribbon Seal** *Histriophoca fasciata* | **Ringed Seal** *Phoca hispida* | **Spotted Seal** *P. largha*

Ice seals are a group of marine mammals adapted to life primarily on ice. Within the Bering, Chukchi, and Beaufort Seas, there are four species of ice seal: bearded (*Erignatus barbatus*), ribbon (*Histriophoca fasciata*), ringed (*Phoca hispida*), and spotted (*P. largha*). All Arctic ice seals belong to the family *Phocidae* (earless seals) within the seal clade Pinnipedia. Bearded and ringed seals are the most common and widespread of the seals, while ribbon and spotted seals are more locally distributed, particularly along the sea-ice margins.

ADAPTATIONS

Seal pups have a natal or fetal layer of hair called lanugo. Lanugo is white in all seals except for the bearded seal, where it is brown (Árnason et al. 2006). Lanugo is important for thermoregulation, although it is quickly shed as the pup gains a layer of insulating blubber during nursing (Burns 1970, Lydersen and Hammill 1993). Bearded seals often shed lanugo in utero and, to compensate, are born with a thicker layer of subcutaneous fat (Kovacs et al. 1996).

Pelage in sub-adults and adults is mainly useful for protection, streamlining while swimming, and traction on ice, rather than for thermoregulation (Ling 1970, 1972). Hair must be annually shed and regrown to maintain its function, a process called molting (Ling 1970).

DISTRIBUTION

The bearded seal is distributed widely across the circumpolar Arctic. The ribbon seal breeds and molts in the Bering Sea and the Sea of Okhotsk, seasonally ranging into the Chukchi Sea and occasionally south of the Aleutian Islands. Ringed seals are very broadly distributed through the Arctic. Subspecies inhabit smaller areas and even some inland lakes. The spotted seal is distributed from the Bering Sea through the Sea of Okhotsk and Sea of Japan to the Yellow Sea, with discrete breeding areas in each of these seas.

Sea-Ice Habitat

Ice seals rely on a balance of sufficient ice conditions for haulout platforms and sufficient access to open water for foraging and escape from predators. Pack ice is particularly important for whelping, so that young have a place to rest while mothers have access to foraging habitats (Kovacs et al. 2011).

LIFE CYCLE

Ice seal life history tracks the seasonal nature of sea-ice extent, balancing suitable marine foraging conditions with the presence of ice for use as haulouts (Lydersen and Kovacs 1999). Most of the key events in seal life histories are condensed into the months between spring and summer (generally, March–June). Whelping (birth) typically peaks in March and April, followed by nursing, when seal pups rapidly gain mass, up to 7.3 pounds (3.3 kg) per day for bearded seals (Lydersen et al. 1996). Immediately after nursing, seals begin to breed. Implantation of the blastocyst is usually delayed a few months, followed by a seven- to nine-month pregnancy, ensuring that pups are born in the spring, when food is most available (Sandell 1990).

After whelping and breeding have been completed, ice seals undertake an annual molt. Seals haul out of the water more during molting, likely because the resulting elevated skin temperatures promote hair shedding and regrowth (Cameron et al. 2010).

Generally, ice seals are highly mobile and follow the distribution of sea ice (MacIntyre et al. 2015), although ribbon seals adapt to a seasonally pelagic life during the open-water season (Boveng et al. 2013).

Diet

Although Arctic ice seal ranges overlap, dietary niches are somewhat partitioned (Dehn et al. 2007). Ringed, ribbon, and spotted seals are pelagic foragers, whereas bearded seals eat benthic prey, typically crustaceans, cephalopods, and occasionally fish (Dehn et al. 2007, Cooper et al. 2009). Bearded seals eat both infaunal and epifaunal benthic prey, although they shift their diets according to seasonal availability and will consume pelagic prey opportunistically (Antonelis et al. 1994, Quakenbush et al. 2011).

Species Description

Bearded Seal

The bearded seal is characterized by the distinctive vibrissae (whiskers) that it uses to detect prey (Dehn et al. 2007). The vibrissae, combined with an ability to use hydraulic jetting and suction to acquire prey (Marshall et al. 2008), make the bearded seal well adapted to benthic foraging (Marshall et al. 2006). Bearded seals also consume pelagic fishes, which suggests opportunistic feeding or diet plasticity (Antonelis et al. 1994, Quakenbush et al. 2011).

TABLE 6.3-1. Ice seal life history characteristics and conservation status. Sources: Conn et al. (2014), Muto et al. (2016).

	Bearded Seal *Erignathus barbatus*	Ribbon Seal *Histriophoca fasciata*	Ringed Seal *Phoca hispida*	Spotted Seal *P. largha*
Body Size Mass Length	**M** 475 pounds (220 kg) **L** 6.5 feet (2 m)	**M** 175 pounds (80 kg) **L** 5 feet (1.5 m)	**M** 150 pounds (70 kg) **L** 5 feet (1.5 m)	**M** 200 pounds (90 kg) **L** 5 feet (1.5 m)
Maximum Life Span (wild)	30 years	30 years	40 years	35 years
Conservation Status ESA IUCN	**ESA:** Threatened Beringia and Okhotsk DPS **IUCN:** Least Concern	**ESA:** Species of Concern **IUCN:** Least Concern	**ESA:** Endangered–Ladoga and Saimaa subspecies **ESA:** Threatened–Okhotsk and Baltic subspecies **ESA:** Not Listed–Arctic subspecies as of 2017 **IUCN:** Least Concern	**ESA:** Threatened Southern DPS **ESA:** Not Listed–Sea of Okhotsk and Bering Sea DPS **IUCN:** Least Concern
Population US Bering Sea Global	**U** 300,000 **G** Unknown	**U** 184,000 **G** Unknown	**U** 170,000 **G** 3,000,000	**U** 460,000 **G** Unknown

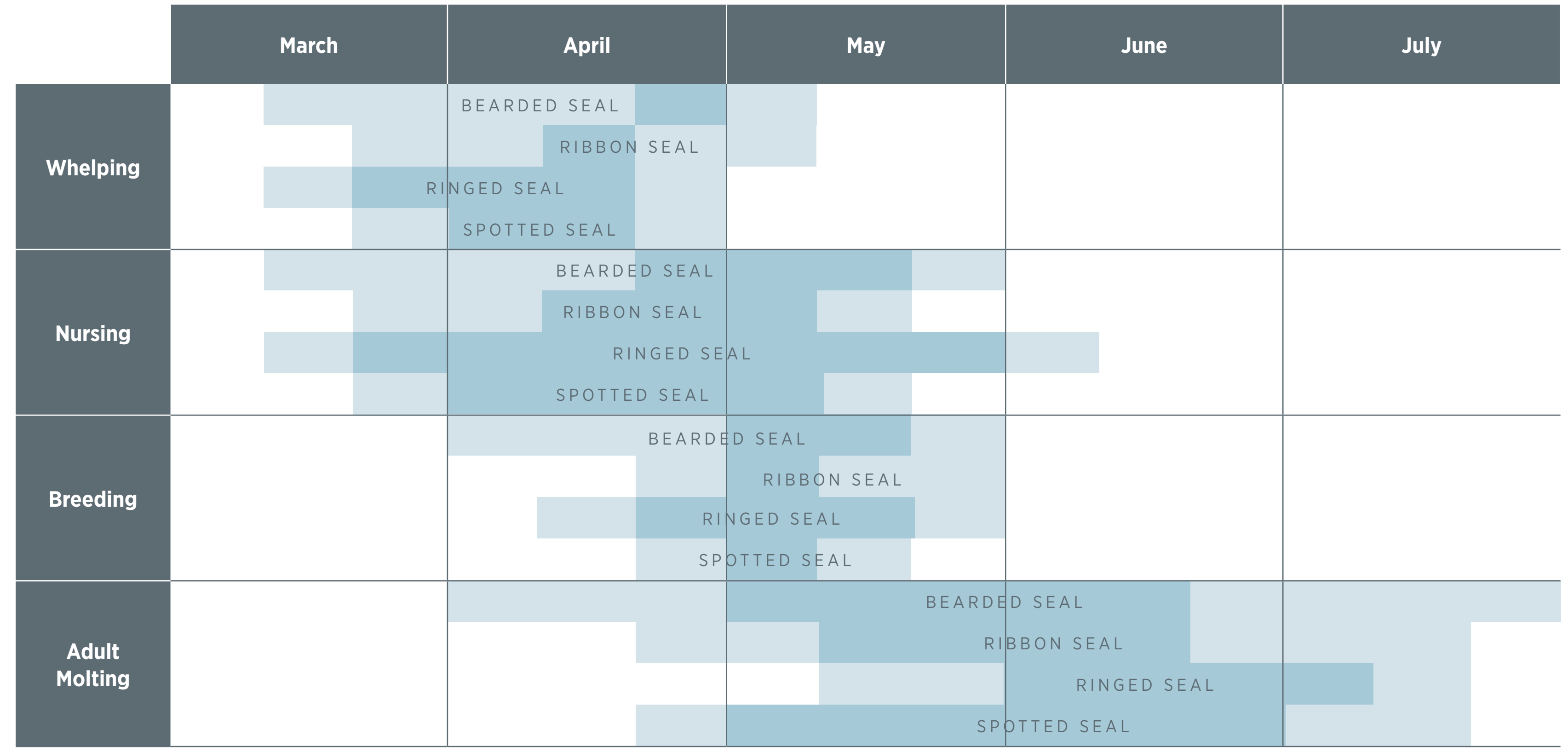


FIGURE 6.3-1. Comparative phenology for ice seals. Modified from Cameron et al. (2010), Kelly et al. (2010b), Boveng et al. (2013) and Boveng et al. (2009). Darker blue indicates peak activity; lighter blue indicates known extent of activity within study area.

There are two main subspecies of bearded seals, *E. b. barbatus* and *E. b. nauticus*, although there is no geographic gap between their ranges. *E. b. nauticus* lives in the Bering, Beaufort, and Chukchi Seas and is migratory (Rice 1998). Bearded seals in this subspecies employ a roaming (rather than territorial) strategy during the breeding season (Van Parijs and Clark 2006), and very rarely haul out on land (Smith 1981).

Although bearded seals have some capacity to create breathing holes in shallow ice, they prefer sea ice with existing access to water (Burns and Frost 1979). Generally, bearded seals prefer dense ice (70–90% coverage) in motion and with natural openings like leads or polynyas, and tend to avoid shorefast or unbroken, multi-year ice (Kingsley et al. 1985, Simpkins et al. 2003). Young bearded seals feed upriver (sometimes many miles) in the summer and fall (Audubon Alaska et al. 2017).

Ribbon Seal

Ribbon seals are named for their distinctive coloration, with four light-colored ribbons on top of dark pelage. This unusual pattern may help disguise the shape of the ribbon seal's body, reducing the risk of detection by predators searching for seals (Naito and Oshima 1976). Ribbon seals are less wary while hauled out than other ice seals, suggesting that they are less vulnerable to predation (Boveng et al. 2013).

Ribbon seals were formerly classified as belonging to the genus *Phoca*, but recent phylogenetic analyses have confirmed that ribbons seals are more appropriately classified as a separate genus *Histriophoca* (Higdon et al. 2007, Fulton and Strobeck 2010).

Ribbon seals dive deeper than other ice seals (Deguchi et al. 2004) and exhibit several adaptations to their cardiovascular system—higher oxygen storage capacity and higher hemoglobin concentrations—that befit deep dives (Lenfant et al. 1970). Ribbon seals regularly forage at depths up to 1,600 feet (500 m), but shift to shallower foraging bouts when ice coverage precludes presence in deeper waters. This suggests that sea ice is more important than access to preferred deeper waters along the continental shelf slope (Boveng et al. 2013).

Ringed Seal

Ringed seals are the only ice seal that create and maintain breathing holes in the ice; they do so using their foreflipper claws. They often excavate snow above their breathing holes to create lairs (Smith and Stirling 1975). These subnivean lairs provide refuge from cold temperatures, particularly for pups, and hide seals from predators (Smith et al. 1991). Multiple lairs are used, most likely as a way to mitigate risk of predation, and ringed seals demonstrate inter-annual site fidelity to subnivean lairs (Kelly et al. 2010a).

There are five subspecies of ringed seals: Arctic ringed seal (*P. h. hispida*), Baltic ringed seal (*P. h. botnica*), Okhotsk ringed seal (*P. h. ochotensis*), Ladoga ringed seal (*P. h. ladogensis*), and Saimaa ringed seal (*P. h. saimensis*). The Arctic subspecies, found across the circumpolar Arctic, has the broadest geographic distribution. Other subspecies are believed to have been derived from this original geographic extent, but became isolated through the years (Amano et al. 2002). These isolated populations have been listed as threatened or endangered under the Endangered Species Act (ESA), but the main circumpolar subspecies is not currently listed (Table 6.3-1, Figure 6.3-2).

Ringed seals have diverse diets, eating mainly gadid (cod family) fishes in the winter months and switching to a more invertebrate-based diet during the open-water months (Dehn et al. 2007, Kovacs 2007).

Spotted Seal

Morphologically and genetically, spotted seals are similar to harbor seals (*P. vitulina*), and these species overlap in the Aleutian Islands. However, spotted seals usually haul out on sea ice during the breeding season, whereas harbor seals haul out on land (Bishop 1967).

Based on breeding area delineations, spotted seals can be divided into three distinct population segments (DPSs): the Bering DPS, the Okhotsk DPS, and the Southern DPS (Boveng et al. 2009). The Southern DPS breeds in the Yellow Sea and the Sea of Japan.

Spotted seals are closely associated with sea ice when sea ice is present. Spotted seals follow the ice front, preferring ice floes less than 70 feet (<20 m) in diameter for hauling out and avoiding areas of dense ice (Lowry et al. 2000). In the summer, spotted seals haul out on shore for extended periods of time, a behavior unusual for the other species of ice seal, and make multiple-day foraging trips (Lowry et al. 1998).

Spotted seals are pelagic foragers, eating primarily fish and favoring higher trophic levels than other ice seals (Dehn et al. 2007).

FIGURE 6.3-2. Ringed seal subspecies and ESA status as of 2017.

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Of the five subspecies of ringed seal, the Arctic ringed seal (pup pictured) is the most numerous and widely distributed.

CONSERVATION ISSUES

Due to rising concern about the impacts of reduced sea ice on ice-obligate and ice-associated wildlife, the National Oceanic and Atmospheric Administration (NOAA) recently assessed ice seal conservation status according to the ESA (Boveng et al. 2009, Cameron et al. 2010, Kelly et al. 2010b, Boveng et al. 2013). The resulting decisions are the subject of ongoing litigation.

For bearded seals, the original 2012 decision to list Pacific subspecies as threatened was challenged, vacated, and has since been appealed and reinstated in October 2016, with the appellate court denying any future rehearings in May of 2017. (DeMarban 2016, Muto et al. 2016). Currently, both of the DPSs of the bearded seals in the Bering, Chukchi, Beaufort, and Okhotsk Seas (*E. b. nauticus* subspecies) are listed as threatened. The range of the Beringia DPS spans the entire Bering, Chukchi, and Beaufort Seas; the Okhotsk DPS is restricted to the Sea of Okhotsk.

Ribbon seal status was reviewed under the ESA in 2013, and although listing was not warranted, ribbon seals were determined to be a species of concern.

Although Arctic ringed seals were listed as threatened under the ESA in 2010, a subsequent lawsuit vacated the decision in 2016 and ringed seals are no longer listed under the ESA (Muto et al. 2016).

One of three DPSs of spotted seals is listed as threatened. This population breeds in the Yellow Sea and Peter the Great Bay and does not typically reach into the Arctic. The spotted seals that inhabit the project area—the Bering Sea DPS—are not warranted for listing under the ESA.

The most severe threat facing ice seals is the reduction and loss of sea ice (Moore and Huntington 2008). Changes are already reducing breeding habitat for ice seals (Meier et al. 2014), and years with poor ice conditions have been shown to increase pup mortality for ice-breeding seals (Stenson and Hammill 2014). Extreme ice fluctuations depress body conditions and female ovulation rates for ringed seals (Harwood et al. 2012). Although some studies do not anticipate significant negative responses to a reduction in ice extent (Laidre et al. 2008), shifts in habitat and/or diet may occur. Changes in prey abundance and distribution may indirectly affect ice seals (MacIntyre et al. 2015). Some experts predict an overall shift to more pelagic-based productivity in the Arctic marine ecosystem, with negative impacts for benthic-reliant taxa such as bearded seals (Bluhm and Gradinger 2008). However, because ice seals are opportunistic or even generalists in diet, bearded seals may be able to switch diet along with prey abundance (Bluhm and Gradinger 2008).

Industrial development and shipping pose concerns, as noise, ship strikes, oil spills, and other discharges may disturb, displace, or directly harm ice seals (Boveng et al. 2009, Cameron et al. 2010, Kelly et al. 2010b, Boveng et al. 2013). Predation, hunting, and bycatch from commercial fishing are not anticipated to be major threats to ice seal populations (Huntington 2009).

Seal populations have been affected by diseases or infections, although it is difficult to predict future trajectories or occurrences. An unusual mortality event (UME) was declared by the NOAA and the US Fish and Wildlife Service (USFWS) for ice seals in 2011. Over 100 ice seals were reported stranded, with hair loss, lesions, and/or weakness (National Oceanic and Atmospheric Administration and US Fish and Wildlife Service 2012). No cause has been identified, and the UME is still an open investigation for ice seals, although few if any new causes have been reported since 2014 (National Oceanic and Atmospheric Administration 2016).

MAPPING METHODS (MAPS 6.3.1–6.3.4)

The ice seal maps show seasonal distribution of each species throughout the project area. Seasonal data are generally grouped into two seasons, winter/spring and summer/fall, with the exception of data that are applicable year-round. Distribution data are also categorized by four intensities: extent of range, regular use, concentration, and high concentration. Areas where winter/spring and summer/fall data of the same intensity level overlap are shown as year-round at that intensity. General methods for mapping each data layer are described below, with specific sources listed by intensity and seasonal grouping in Table 6.3-2. Due to polygon overlap between data sources, some data listed below may be depicted as year-round but listed as winter/spring or summer/fall; see "Map Data Sources" for a list of citations by display layer. Also see *A Closer Look:* Kawerak's Contribution of Traditional Knowledge.

The mapped ice seal range data were provided in the most recent NOAA status reviews for each species. Seasonal range data were not available for ice seals, with the exception of winter/spring range for spotted seals.

Regular-use data for each ice seal species were composited from a variety of sources.

- Bearded seal regular-use data were composited from several sources. Bearded seals regularly use large portions of the map area throughout the year and regularly use other portions of the map area in only the winter/spring season. The year-round data were from National Oceanic and Atmospheric Administration (1988) and three traditional knowledge sources, including data from a February 2017 workshop with Bering Strait region traditional knowledge experts who reviewed Audubon Alaska's draft ice seal maps (Audubon Alaska et al. 2017). The winter/spring data came from two sources: an Audubon Alaska (2016a) GIS file (based on publications by Bengtson et al. (2005), Cameron et al. (2010), and National Oceanic and Atmospheric Administration (1988)) and traditional knowledge from Oceana and Kawerak (2014).

TABLE 6.3-2. Spatial data sources used on ice seal maps, listed by intensity and seasonal grouping. Due to polygon overlap among data sources, some data described as winter/spring or summer/fall below are depicted as year-round on the ice seal maps. For a list of data sources compiled by map display layer, see the Map Data Sources section.

	Bearded Seal *Erignathus barbatus*	Ribbon Seal *Histriophoca fasciata*	Ringed Seal *Phoca hispida*	Spotted Seal *P. largha*
Range	• Cameron et al. (2010)	• Boveng et al. (2013)	• Kelly et al. (2010b)	• Boveng et al. (2009)
Winter/Spring Range	Not available	Not available	Not available	• Audubon Alaska (2016n) based on: > Boveng et al. (2009) > Lowry et al. (1998) > National Oceanic and Atmospheric Administration (1988) > Oceana and Kawerak (2014)
Winter/Spring Regular Use	• Audubon Alaska (2017) based on: > Bengtson et al. (2005) > Cameron et al. (2010) > National Oceanic and Atmospheric Administration (1988) • Oceana and Kawerak (2014)	• Audubon Alaska et al. (2017) • Boveng et al. (2013)	• Audubon Alaska (2017c) based on: > Bogoslovskaya et al. (2016) > Kelly et al. (2010b) > National Oceanic and Atmospheric Administration (1988)	• Boveng et al. (2009) • Lowry et al. (1998) • National Oceanic and Atmospheric Administration (1988)
Summer/Fall Regular Use	• Audubon Alaska et al. (2017)	• Audubon Alaska et al. (2017) • National Oceanic and Atmospheric Administration (1988)	• Audubon Alaska (2009b) • Huntington et al. (2015b) • Stephenson and Hartwig (2010)	• Audubon Alaska (2009d) based on: > Lowry et al. (1998) • Huntington et al. (2015b) • Huntington et al. (2016a) • Lowry et al. (1998) • National Oceanic and Atmospheric Administration (1988)
Year-round Regular Use	• Audubon Alaska et al. (2017) • Huntington et al. (2015b) • National Oceanic and Atmospheric Administration (1988) • Stephenson and Hartwig (2010)	Not available	• Audubon Alaska et al. (2017) • National Oceanic and Atmospheric Administration (1988) • Stephenson and Hartwig (2010)	• Audubon Alaska et al. (2017)
Winter/Spring Concentration	• Oceana and Kawerak (2014) • Oceana (2013) based on: > Bengtson et al. (2005) > National Oceanic and Atmospheric Administration (1988)	• National Oceanic and Atmospheric Administration (1988)	• Audubon Alaska (2017b) based on: > Audubon Alaska (2009c) > Eicken et al. (2009) > Hartwig (2009) > Kelly et al. (2010b) > National Snow and Ice Data Center and Konig Beatty (2012) > National Oceanic and Atmospheric Administration (1988) > Oceana and Kawerak (2014) > Satterthwaite-Phillips et al. (2016) > Stephenson and Hartwig (2010) • National Oceanic and Atmospheric Administration (1988) • Oceana and Kawerak (2014)	• Audubon Alaska et al. (2017) • Boveng et al. (2009) • National Oceanic and Atmospheric Administration (1988) • Oceana and Kawerak (2014)
Summer/Fall Concentration	• Oceana and Kawerak (2014)	• National Oceanic and Atmospheric Administration (1988)	• Hartwig (2009) • Harwood and Stirling (1992) • National Oceanic and Atmospheric Administration (1988) • Oceana and Kawerak (2014) • Satterthwaite-Phillips et al. (2016)	• Audubon Alaska et al. (2017) • Oceana and Kawerak (2014)
Year-round Concentration	• Audubon Alaska et al. (2017)	Not available	• Audubon Alaska et al. (2017) • Hartwig (2009)	• Audubon Alaska et al. (2017)
Winter/Spring High Concentration	• Audubon Alaska et al. (2017) • Oceana and Kawerak (2014)	• National Oceanic and Atmospheric Administration (1988)	• Audubon Alaska et al. (2017) • Huntington et al. (2015a) • Oceana and Kawerak (2014) • Satterthwaite-Phillips et al. (2016)	• Audubon Alaska et al. (2017) • Oceana and Kawerak (2014)
Summer/Fall High Concentration	• Audubon Alaska et al. (2017) • Oceana and Kawerak (2014)	Not available	• Oceana and Kawerak (2014)	• Audubon Alaska et al. (2017) • Oceana and Kawerak (2014) • Satterthwaite-Phillips et al. (2016)
Year-round High Concentration	Not available	Not available	• Audubon Alaska et al. (2017) • Oceana and Kawerak (2014)	• Audubon Alaska et al. (2017) • Oceana and Kawerak (2014)
Haulouts	• Huntington et al. (2012)	Not applicable	Not available	• Huntington and Quakenbush (2013) • Huntington et al. (2012) • Kawerak (2013) • Lowry et al. (1998) • National Oceanic and Atmospheric Administration (1988) • National Oceanic and Atmospheric Administration (2005)

- Ribbon seal regular-use data were shown based on three data sources, including traditional knowledge and data from NOAA.
- The year-round, regular-use data for ringed seals were from traditional knowledge (Stephenson and Hartwig 2010, Audubon Alaska et al. 2017), and also incorporate summer/fall data (Audubon Alaska 2009b, Huntington et al. 2015b, Stephenson and Hartwig 2010).
- Spotted seal data are shown for winter/spring and summer/fall seasons as well as year-round data, and were acquired from several data sources.

As with regular use, concentration data for the four ice seal species also came from a number of sources.

- Bearded seal summer/fall concentration data (displayed as year-round concentration due to seasonal concentration data overlaps) were available from traditional knowledge, while winter/spring data are shown based on traditional knowledge and several other sources.
- Both winter/spring and summer/fall concentration data for ribbon seals were available only from National Oceanic and Atmospheric Administration (1988).
- The ringed seal winter/spring concentration is represented by the maximum extent of shorefast ice (compiled by Audubon Alaska (2016m)) where they are known to congregate while denning, as well as information from National Oceanic and Atmospheric Administration (1988) and Oceana and Kawerak (2014). Summer/fall concentration areas are based on several traditional knowledge publications and National Oceanic and Atmospheric Administration (1988).
- Spotted seal concentration information are from traditional knowledge data and National Oceanic and Atmospheric Administration (1988).

In the Bering Strait region, concentration areas provided by Oceana and Kawerak (2014) (reviewed and updated by Audubon Alaska et al. (2017)) represent areas where people regularly saw groups of seals in above-average densities. Note that the Oceana and Kawerak (2014) bearded and spotted seal spring/early summer data were treated as spring data on our maps; thus, they are shown using our winter/spring symbology.

Winter/spring and summer/fall high-concentration areas for all species are generally based on traditional and/or local knowledge sources, with the exception of ribbon seals for which the only available data are documented by National Oceanic and Atmospheric Administration (1988).

The mapped bearded seal haulouts are shown based on traditional knowledge documented by Huntington et al. (2012). Spotted seal haulout locations were compiled from several data sources.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality
Knowledge of ice seals varies from species to species. While the overall range extent data are comprehensive and consistent for all four species, the quantity of information regarding more detailed habitat use varies across the maps. The available spatial data for ribbon seals, for example, comes from just three data sources while ringed seal data were gathered from over a dozen sources. Much of the habitat use information shown on these maps comes from traditional knowledge and varies in collection method from data source to data source. Lack of concentration and high-concentration areas across these maps does not indicate that these regions are unimportant, rather, that the use or non-use of these areas is unknown. Areas where a specific activity occurs, such as breeding or denning, are labeled where this information is known. This labeling is not intended to indicate that these are the only portions of the project area where these activities occur. Little is known about ice seal distributions in Russian waters.

Reviewers
- Bering Strait Traditional Knowledge-Holder Map Review Workshop participants
- Michael Cameron

Josh London / NOAA Fisheries, Alaska Fisheries Science Center

Ribbon seals are listed as a species of concern under the Endangered Species Act due to their reliance on diminishing sea ice.

MAP DATA SOURCES

BEARDED SEAL MAP

Extent of Range: Cameron et al. (2010)

Regular Use (Winter/Spring): Audubon Alaska (2016a) based on Cameron et al. (2010), Bengtson et al. (2005), and National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014)

Regular Use (Year-round): Audubon Alaska et al. (2017); Huntington et al. (2015b); National Oceanic and Atmospheric Administration (1988); Stephenson and Hartwig (2010)

Concentration Area (Winter/Spring): Oceana (2013) based on Bengtson et al. (2005) and National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014)

Concentration Area (Year-round): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

High Concentration Area (Winter/Spring): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

High Concentration Area (Summer/Fall): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

High Concentration Area (Year-round): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

Haulouts: Huntington et al. (2012)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

RIBBON SEAL MAP

Extent of Range: Boveng et al. (2013)

Regular Use (Winter/Spring): Audubon Alaska et al. (2017); Boveng et al. (2013)

Regular Use (Summer/Fall): National Oceanic and Atmospheric Administration (1988)

Regular Use (Year-round): Audubon Alaska et al. (2017); Boveng et al. (2013b)

Concentration (Winter/Spring): National Oceanic and Atmospheric Administration (1988)

Concentration (Summer/Fall): National Oceanic and Atmospheric Administration (1988)

High Concentration (Winter/Spring): National Oceanic and Atmospheric Administration (1988)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

RINGED SEAL MAP

Extent of Range: Kelly et al. (2010b)

Regular Use (Winter/Spring): Audubon Alaska (2017c) based on Bogoslovskaya et al. (2016), Kelly et al. (2010b), and National Oceanic and Atmospheric Administration (1988)

Regular Use (Year-round): Audubon Alaska (2009b); Audubon Alaska et al. (2017); Huntington et al. (2015b); Huntington et al. (2016a); National Oceanic and Atmospheric Administration (1988); Stephenson and Hartwig (2010)

Concentration (Winter/Spring): Audubon Alaska (2017b) based on Audubon Alaska (2009c), Eicken et al. (2009), Hartwig (2009), Kelly et al. (2010b), National Oceanic and Atmospheric Administration (1988), National Snow and Ice Data Center and Konig Beatty (2012), Oceana and Kawerak (2014), Satterthwaite-Phillips et al. (2016), and Stephenson and Hartwig (2010); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014)

Concentration (Summer/Fall): Hartwig (2009); Harwood and Stirling (1992); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016)

Concentration (Year-round): Audubon Alaska et al. (2017); Hartwig (2009)

High Concentration (Winter/Spring): Audubon Alaska et al. (2017); Huntington et al. (2015a); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016)

High Concentration (Year-round): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

SPOTTED SEAL MAP

Extent of Range: Boveng et al. (2009)

Winter/Spring Range: Audubon Alaska (2016n) based on Boveng et al. (2009), Lowry et al. (1998), National Oceanic and Atmospheric Administration (1988), and Oceana and Kawerak (2014)

Regular Use (Winter/Spring): Boveng et al. (2009); Lowry et al. (1998); National Oceanic and Atmospheric Administration (1988)

Regular Use (Summer/Fall): Audubon Alaska (2009d) based on Lowry et al. (1998); Huntington et al. (2015b); Lowry et al. (1998); National Oceanic and Atmospheric Administration (1988)

Regular Use (Year-round): Audubon Alaska et al. (2017); Lowry et al. (1998); National Oceanic and Atmospheric Administration (1988)

Concentration (Winter/Spring): Audubon Alaska et al. (2017); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014)

Concentration (Summer/Fall): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

Concentration (Year-round): Audubon Alaska et al. (2017)

High Concentration (Winter/Spring): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

High Concentration (Summer/Fall): Audubon Alaska et al. (2017); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016)

High Concentration (Year-round): Audubon Alaska et al. (2017); Oceana and Kawerak (2014)

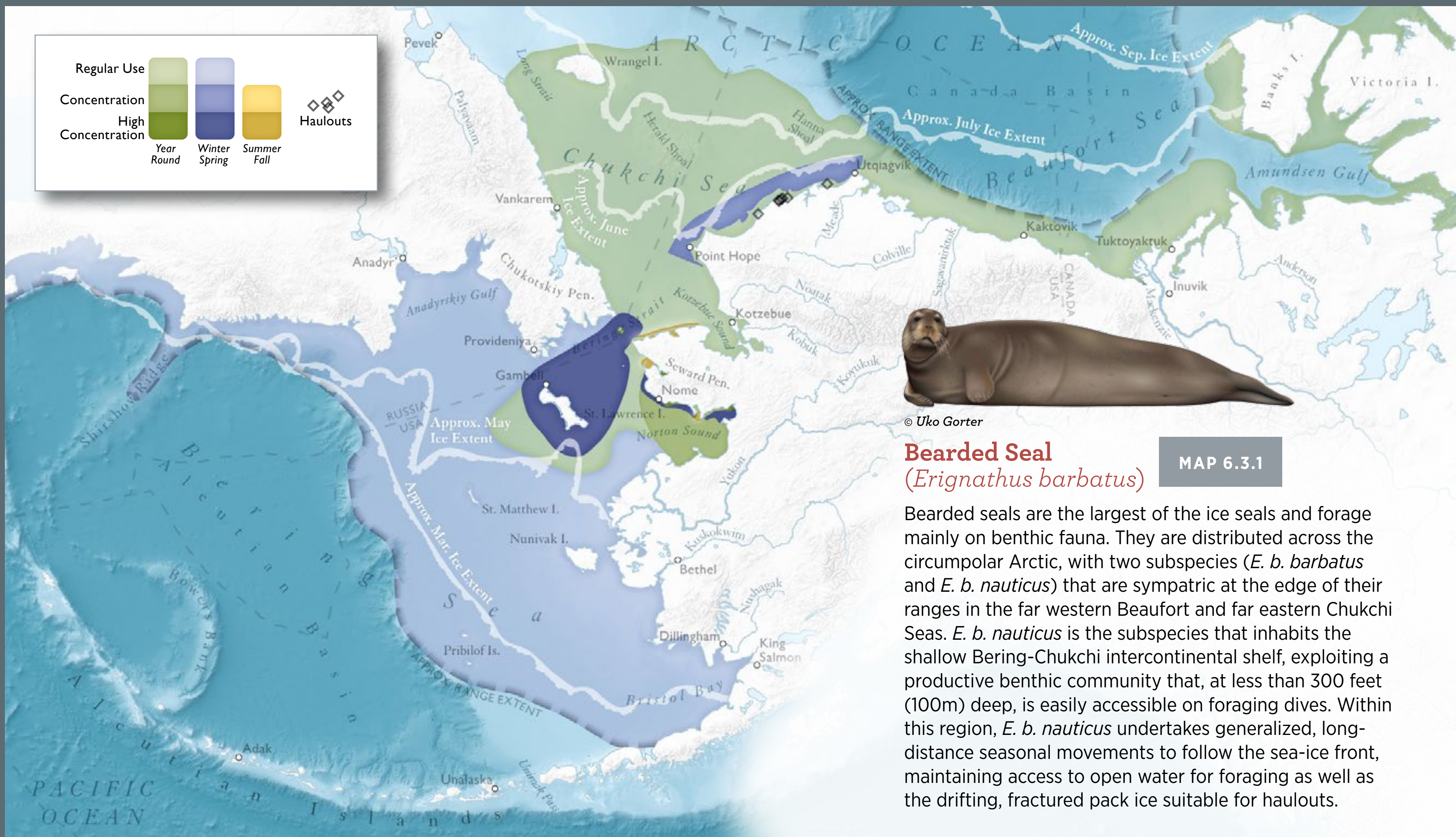
Haulouts: Huntington and Quakenbush (2013); Huntington et al. (2012); Kawerak (2013); Lowry et al. (1998); National Oceanic and Atmospheric Administration (1988); National Oceanic and Atmospheric Administration (2005)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

KAWERAK, INC. OCEANA Audubon ALASKA

Ice Seals

Map Authors: Erika Knight, Melanie Smith, and Max Goldman
Cartographer: Daniel P. Huffman

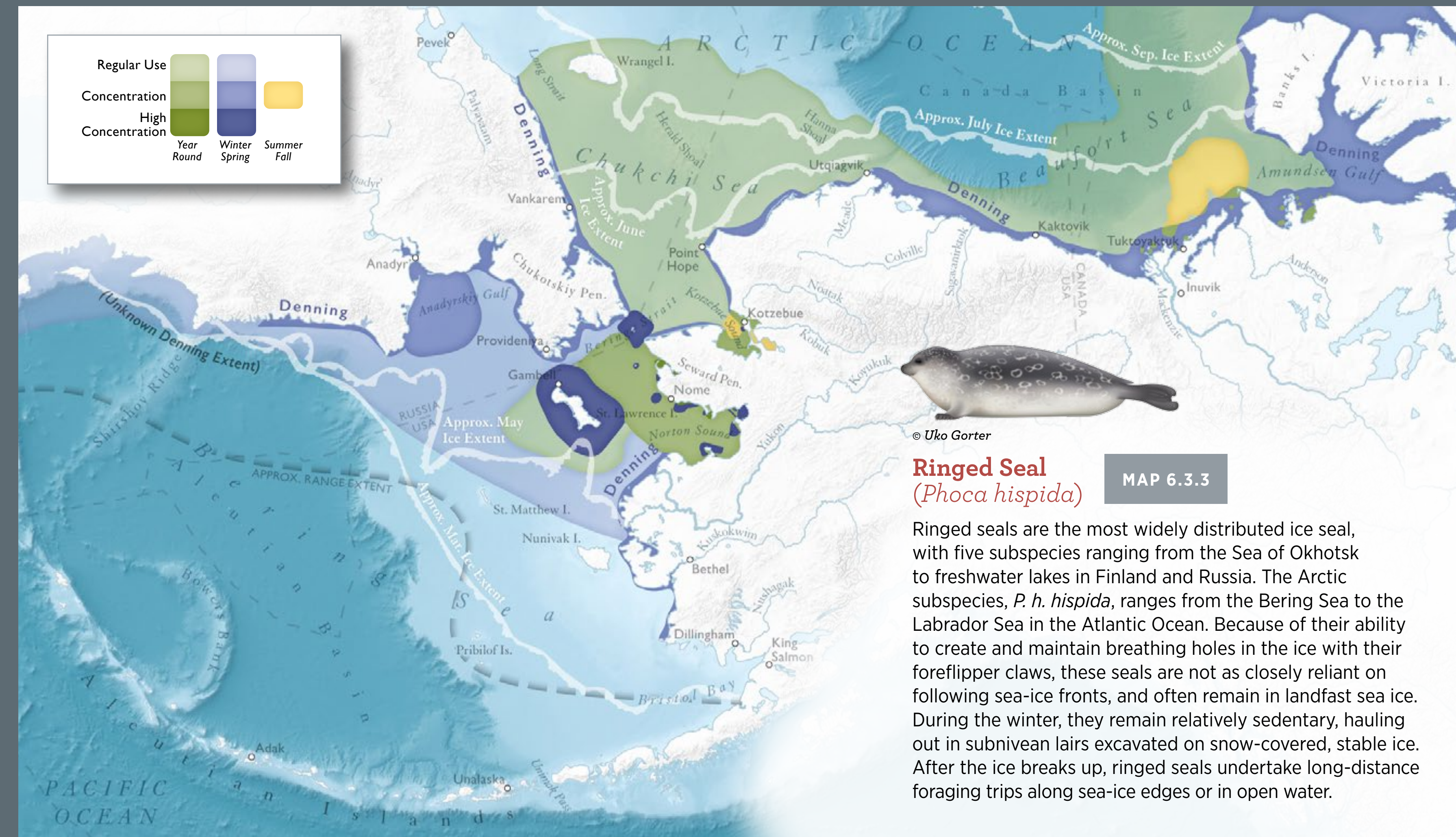


Bearded Seal
(Erignathus barbatus)

MAP 6.3.1

Bearded seals are the largest of the ice seals and forage mainly on benthic fauna. They are distributed across the circumpolar Arctic, with two subspecies (*E. b. barbatus* and *E. b. nauticus*) that are sympatric at the edge of their ranges in the far western Beaufort and far eastern Chukchi Seas. *E. b. nauticus* is the subspecies that inhabits the shallow Bering-Chukchi intercontinental shelf, exploiting a productive benthic community that, at less than 300 feet (100m) deep, is easily accessible on foraging dives. Within this region, *E. b. nauticus* undertakes generalized, long-distance seasonal movements to follow the sea-ice front, maintaining access to open water for foraging as well as the drifting, fractured pack ice suitable for haulouts.

Audubon Alaska (2016a) [based on Cameron et al. (2010), Bengtson et al. (2005), and National Oceanic and Atmospheric Administration (1988)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska et al. (2017); Cameron et al. (2010); Huntington et al. (2012); Huntington et al. (2015b); National Oceanic and Atmospheric Administration (1988); Oceana (2013) [based on Bengtson et al. (2005) and National Oceanic and Atmospheric Administration (1988)]; Oceana and Kawerak (2014); Stephenson and Hartwig (2010)

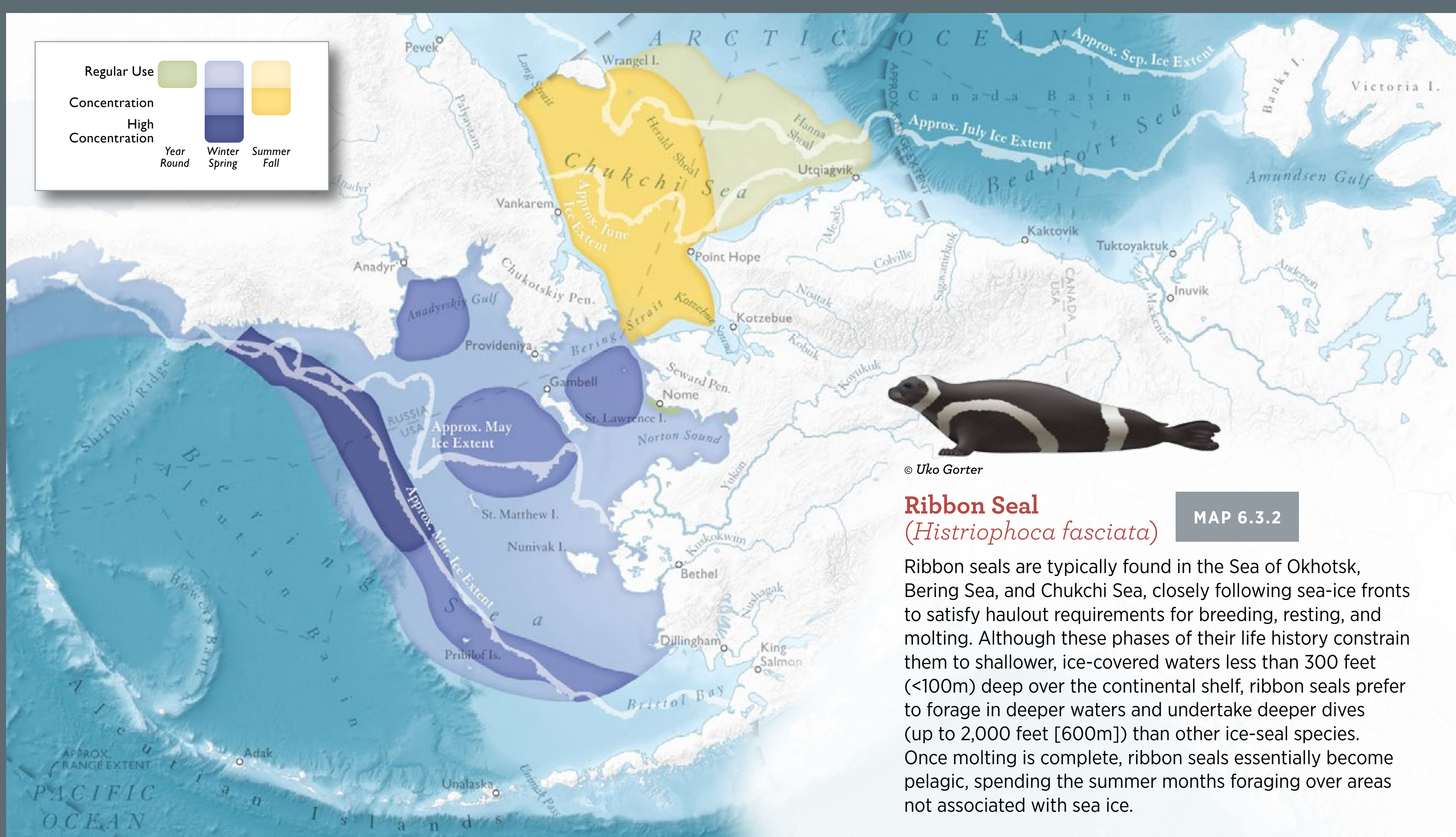


Ringed Seal
(Phoca hispida)

MAP 6.3.3

Ringed seals are the most widely distributed ice seal, with five subspecies ranging from the Sea of Okhotsk to freshwater lakes in Finland and Russia. The Arctic subspecies, *P. h. hispida*, ranges from the Bering Sea to the Labrador Sea in the Atlantic Ocean. Because of their ability to create and maintain breathing holes in the ice with their foreflipper claws, these seals are not as closely reliant on following sea-ice fronts, and often remain in landfast sea ice. During the winter, they remain relatively sedentary, hauling out in subnivean lairs excavated on snow-covered, stable ice. After the ice breaks up, ringed seals undertake long-distance foraging trips along sea-ice edges or in open water.

Audubon Alaska (2009b); Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2017b) [based on Audubon Alaska (2009c), Eicken et al. (2009), Hartwig (2009), Kelly et al. (2010b), National Oceanic and Atmospheric Administration (1988), National Snow and Ice Data Center and Konig Beatty (2012), Oceana and Kawerak (2014), Satterthwaite-Phillips et al. (2016), and Stephenson and Hartwig (2010)]; Audubon Alaska (2017c) [based on Bogoslovskaya et al. (2016), Kelly et al. (2010b), and National Oceanic and Atmospheric Administration (1988)]; Audubon Alaska et al. (2017); Hartwig (2009); Harwood and Stirling (1992); Huntington et al. (2015a); Huntington et al. (2015b); Kelly et al. (2010b); National Oceanic and Atmospheric Administration (1988); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016); Stephenson and Hartwig (2010)

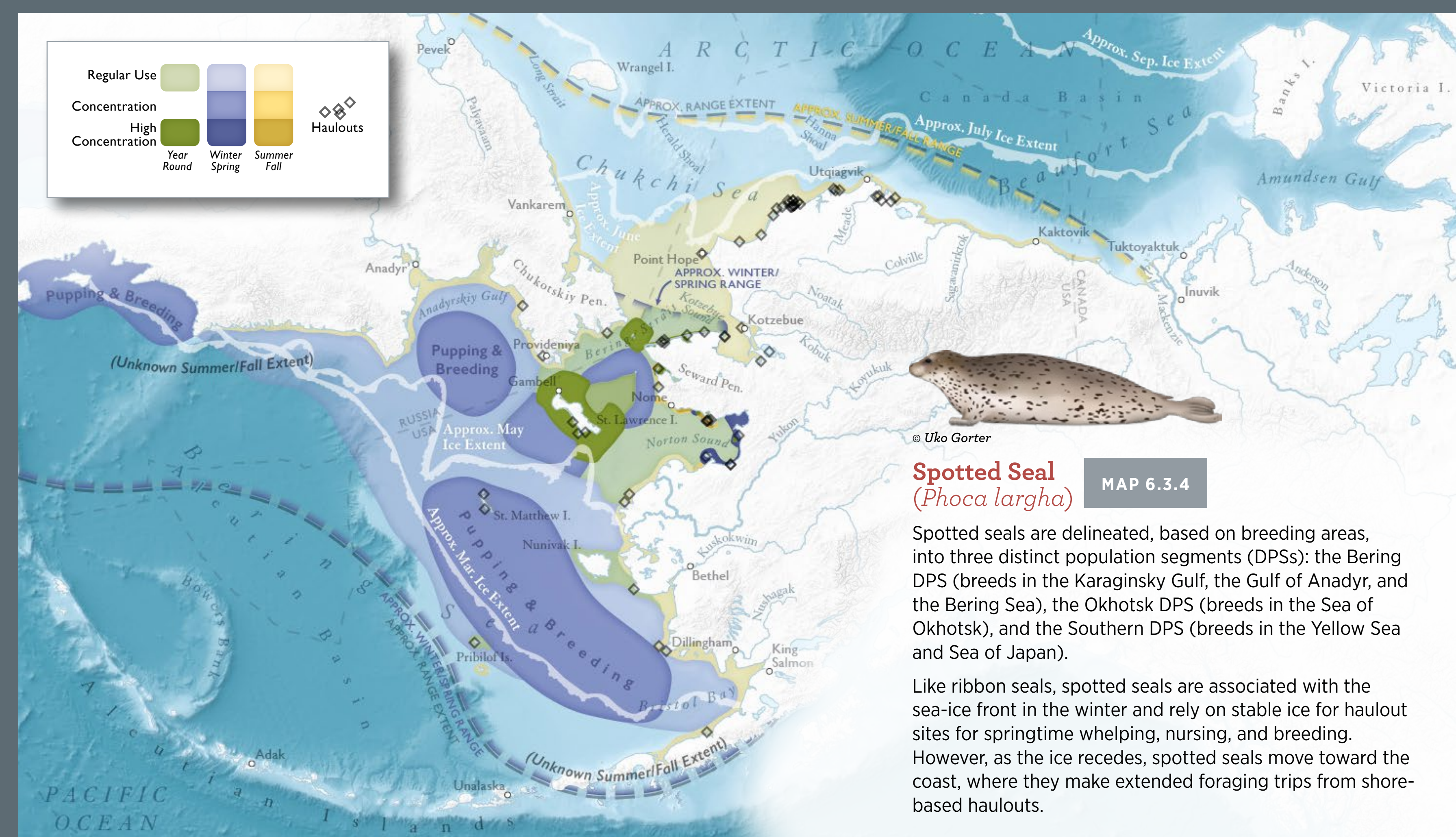


Ribbon Seal
(Histriophoca fasciata)

MAP 6.3.2

Ribbon seals are typically found in the Sea of Okhotsk, Bering Sea, and Chukchi Sea, closely following sea-ice fronts to satisfy haulout requirements for breeding, resting, and molting. Although these phases of their life history constrain them to shallower, ice-covered waters less than 300 feet (<100m) deep over the continental shelf, ribbon seals prefer to forage in deeper waters and undertake deeper dives (up to 2,000 feet [600m]) than other ice-seal species. Once molting is complete, ribbon seals essentially become pelagic, spending the summer months foraging over areas not associated with sea ice.

Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska et al. (2017); Boveng et al. (2013); National Oceanic and Atmospheric Administration (1988)



Spotted Seal
(Phoca largha)

MAP 6.3.4

Spotted seals are delineated, based on breeding areas, into three distinct population segments (DPSs): the Bering DPS (breeds in the Karaginsky Gulf, the Gulf of Anadyr, and the Bering Sea), the Okhotsk DPS (breeds in the Sea of Okhotsk), and the Southern DPS (breeds in the Yellow Sea and Sea of Japan).

Like ribbon seals, spotted seals are associated with the sea-ice front in the winter and rely on stable ice for haulout sites for springtime whelping, nursing, and breeding. However, as the ice recedes, spotted seals move toward the coast, where they make extended foraging trips from shore-based haulouts.

Audubon Alaska (2009d) [based on Lowry et al. (1998)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2016n) [based on Boveng et al. (2009), Lowry et al. (1998), National Oceanic and Atmospheric Administration (1988), and Oceana and Kawerak (2014)]; Audubon Alaska et al. (2017); Boveng et al. (2009); Huntington and Quakenbush (2013); Huntington et al. (2012); Huntington et al. (2015b); Huntington et al. (2016a); Kawerak (2013); Lowry et al. (1998); National Oceanic and Atmospheric Administration (1988); National Oceanic and Atmospheric Administration (2005); Oceana and Kawerak (2014); Satterthwaite-Phillips et al. (2016)

MAP ON PAGES 234–235

Steller Sea Lion

Eumetopias jubatus

Jon Warrenchuk, Brianne Mecum, and Marilyn Zaleski

The Steller sea lion (*Eumetopias jubatus*) is the third largest of the pinnipeds, after the walrus (*Odobenus rosmarus*) and the elephant seal (*Mirounga* spp.), and is a top fish predator. Georg Steller, for whom the Steller sea lion was named, described the species in 1741 after being shipwrecked with them on Bering Island. He called the animals "sea lions" because the males' tawny mane and bellowing roar reminded him of African lions. However, the native Unangan people of the Aleutian Islands had long been intimately familiar with "Steller's" sea lions. They called them qawan, and for thousands of years relied on them as a source of food, clothing, and even transportation, inventing kayaks made from the sea lions' waterproof skins.

The habitat of Steller sea lions extends around the North Pacific Ocean from eastern Japan and Russia through the Aleutian Islands, Bering Sea, Gulf of Alaska (GOA), and down the west coast of North America to Central California. Steller sea lions are gregarious, and during the breeding season they concentrate at traditional terrestrial haulout sites called rookeries to give birth and mate. There are 10 Steller sea lion rookeries in Russia, 50 in Alaska, 7 in British Columbia, 1 in Washington, 2 in Oregon, and 3 in California (Kenyon and Rice 1961; Loughlin et al. 1984, 1987, 1992).

ADAPTATIONS

Steller sea lions are the largest member of the family of eared seals (*Otariidae*) and have external ears and rear flippers that can turn forward, allowing them to "walk" with a gait similar to land mammals. They swim using their strong fore flippers and steer with their rear flippers (unlike true seals, which propel themselves with their rear flippers and by undulating their bodies). Steller sea lions are quick and agile swimmers and reach bursts of speed by porpoising at the surface. They can live for 20 or 30 years, with females weighing up to 770 pounds (350 kg) and males up to 2,500 pounds (1,130 kg). Most females reach maximum size by age 7, and males reach adult size by age 12 (Muto et al. 2016).

At birth, a sea lion pup's chocolate brown coat has a frosty appearance because of the colorless tips of their hair. Color gradually lightens as the animal ages and it periodically molts. Most adult females are a yellowish-cream color on the back, although some remain darker. Nearly all males stay darker on the front of the neck and chest; although some are even a reddish color (Loughlin et al. 1987, Hoover 1988).

Steller sea lions have a thinner blubber layer than seals and tend to be larger and leaner (Mellish et al. 2007). Their likely strategy for survival is to eat voraciously; they have relatively large stomachs and can consume up to 16% of their body weight per day (Rosen and Trites 2004).

Vocalizations

Steller sea lions are amongst the most vocal of marine mammals. Their low-pitched "roars" are distinct from the higher pitched "barking" sounds of the smaller California sea lions where they co-occur. Pups make sounds that could be described as mewling, bleating, or yowling. Females with pups have individually distinct calls, which aid in reuniting mothers and pups on crowded rookeries (Campbell et al. 2002). Roars of territorial males can be "threat calls" that help establish dominance without physical confrontation (Gisiner 1985, Insley et al. 2003). Underwater, Steller sea lions can hear a range of frequencies. Their hearing sensitivity overlaps with the frequencies that orcas use for social calls and echolocation, which may help them avoid these predators (Kastelein et al. 2005).

DISTRIBUTION

The range of Steller sea lions extends around the North Pacific Ocean Rim from northern Japan, the Kuril Islands and Okhotsk Sea, through the Aleutian Islands and the Bering Sea, along Alaska's southern coast, and south to California (Kenyon and Rice 1961; Loughlin et al. 1984, 1987, 1992). The northernmost rookery is in Prince William Sound in the Gulf of Alaska (60°10'N, 146°50'W) and Walrus Island off St. Paul Island in the Pribilofs is the northernmost rookery in the Bering Sea. Currently, Año Nuevo Island off central California is the southernmost rookery (37°06'N), although until 1981, some pups were born farther south at San Miguel Island (34°05'N).

Steller sea lions used to be more abundant in different parts of their range. In the 1980s, the population declined rapidly. Prior to the decline, most large rookeries were in the Gulf of Alaska and Aleutian Islands (Kenyon and Rice 1961; Calkins et al. 1982; Loughlin et al. 1984, 1992; Merrick and Loughlin 1997). However, as the decline continued, rookeries in the west became smaller. The largest rookeries are now in Southeast Alaska and British Columbia.

As many as 15,000 Steller sea lions may have inhabited the Pribilof Islands in the late 19th century, but culling reduced the population to a few hundred by 1914, before regulations were enacted to reduce takes (Kenyon 1962, Loughlin et al. 1984). Now only a few dozen pups are born each year at the last remaining Pribilof rookery at Walrus Island (L. Fritz pers. comm.).

Genetic research has identified three stocks of Steller sea lions (Baker et al. 2005, O'Corry-Crowe et al. 2006), two of which are recognized as distinct population segments (DPSs) under the Endangered Species Act (ESA): the Eastern stock, which breeds on rookeries located east of 144°W in Southeast Alaska, British Columbia, Washington, Oregon, and California; and the Western stock, which breeds on rookeries located primarily west of 144°W in Alaska and Russia. The third, or Asian stock, has not been formally recognized by the National Marine Fisheries Service (NMFS), and breeds on all rookeries in Asia except for the Commander Islands.

Migration

In winter, Steller sea lions may move from their rookeries on the exposed coast to areas more protected from the weather or to the lee sides of islands. They can move over long distances, and adult males, in particular, may disperse widely after the breeding season (Kenyon and Rice 1961, Jemison et al. 2013). During fall and winter, many Steller sea lions disperse from rookeries and increase their use of haulouts, even hauling out on sea ice in the Bering Sea. They also gather at sea in protected bays and channels in tightly packed groups, or "rafts," near haulouts in winter.

LIFE CYCLE

Steller sea lions gather on habitually used rookeries on exposed, remote islands to give birth and breed. Dominant males defend individual territories on their rookery from approximately mid-May through mid-July (Pitcher and Calkins 1981). Females mate with males who can hold the most preferred territory (Parker and Maniscalco 2014). Georg Steller observed that the males "hold the females in great respect" in contrast to northern fur seals (*Callorhinus ursinus*) that treat their females "harshly" (Steller 1899). During the breeding season, males typically do not leave their territory and will not eat for two months.

Females give birth to a single pup from mid-May through July, after 11.5 months of gestation (Pitcher and Calkins 1981). They breed shortly after giving birth, but the fertilized egg does not implant in the uterus and begin growing until October. Some females first breed at the age of three, but by their sixth year, nearly all are breeding and producing pups. They generally return to their rookery of birth to breed (Calkins et al. 1982), but may disperse to a nearby rookery (Raum-Suryan et al. 2002). Males are able to breed at three to six years of age, but they must do so sneakily until they are older than nine, when they are large enough to compete for territories with dominant males (Pitcher and Calkins 1981).

MAP ON PAGES 234–235

Steller sea lion mothers nurse their pups for up to three years, and pups are weaned just prior to the next breeding season (Pitcher and Calkins 1981, Trites et al. 2006). Pups are left onshore for 7 to 62 hours while the mother goes to sea to feed, depending on how long it takes her to find food (Hood and Ono 1997). A pup's early growth is key to its survival. Steller sea lion milk is energy-rich and contains 20–30% fat and a variety of essential fatty acids (Higgins et al. 1988, Miller 2014). The pups are nursed at the rookery for two to three months before dispersing with the mothers to haulouts (Trites and Porter 2002). Pups as young as three months old can start catching their own fish to supplement their milk diet (Raum-Suryan et al. 2002).

Diet

Steller sea lions eat a wide variety of fishes, such as walleye pollock (*Gadus chalcogrammus*), Atka mackerel (*Pleurogrammus monopterygius*), Pacific herring (*Clupea pallasii*), Pacific sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), Pacific cod (*Gadus macrocephalus*), salmon (*Onchorhynchus spp.*), rockfish, sculpins, flatfish, and invertebrates such as squid and octopus. Most of their top-ranked prey are off-bottom, schooling species. Feeding occurs from the intertidal zone to the continental shelf, and Steller sea lions are considered top-level consumers. They have regionally specific diets (Sinclair et al. 2005) and seem to remember when and where predictable concentrations of prey occur (Sigler et al. 2009). In the Gulf of Alaska, their diets include pollock, salmon, and arrowtooth flounder (*Atheresthes stomias*); in the western GOA and eastern Aleutian Islands their most important prey are pollock, salmon, Atka mackerel, sand lance, and herring; while those in the western Aleutians eat Atka mackerel, Pacific cod and cephalopods (Sinclair et al. 2005).

Transient killer whales (*Orcinus orca*), and possibly sleeper sharks (*Somniosus pacificus*) prey on Steller sea lions (Maniscalco et al. 2007, Horning and Mellish 2014). Pups can die from drowning, or starvation if separated from the mother, as well as disease, parasitism, predation, crushing by adults, bites from other Steller sea lions, and complications during birth (Orr and Poulter 1967, Edie 1977, Maniscalco et al. 2002, Maniscalco et al. 2007). Older animals may die from starvation, injuries, disease, predation, subsistence harvests, intentional shooting by humans, entanglement in marine debris, and fishery interactions (Merrick et al. 1987).

CONSERVATION ISSUES

Steller sea lions were listed as a threatened species under the ESA in 1990. In 1997, it was determined that they actually comprised two DPSs: an Eastern stock from California through Southeast Alaska to Cape Suckling, and a Western stock from Cape Suckling through the Aleutian Islands to the Sea of Okhotsk in Russia. The Western DPS (WDPS) was re-classified as endangered, while the Eastern DPS (EDPS) retained the threatened classification (National Marine Fisheries Service 1997). The EDPS is now considered recovered and has been de-listed from the ESA.

Steller sea lions were historically a crucial source of food and tools for inhabitants of the Aleutian Islands. Clothing, boots, and kayaks were made from skins. The blubber and meat is described as "sweet" and "well flavored" and the gelatinous flippers are considered a prime delicacy (Steller 1899). Steller sea lions are still a culturally significant subsistence food source today.

In contrast, the modern era has seen attempts to deliberately exterminate Steller sea lions and reduce their population. During the early development of commercial fisheries in Alaska, they were often shot on sight by fishermen, who perceived them as competitors (Turek et al. 2008). Anecdotal reports told of military planes using sea lions as target practice in the 1940s (National Research Council 2003). The federal Bureau of Commercial Fisheries even instituted a predator control program for seals and sea lions in 1951 (Turek et al. 2008). Between 1964 and 1972, Steller sea lion pups were commercially harvested for their fur (Merrick et al. 1987). A commercial Steller sea lion meat harvest was encouraged for fox farmers to use as fox food (Thorsteinson et al. 1961, Merrick et al. 1987).

Competition between commercial groundfish fisheries that target Steller sea lion prey (pollock, Pacific cod, and Atka mackerel) likely continues to affect the sea lion population, particularly in the western Aleutians where populations declined at 7% per year between 2003 and 2016 (Sweeney et al. 2016). Fishery management measures have been put into place to reduce possible interactions with boats and competition for resources, including area closures and seasonal fishery limits in Steller sea lion critical habitat (National Marine Fisheries Service 2014).

From the 1950s through the 1970s, the worldwide abundance of Steller sea lions was estimated at 240,000 to 300,000 animals (Kenyon and Rice 1961, Loughlin et al. 1984). In the 1980s, the population decreased rapidly, mostly in the range of what is now recognized as the western population and by 1990, the US portion of the population had declined by about 80% (Loughlin et al. 1992). The worldwide population likely reached its smallest size (~105,000 animals) in 2000 when the overall decline of the WDPS stopped.

In 2015, the worldwide population of Steller sea lions was estimated to be around 137,000 animals, which includes about 60,000 animals in the Eastern stock and 50,000 animals in the Western stock, including the Russian population (Muto et al. 2016).

MAPPING METHODS (MAP 6.4)

Steller sea lion general range distribution is from the map figure displayed in the Steller sea lion stock assessment in Muto et al. (2016).

Steller sea lion haulout and rookery locations are from Fritz et al. (2015b) and were joined to non-pup and pup count data also from Fritz et al. (2015a) and Fritz et al. (2015c). Rookeries and haulout locations in Russian waters are from L. Fritz (pers. comm.).

Female foraging areas were created from text descriptions in Merrick and Loughlin (1997), which describe seasonal foraging distance based on satellite telemetry locations of tagged female Steller sea lions. Buffers of described distances were drawn from known haulouts and rookeries. Both maximum and minimum distances are displayed to show the general range of seasonal foraging areas.

The migration of male Steller sea lions in their western range was documented by Kenyon and Rice (1961) and was based on aerial surveys and at-sea observations. The migration arrow was drawn based on text descriptions that describe seasonal movement from the Aleutian and Pribilof Islands in the summer northward past St. Matthew and Hall Islands toward the northern Bering Sea as far as the Bering Strait at 65°45'N.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality

Foraging ranges and movement patterns of Steller sea lions are estimated from field observations and telemetry-tagged animals and may not necessarily be indicative of the population as a whole.

Reviewer

- Lowell Fritz

MAP DATA SOURCES

Range Extent: Muto et al. (2016)

Haulouts: Fritz et al. (2015a, b, c); L. Fritz (pers. comm.)

Adult Female Foraging (Average–Winter): Merrick and Loughlin (1997)

Seasonal Migration: Kenyon and Rice (1961)

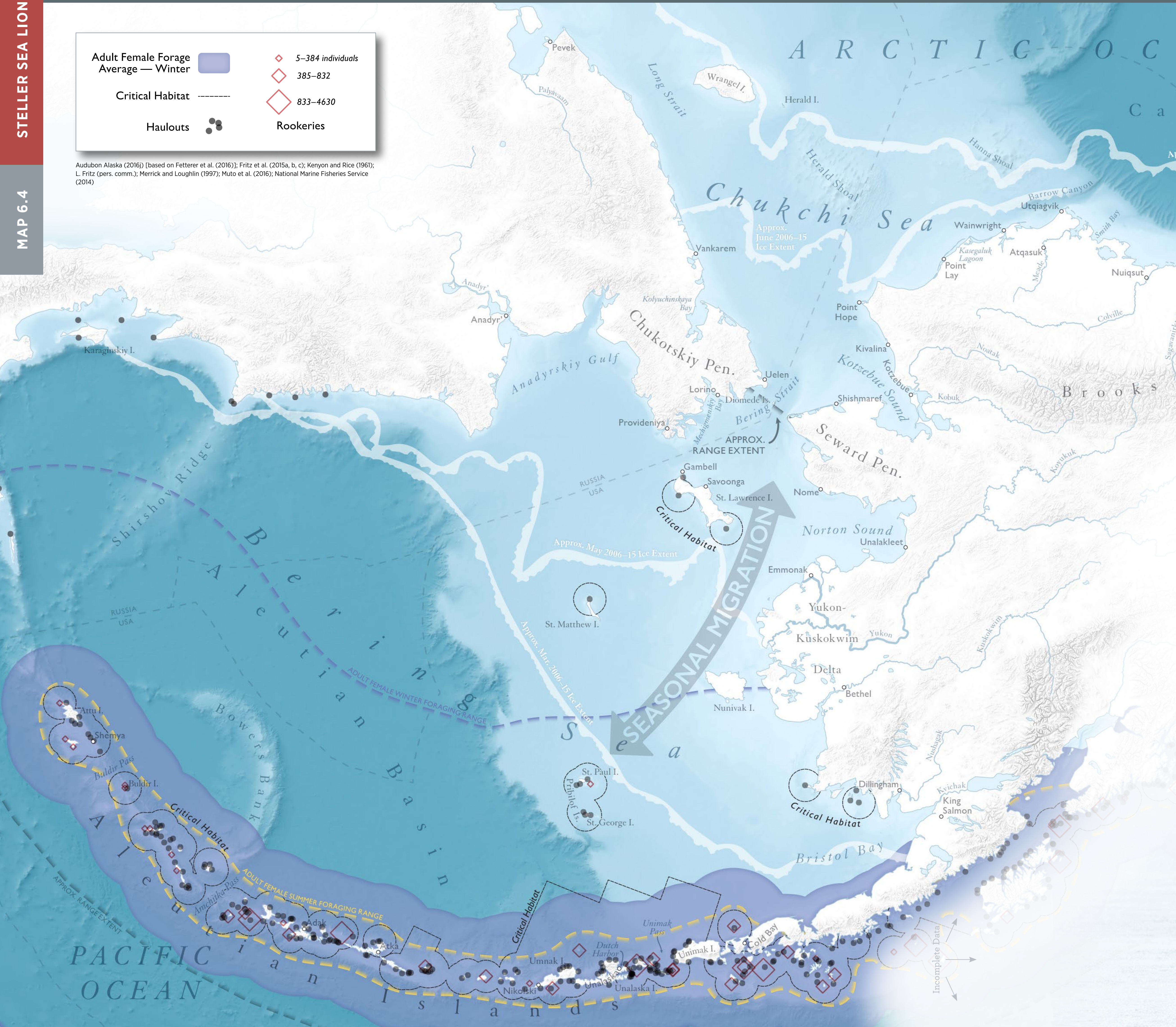
Critical Habitat: National Marine Fisheries Service (2014)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

Steller Sea Lion

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA



Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Fritz et al. (2015a, b, c); Kenyon and Rice (1961); L. Fritz (pers. comm.); Merrick and Loughlin (1997); Muto et al. (2016); National Marine Fisheries Service (2014)

Steller Sea Lion (*Eumetopias jubatus*)

The habitat of Steller sea lions extends around the North Pacific Ocean from eastern Japan and Russia through the Aleutian Islands, Bering Sea, Gulf of Alaska, and down the west coast of North America to Central California. Steller sea lions are gregarious, and during the breeding season they concentrate at traditional terrestrial haulouts called rookeries to give birth and mate. There are 10 Steller sea lion rookeries in Russia, 50 in Alaska, 7 in British Columbia, 1 in Washington, 2 in Oregon and 3 in California.

In winter, Steller sea lions may move from their rookeries on the exposed coast to areas more protected from the weather or to the lee sides of islands. They can move over long distances, and adult males, in particular, may disperse widely after the breeding season. During fall and winter, many Steller sea lions disperse from rookeries and increase their use of haulouts, even hauling out on sea ice in the Bering Sea. They also gather at sea in protected bays and channels in a tightly packed group, or "rafts", near haulouts in winter.

Steller sea lions eat a wide variety of fishes, and invertebrates such as squid and octopus. Feeding occurs from the intertidal zone to the continental shelf, and Steller sea lions are considered top-level predators.

Vladimir Burkanov / NOAA Fisheries, Alaska Fisheries Science Center

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Northern Fur Seal

Callorhinus ursinus

Jon Warrenchuk and Brianne Mecum

The northern fur seal (*Callorhinus ursinus*) is a pinniped, and spends most of its life at sea. It comes ashore in the spring and gathers at colonial breeding sites, or rookeries, on only a few islands in the world. The home range of the northern fur seal covers a vast area—from the Bering Strait to the California Current ecosystem. Despite its expansive range, 50% of the northern fur seal population returns to the Pribilof Island rookeries in the Bering Sea to breed and give birth to their young. Northern fur seals were subject to a major commercial harvest for their fur, first starting when Russian explorers discovered the Pribilof Island rookeries in 1796, and continued by the US after the purchase of Alaska until 1984.

ADAPTATIONS

Northern fur seals are members of the family *Otariidae* (the eared seals) and have external ears and rear flippers that can turn forward, allowing them to "walk" with a gait similar to land mammals. They are likely "visual" predators, and their large eyes aid them in hunting at night or in deep waters. They have a short snout and a stocky body, and were first described as "sea bears" (Steller 1899).

In the animal kingdom, only the sea otter (*Enhydra lutris*) has thicker fur than the northern fur seal (Irving et al. 1962). That thick fur subjected the fur seals to intense historical commercial harvest (Roppel and Davey 1965). Their long flippers, however, are bare, and aid in regulating their body temperature (Irving et al. 1962). Fur seals spend most of their lives at sea, and only come onshore to breed and give birth. They do not regularly haul out on land or ice like Steller sea lions (*Eumetopias jubatus*) or ice seals. Females weigh up to 120 pounds (55 kg) and males up to 600 pounds (275 kg) (Gentry 1998). Females can live for 25–30 years, but males only live 9–12 years as the rigors of defending breeding territory result in a diminished lifespan (Gentry 1998).

Vocalizations

Early biologists believed fur seals to have three different kinds of speech (Steller 1899). A "lowing of cows" when lazing about, a roar or growl of a bear when battling, and a sharp and repeated note like crickets when victorious in battle (Steller 1899). The roars and growls of territorial males can be interpreted as threat calls by other individuals and may help establish dominance without physical confrontation (Insley et al. 2003). Females and their pups find each other on crowded rookeries through vocalization, and pups can remember their mothers' unique calls for at least four years (Insley 2000).

DISTRIBUTION

Five stocks of northern fur seals are identified for management purposes: the Eastern Pacific stock which comprises the northern fur seal population of the Pribilof Islands and Bogoslof Island; the Commander Islands, Kuril Islands, and Robben Island stocks in Russia; and the California stock off southern California (Dizon et al. 1992). The Pribilof Islands used to support most of the world's northern fur seals but now account for about half of the global population. There are 15 rookeries on St. Paul Island and 6 rookeries on St. George Island. Bogoslof Island is a geologically young island; it was an underwater volcano and first emerged from the sea in 1796. Northern fur seals discovered the island and were noticed using it as a rookery in 1980 (Lloyd et al. 1981). Since then, pup production on Bogoslof Island increased exponentially but now may be stabilizing (Kuhn et al. 2014). The Bogoslof volcano erupted multiple times in 2016 and 2017.

Northern fur seals spend most of their life at sea and concentrate at major oceanographic frontal features formed by offshore seamounts, canyons, and the continental shelf break (Loughlin et al. 1999, Ream et al. 2005, Pelland et al. 2014, Sterling et al. 2014). In the winter, males spend more time in the Bering Sea and along the Aleutian Islands, while the females forage further south in the central North Pacific, Gulf of Alaska, and within the California Current ecosystem.

In the 1870s, a US government agent estimated the Pribilof Islands northern fur sea population at 4.7 million animals (Coues 1877, Elliott 1882) although some scientists believe this was an overestimate. In the 1950s, the Eastern Pacific stock of northern fur seals comprised an estimated 1.8–2.1 million animals (National Marine Fisheries Service 2007).

The most recent population estimate for the Eastern Pacific stock of northern fur seals is based on counts of the pups at rookeries from 2008 to 2012 and is estimated at 648,534 animals (Muto et al. 2016). It is likely that the current population is lower given the declining number of pups born at the main breeding rookeries in the Pribilof Islands.

Migration

Northern fur seals disperse widely through the Pacific when they leave their summer breeding rookeries. After the pups are weaned, females leave the rookeries and migrate south, traveling through the passes in the Aleutian Islands and into the central North Pacific, Gulf of Alaska, and California Current (Ream et al. 2005). Older males remain in the Bering Sea longer and do not migrate as far south as the females (Loughlin et al. 1999, Sterling et al. 2014). Unimak Pass is a primary migration corridor, used twice per year as the animals leave and return to the Bering Sea (Ragen et al. 1995). In the winter, the females can be found dispersed from southern California to the Sea of Okhotsk and southern Japan off Asia (Kajimura and Loughlin 1988, Ream et al. 2005, Pelland et al. 2014).

LIFE CYCLE

Northern fur seals are territorial and most return to the rookeries where they were born to breed (Gentry 1998). Reproductive males begin to compete for territories on the rookeries when about seven to nine years old (Johnson 1968). Females become sexually mature between 4 and 7 years old (York 1983) but can remain reproductive up to at least the age of 23 (Lander 1981).

Males arrive on rookeries in mid-May and pregnant females begin to arrive in mid-June (Gentry 1998). The males do not eat while defending their territories and lose a quarter of their body mass over this time period (Gentry 1998). Females give birth to a single pup within two days of arrival on shore, and then mate with the dominant male of the territory three to eight days later (Gentry 1998). Females experience delayed implantation, and the fertilized egg implants later in early winter while the females are at sea (York and Scheffer 1997).

Mothers leave the rookery to forage at sea and return to the rookery to nurse their pups. They spend three to ten days at sea foraging, depending upon how long it takes to find enough food, then return to the rookery for one to two days to nurse. The length of the females' foraging trip, and hence the frequency of pup nursing, can influence the rate of pup growth, as seen in the related Antarctic fur seal (Lunn et al. 1993). Pups are weaned after about four months and then must forage on their own. Pups spend 22 months at sea before returning to their natal rookeries as 2-year olds.

Diet

Northern fur seals rely on schooling forage fish, walleye pollock (*Gadus chalcogrammus*), and squid species, which varies by location and season (Sinclair et al. 1994, Robson et al. 2004, Ream et al. 2005, Gudmundson et al. 2006, Kuhn et al. 2014). The Bogoslof fur seals feed predominantly on deep-sea smelt (bathylagids), northern smoothtongue (*Leruoglossus schmidti*), and armhook (gonatid) squid (Kuhn et al. 2014) at night when the prey field migrates nearer the surface. The Pribilof fur seals feed primarily on walleye pollock and gonatid squid while foraging from their rookeries in the summer (Sinclair et al. 1994, Robson et al. 2004, Gudmundson et al. 2006). In the winter and spring, female fur seals feed on Pacific herring (*Clupea pallasi*), capelin (*Mallotus villosus*), sablefish (*Anoplopoma fimbria*), Pacific sand lance (*Ammodytes hexapterus*), walleye pollock, and squid in the Gulf of Alaska and off British Columbia, and Pacific hake (*Merluccius productus*), northern anchovy (*Engraulis mordax*), market squid (*Doryteuthis opalescens*), Pacific herring, and rockfish off the coasts of Washington, Oregon, and California (Antonelis and Perez 1984, Ream et al. 2005).

CONSERVATION ISSUES

In the early 20th century, after noting a declining and greatly reduced fur seal population, countries agreed to ban pelagic sealing and reduce commercial harvest in the Pribilofs. This Treaty for the Preservation and Protection of Fur Seals and Sea Otters was ratified by Canada, Japan, Russia, and the US in 1911 and was one of the first international wildlife management agreements (National Marine Fisheries Service 2007). The Fur Seal Act was passed in 1966, which further regulated the commercial harvest and also provided for the subsistence use of fur seals on the Pribilof Islands (National Marine Fisheries Service 2007).

After passage of the Marine Mammal Protection Act (MMPA), a commercial harvest moratorium and research sanctuary was established on St. George Island, while commercial harvest continued on St. Paul Island. The commercial harvest there ended in 1984. Northern fur seals were listed as depleted under the MMPA in 1988, when it was observed the population had declined to less than 50% of the levels observed in the 1950s (National Marine Fisheries Service 2007). In 1994, the MMPA was amended to include cooperative co-management of marine mammals by Alaska Native Organizations. The tribal governments of St. Paul and St. George signed fur seal co-management agreements with NMFS in 2000 and 2001 to manage the subsistence harvest.

The northern fur seals in the Pribilof Islands were subject to periods of intense commercial exploitation for their fur, first by Russia and then by the US Government after Alaska was purchased (National Marine Fisheries Service 2007). Seals were also taken at sea, and this practice of commercial pelagic sealing killed the lactating females that were on foraging trips when they were away from their pups on the rookeries (Roppel and Davey 1965, York and Hartley 1981). This at-sea harvest of the mothers also resulted in the deaths of the dependent pups back at the rookeries.

Northern fur seals have also been subject to past culling and predator control programs. From 1958 to 1964, the US Fisheries Service killed hundreds of thousands of breeding female fur seals at their rookeries in response to a request by Japan to reduce the fur seal population (York and Hartley 1981). Japan was concerned the fur seals were eating too much fish (York and Hartley 1981). The fur seal population subsequently plummeted.

Northern fur seals seem to be particularly vulnerable to entanglement in marine debris and fishing gear. Death through entanglement in debris and derelict gear has been thought to have population-level impacts in the past (Trites and Larkin 1989, Fowler et al. 1992). Thousands of northern fur seals were also incidentally killed each year by drift gillnet fisheries for squid in the high seas until the fishing practice was banned (National Marine Fisheries Service 2007).

Commercial fisheries have a potentially significant adverse effect on fur seals through competition for prey resources (National Marine Fisheries Service 2004). The Pribilof northern fur seals rely on walleye pollock for a large part of their diet and there is a high degree of overlap between age classes of pollock consumed by northern fur seals and pollock caught by the commercial fishery (Gudmundson et al. 2006). A great deal of commercial pollock fishing occurs where the fur seals forage around the Pribilof Islands.

The Eastern Pacific stock of northern fur seals is declining, and fewer pups are being produced on their main breeding rookeries of the Pribilof Islands (Muto et al. 2016). Pup production from the newer colony on Bogoslof Island now makes up 21% of the pups born in Alaska each year (Muto et al. 2016). Bogoslof Island was actively erupting in 2016 and 2017 and it is unknown how that will affect the pregnant females when they return in the spring.

MAPPING METHODS (MAP 6.5)

The summer feeding area polygon for Bogoslof Island fur seals was digitized from Figure 1 in Benoit-Bird et al. (2013). The feeding area polygon for St. George Island fur seals was digitized from Figure 3 in Robson et al. (2004). The feeding area for St. Paul Island fur seals was created by combining the digitized feeding areas from Figure 2 in Robson et al. (2004) and Figure 1 in Benoit-Bird et al. (2013). All feeding areas from both studies describe the feeding range from breeding sites for lactating females. Feeding areas from Benoit-Bird et al. (2013) are described by density kernels with the highest use occurring closer to the breeding sites (Bogoslof Island colony or St. Paul Island colony). For the purposes of this map, these areas were digitized to show only areas of either presence or absence.

Colony locations on St. Paul Island, St. George Island, and Bogoslof Island were obtained from National Oceanic and Atmospheric Administration (2015c).

Female fur seal migration data were based on satellite telemetry data from Sterling et al. (2014), who assessed the contrasting wintertime migration strategies of male and female fur seals. Females exhibited a typical migration pattern by leaving the Bering Sea generally through Unimak Pass and traveling southward toward the Gulf of Alaska and California Current. This same migration route has been documented by other studies. In contrast, male fur seals displayed a wide variety of migratory behaviors, so it was not possible to delineate a distinct migration route.

Data Quality

Data and information for northern fur seals were limited to the Eastern Pacific stock only. Because of their behavior and locations on only three islands in the Bering Sea, female northern fur seal foraging areas in the summer, and winter migration behavior for this stock is fairly well documented. Males, however, exhibit less predictable behavior so data for male northern fur seals are lacking.

Reviewers

- Jeremy Sterling

MAP DATA SOURCES

Summer Feeding Areas, Bogoslof Island Fur Seals: Benoit-Bird et al. (2013)

Summer Feeding Areas, St. Paul Island Fur Seals: Benoit-Bird et al. (2013); Robson et al. (2004)

Summer Feeding Areas, St. George Island Fur Seals: Robson et al. (2004)

Rookeries: National Oceanic and Atmospheric Administration (2015c)

Female Migration: Sterling et al. (2014)

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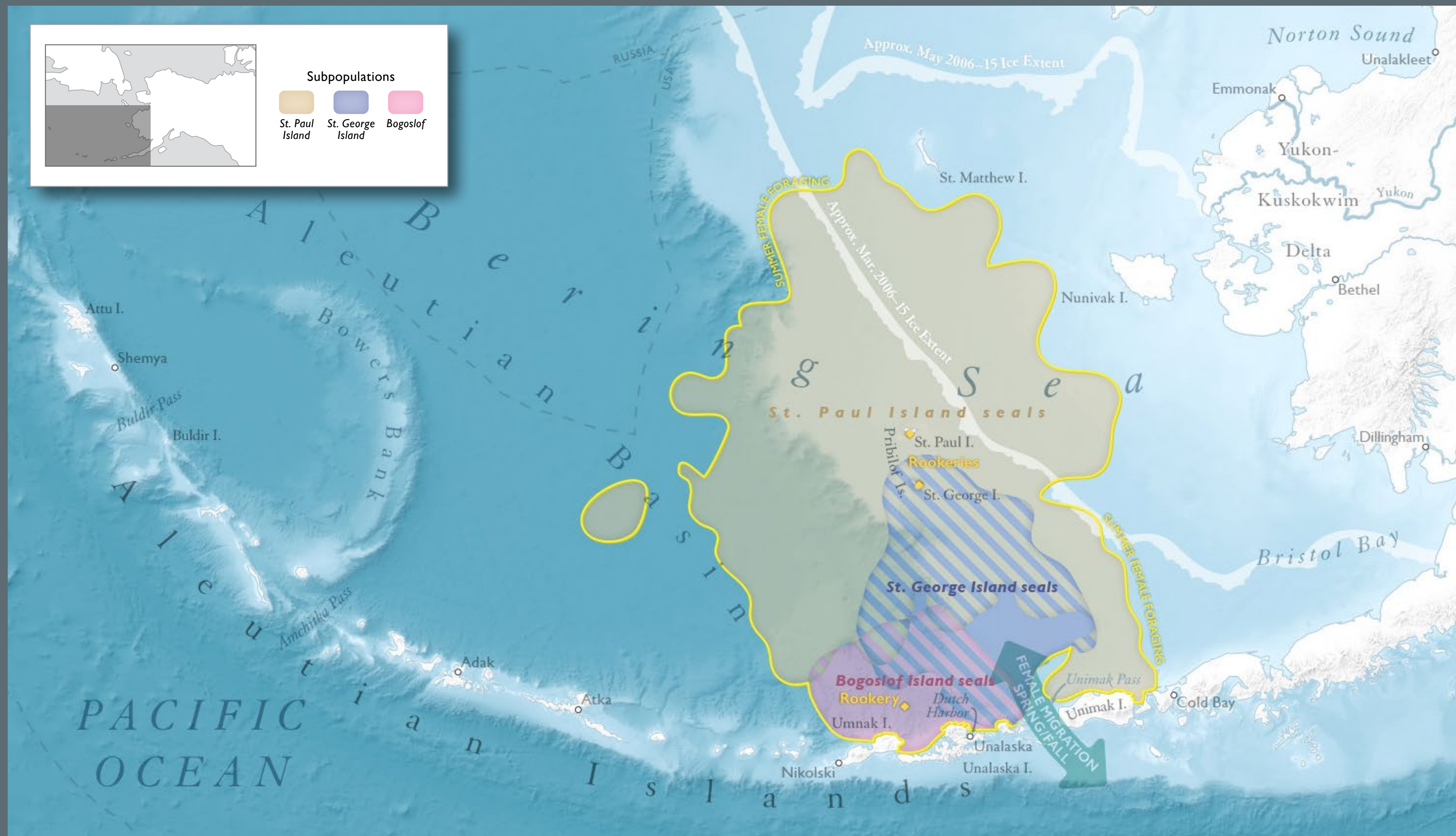
Northern Fur Seal

OCEANA Audubon ALASKA



Benoit-Bird et al. (2013); National Oceanic and Atmospheric Administration (2015); Robson et al. (2004); Sterling et al. (2014)

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

Northern Fur Seal (*Callorhinus ursinus*)

This map shows summer foraging areas and spring rookeries of three subpopulations of northern fur seals in Alaska. The northern fur seal is a pinniped, and spends most of its life at sea. It comes ashore in the spring and gathers at colonial breeding sites, or rookeries, on only a few islands in the world. The home range of the northern fur seal covers a vast area, from the Bering Strait to the California Current. Despite its expansive range, 50% of the northern fur seal population returns to the Pribilof Islands rookeries in the Bering Sea to breed and give birth to their young. When foraging offshore, they concentrate at major oceanographic frontal features formed by offshore seamounts, canyons, and the continental shelf break. After the pups are weaned, females leave the rookeries and migrate south, traveling through the passes in the Aleutian Islands and into the offshore Pacific, Gulf of Alaska, and California Current. Older males remain in the Bering Sea longer and do not migrate as far south as the females. Unimak Pass serves as the primary migration corridor twice per year as the animals leave and return to the Bering Sea.

Northern fur seals were subject to a major commercial harvest for their fur, first starting when Russian explorers discovered the Pribilof Island rookeries in 1796, and continued by the US after purchase of Alaska until 1984.

Dave Withrow / NOAA Fisheries, Alaska Fisheries Science Center

MAP ON PAGE 238

Northern fur seal bull.

John Schoen

Beluga Whale

Delphinapterus leucas

Max Goldman and Erika Knight

Beluga whales (*Delphinapterus leucas*) are unmistakable Arctic specialists broadly distributed throughout the circumpolar northern latitudes. With at least 19 global stocks, or distinct population segments (DPSs), of which 5 use the Bering, Chukchi, or Beaufort Seas, beluga whales are among the very few entirely Arctic marine mammals on the planet (Braham et al. 1984, Solovyev et al. 2012, Laidre et al. 2015). A sixth stock, the critically endangered Cook Inlet DPS, never travels outside of the sheltered waters of Cook Inlet in Alaska.

Beluga whales are extremely social animals, feeding and traveling in and between their distinct wintering and summering grounds in groups that often number in the hundreds. The five DPSs that use the Bering, Chukchi, and Beaufort Seas are the Bristol Bay stock, the Eastern Bering Sea stock, the Anadyr stock, the Eastern Chukchi stock, and the Beaufort stock (Map 6.6.1).

ADAPTATIONS

Known in many regions as the "white whale" due to the white skin color of the adults, beluga whales are small relative to other whales, with an average adult weight and length of 3,150 pounds (1,430 kg) and 13 feet (4 m) (Brodie 1989; Doidge 1990a, b). Female beluga whales are measurably smaller than their male counterparts, usually by 300 hundred pounds (140 kg) and 2–3 feet (less than 1 m). Beluga calves are born weighing more than 150 pounds (50 kg) and measuring around 5 feet long (less than 2 m). As a toothed whale, the beluga's dentition lends insight into their longevity, with the rings of their teeth suggesting typical lifespans of 35–50 years, extending to 70 years in some cases (Luque et al. 2007, Suydam 2009). Unlike most other cetaceans, beluga whales lack true dorsal fins and do not produce a typical mist when surfacing to breathe. Belugas are also unique in that they can move their heads up, down, left and right—a possible benefit while hunting (Brodie 1989; Doidge 1990a, b). Most whales have fused cervical vertebrae that keep them from moving their heads this way. Like all other Arctic marine mammals, the beluga's thick layer of blubber insulates them from the frigid and often ice-covered waters of their Arctic range.

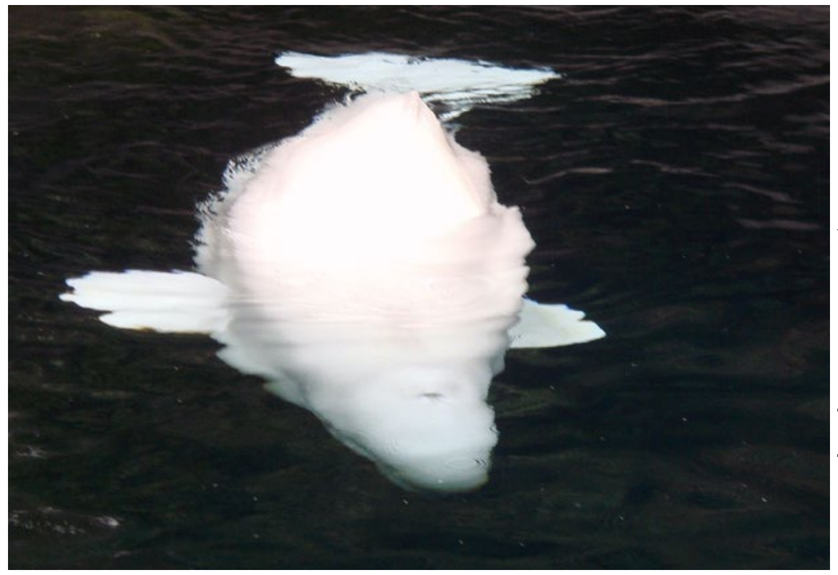
Vocalizations

Beluga whales are highly vocal and are often referred to as the "canaries of the sea," in reference to the vast array of sounds they produce, including whistles, squeals, moos, chirps, and clicks (Sjare and Smith 1986). The need for such a repertoire may stem from their highly social tendencies and their often dark, ice-covered habitat with poor visibility, which necessitates vocal communication. Belugas also have highly developed senses of hearing and vision, and possess a unique organ called a melon, which is a malleable, cranial mass used for echolocation (Mooney et al. 2008). Their closest relative, the narwhal, is of similar size, lives in the same habitat, and also has the melon organ. Like those of other toothed whales, the brains of belugas show no evidence of olfactory bulbs or nerves, which suggests they do not have a sense of smell. Instead, areas of their mouths act as sensitive chemoreceptors, effectively allowing them to "smell" the water (O'Corry-Crow 2002).

DISTRIBUTION

Belugas live throughout the Arctic, from Greenland to North America to Russia, including in the Sea of Okhotsk, the Bering Sea, Cook Inlet, Gulf of Alaska, Beaufort Sea, Baffin Bay, Hudson Bay, and the Gulf of St. Lawrence (Hauser et al. 2014). They prefer coastal or continental shelf waters, although belugas also use the much deeper water of the Canada Basin (Hauser et al. 2017b, Stafford et al. in press).

Five separate stocks of beluga whales winter in the Bering Sea, including the Bristol Bay, Eastern Bering Sea, Anadyr, Eastern Chukchi Sea, and Beaufort Sea populations. Each stock winters in a different portion of the Bering Sea, and exhibits site fidelity from year to year, suggesting that belugas from different populations have population-specific winter ranges (Citta et al. 2016).



Dr. Kristin Laidre, Polar Science Center, UW / NOAA

The unique, white skin of the beluga whale makes them one of the most familiar and easily recognized cetaceans.

In summer, the Eastern Chukchi Sea and Beaufort Sea beluga stock ranges overlap in the Arctic, while the Bristol Bay, Eastern Bering Sea, and Anadyr stocks are restricted to their respective ranges (Suydam et al. 2001, Harwood et al. 2014, Hauser et al. 2017b). During certain times of the year, belugas are also known to travel far upstream to feed in large, freshwater rivers, and seem to be unaffected by salinity changes (Watts and Draper 1988, Hobbs et al. 2005, Harwood et al. 2014).

Sea-Ice Habitat

During the winter, beluga whales are found in offshore waters near the pack ice margin, and are closely associated with polynyas and leads. Belugas swim in the marginal ice zone of Arctic and subarctic waters, where water temperatures may be lower than 32° F (0° C), (Moore et al. 2000, Laidre et al. 2008). The role of sea ice in the life of Arctic whales is still unclear. Evidence suggests that factors such as bathymetry and hydrography play larger roles in beluga whale habitat selection than sea ice. It is clear, however, that sea ice plays a large role in beluga natural history, informing the seasonal movements through their range (Hauser et al. 2017b). These whales are clearly adaptable to a wide range of conditions, and show elasticity in their behavior as new conditions present themselves (Hauser et al. 2017a, O'Corry-Crowe et al. 2016).

LIFE CYCLE

In the Bering, Chukchi, and Beaufort Seas, beluga whales mate in the spring, usually in March or April. Gestation lasts about 14–15 months, and in the northernmost portions of their respective ranges, most calves are born between May and July, when the water is warmest, as newborn calves lack a thick blubber layer. The calves are born toothless and nurse exclusively for 12–18 months. When their teeth emerge, they begin to supplement their diets with shrimp and small fishes, although they will often continue to nurse. Females are old enough to reproduce at around four to seven years, and give birth to single calves every two to three years. Males reach sexual maturity between ages seven and nine (Doidge 1990a, b).

Molting

Belugas shed their outer layer of skin, or molt, each summer around July. They concentrate in shallow water and rub against coarse gravel, removing the top layer of old skin to reveal the new skin (St. Aubin et al. 1990).

Diet

Opportunistic feeders, the belugas of the Bering, Chukchi, and Beaufort Seas move between seasonally disparate habitats and consume equally diverse prey. They concentrate their hunting efforts on calorically beneficial prey, such as cephalopods, bivalves, gastropods, arthropods, annelids, and a variety of fishes, including salmon, eulachon, cod, and flounder (Loseto et al. 2009, Marcoux et al. 2012, Quakenbush et al. 2015). The unique movements of water through Barrow Canyon in the far eastern Chukchi Sea results in high concentrations of Arctic cod (*Arctogadus glacialis*) during the summer months, a resource the belugas of the Chukchi and Beaufort Seas exploit each year (Hauser et al. 2015, Stafford et al. in press).

CONSERVATION ISSUES

The critically endangered Cook Inlet DPS is the only population of belugas listed under the Endangered Species Act (ESA). Genetically isolated for millennia, the population has been reduced in the last 40 years from 1,300 individuals in the late 1970s to approximately 280 whales in 2015 (Allen and Angliss 2014, Muto et al. 2016). In 2011, 3,016 square miles (7,809 square km) of marine habitat were designated as Critical Habitat for the Cook Inlet beluga whale DPS (76 FR 20180; 50 CFR part 226.220). As of 2012, the International Union for the Conservation of Nature (IUCN) lists the entire species as near-threatened (Jefferson et al. 2012). They are protected under the Marine Mammal Protection Act (MMPA), and were listed as depleted in the late 1990s.

The Arctic climate continues to change significantly, requiring adaptation by the species that rely upon this unique ecosystem. Changes in sea-ice extent, quality, and timing directly and indirectly impact the life history of beluga whales (Johannessen et al. 2004, Hauser et al. 2017a, O'Corry-Crowe et al. 2016). Ice-associated and ice-obligated species will be forced to adapt to shifts and changes in water temperatures, habitat availability, prey species quantities and composition, and weather patterns, although there is evidence that the beluga whale may be less susceptible to the potentially drastic changes they face, owing to their broad distribution and exhibited adaptability (Laidre et al. 2008, Moore and Huntington 2008, Heide-Jørgensen et al. 2010).

Hydrocarbon exploration may affect whales due to noise, especially seismic activities. Offshore energy development may result in pollution or oil spills. A large oil spill could be catastrophic due to sea-ice conditions that make a spill difficult to clean up, coupled with very little localized response infrastructure or capability (Miles et al. 1987, LGL and Greeneridge 1995, LGL 1996, Suydam et al. 2005).

In far northern latitudes, such as the Bering and Chukchi Seas, large fluctuations in lower trophic recruitment have been observed as a result of a changing climate (Bakun et al. 2015). Beluga whales, along with all other life in the Arctic, will be impacted by those changes (O'Corry-Crowe et al. 2016).

Beluga whales are an important subsistence species as their meat and blubber are a traditional food source for indigenous Arctic communities. Additionally, beluga whales are the only cetacean with skin thick enough to be used as leather when tanned, and are coveted among subsistence hunters. While the Bering, Chukchi, and Beaufort Sea populations are harvested in sustainable numbers, the reported annual subsistence harvest of Cook Inlet belugas by Alaska Natives during 1995–1998 was unsustainable, averaging 77 belugas per year and likely resulted in substantial population decline from 1994 to 1998. This decline prompted the depleted designation under the MMPA (Frost and Suydam 2005). Today, subsistence harvest of belugas by native populations in the US, Canada, and Russia is ongoing and at current levels is not likely to have any noticeable impact on the health of beluga stocks (Huntington 2002, Muto et al. 2016). Between 1999 and 2015, five Cook Inlet beluga whales were taken through subsistence harvest.

MAPPING METHODS (MAPS 6.6.1–6.6.2)

The beluga whale map shows migration and species distribution broken into groups of "winter" and "non-winter" data to show seasonality, and is categorized into four levels of intensity: extent of range, regular use, concentration, and high concentration.

Beluga whale range information was compiled by Audubon Alaska (2016c) based on figures published in the 2007 Alaska Marine Mammal

Vicki Beaver / NOAA Fisheries, Alaska Fisheries Science Center

A highly social species, beluga whales have been referred to as the "canaries of the sea" because of their vocal nature, employing a complex language of clicks, whistles, and clangs to communicate among pod members.

Stock Assessment (Angliss and Outlaw 2008), papers by Citta et al. (2016) and Hauser et al. (2014), and data provided in an assessment of Biologically Important Areas (BIAs) for Cetaceans in US waters (Clarke et al. 2015, Ferguson et al. 2015).

Areas that belugas regularly use in winter are represented by wintering areas defined in a satellite telemetry study by Citta et al. (2016). These areas are specific to each beluga stock; we have merged and smoothed these stock-specific areas to show the general area regularly used by all beluga stocks in winter. Regular use, non-winter areas are also shown, based on analyses of satellite telemetry data by both Citta et al. (2016) and Hauser et al. (2014). Citta et al. (2016) delineated summer locations of each beluga stock; Hauser et al. (2014) analyzed 95% kernel density contours for males and females from the Beaufort and Chukchi stocks. The regular use, non-winter areas shown on our map represent the merged output of these data.

Concentration areas are shown for the non-winter season. These concentration areas come from several publications: Citta et al. (2016), Clarke et al. (2015), Ferguson et al. (2015), Hauser et al. (2014), Muto et al. (2016), Suydam and Alaska Department of Fish and Game (2004); and an Audubon Alaska and Oceana analysis of data from the Aerial Survey of Arctic Marine Mammals (ASAMM) (National Oceanic and Atmospheric Administration 2015a), which were collected between 2000 and 2015 (Audubon Alaska and Oceana 2016). The ASAMM data (formerly Bowhead Whale Aerial Survey Project [BWASP]) were analyzed in consultation with Megan Ferguson and Janet Clarke, the points of contact for this database and associated reports, who provided valuable advice and feedback. Aerial survey methods, data, and metadata for the ASAMM database are available at: http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php. The Audubon Alaska and Oceana analysis used only on-transect data where there were more than 62 miles (100 km) of survey effort in a 12.4-mile by 12.4-mile (20-km by 20-km) grid cell. An observation rate (i.e. relative density) was calculated in each grid cell by dividing the observed number of animals over all years by the measure of total transect length over all years. This observation rate was converted into point data with one point per grid cell (at the centroid), and a kernel density function was run with a 24.8-mile (40-km) search radius (two grid-cell radius in all directions) to smooth the data.

High-concentration areas are also shown for the non-winter season. In the eastern Chukchi and western Beaufort, these data were compiled by Audubon Alaska (2017a) based on Audubon Alaska and Oceana (2016), Audubon Alaska et al. (2015), Daniel et al. (2015), and Stafford et al. (in press). High-concentration areas also incorporate traditional knowledge published in Stephenson and Hartwig (2010) and Huntington and the Communities of Buckland, Elim, Koyuk, Point Lay, and Shaktoolik (1999); as well as data published in Paulic et al. (2012), Harwood et al. (2014), and in the 2004 North Slope Borough Area Wide Comprehensive Plan (Suydam and Alaska Department of Fish and Game 2004). Where such information is known (based on traditional knowledge by Huntington et al. (1999) and/or analysis conducted as part of the BIA assessment (Clarke et al. 2015)), high-concentration (and concentration) areas are labeled with information on how belugas use these areas (i.e., for molting or calving).

Migration information was derived from a combination of sources, including governmental studies by Muto et al. (2016), and National Oceanic and Atmospheric Administration (1988), and peer-reviewed papers by Citta et al. (2016), Richard et al. (2001), Suydam et al. (2005), and Hauser et al. (2014).

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality
Data quality of beluga range and regular use areas, as well as migration data, is generally good across the project area. Range information is based primarily on one assessment that was consistent throughout the map area (Angliss and Outlaw 2008), which we modified based on more recent studies. Regular use areas are based on two satellite telemetry studies of tagged belugas from each of the five stocks encompassed in our map area (Citta et al. 2016, Hauser et al. 2014). Similarly, migration information is based on many data sources, including telemetry data of whales tagged in each of these five stocks (Citta et al. 2016).

By contrast, concentration and high-concentration data are primarily available for US and Canadian waters. The mapped concentration areas extend into the Russian portion of the Chukchi Sea, but these data are based on telemetry data for belugas tagged in the US and in Canada (see Map Data Sources below). High-concentration area information is available for US waters only. Additional concentration and high-concentration areas may be present in regions where such information was not available as of our publication date.

Reviewers
- Bering Strait Traditional Knowledge-Holder Map Review Workshop participants
- Donna Hauser
- Megan Ferguson

MAP DATA SOURCES

BELUGA WHALE MAP

Extent of Range: Audubon Alaska (2016c) based on Angliss and Outlaw (2008), Citta et al. (2016), Clarke et al. (2015), Hauser et al. (2014)

Regular Use (Winter): Audubon Alaska et al. (2017); Citta et al. (2016)

Regular Use (Non-winter): Citta et al. (2016); Hauser et al. (2014)

Concentration (Non-winter): Audubon Alaska and Oceana (2016); Citta et al. (2016); Clarke et al. (2015); Ferguson et al. (2015); Hauser et al. (2014); Muto et al. (2016); Suydam and Alaska Department of Fish and Game (2004)

High Concentration (Non-winter): Audubon Alaska (2017a) based on Audubon Alaska and Oceana (2016), Audubon Alaska et al. (2015), Daniel et al. (2015), Stafford et al. (in press); Harwood et al. (2014); Huntington and the Communities of Buckland, Elim, Koyuk, Point Lay, and Shaktoolik (1999); Paulic et al. (2012); Stephenson and Hartwig (2010); Suydam and Alaska Department of Fish and Game (2004)

Reproduction: Audubon Alaska et al. (2017); Clarke et al. (2015); Huntington and the Communities of Buckland, Elim, Koyuk, Point Lay, and Shaktoolik (1999)

Migration: Audubon Alaska (2016b) based on Audubon Alaska et al. (2017), Citta et al. (2016), and Muto et al. (2016); Hauser et al. (2014); National Oceanic and Atmospheric Administration (1988); Richard et al. (2001); Suydam et al. (2005)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

BELUGA STOCKS MAP

Anadyr Stock: Summer and winter—Citta et al. (2016)

Bristol Bay Stock: Summer and winter—Citta et al. (2016)

Cook Inlet Stock: Year-round—Muto et al. (2016)

Beaufort Sea Stock: Summer—Hauser (2017a); Winter—Citta et al. (2016)

Eastern Bering Sea Stock: Summer and winter—Citta et al. (2016)

Eastern Chukchi Sea Stock: Summer—Hauser (2017a); Winter—Citta et al. (2016)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

Beluga Whale Stocks

Audubon ALASKA

Beluga Whale Stocks
(Delphinapterus leucas)

This map shows the ranges of the five stocks of beluga whale that live in the Bering, Chukchi, and Beaufort Seas throughout the year, as well as the Cook Inlet stock. The Anadyr Stock stays close to the Chukotka Peninsula in both summer and winter, while the Beaufort Sea and Eastern Chukchi Sea stocks move from far northern latitudes, through the Bering Strait and into the Bering Sea. Notably, although there are five distinct stocks inhabiting the project area, there is very little overlap throughout the year, and presumably little or no genetic exchange.

Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Citta et al. (2016); Hauser (2017a); Muto et al. (2016)

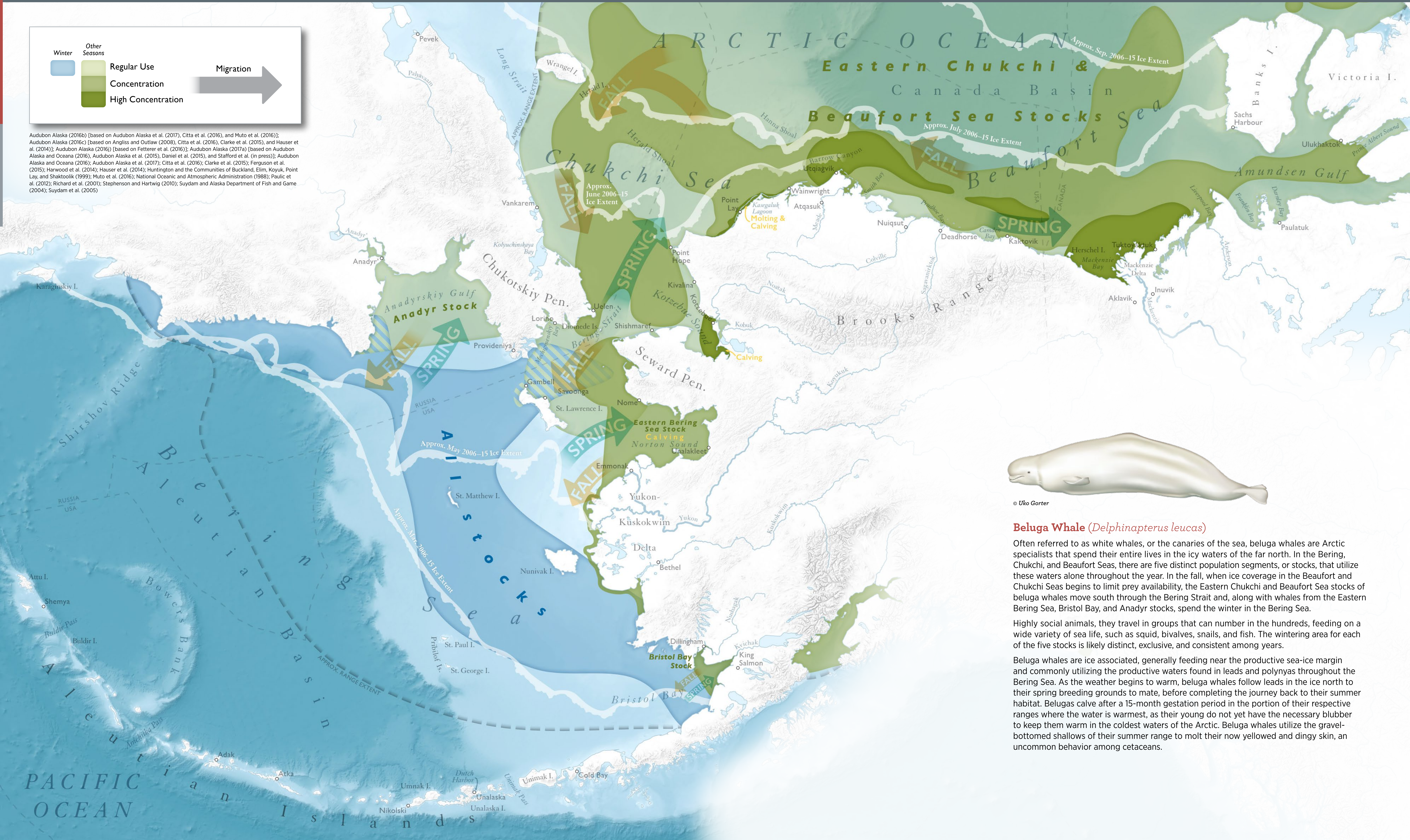
Map Authors: Erika Knight and Max Goldman
Cartographer: Daniel P. Huffman

Laura Morse / NOAA Fisheries, Alaska Fisheries Science Center

Beluga Whale

Map Authors: Erika Knight, Max Goldman, and Melanie Smith
Cartographer: Daniel P. Huffman

KAWERAK, INC. Audubon ALASKA



Audubon Alaska (2016b) [based on Audubon Alaska et al. (2017), Citta et al. (2016), and Muto et al. (2016)]; Audubon Alaska (2016c) [based on Angliss and Outlaw (2008), Citta et al. (2016), Clarke et al. (2015), and Hauser et al. (2014)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska (2017a) [based on Audubon Alaska and Oceana (2016), Audubon Alaska et al. (2015), Daniel et al. (2015), and Stafford et al. (in press)]; Audubon Alaska and Oceana (2016); Audubon Alaska et al. (2017); Citta et al. (2016); Clarke et al. (2015); Ferguson et al. (2015); Harwood et al. (2014); Hauser et al. (2014); Huntington and the Communities of Buckland, Elim, Koyuk, Point Lay, and Shaktoolik (1999); Muto et al. (2016); National Oceanic and Atmospheric Administration (1988); Paulic et al. (2012); Richard et al. (2001); Stephenson and Hartwig (2010); Suydam and Alaska Department of Fish and Game (2004); Suydam et al. (2005)

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Beluga Whale (*Delphinapterus leucas*)

Often referred to as white whales, or the canaries of the sea, beluga whales are Arctic specialists that spend their entire lives in the icy waters of the far north. In the Bering, Chukchi, and Beaufort Seas, there are five distinct population segments, or stocks, that utilize these waters alone throughout the year. In the fall, when ice coverage in the Beaufort and Chukchi Seas begins to limit prey availability, the Eastern Chukchi and Beaufort Sea stocks of beluga whales move south through the Bering Strait and, along with whales from the Eastern Bering Sea, Bristol Bay, and Anadyr stocks, spend the winter in the Bering Sea.

Highly social animals, they travel in groups that can number in the hundreds, feeding on a wide variety of sea life, such as squid, bivalves, snails, and fish. The wintering area for each of the five stocks is likely distinct, exclusive, and consistent among years.

Beluga whales are ice associated, generally feeding near the productive sea-ice margin and commonly utilizing the productive waters found in leads and polynyas throughout the Bering Sea. As the weather begins to warm, beluga whales follow leads in the ice north to their spring breeding grounds to mate, before completing the journey back to their summer habitat. Belugas calve after a 15-month gestation period in the portion of their respective ranges where the water is warmest, as their young do not yet have the necessary blubber to keep them warm in the coldest waters of the Arctic. Beluga whales utilize the gravel-bottomed shallows of their summer range to molt their now yellowed and dingy skin, an uncommon behavior among cetaceans.

MAPS ON PAGES 250–251

Bowhead Whale

Balaena mysticetus

Max Goldman and Erika Knight

Bowhead whales (*Balaena mysticetus*) are endemic to northern latitudes, living out their entire lives in Arctic or subarctic waters (Niebauer and Schell 1993). Closely related and similar in appearance to right whales of the genus *Eubalaena*, the bowhead whale is the sole extant species in the genus *Balaena*. While bowheads came under enormous hunting pressure in the late 19th and 20th centuries, environmental protection and moratoria on commercial whaling have secured a future for this unique animal, and population numbers have rebounded significantly. Scientists classify the bowhead whale into five subpopulations or stocks: The Hudson Bay-Foxe Basin stock, the Baffin Bay-Davis Strait stock, the Okhotsk Sea stock, the Spitsbergen stock, and the Western Arctic or Bering Chukchi Beaufort stock (International Whaling Commission 2010). For management purposes, four bowhead whale stocks are currently recognized by the International Whaling Commission, with the Hudson Bay-Foxe Basin and Baffin Bay-Davis Strait stocks combined into the eastern Arctic-West Greenland stock (International Whaling Commission 2010).

ADAPTATIONS

Bowhead whales are mysticetes, meaning they have baleen plates instead of teeth for filtering food out of the ocean. They have the largest mouths of any animal on the planet, containing enormous baleen plates up to 14 feet (4.3 m) long (Quakenbush et al. 2008). Distinctively, bowheads have a dark body, a white chin, and lack a dorsal fin. Their 17–19 inch (43–50 cm) thick blubber layer is thicker than that of any other living animal, allowing them to thrive in the frigid waters of the high Arctic (Quakenbush et al. 2008; Quakenbush et al. 2010a, b). Their paired blowholes are positioned at the elevated peak of their massive heads, presumably allowing them to breathe through small openings in the frozen surface of the Arctic Ocean (Burns et al. 1993, Quakenbush et al. 2008).

The huge, 16-foot (5-m) long skull of the bowhead whale makes up nearly a third of their overall body length and is used to break through or lift thick ice sheets to breathe, granting the bowhead whale access to otherwise unattainable food sources. At about 45–60 feet (14–18 m) long and weighing 150,000–200,000 pounds (68,000–90,000 kg), bowheads are among the largest animals on the planet (Burns et al. 1993).

Vocalizations

Bowhead whales spend their entire lives in the often icy waters of the far north. For a substantial portion of the year, this habitat is shrouded in darkness and crusted with ice, making communication between individuals and groups using visual stimuli difficult or impossible. Bowhead calls add to the varied arctic soundscape that includes sounds produced by animals, wind, ice, and people (Blackwell et al. 2007, Hildebrand 2009). Bowhead whales have evolved to communicate by producing both simple calls and elaborate songs based in part on external stimuli in the aural environment (Clarke et al. 2015).

DISTRIBUTION

Bowhead whales are distributed in seasonally ice-covered waters of the Arctic and subarctic (Moore and Reeves 1993). Bowhead stocks occur in the Sea of Okhotsk (Russian waters), Baffin Bay-Davis Strait and Hudson Bay-Foxe Basin (western Greenland and eastern Canadian waters, sometimes split into two separate stocks), in the eastern North Atlantic (the Spitsbergen stock near Svalbard), and in the Bering-Chukchi-Beaufort Seas (the Western Arctic stock), which is the largest subpopulation and only stock found within US waters (Rugh et al. 2003).

The Western Arctic stock occurs from Chaunskaya Bay (Russia) in the western Chukchi Sea east to the Canadian Arctic Archipelago, and the northern Bering Sea south from near Cape Navarin (Russian Federation) along the Bering slope and St. Matthew Island (Rice 1998, Quakenbush et al. 2013). Despite the geographical proximity of wintering bowhead whales from the Western Arctic stock in the northern Bering Sea to those from the Sea of Okhotsk stock, there is no evidence of any geographical or temporal overlap of these stocks (Ivashchenko and Clapham 2010).

Sea-Ice Habitat

Bowhead whales are found only in Arctic and subarctic regions. Western Arctic bowheads spend much of their lives in, near, and even under the pack ice, migrating north to the Beaufort shelf and northeastern Chukotkan coast in summer, and retreating south through the Bering Strait with the advancing ice edge in winter (Moore and Reeves 1993). During winter, bowhead whales frequent areas near the sea-ice margin, utilizing leads (large cracks in ice) and polynyas (areas of open water in ice caused by wind or warm-water upwelling), and in areas of unconsolidated pack ice, though recent evidence suggests they are not as closely tied to these areas as previously understood (Nerini et a. 1984). During the spring these whales use leads to penetrate areas that were inaccessible during the winter due to heavy ice coverage. If no open water is available, they will locate a thin portion of the ice cover and use their massive heads to push up or break the ice sheet so they can breathe. Bowheads can break ice up to 2 feet (0.6 meters) thick (Quakenbush et al. 2008).

Migration

Bowhead whales of the Western Arctic stock migrate each spring from the Bering Sea through the Chukchi Sea to the eastern Beaufort Sea where they spend most of the summer (Moore and Reeves 1993). By early September bowheads begin their fall migration, leaving the eastern Beaufort Sea during September and October. The bowheads move past Barrow before heading west across the Chukchi Sea toward Russian waters (Moore and Reeves 1993, Clarke and Ferguson 2010, Clarke et al. 2016), where many feed in late fall off the northern coast of Chukotka before returning to the Bering Sea.

During the spring migration, bowhead whales typically begin arriving in the Utqiagvik area (formerly Barrow) area in early April and continue migrating past Utqiagvik until well into June. Most of this migration appears to be a fairly steady flow of whales traveling from the Chukchi Sea to the Beaufort Sea, but in late spring some whales have been seen making frequent turns in a small area, and are presumably feeding (Carroll et al. 1987). Although bowheads are more commonly seen off the coast of Utqiagvik during the spring and fall migrations, there have also been reports of whales feeding near Utqiagvik from late July to early September (Moore 1992, George et al. 2004, Moore et al. 2010). A smaller portion of the population follows an atypical migration path, instead migrating west along the northern Chukotka coast in spring and milling about during summer and fall, before returning to the Bering Sea in winter.

LIFE CYCLE

Bowhead whales reach sexual maturity at approximately 20 years of age. During northward spring migration in April, displays of breaching and fluke slapping ensue prior to mating. It is not clear if this activity is competitive in nature or a part of a cooperative mating strategy (Foote 1964, Everitt and Krogman 1979, Würsig et al. 1993, Audubon Alaska et al. 2017).

After a gestation period of 13–14 months, females give birth to a calf about 13 feet (4 m) long and weighing about 2,000 pounds (900 kg) (Nerini et al. 1984). Calves are born able to swim during the spring migration between April and June (Burns et al. 1993, Quakenbush et al. 2008). They form close bonds with their mothers, staying together for 9–12 months. Females give birth every three to four years (Nerini et al. 1984).

MAPS ON PAGES 250–251

Bowhead whales are very long-lived, as suggested by biochemical methods and the discovery of stone, slate, and ivory harpoon heads in contemporary, hunter-killed animals, indicating a failed hunt from over 100 years ago (George et al. 1999). Biochemical age determination methods estimated the age of one male bowhead's tissue sample to be from 177 to 245 years old, indicating a possible lifespan of over 200 years, which makes bowhead whales the longest-lived mammal on earth (George et al. 1999, George and Bockstoce 2008).

Diet

Bowhead whales use their huge keratin baleen plates to filter-feed almost exclusively on zooplankton, including over 60 species of small to moderately sized (most 1 inch [2.5 cm] or less) crustaceans such as copepods, euphausiids, and mysids, as well as other invertebrates and fishes (Hoekstra et al. 2002, Lowry et al. 2004, Lee et al. 2005, Citta et al. 2015).

Bowheads feed from the surface to the bottom, under the ice, and in open water (Quakenbush et al. 2008). Bowheads with mud on their dorsal surfaces have been reported during the spring migration, indicating that they were near the sea bottom, presumably feeding on epibenthic prey. However, there is no evidence from the stomach contents of harvested whales that they, like gray whales (*Eschrichtius robustus*), ingest sediments. (Angliss and Outlaw 2008, Mocklin et al. 2012).

CONSERVATION ISSUES

The International Whaling Commission has attempted to protect bowhead whales from commercial whaling since its inception in 1946. The Aboriginal Whaling and Management Procedure has successfully managed subsistence hunting of bowhead whales, with take numbers consistently below the thresholds for impact to the overall population (Givens and Thomas 1997).

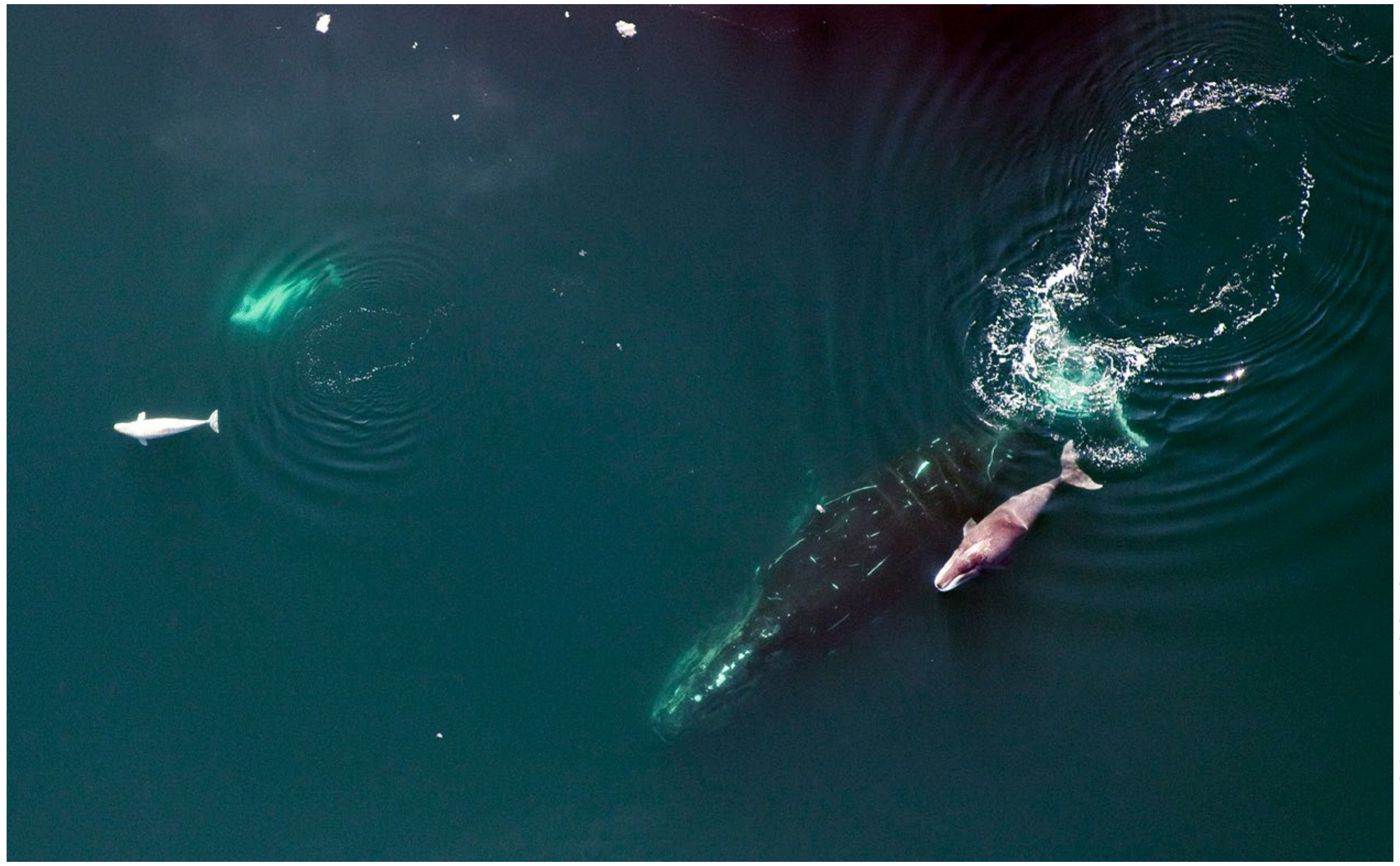
The Marine Mammal Protection Act of 1972 (MMPA) ensures protection against "take," which means "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal." The MMPA does this by enacting a moratorium on the import, export, and sale of any marine mammal or marine mammal product within the US. Subsistence hunting is exempted from this legislation, and currently up to 67 bowhead whales are harvested via subsistence hunts annually to feed and to preserve the cultural heritage of the communities of the US Arctic coasts (Alaska Eskimo Whaling Commission 2007, 2013; Huntington et al. 2016b).

All bowhead whale stocks are currently listed as endangered under the US Endangered Species Act (ESA) and have been since the inception of the ESA in 1973. They were initially designated as endangered as a result of depletion by commercial whaling during the late 19th and 20th centuries. Due to the efforts put forth under these protections, the population has recovered considerably.

The International Union for Conservation of Nature (IUCN) has recognized the need for conservation efforts directed toward the bowhead whale since they first listed it as very rare in 1965. Their subsequent designations are shown in Table 6.7-1

TABLE 6.7-1. IUCN RedList Assessments for Bowhead Whales

Year	IUCN RedList Assessment
2008	Least concern (LC)
1996	Lower risk/conservation dependent (LR/CD)
1994	Vulnerable (V)
1990	Vulnerable (V)
1988	Endangered (E)
1986	Endangered (E)
1965	Very rare but believed to be stable or increasing



Corey Accardo / NOAA Fisheries, Alaska Fisheries Science Center

Among the largest animals on the planet, bowhead whales give birth every three to four years. A bowhead whale calf (pictured next to its mother) spends the first year of its life with its mother. For perspective, the adult beluga whales pictured are approximately 13 feet (4 m) long.

Commercial whaling in the north Pacific began in the mid-19th century, escalating and continuing into the 20th century before a near-global moratorium was agreed upon in 1982 (International Whaling Commission 2017). Minimum pre-whaling subpopulation sizes are estimated to have been 3,000 for the Okhotsk Sea stock; 12,000 for the Hudson Bay-Foxe Basin and Baffin Bay-Davis Strait stocks; and 24,000 for the Spitsbergen stock (Woodby and Botkin 1993). The Western Arctic stock was estimated to be 10,000–20,000 animals (Brandon and Wade 2006).

The current range-wide abundance of all five stocks of bowhead whales is not known. Estimates of the Western Arctic stock suggest a population of nearly 17,000 (George et al. 2004, Givens et al. 2013). Estimates of portions of the ranges of the Hudson Bay-Foxe Basin and Baffin Bay-Davis Strait stocks suggest populations of 3,500 and 7,300 respectively (Cosens and Blouw 2003, Koski et al. 2006b).

The Western Arctic stock has been increasing at a rate of approximately 3.4% per year over 30 years (Zeh and Punt 2005). Interviews with Native elders and subsistence hunters also suggest that bowhead whales have expanded their distribution in recent years (Koski et al. 2006a, Noongwook et al. 2007).

There are many areas of concern regarding the health of bowhead populations. While the biggest threat of the past was overharvest from commercial whaling activities, bowhead harvest for subsistence is currently well managed (National Oceanic and Atmospheric Administration 2013). However, broad-scale habitat degradation from human activities could affect bowhead behavior and/or abundance, which should be carefully considered for stock management in the future (Richardson 1995, Croll et al. 2001). Climate change and loss of sea ice affects productivity and availability of food resources—a yet unknown effect on the future of bowhead whale populations (George et al. 2015). Bowheads may be sensitive to noise disturbance from ships and are vulnerable to ship strikes, which will likely increase along with an increase in vessel traffic (Reeves et al. 2012). Hydrocarbon exploration may affect bowheads due to noise, especially from seismic activities (Ljungblad et al. 1988, Richardson 1995). Offshore energy development may result in pollution or oil spills. A large oil spill could be catastrophic due to sea ice conditions that make a spill hard to clean up, coupled with very little localized response infrastructure or capability. Commercial fishing gear entanglement is another issue of concern (Reeves et al. 2012, Reeves et al. 2014). Although commercial fisheries are not currently estimated to have a significant impact on bowheads, Native subsistence hunters have reported entanglement of bowheads (National Oceanic and Atmospheric Administration 2013).

MAPPING METHODS (MAPS 6.7a–6.7d)

Bowhead whale data are mapped on four season-specific maps (spring, summer, fall, and winter). Each map shows the overall (year-round) range extent of bowhead whales, as well as the season-specific range extent. Bowhead whale distribution for each season was further categorized into areas where there are known concentrations of bowheads and areas where there are known high concentrations of bowheads. Migration arrows and reproduction areas are shown where this information is available.

Bowhead whale year-round range was compiled from seasonal range data, which was primarily based on figures published in Quakenbush et al. (2013). The spring seasonal range extent from Quakenbush et al. (2013) was expanded based on Bogoslovskaya et al. (2016), spring Biologically Important Areas (BIAs) for bowhead whales published in Clarke et al. (2015), and data from a February 2017 workshop with Bering Strait region traditional knowledge experts who reviewed Audubon Alaska's draft bowhead maps (Audubon Alaska et al. 2017). The summer and winter ranges were based on Quakenbush et al. (2013) and expanded based on Bogoslovskaya et al. (2016) and Audubon Alaska et al. (2017). No modifications were made to the fall range from Quakenbush et al. (2013).

Seasonal concentration areas were merged by Audubon Alaska (2016d) based on BIAs (Clarke et al. 2015), density information from satellite telemetry from Citta et al. (2015), and seasonal information from Quakenbush et al. (2013). Data regarding summer feeding aggregations (Paulic et al. 2012) were included in the summer concentration area. Summer and fall concentration areas also incorporate the 95% isopleth from an Audubon Alaska and Oceana analysis (Audubon Alaska and Oceana 2016) of data from 2000 through 2014 from the Aerial Survey of Arctic Marine Mammals (ASAMM) (National Oceanic and Atmospheric Administration 2015a). The ASAMM data (formerly Bowhead Whale Aerial Survey Project [BWASP]) were analyzed in consultation with Megan Ferguson and Janet Clarke. Aerial survey methods, data, and metadata for the ASAMM database are available at: http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php. The Audubon Alaska and Oceana analysis used only on-transect data where there were more than 62 miles (100 km) of survey effort in a 12.4-mile by 12.4-mile (20-km by 20-km) grid cell. An observation rate (i.e. relative density) was calculated in each grid cell by dividing the observed number of animals over all years by the measure of total transect length over all years. This observation rate was converted into point data with one point per grid cell (at the centroid), and a kernel density function was run with an anisotropic kernel density function with a 24.8 mile (40 km) north-south search radius and a 49.6 mile (80 km) east-west search radius to smooth the data.

Seasonal high-concentration areas were also compiled by Audubon Alaska (2016e), largely based on density information from satellite telemetry (Citta et al. 2015) and seasonal information from Quakenbush et al. (2013), as described for concentration areas. The summer and fall high-concentration areas incorporate the 50% isopleth from the Audubon Alaska and Oceana analysis (Audubon Alaska and Oceana 2016) of 2000 through 2014 ASAMM data described above. Each seasonal high-concentration area also includes traditional knowledge information from Huntington and Quakenbush (2009) (spring, summer, and fall) and/or Noongwook et al. (2007) (winter and spring).

Reproduction information is labeled where such information is known based on traditional knowledge (Huntington and Quakenbush (2009) and Noongwook et al. (2007)) and/or the BIA assessment (Clarke et al. 2015).

Migration information was derived from a combination of sources, including National Oceanic and Atmospheric Administration (1988), Alaska Department of Fish and Game (1986), Alaska Department of Fish and Game (2009), Audubon Alaska et al. (2017), and the North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003).

Bowhead whaling communities shown in a NOAA environmental impact statement are also mapped (National Oceanic and Atmospheric Administration 2013). Shaktoolik was removed from this dataset based on draft map review by Bering Strait region traditional knowledge experts (Audubon Alaska et al. 2017).

The sea-ice data shown on these maps approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See "Sea Ice Mapping Methods" section for details.

Data Quality

Data quality for the maps is good. The data come from a variety of sources, including satellite telemetry studies, traditional knowledge, and long-term aerial surveys, which have delineated seasonal usage and densities of bowheads across the map area. The high-concentration and reproduction information shown may be an incomplete representation, especially in the Russian portions of the map area.

Reviewers

- Bering Strait Traditional Knowledge-Holder Map Review Workshop participants
- Sue Moore
- Lori Quakenbush

MAP DATA SOURCES

WINTER MAP

Overall Range: Audubon Alaska (2016f) based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)

Winter Range: Audubon Alaska (2016f) based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)

Concentration: Audubon Alaska (2016d) based on Citta et al. (2015), Clarke et al. (2015), and Quakenbush et al. (2013)

High Concentration: Audubon Alaska (2016e) based on Citta et al. (2015), Clarke et al. (2015), Noongwook et al. (2007), and Quakenbush et al. (2013)

Reproduction: Noongwook et al. (2007)

Migration: Alaska Department of Fish and Game (1986); Audubon Alaska (2016g) based on Alaska Department of Fish and Game (2016b); National Oceanic and Atmospheric Administration (1988); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003)

Whaling Communities: National Oceanic and Atmospheric Administration (2013) (revised based on Audubon Alaska et al. (2017))

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

SPRING MAP

Overall Range: Audubon Alaska (2016f) based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)

Spring Range: Audubon Alaska (2016f) based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), Clarke et al. (2015), and Quakenbush et al. (2013)

Concentration: Audubon Alaska (2016d) based on Citta et al. (2015), Clarke et al. (2015), and Quakenbush et al. (2013)

High Concentration: Audubon Alaska (2016e) based on Citta et al. (2015), Huntington and Quakenbush (2009), Noongwook et al. (2007), and Quakenbush et al. (2013)

Reproduction: Clarke et al. (2015), Huntington and Quakenbush (2009), and Noongwook et al. (2007)

Migration: Alaska Department of Fish and Game (1986); Audubon Alaska (2016g) based on Alaska Department of Fish and Game (2016b); National Oceanic and Atmospheric Administration (1988); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003)

Whaling Communities: National Oceanic and Atmospheric Administration (2013) (revised based on Audubon Alaska et al. (2017))

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

MAP DATA SOURCES (CONTINUED)

SUMMER MAP

Overall Range: Audubon Alaska (2016f) based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)

Summer Range: Audubon Alaska (2016f) based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)

Concentration: Audubon Alaska (2016d) based on Audubon Alaska and Oceana (2016), Citta et al. (2015), Clarke et al. (2015), Paulic et al. (2012), and Quakenbush et al. (2013)

High Concentration: Audubon Alaska (2016e) based on Audubon Alaska and Oceana (2016), Citta et al. (2015), Huntington and Quakenbush (2009), and Quakenbush et al. (2013)

Reproduction: Clarke et al. (2015)

Migration: Alaska Department of Fish and Game (1986); Audubon Alaska (2016g) based on Alaska Department of Fish and Game (2016b); National Oceanic and Atmospheric Administration (1988); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003)

Whaling Communities: National Oceanic and Atmospheric Administration (2013) (revised based on Audubon Alaska et al. (2017))

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

FALL MAP

Overall Range: Audubon Alaska (2016f) based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)

Fall Range: Quakenbush et al. (2013)

Concentration: Audubon Alaska (2016d) based on Audubon Alaska and Oceana (2016), Citta et al. (2015), Clarke et al. (2015), and Quakenbush et al. (2013)

High Concentration: Audubon Alaska (2016e) based on Audubon Alaska and Oceana (2016), Citta et al. (2015), Huntington and Quakenbush (2009), and Quakenbush et al. (2013)

Reproduction: Clarke et al. (2015)

Migration: Alaska Department of Fish and Game (1986); Alaska Department of Fish and Game (2009); Audubon Alaska (2016g) based on Alaska Department of Fish and Game (2016b); Audubon Alaska et al. (2017); National Oceanic and Atmospheric Administration (1988); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003)

Whaling Communities: National Oceanic and Atmospheric Administration (2013) (revised based on Audubon Alaska et al. (2017))

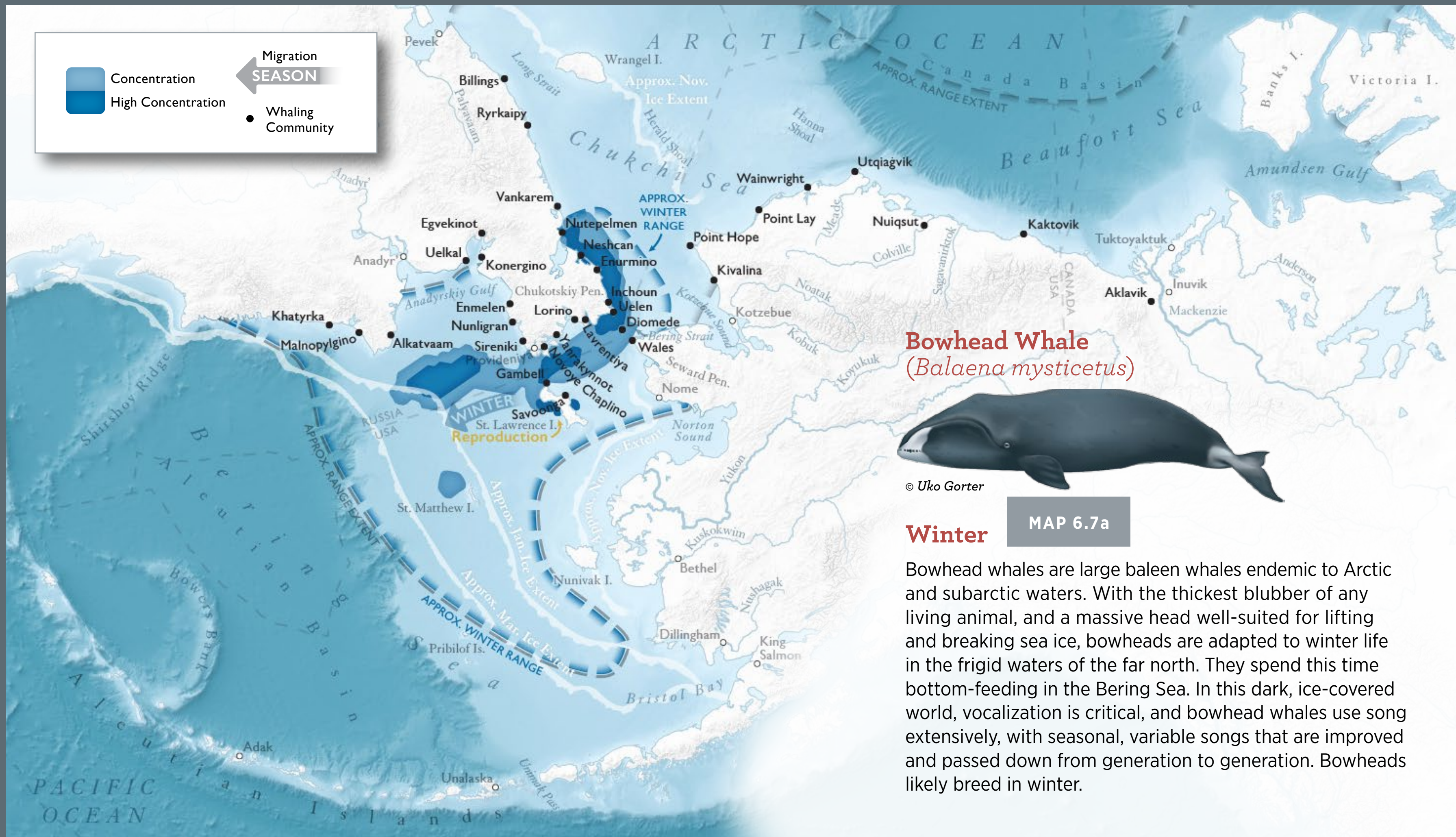
Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

Bowhead Whale

Map Authors: Melanie Smith, Erika Knight, and Max Goldman
Cartographer: Daniel P. Huffman

KAWERAK, INC.

Audubon ALASKA



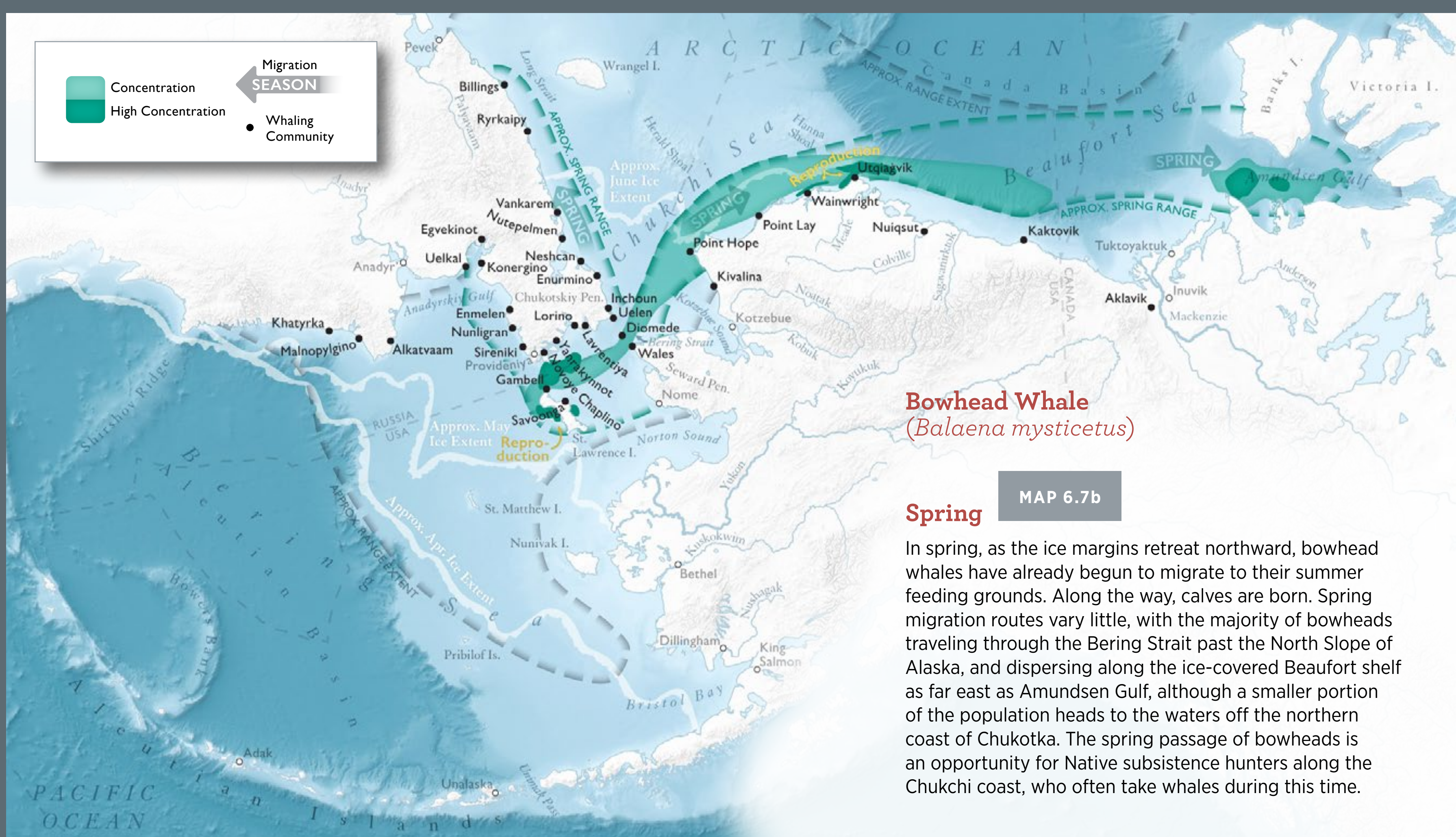
Bowhead Whale
(Balaena mysticetus)

MAP 6.7a

Winter

Bowhead whales are large baleen whales endemic to Arctic and subarctic waters. With the thickest blubber of any living animal, and a massive head well-suited for lifting and breaking sea ice, bowheads are adapted to winter life in the frigid waters of the far north. They spend this time bottom-feeding in the Bering Sea. In this dark, ice-covered world, vocalization is critical, and bowhead whales use song extensively, with seasonal, variable songs that are improved and passed down from generation to generation. Bowheads likely breed in winter.

Alaska Department of Fish and Game (1986); Audubon Alaska (2016d) [based on Citta et al. (2015), Clarke et al. (2015), and Quakenbush et al. (2013)]; Audubon Alaska (2016e) [based on Citta et al. (2015), Clarke et al. (2015), Noongwook et al. (2007), and Quakenbush et al. (2013)]; Audubon Alaska (2016f) [based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)]; Audubon Alaska (2016g) [based on Alaska Department of Fish and Game (2016b)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; National Oceanic and Atmospheric Administration (2013) [revised based on Audubon Alaska et al. (2017)]; National Oceanic and Atmospheric Administration (1988); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003); Noongwook et al. (2007); Quakenbush et al. (2013)



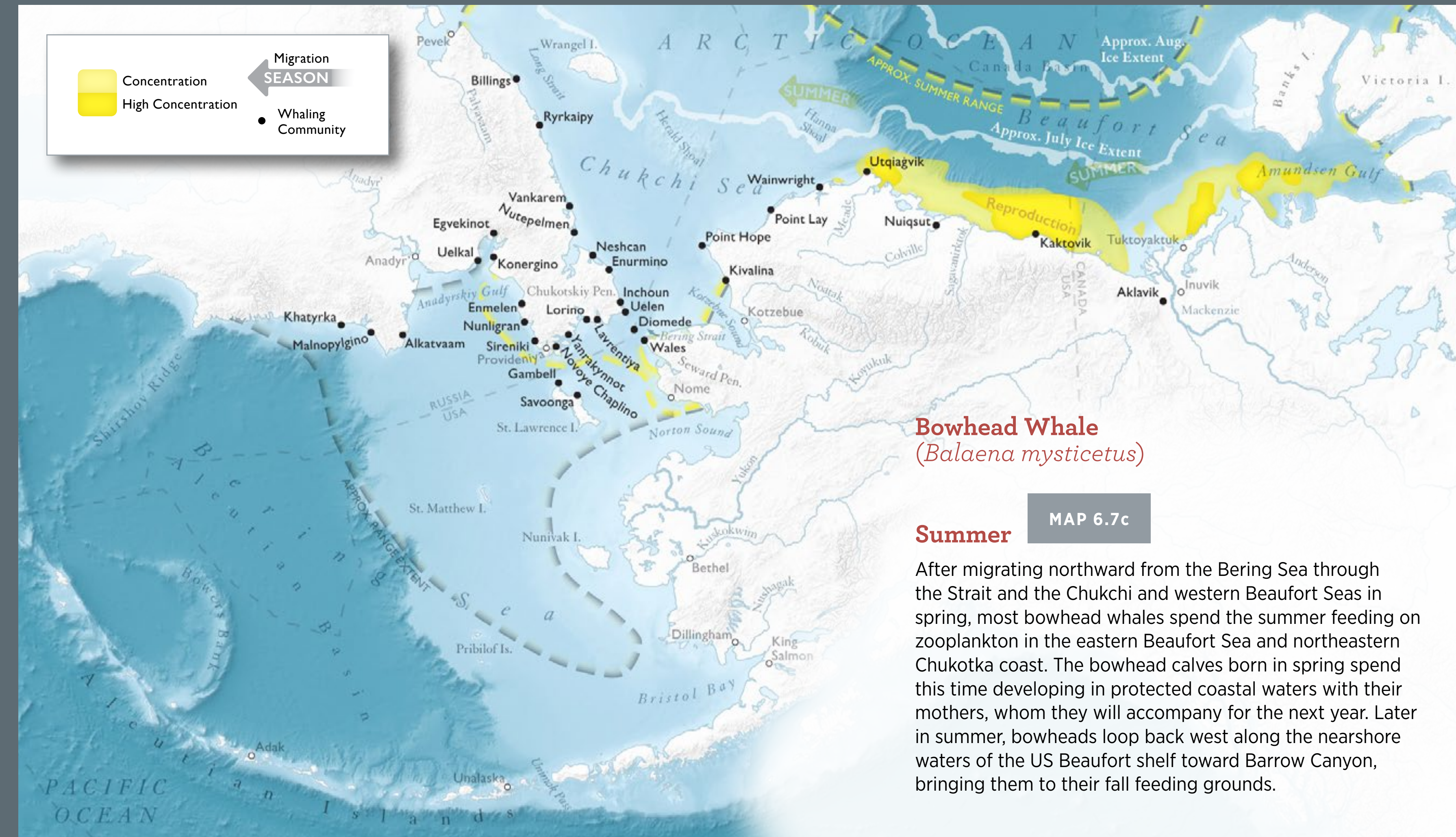
Bowhead Whale
(Balaena mysticetus)

MAP 6.7b

Spring

In spring, as the ice margins retreat northward, bowhead whales have already begun to migrate to their summer feeding grounds. Along the way, calves are born. Spring migration routes vary little, with the majority of bowheads traveling through the Bering Strait past the North Slope of Alaska, and dispersing along the ice-covered Beaufort shelf as far east as Amundsen Gulf, although a smaller portion of the population heads to the waters off the northern coast of Chukotka. The spring passage of bowheads is an opportunity for Native subsistence hunters along the Chukchi coast, who often take whales during this time.

Alaska Department of Fish and Game (1986); Audubon Alaska (2016d) [based on Citta et al. (2015), Clarke et al. (2015), and Quakenbush et al. (2013)]; Audubon Alaska (2016e) [based on Citta et al. (2015), Clarke et al. (2015), Noongwook et al. (2007), and Quakenbush et al. (2013)]; Alaska (2016f) [based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)]; Audubon Alaska (2016g) [based on Alaska Department of Fish and Game (2016b)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Clarke et al. (2015); Huntington and Quakenbush (2009); National Oceanic and Atmospheric Administration (2013) [revised based on Audubon Alaska et al. (2017)]; National Oceanic and Atmospheric Administration (1988); Noongwook et al. (2007); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003); Quakenbush et al. (2013)



Bowhead Whale
(Balaena mysticetus)

MAP 6.7c

Summer

After migrating northward from the Bering Sea through the Strait and the Chukchi and western Beaufort Seas in spring, most bowhead whales spend the summer feeding on zooplankton in the eastern Beaufort Sea and northeastern Chukotka coast. The bowhead calves born in spring spend this time developing in protected coastal waters with their mothers, whom they will accompany for the next year. Later in summer, bowheads loop back west along the nearshore waters of the US Beaufort shelf toward Barrow Canyon, bringing them to their fall feeding grounds.

Alaska Department of Fish and Game (1986); Audubon Alaska (2016d) [based on Citta et al. (2015), Clarke et al. (2015), and Quakenbush et al. (2013)]; Audubon Alaska (2016e) [based on Citta et al. (2015), Clarke et al. (2015), Noongwook et al. (2007), and Quakenbush et al. (2013)]; Alaska (2016f) [based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)]; Audubon Alaska (2016g) [based on Alaska Department of Fish and Game (2016b)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Clarke et al. (2015); National Oceanic and Atmospheric Administration (2013) [revised based on Audubon Alaska et al. (2017)]; National Oceanic and Atmospheric Administration (1988); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003); Quakenbush et al. (2013)

Bowhead Whale
(Balaena mysticetus)

MAP 6.7d

Fall

Fall marks the start of the journey to return to the southern portion of their range. As colder temperatures move in, ice begins to form in the Beaufort Sea and food becomes scarce, necessitating the bowhead whale fall migration. Bowheads gather in the nearshore waters along the US Beaufort shelf to feed in the fall, before crossing the Chukchi Sea to congregate at fall feeding areas along the northern Chukotka coast. Later in the fall, the newly forming ice margins slowly push the whales further south from their feeding, breeding, and calving grounds until they reach the leads and polynyas they will rely on for the coming winter months. Newborn calves follow their mothers away from their birthplace for the first time, but will return again when the winter ends and the ice melts away.

Alaska Department of Fish and Game (1986); Alaska Department of Fish and Game (2009); Audubon Alaska (2016d) [based on Citta et al. (2015), Clarke et al. (2015), and Quakenbush et al. (2013)]; Audubon Alaska (2016e) [based on Citta et al. (2015), Clarke et al. (2015), Noongwook et al. (2007), and Quakenbush et al. (2013)]; Audubon Alaska (2016f) [based on Audubon Alaska et al. (2017), Bogoslovskaya et al. (2016), and Quakenbush et al. (2013)]; Audubon Alaska (2016g) [based on Alaska Department of Fish and Game (2016b)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska et al. (2017); Clarke et al. (2015); National Oceanic and Atmospheric Administration (2013) [revised based on Audubon Alaska et al. (2017)]; National Oceanic and Atmospheric Administration (1988); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003); Quakenbush et al. (2013)

6.8
GRAY WHALE
MAP ON PAGE 254

Gray Whale

Eschrichtius robustus

Max Goldman and Erika Knight

Gray whales (*Eschrichtius robustus*) are large mysticetes, or baleen whales, that forage from the southern tip of Baja, Mexico in the winter to the Chukchi and Beaufort Seas in northern Alaska in the summer. The only species in the family *Eschrichtiidae*, gray whales are not closely related to any living cetacean (Árnason et al. 1993, Sasaki et al. 2005). There are two isolated geographic distributions of gray whales in the North Pacific Ocean during summer breeding: the Eastern North Pacific (ENP) stock, found along the west coast of North America, and the critically endangered Western North Pacific (WNP) stock, found along the coast of eastern Asia. In winter, these two stocks overlap in range, and limited genetic data seems to suggest overlap in genotype. Gray whales are generally observed alone or traveling in small, loosely affiliated groups, although large aggregations have been observed on feeding and breeding grounds (Zimushko and Lenskaya 1970, Berzin 1984).

ADAPTATIONS

Gray whales have a mottled, slate-gray body with small eyes located just above the corners of the mouth. The baleen of the gray whale is distinctively short and cream colored, and the whale has few of the ventral furrows that denote the closely related rorqual baleen whales. The length of their baleen is presumably linked to their unique strategy of scooping heavy sediments into their mouths in order to feed on benthic biomass within the top layer of the ocean floor (Nerini 1984). Instead of the dorsal fin of most cetaceans, gray whales have a dorsal ridge made up of 8–14 bumps or "knuckles" between the dorsal hump and the tail flukes. The tail flukes are more than 15 feet (3 m) wide and can be used by scientists to identify individual whales, based on the tail shape and the distinct white scarring left by parasites that fall off when gray whales enter the cold, Arctic waters of their summer habitat. Gray whales can grow to about 50 feet (15 m) long and weigh approximately 80,000 pounds (35,000 kg). Females are often slightly larger than males (Jones and Swartz 1984).

DISTRIBUTION

Gray whales are distributed throughout the North Pacific Ocean, generally staying within shallow coastal waters. Most of the ENP stock spends the summer feeding in the northern Bering and Chukchi Seas (Clapham et al. 1999), with some small groups or individuals feeding farther south along the Pacific coast of the US. In the fall, many gray whales migrate south along the coast of North America to winter off the coast of Baja California, Mexico, in their breeding and calving areas. However, studies indicate that gray whales move widely within their range on the Pacific coast, and are not always found in the same area each year (Calambokidis et al. 1999, Quan 2000, Calambokidis et al. 2002). There is some evidence of gray whales off of the northern coast of Alaska during winter (Stafford et al. 2007).

Migration

Gray whales make the longest known annual migration of any mammal: they travel about 10,000 miles (16,000 km) round trip, with the longest recorded migration of over 13,670 miles (22,000 km) by a female gray whale (Mate et al. 2015). From mid-February to May, the ENP stock of gray whales migrates north along the coast, often accompanied by their newborn calves (Ferguson et al. 2015).

LIFE CYCLE

Gray whales become sexually active around eight years of age (Rice et al. 1984). Courting and mating rituals are complex, consisting of arching out of the water, rolling in the water, side-swimming, flipper displays, and often involve three or more whales of mixed sexes. Breeding synchronized with their annual migration patterns ensures that newborns are calved in the warm waters off the coast of Mexico (Swartz et al. 2006). After 13 months of gestation, females give birth to a single, 15-foot-long (4.5 m), 2,000-pound (900-kg) calf (Rice et al. 1984). Calves are born in shallow coastal areas from early January to mid-February.

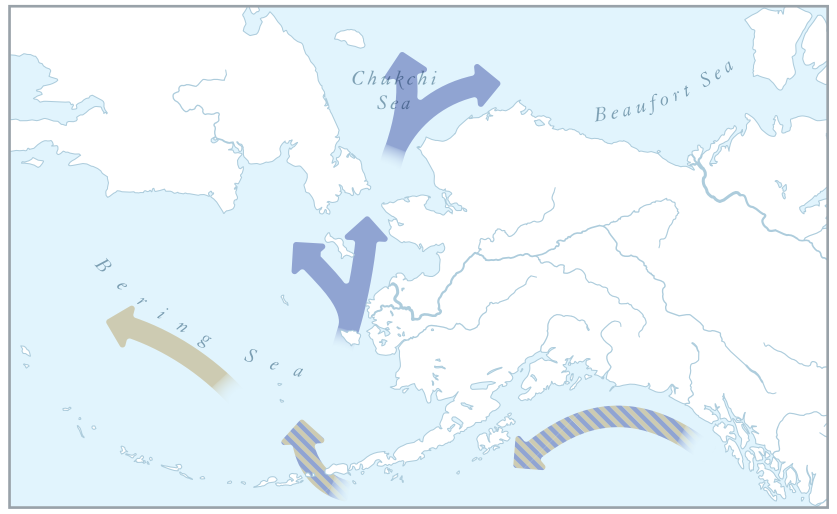


FIGURE 6.8-1. The Eastern and Western North Pacific gray whale stocks' spring migration routes through the Gulf of Alaska and the Bering, Chukchi, and Beaufort Seas.

By counting the layers of wax in the ear canal after death, researchers estimated that 1 female gray whale had lived for 75–80 years (Hohn 2002, Jones and Swartz 2002). Killer whales (*Orcinus orca*) are the only non-human predator of gray whales.

Diet

Gray whales feed on benthic and epibenthic invertebrates such as amphipods and isopods, as well as any other sea creatures that get stuck behind their short, stiff baleen when they turn on their side and scoop up a mouthful of water and seafloor sediment. When feeding, gray whales are often streaked with mud and are commonly observed leaving a trail of sediment behind them (Calambokidis et al. 2002, Jones and Swartz 2002, Brower et al. in press).

CONSERVATION ISSUES

In the mid-1930s, the League of Nations adopted a ban on commercial gray whale and right whale (*Eubalaena* spp.) hunting, entering into the first international conservation agreement. The ban on commercial gray whale catches continues under the International Whaling Commission (IWC), established in 1946 when the League of Nations faltered during the Second World War. Although gray whales are still hunted by the native people of Chukotka in Russia and Washington State in the US, they are subject to sustainable catch limits under the IWC.

The ENP stock of gray whales was removed from Endangered Species Act (ESA) protection after research estimated their population had recovered to pre-whaling numbers, with an expectation of sustained growth (50 CFR 222, June 16, 1994). In 1999, a review of the status of the ENP stock of gray whales recommended the continuation of this stock's classification as non-threatened, based on sustained growth of the population without evidence of any imminent threats to the stock.

The WNP stock of gray whales has not recovered, and is either severely depleted or is functionally extinct and is now made up of colonizing gray whales of the ENP stock (Mate et al. 2015). It is also possible that the 130 or so whales found in Asian waters are a combination of eastern gray whales inhabiting a larger-than-known range along with a smaller-than-estimated "true" Western gray whale population (Weller et al. 2002, Scheinin et al. 2011, Mate et al. 2015). This stock is listed as endangered under the ESA and depleted under the Marine Mammal Protection Act (MMPA).

Due to their annual migration along the highly populated coastline of the western US as well as their concentration in limited winter and summer areas (Ferguson et al. 2015), the ENP stock may be particularly vulnerable to impacts from commercial and industrial development and local catastrophic events. While the immediate threat of over-harvesting has been quelled for the time being and this stock has been removed from the ESA, other issues remain.

As the Bering Sea is one of the world's most productive fisheries, bycatch is a perpetual concern for gray whale conservation, and entanglement in fishing gear such as nets, long lines, and crab pots are responsible for a number of gray whale deaths each year (Zerbini and Kotas 1998, Kiszka et al. 2009). This issue is exacerbated by the fact that Korean and Japanese fishermen are legally allowed to keep and sell any whales caught as bycatch, potentially incentivizing "accidental" entanglements of marine mammals (Lukoschek et al. 2009). They are also susceptible to other anthropogenic disturbances, such as ship strikes. Gray whales are particularly vulnerable to inadvertent ship strikes in summer off the Alaska Coast near Unimak Pass, and increasingly in the Bering Strait (Zerbini and Kotas 1998, Kiszka et al. 2009).

Subsistence harvest of gray whales by native Chukotkans in Russia is ongoing, adhering to the International Whaling Commission (IWC) quota that less than 140 gray whales be taken each year (Weller et al. 2002). The Makah people of Neah Bay in Washington State have applied for exemption from the MMPA in order to resume sustainable subsistence harvesting of gray whales, a cultural practice that has been halted due to protections by the US government (Jenkins and Romanzo 1998).

Aggregations of whales are often accompanied by guided tourist vessels (O'Connor et al. 2009). Harassment by whale watchers is an increasingly serious problem, and is likely responsible for increased stress in targeted whales and has resulted in inadvertent ship strikes (Carlson 2001, Wiley et al. 2008, Gabriele et al. 2011). While ecotourism is commonly thought of as a monetary replacement for more impactful practices such as harvest, care needs to be exercised and guidelines developed and implemented to ensure the safety of the whales (Weinrich and Corbelli 2009).

Hydrocarbon exploration may affect whales due to noise, especially from seismic activities. Offshore energy development may result in pollution or oil spills (Clapham et al. 1999). A large oil spill could be catastrophic due to sea-ice conditions that make a spill hard to clean up, coupled with very little localized response infrastructure or capability.

In far northern latitudes, such as the Bering and Chukchi Seas, large fluctuations in lower trophic recruitment have been observed as a result of a changing climate (Bakun et al. 2015). Gray whales, along with all other life in the Arctic, will be impacted by those changes (McBride et al. 2014).

MAPPING METHODS (MAP 6.8)

The gray whale map shows their migration as well as areas used for feeding and/or reproduction. Because gray whales only inhabit the project area during the summer, the mapped data are not differentiated seasonally.

Gray whale range information was compiled by Audubon Alaska (2016i) based on figures published in the 2013 Alaska Marine Mammal Stock Assessment (Allen and Angliss 2014), shapefiles of species range provided by Alaska Department of Fish and Game (2016c), observations recorded in Brower et al. (2015), and an assessment of Biologically Important Areas (BIAs) for Cetaceans in US waters (Clarke et al. 2015, Ferguson et al. 2015).

Similarly, feeding areas are shown based on information from many sources including the BIA assessment (Clarke et al. 2015, Ferguson et al. 2015); academic papers (Clarke and Moore (2002), Heide-Jørgensen et al. (2012), and Moore et al. (2003)); and book chapters (Bogoslovskaya et al. (2016), Highsmith et al. (2007), and Yablokov and Bogoslovskaya (1984)). Feeding areas also incorporate the 95% isopleth from an Audubon Alaska and Oceana analysis (Audubon Alaska and Oceana 2016) of data from 2000 through 2014 from the Aerial Survey of Arctic Marine Mammals (ASAMM) (National Oceanic and Atmospheric Administration 2015a). The ASAMM data (formerly Bowhead Whale Aerial Survey Project [BWASP]) were analyzed in consultation with Megan Ferguson and Janet Clarke. Aerial survey methods, data, and metadata for the ASAMM database are available at: http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php. The Audubon Alaska and Oceana analysis used only on-transect data where there were more than 62 miles (100 km) of survey effort in a 12.4-mile x 12.4-mile (20-km by 20-km) grid cell. An observation rate (i.e. relative density) was calculated in each grid cell by dividing the observed number of animals over all years by the measure of total transect length over all years. This observation rate was converted into point data with one point per grid cell (at the centroid), and a kernel density function was run with an anisotropic kernel density function with a 24.8 mile (40 km) north-south search radius and a 49.6 mile (80 km) east-west search radius to smooth the data.

Rearing concentration areas were provided in the BIA assessment (Clarke et al. 2015, Ferguson et al. 2015). Additional rearing data were incorporated from Clarke et al. (2017) and based on personal communication with biologist Janet Clarke.

Migration data were compiled by Audubon Alaska (2016h) based on the BIA assessment, the National Oceanic and Atmospheric Administration's (NOAA's) Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones Strategic Assessment: Data Atlas (1988), Yablokov and Bogoslovskaya (1984), and Mate et al. (2015).

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality

Spatial information regarding gray whale distribution and use of the map area is sparse. Data regarding feeding concentration areas are available for both US and Russian waters, however, we only found spatial reproduction information for US waters.

Reviewer

- Janet Clarke

MAP DATA SOURCES

Extent of Range: Audubon Alaska (2016i) based on Alaska Department of Fish and Game (2016c), Allen and Angliss (2014), Clarke et al. (2015), and Ferguson et al. (2015)

Feeding: Audubon Alaska and Oceana (2013) based on Moore et al. (2003); Audubon Alaska and Oceana (2016); Bogoslovskaya et al. (2016); Clarke and Moore (2002); Clarke et al. (2015); Ferguson et al. (2015); Highsmith et al. (2007); Heide-Jørgensen et al. (2012); Yablokov and Bogoslovskaya (1984)

Rearing: Clarke et al. (2015); Clarke et al. (2017); Ferguson et al. (2015); J. Clarke (pers. comm.)

Migration: Audubon Alaska (2016h) based on Ferguson et al. (2015) and National Oceanic and Atmospheric Administration (1988); Mate et al. (2015); Yablokov and Bogoslovskaya (1984)

Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

6.8
GRAY WHALE
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Gray Whale

Audubon ALASKA

Gray Whale (*Eschrichtius robustus*)

Gray whales are large baleen whales that use Arctic and subarctic waters to feed on benthic invertebrates in the summer and fall, after migrating over 10,000 miles (16,000 km) from their subtropical breeding grounds. They are split into two stocks, the critically endangered Western North Pacific (WNP) and the Eastern North Pacific (ENP) stocks. Some WNP whales migrate across the Bering Sea from Unimak Pass to their summer feeding grounds in the Sea of Okhotsk. ENP whales head north to feed in coastal areas of the Bering and Chukchi Seas.

Audubon Alaska (2016h) [based on Ferguson et al. (2015) and National Oceanic and Atmospheric Administration (1988)]; Audubon Alaska (2016i) [based on Alaska Department of Fish and Game (2016c), Allen and Angliss (2014), Brower et al. (2015), Clarke et al. (2015), and Ferguson et al. (2015)]; Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Audubon Alaska and Oceana (2013) [based on Moore et al. (2003)]; Audubon Alaska and Oceana (2016); Bogoslovskaya et al. (2016); Clarke and Moore (2002); Clarke et al. (2015); Clarke et al. (2017); Ferguson et al. (2015); Highsmith et al. (2007); Heide-Jørgensen et al. (2012); J. Clarke (pers. comm.); Mate et al. (2015); Yablokov and Bogoslovskaya (1984)

Map Authors: Erika Knight, Melanie Smith, and Max Goldman
Cartographer: Daniel P. Huffman

Merrill Gosho / NOAA Fisheries, Alaska Fisheries Science Center

The gray whale migration is the longest of any mammal, with adults regularly traveling a staggering 10,000 miles (16,000 km) each year.

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Humpback Whale

Megaptera novaeangliae

Max Goldman and Erika Knight

Humpback whales (*Megaptera novaeangliae*) are a cosmopolitan species of Balaenopterid, or rorqual whales, known for their long migrations, male singing, and acrobatics. They are currently considered to be a single species, although humpback whales from the North Pacific, North Atlantic, and Southern Oceans show divergence in traits such as coloration, migratory and reproductive timing, and regional diet and feeding strategies (Jackson et al. 2014). Within the global humpback whale population, 14 discrete breeding units have been recently recognized—each considered a distinct population segment (DPS), with five in the North Pacific (National Oceanic and Atmospheric Administration 2015b).

As with most other large whales, heavy commercial hunting in the 19th century depleted the global humpback whale population by up to 90% (Breiwick et al. 1983). Since commercial humpback whale hunting was banned in the mid-20th century, orcas (*Orcinus orca*) have again become the most common predators of humpback whales (Dahlheim and White 2010).

ADAPTATIONS

Humpback whales are among the largest animals on the planet, regularly reaching lengths of 55 feet (16–17 m) and weighing in excess of 90,000 lbs (41,000 kg), with females often measuring up to 6 feet (2 m) longer than their male counterparts (Ohsumi 1966). They feed using their large, keratin baleen. They have long pectoral fins and distinct color pattern variation on the ventral side of their fluke, allowing for individual identification. Their dorsal surface is generally dark gray, although ventral coloration varies substantially from white to black to a marbled intermediate (Perrin et al. 2009). Humpback whales exhibit highly varied acoustic calls or songs, and a diverse repertoire of surface behaviors.

Vocalizations

Humpback whale songs have been studied for many years, yet their specific function remains unknown. The most likely utility for complex male humpback singing is interaction with female humpbacks or dominance over other males (Darling et al. 2006). What is known is that all males in a population sing the same song, yet that song changes and evolves over time, with individuals offering intermittent variation, and the group either adopting or rejecting the variations (Sousa-Lima 2005).

DISTRIBUTION

Humpback whales are a globally occurring species with breeding areas located in a latitudinal band from the 30°N to 30°S parallels (Melnikov et al. 2000, Gabriele et al. 2017; Figure 6.9-1). When not breeding or calving, many populations travel to areas of high latitude in both temperate, Arctic, sub-Antarctic and Antarctic waters to feed, often traveling 3,000 miles (5,000 km) or more (Gabriele et al. 1996, Rasmussen et al. 2007, Robbins et al. 2011). The humpback whales that utilize the Bering Sea in the summer are of the Western North Pacific DPS with breeding areas near southern Japan and the Philipines, (Fig. 6.9-1, #3), as well as the Hawaii-breeding DPS (Fig. 6.9-1, #4), and the Mexico-breeding DPS (Fig. 6.9-1, #5).

LIFE CYCLE

Humpback whales spend the colder months in low-latitude breeding grounds. Their mating system is thought to be male-dominated, described by Clapham (Clapham 1996) as a "floating lek." Males compete with each other for the affection of a female humpback whale by engaging in a complex series of aggressive behaviors, such as chasing and tail thrashing, with competing whales often colliding or surfacing on top of each other (Tyack 1981, Baker and Herman 1984, Clapham 1996). These behavioral displays are often accompanied by complex songs that may last nearly a half-hour and can be heard 20 miles (32 km) away (Clapham and Mattila 1990, Cato 1991).

Humpback whale gestation is 11–12 months and calves are typically born in tropical waters (Matthews 1937). Lactation lasts for approximately

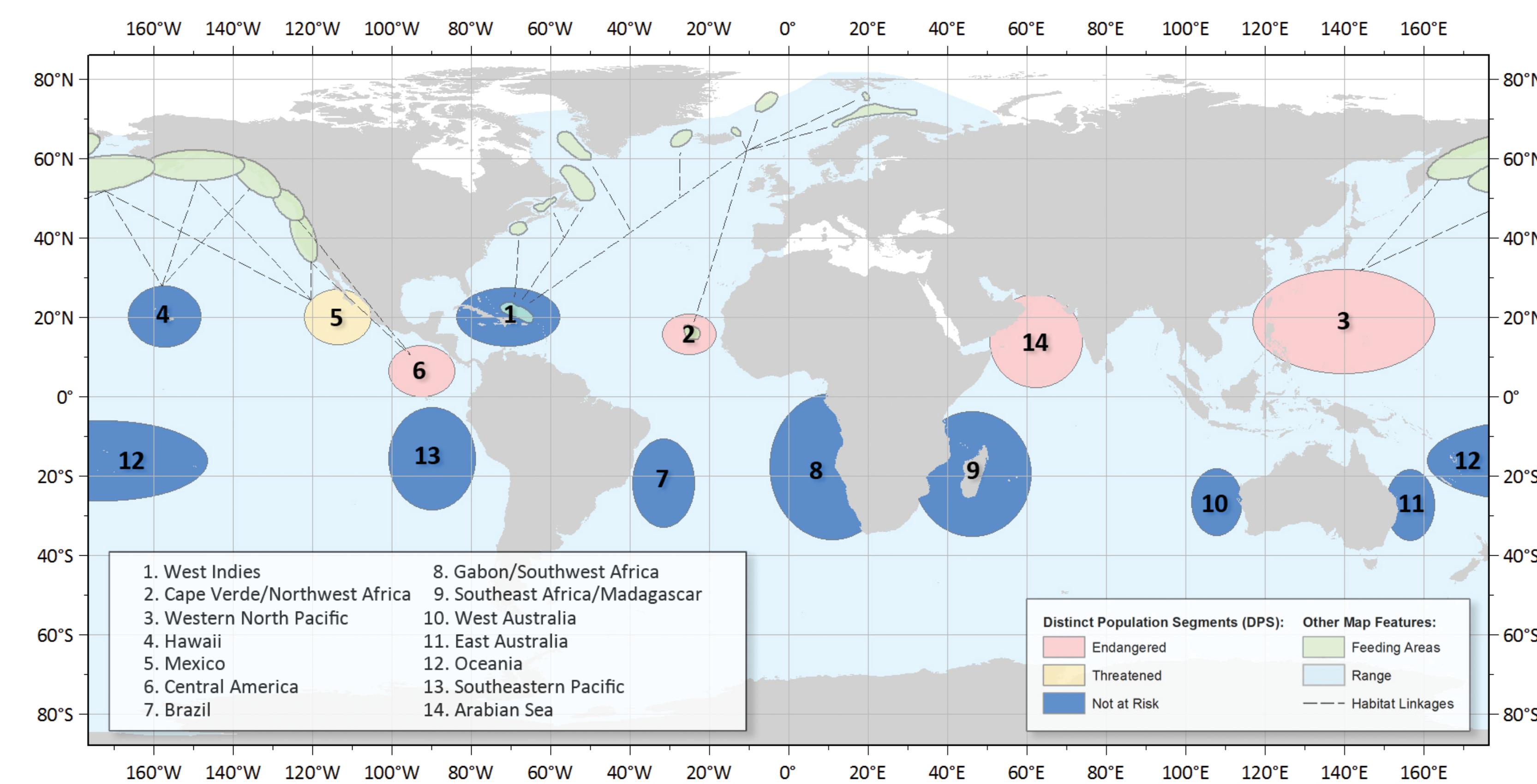

FIGURE 6.9-1. Global humpback whale distinct population segment (DPS) breeding/wintering grounds, and their respective summer feeding areas (National Oceanic and Atmospheric Administration 2017).

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11 months, and weaning begins at about age 6 months and culminates with calves reaching independence near the end of their first year (Clapham and Mayo 1990).

Diet

After migrating to summer and fall feeding areas in high latitudes, humpback whales spend their time storing energy in the form of blubber deposits for the long trip back to their breeding and calving range, where they will likely feed very little or not at all (Zerbini et al. 2006). In the Bering Sea, they concentrate their feeding efforts over the productive waters of the continental shelf, avoiding the relatively barren areas of the basin (Moore et al. 2002, Zerbini et al. 2006).

Humpback whales utilize many food sources and strategies. They are known to feed both in cooperative groups and as solitary animals (Clapham 1993). Most of the time they lunge feed, advancing on prey with wide-open mouths, then closing their mouths and filtering the water out through their baleen plates. Groups of whales will work together to trap schooling fish using bubble curtains and kick-feeding, unique methods likely taught and learned between individuals and populations (Weinrich et al. 1992, Friedlaender et al. 2009).

Their main prey species are euphausiids and small schooling fish, such as herring (*Clupea pallasii*), mackerel (*Scomber scombrus*), sand lance (*Ammodytes hexapterus*), and capelin (*Mallotus villosus*) (Baker et al. 1985, Calambokidis et al. 2001).

CONSERVATION ISSUES

Humpback whales were first listed as endangered in 1970 under the precursor to the Endangered Species Act (ESA), the Endangered Species Conservation Act of 1969. When the ESA was formally enacted in 1973, humpback whales were again listed as endangered. They are protected from any hunting under the Marine Mammal Protection Act of 1972. The International Whaling Commission (IWC) has protected all large cetaceans since the 1970s.

In September of 2016, the ESA listing for humpback whales was updated to specify 14 DPSs, with 1 considered threatened (Mexico DPS) and 4 listed as endangered (Cape Verde Islands/Northwest Africa, Arabian Sea, Western North Pacific, and Central America DPSs) (National Oceanic and Atmospheric Administration 2015b). Humpback whales from the Western North Pacific DPS venture into the Bering Sea in the summer (see Fig. 6.9-1).

While humpback whales have made a substantial recovery through much of their range, there are many areas of concern, especially regarding the endangered Western North Pacific DPS, which spends the summer in the Bering Sea. As the Bering Sea is one of the world's most productive fisheries, bycatch is a perpetual concern for humpback whale conservation, and entanglement in fishing gear, such as nets, long lines, and crab pots, is responsible for a number of humpback whale deaths worldwide each year (Zerbini and Kotas 1998, Kiszka et al. 2009). This issue is exacerbated by the fact that Korean and Japanese fishermen are legally allowed to keep and sell any whales caught as by-catch, potentially incentivizing "accidental" entanglements of marine mammals (Lukoschek et al. 2009). They are also susceptible to other anthropogenic disturbances such as ship strikes. Humpback whales are particularly vulnerable to inadvertent ship strike in summer off the Alaska Coast near Unimak Pass (Williams and O'Hara 2010).

While commercial hunting of humpback whales ended in 1966, humpbacks have been a proposed target for lethal sampling research conducted by Japan through the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA, JARPA II), although no humpbacks were actually ever killed under those programs (Nishiwaki et al. 2009). In 2014, IWC pressure resulted in Japan abandoning the JARPA II program and its harvest goal of 50 humpback whales per year for the New Scientific Whale Research Program in the Antarctic Ocean (NEWREP-A), which does not include humpbacks as a species for lethal sampling, although more than 300 minke whales are included in the lethal sampling goals (International Whaling Commission 2015). Subsistence harvest of humpbacks is not widespread, although western Greenland (Denmark) and St. Vincent and the Grenadines (in the Lesser Antilles Islands) each participate in subsistence hunting of humpback whales, with Greenland adhering to the ten humpback whales per year quota recommended by the IWC and St. Vincent and the Grenadines taking two or fewer each year (Reeves 2002).

Aggregations of whales in areas such as the Gulf of Maine, Hawaii, and Southeast Alaska are often accompanied by guided tourist vessels (O'Connor et al. 2009, Gabriele et al. 2011). Harassment and noise by irresponsible whale watchers is a concern, and is likely responsible for increased stress in targeted whales and has resulted in inadvertent ship strikes (Carlson 2001, Wiley et al. 2008). While ecotourism is commonly thought of as a monetary replacement for more impactful practices such as whaling, care needs to be exercised to ensure the safety of the whales (Weinrich and Corbelli 2009).

In far northern latitudes, such as the Bering Sea, large fluctuations in lower trophic recruitment have been observed as a result of a changing climate (Bakun et al. 2015). Humpback whales, along with all other life in the Arctic, will be impacted by those changes, and substantial decreases in available food could prove detrimental to the already endangered Western North Pacific DPS as they rely on feeding in the Bering Sea to store up the energy needed to make the long migration south to their perennial breeding grounds (McBride et al. 2014).

MAPPING METHODS (MAP 6.9)

The humpback whale map shows summer and fall use of the project area; because humpbacks only inhabit our map area during the summer and fall, the data are not differentiated seasonally. The summer/fall northern range extent and regular-use areas are shown, as well as areas where humpbacks congregate to feed.

Humpback whale data were derived from two sources: a 2015 Alaska Marine Mammal Stock Assessment (Muto et al. 2016) and an assessment of Biologically Important Areas (BIAs) for Cetaceans in US waters (Ferguson et al. 2015). The range extent and regular use areas were digitized from the Marine Mammal Stock Assessment. Feeding concentration areas in Ferguson et al. (2015) were downloaded from the National Oceanic and Atmospheric Administration (NOAA) website.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016j) analysis of 2006–2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality

The information regarding humpback whale distribution shown on this map area is fairly general. Fine scale distribution data exist for US waters (e.g. Friday et al. (2013), Zerbini et al. (2006), and Zerbini et al. (2016) among others), and this detailed spatial information has been summarized by Ferguson et al. (2015) into the feeding BIAs shown as summer feeding concentration areas on our map. We were unable to find information regarding concentration and high-concentration areas for the Russian portion of the project area.

Reviewers

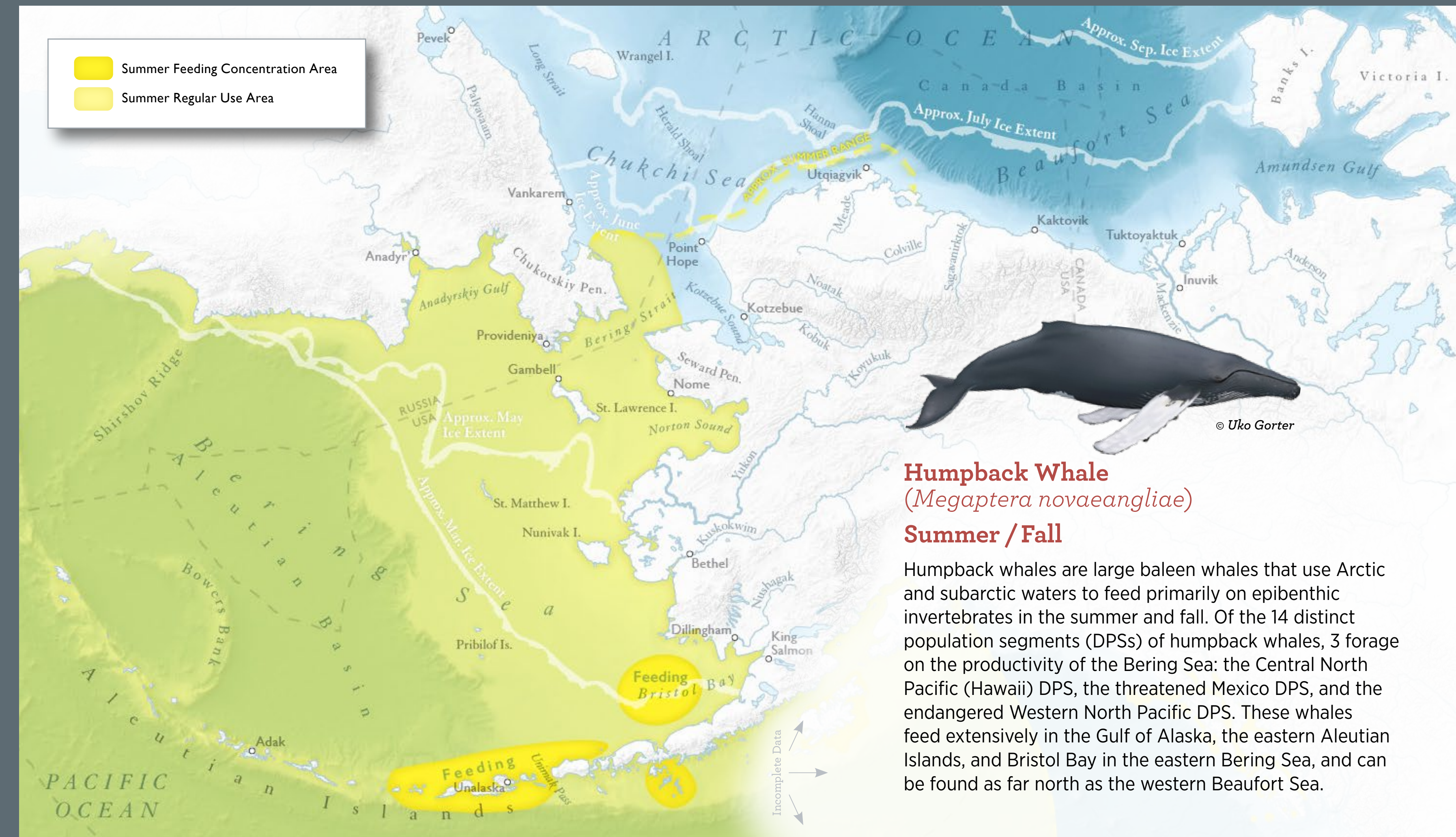
- Alex Zerbini
- Bering Strait Traditional Knowledge-Holder Map Review Workshop participants

MAP DATA SOURCES

Extent of Range: Muto et al. (2016)
Regular Use: Muto et al. (2016)
Feeding Concentration: Ferguson et al. (2015)
Sea Ice: Audubon Alaska (2016j) based on Fetterer et al. (2016)

Humpback Whale

Audubon ALASKA



Humpback Whale
(Megaptera novaeangliae)
Summer / Fall

Humpback whales are large baleen whales that use Arctic and subarctic waters to feed primarily on epibenthic invertebrates in the summer and fall. Of the 14 distinct population segments (DPSs) of humpback whales, 3 forage on the productivity of the Bering Sea: the Central North Pacific (Hawaii) DPS, the threatened Mexico DPS, and the endangered Western North Pacific DPS. These whales feed extensively in the Gulf of Alaska, the eastern Aleutian Islands, and Bristol Bay in the eastern Bering Sea, and can be found as far north as the western Beaufort Sea.

Audubon Alaska (2016j) [based on Fetterer et al. (2016)]; Ferguson et al. (2015); Muto et al. (2016)

Map Authors: Erika Knight and Max Goldman
Cartographer: Daniel P. Huffman

Cooperative feeding by humpback whales drives prey species to the surface, where seabirds also partake in the bounty.

John Schoen

REFERENCES

Aars, J., N. J. Lunn, and A. E. Derocher. 2006. *Polar bears: Proceedings of the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 20–24 June 2005, Seattle, USA. Occasional Paper of the IUCN Species Survival Commission 32*. International Union for Conservation of Nature, Gland, Switzerland and Cambridge, United Kingdom.

Alaska Department of Fish and Game. 1986. *Alaska Habitat Management Guide Arctic Region Map Atlas*. Alaska Department of Fish and Game, Juneau, AK.

______. 2009. Summary Maps of Fall Movements of Bowhead Whales in the Chukchi Sea: February. Alaska Department of Fish and Game, Juneau, AK.

______. 2016a. Refuges, Sanctuaries, Critical Habitat Areas & Wildlife Ranges KML Files. Alaska Department of Fish and Game, Juneau, AK.

______. 2016b. Satellite Tracking of Western Arctic Bowhead Whales. Alaska Department of Fish and Game, Juneau, AK. Accessed online at http://www.adfg.alaska.gov/index.cfm?adfg=marinemam-malprogram.bowheadmaps.

______. 2016c. Species Range Maps. Alaska Department of Fish and Game, Juneau, AK.

Alaska Eskimo Whaling Commission. 2007. *Alaska Eskimo Whaling Commission Booklet*. Alaska Eskimo Whaling Commission, Barrow, AK.

______. 2013. Alaska Eskimo Whaling Commission Website. Accessed online 15 Jun 2013 at http://www.aewc-alaska.com/.

Allen, B. M. and R. P. Angliss. 2014. Alaska Marine Mammal Stock Assessments, 2013. National Oceanic and Atmospheric Administration, Seattle, WA.

Allen, J. A. 1877. The influence of physical conditions in the genesis of species. *Radical Review* 1:108–140.

Amano, M., A. Hayano, and N. Miyazaki. 2002. Geographic variation in the skull of the ringed seal, *Pusa hispida*. *Journal of Mammalogy* 83:370–380.

Amstrup, S. C., G. M. Durner, T. L. McDonald, and W. R. Johnson. 2006. Estimating Potential Effects of Hypothetical Oil Spills on Polar Bears. US Geological Survey Alaska Science Center, Anchorage, AK.

Amstrup, S. C., G. M. Durner, I. Stirling, and T. L. McDonald. 2005. Allocating harvests among polar bear stocks in the Beaufort Sea. *Arctic* 58:247–259.

Amstrup, S. C., B. G. Marcot, and D. C. Douglas. 2008. A Bayesian network modeling approach to fore-casting the 21st century worldwide status of polar bears, *In Arctic Sea Ice Decline: Observations, Projections, Mechanisms, and Implications*. E. T. DeWeaver, C. M. Bitz, and L. B. Tremblay eds., pp. 213–268. American Geophysical Union, Washington, DC.

Amstrup, S. C., I. Stirling, and J. W. Lentfer. 1986. Past and present status of polar bears in Alaska. *Wildlife Society Bulletin (1973–2006)* 14:241–254.

Angliss, R. P. and R. B. Outlaw. 2008. Alaska Marine Mammal Stock Assessments, 2007. NOAA Technical Memorandum NMFS-AFSC-180. National Oceanic and Atmospheric Administration, Seattle, WA.

Antonelis, G. A., Jr and M. A. Perez. 1984. Estimated annual food consumption by northern fur seals in the California Current. *CalCOFI Rep* 25:135–145.

Antonelis, G. A., S. R. Melin, and Y. A. Bukhtiyarov. 1994. Early spring feeding habits of bearded seals (*Erignathus barbatus*) in the central Bering Sea, 1981. *Arctic* 47:74–79.

Árnason, Ú., S. Grétarsdóttir, and A. Gullberg. 1993. Comparisons between the 12S rRNA, 16S rRNA, NADH1 and COI genes of sperm and fin whale mitochondrial DNA. *Biochemical Systematics and Ecology* 21:115–122.

Árnason, Ú., A. Gullberg, A. Janke, M. Kullberg, N. Lehman, E. A. Petrov, and R. Väinölä. 2006. Pinniped phylogeny and a new hypothesis for their origin and dispersal. *Molecular Phylogenetics and Evolution* 41:345–354.

Atwood, T. C., B. G. Marcot, D. C. Douglas, S. C. Amstrup, K. D. Rode, G. M. Durner, and J. F. Bromaghin. 2015a. Evaluating and Ranking Threats to the Long-term Persistence of Polar Bears. USGS Open-File Report 2014-1254. US Geological Survey, Reston, VA.

Atwood, T. C., E. Peacock, M. A. McKinney, K. Lillie, R. Wilson, and S. Miller. 2015b. Demographic Composition and Behavior of Polar Bears Summering on Shore in Alaska. US Geological Survey, Anchorage, AK.

Audubon Alaska. 2009a. Recurring Leads (Average Extent 1993–2004) GIS File. Audubon Alaska, Anchorage, AK.

______. 2009b. Ringed Seal GIS File. Audubon Alaska, Anchorage, AK.

______. 2009c. Shorefast Ice GIS File. Audubon Alaska, Anchorage, AK.

______. 2009d. Spotted Seal GIS File. Audubon Alaska, Anchorage, AK.

______. 2014. Predicted Polar Bear Habitat Use, By Season. Audubon Alaska, Anchorage, AK.

______. 2016a. Bearded Seal Regular Use Winter/Spring GIS File. Audubon Alaska, Anchorage, AK.

______. 2016b. Beluga Migration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016c. Beluga Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016d. Bowhead Seasonal Concentration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016e. Bowhead Seasonal High-Concentration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016f. Bowhead Seasonal Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016g. Bowhead Whale Migration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016h. Gray Whale Migration GIS File. Audubon Alaska, Anchorage, AK.

______. 2016i. Gray Whale Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016j. Landfast Ice GIS File. Audubon Alaska, Anchorage, AK.

______. 2016k. Monthly Sea Ice Approximate 2006–2015 Medians GIS File. Audubon Alaska, Anchorage, AK.

______. 2016l. Polar Bear Denning Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016m. Polar Bear Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016n. Spotted Seal Winter/Spring Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016o. Walrus Summer/Fall Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2016p. Walrus Winter/Spring Range GIS File. Audubon Alaska, Anchorage, AK.

______. 2017a. Beluga Whale High Concentration Non-Winter GIS File. Audubon Alaska, Anchorage, AK.

______. 2017b. Ringed Seal Concentration Winter/Spring GIS File. Audubon Alaska, Anchorage, AK.

______. 2017c. Ringed Seal Regular Use Winter/Spring GIS File. Audubon Alaska, Anchorage, AK.

______. 2017d. Walrus Regular Use Winter/Spring GIS File. Audubon Alaska, Anchorage, AK.

Audubon Alaska, Kawerak, and Sandhill.Culture.Craft. 2017. Traditional Knowledge-Holder Map Review Workshop. February 21–22, 2017. Nome, AK.

Audubon Alaska and Oceana. 2013. Gray Whale Concentration Areas. Audubon Alaska and Oceana, Anchorage and Juneau, AK.

______. 2016. Marine Mammal Species Core Area Analysis. Audubon Alaska, Anchorage and Juneau, AK.

Audubon Alaska, Oceana, Ocean Conservancy, Pew Charitable Trusts, and World Wildlife Fund. 2016. A Synthesis of Important Areas in the US Chukchi and Beaufort Seas: The Best Available Data to Inform Managment Decisions. Audubon Alaska, Anchorage, AK.

Baker, C. S. and L. M. Herman. 1984. Aggressive behavior between humpback whales (*Megaptera novaeangliae*) wintering in Hawaiian waters. *Canadian Journal of Zoology* 62:1922–1937.

Baker, C. S., L. M. Herman, A. Perry, W. S. Lawton, J. M. Straley, and J. H. Straley. 1985. Population characteristics and migration of summer and late-season humpback whales (*Megaptera novae-angliae*) in southeastern Alaska. *Marine Mammal Science* 1:304–323.

Baker, C. S., T. R. Loughlin, V. Burkanov, C. W. Matson, R. G. Trujillo, D. G. Calkins, J. K. Wickliffe, and J. W. Bickham. 2005. Variation of mitochondrial control region sequences of Steller sea lions: The three-stock hypothesis. *Journal of Mammalogy* 86:1075–1084.

Bakun, A., B. Black, S. J. Bograd, M. Garcia-Reyes, A. Miller, R. Rykaczewski, and W. Sydeman. 2015. Anticipated effects of climate change on coastal upwelling ecosystems. *Current Climate Change Reports* 1:85–93.

Belikov, S., A. Boltunov, and Y. Gorbunov. 1996. Distribution and migration of polar bears, Pacific walruses, and gray whales depending on ice conditions in the Russian Arctic. *Proceedings of the NIPR Symposium on Polar Biology* 9:263–274.

Belikov, S. E. 1992. Number, distribution, and migrations of the polar bear in the Soviet Arctic. *Krupnye Khishniki (Big Predators).* Moskva, CNIL Glavokhoty RSFSR:74–84.

Bengtson, J. L., L. M. Hiruki-Raring, M. A. Simpkins, and P. L. Boveng. 2005. Ringed and bearded seal densities in the eastern Chukchi Sea, 1999–2000. *Polar Biology* 28:833–845.

Benoit-Bird, K. J., B. C. Battaile, C. A. Nordstrom, and A. W. Trites. 2013. Foraging behavior of northern fur seals closely matches the hierarchical patch scales of prey. *Marine Ecology Progress Series* 479:283–302.

Berzin, A. A. 1984. Soviet studies of the distribution and numbers of the gray whale in the Bering and Chukchi Seas, from 1968 to 1982, *In The Gray Whale: Eschrichtius robustus*. M. L. Jones, S. L. Swartz, and S. Leatherwood eds., pp. 409–450. Academic Press, New York, NY.

Best, R. C. 1985. Digestibility of ringed seals by the polar bear. *Canadian Journal of Zoology* 63:1033–1036.

Bishop, R. H. 1967. Reproduction, age determination, and behavior of the harbor seal, *Phoca vitulina L.*, in the Gulf of Alaska. MS thesis, University of Alaska, Fairbanks, AK.

Blackwell, S. B., W. J. Richardson, C. R. Greene, and B. Streever. 2007. Bowhead whale (*Balaena mysticetus*) migration and calling behaviour in the Alaskan Beaufort Sea, autumn 2001–04: An acoustic localization study. *Arctic* 60:255–270.

Bluhm, B. A. and R. Gradinger. 2008. Regional variability in food availability for Arctic marine mammals. *Ecological Applications* 18:77–96.

Bogoslovskaya, L. S., I. V. Slugin, I. A. Zagrebin, and I. Krupnik. 2016. *Maritime Hunting Culture of Chukotka: Traditions and Modern Practices*. Shared Beringian Heritage Program, US Department of the Interior, Anchorage, AK.

Born, E. W., M. Aquarone, L. Ø. Knutsen, and L. T. Pedersen. 2005. Homing behaviour in an Atlantic walrus (*Odobenus rosmarus rosmarus*). *Aquatic Mammals* 31:23–33.

Boveng, P. L., J. L. Bengtson, T. W. Buckley, M. F. Cameron, S. P. Dahle, B. P. Kelly, B. A. Megrey, J. E. Overland, and N. J. Williamson. 2009. Status Review of the Spotted Seal (*Phoca largha*). NOAA Technical Memorandum NMFS-AFSC-200. National Oceanic and Atmospheric Administration, Seattle, WA.

Boveng, P. L., J. L. Bengtson, M. F. Cameron, S. P. Dahle, E. A. Logerwell, J. M. London, J. E. Overland, J. T. Sterling, D. E. Stevenson, B. L. Taylor, and H. L. Ziel. 2013. Status Review of the Ribbon Seal (*Histriophoca fasciata*). NOAA Technical Memorandum NMFS-AFSC-255. National Oceanic and Atmospheric Administration, Seattle, WA.

Bowen, W. D. and D. B. Siniff. 1999. Distribution, population biology, and feeding ecology of marine mammals, *In Biology of Marine Mammals*. J. E. Reynolds, III and S. A. Rommel eds., pp. 423–484. Smithsonian Institute Press, Washington, DC.

Braham, H. W., B. D. Krogman, and G. M. Carroll. 1984. Bowhead and White Whale Migration, Distribution, and Abundance in the Bering, Chukchi, and Beaufort Seas, 1975–78. NOAA Technical Report, NMFS, SSRF-778. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Rockville, MD.

Brandon, J. R. and P. R. Wade. 2006. Assessment of the Bering-Chukchi-Beaufort Seas stock of bowhead whales using Bayesian model averaging. *Journal of Cetacean Research and Management* 8:225–239.

Breiwick, J. M., E. Mitchell, and R. R. Reeves. 1983. Simulated population trajectories for northwest Atlantic humpback whales, 1865–1980, *In 5th Biennial Conference on the Biology of Marine Mammals*. Boston, MA.

Brodie, P. F. 1989. The white whale *Delphinapterus leucas* (Pallas, 1776), *In Handbook of Marine Mammals. Volume 4: River Dolphins and the Larger Toothed Whales*. S. H. Ridgway and R. Harrison eds., pp. 119–144. Academic Press, San Diego, CA.

Bromaghin, J. F., T. L. McDonald, I. Stirling, A. E. Derocher, E. S. Richardson, E. V. Regehr, D. C. Douglas, G. M. Durner, T. Atwood, and S. C. Amstrup. 2015. Polar bear population dynamics in the southern Beaufort Sea during a period of sea ice decline. *Ecological Applications* 25:634–651.

Brower, A., J. Clarke, and M. Ferguson. 2015. Gray whale occurrence in the Beaufort Sea, *In Alaska Marine Science Symposium*. Anchorage, AK.

Brower, A. A., M. C. Ferguson, S. V. Schonberg, S. C. Jewett, and J. T. Clarke. In press. Gray whale distribution relative to benthic invertebrate biomass and abundance: Northeastern Chukchi Sea 2009–2012. *Deep Sea Research Part II: Topical Studies in Oceanography*.

Burn, D. M., M. S. Udevitz, S. G. Speckman, and R. B. Benter. 2009. An improved procedure for detection and enumeration of walrus signatures in airborne thermal imagery. *International Journal of Applied Earth Observation and Geoinformation* 11:324–333.

Burns, J. J. 1970. Remarks on the distribution and natural history of pagophilic pinnipeds in the Bering and Chukchi seas. *Journal of Mammalogy* 51:445–454.

Burns, J. J. and K. J. Frost. 1979. Natural History and Ecology of the Bearded Seal, *Erignathus barbatus*. Alaska Department of Fish and Game, Fairbanks, AK.

Burns, J. J., J. J. Montague, and C. J. Cowles. 1993. *The Bowhead Whale*. Society for Marine Mammalogy Special Publication No. 2, Allen Press, Lawrence, KS.

Burns, J. J., L. H. Shapiro, and F. H. Fay. 1981. Ice as marine mammal habitat in the Bering Sea, *In The Eastern Bering Sea Shelf: Oceanography and Resources*. D. W. C. Hood, J.A. ed., pp. 781–797. Office of Marine Pollution Assessment, Washington, DC.

Calambokidis, J., J. D. Darling, V. Deeke, P. Gearin, M. Gosho, W. Megill, C. Tombach, D. Goley, C. Toropova, and B. Gisborne. 2002. Abundance, range and movements of a feeding aggregation of gray whales (*Eschrictius robustus*) from California to southeastern Alaska in 1998. *Journal of Cetacean Research and Management* 4:267–276.

Calambokidis, J., J. Quan, L. Schlender, M. Gosho, and P. Gearin. 1999. Gray Whale Photographic Identification in 1998: Report on Research in 1998, Final Report. Cascadia Research Collective for the National Marine Mammal Laboratory, Olympia and Seattle, WA.

Calambokidis, J., G. H. Steiger, J. M. Straley, L. M. Herman, S. Cerchio, D. R. Salden, U. R. Jorge, J. K. Jacobsen, O. V. Ziegesar, and K. C. Balcomb. 2001. Movements and population structure of humpback whales in the North Pacific. *Marine Mammal Science* 17:769–794.

Calkins, D. G., K. W. Pitcher, K. B. Schneider, and N. Murray. 1982. Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska. Final Report Outer Continental Shelf Environmental Assessment Program, Research Unit 243, Contract Number 03-5-022-69. Alaska Department of Fish and Game, Anchorage, AK.

Cameron, M. F., J. L. Bengtson, P. L. Boveng, J. Jansen, B. P. Kelly, S. Dahle, E. Logerwell, J. Overland, C. Sabine, and G. Waring. 2010. Status Review of the Bearded Seal (*Erignathus barbatus*). NOAA Technical Memorandum NMFS-AFSC-211. National Oceanic and Atmospheric Administration, Seattle, WA.

Campbell, G. S., R. C. Gisiner, D. A. Helweg, and L. L. Milette. 2002. Acoustic identification of female Steller sea lions *(Eumetopias jubatus)*. *Journal of the Acoustical Society of America* 111:2920–2928.

Carlson, C. 2001. A Review of Whale Watch Guidelines and Regulations Around the World: Version 2001. IWC SC/53/WW4. International Whaling Commission, Cambridge, United Kingdom.

Carmack, E. C. and R. W. MacDonald. 2002. Oceanography of the Canadian shelf of the Beaufort Sea: A setting for marine life. *Arctic* 55:29–45.

Carroll, G. M., J. C. George, L. F. Lowry, and K. O. Coyle. 1987. Bowhead whale (*Balaena mysticetus*) feeding near Point Barrow, Alaska, during the 1985 spring migration. *Arctic* 40:105–110.

Cato, D. H. 1991. Songs of humpback whales: The Australian perspective. *Memoirs of the Queensland Museum* 30:277–290.

Cherry, S. G., A. E. Derocher, K. A. Hobson, I. Stirling, and G. W. Thiemann. 2011. Quantifying dietary pathways of proteins and lipids to tissues of a marine predator. *Journal of Applied Ecology* 48:373–381.

Cherry, S. G., A. E. Derocher, G. W. Thiemann, and N. J. Lunn. 2013. Migration phenology and seasonal fidelity of an Arctic marine predator in relation to sea ice dynamics. *Journal of Animal Ecology* 82:912–921.

Chivers, S. 1999. Biological indices for monitoring population status of walrus evaluated with an individ-ual-based model, *In Marine Mammal Survey and Assessment Methods*. G. W. Garner, S. C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald, and D. G. Robertson eds., pp. 239–248. AA Balkema, Rotterdam, Netherlands.

Citta, J. J., L. T. Quakenbush, S. R. Okkonen, M. L. Druckenmiller, W. Maslowski, J. Clement-Kinney, J. C. George, H. Brower, R. J. Small, C. J. Ashjian, L. A. Harwood, and M. P. Heide-Jørgensen. 2015. Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012. *Progress in Oceanography* 136:201–222.

Citta, J. J., P. Richard, L. F. Lowry, G. O'Corry-Crowe, M. Marcoux, R. Suydam, L. T. Quakenbush, R. C. Hobbs, D. I. Litovka, K. J. Frost, T. Gray, J. Orr, B. Tinker, H. Aderman, and M. L. Druckenmiller. 2016. Satellite telemetry reveals population specific winter ranges of beluga whales in the Bering Sea. *Marine Mammal Science* 33:236–250.

Clapham, P. and D. K. Mattila. 1990. Humpback whale songs as indicators of migration routes. *Marine Mammal Science* 6:155–160.

Clapham, P. J. 1993. Social organization of humpback whales on a North Atlantic feeding ground. *Symposium of the Zoological Society of London* 66:131–145.

______. 1996. The social and reproductive biology of humpback whales: An ecological perspective. *Mammal Review* 26:27–49.

Clapham, P. J. and C. A. Mayo. 1990. Reproduction of humpback whales (*Megaptera novaeangliae*) observed in the Gulf of Maine, *In Individual Recognition of Cetaceans: Use of Photo-Identification and Other Techniques to Estimate Population Parameters*. P. S. Hammond, S. A. Mizroch, and G. P. Donovan eds., pp. 171–175. International Whaling Commission, Cambridge, United Kingdom.

Clapham, P. J., S. B. Young, and R. L. Brownell. 1999. Baleen whales: Conservation issues and the status of the most endangered populations. *Mammal Review* 29:37–62.

Clarke, J. T., A. A. Brower, M. C. Ferguson, and A. L. Willoughby. 2017. Distribution and Relative Abundance of Marine Mammals in the Eastern Chukchi and Western Beaufort Seas, 2015. Annual Report, OCS Study BOEM 2017-019. National Oceanic and Atmospheric Administration, National Marine Mammal Laboratory, Alaska Fisheries Science Center, Seattle, WA.

Clarke, J. T. and M. C. Ferguson. 2010. Aerial surveys of large whales in the northeastern Chukchi Sea, 2008–2009, with review of 1982–1991 data. Paper SC/61/BRG13, *In International Whaling Commission Scientific Committee Meetings*. Morocco.

Clarke, J. T., M. C. Ferguson, C. Curtice, and J. Harrison. 2015. Biologically important areas for cetaceans within US waters—Arctic region. *Aquatic Mammals* 41:2–16.

Clarke, J. T., A. S. Kennedy, and M. C. Ferguson. 2016. Bowhead and gray whale distributions, sighting rates, and habitat associations in the eastern Chukchi Sea, summer and fall 2009–15, with a retrospective comparison to 1982–91. *Arctic* 69:359–377.

Clarke, J. T. and S. E. Moore. 2002. A note on observations of gray whales in the southern Chukchi and northern Bering Seas, August–November, 1980–89. *Journal of Cetacean Research and Management* 4:283–288.

Community of Aklavik, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Aklavik Inuvialuit Community Conservation Plan. Community of Aklavik, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Aklavik, Canada.

Community of Inuvik, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Inuvik Inuvialuit Community Conservation Plan. Community of Inuvik, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Inuvik, Canada.

Community of Olokhaktomiut, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Olokhaktomiut Inuvialuit Community Conservation Plan. Community of Olokhaktomiut, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Olokhaktomiut, Canada.

Community of Paulatuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Paulatuk Inuvialuit Community Conservation Plan. Community of Paulatuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Paulatuk, Canada.

Community of Sachs Harbour, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Sachs Harbour Inuvialuit Community Conservation Plan. Community of Sachs Harbour, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Sachs Harbour, Canada.

Community of Tuktoyaktuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Tuktoyaktuk Inuvialuit Community Conservation Plan. Community of Tuktoyaktuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Tuktoyaktuk, Canada.

Conn, P. B., J. M. Ver Hoef, B. T. McClintock, E. E. Moreland, J. M. London, M. F. Cameron, S. P. Dahle, and P. L. Boveng. 2014. Estimating multispecies abundance using automated detection systems: Ice-associated seals in the Bering Sea. *Methods in Ecology and Evolution* 5:1280–1293.

Cooper, M. H., S. M. Budge, A. M. Springer, and G. Sheffield. 2009. Resource partitioning by sympatric pagophilic seals in Alaska: Monitoring effects of climate variation with fatty acids. *Polar Biology* 32:1137–1145.

Cosens, S. E. and A. Blouw. 2003. Size-and age-class segregation of bowhead whales summering in northern Foxe Basin: A photogrammetric analysis. *Marine Mammal Science* 19:284–296.

Coues, E. 1877. *Fur-bearing Animals: A Monograph of North American Mustelidae*. US Geological Survey of the Territories, Miscellaneous Publications No. 8. US Government Printing Office, Washington, DC.

Croll, D. A., C. W. Clark, J. Calambokidis, W. T. Ellison, and B. R. Tershy. 2001. Effect of anthropogenic low-frequency noise on the foraging ecology of Balaenoptera whales. *Animal Conservation* 4:13–27.

Dahlheim, M. E. and P. A. White. 2010. Ecological aspects of transient killer whales *Orcinus orca* as predators in southeastern Alaska. *Wildlife Biology* 16:308–322.

Daniel, R., C. Krenz, M. Smith, N. Walker, B. Robson, E. Huffines, A. Hartsig, and H. Huntington. 2015. A synthesis of important areas in the US Beaufort Sea, *In Alaska Marine Science Symposium*. Anchorage, AK.

Darling, J. D., M. E. Jones, and C. P. Nicklin. 2006. Humpback whale songs: Do they organize males during the breeding season? *Behaviour* 143:1051–1101.

Deguchi, T., Y. Goto, and Y. Sakurai. 2004. Importance of walleye pollock (*Theragra chalcogramma*) to wintering ribbon seals (*Phoca fasciata*) in Nemuro Strait, Hokkaido Japan. *Mammal Study* 29:55–63.

Dehn, L. A., G. G. Sheffield, E. H. Follmann, L. K. Duffy, D. L. Thomas, and T. M. O'Hara. 2007. Feeding ecology of phocid seals and some walrus in the Alaskan and Canadian Arctic as determined by stomach contents and stable isotope analysis. *Polar Biology* 30:167–181.

DeMarban, A. 2016. Appeals Court Supports Climate-Based Listing of Bearded Seals as Threatened. Alaska Dispatch News, 25 October.

Derocher, A. and I. Stirling. 1998. Maternal investment and factors affecting offspring size in polar bears (*Ursus maritimus*). *Journal of Zoology* 245:253–260.

Derocher, A. E. 2012. *Polar Bears: A Complete Guide to Their Biology and Behavior*. John Hopkins University Press, Baltimore, MD.

Derocher, A. E., N. J. Lunn, and I. Stirling. 2004. Polar bears in a warming climate. *Integrative and Comparative Biology* 44:163–176.

Derocher, A. E. and I. Stirling. 1990. Observations of aggregating behaviour in adult male polar bears (*Ursus maritimus*). *Canadian Journal of Zoology* 68:1390–1394.

Dizon, A. E., C. Lockyer, W. F. Perrin, D. P. Demaster, and J. Sisson. 1992. Rethinking the stock concept: A phylogeographic approach. *Conservation Biology* 6:24–36.

Doidge, D. W. 1990a. Age-length and length-weight comparisons in the beluga, *Delphinapterus leucas*, *In Advances in Research on the Beluga Whale Delphinapterus leucas*. T. G. Smith, D. J. St. Aubin, and J. R. Geraci eds. *Canadian Bulletin of Fisheries and Aquatic Sciences* 224:59–68.

______. 1990b. Integumentary heat loss and blubber distribution in the beluga, *Delphinapterus leucas*, with comparisons to the narwhal, *Monodon monoceros. Canadian Bulletin of Fisheries and Aquatic Sciences* 224:129–140.

Durner, G. M., S. C. Amstrup, and K. J. Ambrosius. 2006. Polar bear maternal den habitat in the Arctic National Wildlife Refuge, Alaska. *Arctic* 59:31–36.

Durner, G. M., S. C. Amstrup, R. Neilson, and T. McDonald. 2004. The Use of Sea Ice Habitat by Female Polar Bears in the Beaufort Sea. US Geological Survey, Alaska Science Center, Anchorage, AK.

Durner, G. M., D. C. Douglas, R. M. Nielson, S. C. Amstrup, T. L. McDonald, I. Stirling, M. Mauritzen, E. W. Born, O. Wiig, E. DeWeaver, M. C. Serreze, S. E. Belikov, M. M. Holland, J. Maslanik, J. Aars, D. C. Bailey, and A. E. Derocher. 2009. Predicting 21st century polar bear habitat distribution from global climate models. *Ecological Monographs* 79:107–120.

Durner, G. M., A. S. Fischbach, S. C. Amstrup, and D. C. Douglas. 2010. Catalogue of Polar Bear (*Ursus maritimus*) Maternal Den Locations in the Beaufort Sea and Neighboring Regions, Alaska, 1910–2010. US Geological Survey Data Series 568. US Geological Survey, Reston, VA.

Durner, G. M., J. P. Whiteman, H. J. Harlow, S. C. Amstrup, E. V. Regehr, and M. Ben-David. 2011. Consequences of long-distance swimming and travel over deep-water pack ice for a female polar bear during a year of extreme sea ice retreat. *Polar Biology* 34:975–984.

Dutton, K., S. Miller, and T. DeBruyn. 2011. Polar Bear Divisionary Feeding Workshop Report. 8–9 June 2011. US Fish and Wildlife Service and Defenders of Wildlife, Anchorage, AK.

Dyke, A. S., J. Hooper, C. R. Harington, and J. M. Savelle. 1999. The late Wisconsinan and Holocene record of walrus (*Odobenus rosmarus*) from North America: A review with new data from Arctic and Atlantic Canada. *Arctic* 52:160–181.

Edie, A. G. 1977. Distribution and Movements of Steller Sea Lion Cows (*Eumetopias jubata*) on a Pupping Colony. MS thesis, University of British Columbia, Vancouver, Canada.

Eicken, H., L. H. Shapiro, A. G. Gaylord, A. Mahoney, and P. W. Cotter. 2005. Mapping and Characterization of Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas. Minerals Management Service, Alaska OCS Region, Anchorage, AK.

______. 2009. Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas, 1993–2004. National Snow and Ice Data Center, Boulder, CO.

Elliott, H. W. 1882. *A Monograph of the Seal-Islands of Alaska*. US Commission of Fish and Fisheries, Special Bulletin 176. US Government Printing Office, Washington, DC.

Everitt, R. D. and B. D. Krogman. 1979. Sexual behavior of bowhead whales observed off the north coast of Alaska. *Arctic* 32:277–280.

Fay, F. H. 1960. Structure and function of the pharyngeal pouches of the walrus (*Odobenus rosmarus L.*). *Mammalia* 24:361–371.

______. 1982. Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. *North American Fauna* 74:1–279.

______. 1985. *Odobenus rosmarus*. *Mammalian Species* 238:1–7.

Fay, F. H. and J. J. Burns. 1988. Maximal feeding depths of walruses. *Arctic* 41:239–240.

Fay, F. H. and G. A. Fedoseev. 1984. Soviet-American Cooperative Research on Marine Mammals. Volume 1–Pinnipeds. NOAA Technical Report NMFS 12. National Oceanic and Atmospheric Administration, Rockville, MD.

Fay, F. H. and B. P. Kelly. 1980. Mass natural mortality of walruses (*Odobenus rosmarus*) at St. Lawrence Island, Bering Sea, autumn 1978. *Arctic* 33:226–245.

Fay, F. H., B. P. Kelly, and J. L. Sease. 1989. Managing the exploitation of Pacific walruses—a tragedy of delayed-response and poor communication. *Marine Mammal Science* 5:1–16.

Fay, F. H., G. C. Ray, and A. A. Kibal'chich. 1984. Time and location of mating and associated behavior of the Pacific walrus, *Odobenus rosmarus divergens* Illiger, *In Soviet-American Cooperative Research on Marine Mammals. Volume 1–Pinnipeds. NOAA Technical Report NMFS 12*. F. H. Fay and G. A. Fedoseev eds., pp. 89–99. National Oceanic and Atmospheric Administration, Rockville, MD.

Fedoseev, G. 1984. Present status of the population of walruses (*Odobenus rosmarus*) in the eastern Arctic and Bering Sea, *In Marine Mammals of the Far East*. V. E. Rodin, A. S. Perlov, A. A. Berzin, G. M. Gavrilov, A. I. Shevchenko, N. S. Fadeev, and E. B. Kucheriavenko eds., pp. 73–85. TINRO, Vladivostok, Russia.

Ferguson, M. C., J. Waite, C. Curtice, J. Clarke, and J. Harrison. 2015. Biologically important areas for cetaceans within US waters—Aleutian Islands and Bering Sea region. *Aquatic Mammals* 41:79–93.

Fetterer, F., K. Knowles, W. Meier, and M. Savoie. 2016. Sea Ice Index, Version 2. National Snow and Ice Data Center, Boulder, CO.

Fischbach, A., S. C. Amstrup, and D. C. Douglas. 2007. Landward and eastward shift of Alaskan polar bear denning associated with recent sea ice changes. *Polar Biology* 30:1395–1405.

Fischbach, A., D. Monson, and C. Jay. 2009. Enumeration of Pacific Walrus Carcasses on Beaches of the Chukchi Sea in Alaska Following a Mortality Event, September 2009. US Geological Survey Open-File Report 2009-1291. US Geological Survey, Reston, VA.

Fischbach, A. S., A. A. Kochnev, J. L. Garlich-Miller, and C. V. Jay. 2016. Pacific Walrus Coastal Haulout Database, 1852–2016—Background Report. US Geological Survey Open-File Report 2016-1108. US Geological Survey, Reston, VA.

Fisher, K. and R. Stewart. 1997. Summer foods of Atlantic walrus, *Odobenus rosmarus rosmarus*, in northern Foxe Basin, Northwest Territories. *Canadian Journal of Zoology* 75:1166–1175.

Foote, D. C. 1964. Observations of the bowhead whale at Point Hope, Alaska. Unpublished manuscript. McGill University, Montreal, Canada.

Fowler, C. W., R. Ream, B. Robson, and M. Kiyota. 1992. Entanglement Studies, St. Paul Island, 1991: Juvenile male northern fur seals. AFSC Processed Report 92-07. National Oceanic and Atmospheric Administration, National Marine Mammal Lab., Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, WA.

Freitas, C., K. Kovacs, M. Andersen, J. Aars, S. Sandven, M. Skern-Mauritzen, O. Pavlova, and C. Lydersen. 2012. Importance of fast ice and glacier fronts for female polar bears and their cubs during spring in Svalbard, Norway. *Marine Ecology Progress Series* 447:289–304.

Friday, N. A., A. N. Zerbini, J. M. Waite, S. E. Moore, and P. J. Clapham. 2013. Cetacean distribution and abundance in relation to oceanographic domains on the eastern Bering Sea shelf, June and July of 2002, 2008, and 2010. *Deep Sea Research Part II: Topical Studies in Oceanography* 94:244–256.

Friedlaender, A. S., E. L. Hazen, D. P. Nowacek, P. N. Halpin, C. Ware, M. T. Weinrich, T. P. Hurst, and D. N. Wiley. 2009. Diel changes in humpback whale *Megaptera novaeangliae* feeding behavior in response to sand lance *Ammodytes* spp. behavior and distribution. *Marine Ecology Progress Series* 395:91–100.

Fritz, L., K. Sweeney, M. Lynn, T. Gelatt, J. Gilpatrick, and R. Towell. 2015a. Counts of Alaska Steller Sea Lion Adult and Juvenile (Non-pup) Conducted on Rookeries and Haul-outs in Alaska Aleutian Islands, Bering Sea, and others from 1904-01-01 to 2014-07-09 (NCEI Accession 0128190). National Oceanic and Atmospheric Administration, National Centers for Environmental Information. Accessed online at https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0128190.

______. 2015b. Counts of Alaska Steller Sea Lion Pups Conducted on Rookeries in Alaska from 1961-06-22 to 2014-07-09 (NCEI Accession 0128189). NOAA National Centers for Environmental Information. Accessed online at https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0128189.

Fritz, L., K. Sweeney, R. Towell, and T. Gelatt. 2015c. Steller Sea Lion Haulout and Rookery Locations in the United States for 2015-05-14 (NCEI Accession 0129877). Version 2.3. NOAA National Centers for Environmental Information. Accessed online at https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0129877.

Frost, K. J. and R. Suydam. 2005. Harvest of Beluga Whales, *Delphinapterus leucas*, in Northern and Western Alaska, 1987–2004. Alaska Beluga Whale Committee Report, Barrow, AK.

Fulton, T. L. and C. Strobeck. 2010. Multiple fossil calibrations, nuclear loci and mitochondrial genomes provide new insight into biogeography and divergence timing for true seals (Phocidae, Pinnipedia). *Journal of Biogeography* 37:814–829.

Gabriele, C. M., C. W. Clark, A. S. Frankel, and B. Kipple. 2011. Glacier Bay's underwater sound environment: The effects of cruise ship noise on humpback whale habitat. *Alaska Park Science* 9:12–17.

Gabriele, C. M., J. L. Neilson, J. M. Straley, C. S. Baker, J. A. Cedarleaf, and J. F. Saracco. 2017. Natural history, population dynamics, and habitat use of humpback whales over 30 years on an Alaska feeding ground. *Ecosphere* 8:e01641.

Gabriele, C. M., J. M. Straley, L. M. Herman, and R. J. Coleman. 1996. Fastest documented migration of a North Pacific humpback whale. *Marine Mammal Science* 12:457–464.

Garner, G. W., S. E. Belikov, M. S. Stishov, V. G. Barnes, and S. M. Arthur. 1994. Dispersal patterns of maternal polar bears from the denning concentration on Wrangel Island. *Bears: Their Biology and Management* 9:401–410.

Garner, G. W., S. T. Knick, and D. C. Douglas. 1990. Seasonal movements of adult female polar bears in the Bering and Chukchi Seas. *Bears: Their Biology and Management* 8:219–226.

Gentry, R. L. 1998. *Behavior and Ecology of the Northern Fur Seal*. Princeton University Press, Princeton, NJ.

George, J. C., J. Bada, J. Zeh, L. Scott, S. E. Brown, T. O'hara, and R. Suydam. 1999. Age and growth estimates of bowhead whales (*Balaena mysticetus*) via aspartic acid racemization. *Canadian Journal of Zoology* 77:571–580.

George, J. C. and J. R. Bockstoce. 2008. Two historical weapon fragments as an aid to estimating the longevity and movements of bowhead whales. *Polar Biology* 31:751–754.

George, J. C., M. L. Druckenmiller, K. L. Laidre, R. Suydam, and B. Person. 2015. Bowhead whale body condition and links to summer sea ice and upwelling in the Beaufort Sea. *Progress in Oceanography* 136:250–262.

George, J. C., J. Zeh, R. Suydam, and C. Clark. 2004. Abundance and population trend (1978–2001) of western Arctic bowhead whales surveyed near Barrow, Alaska. *Marine Mammal Science* 20:755–773.

Gilbert, J. R. 1989. Aerial census of Pacific walruses in the Chukchi Sea, 1985. *Marine Mammal Science* 5:17–28.

______. 1992. Aerial Census of Pacific Walrus, 1990. Marine Mammals Management, US Fish and Wildlife Service, Region 7, Anchorage, AK.

______. 1999. Review of previous Pacific walrus surveys to develop improved survey designs, *In Marine Mammal Survey and Assessment Methods*. G. W. Garner, S. C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald, and D. G. Robertson eds., pp. 75–84. AA Balkema, Rotterdam, Netherlands.

Gilbert, J. R., G. A. Fedoseev, D. Seagars, E. Razlivalov, and A. LaChugin. 1992. Aerial census of Pacific walrus, 1990. USFWS R7/MMM,

Gisiner, R. C. 1985. Male Territorial and Reproductive Behavior in the Steller Sea Lion *(Eumetopias jubatus)*. PhD thesis, University of California, Santa Cruz, CA.

Givens, G., S. Edmondson, J. George, R. Suydam, R. Charif, A. Rahaman, D. Hawthorne, B. Tudor, R. DeLong, and C. Clark. 2013. Estimate of 2011 Abundance of the Bering-Chukchi-Beaufort Seas Bowhead Whale Population. Paper SC/65a/BRG01. Scientific Committee of the International Whaling Commission, Jeju Island, South Korea.

Givens, G. H. and D. J. Thomas. 1997. Bowhead Aboriginal Whaling Management Procedure Trials and Statistics. SC/48/Mg1. International Whaling Commission, Cambridge, United Kingdom.

Gudmundson, C. J., T. K. Zeppelin, and R. R. Ream. 2006. Application of two methods for determining diet of northern fur seals (*Callorhinus ursinus*). *Fishery Bulletin* 104:445–455.

Harington, C. R. 2008. The evolution of Arctic marine mammals. *Ecological Applications* 18:S23–S40.

Harington, C. R. and G. Beard. 1991. The Qualicum walrus: A late Pleistocene walrus (*Odobenus rosmarus*) skeleton from Vancouver Island, British Columbia, Canada. *Annales Zoologici Fennici* 28:311–319.

Hartwig, L. 2009. Mapping Traditional Knowledge Related to the Identification of Ecologically and Biologically Significant Areas in the Beaufort Sea. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2895. Fisheries and Oceans Canada, Winnipeg, Canada.

Harwood, L. A., J. Iacozza, J. C. Auld, P. Norton, and L. Loseto. 2014. Belugas in the Mackenzie River estuary, NT, Canada: Habitat use and hot spots in the Tarium Niryutait Marine Protected Area. *Ocean & Coastal Management* 100:128–138.

Harwood, L. A., T. G. Smith, H. Melling, J. Alikamik, and M. C. S. Kingsley. 2012. Ringed seals and sea ice in Canada's western Arctic: Harvest-based monitoring 1992–2011. *Arctic* 65:377–390.

Harwood, L. A. and I. Stirling. 1992. Distribution of ringed seals in the southeastern Beaufort Sea during late summer. *Canadian Journal of Zoology* 70:891–900.

Hauser, D. D., K. L. Laidre, R. S. Suydam, and P. R. Richard. 2014. Population-specific home ranges and migration timing of Pacific Arctic beluga whales (*Delphinapterus leucas*). *Polar Biology* 37:1171–1183.

Hauser, D. D. W. 2016. Beluga Whale Distribution, Migration, and Behavior in a Changing Pacific Arctic. PhD thesis, University of Washington, Seattle, WA.

Hauser, D. D. W., K. L. Laidre, S. L. Parker-Stetter, J. K. Horne, R. S. Suydam, and P. R. Richard. 2015. Regional diving behavior of Pacific Arctic beluga whales *Delphinapterus leucas* and possible associations with prey. *Marine Ecology Progress Series* 541:245–264.

Hauser, D. D. W., K. L. Laidre, K. M. Stafford, H. L. Stern, R. S. Suydam, and P. R. Richard. 2017a. Decadal shifts in autumn migration timing by Pacific Arctic beluga whales are related to delayed annual sea ice formation. *Global Change Biology* 23:2206–2217.

Hauser, D. D. W., K. L. Laidre, H. L. Stern, S. E. Moore, R. S. Suydam, and P. R. Richard. 2017b. Habitat selection by two beluga whale populations in the Chukchi and Beaufort seas. *PLoS ONE* 12:e0172755.

Heide-Jørgensen, M., K. Laidre, D. Litovka, M. V. Jensen, J. Grebmeier, and B. Sirenko. 2012. Identifying gray whale (*Eschrichtius robustus*) foraging grounds along the Chukotka Peninsula, Russia, using satellite telemetry. *Polar Biology* 35:1035–1045.

Heide-Jørgensen, M., K. Laidre, D. Borchers, T. A. Marques, H. Stern, and M. Simon. 2010. The effect of sea-ice loss on beluga whales (*Delphinapterus leucas*) in West Greenland. *Polar Research* 29:198–208.

Higdon, J. W., O. R. Bininda-Emonds, R. M. Beck, and S. H. Ferguson. 2007. Phylogeny and divergence of the pinnipeds (Carnivora: Mammalia) assessed using a multigene dataset. *BMC Evolutionary Biology* 7:216.

Higgins, L. V., D. P. Costa, A. C. Huntley, and B. J. Boeuf. 1988. Behavioral and physiological measurements of maternal investment in the Steller sea lion, *Eumetopias jubatus*. *Marine Mammal Science* 4:44–58.

Highsmith, R. C., K. O. Coyle, B. A. Bluhm, and B. Konar. 2007. Gray whales in the Bering and Chukchi Seas, *In Whales, Whaling, and Ocean Ecosystems*. J. A. Estes, D. P. DeMaster, and D. F. Doak eds., pp. 303–313. University of California Press, Berkeley, CA.

Hildebrand, J. A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395:5–20.

Hilderbrand, G. V., C. Schwartz, C. Robbins, M. Jacoby, T. Hanley, S. Arthur, and C. Servheen. 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. *Canadian Journal of Zoology* 77:132–138.

Hobbs, R. C., K. L. Laidre, D. J. Vos, B. A. Mahoney, and M. Eagleton. 2005. Movements and area use of belugas, *Delphinapterus leucas*, in a subarctic Alaskan estuary. *Arctic* 58:331–340.

Hobson, K., I. Stirling, and D. Andriashek. 2009. Isotopic homogeneity of breath CO_2 from fasting and berry-eating polar bears: Implications for tracing reliance on terrestrial foods in a changing Arctic. *Canadian Journal of Zoology* 87:50–55.

Hoekstra, P. F., L. A. Dehn, J. C. George, K. R. Solomon, D. C. G. Muir, and T. M. O'Hara. 2002. Trophic ecology of bowhead whales (*Balaena mysticetus*) compared with that of other Arctic marine biota as interpreted from carbon-, nitrogen-, and sulfur-isotope signatures. *Canadian Journal of Zoology* 80:223–231.

Hohn, A. A. 2002. Age estimation, *In Encyclopedia of Marine Mammals*. W. F. Perrin, B. Würsig, and J. G. M. Thewissen eds., pp. 6–13. Academic Press, San Diego, CA.

Hood, W. R. and K. A. Ono. 1997. Variation in maternal attendance patterns and pup behavior in a declining population of Steller sea lions *(Eumetopias jubatus)*. *Canadian Journal of Zoology* 75:1241–1246.

Hoover, A. A. 1988. Steller sea lion *(Eumetopias jubatus)*, *In Selected Marine Mammals of Alaska: Species Accounts with Research and Management Recommendations*. J. W. Lentfer ed., pp. 159–193. Marine Mammal Commission, Washington, DC.

Horning, M. and J. A. E. Mellish. 2014. In cold blood: Evidence of Pacific sleeper shark (*Somniosus pacificus*) predation on Steller sea lions *(Eumetopias jubatus)* in the Gulf of Alaska. *Fishery Bulletin* 112:297–310.

Huntington, H. P. 2002. Traditional knowledge of the ecology of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. *Marine Fisheries Review* 62:134–140.

______. 2009. A preliminary assessment of threats to Arctic marine mammals and their conservation in the coming decades. *Marine Policy* 33:77–82.

Huntington, H. P., M. Nelson, and L. T. Quakenbush. 2012. Traditional Knowledge Regarding Walrus near Point Lay and Wainwright, Alaska. Huntington Consulting and Alaska Department of Fish and Game, Eagle River and Fairbanks, AK.

______. 2015a. Traditional Knowledge Regarding Ringed Seals, Bearded Seals, and Walrus near Elim, Alaska. Huntington Consulting and Alaska Department of Fish and Game, Eagle River and Fairbanks, AK.

______. 2015b. Traditional Knowledge Regarding Walrus, Ringed Seals, and Bearded Seals near Point Barrow, Alaska. Huntington Consulting and Alaska Department of Fish and Game, Eagle River and Fairbanks, AK.

______. 2016a. Traditional Knowledge Regarding Ringed Seals, Bearded Seals, and Walrus near Shishmaref, Alaska. Final report to the Eskimo Walrus Commission, the Ice Seal Committee, and the Bureau of Ocean Energy Management for contract #M13PC00015, Eagle River and Fairbanks, AK.

______. 2016b. Traditional Knowledge Regarding Ringed Seals, Bearded Seals, Walrus, and Bowhead Whales near Kivalina, Alaska. Final report to the Eskimo Walrus Commission, the Ice Seal Committee, and the Bureau of Ocean Energy Management for contract #M13PC00015, Eagle River and Fairbanks, AK.

Huntington, H. P. and L. T. Quakenbush. 2009. Traditional Knowledge of Bowhead Whale Migratory Patterns near Wainwright, Alaska. Report to the Alaska Eskimo Whaling Commission and the Wainwright Whaling Captains Association. Eagle River, AK.

______. 2013. Traditional Knowledge Regarding Walrus near Point Hope, Alaska. Huntington Consulting and Alaska Department of Fish and Game, Eagle River and Fairbanks, AK.

Huntington, H. P. and the Communities of Buckland, Elim, Koyuk, Point Lay, and Shaktoolik. 1999. Traditional knowledge of the ecology of beluga whales (*Delphinapterus leucas*) in the eastern Chukchi and northern Bering Seas, Alaska. *Arctic* 52:49–61.

Iles, D., S. Peterson, L. Gormezano, D. N. Koons, and R. Rockwell. 2013. Terrestrial predation by polar bears: Not just a wild goose chase. *Polar Biology* 36:1373–1379.

Insley, S. J., A. V. Phillips, and I. Charrier. 2003. A review of social recognition in pinnipeds. *Aquatic Mammalogy* 29:181–201.

International Whaling Commission. 2010. Report of the Scientific Committee. Annex F. Report of the subcommittee on bowhead, right and gray whales. *Journal of Cetacean Research and Management (Supplement)* 11:154–179.

______. 2015. Report of the expert workshop to review the Japanese JARPA II Special Permit Research Programme, 24–28 February 2014, Tokyo, Japan. *Journal of Cetacean Research and Management (Supplement)* 16:369–409.

______. 2017. Commercial Whaling. International Whaling Commission. Accessed online 20 March 2017 at https://iwc.int/commercial.

Irving, L., L. J. Peyton, C. H. Bahn, and R. S. Peterson. 1962. Regulation of temperature in fur seals. *Physiological Zoology* 35:275–284.

Ivashchenko, Y. and P. Clapham. 2010. Bowhead whales *Balaena mysticetus* in the Okhotsk Sea. *Mammal Review* 40:65–89.

Iverson, S. A., H. G. Gilchrist, P. A. Smith, A. J. Gaston, and M. R. Forbes. 2014. Longer ice-free seasons increase the risk of nest depredation by polar bears for colonial breeding birds in the Canadian Arctic. *Proceedings of the Royal Society B-Biological Sciences* 281:20133128.

Jay, C. V. and A. S. Fischbach. 2008. Pacific Walrus Response to Arctic Sea Ice Losses. US Geological Survey, Alaska Science Center, Anchorage, AK.

Jay, C. V., A. S. Fischbach, and A. A. Kochnev. 2012a. Walrus areas of use in the Chukchi Sea during sparse sea ice cover. *Marine Ecology Progress Series* 468:1–13.

Jay, C. V., J. M. Gerebmeier, and A. S. Fischbach. 2012b. Walrus Distributional and Foraging Response to Changing Ice and Benthic Conditions in the Chukchi Sea. NPRB Project 818 Final Report. North Pacific Research Board, Anchorage, AK and Solomons, MD.

Jay, C. V., B. G. Marcot, and D. C. Douglas. 2011. Projected status of the Pacific walrus (*Odobenus rosmarus divergens*) in the twenty-first century. *Polar Biology* 34:1065–1084.

Jefferson, T. A., L. Karkzmarski, K. Laidre, G. O'Corry-Crowe, R. Reeves, L. Rojas-Bracho, E. Secchi, E. Slooten, B. D. Smith, J. Y. Wang, and K. Zhou. 2012. *Delphinapterus leucas*. The IUCN Red List of Threatened Species 2015. International Union for Conservation of Nature and Natural Resources. Accessed online 21 July 2017 at http://dx.doi.org/10.2305/IUCN.UK.2012.RLTS.T6335A17690692.en.

Jefferson, T. A., M. A. Webber, and R. L. Pitman. 2011. *Marine Mammals of the World: A Comprehensive Guide to Their Identification*. Academic Press, London, United Kingdom.

Jemison, L. A., G. W. Pendleton, L. W. Fritz, K. K. Hastings, J. M. Maniscalco, A. W. Trites, and T. S. Gelatt. 2013. Inter-population movements of Steller sea lions in Alaska with implications for population separation. *PLoS ONE* 8:e70167.

Jenkins, L. and C. Romanzo. 1998. Makah whaling: Aboriginal subsistence or a stepping stone to undermining the commercial whaling moratorium. *Colorado Journal of International Environmental Law and Policy* 9:71–114.

Johannessen, O. M., L. Bengtsson, M. W. Miles, S. I. Kuzmina, V. A. Semenov, G. V. Alekseev, A. P. Nagurnyi, V. F. Zakharov, L. P. Bobylev, and L. H. Pettersson. 2004. Arctic climate change: Observed and modelled temperature and sea-ice variability. *Tellus A* 56:328–341.

Johnson, A., J. Burns, W. Dusenberry, and R. Jones. 1982. Aerial Survey of Pacific Walrus, 1980. US Fish and Wildlife Service, Anchorage, AK.

Johnson, A. M. 1968. Annual mortality of territorial male fur seals and its management significance. *Journal of Wildlife Management* 32:94–99.

Jones, M. L. and S. L. Swartz. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico, *In The Gray Whale: Eschrichtius robustus*. M. L. Jones, S. L. Swartz, and S. Leatherwood eds., pp. 309–374. Academic Press, New York, NY.

______. 2002. Gray whale, *In Encyclopedia of Marine Mammals*. W. F. Perrin, B. Würsig, and J. G. M. Thewissen eds., pp. 524–536. Academic Press, San Diego, CA.

Kajimura, H. and T. R. Loughlin. 1988. Marine mammals in the oceanic food web of the eastern subarctic Pacific. *Bulletin of the Ocean Research Institute* 26:187–223.

Kastelein, R., S. Stevens, and P. Mosterd. 1990. The tactile sensitivity of the mystacial vibrissae of a Pacific walrus (*Odobenus rosmarus divergens*). Part 2: Masking. *Aquatic Mammals* 16:78–87.

Kastelein, R. A. 2009. Walrus (*Odobenus rosmarus*), *In Encyclopedia of Marine Mammals*. W. F. Perrin, B. Würsig, and J. G. M. Thewissen eds., pp. 1294–1300. Academic Press, Burlington, MA.

Kastelein, R. A. and N. M. Gerrits. 1990. The anatomy of the walrus head (*Odobenus rosmarus*). Part 1: The skull. *Aquatic Mammals* 16:101–119.

Kastelein, R. A., R. van Schie, W. C. Verboom, and D. de Haan. 2005. Underwater hearing sensitivity of a male and a female Steller sea lion *(Eumetopias jubatus)*. *Journal of the Acoustical Society of America* 118:1820–1829.

Kavry, V., A. Boltunov, and V. Nikiforov. 2008. New coastal haulouts of walruses (*Odobenus rosmarus*)–response to the climate changes. *In* Collection of scientific papers from the Marine Mammals of the Holarctic V Conference, Odessa, Ukraine.

Kawerak. 2013. Seal and Walrus Harvest and Habitat Area for Nine Bering Strait Region Communities. Kawerak Social Science Program, Nome, AK.

Kelly, B. P. 2001. Climate change and ice breeding pinnipeds, *In "Fingerprints" of Climate Change*. G. R. Walther, C. A. Burga, and P. J. Edwards eds., pp. 43–55. Kluwer Academic/Plenum Publishers, New York, NY.

Kelly, B. P., O. H. Badajos, M. Kunnasranta, J. R. Moran, M. Martinez-Bakker, D. Wartzok, and P. Boveng. 2010a. Seasonal home ranges and fidelity to breeding sites among ringed seals. *Polar Biology* 33:1095–1109.

Kelly, B. P., J. L. Bengtson, P. L. Boveng, M. F. Cameron, S. P. Dahle, J. K. Jansen, E. A. Logerwell, J. E. Overland, C. L. Sabine, and G. T. Waring. 2010b. Status Review of the Ringed Seal (*Phoca hispida*). NOAA Technical Memorandum NMFS-AFSC-212. National Oceanic and Atmospheric Administration, Springfield, VA.

Kenyon, K. W. 1962. History of the Steller sea lion at the Pribilof Islands, Alaska. *Journal of Mammalogy* 43:68–75.

Kenyon, K. W. and D. W. Rice. 1961. Abundance and distribution of the Steller sea lion. *Journal of Mammalogy* 42:223–234.

Kingsley, M., I. Stirling, and W. Calvert. 1985. The distribution and abundance of seals in the Canadian High Arctic, 1980–82. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1189–1210.

Kiszka, J., C. Muir, C. Poonian, T. M. Cox, O. A. Amir, J. Bourjea, Y. Razafindrakoto, N. Wambitji, and N. Bristol. 2009. Marine mammal bycatch in the southwest Indian Ocean: Review and need for a comprehensive status assessment. *Western Indian Ocean Journal Marine Science* 7:119–136.

Klaus, A., J. Oliver, and R. Kvitek. 1990. The effects of gray whale, walrus, and ice gouging disturbance on benthic communities in the Bering Sea and Chukchi Sea, Alaska. *National Geographic Research* 6:470–484.

Kochnev, A. A. 2004. Warming of eastern Arctic and present status of the Pacific walrus (*Odobenus rosmarus divergens*) population, *In Marine Mammals of the Holarctic*. V. M. Belkovich ed., pp. 284–288. KMK Scientific Press, Moscow, Russia.

Kochnev, A. A., V. M. Etylin, V. I. Kavry, E. B. Siv-Siv, and I. V. Tanko. 2003. Traditional Knowledge of Chukotka Native Peoples Regarding Polar Bear Habitat Use. The Chukotka Association of Traditional Maine Mammal Hunters, the Alaska Nanuuq Commission, and the Pacific Fisheries Research Center (Chukotka Branch) for the US National Park Service, Anadyr, Russia.

Kohno, N. 2006. A new Miocene odobenid (Mammalia: Carnivora) from Hokkaido, Japan, and its implications for odobenid phylogeny. *Journal of Vertebrate Paleontology* 26:411–421.

Koski, W. R., M. Heide-Jorgensen, and K. L. Laidre. 2006a. Winter abundance of bowhead whales, *Balaena mysticetus*, in the Hudson Strait, March 1981. *Journal of Cetacean Research and Management* 8:139–144.

Koski, W. R., D. J. Rugh, A. E. Punt, and J. Zeh. 2006b. An approach to minimize bias in estimation of the length-frequency distribution of bowhead whales (*Balaena mysticetus*) from aerial photogrammetric data. *Journal of Cetacean Research and Management* 8:45–54.

Kovacs, K. M. 2007. Background Document for Development of a Circumpolar Ringed Seal (*Phoca hispida*) Monitoring Plan. Report to the US Marine Mammal Commission. L'Oceanogràfic, Valencia, Spain.

Kovacs, K. M. and C. Lydersen. 2008. Climate change impacts on seals and whales in the North Atlantic Arctic and adjacent shelf seas. *Science Progress* 91:117–150.

Kovacs, K. M., C. Lydersen, and I. Gjertz. 1996. Birth-site characteristics and prenatal molting in bearded seals (*Erignathus barbatus*). *Journal of Mammalogy* 77:1085–1091.

Kovacs, K. M., C. Lydersen, J. E. Overland, and S. E. Moore. 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. *Marine Biodiversity* 41:181–194.

Krupnik, I. and G. C. Ray. 2007. Pacific walruses, indigenous hunters, and climate change: Bridging scientific and indigenous knowledge. *Deep Sea Research Part II: Topical Studies in Oceanography* 54:2946–2957.

Kuhn, C. E., R. R. Ream, J. T. Sterling, J. R. Thomason, and R. G. Towell. 2014. Spatial segregation and the influence of habitat on the foraging behavior of northern fur seals (*Callorhinus ursinus*). *Canadian Journal of Zoology* 92:861–873.

Laidre, K. L., H. Stern, K. M. Kovacs, L. F. Lowry, S. E. Moore, E. V. Regehr, S. H. Ferguson, O. Wiig, P. Boveng, R. P. Angliss, E. W. Born, D. Litovka, L. T. Quakenbush, C. Lydersen, D. Vongraven, and F. Ugarte. 2015. Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. *Conservation Biology* 29:724–737.

Laidre, K. L., I. Stirling, L. F. Lowry, Ø. Wiig, M. P. Heide-Jørgensen, and S. H. Ferguson. 2008. Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. *Ecological Applications* 18:S97–S125.

Lander, R. H. 1981. A life table and biomass estimate for Alaskan fur seals. *Fisheries Research* 1:55–70.

Lee, S. H., D. M. Schell, T. L. McDonald, and W. J. Richardson. 2005. Regional and seasonal feeding by bowhead whales *Balaena mysticetus* as indicated by stable isotope ratios. *Marine Ecology Progress Series* 285:271–287.

Lenfant, C., K. Johansen, and J. D. Torrance. 1970. Gas transport and oxygen storage capacity in some pinnipeds and the sea otter. *Respiration Physiology* 9:277–286.

Levermann, N., A. Galatius, G. Ehlme, S. Rysgaard, and E. W. Born. 2003. Feeding behaviour of free-ranging walruses with notes on apparent dextrality of flipper use. *BMC Ecology* 3:9.

LGL. 1996. Northstar Marine Mammal Monitoring Program 1995: Baseline Surveys and Retrospective Analyses of Marine Mammal and Ambient Noise Data from the Central Alaskan Beaufort Sea. LGL Report TA 2102-2. LGL Ecological Research Associates, Inc., King City, Canada.

LGL and Greeneridge. 1995. Acoustic Effects of Oil Production Activities on Bowhead and White Whales Visible During Spring Migration near Pt. Barrow, Alaska—1991–1994 Phases: Sound Propogation and Whale Responses to Playbacks of Icebreaker Noise. US Department of the Interior, Minerals Management Service, Alaska OCS Region, Anchorage, AK.

Ling, J. K. 1970. Pelage and molting in wild mammals with special reference to aquatic forms. *Quarterly Review of Biology* 45:16–54.

______. 1972. Adaptive functions of vertebrate molting cycles. *American Zoologist* 12:77–93.

Liu, S., E. D. Lorenzen, M. Fumagalli, B. Li, K. Harris, Z. Xiong, L. Zhou, T. S. Korneliussen, M. Somel, and C. Babbitt. 2014. Population genomics reveal recent speciation and rapid evolutionary adaptation in polar bears. *Cell* 157:785–794.

Ljungblad, D. K., B. Würsig, S. L. Swartz, and J. M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. *Arctic* 41:183–194.

Lloyd, D. S., C. P. McRoy, and R. H. Day. 1981. Discovery of northern fur seals (*Callorhinus ursinus*) breeding on Bogoslof Island, Southeastern Bering Sea. *Arctic* 34:318–320.

Loseto, L., G. Stern, T. Connelly, D. Deibel, B. Gemmill, A. Prokopowicz, L. Fortier, and S. Ferguson. 2009. Summer diet of beluga whales inferred by fatty acid analysis of the eastern Beaufort Sea food web. *Journal of Experimental Marine Biology and Ecology* 374:12–18.

Loughlin, T. R., W. J. Ingraham, Jr, N. Baba, and B. W. Robson. 1999. Use of a surface current model and satellite telemetry to assess marine mammal movements in the Bering Sea, *In Dynamics of the Bering Sea*. T. R. Loughlin and K. Ohtani eds., pp. 615–630. University of Alaska Sea Grant Press, AK-SG-99-03, Fairbanks, AK.

Loughlin, T. R., M. A. Perez, and R. L. Merrick. 1987. *Eumetopias jubatus*. *Mammalian Species* 283:1–7.

Loughlin, T. R., A. S. Perlov, and V. A. Vladimirov. 1992. Range-wide survey and estimation of total number of Steller sea lions in 1989. *Marine Mammal Science* 8:220–239.

Loughlin, T. R., D. J. Rugh, and C. H. Fiscus. 1984. Northern sea lion distribution. *Journal of Wildlife Management* 48:729–740.

Lowry, L. F., V. N. Burkanov, K. J. Frost, M. A. Simpkins, R. Davis, D. P. DeMaster, R. Suydam, and A. Springer. 2000. Habitat use and habitat selection by spotted seals (*Phoca largha*) in the Bering Sea. *Canadian Journal of Zoology* 78:1959–1971.

Lowry, L. F., K. J. Frost, R. Davis, D. P. DeMaster, and R. S. Suydam. 1998. Movements and behavior of satellite-tagged spotted seals (*Phoca largha*) in the Bering and Chukchi seas. *Polar Biology* 19:221–230.

Lowry, L. F., G. Sheffield, and J. C. George. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses. *Journal of Cetacean Research and Management* 6:215–223.

Lukoschek, V., N. Funahashi, S. Lavery, M. Dalebout, F. Cipriano, and C. Baker. 2009. The rise of commercial 'by-catch whaling' in Japan and Korea. *Animal Conservation* 12:398–399.

Lunn, N., I. Boyd, T. Barton, and J. Croxall. 1993. Factors affecting the growth rate and mass at weaning of Antarctic fur seals at Bird Island, South Georgia. *Journal of Mammalogy* 74:908–919.

Luque, S. P., J. W. Higdon, and S. H. Ferguson. 2007. Dentine deposition rates in belugas (*Delphinapterus leucas*): An analysis of the evidence. *Aquatic Mammals* 33:241–245.

Lydersen, C. and M. O. Hammill. 1993. Diving in ringed seal (*Phoca hispida*) pups during the nursing period. *Canadian Journal of Zoology* 71:991–996.

Lydersen, C., K. Kovacs, M. Hammill, and I. Gjertz. 1996. Energy intake and utilisation by nursing bearded seal (*Erignathus barbatus*) pups from Svalbard, Norway. *Journal of Comparative Physiology B* 166:405–411.

Lydersen, C. and K. M. Kovacs. 1999. Behaviour and energetics of ice-breeding, North Atlantic phocid seals during the lactation period. *Marine Ecology Progress Series* 187:265–281.

MacIntyre, K. Q., K. M. Stafford, P. B. Conn, K. L. Laidre, and P. L. Boveng. 2015. The relationship between sea ice concentration and the spatio-temporal distribution of vocalizing bearded seals (*Erignathus barbatus*) in the Bering, Chukchi, and Beaufort Seas from 2008 to 2011. *Progress in Oceanography* 136:241–249.

Maniscalco, J., S. Atkinson, and P. Armato. 2002. Early maternal care and pup survival in Steller sea lions: A remote video monitoring project in the northern Gulf of Alaska. *Arctic Research of the United States* 16:36–36.

Maniscalco, J. M., C. O. Matkin, D. Maldini, D. G. Calkins, and S. Atkinson. 2007. Assessing killer whale predation on Steller sea lions from field observations in Kenai Fjords, Alaska. *Marine Mammal Science* 23:306–321.

Marcoux, M., B. C. McMeans, A. T. Fisk, and S. H. Ferguson. 2012. Composition and temporal variation in the diet of beluga whales, derived from stable isotopes. *Marine Ecology Progress Series* 471:283–291.

Marshall, C. D., H. Amin, K. M. Kovacs, and C. Lydersen. 2006. Microstructure and innervation of the mystacial vibrissal follicle-sinus complex in bearded seals, *Erignathus barbatus* (Pinnipedia: Phocidae). *The Anatomical Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology* 288:13–25.

Marshall, C. D., K. M. Kovacs, and C. Lydersen. 2008. Feeding kinematics, suction and hydraulic jetting capabilities in bearded seals (*Erignathus barbatus*). *Journal of Experimental Biology* 211:699–708.

Mate, B. R., V. Y. Ilyashenko, A. L. Bradford, V. V. Vertyankin, G. A. Tsidulko, V. V. Rozhnov, and L. M. Irvine. 2015. Critically endangered western gray whales migrate to the eastern North Pacific. *Biology Letters* 11:20150071.

Matthews, L. H. 1937. *The Humpback Whale, Megaptera nodosa*. Cambridge University Press, Glasgow, United Kingdom.

McBride, M. M., P. Dalpadado, K. F. Drinkwater, O. R. Godø, A. J. Hobday, A. B. Hollowed, T. Kristiansen, E. J. Murphy, P. H. Ressler, S. Subbey, E. E. Hofmann, and H. Loeng. 2014. Krill, climate, and contrasting future scenarios for Arctic and Antarctic fisheries. *ICES Journal of Marine Science* 71:1934–1955.

McKinney, M. A., E. Peacock, and R. J. Letcher. 2009. Sea ice-associated diet change increases the levels of chlorinated and brominated contaminants in polar bears. *Environmental Science & Technology* 43:4334–4339.

Meier, W. N., G. K. Hovelsrud, B. E. H. Oort, J. R. Key, K. M. Kovacs, C. Michel, C. Haas, M. A. Granskog, S. Gerland, and D. K. Perovich. 2014. Arctic sea ice in transformation: A review of recent observed changes and impacts on biology and human activity. *Reviews of Geophysics* 52:185–217.

Mellish, J. A. E., M. Horning, and A. E. York. 2007. Seasonal and spatial blubber depth changes in captive harbor seals (*Phoca vitulina*) and Steller's sea lions (*Eumetopias jubatus*). *Journal of Mammalogy* 88:408–414.

Melnikov, V. V., M. A. Zelensky, and L. I. Ainana. 2000. Humpback whales in the waters off Chukotka Peninsula. *Oceanology* 6:895–900.

Merrick, R. L. and T. R. Loughlin. 1997. Foraging behavior of adult female and young-of-the-year Steller sea lions in Alaskan waters. *Canadian Journal of Zoology* 75:776–786.

Merrick, R. L., T. R. Loughlin, and D. G. Calkins. 1987. Decline in abundance of the northern sea lion, *Eumetopias jubatus*, in Alaska, 1956–86. *Fishery Bulletin* 85:351–365.

Miles, P. R., C. I. Malme, and W. J. Richardson. 1987. Prediction of drilling site-specific interaction of industrial acoustic stimuli and endangered whales in the Alaskan Beaufort Sea. US Department of the Interior, Minerals Management Service, Alaska OCS Region, Anchorage, AK.

Miller, C. N. 2014. Milk Fatty Acid Composition of Perinatal and Foraging Steller Sea Lions: Examination from Pup Stomachs. PhD thesis, University of Alaska Fairbanks, Fairbanks, AK.

Minerals Management Service. 2010. Preliminary Revised Program Outer Continental Shelf Oil and Gas Leasing Program 2007-2012. Minerals Management Service, Washington, DC.

Mocklin, J. A., D. J. Rugh, S. E. Moore, and R. P. Angliss. 2012. Using aerial photography to investigate evidence of feeding by bowhead whales. *Marine Mammal Science* 28:602–619.

Mooney, T. A., P. E. Nachtigall, M. Castellote, K. A. Taylor, A. F. Pacini, and J. A. Esteban. 2008. Hearing pathways and directional sensitivity of the beluga whale, *Delphinapterus leucas*. *Journal of Experimental Marine Biology and Ecology* 362:108–116.

Moore, S. E. 1992. Summer records of bowhead whales in the northeastern Chukchi Sea. *Arctic* 45:398–400.

Moore, S. E., D. P. DeMaster, and P. K. Dayton. 2000. Cetacean habitat selection in the Alaskan Arctic during summer and autumn. *Arctic* 53:432–447.

Moore, S. E., J. C. George, G. Sheffield, J. Bacon, and C. J. Ashjian. 2010. Bowhead whale distribution and feeding near Barrow, Alaska, in late summer 2005–06. *Arctic* 63:195–205.

Moore, S. E., J. M. Grebmeier, and J. R. Davies. 2003. Gray whale distribution relative to forage habitat in the northern Bering Sea: Current conditions and retrospective summary. *Canadian Journal of Zoology* 81:734–742.

Moore, S. E. and H. P. Huntington. 2008. Arctic marine mammals and climate change: Impacts and resilience. *Ecological Applications* 18:S157–S165.

Moore, S. E. and R. R. Reeves. 1993. Distribution and movements, *In The Bowhead Whale*. J. J. Burns, J. J. Montague, and C. J. Cowles eds., pp. 313–386. Society for Marine Mammalogy Special Publication No. 2. Allen Press, Lawrence, KS.

Moore, S. E., J. M. Waite, N. A. Friday, and T. Honkalehto. 2002. Cetacean distribution and relative abundance on the central-eastern and the southeastern Bering Sea shelf with reference to oceanographic domains. *Progress in Oceanography* 55:249–261.

Muto, M., V. T. Helker, R. P. Angliss, B. A. Allen, P. L. Boveng, J. M. Breiwick, M. F. Cameron, P. J. Clapham, S. P. Dahle, M. E. Dahlheim, B. S. Fadely, M. C. Ferguson, L. W. Fritz, R. C. Hobbs, Y. V. Ivashchenko, A. S. Kennedy, J. M. London, S. A. Mizroch, R. R. Ream, E. L. Richmond, K. E. W. Shelden, R. G. Towell, P. R. Wade, J. M. Waite, and A. N. Zerbini. 2016. Alaska Marine Mammal Stock Assessments 2015. National Oceanic and Atmospheric Administration, Seattle, WA.

Mymrin, N., G. Smirnov, A. Gaevskiy, and V. Kovalenko. 1990. Seasonal distribution and abundance of walruses in the Gulf of Anadyr of the Bering Sea. *Zoological Journal* 3:105–113.

Naito, Y. and M. Oshima. 1976. The variation in the development of pelage of the ribbon seal with reference to the systematics. *Scientific Reports of the Whales Research Institute* 28:187–197.

National Marine Fisheries Service. 1997. Threatened fish and wildlife; change in listing status of Steller sea lions under the Endangered Species Act. *Federal Register* 62:24345–24355.

______. 2004. Programmatic Supplemental Environmental Impact Statement for the Alaska Groundfish Fisheries Implemented Under the Authority of the Fishery Management Plans for the Groundfish Fishery of the Gulf of Alaska and the Groundfish of the Bering Sea and Aleutian Islands Area. National Marine Fisheries Service, Juneau, AK and Seattle, WA.

______. 2007. Conservation Plan for the Eastern Pacific Stock of Northern Fur Seal (*Callorhinus ursinus*). National Marine Fisheries Service, Juneau, AK.

______. 2014. Fisheries of the Exclusive Economic Zone off Alaska; Steller sea lion protection measures for the Bering Sea and Aleutian Islands groundfish fisheries off Alaska. *Federal Register* 79:70285–70338.

National Oceanic and Atmospheric Administration. 1988. Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones: Strategic Assessment Data Atlas. National Oceanic and Atmospheric Administration, Rockville, MD.

______. 2005. Environmental Sensitivity Index, Version 3.0. National Oceanic and Atmospheric Administration Office of Response and Restoration, Seattle, WA. Accessed online at http://response.restoration.noaa.gov/maps-and-spatial-data/download-esi-maps-and-gis-data.html#Alaska.

______. 2013. Final Environmental Impact Statement for Issuing Annual Quotas to the Alaska Eskimo Whaling Commission for a Subsistence Hunt on Bowhead Whales for the Years 2013 Through 2018. National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center, Juneau, AK.

______. 2014. NOAA's Aerial Surveys of Arctic Marine Mammals Photograph Walrus Haulout Site—Scientists Call Behavior a New Phenomenon. National Marine Fisheries Service, Alaska Regional Office, Anchorage, AK. Accessed online 1 December 2014 at http://alaskafisheries.noaa.gov/newsreleases/2013/walrushaulout093013.htm.

______. 2015a. Aerial Survey of Arctic Marine Mammals, 1979–2014 (ASAMM; including the Historical BWASP and COMIDA Databases). NOAA Fisheries, Alaska Fisheries Science Center, National Marine Mammal Labratory, Anchorage, AK. Accessed online December 2015 at http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php.

______. 2015b. Endangered and threatened species; identification of 14 Distinct Population Segments of the humpback whale (*Megaptera novaeangliae*) and proposed revision of species-wide listing. *Federal Register* 80:62259–62320.

______. 2015c. Northern Fur Seals NMML Research—Distibution and US Breeding Sites. National Marine Mammal Laboratory, Anchorage, AK. Accessed online at http://www.afsc.noaa.gov/nmml/alaska/nfs/smallfsrange.php.

______. 2016. 2011 Arctic Pinniped Unusual Mortality Event (UME): June 2016 Update. National Oceanic and Atmospheric Administration Fisheries, Alaska Regional Office, Anchorage, AK.

______. 2017. Humpback Whale (*Megaptera novaeangliae*). National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, WA. Accessed online 6 June 2017 at http://www.nmfs.noaa.gov/pr/species/mammals/whales/humpback-whale.html.

National Oceanic and Atmospheric Administration and US Fish and Wildlife Service. 2012. Northern Pinnipeds (Ice Seals and Walruses) Unusual Mortality Event Q&A. National Oceanic and Atmospheric Administration Fisheries, Alaska Regional Office, Anchorage, AK.

National Research Council. 2003. *The Decline of the Steller Sea Lion in Alaskan Waters: Untangling Food Webs and Fishing Nets*. National Academies Press, Washington, DC.

National Snow and Ice Data Center. 2014. Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data. National Snow and Ice Data Center, Boulder, CO. Accessed online at http://nsidc.org/data/nsidc-0051.

National Snow and Ice Data Center and C. S. Konig Beatty. 2012. Arctic Landfast Sea Ice 1953–1998, Version 1. National Snow and Ice Data Center, Boulder, CO.

Nerini, M. 1984. A review of gray whale feeding ecology, *In The Gray Whale: Eschrichtius robustus*. M. L. Jones, S. L. Swartz, and S. Leatherwood eds., pp. 451–463. Academic Press, San Diego, CA.

Nerini, M. K., H. W. Braham, W. M. Marquette, and D. J. Rugh. 1984. Life history of the bowhead whale, *Balaena mysticetus* (Mammalia: Cetacea). *Journal of Zoology* 204:443–468.

Niebauer, H. and D. Schell. 1993. Physical environment of the Bering Sea population, *In The Bowhead Whale*. J. J. Burns, J. J. Montague, and C. J. Cowles eds., pp. 23–43. Society for Marine Mammalogy Special Publication No. 2. Allen Press, Lawrence, KS.

Nishiwaki, S., T. Ogawa, K. Matsuoka, T. Bando, T. Mogoe, S. Otani, K. Konishi, H. Sato, K. Nakai, and I. Nomura. 2009. Cruise Report of the Second Phase of the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA II) in 2008/2009. Paper SC/61/O3 presented to the International Whaling Commission Scientific Committee, Cambridge, United Kingdom.

Noongwook, G., The Native Village of Savoonga, The Native Village of Gambell, H. P. Huntington, and J. C. George. 2007. Traditional knowledge of the bowhead whale (*Balaena mysticetus*) around St. Lawrence Island, Alaska. *Arctic* 60:47–54.

North Atlantic Marine Mammal Commission. 2004. Report of the NAMMCO Workshop on Hunting Methods for Seals and Walrus. North Atlantic Marine Mammals Commission, Copenhagen, Denmark.

North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division. 2003. Bowhead Whale Subsistence Sensitivity Map. Barrow, AK.

O'Corry-Crowe, G., A. R. Mahoney, R. Suydam, L. Quakenbush, A. Whiting, L. Lowry, and L. Harwood. 2016. Genetic profiling links changing sea-ice to shifting beluga whale migration patterns. *Biology Letters* 12:20160404.

O'Corry-Crowe, G. M. 2002. Beluga whale *Delphinapterus leucas*, *In Encyclopedia of Marine Mammals*. W. F. Perrin, B. Würsig, and J. G. M. Thewissen eds., pp. 94–99. Academic Press, San Diego, CA.

O'Corry-Crowe, G. M., B. L. Taylor, T. Gelatt, T. R. Loughlin, J. Bickham, M. Basterretche, K. W. Pitcher, and D. P. DeMaster. 2006. Demographic independence along ecosystem boundaries in Steller sea lions revealed by mtDNA analysis: Implications for management of an endangered species. *Canadian Journal of Zoology* 84:1796–1809.

O'Connor, S., R. Campbell, H. Cortez, and T. Knowles. 2009. Whale Watching Worldwide: Tourism Numbers, Expenditures, and Expanding Economic Benefits. Special report from the International Fund for Animal Welfare. Economists at Large, Yarmouth, MA.

Obbard, M. E., G. W. Thiemann, E. Peacock, and T. D. DeBruyn (eds). 2010. Polar Bears: Proceedings of the 15th Working Meeting of the IUCN/SCC Polar Bear Specialist Group, Copenhagen, Denmark, 29 June–3 July 2009. IUCN, Gland, Switzerland and Cambridge, UK.

Oceana. 2013. Bearded Seal Spring Concentration Areas. Oceana, Juneau, AK.

Oceana and Kawerak. 2014. Bering Strait Marine Life and Subsistence Use Data Synthesis. Oceana and Kawerak, Juneau, AK.

Ohsumi, S. 1966. Allomorphosis between body length at sexual maturity and body length at birth in the Cetacea. *Journal of the Mammalogical Society of Japan* 3:3–7.

Olson, J. W., K. D. Rode, D. Eggett, T. S. Smith, R. R. Wilson, G. M. Durner, A. Fischbach, T. C. Atwood, and D. C. Douglas. 2017. Collar temperature sensor data reveal long-term patterns in southern Beaufort Sea polar bear den distribution on pack ice and land. *Marine Ecology Progress Series* 564:211–224.

Orr, R. T. and T. C. Poulter. 1967. Some observations on reproduction, growth, and social behavior in the Steller sea lion. *Proceedings of the California Academy of Sciences* 35:193–226.

Ovsyanikov, N. G. 2005. Behaviour of polar bear in coastal congregations. *Zoologichesky Zhurnal* 84:94–103.

______. 2009. Polar bear research on Wrangel Island and in the central Arctic Basin, *In Polar Bears: Proceedings of the 15th Working Meeting of the IUCN/SCC Polar Bear Specialist Group, Copenhagen, Denmark, 29 June–3 July 2009*. Gland, Switzerland and Cambridge, UK.

Ovsyanikov, N. G. and I. E. Menyushina. 2008. Specifics of polar bears surviving an ice free season on Wrangel Island in 2007, *In Proceedings of the Marine Mammals of the Holarctic*. Odessa, Ukraine.

Pagano, A. M., G. Durner, S. Amstrup, K. Simac, and G. York. 2012. Long-distance swimming by polar bears (*Ursus maritimus*) of the southern Beaufort Sea during years of extensive open water. *Canadian Journal of Zoology* 90:663–676.

Parker, P. and J. M. Maniscalco. 2014. A long-term study reveals multiple reproductive behavior strategies among territorial adult male Steller sea lions (*Eumetopias jubatus*). *Canadian Journal of Zoology* 92:405–415.

Paulic, J. E., B. Bartzen, R. Bennett, K. Conlan, L. Harwood, K. Howland, V. Kostylev, L. Loseto, A. Majewski, H. Melling, A. Neimi, J. Reist, P. Richard, E. Richardson, S. Solomon, W. Walkusz, and B. Williams. 2012. Ecosystem Overview Report for the Darnley Bay Area of Interest. DFO Canadian Science Advisory Secretariat Research Document 2011/062.

Pelland, N. A., J. T. Sterling, M. A. Lea, N. A. Bond, R. R. Ream, C. M. Lee, and C. C. Eriksen. 2014. Fortuitous encounters between seagliders and adult female northern fur seals (*Callorhinus ursinus*) off the Washington (USA) coast: Upper ocean variability and links to top predator behavior. *PLoS ONE* 9:e101268.

Perrin, W. F., B. Würsig, and J. G. M. Thewissen. 2009. *Encyclopedia of Marine Mammals*. Academic Press, Burlington, MA.

Pitcher, K. W. and D. G. Calkins. 1981. Reproductive biology of Steller sea lions in the Gulf of Alaska. *Journal of Mammalogy* 62:599–605.

Polar Bear Specialist Group. 2015. Summary of Polar Bear Population Status per 2014. Polar Bear Specialist Group. Accessed online 2015 at http://pbsg.npolar.no/en/status/status-table.html.

Pritchard, G. T. and C. T. Robbins. 1990. Digestive and metabolic efficiencies of grizzly and black bears. *Canadian Journal of Zoology* 68:1645–1651.

Quakenbush, L. T., J. Citta, and J. Crawford. 2011. Biology of the Bearded Seal (*Erignathus barbatus*) in Alaska, 1961–2009. Alaska Department of Fish and Game Arctic Marine Mammal Program, Fairbanks, AK.

Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen. 2008. Satellite tracking of the Western Arctic stock of bowhead whales, *In Alaska Marine Science Symposium*. Anchorage, AK.

______. 2010a. Fall and winter movements of bowhead whales (*Balaena mysticetus*) in the Chukchi Sea and within a potential petroleum development area. *Arctic* 63:289–307.

Quakenbush, L. T., R. J. Small, and J. J. Citta. 2010b. Satellite Tracking of Western Arctic Bowhead Whales, Final Report. OCS Study BOEMRE 2010-033. Alaska Department of Fish and Game, Juneau, AK.

______. 2013. Satellite Tracking of Bowhead Whales: Movements and Analysis from 2006 to 2012. Alaska Department of Fish and Game for US Department of the Interior, Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, AK.

Quakenbush, L. T., R. S. Suydam, A. L. Bryan, L. F. Lowry, K. J. Frost, and B. A. Mahoney. 2015. Diet of beluga whales (*Delphinapterus leucas*) in Alaska from stomach contents, March–November. *Marine Fisheries Review* 77:70–84.

Quan, J. L. 2000. Summer Resident Gray Whales of Washington State: Policy, Biological, and Management Implications of Makah Whaling. MS thesis, University of Washington, Seattle, WA.

Ragen, T. J., G. A. Antonelis, and M. Kiyota. 1995. Early migration of northern fur seal pups from St. Paul Island, Alaska. *Journal of Mammalogy* 76:1137–1148.

Ramsay, M. A. and I. Stirling. 1988. Reproductive biology and ecology of female polar bears (*Ursus maritimus*). *Journal of Zoology* 214:601–633.

______. 1990. Fidelity of female polar bears to winter-den sites. *Journal of Mammalogy* 71:233–236.

Rasmussen, K., D. M. Palacios, J. Calambokidis, M. T. Saborío, L. Dalla Rosa, E. R. Secchi, G. H. Steiger, J. M. Allen, and G. S. Stone. 2007. Southern hemisphere humpback whales wintering off Central America: Insights from water temperature into the longest mammalian migration. *Biology Letters* 3:302–305.

Raum-Suryan, K. L., K. W. Pitcher, D. G. Calkins, J. L. Sease, and T. R. Loughlin. 2002. Dispersal, rookery fidelity, and metapopulation structure of Steller sea lions *(Eumetopias jubatus)* in an increasing and decreasing population in Alaska. *Marine Mammal Science* 18:746–764.

Ray, C. E. 1971. Polar bear and mammoth on the Pribilof Islands. *Arctic* 24:9–18.

Ray, G. C., J. McCormick-Ray, P. Berg, and H. E. Epstein. 2006. Pacific walrus: Benthic bioturbator of Beringia. *Journal of Experimental Marine Biology and Ecology* 330:403–419.

Ream, R. R., J. Sterling, and T. R. Loughlin. 2005. Oceanographic features related to northern fur seal migratory movement. *Deep Sea Research Part II: Topical Studies in Oceanography* 52:823–843.

Reeves, R., C. Rosa, J. C. George, G. Sheffield, and M. Moore. 2012. Implications of Arctic industrial growth and strategies to mitigate future vessel and fishing gear impacts on bowhead whales. *Marine Policy* 36:454–462.

Reeves, R. R. 2002. The origins and character of 'aboriginal subsistence' whaling: A global review. *Mammal Review* 32:71–106.

Reeves, R. R., P. J. Ewins, S. Agbayani, M. P. Heide-Jørgensen, K. M. Kovacs, C. Lydersen, R. Suydam, W. Elliott, G. Polet, and Y. van Dijk. 2014. Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. *Marine Policy* 44:375–389.

Regehr, E. V., S. C. Amstrup, and I. Stirling. 2006. Polar Bear Population Status in the Southern Beaufort Sea. US Geological Survey Open-File Report 2006-1337. US Geological Survey, Reston, VA.

Regehr, E. V., K. L. Laidre, H. R. Akçakaya, S. C. Amstrup, T. C. Atwood, N. J. Lunn, M. Obbard, H. Stern, G. W. Thiemann, and Ø. Wiig. 2016. Conservation status of polar bears (*Ursus maritimus*) in relation to projected sea-ice declines. *Biology Letters* 12:20160556.

Rice, D. W. 1998. *Marine Mammals of the World: Systematics and Distribution*. Society for Marine Mammalogy, Lawrence, KS.

Rice, D. W., A. A. Wolman, and H. W. Braham. 1984. The gray whale, *Eschrichtius robustus*. *Marine Fisheries Review* 46:7–14.

Richard, P. R., A. R. Martin, and J. R. Orr. 2001. Summer and autumn movements of belugas of the Eastern Beaufort Sea stock. *Arctic* 54:223–236.

Richardson, W. J. 1995. *Marine Mammals and Noise*. Academic Press, San Diego, CA.

Robbins, J., L. D. Rosa, J. Allen, D. Mattila, E. R. Secchi, A. Friedlaender, P. Stevick, D. Nowacek, and D. Steel. 2011. Return movement of a humpback whale between the Antarctic Peninsula and American Samoa: A seasonal migration record. *Endangered Species Research* 13:117–121.

Robson, B. W., M. E. Goebel, J. D. Baker, R. R. Ream, T. R. Loughlin, R. C. Francis, G. A. Antonelis, and D. P. Costa. 2004. Separation of foraging habitat among breeding sites of a colonial marine predator, the northern fur seal (*Callorhinus ursinus*). *Canadian Journal of Zoology* 82:20–29.

Rode, K. D., S. D. Farley, and C. T. Robbins. 2006a. Behavioral responses of brown bears mediate nutritional effects of experimentally introduced tourism. *Biological Conservation* 133:70–80.

______. 2006b. Sexual dimorphism, reproductive strategy, and human activities determine resource use by brown bears. *Ecology* 87:2636–2646.

Rode, K. D., E. V. Regehr, D. C. Douglas, G. Durner, A. E. Derocher, G. W. Thiemann, and S. M. Budge. 2014. Variation in the response of an Arctic top predator experiencing habitat loss: Feeding and reproductive ecology of two polar bear populations. *Global Change Biology* 20:76–88.

Rode, K. D., J. D. Reist, E. Peacock, and I. Stirling. 2010. Comments in response to "Estimating the energetic contribution of polar bear (*Ursus maritimus*) summer diets to the total energy budget" by Dyck and Kebreab (2009). *Journal of Mammalogy* 91:1517–1523.

Rode, K. D., R. R. Wilson, E. V. Regehr, M. St. Martin, D. C. Douglas, and J. Olson. 2015a. Data from: Increased land use by Chukchi Sea polar bears in relation to changing sea ice conditions. Dryad Digital Repository.

______. 2015b. Increased land use by Chukchi Sea polar bears in relation to changing sea ice conditions. *PLoS ONE* 10:e0142213.

Rogers, M. C., E. Peacock, K. Simac, M. B. O'Dell, and J. M. Welker. 2015. Diet of female polar bears in the southern Beaufort Sea of Alaska: Evidence for an emerging alternative foraging strategy in response to environmental change. *Polar Biology* 38:1035–1047.

Roppel, A. Y. and S. P. Davey. 1965. Evolution of fur seal management on the Pribilof Islands. *Journal of Wildlife Management* 29:448–463.

Rosen, D. A. S. and A. W. Trites. 2004. Satiation and compensation for short-term changes in food quality and availability in young Steller sea lions (*Eumetopias jubatus*). *Canadian Journal of Zoology* 82:1061–1069.

Rosing-Asvid, A. 2006. The influence of climate variability on polar bear (*Ursus maritimus*) and ringed seal (*Pusa hispida*) population dynamics. *Canadian Jounal of Zoology* 84:357–364.

Rugh, D., D. Demaster, A. Rooney, J. Breiwick, K. Shelden, and S. Moore. 2003. A review of bowhead whale (*Balaena mysticetus*) stock identity. *Journal of Cetacean Research and Management* 5:267–280.

Sandell, M. 1990. The evolution of seasonal delayed implantation. *Quarterly Review of Biology* 65:23–42.

Sasaki, T., M. Nikaido, H. Hamilton, M. Goto, H. Kato, N. Kanda, L. A. Pastene, Y. Cao, R. E. Fordyce, and M. Hasegawa. 2005. Mitochondrial phylogenetics and evolution of mysticete whales. *Systematic Biology* 54:77–90.

Satterthwaite-Phillips, D., C. Krenz, G. Gray, and L. Dodd. 2016. Iñuuniaļiqput Iļiļugu Nunaŋŋuanun: Documenting Our Way of Life through Maps. Northwest Arctic Borough, Kotzebue, AK.

Scheinin, A. P., D. Kerem, C. D. MacLeod, M. Gazo, C. A. Chicote, and M. Castellote. 2011. Gray whale (*Eschrichtius robustus*) in the Mediterranean Sea: Anomalous event or early sign of climate-driven distribution change? *Marine Biodiversity Records* 4:e28.

Schliebe, S., T. Evans, K. Johnson, M. Roy, S. Miller, C. Hamilton, R. Meehan, and S. Jahrsdoerfer. 2006. Range Wide Status Review of the Polar Bear (*Ursus maritimus*). US Fish and Wildlife Service, Anchorage, AK.

Schliebe, S., K. D. Rode, J. S. Gleason, J. M. Wilder, K. Proffitt, T. J. Evans, and S. Miller. 2008. Effects of sea ice extent and food availability on spatial and temporal distribution of polar bears during the fall open-water period in the southern Beaufort Sea. *Polar Biology* 31:999–1010.

Sheffield, G. and J. M. Grebmeier. 2009. Pacific walrus (*Odobenus rosmarus divergens*): Differential prey digestion and diet. *Marine Mammal Science* 25:761–777.

Sigler, M. F., D. J. Tollit, J. J. Vollenweider, J. F. Thedinga, D. J. Csepp, J. N. Womble, M. A. Wong, M. J. Rehberg, and A. W. Trites. 2009. Steller sea lion foraging response to seasonal changes in prey availability. *Marine Ecology Progress Series* 388:243–261.

Simpkins, M. A., L. M. Hiruki-Raring, G. Sheffield, J. M. Grebmeier, and J. L. Bengtson. 2003. Habitat selection by ice-associated pinnipeds near St. Lawrence Island, Alaska in March 2001. *Polar Biology* 26:577–586.

Sinclair, E., T. R. Loughlin, and W. Pearcy. 1994. Prey selection by northern fur seals (*Callorhinus ursinus*) in the eastern Bering Sea. *Fishery Bulletin* 92:144–156.

Sinclair, E. H., S. E. Moore, N. A. Friday, T. K. Zeppelin, and J. M. Waite. 2005. Do patterns of Steller sea lion (*Eumetopias jubatus*) diet, population trend and cetacean occurrence reflect oceanographic domains from the Alaska Peninsula to the central Aleutian Islands? *Fisheries Oceanography* 14:223–242.

Sjare, B. and I. Stirling. 1996. The breeding behavior of Atlantic walruses, *Odobenus rosmarus rosmarus*, in the Canadian High Arctic. *Canadian Journal of Zoology* 74:897–911.

Sjare, B. L. and T. G. Smith. 1986. The relationship between behavioral activity and underwater vocalizations of the white whale, *Delphinapterus leucas*. *Canadian Journal of Zoology* 64:2824–2831.

Smith, T. G. 1981. Notes on the Bearded Seal, *Erignathus barbatus*, in the Canadian Arctic. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1042. Department of Fisheries and Oceans, Ste. Anne de Bellevue, Canada.

Smith, T. G., M. O. Hammill, and G. Taugbøl. 1991. A review of the developmental, behavioural and physiological adaptations of the ringed seal, *Phoca hispida*, to life in the Arctic winter. *Arctic* 44:124–131.

Smith, T. G. and I. Stirling. 1975. The breeding habitat of the ringed seal (*Phoca hispida*). The birth lair and associated structures. *Canadian Journal of Zoology* 53:1297–1305.

Solovyev, B. A., N. G. Platonov, D. M. Glazov, O. V. Shpak, and V. V. Rozhnov. 2012. Distribution of beluga whales (*Delphinapterus leucas*) in the Russian Arctic seas according to the results of expedition aboard RV *Mikhail Somov*, September–November 2010. *Biology Bulletin* 39:654–658.

Sousa-Lima, R. S. 2005. Songs indicate interaction between humpback whale (*Megaptera novaeangliae*) populations in the western and eastern South Atlantic Ocean. *Marine Mammal Science* 21:557–566.

Speckman, S. G., V. I. Chernook, D. M. Burn, M. S. Udevitz, A. A. Kochnev, A. Vasilev, C. V. Jay, A. Lisovsky, A. S. Fischbach, and R. B. Benter. 2011. Results and evaluation of a survey to estimate Pacific walrus population size. *Marine Mammal Science* 27:514–553.

St. Aubin, D. J., T. G. Smith, and J. R. Geraci. 1990. Seasonal epidermal molt in beluga whales, *Delphinapterus leucas*. *Canadian Journal of Zoology* 68:359–367.

Stafford, K. M., M. C. Ferguson, D. D. W. Hauser, S. R. Okkonen, C. L. Berchok, J. J. Citta, J. T. Clarke, E. C. Garland, J. Jones, and R. S. Suydam. In press. Beluga whales in the western Beaufort Sea: Current state of knowledge on timing, distribution, habitat use and environmental drivers. *Deep Sea Research Part II: Topical Studies in Oceanography*.

Stafford, K. M., S. E. Moore, M. Spillane, and S. Wiggins. 2007. Gray whale calls recorded near Barrow, Alaska, throughout the winter of 2003–04. *Arctic* 60:167–172.

Steller, G. W. 1899. The Beasts of the Sea (Translated), *In The Fur Seals and Fur-seal Islands of the North Pacific Ocean. Part 3: Special Papers Relating to the Fur Seal and to the Natural History of the Pribilof Islands*. D. S. Jordan, L. Steineger, F. A. Lucas, J. Moser, C. H. Townsend, G. A. Clark, and J. Murray eds., pp. 179–218. Government Printing Office, Washington, DC.

Stenson, G. B. and M. Hammill. 2014. Can ice breeding seals adapt to habitat loss in a time of climate change? *ICES Journal of Marine Science* 71:1977–1986.

Stephenson, S. A. and L. Hartwig. 2010. Canadian Manuscript Report of Fisheries and Aquatic Sciences. The Arctic Marine Workshop. Fisheries and Oceans Canada, Winnipeg, Canada.

Sterling, J. T., A. M. Springer, S. J. Iverson, S. P. Johnson, N. A. Pelland, D. S. Johnson, M. A. Lea, and N. A. Bond. 2014. The sun, moon, wind, and biological imperative–shaping contrasting wintertime migration and foraging strategies of adult male and female northern fur seals (*Callorhinus ursinus*). *PLoS ONE* 9:e93068.

Stirling, I., D. Andriashek, C. Spencer, and A. Derocher. 1988. Assessment of the Polar Bear Population in the Eastern Beaufort Sea. Canadian Wildlife Service, Ottawa, Canada.

Stirling, I., C. Jonkel, P. Smith, R. Robertson, and D. Cross. 1977. The Ecology of the Polar Bear (*Ursus maritimus*) Along the Western Coast of Hudson Bay. Occasional Paper Number 33. Canadian Wildlife Service, Ottawa, Canada.

Stirling, I., N. J. Lunn, and J. Lacozza. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. *Arctic* 52:294–306.

Stirling, I. and E. H. McEwan. 1975. The caloric value of whole ringed seals (*Phoca hispida*) in relation to polar bear (*Ursus maritimus*) ecology and hunting behavior. *Canadian Journal of Zoology* 53:1021–1027.

Stishov, M. 1991. Results of aerial counts of the polar bear dens on the Arctic coasts of extreme northeast Asia, *In Polar Bears: 10th Working Meeting of the IUCN/SSC Polar Bear Specialist Group*. Gland, Switzerland, and Cambridge, United Kingdom.

Stringer, W. J. and J. E. Groves. 1991. Location and areal extent of polynyas in the Bering and Chukchi Seas. *Arctic* 44:164–171.

Suydam, R. and Alaska Department of Fish and Game. 2004. Beluga whale coastal concentration areas, *In North Slope Borough Area Wide Comprehensive Plan*. North Slope Borough, Barrow, AK.

Suydam, R., L. F. Lowry, and K. J. Frost. 2005. Distribution and Movements of Beluga Whales from the Eastern Chukchi Sea Stock During Summer and Early Autumn. North Slope Borough Department of Wildlife Management and University of Alaska Fairbanks Institute of Marine Science, Barrow and Fairbanks, AK.

Suydam, R. S. 2009. Age, Growth, Reproduction, and Movements of Beluga Whales (*Delphinapterus leucas*) from the Eastern Chukchi Sea. PhD thesis, University of Washington, Seattle, WA.

Suydam, R. S., L. F. Lowry, K. J. Frost, G. M. O'Corry-Crowe, and D. Pikok. 2001. Satellite tracking of eastern Chukchi Sea beluga whales into the Arctic Ocean. *Arctic* 54:237–243.

Swartz, S. L., B. L. Taylor, and D. J. Rugh. 2006. Gray whale (*Eschrichtius robustus*) population and stock identity. *Mammal Review* 36:66–84.

Sweeney, K., L. Fritz, R. Towell, and T. Gelatt. 2016. Results of Steller Sea Lion Surveys in Alaska, June–July 2016. National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA.

Taylor, R. L. and M. S. Udevitz. 2015. Demography of the Pacific walrus (*Odobenus rosmarus divergens*): 1974–2006. *Marine Mammal Science* 31:231–254.

Thorsteinson, F. V., R. W. Nelson, and D. F. Lall. 1961. Experimental Harvest of the Steller Sea Lion in Alaska Waters. Special Scientific Report Fisheries No. 371. US Fish and Wildlife Service, Washington, DC.

Trites, A. W. and P. A. Larkin. 1989. The decline and fall of the Pribilof fur seal (*Callorhinus ursinus*): A simulation study. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1437–1445.

Trites, A. W., B. P. Porter, V. B. Deecke, A. P. Coombs, M. L. Marcotte, and D. A. Rosen. 2006. Insights into the timing of weaning and the attendance patterns of lactating Steller sea lions (*Eumetopias jubatus*) in Alaska during winter, spring, and summer. *Aquatic Mammals* 32:85–97.

Trites, A. W. and B. T. Porter. 2002. Attendance patterns of Steller sea lions (*Eumetopias jubatus*) and their young during winter. *Journal of Zoology* 256:547–556.

Turek, M. F., S. Pedersen, N. Ratner, and M. G. See. 2008. Steller Sea Lions *Eumetopias jubatus*: Direct Mortality by Humans. Alaska Department of Fish and Game, Juneau, AK.

Tyack, P. 1981. Interactions between singing Hawaiian humpback whales and conspecifics nearby. *Behavioral Ecology and Sociobiology* 8:105–116.

Tynan, C. T. and D. P. DeMaster. 1997. Observations and predictions of Arctic climatic change: Potential effects on marine mammals. *Arctic* 50:308–322.

Udevitz, M. S., J. R. Gilbert, and G. A. Fedoseev. 2001. Comparison of methods used to estimate numbers of walruses on sea ice. *Marine Mammal Science* 17:601–616.

US Fish and Wildlife Service. 1995. Habitat Conservation Strategy for Polar Bears in Alaska. US Fish and Wildlife, Anchorage, AK.

______. 2002. Stock Assessment of the Pacific Walrus (*Odobenus rosmarus divergens*). US Fish and Wildlife Service, Anchorage, AK.

______. 2008. Endangered and threatened wildlife and plants; determination of threatened status for the polar bear (*Ursus maritimus*) throughout its range. *Federal Register* 73:28211–28303.

______. 2013. Hanna Shoal Walrus Use Area Outer Boundary. US Fish and Wildlife Service Marine Mammals Management, Anchorage, AK.

______. 2014. Pacific Walrus (*Odobenus rosmarus divergens*): Alaska Stock. US Fish & Wildlife Service, Anchorage, AK.

______. 2015. Polar Bear (*Ursus maritimus*) Conservation Management Plan, Draft. US Fish and Wildlife, Anchorage, AK.

______. 2016. Polar Bear (*Ursus maritimus*) Conservation Management Plan, Final. US Fish and Wildlife, Anchorage, AK.

US Geological Survey. 2016. Walrus Tracking Animations. US Geological Survey, Alaska Science Center, Anchorage, AK. Accessed online Aug 2016 at https://alaska.usgs.gov/science/biology/walrus/tracking.html.

Van Parijs, S. M. and C. W. Clark. 2006. Long-term mating tactics in an aquatic-mating pinniped, the bearded seal, *Erignathus barbatus*. *Animal Behaviour* 72:1269–1277.

Wallenius, T. H. 1999. Yield variations of some common wild berries in Finland in 1956–1996. *Annales Botanici Fennici* 36:299–314.

Ware, J. V., K. D. Rode, J. F. Bromaghin, D. C. Douglas, R. R. Wilson, E. V. Regehr, S. C. Amstrup, G. M. Durner, A. M. Pagano, J. Olson, C. T. Robbins, and H. T. Jansen. 2017. Habitat degradation affects the summer activity of polar bears. *Oecologia* 184:87–89.

Watts, P. D. and B. A. Draper. 1988. Beluga whale ecology: A concern of freshwater biologists? *Freshwater Biology* 20:211–213.

Watts, P. D. and S. E. Hansen. 1987. Cyclic starvation as a reproductive strategy in the polar bear. *Symposium of the Zoological Society of London* 57:305–318.

Weeks, W. 2010. *On Sea Ice*. University of Alaska Press, Fairbanks, AK.

Weinrich, M. and C. Corbelli. 2009. Does whale watching in Southern New England impact humpback whale (*Megaptera novaeangliae*) calf production or calf survival? *Biological Conservation* 142:2931–2940.

Weinrich, M. T., M. R. Schilling, and C. R. Belt. 1992. Evidence for acquisition of a novel feeding behaviour: Lobtail feeding in humpback whales, *Megaptera novaeangliae*. *Animal Behaviour* 44:1059–1072.

Welch, A. J., O. C. Bedoya-Reina, L. Carretero-Paulet, W. Miller, K. D. Rode, and C. Lindqvist. 2014. Polar bears exhibit genome-wide signatures of bioenergetic adaptation to life in the Arctic environment. *Genome Biology and Evolution* 6:433–450.

Welch, C. A., J. Keay, K. C. Kendall, and C. T. Robbins. 1997. Constraints on frugivory by bears. *Ecology* 78:1105–1119.

Weller, D., A. Burdin, B. Wursig, B. Taylor, and R. Brownell, Jr. 2002. The western gray whale: A review of past exploitation, current status and potential threats. *Journal of Cetacean Research and Management* 4:7–12.

Whiteman, J., H. Harlow, G. M. Durner, R. Anderson-Sprecher, S. E. Albeke, E. V. Regehr, S. C. Amstrup, and M. Ben-David. 2015. Summer declines in activity and body temperature offer polar bears limited energy savings. *Science* 349:295–298.

Wiig, Ø., S. Amstrup, T. Atwood, K. Laidre, N. Lunn, M. Obbard, E. Regehr, and G. Thiemann. 2015. *Ursus maritimus*. The IUCN Red List of Threatened Species 2015. International Union for Conservation of Nature and Natural Resources. Accessed online 21 July 2017 at http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T22823A14871490.en.

Wiley, D. N., J. C. Moller, R. M. Pace, and C. Carlson. 2008. Effectiveness of voluntary conservation agreements: Case study of endangered whales and commercial whale watching. *Conservation Biology* 22:450–457.

Williams, R. and P. O'Hara. 2010. Modelling ship strike risk to fin, humpback and killer whales in British Columbia, Canada. *Journal of Cetacean Research and Management* 11:1–8.

Woodby, D. A. and D. B. Botkin. 1993. Stock sizes prior to commercial whaling, *In The Bowhead Whale*. J. J. Burns, J. J. Montague, and C. J. Cowles eds., pp. 387–407. Society for Marine Mammalogy Special Publication No. 2. Allen Press, Lawrence, KS.

Wozencraft, W. C. 2005. Order carnivora, *In Mammal Species of the World: A Taxonomic and Geographic Reference*. D. E. Wilson and D. M. Reeder eds., pp. 532–628. Johns Hopkins University Press, Baltimore, MD.

Würsig, B., J. Guerrero, and G. K. Silber. 1993. Social and sexual behavior of bowhead whales in fall in the western Arctic: A re-examination of seasonal trends. *Marine Mammal Science* 9:103–115.

Yablokov, A. V. and L. S. Bogoslovskaya. 1984. A review of Russian research on the biology and commercial whaling of the gray whale, *In The Gray Whale: Eschrichtius robustus*. M. L. Jones, S. L. Swartz, and S. Leatherwood eds., pp. 465–485. Academic Press, New York, NY.

York, A. E. 1983. Average age at first reproduction of the northern fur seal (*Callorhinus ursinus*). *Canadian Journal of Fisheries and Aquatic Sciences* 40:121–127.

York, A. E. and J. R. Hartley. 1981. Pup production following harvest of female northern fur seals. *Canadian Journal of Fisheries and Aquatic Sciences* 38:84–90.

York, A. E. and V. B. Scheffer. 1997. Timing of implantation in the northern fur seal, *Callorhinus ursinus*. *Journal of Mammalogy* 78:675–683.

Zeh, J. E. and A. E. Punt. 2005. Updated 1978–2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. *Journal of Cetacean Research and Management* 7:169–175.

Zerbini, A. N., N. A. Friday, D. M. Palacios, J. M. Waite, P. H. Ressler, B. K. Rone, S. E. Moore, and P. J. Clapham. 2016. Baleen whale abundance and distribution in relation to environmental variables and prey density in the Eastern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 134:312–330.

Zerbini, A. N. and J. E. Kotas. 1998. A Note on Cetacean Bycatch in Pelagic Driftnetting Off Southern Brazil. International Whaling Commission, Cambridge, United Kingdom.

Zerbini, A. N., J. M. Waite, J. L. Laake, and P. R. Wade. 2006. Abundance, trends and distribution of baleen whales off western Alaska and the central Aleutian Islands. *Deep Sea Research Part I: Oceanographic Research Papers* 53:1772–1790.

Zimushko, V. and S. Lenskaya. 1970. Feeding of the gray whale (*Eschrichtius gibbosus Erx.*) at foraging grounds. *Ekologiya* 1:26–35.

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HUMAN USES

Melanie Smith / USFWS

HUMAN USES MAP INDEX

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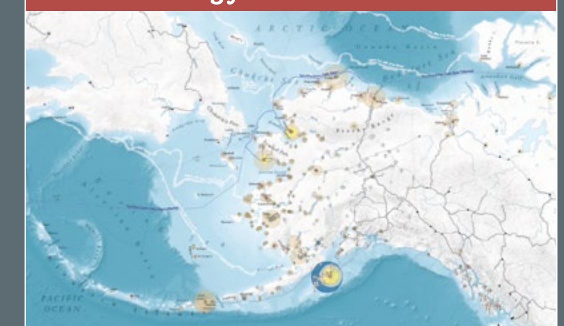

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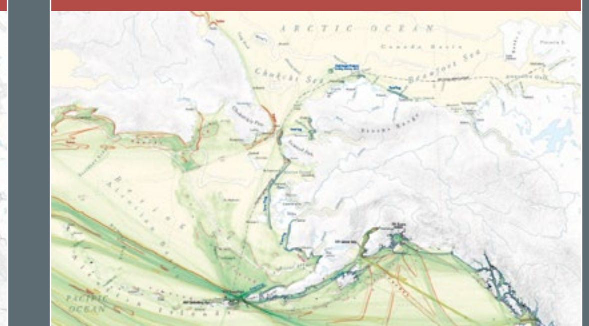

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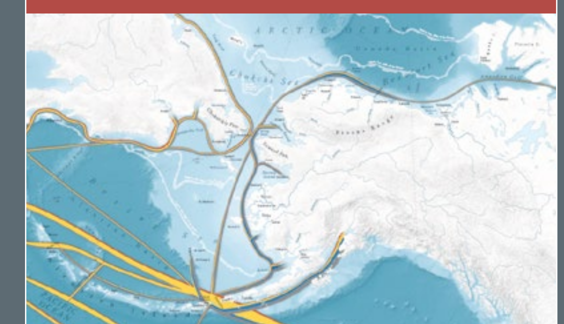

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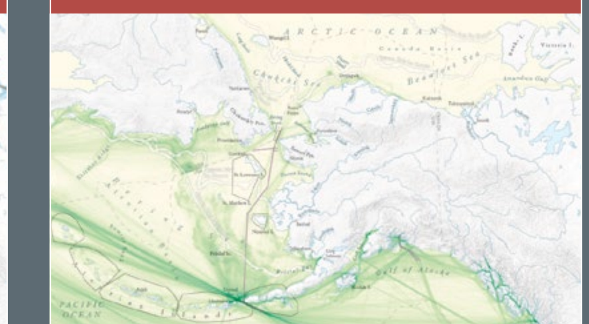

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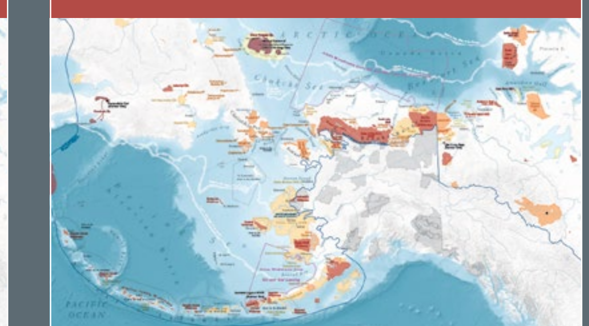

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A Closer Look: Historical Perspective

Max Goldman, Melanie Smith, and Susan Culliney

To the untrained eye, the Arctic at first glance may appear unfit for human life to flourish; but a closer look exposes that an abundance of biological resources have supported human settlement in the region for millennia. Humans have inhabited the land and coasts of the Bering, Chukchi, and Beaufort Seas for over 10,000 years, though the light touch of Arctic people left little evidence of their presence. During the last two centuries, technological advancement and burgeoning world markets have made Arctic resources accessible and attractive. Whales, seals, sea otters, and mineral deposits were the first assets targeted here, with Russia, Japan, Britain, and the US arriving to meet demand for fuel, fur, and gold throughout the late 19th century and the first part of the 20th century. Gold discoveries near the Yukon River in Canada and in Nome, Alaska, in the late 1890s effectively doubled the population of Alaska. European, Asian, and American influences were introduced to Alaska Natives.

With the onset of World War II, it became clear that the Arctic also offered a different sort of resource: strategic proximity to Asia, the Empire of Japan, and eventually, the USSR. The US established military outposts and airfields throughout its Alaska territory. Later, during the Cold War, the nation completed construction of the Distant Early Warning (DEW) line, a system of radar stations strategically placed by the US and Canada in the Arctic (the DEW line extended into Greenland and Iceland, as well) as a system of warning against attack from incoming Soviet Bombers. Permanent Arctic military presence became a priority throughout the Cold War, as the threat of imminent armed conflict loomed over the world. During that time, the island of Amchitka in the Aleutian Islands was used as a military testing grounds for three underground atomic bombs. The Unangax̂ inhabitants of the island were permanently displaced, a cultural casualty in the ongoing human use of Arctic resources.

During the 1960s, petroleum exploration became the new regional priority, and picked up pace when oil was discovered in Prudhoe Bay in 1968. This led to an Arctic rush that brought new roads, airstrips, pipelines, and shipping needs, with billions of dollars at stake. Since this time, Alaska's state economy has been largely based in oil and gas. The Alaska Native Claims Settlement Act (ANCSA) of 1971 ostensibly put to rest Alaska Native land claims and cleared the way for the State and federal government to begin tapping the state's newly discovered petroleum resources, but the details of this law are fraught with significant controversy even today.

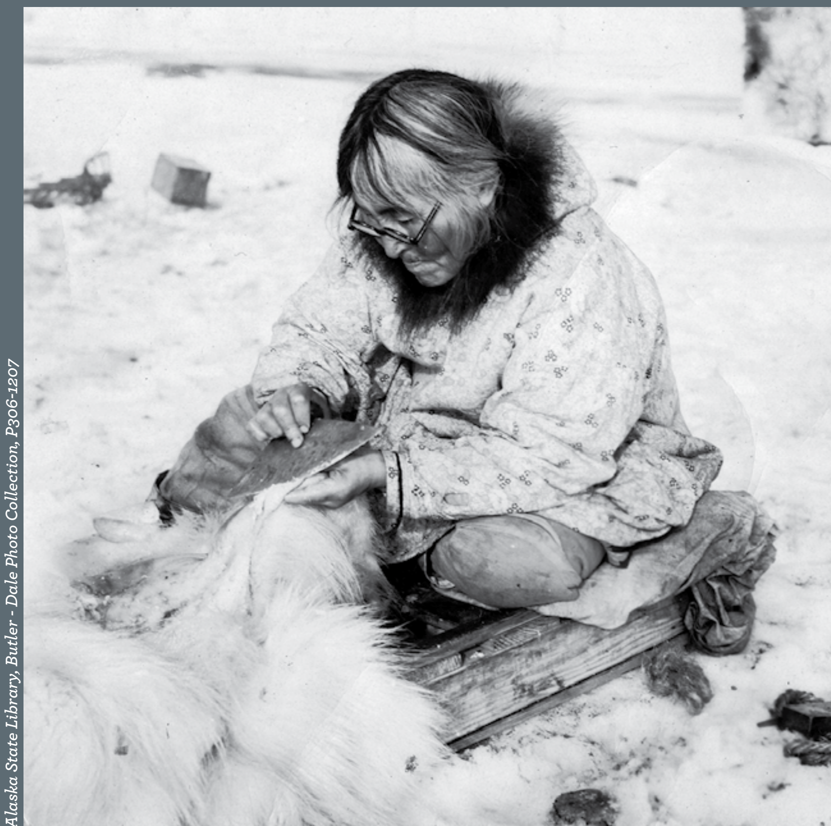
During the ongoing era of resource exploration, extraction, growth, and development, protecting Alaska's ecological systems and expanding economic opportunities are often at odds, though wildlife and habitat are protected in part by simple remoteness and inaccessibility. In the past, explorers spent centuries searching for the fabled Northwest Passage through North America, many of them dying during their struggle through the frigid Arctic, until Roald Amundsen successfully completed the trek from 1903 to 1906 (wherein he spent three winters with his ship frozen into the ice). Today the Passage is ice-free for a much longer period each summer, and can be completed in a single season. In 2016, a cruise ship called the *Crystal Serenity* (the largest ship to ever complete the Passage) sailed from Alaska to New York in only 32 days, carrying over 900 passengers and 600 crew members. Access, the next big resource, is finally freeing up the Arctic.

Throughout the times of change and development, many Alaska Natives have continued to harvest the most fundamental and local biological resources, using many of the same techniques in many of the same places, as their ancestors have done before them. However, the biggest change yet is knocking on the door of the Arctic. It is widely observed, especially among residents, that the Arctic is warming and the landscape is changing. Sea ice moves farther offshore than in recent decades, as well as forms later and melts earlier. Warming and loss of sea ice open up ever more opportunities to explore and develop the Arctic. This, in turn, is likely to result in increasing pressures from vessel traffic, fishing, energy extraction, research, management, and tourism. Human uses in the Arctic will certainly be affected, yet the magnitude of change, and the response to it, remain to be seen.

SOURCES

Amundsen and Hansen (1908), Bancroft et al. (1886), Hulley (1953), Kohlhoff (2011), Price (1979)

Alaska State Library, Emil Krulish Photo Collection, P431-44



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Transportation and Energy Infrastructure

Benjamin Sullender

Together, transportation and energy infrastructure comprise core components of successful human settlements along the coasts and islands of the Bering, Chukchi, and Beaufort Seas. Although people have inhabited these areas for millennia, conspicuous permanent infrastructure first became prevalent around the 20th century, as trails and ports were constructed to support individual-level extraction of biotic resources (Young 1992). During and after World War II, the Arctic gained strategic importance for the military, and projects such as the Distant Early Warning (DEW) Line radar stations were undertaken in the interest of national security (Lackenbauer and Farish 2007, Hird 2016). Intensifying oil, gas, and mineral extraction in the mid- and late-1900s led industry to establish their own supply chains and privately operated infrastructure networks (Young 1992, Bennett 2016b). Still today, infrastructure networks only infrequently reach existing communities, and the region's remoteness makes the transportation and provision of utilities a major challenge. Electricity must be produced within each community since very few settlements are connected to a broader grid. Given the very limited road network accessing these communities, most supplies—and people—arrive by water or air.

ENERGY

Due to its large size and widely dispersed population, Alaska faces unique challenges in the generation and transmission of electricity. Alaska's electric grid is not connected to the rest of North America, and the main grid system, called the Railbelt, only runs south from Fairbanks to the Kenai Peninsula (Fay et al. 2013). Smaller communities in western, Arctic, and interior Alaska are outside of the service area and must generate their own electricity—over 150 stand-alone grids have been developed to support these communities (Renewable Energy Alaska Project 2016), many of which experience technical and service problems related to their small scale (Alaska Energy Authority 2017b). Coastal communities typically run power plants through consumer-owner cooperatives, which are primarily fueled by diesel or other petroleum liquids (US Energy Information Administration 2017a).

The use of fossil fuels in remote communities raises logistical challenges: fuel must be purchased and transported from distant refineries, and delivered and stored on site. Diesel and gasoline are generally brought in by barge from refineries in the Lower 48 states, or the Alaska towns of Nikiski, North Pole, or Valdez. Delivery of fuel through tanker aircraft is possible, but often prohibitively expensive (Renewable Energy Alaska Project 2016). Once delivered, petroleum liquids are then stored in bulk fuel facilities, also called tank farms.

In Arctic communities, enough fuel must be stored to last through the winter before seasonal ice cover makes transport virtually impossible. Even for small villages, tank farms must be large enough to store and distribute hundreds of thousands of gallons of fuel per year to ensure a consistent supply of energy (Alaska Energy Authority 2017a). Even recently, the uncertainty in supply, and imminent shortages, have had profound impacts on remote communities. In 2011, weather and logistical difficulties prevented the arrival of two of three scheduled fuel barges into the city of Nome, and concerns about running out of fuel in the winter of 2012 led to an emergency delivery from an icebreaker-escorted Russian tanker (Burke 2012).

Although diesel is still the primary source of energy in remote communities, the use of renewable energy is expanding (Melendez and Fay 2012). Renewables are attractive in many areas because of high oil costs. Residents of remote communities in Arctic Alaska pay nearly double the national average price for energy (Herrmann 2017) and also face continual reliance on long-distance supply and the need for high-volume storage of fuel. The goal of displacing most diesel usage with regionally available alternatives is an economic reality, and is seen by many as a key part of sustaining resilient communities (Hobson 2015, Herrmann 2017). Despite some initial challenges in the integration of renewables into a diesel-based microgrid, small-scale wind installations are becoming more commonplace in western Alaska (Hobson 2015), and, where environmentally feasible, many communities are adding hydroelectric capacity (Renewable Energy Alaska Project 2016).

Benjamin Sullender

Kodiak Island gets over 99% of its energy from renewable sources, including these wind turbines on Pillar Mountain. Other communities such as Nome and Kotzebue are turning to wind power to meet demand for electricity without relying on diesel.

Arctic Russia and Canada face many of the same issues, where isolated electric grids are currently reliant on small-scale diesel power plants (Natural Resources Canada 2011, Pollon 2017). Both the Russian and Canadian federal governments have announced recent policies to encourage the adoption of renewables and hybrid diesel-renewable systems in remote areas (Bhattarai and Thompson 2016, Boute 2016). Regional governments are also supporting these initiatives.

ROADS

There are no current road connections among coastal communities on the Bering Sea and interior ground transportation networks that link to the Lower 48 states. Limited paved and unpaved roads allow vehicular travel within communities, and ice and snow roads may provide seasonal connections when conditions permit. Formally constructed ice roads involve pumping water onto the surface and allowing it to freeze. The elevated temperatures in spring and summer naturally melt the ice road, and no mitigation activities are typically required.

Within Alaska, the Dalton Highway runs 414 miles (670 km) north from near Fairbanks to Deadhorse, a few miles from the Beaufort Sea. The Dalton Highway also serves as an access road for the Trans-Alaska Pipeline System (TAPS). Outside of Deadhorse, there are no coastal Arctic connections with the rest of the North American road system. A large independent road network extends from Nome across portions of the Seward Peninsula. From Nome, gravel roads run 73 miles (117 km) northwest to Teller, 85 miles (137 km) north to Taylor, and 72 miles (116 km) east to Council.

In Canada, the Dempster Highway currently runs north to Inuvik, although construction of a 75-mile (120-km) gravel road will connect with Tuktoyaktuk, on the Beaufort Sea coast, in late 2017 (Barton 2016). A winter-only ice road has previously linked Inuvik and Tuktoyaktuk (Kujawinski 2016).

Industrial resource extraction has driven construction of a network of gravel and ice roads to provide access to oil-drilling pads, processing facilities, and other sites. These roads are often, but not always, aligned with pipelines transporting oil from production wells through a variety of intermediate staging areas and eventually to the Trans-Alaska Pipeline System. A series of nine pipelines transport oil from other producing units east or west to the main TAPS corridor. Pipelines and oil development-related gravel roads are discussed further in the Petroleum Exploration and Development summary. Just north of Kotzebue, a 52-mile (84-km) gravel access road runs from the DeLong Mountain Terminal to the Red Dog Mine. Large vehicles transport minerals to and from the port, where they are loaded onto barges during the open-water season (Northern Alaska Environmental Center 2010).

PORTS AND MARINE TRANSPORTATION

Coastal communities rely on large barges, typically towed by tugboats, for deliveries of goods and fuel. Further details are provided in the Vessel Traffic summary.

Deep-draft ports and associated services are a critical feature of marine infrastructure. Deep-draft ports are able to accommodate ships that have drafts of up to 35 feet (11 m), allowing them to harbor icebreakers and larger vessels, which enhances commerce and supports a wider range of vessels in the Arctic (Holthus et al. 2013). There is a widely noted paucity of deep-draft ports in the Arctic (US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities 2013). Many current transportation patterns rely on lightering—the transfer of supplies from one vessel to a shallower one—or the use of barges.

The nearest deep-water ports to the Bering Strait are in Provideniya and Pevek from Russian waters, and Unalaska from the US (Arctic Council 2009). Although Canada's only Arctic deep-draft port in Churchill recently closed (Bennett 2016a), discussions regarding construction of a deep-draft port in Tuktoyaktuk have continued (Northwest Territories Transportation 2015). In the US, the Army Corps of Engineers and the State of Alaska have recently begun efforts to identify and propose Arctic deep-draft ports in Alaska. The Army Corps of Engineers recommended Nome or Teller (Port Clarence) as the two most suitable sites for expansion into deep-water capacity (US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities 2013), and follow-up work has focused on Nome's current 22-foot (7-m) draft port (Joling 2015). Russia has a number of deep-draft ports along its Arctic coast, and continues to expand harbor facilities (US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities 2013).

Within Alaska, the Alaska Marine Highway System provides passenger service to the Alaska Peninsula and the eastern Aleutian Islands, terminating at Unalaska. The ferry transports passengers, vehicles, and some freight to Unalaska (Dutch Harbor), Akutan, False Pass, Cold Bay, King Cove, Sand Point, Chignik, Kodiak Island, and destinations further east. Typically, 500–600 passengers use the Alaska Marine Highway System to reach Dutch Harbor each year (Alaska Marine Highway System 2016a).

The Nome-Taylor highway, one of three major roads connecting communities on the Seward Peninsula, extends 85 miles (137 km) north from Nome.

Benjamin Sullender

MAP ON PAGES 274–275

MAP ON PAGES 274–275

AVIATION

Because marine access is dependent upon seasonal ice extent, aircraft play an important role in year-round transportation among coastal Arctic communities (see Map 7.2). Long distances, small populations, and high costs would make aircraft-based transportation uneconomical in many of these places, but government-sponsored programs help ensure regular aircraft access across Canada and the US. In particular, the Alaska Bypass program, introduced in the 1970s by Senator Ted Stevens, subsidizes the costs of transporting goods into remote Alaska communities. Under this program, items bypass central US Postal Service (USPS) processing and are directly delivered from shippers to airlines to recipients, with the USPS buying cargo room and paying for transportation at pre-determined rates (US Postal Service Office of Inspector General 2011). These stable rates encourage regular air service to rural areas for both cargo and passengers, although the USPS loses over $70 million per year on the program as a whole (Rein 2014).

OTHER INFRASTRUCTURE

The Quintillion Subsea Cable System plans to provide a high-speed internet link between Asia and Europe, with a fiber-optic cable laid along Alaska's coast and through the Northwest Passage. Phase One—an 1,183-mile (1,904 km) span from Nome to Prudhoe Bay—was constructed in 2016, and is anticipated to be in service in late 2017. As part of this project, a series of underwater vessels laid heavily armored cable along or underneath the seafloor (National Oceanic and Atmospheric Administration 2016c). Phase Two is currently being planned, and will extend from Prudhoe Bay east through the Northwest Passage.

CONSERVATION ISSUES

Energy

Current reliance on fossil fuels exposes the environment to risks of oil spills during transportation, lightering, storage, and consumption. Because coastal communities primarily have fuel delivered via ships, large vessels with a high volume of oil regularly transit nearshore areas. Since deep-draft tankers or cargo ships cannot access most Arctic ports, fuel must be transferred, or lightered, to smaller boats to make the final delivery to the community. The lightering process exposes additional risks of spillage as it undergoes an extra transfer step (Nuka Research and Planning Group 2016).

Once fuel has been transported to communities, further risks arise from storage. Tank farms, in particular, have been identified as a major issue by the Alaska Energy Authority. Most tank farms are decades old, and some are dilapidated, improperly installed, or insufficiently maintained, in addition to not being built according to national standards and regulations (Alaska Energy Authority 2017a). A 2015 assessment of bulk fuel tank farms in rural Alaska found that 16% of the tanks surveyed should be replaced and that 27% were directly threatened by flooding or erosion (Lockard 2016). Besides technical equipment failure, damage from storms or simple human error can result in spills. In the past 2 years, each of these 3 factors has caused notable spills of over 3,400 gallons (13,000 liters) each in small northern Canadian and Alaskan communities (CBC News 2015a, b; DeMarban 2017b; Pollon 2017).

Finally, burning of carbon-intensive fuels releases black carbon—commonly referred to as soot—which has major impacts on local, regional, and global scales. Black carbon reduces the albedo (reflectivity) of ice, snow, and clouds, absorbing incoming and outgoing radiation of all wavelengths. Primarily due to these changes in reflectance, black carbon is estimated to contribute more than 30% of current Arctic warming (Shindell and Faluvegi 2009) and, after carbon dioxide, has the strongest contribution to global climate change (Ramanathan and Carmichael 2008). Additionally, black carbon and associated airborne particulate matter and toxins pose significant human health risks to local communities, including higher rates of respiratory issues ranging from asthma to cardiopulmonary mortality (Janssen et al. 2012).

As diesel is displaced by renewable energy sources in Arctic communities, these alternatives can also have negative environmental impacts.

John Schoen

Due to the limited extent of Arctic road networks, aircraft-based transportation of people and supplies is a necessity for coastal communities along the Bering, Chukchi, and Beaufort Seas.

Wind turbines have impacts, in some cases fatal, on migratory birds, and may result in displacement (Furness et al. 2013), changes in flight paths (Masden et al. 2009), or even population-scale declines if improperly sited (Drewitt and Langston 2008). Dams constructed for hydroelectric power can serve as barriers to migratory fishes, again with potential population-level impacts (Cott et al. 2015).

Hydroelectric projects pose considerable threats beyond obstruction of movement or habitat loss, as larger-scale hydroelectric power generation alters water chemistry and poses significant risks to freshwater ecosystems and subsistence users. In addition to releasing significant quantities of greenhouse gases as organic carbon decomposes (St. Louis et al. 2000), recently flooded reservoirs may contain elevated concentrations of methylmercury (Schartup et al. 2015), a highly toxic compound with severe neurodevelopmental and cardiovascular effects on humans and wildlife (National Research Council 2000). After a dam is constructed, upstream water backs up and creates a reservoir. As soils containing organic carbon are flooded, microbes begin a process of accelerated methylation, converting both anthropogenic and naturally occurring inorganic mercury into bioavailable methylmercury (Hall et al. 2005). Methylmercury levels in a recently flooded reservoir increased by 25–200% (Schartup et al. 2015), with some sites predicted to experience as much as a ten-fold increase in mercury concentrations in freshwater biota (Calder et al. 2016). These mercury spikes can persist for 20–30 years at higher trophic levels (Hall et al. 2005), and would likely pose significant health risks for subsistence-based communities in the Arctic (Calder et al. 2016).

In James Bay, Canada, construction of a major dam complex created a series of reservoirs with elevated methylmercury levels—the average concentration of mercury in northern pike (*Esox lucius*) was more than four times greater than the Canadian commercial guidelines for fish (Girard and Dumont 1996). Members of the surrounding Cree communities rely on fish as a major part of their lifestyle, and individuals had mercury concentrations up to 49.9 mg/kg, over 8 times the World Health Organization's recommended mercury exposure level of 6 mg/kg, likely as a result of eating contaminated fish (Girard and Dumont 1996).

Roads

Arctic roads, especially those with regular vehicle traffic, generally displace wildlife such as caribou (*Rangifer tarandus*) (Vistnes and Nellemann 2007) and shorebirds (Troy 2000). For caribou, observations of roads and vehicles disturbing individuals and changing behavior patterns are common (Reimers and Colman 2006, Wilson et al. 2016). However, species-specific demographic factors and seasonal effects mediate population-level effects (Cronin et al. 1998). In areas underlain by permafrost, roads have significant geophysical effects including reduced above-ground plant biomass (Auerbach et al. 1997), earlier snowmelt (Walker and Everett 1987), deeper permafrost thawing (Auerbach et al. 1997), and the development of topographic features known as thermokarst (Raynolds et al. 2014). To mitigate some of these effects, gravel roads are typically a minimum of 5 feet (1.5 m) thick to provide adequate insulation for the underlying tundra (Bureau of Land Management 2014), and the gravel mines used to provide the source material have significant environmental impacts, particularly on streams (Kondolf 1994), and on localized drainage patterns (Bureau of Land Management 2014).

Although ice roads are generally considered temporary infrastructure, construction and natural degradation of ice roads alters hydrology, with consequences for fishes and migratory wildlife. The water demands of ice roads are significant—two-thirds of a mile (1 km) of road on tundra requires about 925,000 gallons (3.5 million L) of water (Nolan 2005). Once this water is moved, it may not return to its watershed of origin (Bureau of Land Management 2014).

Ports and Marine Transportation

The conservation implications of ports and marine transportation are covered in the Vessel Traffic summary.

Aviation

Aircraft can trigger behavioral responses from a wide range of terrestrial and marine wildlife, causing disturbance, displacement, or long-term habitat loss. Most common are startle-and-escape responses, observed in a variety of birds (Derksen et al. 1982, Mosbech and Boertmann 1999) and mammals (Calef et al. 1976). Beluga (*Delphinapterus leucas*) and bowhead whales (*Balaena mysticetus*) have been observed to dramatically alter movement patterns in response to fixed-wing aircraft and especially helicopters (Richardson et al. 1995, Patenaude et al. 2002). Pinnipeds, such as Pacific walrus (*Odobenus rosmarus divergens*) and ringed seals (*Phoca hispida*), also respond to aircraft overflights, showing heightened sensitivity when hauled out on ice or land (Born et al. 1999, Bureau of Ocean Energy Management 2015). Chronic aircraft activity may displace individuals from migration routes or preferred foraging, breeding, or wintering areas, although more research is needed before these effects can be adequately understood or modeled (Nowacek et al. 2007).

MAPPING METHODS (MAP 7.2)

Map 7.2 shows three main types of infrastructure: terrestrial, marine, and aviation. Terrestrial data include roads and power plants. Power plant data for the US were compiled from a series of surveys conducted, collected, and aggregated by the US Energy Information Administration (2016): Annual Electric Generator Report (EIA-860), Monthly Update to the Annual Electric Generator Report (EIA-860M), and Power Plant Operations Report (EIA-923). Smaller power plants, with no capacity reported, were georeferenced from a report by Melendez and Fay (2012). For Russia, only the locations of power plants were used from the Carbon Monitoring for Action (CARMA) database (Ummel 2012, Carbon Monitoring for Action 2016) due to issues with accuracy. Canadian power plants were manually digitized from Canadian Electricity Association (2016).

Marine data—ports, harbors, ferry terminals, and ferry routes—were downloaded from the Alaska Department of Transportation and Public Facilities (2016a, b) and georeferenced from Alaska Marine Highway System (2016b).

Aviation data were based on information from the US Department of Transportation: US airports (with passenger and cargo/mail volume by year) and Russian and Canadian airport locations (US Department of Transportation 2016a, b). The Quintillion Subsea Cable System was manually digitized from maps showing the project's extent (National Oceanic and Atmospheric Administration 2016c).

Data Quality

Based on comparisons with US Energy Information Administration data, the CARMA estimates for power plant capacity were vastly different from actual output for power plants in the US. Because of this, only the locations of power plants in Russia were used from the CARMA dataset.

Many datasets were not available in a spatial format and were instead manually digitized from existing maps. We attempted to ensure that the estimated locations were as close as possible to the original data, but the locations of Canadian power plants, the Alaska Marine Highway System route, and the Quintillion Cable System should still be considered approximate rather than exact.

Reviewer

- Lois Epstein

MAP DATA SOURCES

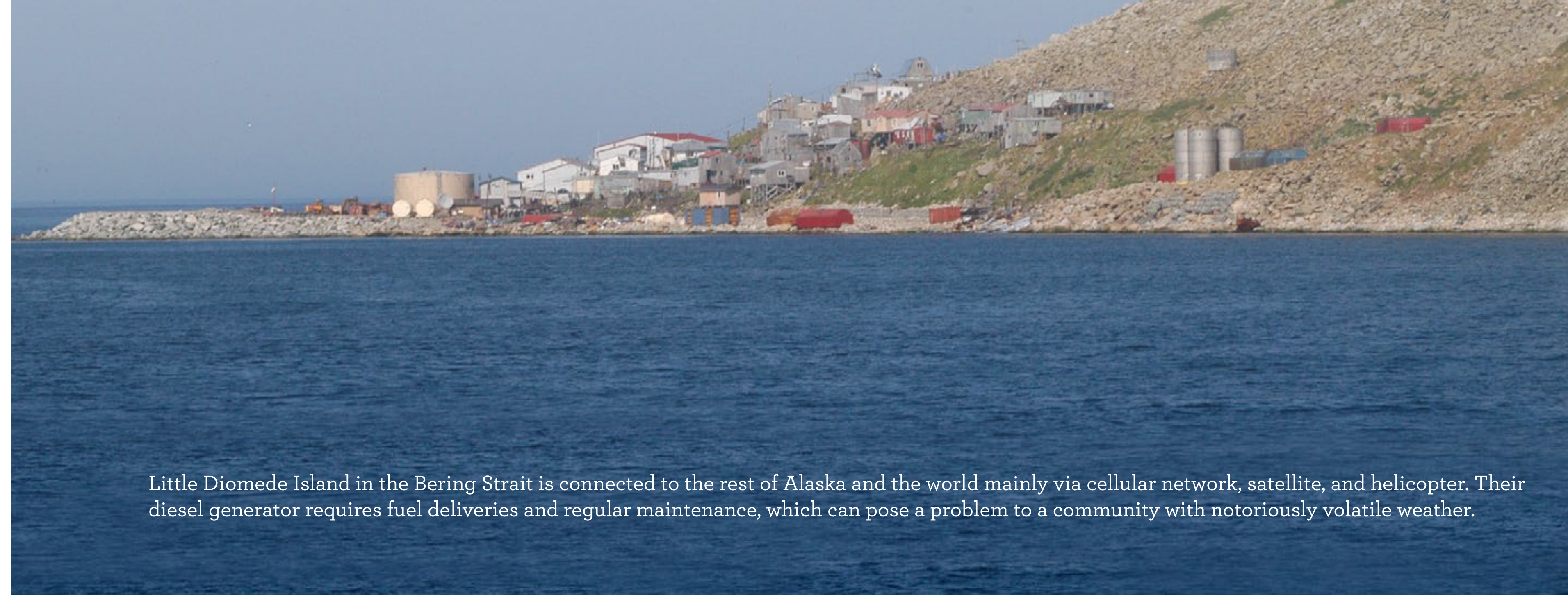
Power Plants: Canadian Electricity Association (2016); Carbon Monitoring for Action (2016); Melendez and Fay (2012); Ummel (2012); US Energy Information Administration (2016)

Airports: US Department of Transportation (2016a, b)

Ports, Harbors, and Ferry Terminals: Alaska Department of Transportation and Public Facilities (2016a, b)

Ferry Routes: Alaska Marine Highway System (2016b)

Quintillion Subsea Cable System: National Oceanic and Atmospheric Administration (2016c)



Little Diomede Island in the Bering Strait is connected to the rest of Alaska and the world mainly via cellular network, satellite, and helicopter. Their diesel generator requires fuel deliveries and regular maintenance, which can pose a problem to a community with notoriously volatile weather.

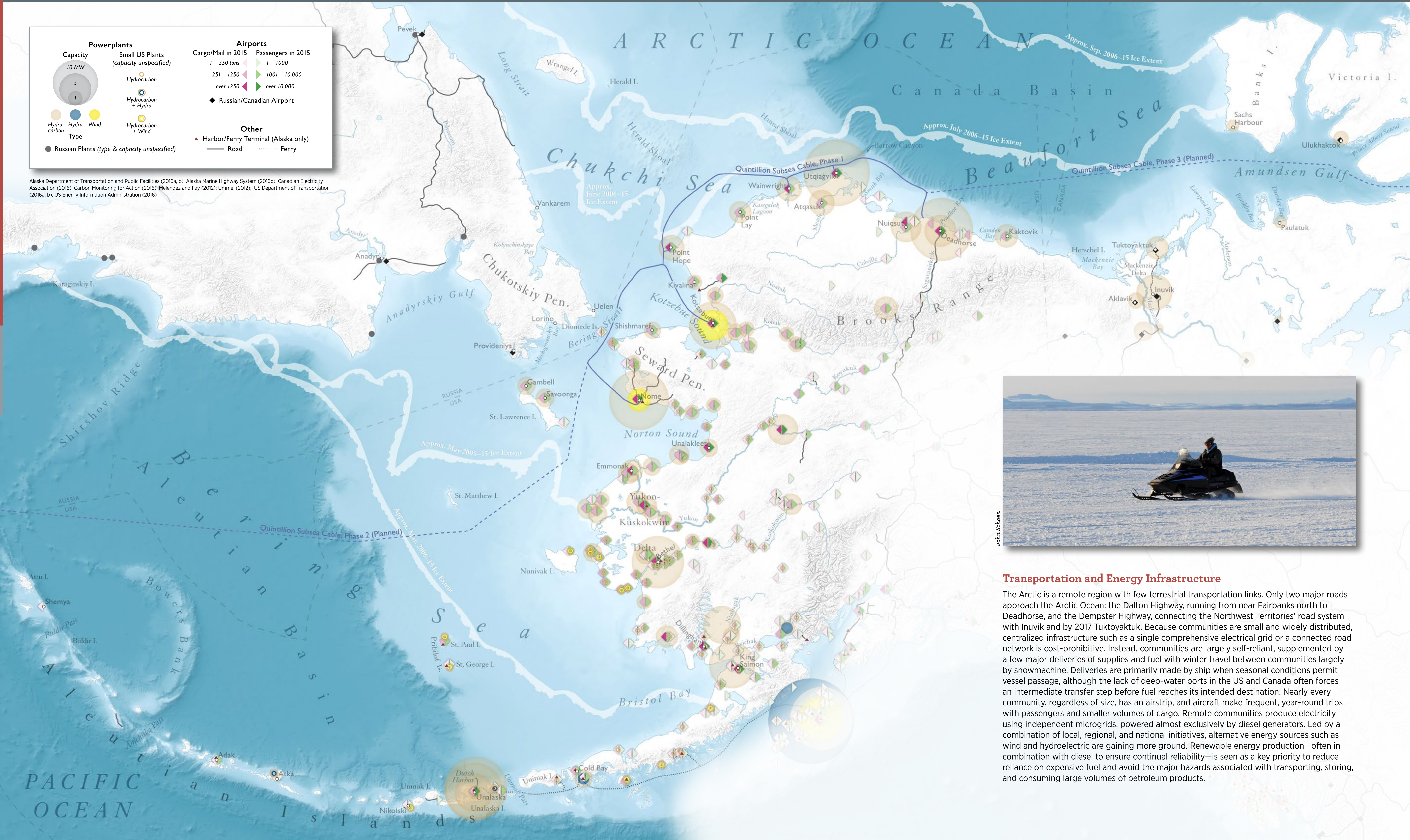
John Schoen

MAP ON PAGES 274–275

Transportation and Energy Infrastructure

Map Author: Benjamin Sullender
Cartographer: Daniel P. Huffman

Audubon ALASKA



Alaska Department of Transportation and Public Facilities (2016a, b); Alaska Marine Highway System (2016b); Canadian Electricity Association (2016); Carbon Monitoring for Action (2016); Melendez and Fay (2012); Ummel (2012); US Department of Transportation (2016a, b); US Energy Information Administration (2016)

John Schoen

Transportation and Energy Infrastructure

The Arctic is a remote region with few terrestrial transportation links. Only two major roads approach the Arctic Ocean: the Dalton Highway, running from near Fairbanks north to Deadhorse, and the Dempster Highway, connecting the Northwest Territories' road system with Inuvik and by 2017 Tuktoyaktuk. Because communities are small and widely distributed, centralized infrastructure such as a single comprehensive electrical grid or a connected road network is cost-prohibitive. Instead, communities are largely self-reliant, supplemented by a few major deliveries of supplies and fuel with winter travel between communities largely by snowmachine. Deliveries are primarily made by ship when seasonal conditions permit vessel passage, although the lack of deep-water ports in the US and Canada often forces an intermediate transfer step before fuel reaches its intended destination. Nearly every community, regardless of size, has an airstrip, and aircraft make frequent, year-round trips with passengers and smaller volumes of cargo. Remote communities produce electricity using independent microgrids, powered almost exclusively by diesel generators. Led by a combination of local, regional, and national initiatives, alternative energy sources such as wind and hydroelectric are gaining more ground. Renewable energy production—often in combination with diesel to ensure continual reliability—is seen as a key priority to reduce reliance on expensive fuel and avoid the major hazards associated with transporting, storing, and consuming large volumes of petroleum products.

MAP ON PAGES 282–283

Petroleum Exploration and Development

Skye Cooley, Erika Knight, Benjamin Sullender, and Max Goldman

Hydrocarbons, though abundant throughout the circumpolar Arctic (Gautier et al. 2009, Grantz et al. 2010) are not present everywhere. Large oil and gas accumulations form only where optimal geological conditions occur. Much time, energy, and money have been put toward discovering and developing petroleum resources both onshore and offshore of Alaska, and there is additional interest in offshore exploration in the Canadian Beaufort Sea and Russian Chukchi Sea. Ocean drilling is expensive, highly technical, controversial, and risky—a quintessential high-risk, high-reward pursuit.

Despite the expense and risk, the Arctic region is an enticing target for drilling. A 2011 US Geological Survey (USGS) estimate indicated that 30% of the world's undiscovered oil and 13% of the world's undiscovered gas may occur north of the Arctic Circle, with most of these resources occurring offshore on Arctic continental shelves (Gautier et al. 2009, Charpentier and Gautier 2011, Kolak 2011). Based on this assessment, the Chukchi and Beaufort Seas offshore of Alaska and the adjacent Beaufort-Mackenzie Basin offshore of Canada may be the most important areas for future petroleum supply in North America (Charpentier and Gautier 2011, Kolak 2011).

OIL DISCOVERY, EXPLORATION, AND DEVELOPMENT IN ALASKA

Oil was first discovered in Alaska in 1902 at Katalia, near Cordova. Arctic Alaska saw its first discovery by the US Navy in 1944, in what is now known as the National Petroleum Reserve—Alaska (NPRA). Industrial-scale production began with discoveries of oil at Swanson River (1957) and oil and gas in Cook Inlet (1959). The Swanson River field, a small field within the Kenai National Wildlife Refuge (then the Kenai National Moose Range), produced significant volumes of oil and is now in its final stage of production. The Cook Inlet Basin, located west of the Kenai Peninsula, consists of many oil and gas fields in Cook Inlet. Since 1959, Cook Inlet development has grown modestly with 16 offshore platforms as of 2013. Offshore operations in Cook Inlet currently yield some oil but mostly natural gas (Alaska Oil and Gas Conservation Commission 2004, Alaska Department of Natural Resources 2009, Alaska Oil and Gas Association 2015). Bristol Bay has a long history of oil exploration, as well. Many wells were drilled beginning early in the 20th century, and ending in the mid-1980s (Sherwood et al. 2006). The lack of any meaningful discoveries paired with the 2014 withdrawal of Bristol Bay from future drilling by President Obama has effectively removed the area from future oil and gas production consideration (Sherwood et al. 2006).

The 1968 discovery of oil on Alaska's North Slope at Prudhoe Bay was significant to Alaska's economy and set the stage for future petroleum development in the region, especially with the construction of the Trans-Alaska Pipeline System (TAPS), completed in 1977. The largest oil field in North America, Prudhoe Bay is an enormous onshore oil and gas field which has expanded into numerous satellite fields (Houseknecht and Bird 2006). Development of these smaller satellite fields, including nearby offshore development, has been economically feasible because much of the supporting infrastructure, such as TAPS, is already in place (Kolak 2011), and early engineering challenges posed by shorefast ice, deep seasonal cold, and permafrost have been largely overcome during Prudhoe Bay development.

The first offshore exploration wells (advanced either from a bottom-anchored drilling platform or from an artificial island depending on water depth) were drilled in the Beaufort Sea Outer Continental Shelf (OCS) in 1981, and oil discoveries soon followed in 1983–1986. Twenty exploration wells had been drilled by 1989 (Kolak 2011). Since then, hundreds of thousands of miles of seismic survey data have been acquired by industry in both the Chukchi and Beaufort Seas, and exploration wells have also been drilled on the Chukchi OCS. Geologic information gained from these surveys and wells will serve to refine estimates of

> "The Outer Continental Shelf is a vital national resource reserve held by the Federal Government for the public, which should be made available for expeditious and orderly development, subject to environmental safeguards, in a manner which is consistent with the maintenance of competition and other national needs…"
>
> ~ Outer Continental Shelf Lands Act (OCSLA)

petroleum potential. Production from the Beaufort OCS began in the early 2000s from the Northstar field, which spans the state-federal boundary, lying partially within the OCS, and is connected to shore by the North Slope's first under-sea pipeline. Preparations are underway to begin production at the Liberty OCS field (Kolak 2011).

Exploration and development activity in state waters along the coast of Alaska, especially in areas where sea ice is absent for at least 90 days of the year, also continues, including development of 4 gravel-island based oil fields (see *A Closer Look:* Artificial Islands). In 2016, a discovery in the state waters of Smith Bay, offshore from the NPRA, was reported by Caelus Energy to have 6–10 billion barrels of oil. Development of this possible field has been delayed indefinitely by Caelus Energy as of 2017 (Caelus Energy 2017).

Along with advancements in offshore platform design, pipeline engineering, supply routing, and ice management protocols, investments made in projects such as Hibernia (Newfoundland), Molikpaq-Sakhalin (Russia), and Snohvit (Norway) have bolstered the confidence of investors and regulators that safe, profitable operations are possible in the offshore Arctic. Future increases in industry activity in US Arctic waters are likely, especially if the open water season continues to lengthen and the 10-year barrel price forecast returns to $80 or more.

EXPLORATION METHODS

The goal of petroleum exploration is to define the petroleum system in three dimensions over time, including the stratigraphy and migration history of potential oil plays (oil fields or prospects in the same region defined by the same set of geological circumstances). Controlled-source, deep-penetration reflection seismology, similar to sonar and echolocation, is the primary tool used in both onshore and offshore exploration, supplemented with data collected through other methods such as direct sampling via drilling test wells.

Seismology

Seismic exploration theory is this: If you control the waveform of the sound energy produced (air guns) and you know the waveform of the returned signal (geophones), then the subsurface geology can be digitally constructed in three dimensions with precision via seismic images. Both the USGS and major oil companies have conducted numerous marine seismic surveys in the Beaufort and Chukchi OCS, along tracks totaling many hundreds of thousands of miles (Kolak 2011). The primary method to collect seismic data at sea is by long arrays of sensors (geophones affixed to wires) towed at approximately 10 knots behind 230–400 foot (70–120 m) vessels following a predetermined, grid-like route over prospective areas of the seafloor. High-power air canons are fired below the surface at set time intervals, usually 15 seconds. The sound waves propagate through the water and into the seafloor to a depth of approximately 6 miles (10 km). The waves bounce back when they encounter strong impedance contrasts, such as faults, contacts between rock layers, or erosional surfaces. The reflected signal is sensed by the geophone array and recorded on board the ship to be processed and interpreted by geologists. Seismic images provide a detailed picture into both the layer stratigraphy, tectonic history, and phase of trapped hydrocarbons (liquid oil, natural gas, natural gas liquids). Drilling nearly always targets stacked sets of permeable sandstone layers with distinctive seismic signatures consistent with the presence of hydrocarbons. Petroleum-bearing sedimentary units are most often the deposits of ancient beaches, river channels, deltas, and fans (permeable sandstones with some shale), but reservoirs in limestone and fractured basement rocks are not uncommon.

Other Offshore Data

Non-seismic information, where available, enhances the seismic imagery. Non-seismic datasets include seafloor drill cores, airborne geophysical surveys (gravity, aeromagnetics), well logs, oil and gas seep locations, tephra chronologies (aging rocks using volcanic ash layers), biostratigraphy (aging rocks using fossils), and geological projections based on known geology in nearby areas, among others. Well logs from Popcorn, Crackerjack, Klondike, Diamond, Burger, and other test wells are an important part of the non-seismic US Arctic offshore record. Geophysical logs collected from onshore wells near the coast in both Alaska and the Russian Chukotka Peninsula are relatively plentiful but distant from offshore lease blocks (Verzhbitsky et al. 2012). Highly detailed bedrock geologic maps of onshore areas in the US and Russia provide geologic sideboards for constructing trends across the ocean basin (Miller et al. 2002, Malyshev et al. 2011). Reconnaissance-level aeromagnetic surveys have been flown over the entire Arctic. Aeromagnetic mapping produces coarse-resolution images of the magnetic properties of the seafloor at the regional scale, also useful in connecting major structural trends (large faults, edges of tectonic plates) across ocean basins. Once drill sites are approved, high resolution seismic profiles, side-scanning sonar, and topographic mapping of the seafloor are completed prior to drilling.

GEOLOGY

Making a hydrocarbon discovery of a size sufficient to justify the massive costs of developing and operating in the offshore Arctic is an enormous challenge. Hydrocarbon presence depends on several geologic factors:

- sufficient sediment thickness for hydrocarbon formation (more than 2-mile [3-km] burial) during geologic history;
- appropriate age of the sediments (not too young or too old);
- presence of source rocks, usually marine shales (may now be distant or absent);
- presence of reservoir rocks (porous or fractured rock which acts as a resevoir for oil and gas);
- presence of a trap (rock strata conditions that block upward movement of oil or gas, resulting in accumulation);
- suitable geothermal history (an "oil window", or range of temperatures at which oil forms from kerogen);
- appropriate vitrinite reflectance values (a thermal maturity index for hydrocarbons); and
- regional tectonic history conducive to oil accumulation (formation, maturation, migration, retention) (Kolak 2011).

Available geologic data must be evaluated within a broad geologic context, taking into account the timing of source-rock maturation, generation of oil or gas, and migration and accumulation of oil or gas within a geologic trap. The actual existence of appropriate conditions is unknown until an exploration well is drilled (Kolak 2011).

In the circumpolar Arctic, above the Arctic Circle, four major provinces (hydrocarbon assessment units) constitute the hydrocarbon resource picture: West Siberia-South Kara Province (Russia), Barents Sea East Province (Norway), Timan-Pechora Province (Russia), and Arctic Alaska Province (Spencer et al. 2011).

Alaska's North Slope lies within the Arctic Alaska Province and is a "classic petroleum system"—that is, one with geology that is consistent

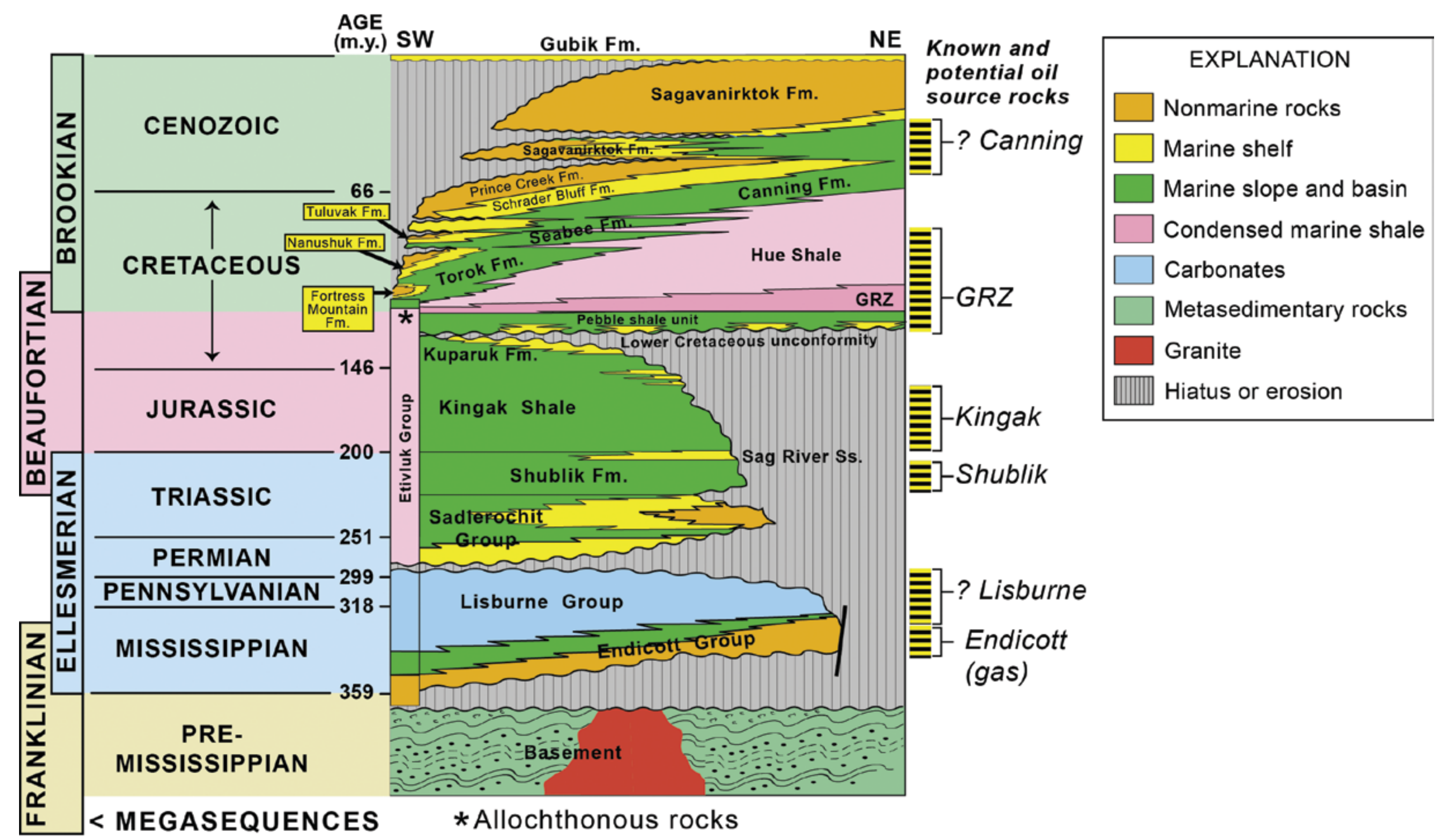


FIGURE 7.3-1. Generalized stratigraphic column for the Arctic Alaska Petroleum Province, emphasizing petroleum-prospective rocks (Houseknecht and Bird 2006).

MAP ON PAGES 282–283

MAP ON PAGES 282–283

with other large, mature petroleum basins of the world. Prudhoe Bay, one small part of the Province, is North America's largest oil pool (approximately 25 billion barrels). It ranks amongst the world's top 20 largest, but its geology is not unique. Production wells on the North Slope tap marginal marine sediments that drape across a jagged, rifted continental margin of Jurassic–Early Cretaceous age (Figure 7.3-1 shows potential petroleum source rocks in the North Slope region). Rift-margin sediment wedges with similar source rocks, stacking patterns, and burial histories are common worldwide (Charpentier et al. 2008).

The geology becomes less understood with distance offshore. Oil-and-gas potential is directly dependent on local variations in geologic structure (folds, faults) and local geologic history (e.g., sedimentation, heating, leakage). Therefore, offshore reservoir characteristics may contrast significantly with the more familiar onshore reservoirs.

LIMITATIONS TO FUTURE OFFSHORE DEVELOPMENT

The Arctic Alaska region, excluding Prudhoe Bay, is not a mature petroleum province in terms of geological understanding (or infrastructure). Offshore areas firmly remain on the frontier. Resource estimates are subject to a great deal of uncertainty and are routinely revised to reflect increases in geological knowledge (Kolak 2011). The limits to future offshore development in this remote region are clearly recognized and include sea ice, water depth, regulatory structure, barrel price forecast, and port infrastructure.

Sea-Ice Limitations

Operating in areas where open water conditions persist for less than 90 days of the year are considered theoretically workable. Gravity-based rig structures (GBS) are proven solutions for drilling in depths shallower than 330 feet (100 m), while ship-based drilling and sub-sea tie-back configurations are proven for greater depths.

The technological frontier exists in waters where ice-free conditions persist for less than 60 days, and water depths reach deeper than 330 feet (100 m). Research breakthroughs are needed for engineered structures in waters with a year-round ice cover. Spill-containment systems for these remote, ice-covered waters remain in the research stages.

Water Depth Limitations

Water depth alone is not a controlling factor on ocean drilling. Bottom-resting (jack-up type) drilling platforms are routinely used in shallow, nearshore areas and lagoons of the Canadian Beaufort Sea coast, where water depths are less than 330 feet (100 m). In the Gulf of Mexico, offshore drilling is taking place in waters deeper than 3 miles (5 km). Deep-water platforms are mature technologies in sub-Arctic oil basins around the world, but remain unproven in the US Arctic, although Norway and Canada have operated Arctic platforms for years. The structural upgrades required to operate in Arctic waters are not generally viewed as limitations, but the increased up-front costs of customized equipment may be a limitation in certain barrel-price environments.

Department of Defense photo by Petty Officer 2nd Class Zachary Painter / USCG / Released

The tugs *Corbin Foss, Ocean Wave*, and *Lauren Foss* begin the tow of the recently grounded Royal Dutch Shell conical drilling unit *Kulluk* from Kiliuda Bay near Kodiak Island, Alaska, February 26, 2013. The tugs *Guardsman, Warrior, Nanuq,* and tow supply vessel *Aiviq* were on scene to assist. A safety zone was established around the *Kulluk*, and a US Coast Guard MH-60T Jayhawk helicopter crew assigned to Air Station Kodiak overflew the area for security.

7.3 PETROLEUM EXPLORATION AND DEVELOPMENT

MAP ON PAGES 282–283

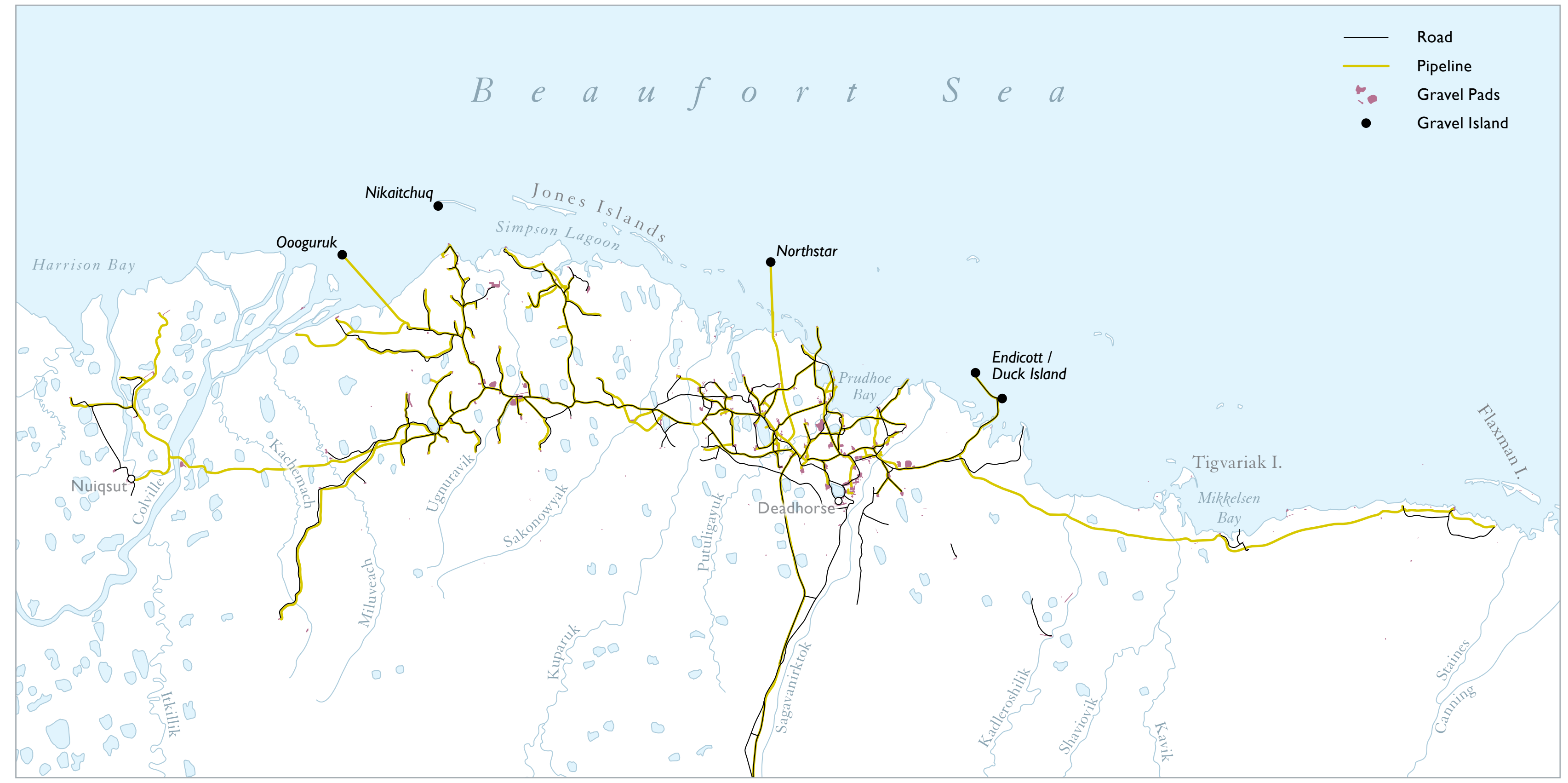


FIGURE 7.3-2. Oil and gas infrastructure (roads, pipelines, gravel pads, and gravel islands) on the North Slope of Alaska.

Regulatory Limitations

In the US, there are 27 separate agencies involved in the planning and permitting process for the US OCS. Permitting involves six steps: stakeholder engagement, leasing, seismic acquisition, site selection, exploration drilling, and development/production planning (National Petroleum Council 2015). The US Department of Interior has primary influence over US domestic oil-and-gas policy, but the multinational Arctic Council lends input, along with several other working groups and coordination bodies. The permitting process for oil and gas projects on Alaska state lands and waters within 3 miles (5 km) of the coast are managed by the State of Alaska (Alaska Department of Natural Resources 2017), and US federal offshore leasing beyond state waters is managed by the Bureau of Ocean Energy Management (BOEM).

Solutions to regulatory hurdles have been proposed by the National Petroleum Council (NPC), an independent commission whose stated purpose is to "advise, inform, and make recommendations to the Secretary of Energy on any matter requested by the Secretary relating to oil and natural gas or to the oil and gas industries" (National Petroleum Council 2015). In their March 2015 report, *Arctic Potential: Realizing the Promise of US Oil and Gas Resources* (National Petroleum Council 2015), the NPC identifies what many believe to be the primary weakness in the way Arctic oil and gas permits are currently administered: the Arctic is not the Lower 48 and permitting here should reflect real-world challenges specific to the Arctic. Among others, their 2015 recommendations regarding oil and gas regulation include using the Arctic Executive Steering Committee (established via a January 2015 Executive Order) to coordinate and assess alignment across federal agencies involved in oil and gas regulation as well as clarifying how the federal government will collaborate with the State of Alaska and Alaska Native tribal governments (National Petroleum Council 2015).

Barrel Price and Investment Limitations

Petroleum is a global industry governed by global economic forces: supply, demand, international politics, and investor confidence. The reasons why major oil companies choose to explore and develop offshore oil leases are many, but two factors outweigh all others: short-term barrel price and long-term price forecasts. Price drives investment. Investment capital puts people and equipment in the field. Price is such a dominant factor that when it dips below a certain threshold, development of the reservoir simply stops: production activity is cut back, employees are laid off, and rigs shut down. Conversely, inflated price environments cause field boundaries to expand to encompass marginal areas previously considered uneconomic.

Other factors that influence decisions to invest in offshore projects include shareholder concerns, military events, major accidents, lease sales, technical limitations, regulatory delays, shifts in corporate tax rates, public sentiment, and legal pushback from the environmental community. Oil companies, like multinational shipping and mining companies, operate on very long timelines, spanning decades. These companies are financially stable and influential.

The forecast price of crude oil is a reasonable predictor for future investment and development activity in the offshore Arctic. Capital investment drives development. Long-term and short-term forecasts are regularly published by the World Bank in their Commodity Markets Outlook (World Bank 2017) and in the US Energy Information Administration's Short-term Energy Outlook (US Energy Information Administration 2017b). Other sources of historical price information are available from various outlets, including Organization of the Petroleum Exporting Countries (OPEC) Oil Market Reports available on the OPEC website (Organization of the Petroleum Exporting Countries 2017). Price stability around $80 per barrel (in 2016 dollars) is a strong positive signal for companies considering entry/re-entry of Arctic leases. Currently, there exists high uncertainty in the price outlook. This, coupled with a broad expectation that threshold barrel prices (around $80/barrel) will not return any earlier than 2020, is currently suppressing investor interest in offshore Arctic projects.

Port and Infrastructure Limitations

The Arctic Ocean is remote and harsh. Long transport distances exist between offshore fields and industrial ports. Long distances multiply supply chain transportation costs and introduce delays. Currently, no deep-draft ports capable of servicing offshore production exist along the western coast (Chukchi Sea) and northern coast (Beaufort Sea) of Alaska.

Likewise, no suitable ports are present on the Russian Chukotka Peninsula. Connections between seaports and overland transportation networks are a significant limitation to offshore oil development going forward. In general, major overland routes (rail, road), common in the Lower 48 states of the US and southern Canada, are rare in Alaska and the Russian Far East. Basic marine navigational infrastructure in ice-free corridors of the

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Chukchi-Beaufort Seas region is another deficiency. Figure 7.3-2 shows existing oil and gas infrastructure on Alaska's North Slope.

A recent study by the US Army Corps of Engineers (US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities 2013) identified four candidate locations for future development of deep-draft port facilities and associated infrastructure. Nome and Port Clarence were the top two choices, with Cape Darby and Barrow also short-listed. Construction of one or more Arctic ports large enough to accommodate offshore production that would serve as a transportation hub, a repair and resupply center, and house industrial-scale safety vessels is at least a decade away, and ecological and cultural impacts have not been fully investigated. See the Transportation and Energy Infrastructure and Vessel Traffic summaries for further discussion of these issues.

CONSERVATION ISSUES

Arctic hydrocarbon development impacts vary in intensity, certainty, and duration based on the stage of development. After an area has been leased for oil-and-gas production, there are four main stages of activities, per Hillmer-Pegram (2014): exploration, development, production and transportation, and decommissioning and abandonment.

During exploration, seismic surveying and drilling provide data about underlying geology. Seismic surveying generates primarily noise- and emission-based impacts in marine ecosystems (Bureau of Ocean Energy Management 2012), and, when conducted on land, seismic surveys and associated vehicle tracks have previously severely disturbed vegetation over long time horizons (Felix and Raynolds 1989, Jorgenson et al. 2010). In the marine environment, the sound impulses have been linked to acute behavioral disturbance of wildlife, masking cetacean communication, and potential auditory damage, all of which may aggregate into cumulative and chronic effects (Nowacek et al. 2015, National Marine Fisheries Service 2016b). Test drilling involves fewer direct impacts than seismic exploration, but carries risks with broader consequences (principally, oil spills).

If the results of exploration are successful, development may occur. There are a variety of development methods, from building offshore gravel islands (see *A Closer Look:* Artificial Islands) to positioning a deep-water platform to constructing a network of gravel-pad-based operational facilities. Each of these methods involves the transport of people, equipment, and materials, and associated increases in vehicle, aircraft, and/or vessel traffic would expose wildlife to visual and auditory disturbances (Hillmer-Pegram 2014). Permanent infrastructure, such as gravel pads, pipelines, or roads, could alter wildlife movement patterns, change surface and subsurface thermal regimes, block or impede hydrological patterns, and directly alter habitat (Walker et al. 1987, National Research Council 2003). Temporary infrastructure such as ice roads or staging camps can also have seasonal impacts or, if improperly managed, may leave lasting impacts by eliminating fish overwintering habitat or permanently altering water flow patterns (Williams et al. 2013, Heim et al. 2015).

After a site has been developed, oil and gas are brought to market during the production and transportation phase. Subsurface fluids are extracted, processed, and either disposed of or transferred to a pipeline or holding tank en route to market (Hillmer-Pegram 2014). Each of these processes exposes the environment to the risk of hydrocarbon spills, which have serious consequences in the marine environment (National Research Council 2014). About 22,000 gallons (83,300 L) of crude oil and 11,000 gallons (42,000 L) of other petroleum products are spilled annually (National Research Council 2003), and the largest recorded spill on the North Slope to date, stemming from a single hole in a pipeline, released over 250,000 gallons (950,000 L) of crude oil (Barringer 2006). Although unplanned hydrocarbon releases (spills) in the US Arctic marine environment have generally been small, with the exception of the *Exxon Valdez* tanker spill, offshore drilling operations and sub-sea pipelines expose the marine ecosystem to these very tangible risks.

Oil is both acutely and chronically toxic to a wide range of organisms, even at small doses (National Research Council 2014), and species whose behavior increases their exposure to oil (e.g. seals, which are frequently active on or near the water surface) or that rely on physical properties for insulation (e.g. marine-foraging birds and polar bears (*Ursus maritimus*)) are particularly at risk from oil spills. In the Bering, Chukchi, and Beaufort Seas, natural oceanographic factors further complicate oil spills: sea ice, wind, and currents may retard natural weathering processes, impair clean-up efforts, and disperse oil (National Oceanic and Atmospheric Administration 2002). Despite these consequences, oil response capabilities and infrastructure are severely lacking in the US Arctic (Arctic Council 2009, National Research Council 2014). Given the likelihood of an oil spill and the severe ecological consequences, emergency preparedness and management action to mitigate impacts are of paramount importance in the region (Huntington et al. 2015). Additional conservation issues around oil spills in the marine environment are covered in the Vessel Traffic summary.

The production drilling process produces large volumes of waste liquids, including water saturated with toxic metals and organic pollutants, tank-bottom sludge, waste muds, and hazardous waste that must be transported outside of Alaska to appropriate disposal facilities. As of 2003, over 1.5 billion barrels of hazardous waste had been re-injected into subsurface formations in the North Slope (National Research Council 2003). Large-scale hydraulic fracturing (fracking) has not yet been implemented on the North Slope, but about 25% of existing wells have used fracking in some form to stimulate production (Forgey 2012) and oil-and-gas companies are currently considering several on-shore prospects that would rely primarily on fracking to produce marketable quantities of oil (DeMarban 2017a, Nussbaum 2017).

Finally, after production has ceased, facilities are then decommissioned and abandoned. Very few sites have been abandoned so far, due to the relatively recent start of oil production on the North Slope. Rehabilitation efforts and removal of infrastructure will be expensive (National Research Council 2003) and require very long time horizons (centuries or even millennia) before complete ecological recovery (Raynolds et al. 2014, Becker and Pollard 2015).

MAPPING METHODS (MAP 7.3)

Map 7.3 shows likely target areas for future offshore petroleum exploration and development (sedimentary basins), as well as offshore areas where exploration, leasing, and development have already occurred. Data are based on a synthesis of literature on the geology and petroleum potential of the region.

The offshore sedimentary basin data are mapped based on published figures and maps showing acoustic basement depth, highlighting sediments located 2–4 miles (3–6 km) below the seafloor, a region with the highest likelihood of maturation inside the oil window. Data are displayed with shaded contours to give a general impression of basin shape. This information was compiled from Drachev et al. (2010), Grantz et al. (2010), Grantz et al. (2011), Miller et al. (2002), and Worrall (1991).

In Alaska, OCS leasing information includes BOEM program areas and Presidential Withdrawals, as well as active and historical leases. The mapped program areas and Presidential Withdrawals are published in BOEM's 2017–2022 OCS Oil and Gas Leasing Proposed Final Program (Bureau of Ocean Energy Management 2016a); GIS data were downloaded from Bureau of Ocean Energy Management (2016b) and are current as of early April 2017. Since the withdrawl publication, President Trump issued an Executive Order that, among other actions, retracted the Chukchi and Beaufort Sea withdrawals. The President's authority to undo these withdrawals has been challenged in court, therefore these areas were left on the map and labeled as contested. Active and historical lease data for Alaska were downloaded from Bureau of Ocean Energy Management (2016b) and are current as of May 2017.

Leasing data for Canada were available from Indigenous and Northern Affairs Canada (2016), while leasing data for Russia were from Rosneft (2016).

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Well data, shown for both exploration and production wells, were available for Alaska and Canada from Alaska Oil and Gas Conservation Commission (2016) and National Energy Board (2014), respectively.

Potential deep-water ports are shown based on the top two candidate locations identified in a US Army Corps of Engineers Deep-Draft Arctic Port Study (US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities 2013).

Data Quality

Our current understanding of the region's offshore geology and its petroleum system remains surprisingly broad-brush and decidedly incomplete. First-order conceptual models concerning tectonic effects on hydrocarbon generation and migration are still being tested. While abundant source rocks occur throughout the circumpolar Arctic in rock formations young and old (Proterozoic to Paleogene age), uncertainty remains as to where the resource has been trapped by the folds, faults, and unconformities visible in seismic images (Spencer et al. 2011).

Seismic imagery, gravity data, limited shallow scientific well logs, and five industry well logs are the primary sources of subsurface geologic knowledge for offshore areas of the Chukchi and Beaufort Seas region. Two-dimensional and three-dimensional seismic data acquired by vessel-towed arrays are by far the most important. There is, however, no single seismic coverage for the map area. Likewise, there is no single sensor used to acquire seismic data, nor to process the raw signal into depth-converted, interpretable images. Dozens of companies have collected, processed, and interpreted their own data for use on specific, local projects without regard for non-industry users. Publications that result from these interpretations do not often conform to mapping standards. Basin boundaries and sediment thickness isopachs depicted here were compiled from publicly available sources, and sediment thickness contours on published maps routinely differed. The data are displayed using unlabeled, shaded contours to give a general impression of basin shape.

The leasing and well data are most complete for Alaska and Canada. These data are most detailed for Alaska, the portion of the project area where the majority of petroleum exploration and production has taken place to date. Little to no petroleum production has yet occurred in the Canadian and Russian portions of the project area. Leasing and well data in the Russian portion of the Bering Sea were unavailable.

Reviewers

- Curtis Bennett
- Michael Short

MAP DATA SOURCES

Sedimentary Basins: Drachev et al. (2010); Grantz et al. (2010, 2011); Miller et al. (2002); Worrall (1991)

BOEM Program Areas and Presidential Withdrawals: Bureau of Ocean Energy Management (2016a, b)

Leases: Alaska – Bureau of Ocean Energy Management (2016b)
Canada – Indigenous and Northern Affairs Canada (2016)
Russia – Rosneft (2016)

Wells: Alaska – Alaska Oil and Gas Conservation Commission (2016)
Canada – National Energy Board (2014)

Potential Deepwater Ports: US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities (2013)

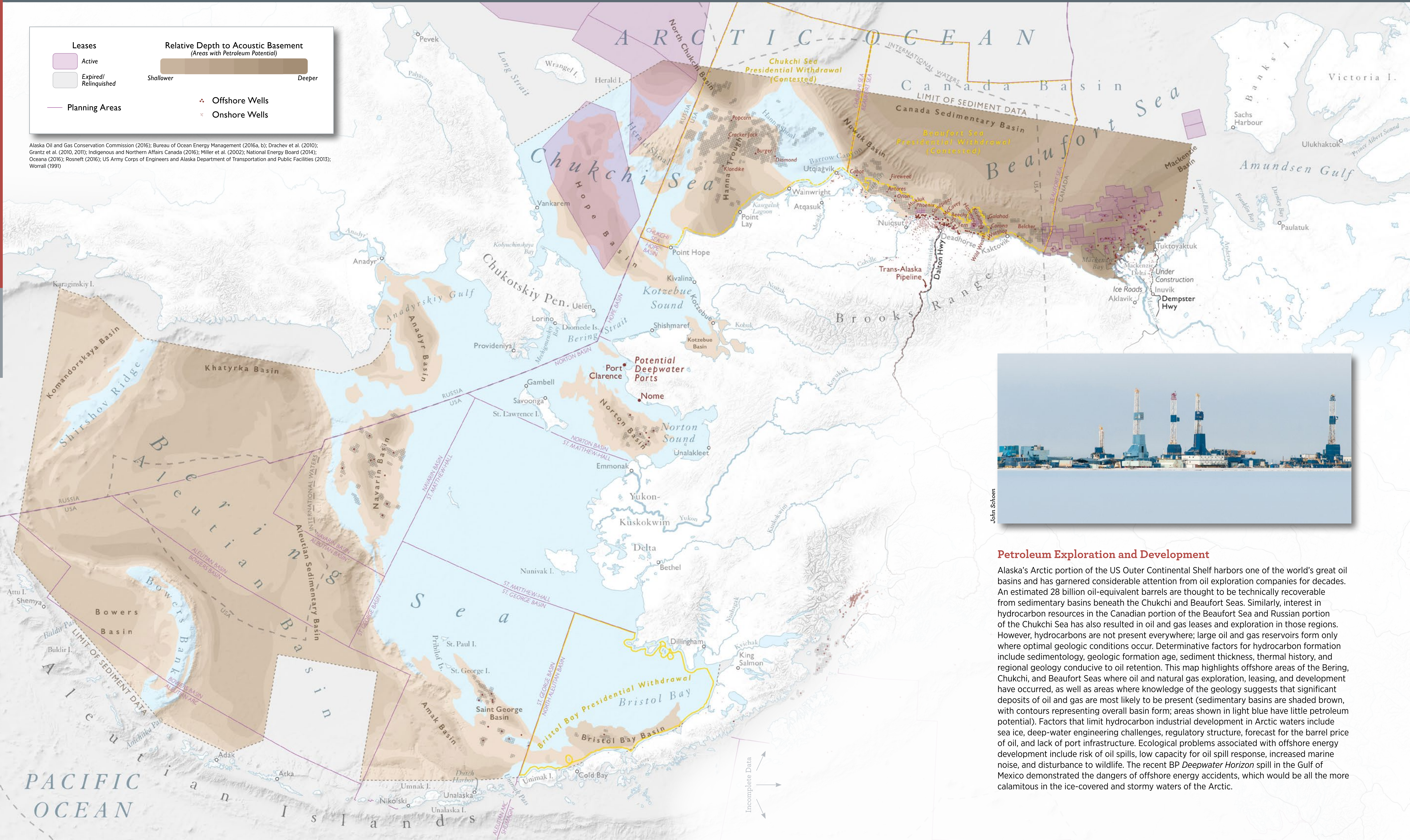
Oil Infrastructure on the North Slope, Alaska.

John Schoen

Petroleum Exploration and Development

Map Authors: Skye Cooley and Erika Knight
Cartographer: Daniel P. Huffman

Audubon ALASKA



Alaska Oil and Gas Conservation Commission (2016); Bureau of Ocean Energy Management (2016a, b); Drachev et al. (2010); Grantz et al. (2010, 2011); Indigenous and Northern Affairs Canada (2016); Miller et al. (2002); National Energy Board (2014); Oceana (2016); Rosneft (2016); US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities (2013); Worrall (1991)

John Schoen

Petroleum Exploration and Development

Alaska's Arctic portion of the US Outer Continental Shelf harbors one of the world's great oil basins and has garnered considerable attention from oil exploration companies for decades. An estimated 28 billion oil-equivalent barrels are thought to be technically recoverable from sedimentary basins beneath the Chukchi and Beaufort Seas. Similarly, interest in hydrocarbon resources in the Canadian portion of the Beaufort Sea and Russian portion of the Chukchi Sea has also resulted in oil and gas leases and exploration in those regions. However, hydrocarbons are not present everywhere; large oil and gas reservoirs form only where optimal geologic conditions occur. Determinative factors for hydrocarbon formation include sedimentology, geologic formation age, sediment thickness, thermal history, and regional geology conducive to oil retention. This map highlights offshore areas of the Bering, Chukchi, and Beaufort Seas where oil and natural gas exploration, leasing, and development have occurred, as well as areas where knowledge of the geology suggests that significant deposits of oil and gas are most likely to be present (sedimentary basins are shaded brown, with contours representing overall basin form; areas shown in light blue have little petroleum potential). Factors that limit hydrocarbon industrial development in Arctic waters include sea ice, deep-water engineering challenges, regulatory structure, forecast for the barrel price of oil, and lack of port infrastructure. Ecological problems associated with offshore energy development include risk of oil spills, low capacity for oil spill response, increased marine noise, and disturbance to wildlife. The recent BP *Deepwater Horizon* spill in the Gulf of Mexico demonstrated the dangers of offshore energy accidents, which would be all the more calamitous in the ice-covered and stormy waters of the Arctic.

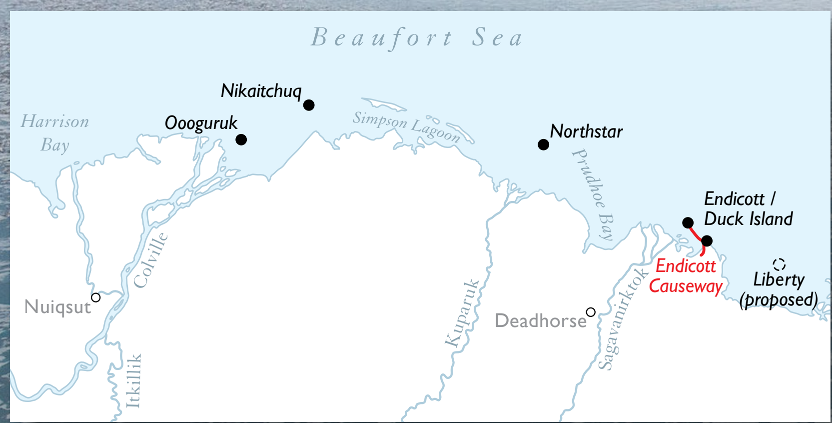
A Closer Look: Artificial Islands

Benjamin Sullender

An aerial view of Endicott's main production island.

Design Pics Inc/ Alamy Stock Photo

FIGURE 7.4-1



Artificial islands have been used to develop offshore oil fields in Arctic Alaska, and are more economically viable than platform-based drilling in shallow water (Robertson et al. 1989). Typically, an ice road is constructed in the winter months and a series of truckloads transport gravel to the drilling site, pouring the gravel through holes in the sea ice to build a foundation. After this gravel base is complete, a variety of technologies such as sheet metal walls and sloped concrete blocks are used to protect the island from ice floes and storms (Hall 2008, Hilcorp Alaska 2016). Gravel islands typically rely on connecting pipelines, tie-in pads, and offsite processing facilities to bring oil online, and face logistical challenges regarding year-round transportation of personnel and supplies (Lidji 2010).

There are four gravel island-based oil fields currently producing in Alaska, and a fifth is in the permitting process (see Table 7-1). Endicott, also known as Duck Island, began production in 1989, making it the first continuously producing offshore oil project on the North Slope. Endicott's production islands are connected to the mainland via a gravel causeway spanning over 4 miles (6 km). Northstar, operating across a combination of state and federal leases, was constructed in 1999 and began producing oil in late 2001. Oooguruk began production in 2008 under ownership from Pioneer Natural Resources Inc., which sold its Alaskan assets to Caelus Energy LLC in 2014 (Lidji 2014). Eni Petroleum, a minority partner in Oooguruk, is the sole owner and operator of the Nikaitchuq field, which saw first production in 2011. Currently, wells have been drilled both from onshore at Oliktok Point and offshore at Spy Island, although Eni is proposing to expand into adjacent federal water leases co-owned by Royal Dutch Shell and Repsol SA (Dlouhy 2017). Hilcorp, which purchased BP Exploration (Alaska) Inc's (BPXA's) stakes in Endicott and Northstar, is currently entering permitting operations for wells on the Liberty oil field (Hobson 2017). Current plans for Liberty call for the construction of a 31-acre (12.5-ha) gravel island on federal waters (Hilcorp Alaska 2016).

Due to the technical difficulty of developing offshore oilfields and the economic uncertainty surrounding the oil market, offshore oil development has been marked by stalled or entirely cancelled plans and changes in ownership of leases and infrastructure. More tangibly, operations at Endicott have been marred by illegal waste dumping. From 1993 to 1995, contractors with Doyon Drilling Inc. re-injected hazardous wastes into wells. BPXA learned about and failed to report the illegal disposal. Subsequent investigations resulted in BPXA pleading guilty to felony charges and being forced to pay over $22 million in penalties (Environmental Protection Agency 1999).

Although construction of gravel islands, and especially causeways, threatens habitat connectivity and creates barriers to fish movement (Fechhelm 1999), studies of several fish species found that the mitigation measures (breach passageways, for example) implemented for the Endicott Causeway were effective in enabling fish passage (Griffiths et al. 1998, Fechhelm et al. 1999). The extraction of the gravel used to raise the island from the seafloor can be a major environmental impact, especially if gravel is mined from in-stream sources or threatens deep-water refugia for overwintering fish. Underwater noise from the construction, drilling, and production phases may interfere with marine mammals, including migratory bowhead (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*) (Hilcorp Alaska 2015).

TABLE 7.4-1. Current and proposed gravel island production facilities (see Figure 7.4-1).

Oil Field Name	Island Name(s)	Majority Developer	Majority Operator	Lease Type	First Production	Total Area, ac (ha)	Water Depth, ft (m)	Distance to Shore, mi (km)
Oooguruk	Oooguruk	Pioneer	Caelus	State	2008	6 (2.4)	5 (1.5)	5.9 (9.5)
Nikaitchuq	Spy	Eni	Eni	State	2011	11 (4.5)	10 (3)	3.8 (6.1)
Northstar	Seal	BPXA	Hilcorp	State / Federal	2001	6 (2.4)	10 (3)	5.8 (9.3)
Endicott/Duck Island	Endeavor; Endicott MPI	BPXA	Hilcorp	State	1989	45 (18.2)	14 (4)	2.6 (4.1)
Liberty (proposed)	Liberty	BPXA	Hilcorp	Federal	N/A	31 (12.5)	19 (6)	4.5 (7.2)

MAPS ON PAGES 288-293

Vessel Traffic

Benjamin Sullender

Marine transportation in the Bering, Chukchi, and Beaufort Seas has long been a critical aspect of life in coastal communities. In a warming Arctic, the region's importance for commercial fisheries, resource extraction, and long-distance commerce is growing rapidly. The physical environment is characterized by severe storms, strong currents, and largely unpredictable sea ice (Arctic Council 2009). The natural challenges posed to transiting vessels are compounded by widely dispersed support services, a paucity of navigational aids, and few harbors or places of refuge for deep-draft vessels (Serumgard and Krause 2013, Huntington et al. 2015). The major drivers of Arctic marine transportation—resource development and regional trade—portend future increases in vessel traffic, especially when coupled with increasingly favorable sea ice conditions (Arctic Council 2009).

Currently, the most heavily trafficked marine transport route in the region is the North Pacific Great Circle Route, an arc that connects the west coast of North America with Asia, running through the Aleutian Islands. Several thousand ships transit the Great Circle Route each year (Nuka Research and Planning Group 2015), primarily large container ships and freighters (Nuka Research and Planning Group and Cape International 2006). A smaller but increasing number of cargo ships transit north through the Bering Strait to Russian ports and to the Red Dog Mine in Alaska. Tugs and barges transporting oil, consumables, and building supplies also serve coastal communities and the oil production operations on the North Slope. There are a number of more localized routes in the southern Bering Sea, primarily used by smaller fishing vessels.

Two main international shipping routes transit the international Arctic: the Northern Sea Route and the Northwest Passage. Ships have been operating in the Northern Sea Route, along Russia's coast, for many decades, and unpredictable sea ice and weather conditions currently limit traffic through the Northwest Passage. However, as sea ice declines in the future, many experts predict dramatically increased vessel traffic through the Arctic, as it becomes the most efficient way to move goods between Asian and European markets (Arctic Council 2009).

CONSERVATION ISSUES

Vessels pose five main risk factors to the marine environment: oil spills, ship strikes, noise, discharges and emissions, and invasive species.

Oil Spills

An oil spill is considered the greatest threat from vessels to the Arctic marine environment (Arctic Council 2009). Nearly all marine vessels carry some amount of oil, whether for use on-board as fuel or carriage for cargo. Ships can run aground or otherwise accidentally spill some of this oil. Most damaging is heavy fuel oil (HFO), which can be 50 times as toxic to marine organisms as regular fuel oil (Bornstein et al. 2014).

Oil is acutely and chronically toxic to a wide range of organisms, even at small doses (National Research Council 2014). For the best-studied organisms (marine vertebrates and birds), oil causes myriad acute effects including emphysema, dramatically compromised mobility, gastrointestinal irregularities, depressed immune responses, malfunctioning nervous and adrenal systems, and damage to a wide range of internal organs (Burger and Fry 1993, Rocque 2006, Nahrgang et al. 2016). Chronic exposure to oil may have a greater impact at the population scale than acute toxicity due to changes in reproduction, survival, and behavior (Rocque 2006, Nahrgang et al. 2016). Furthermore, indirect effects such as habitat loss and predator or prey abundance shifts (trophic cascades) may significantly impair ecosystem recovery (Peterson et al. 2003). Unfortunately, there are many examples of bird mortality due to oil exposure (Piatt et al. 1990, National Oceanic and Atmospheric Administration 2002, Munilla et al. 2011).

Species whose behavior increases their exposure to oil (e.g. seals and sea lions frequently active on or near the water surface) or species that rely on physical properties for insulation (e.g. sea otters' (*Enhydra lutris*) fur or marine-foraging birds' feathers) are particularly at risk from oil spills. Oil alters the thermal balance of these organisms by reducing the water-repelling properties of fur (Davis et al. 1988) and feathers (Burger and Fry 1993). Reactionary grooming or preening spreads the oil deeper, exacerbating its effects (Davis et al. 1988, Jenssen 1994). Furthermore, wildlife may not avoid oiled areas—gray whales (*Eschrichtius robustus*) were observed surfacing through oiled areas in Prince William Sound after the *Exxon Valdez* oil spill (Moore and Clarke 2002), and Red Phalaropes (*Phalaropus fulicarius*) do not differentiate between oiled and clear habitats (Connors et al. 1981).

Natural oceanographic factors of the Bering, Chukchi, and Beaufort Seas further complicate oil spills. Sea ice, wind, and currents may retard natural weathering processes, impair clean-up efforts, and disperse oil (National Oceanic and Atmospheric Administration 2002).

Currently, oil response capabilities and infrastructure are severely lacking in the US Arctic (Arctic Council 2009, National Research Council 2014). Given the likelihood of an oil spill, the increasing volume of traffic, and the severe ecological consequences, emergency preparedness and management action to mitigate impacts are of paramount importance in the Bering, Chukchi, and Beaufort Seas (Huntington et al. 2015). The closest Coast Guard facility—in Kodiak (see Figure 7.5-1)—is approximately seven days away from the Arctic Ocean by cutter (US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities 2013).

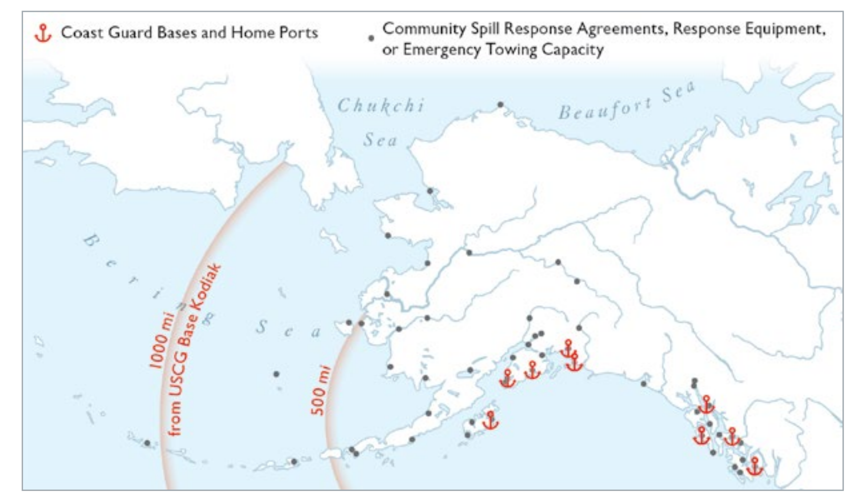


FIGURE 7.5-1. Approximate distance to the closest US Coast Guard facility (Air Station Kodiak) from the Bering Sea and Arctic Ocean.

Ship Strikes

Ship strikes, when a vessel accidentally collides with a marine organism, have long been noted by Alaskan subsistence users. Although the incidence of vessel strikes is difficult to estimate (Moore and Clarke 2002), opportunistic surveys have indicated that fatal and non-fatal injuries occur with some regularity (George et al. 1994). Evidence also suggests that whales can become entangled, sometimes fatally, in fishing gear (Moore and Clarke 2002). As with the risks of oil spills, ship strikes may become more of an acute issue as vessel traffic increases.

Noise

The noise emitted by vessels can be disturbing to wildlife, especially cetaceans. A variety of marine mammals rely on sound to interact with their environment, using sound as part of predator avoidance, communication, prey detection, and navigation strategies (Richardson 1995).

7.5 VESSEL TRAFFIC MAPS ON PAGES 288–293

There are three commonly recognized types of noise-related impacts: behavioral (changes in swimming patterns), acoustic (changes in vocalizations), and physiological (stress responses and hearing system damage) (Nowacek et al. 2007, Peng et al. 2015, National Marine Fisheries Service 2016b). Acoustic masking may be another major factor, occurring when anthropogenic sound reduces the area over which marine mammals can hear and communicate, leading to a functional degradation of habitat (Moore et al. 2012). Chronic exposure to elevated underwater noise levels leads to stress responses in marine mammals, with predicted detrimental health effects (Rolland et al. 2012).

Discharges and Emissions
Vessels emit particulate matter and other pollutants as exhaust, and also may discharge sewage, solid waste, or oily bilge water during their voyages (Huntington et al. 2015). Although there are rules governing the discharge of pollutants, limited on-shore treatment capabilities and similarly limited on-board storage options make management a pressing concern in the shipping industry, and particularly in the burgeoning cruise ship industry (Arctic Council 2009). The Polar Code, international guidelines established to provide for both safe ship operation and protection of the marine environment, has specific standards on acceptable and prohibited discharges for vessels operating in both the Arctic and Antarctic (International Maritime Organization 2016).

Invasive Species
Vessels transiting long distances provide a number of vectors for invasive marine species introductions, from the discharge of ballast water to hull fouling to discarded gear (Bax et al. 2003). Particular emphasis has been placed on ballast water, taken on and released by ships to maintain buoyancy under changing load weights. Globally, as many as 10,000 marine species may be contained in ballast water on any given day (Carlton 2001). While many of these organisms will not survive transport or will not flourish in their new environments, some may become established as invasive species. Likely transported through attachment to vessel hulls (hull fouling), skeleton shrimp (*Caprella mutica*) populations have recently become established in a number of sites from Southeast Alaska to Dutch Harbor (Ashton et al. 2008). Evidence suggests that skeleton shrimp may negatively impact shellfish reproduction and alter fish diets (Turcotte and Sainte-Marie 2009). Although very few marine invasive species have been documented to this point, climate change is predicted to make Alaska waters more suitable for a wide range of invasive taxa, increasing the likelihood of establishment (de Rivera et al. 2011).

The ecosystems of some Aleutian Islands have also been disrupted by the introduction of terrestrial mammals from shipping. Accidental rat (*Rattus* spp.) introductions can create a longer and more pervasive legacy of environmental damage than oil spills (Morkill 2006). Rats can completely extirpate burrow-nesting seabirds and severely depress populations of ground-nesting shorebirds (Ebbert and Byrd 2002). Rats consume their way through an island's entire foodweb, from marine invertebrates to nesting birds, and due to rapid reproductive capabilities, can expand populations rapidly (Morkill 2006).

Incidents
Fortunately, there have been relatively few major shipping accidents in Alaska waters. Four high-profile freighter groundings have occurred in the last 30 years: T/V *Glacier Bay* (July 1987), T/V *Exxon Valdez* (March 1989), M/V *Kuroshima* (November 1997), and the M/V *Selendang Ayu* (December 2004). The *Exxon Valdez* oil spill is the largest tanker spill in US history, releasing over 10 million gallons (38 million L) of oil after striking a reef in Prince William Sound. Oil contaminated an estimated 1,300 miles (2,000 km) of shoreline, and the spill was directly responsible for the mortality of approximately 250,000 seabirds, 2,800 sea otters, 300 harbor seals (*Phoca vitulina*), 250 Bald Eagles (*Haliaeetus leucocephalus*), 20 killer whales (*Orcinus orca*), and billions of salmon (*Exxon Valdez* Oil Spill Trustee Council 2014). Two years prior to the *Exxon Valdez* spill, the tank vessel *Glacier Bay* struck a rock near the mouth of the Kasilof River and spilled over 100,000 gallons (380,000 L) of crude oil, temporarily closing the Cook Inlet salmon fishery (Bernton 1987).

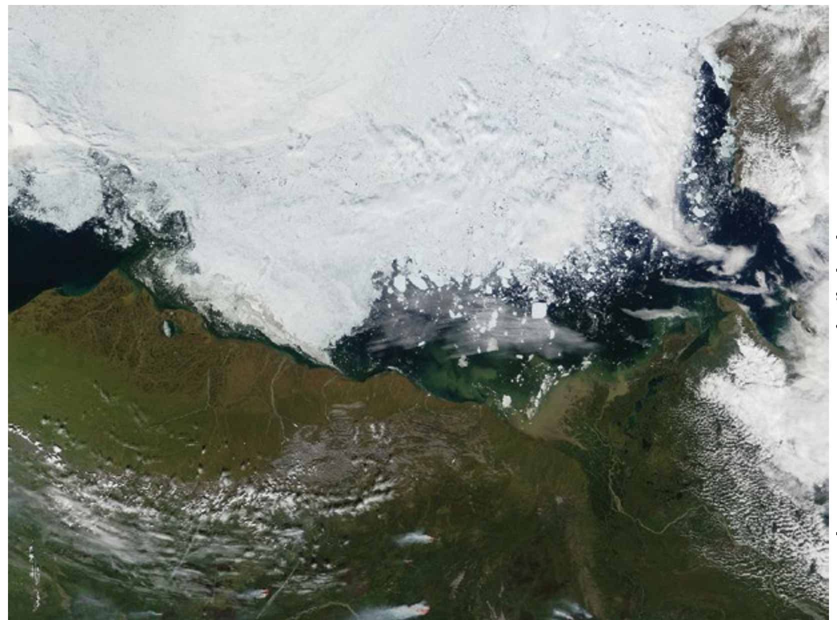


Image and caption: NASA, courtesy of Jeff Schmaltz

From the time Europeans arrived on the North American continent to the mid-twentieth century, sailors searched for a northwest passage that would connect the Atlantic Ocean (and Europe) to the Pacific Ocean (and Asia). No such passage exists through the continent, but during the summer, a northwest route through the Arctic opens up. By sailing around Greenland, threading the islands of the Canadian Arctic, and skimming along the Canadian and Alaska northern shores, a ship traveling from Europe to East Asia can save as much as 2,500 miles (4,000 km). However, the Northwest Passage is not a viable shipping route most of the year. During the winter, thick sea ice builds up, blocking the passage of all ships. Even during the summer, when the sea ice has melted or thinned, icebreakers must often accompany ships through the passage.

The challenges of navigating the Northwest Passage are evident in images of the Beaufort Sea north of Alaska and Canada's Yukon and Northwest Territories. The passage is often clear by the end of July, as it was in this 2005 image, but varies greatly by year. Very little of the inky, blue-black sea is visible under the white expanse of ice. The ice is not smooth; rather, chunks can be seen where new ice has formed around pieces of older ice from previous years. The section of the Beaufort Sea that is visible is clouded with brown sediment flowing into the water from the Mackenzie River.

The F/V *Kuroshima* and M/V *Selendang Ayu* incidents both occurred in close proximity to Unalaska Island in the eastern Aleutians. The Kuroshima was ripped away from its anchorage while waiting to load frozen seafood in Dutch Harbor, killing 2 crew members and releasing 39,000 gallons (148,000 L) of oil when it ran aground (National Oceanic and Atmospheric Administration 2002). The *Selendang Ayu*, a Malaysian-flagged freighter transporting soybeans from Seattle to China, ran aground in the Aleutians and split in half, killing 6 crew members and spilling nearly 350,000 gallons (1,325,000 L) of oil and 66,000 tons (60,000 metric tons) of soybeans (Ropeik 2014). Forty-one species of birds were directly injured by the oil spill (Byrd and Daniel 2008), and over 100,000 seabird mortalities were estimated (Munilla et al. 2011).

With the projected increases in vessel traffic, there is elevated concern that exposure to these impacts will increase in the future, particularly with marine mammals (Reeves et al. 2012). The potential for temporal and geographic overlap between vessels and wildlife is already substantial, especially in two major bottlenecks: the Bering Strait and Unimak Pass (see *A Closer Look:* Unimak Pass and Bering Strait Vessel Traffic). The US Coast Guard recently recommended a series of Areas to be Avoided (ATBAs) in the Bering Sea in an effort to reconcile safe

7.5 VESSEL TRAFFIC MAPS ON PAGES 288–293

vessel passage with key areas of ecosystem function, among other objectives (US Coast Guard 2016). These ATBAs and other vessel-based conservation measures are discussed further in the Conservation Areas summary.

MAPPING METHODS (MAPS 7.5.1–7.5.3)

Vessel traffic data were acquired in CSV format from exactEarth (2017) in the form of satellite-based Automatic Identification System (AIS) data. We built an R script to clean the data, remove spurious records, and build tracks. A separate track was built for each vessel for each day. Due to data volume (>100 GB in total; ~10,000,000 records for each month), data were first sorted by date and vessel ID, then parsed into sequences of 1 million points, and finally batch processed.

The output tracks were intersected with a 3-mile (5-km) buffer of Alaska, Canada, and Russia landmasses to remove tracks that ran on land, producing a cleaned track file.

After the cleaned track files were developed, all tracks for 2015 and 2016 were merged, and a pixelate function with cell size of 6 miles (10 km) was run to calculate how many total miles were traveled by all vessels in each cell. To generate finer-scale data suitable for representation in regional maps, these processes were re-run at a cell size of 0.6 mile (1 km) and 1.5 miles (2.5 km) for Unimak Pass and Bering Strait, respectively.

To calculate concentration areas, we filtered data by ship type. For each type, we used a 75% contour from the isopleth function from the Geospatial Modeling Environment in ArcMap. Resulting contours were manually smoothed.

To prepare the Vessel Traffic Patterns map, we began with the prepared 2016 vessel traffic rasters for each ship type: Tow/Tug, Cargo, Tanker, and Other (excluding Fishing). Focal Statistics were calculated on each in ArcMap, generating new rasters representing the maximum value within 31 miles (50 km) of each original pixel. Point samples of these new rasters were taken at hand-selected intervals along the visually-apparent main traffic routes. By taking the maximum value within 31 miles (50 km), our results were less sensitive to variations in the choice of point sample location. The approximate routes for each ship were then manually drawn, connecting the sampling points. For each ship type, the width of the line was fixed at each sample point to be proportional to the square root of the sample value; line widths were tapered smoothly between sample points.

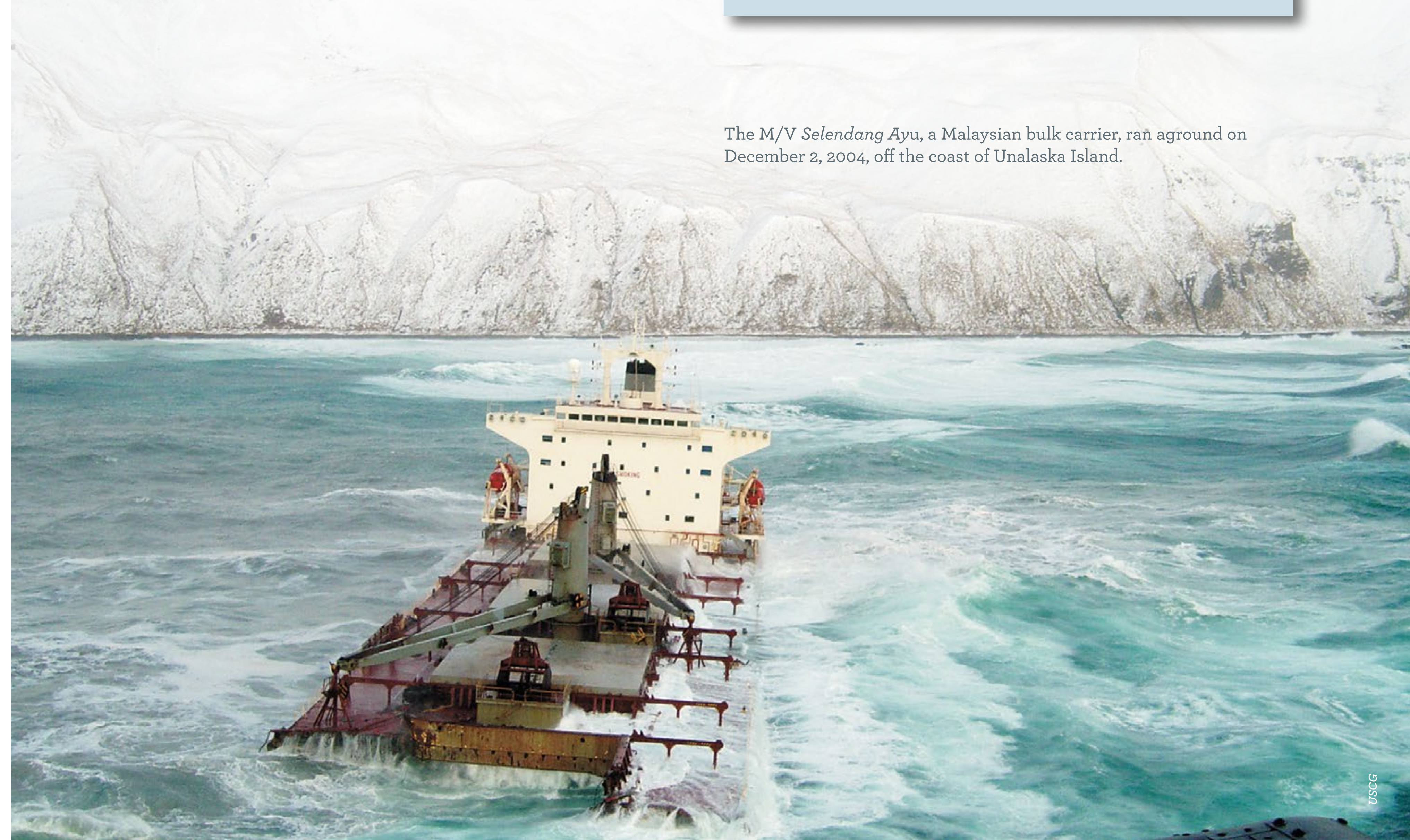
Data Quality
AIS data accuracy and completeness is limited by the distribution of AIS receivers. We used data collected by a series of polar-orbiting satellites, which provide more extensive geographic coverage but more limited precision than a network of land-based receivers.

Due to AIS latency (periods of time when no satellite is in range) and potential errors in the data, some accuracy issues may exist for individual tracks. Approximately 0.001% of the date/time data were received incorrectly and omitted. Approximately 0.4% of the latitude/longitude data were invalid (either latitude = 91 or longitude = 181). Depending on the month, between 0.9% and 6% of generated tracks ran on land (and were therefore omitted from the analysis). Finally, a few individual AIS locations were transmitted incorrectly and represented significant divergence from previous and subsequent points. Although tracks were constructed using these incorrect locations, these were manually identified and removed in the finer-scale Unimak Pass and Bering Strait data analysis.

Reviewers
- Ed Page
- Andrew Hartsig
- Sarah Bobbe

MAP DATA SOURCES

Vessel Traffic Data: Audubon Alaska (2017) based on exactEarth (2017)

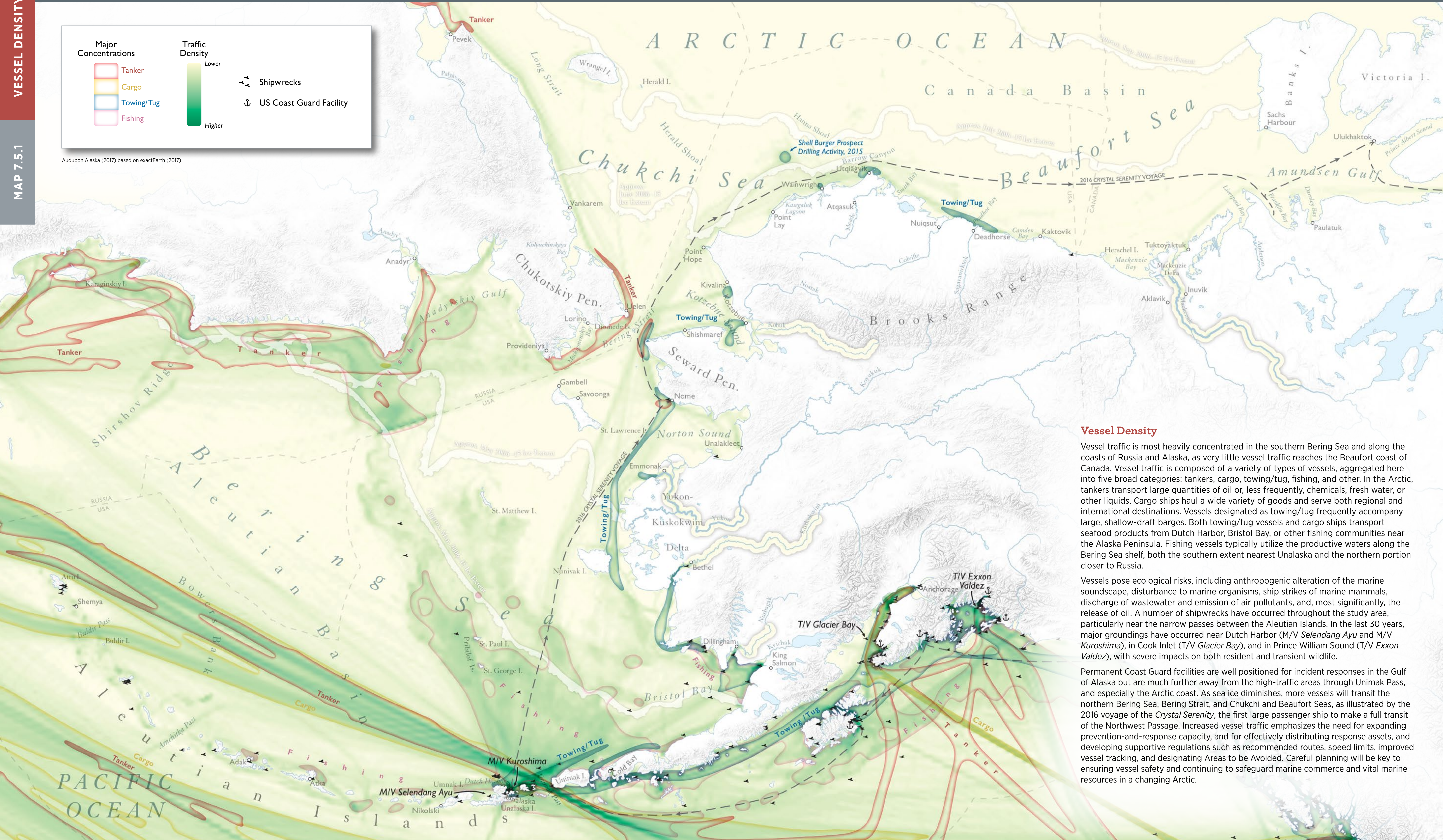


The M/V *Selendang Ayu*, a Malaysian bulk carrier, ran aground on December 2, 2004, off the coast of Unalaska Island.

Vessel Density

Map Author: Benjamin Sullender
Cartographer: Daniel P. Huffman

Audubon ALASKA



Vessel Density

Vessel traffic is most heavily concentrated in the southern Bering Sea and along the coasts of Russia and Alaska, as very little vessel traffic reaches the Beaufort coast of Canada. Vessel traffic is composed of a variety of types of vessels, aggregated here into five broad categories: tankers, cargo, towing/tug, fishing, and other. In the Arctic, tankers transport large quantities of oil or, less frequently, chemicals, fresh water, or other liquids. Cargo ships haul a wide variety of goods and serve both regional and international destinations. Vessels designated as towing/tug frequently accompany large, shallow-draft barges. Both towing/tug vessels and cargo ships transport seafood products from Dutch Harbor, Bristol Bay, or other fishing communities near the Alaska Peninsula. Fishing vessels typically utilize the productive waters along the Bering Sea shelf, both the southern extent nearest Unalaska and the northern portion closer to Russia.

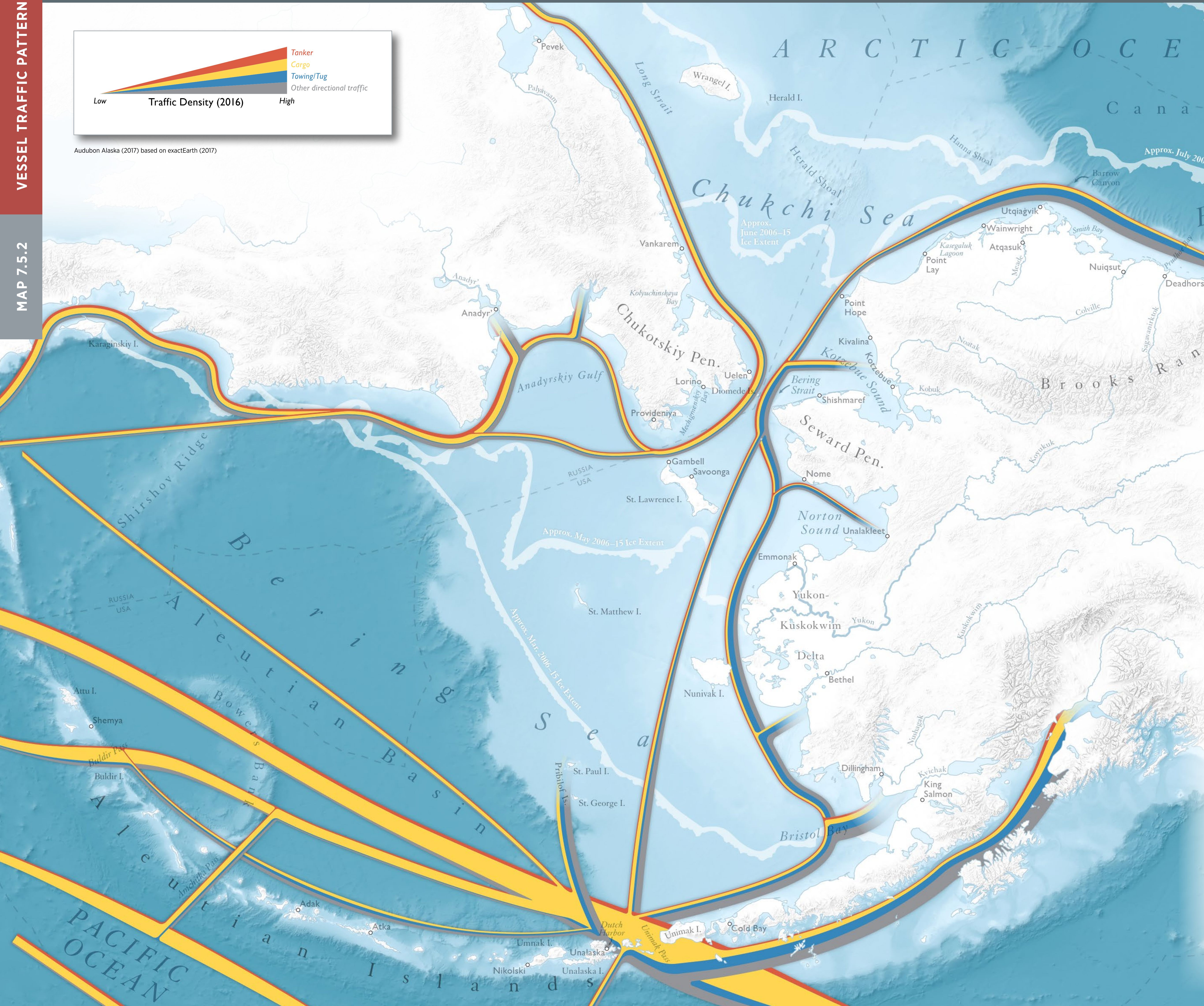
Vessels pose ecological risks, including anthropogenic alteration of the marine soundscape, disturbance to marine organisms, ship strikes of marine mammals, discharge of wastewater and emission of air pollutants, and, most significantly, the release of oil. A number of shipwrecks have occurred throughout the study area, particularly near the narrow passes between the Aleutian Islands. In the last 30 years, major groundings have occurred near Dutch Harbor (M/V *Selendang Ayu* and M/V *Kuroshima*), in Cook Inlet (T/V *Glacier Bay*), and in Prince William Sound (T/V *Exxon Valdez*), with severe impacts on both resident and transient wildlife.

Permanent Coast Guard facilities are well positioned for incident responses in the Gulf of Alaska but are much further away from the high-traffic areas through Unimak Pass, and especially the Arctic coast. As sea ice diminishes, more vessels will transit the northern Bering Sea, Bering Strait, and Chukchi and Beaufort Seas, as illustrated by the 2016 voyage of the *Crystal Serenity*, the first large passenger ship to make a full transit of the Northwest Passage. Increased vessel traffic emphasizes the need for expanding prevention-and-response capacity, and for effectively distributing response assets, and developing supportive regulations such as recommended routes, speed limits, improved vessel tracking, and designating Areas to be Avoided. Careful planning will be key to ensuring vessel safety and continuing to safeguard marine commerce and vital marine resources in a changing Arctic.

Vessel Traffic Patterns

Map Authors: Daniel P. Huffman and Benjamin Sullender
Cartographer: Daniel P. Huffman

Audubon ALASKA



Patrick Kelley / USCG

Vessel Traffic Patterns

Vessels often follow particular courses that offer the shortest, safest, or most efficient way to connect specific ports or regions. This map shows generalized traffic patterns across the Bering, Chukchi, and Beaufort Seas. The North Pacific Great Circle Route connects ports on the west coast of North America with Asia. Ships transit the Bering Sea through Unimak Pass in the east and either Buldir Pass (east of Attu Island) or Near Strait (north of Attu Island) in the west. A much smaller number of vessels transit the Bering Strait, typically keeping to either Russian or American waters with relatively little crossover.

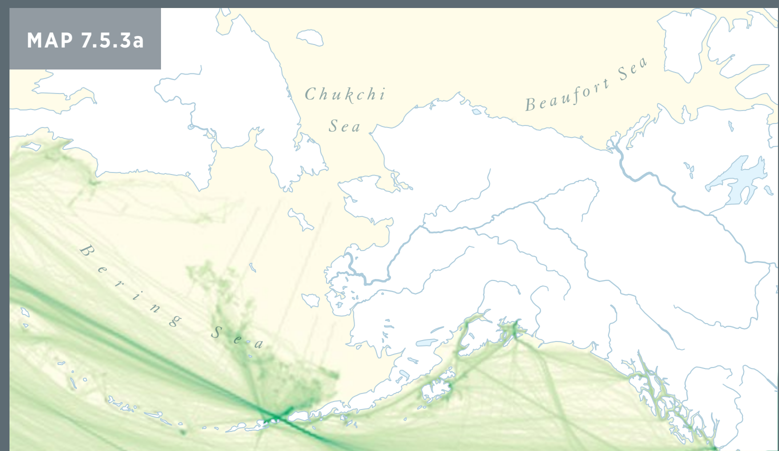
Vessels engaged in directional travel—excluding fishing vessels—are split into four main categories: tankers, cargo, towing/tug, and other. Many tankers hauling oil or other liquids may transit the southern Bering Sea, travel along the Russian coastline to Pevek; or serve major Alaska ports including Nome, Anchorage, and Valdez. Cargo ships typically transit the Great Circle Route through the Bering Sea, staying south of areas frequently covered by sea ice. Incoming towing/tug vessels usually accompany a barge to resupply Alaska coastal communities and may travel up major rivers to communities further inland. A number of bulk cargo and towing/tug vessels are engaged in transporting minerals from the Red Dog Mine, a process that typically involves lightering (transfer of supplies or fuel from one vessel to another with a shallower draft for port access or a deeper draft for longer-range transport). A combination of towing/tug and cargo vessels transport seafood from Dutch Harbor and Bristol Bay communities directly to market or for secondary processing outside of the region. Vessels classified as "other" include law enforcement, medical transport, passenger ships, research, and unknown ship types.

Through the establishment of recommended routes, designation of Areas to be Avoided, and further improvements in navigational standards, commonly traveled routes can be formalized, thereby reducing the risk of collisions, mitigating environmental impact as feasible, and enhancing the efficiency of marine transit.

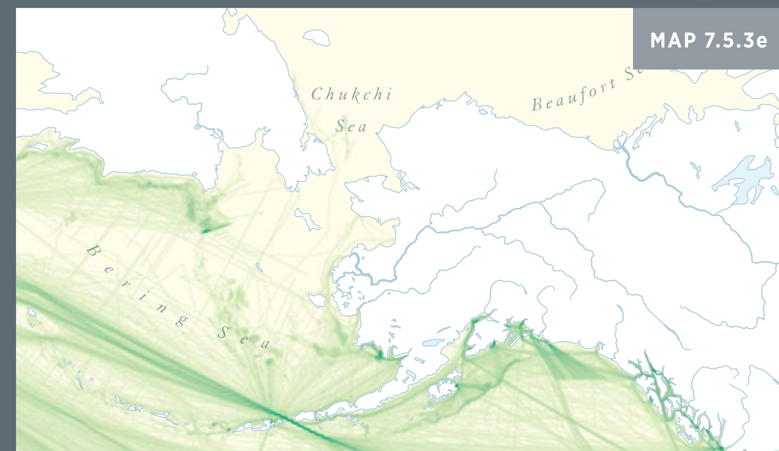
Vessel Traffic By Month

Map Author: Benjamin Sullender
Cartographer: Daniel P. Huffman

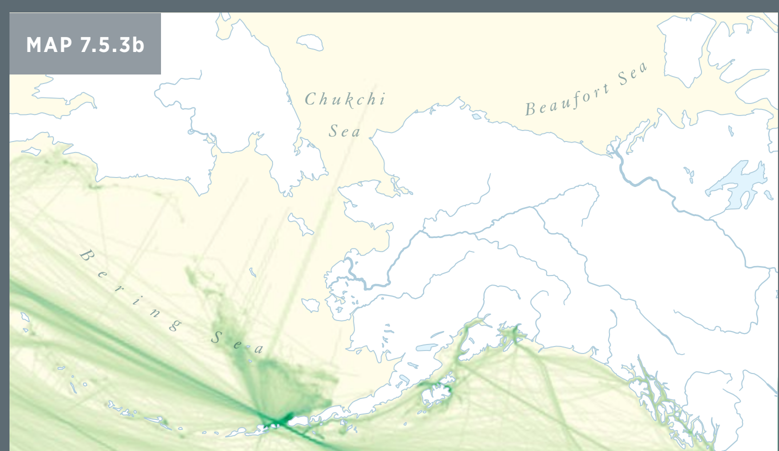
January 2015–16



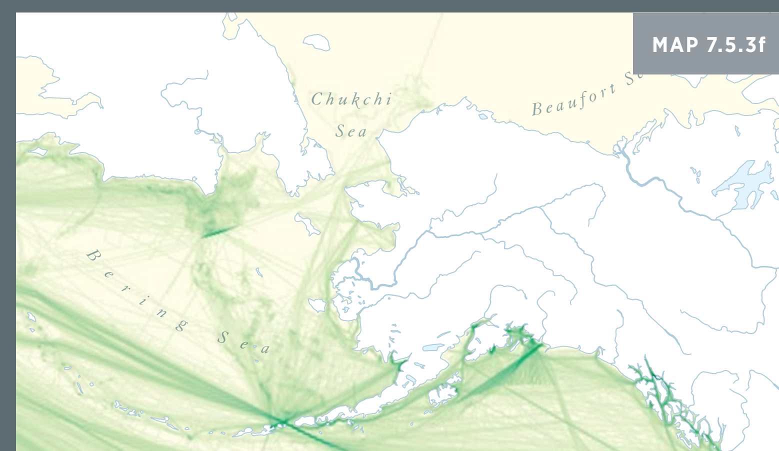
May 2015–16



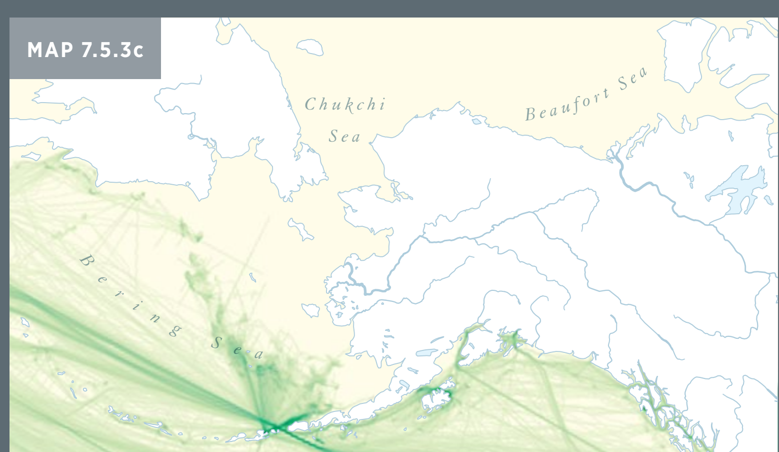
February 2015–16



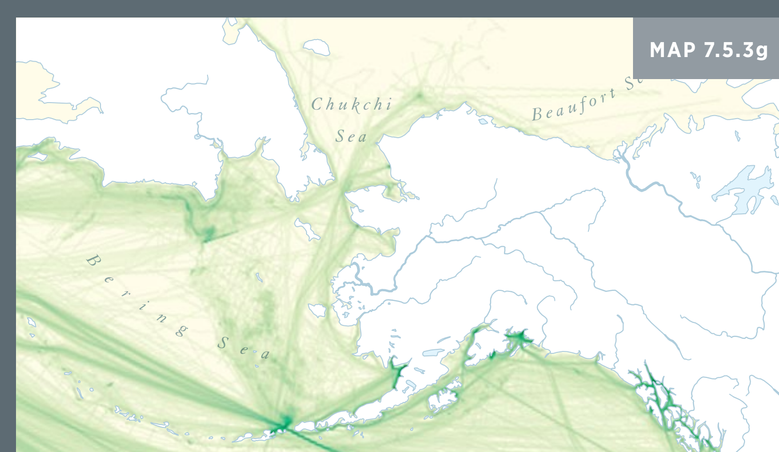
June 2015–16



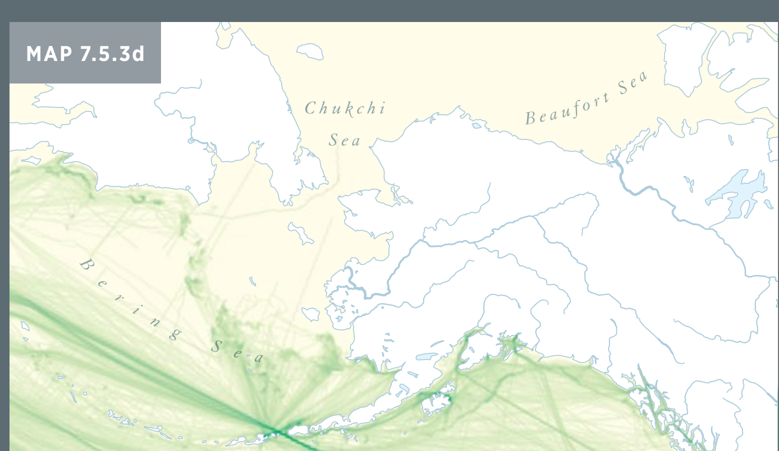
March 2015–16



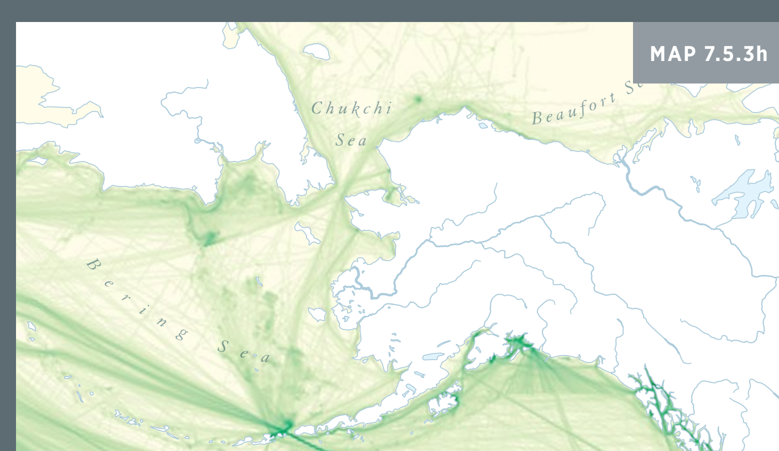
July 2015–16



April 2015–16

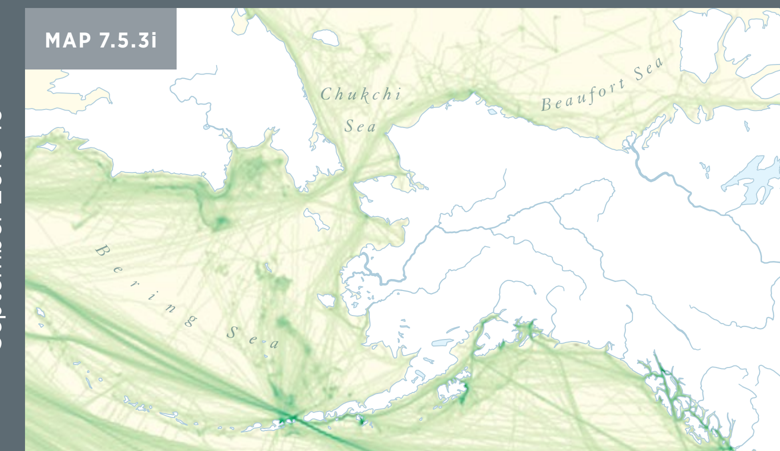


August 2015–16

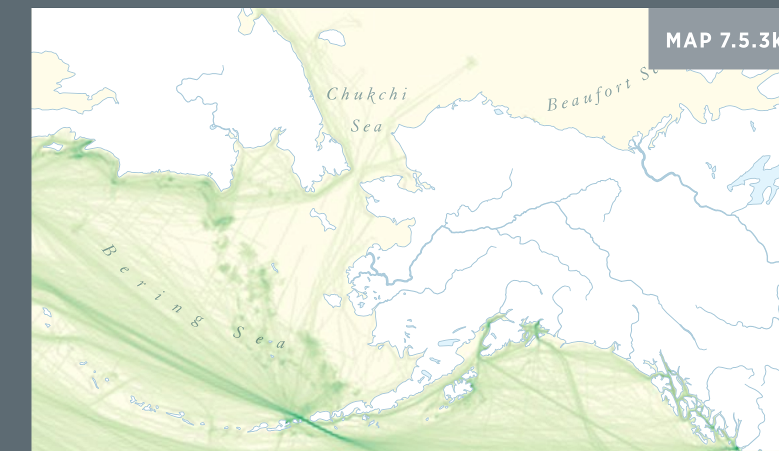


Audubon ALASKA

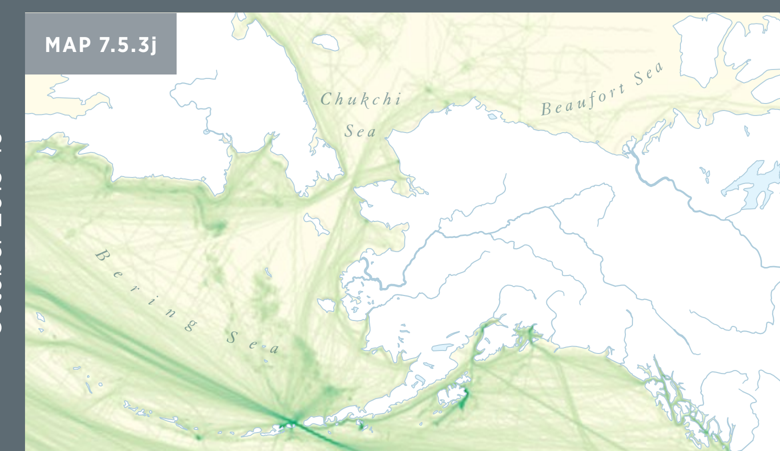
September 2015–16



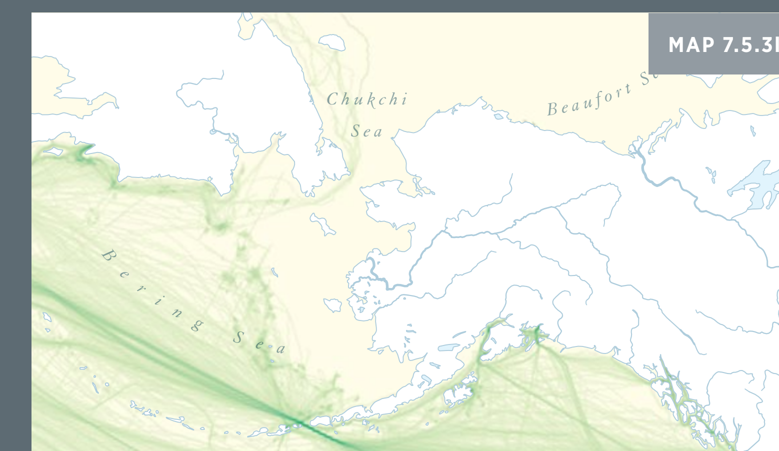
November 2015–16



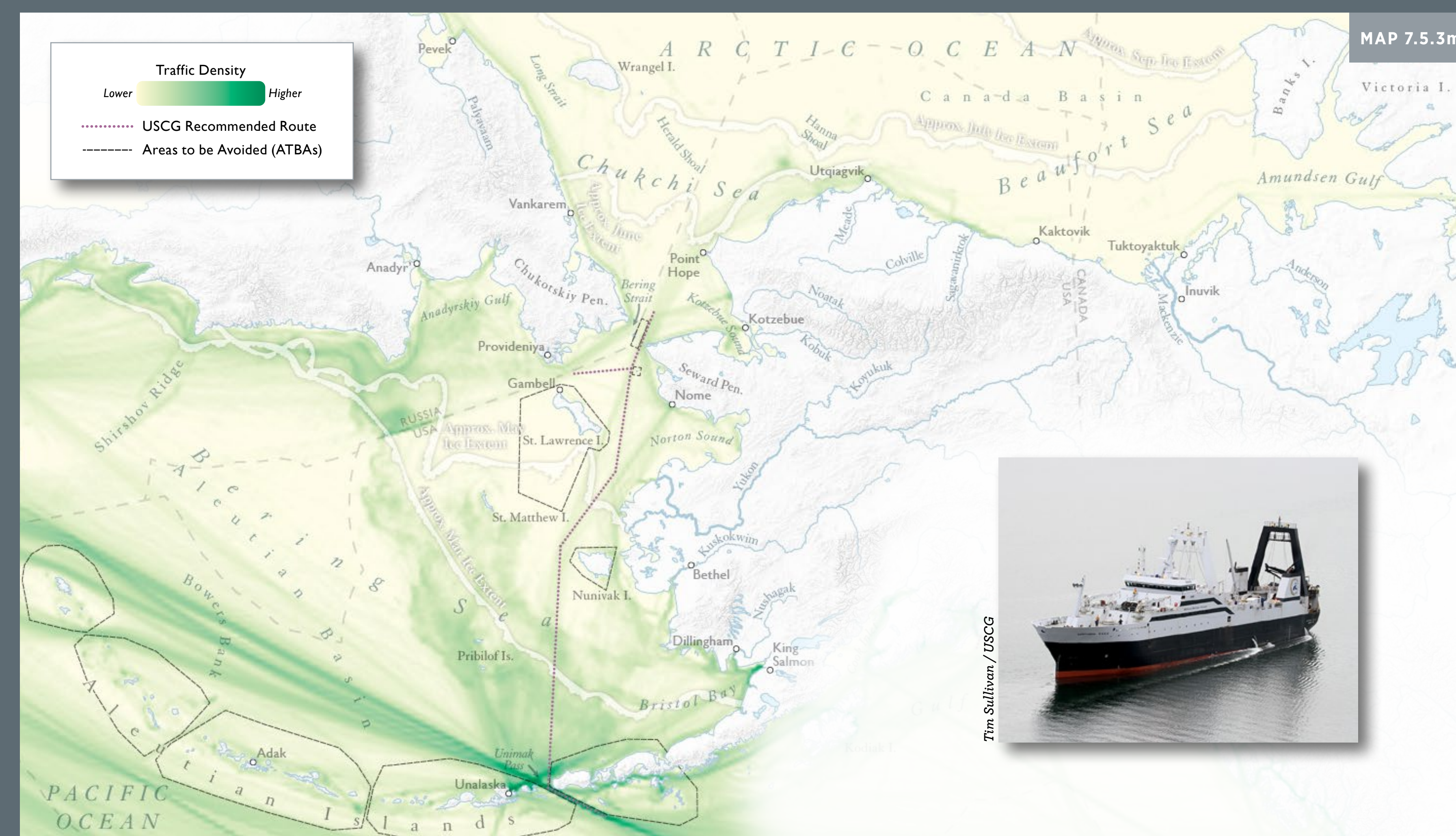
October 2015–16



December 2015–16



Total 2015–2016 Traffic Density



Audubon Alaska (2017) based on exactEarth (2017)

A Closer Look: Unimak Pass and Bering Strait Vessel Traffic

Benjamin Sullender

Unimak Pass and the Bering Strait are two major marine transport corridors in the Bering, Chukchi, and Beaufort Seas. These corridors are biologically, ecologically, and economically important. The physical processes associated with shallow, narrow passes—vertical advection, upwelling, and surface convergences—couple with tidal mixing to stimulate primary productivity over a wider region (Nihoul et al. 1993, Springer et al. 1996, Ladd et al. 2005a), making these regions especially productive for higher trophic levels (Stabeno et al. 2002, Ladd et al. 2005b, Renner et al. 2008). These food webs are moderated by seasonal biophysical pulses in water transport, sea-ice cover, and freshwater input (Moore and Stabeno 2015), and, in turn, the temporal variations in prey abundance drive use of foraging hotspots and migration patterns for upper trophic levels (Hunt and Stabeno 2005, Ladd et al. 2005b, Citta et al. 2015). As a result, Unimak Pass and the Bering Strait not only provide seasonally important habitat of their own, but also serve as movement corridors for migratory wildlife following conditions of high productivity across a broader spatial extent (Moore and DeMaster 1998).

Both Unimak Pass and the Bering Strait are also important routes for maritime commerce. Unimak Pass is the easternmost pass of the North Pacific Great Circle Route, the most efficient route between North America's west coast and Asia, and the Bering Strait is the only entrance into the Arctic Ocean from the Pacific Ocean (Nuka Research and Planning Group 2015). Given the spatial overlap between biological hotspots and potentially dangerous anthropogenic activity (Huntington et al. 2015, Renner and Kuletz 2015), these two passes merit special consideration. The risks from vessels are described further in the Vessel Traffic summary.

UNIMAK PASS

Geography

Unimak Pass is a narrow strait in the eastern Aleutians. The narrowest point of the main passage is about 10 miles (16 km) wide, between Ugamak Island and Unimak Island. The pass has a minimum depth of around 180 feet (55 m), although some localized bathymetric features may be as shallow as 156 feet (47 m).

Unimak Pass is in close proximity to Unalaska Island and the city of Unalaska, also known as Dutch Harbor. Other nearby islands include Akutan, Akun, and Tigalda Islands. All of the islands bounding Unimak Pass are part of the 3.4-million acre (13,760 km²) Alaska Maritime National Wildlife Refuge, a dispersed protected area encompassing coastlines from Southeast Alaska to Peard Bay in the Chukchi Sea.

Ecology

The Alaska Coastal Current is the primary source of water flowing through Unimak Pass and brings water from the Gulf of Alaska southwestward along the Alaska Peninsula before a portion diverges north through Unimak Pass to the broader continental shelf underlying the Bering Sea. A significant portion of the Alaska Coastal Current is composed of terrestrial inflows, and as a result, this water mass is fresher and warmer than waters in the Bering Sea (Hunt and Stabeno 2005, Ladd et al. 2005a). Along with this water mass, nutrients are advected northward from Unimak Pass, contributing significantly to the productivity of the Bering Sea shelf ecosystem (Stabeno et al. 2002).

The rugged islands and rocky coastlines bounding Unimak Pass have immense biodiversity and large abundances of many species. Marine mammals that frequent this area include Steller sea lions (*Eumetopias jubatus*), sea otters (*Enhydra lutris*), harbor seals (*Phoca vitulina*), and northern fur seals (*Callorhinus ursinus*). Migratory cetaceans such as gray whale (*Eschrichtius robustus*) and humpback whales (*Megaptera novaeangliae*) use Unimak Pass to access the Bering Sea (Ferguson et al. 2015, Zerbini et al. 2016). Although little is known about their migration patterns, the North Pacific right whale (*Eubalaena japonica*) and the fin whale (*Balaenoptera physalus*) (both endangered) use seasonal habitats in very close proximity to Unimak Pass (Mizroch et al. 2009, Zerbini et al. 2015).

Unimak Pass provides critical foraging and nesting habitat for birds year-round, although species diversity, abundance, and distribution varies considerably over the course of a year (Renner et al. 2008). In July and August, millions of Short-tailed (*Ardenna tenuirostris*) and Sooty Shearwaters

FIGURE 7.6-1. Weekly transits of Unimak Pass, 2015–2016, grouped by vessel type.

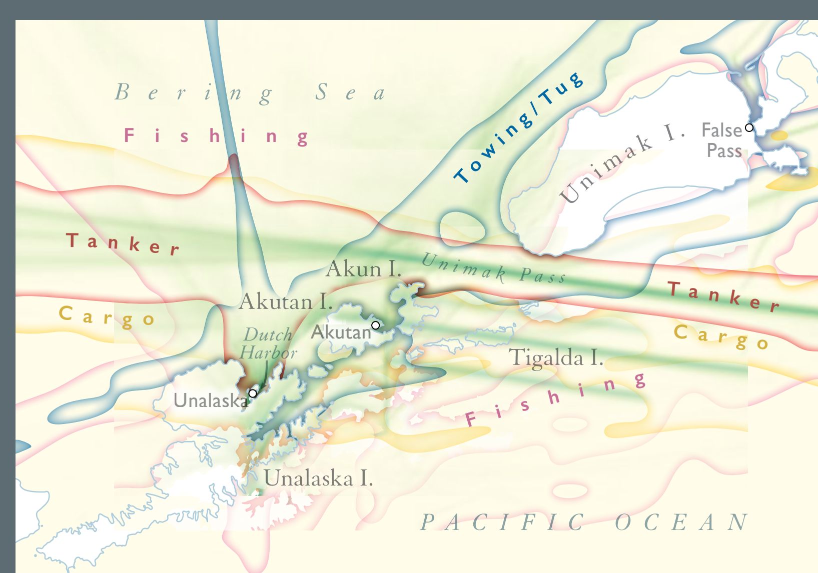


FIGURE 7.6-2. Vessel traffic in and around Unimak Pass.

(*A. grisea*) arrive in Unimak Pass to forage for krill and small fish, constituting the highest bird densities anywhere in Alaska. In the winter, Crested Auklets (*Aethia cristatella*) and Thick-billed Murres (*Uria lomvia*) dominate seabird biomass in the region, also foraging extensively on krill (Renner et al. 2008). The 3 Important Bird Areas (IBAs) that include Unimak Pass host significant abundances of 22 species, 16 of which gather in globally significant numbers (Smith et al. 2014).

Vessel Traffic

Dutch Harbor is the major port in the southern Bering Sea and is home to the largest seafood industry in the US. Commercial fishery landings in Dutch Harbor have been the highest in the US for the last 19 years, most recently landing 787 million pounds (357 million kg) of seafood in 2015 (National Marine Fisheries Service 2016a). Much of this seafood is processed on shore and shipped out to consumers or for secondary processing, requiring the use of large cargo vessels (Nuka Research and Planning Group 2016). Many ships also transit Unimak Pass without stopping at Dutch Harbor, as part of the North Pacific Great Circle Route.

Using a compilation of data sources, Nuka Research recorded an average of 4,156 annual transits between 2006 and 2015 for Unimak Pass (Nuka Research and Planning Group 2016). Based on our own vessel traffic data analysis, in 2015, Unimak Pass had 5,287 vessel transits, 4,149 (78%) of which were cargo vessels, and in 2016, Unimak Pass had 5,744 vessel transits, 4,461 (78%) of which were cargo vessels.

BERING STRAIT

Geography

The Bering Strait is a 53-mile-wide (85-km-wide) corridor that provides the only connection between the Arctic and Pacific Oceans. The strait is roughly bisected by the Diomede Islands. Just over two miles apart, Big Diomede Island belongs to Russia, while Little Diomede belongs to the US. Away from land, the Bering Strait has a minimum depth of around 162 feet (49 m), a similar depth to the surrounding Bering and Chukchi Seas.

Ecology

Three water masses converge at the entrance to the Bering Strait: the Anadyr Current, the Alaska Coastal Current, and the Bering Shelf Current. Although strong winds may occasionally reverse the flow at the Strait, all three of these currents move predominantly northward from the Bering Sea into the southern Chukchi Sea (Stabeno et al. 1999). Upwelling of the Anadyr Current near St. Lawrence Island and lateral mixing with the Alaska Coastal Current create conditions of immense primary productivity (Nihoul et al. 1993) as well as a nutrient, plankton, and organic carbon "highway" of critical importance for marine ecosystems in the Chukchi and Beaufort Seas (Grebmeier et al. 2006, Grebmeier et al. 2015b). Hydrography and seasonal but consistent nutrient supply pathways drive a number of benthic hotspots in and around the Bering Strait, which support high concentrations of foraging benthivores, such as Pacific walrus (*Odobenus rosmarus divergens*), gray whales, and bearded seals (*Erignathus barbatus*) (Grebmeier et al. 2015a).

Other wildlife abounds in the Bering Strait. All four species of ice seals can be found seasonally in or moving through the Bering Strait, and globally significant abundances of Parakeet Auklets (*Aethia psittacula*), Black-legged Kittiwakes (*Rissa tridactyla*), Crested Auklets, and Least Auklets (*Aethia pusilla*) nest on the Diomede Islands and forage in nearshore areas in the summer (Smith et al. 2014). The Bering Strait is a key movement corridor for marine mammals, such as Pacific walrus, beluga (*Delphinapterus leucas*), bowhead (*Balaena mysticetus*), and the Eastern stock of gray whales (Jay et al. 2012, Clarke et al. 2015, Ferguson et al. 2015).

Vessel Traffic

The Bering Strait is a narrow passageway for vessels, mainly barges from Red Dog Mine or transport ships bound for the Arctic Ocean (Nuka Research and Planning Group 2016).

Using a compilation of data sources, Nuka Research recorded an average of 393 annual transits of the Bering Strait between 2006 and 2015 (Nuka Research and Planning Group 2016). According to our own analysis, in 2015, Bering Strait had 458 vessel transits, 156 (34%) of which were cargo and 166 (36%) of which were tankers. In 2016, Bering Strait had 470 vessel transits, 187 (40%) of which were cargo and 146 (31%) of which were tankers. Although the Bering Strait typically sees only about 10% of the vessel traffic that Unimak Pass does, vessel traffic has more than doubled since 2008 (Nuka Research and Planning Group 2016) and is projected to continue to increase rapidly in the future. Moderate growth scenarios predict that nearly 2,000 transits will occur by 2025 (International Council on Clean Transportation 2015).

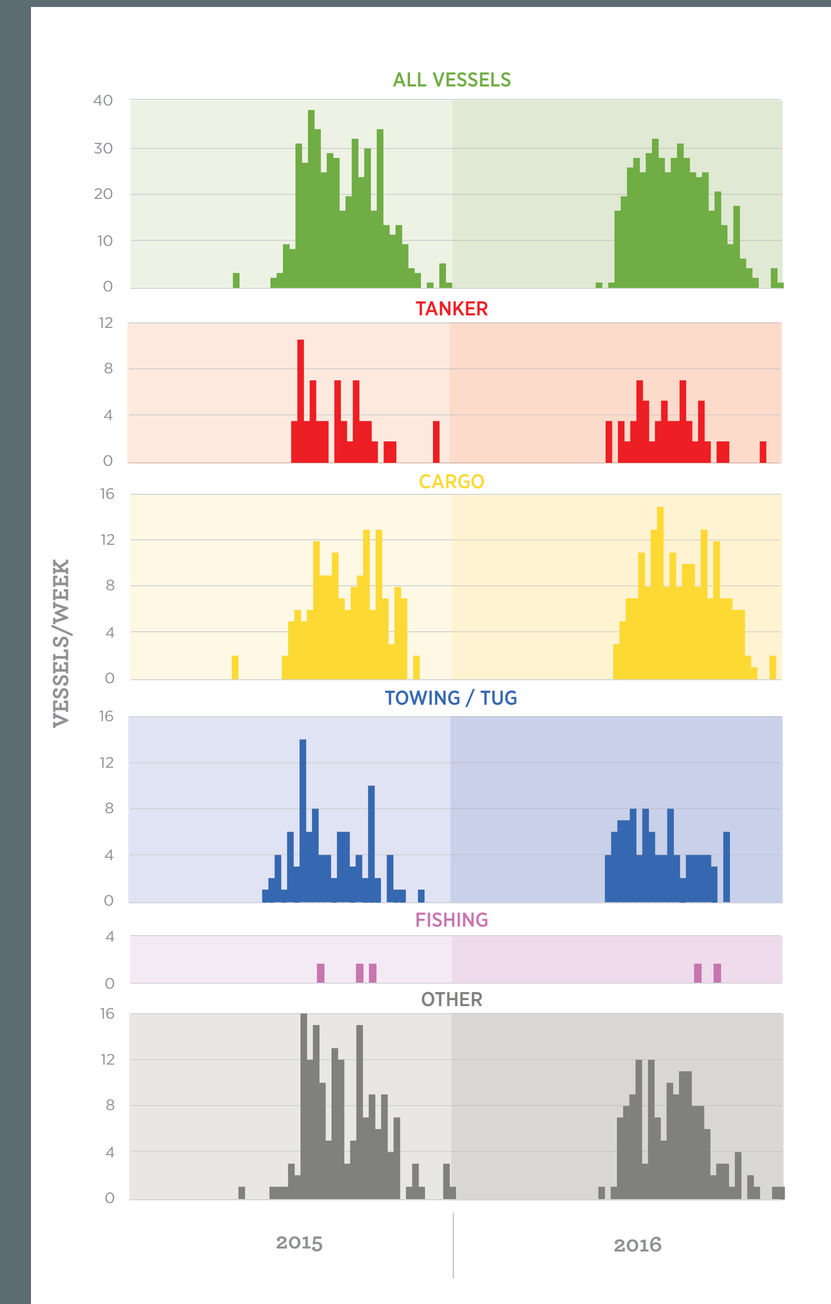


FIGURE 7.6-3. Weekly transits of Bering Strait, 2015–2016, grouped by vessel type.

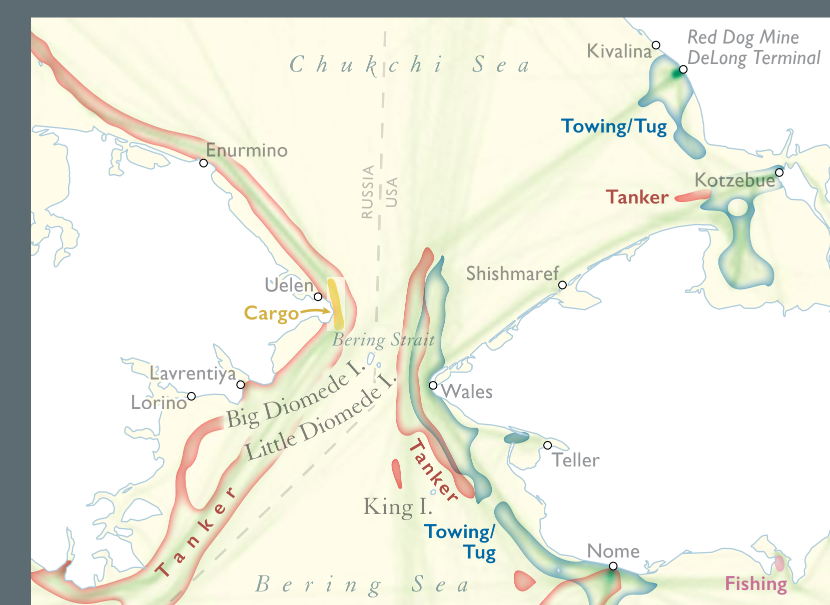


FIGURE 7.6-4. Vessel traffic in and around the Bering Strait.

MAP ON PAGES 298–299

Fisheries Management Conservation Areas

Jon Warrenchuk, Marilyn Zaleski and Brianne Mecum

Modern fishery management in Alaska began in 1976 with the Fishery Conservation and Management Act, enacted by Congress and later renamed the Magnuson-Stevens Fishery Conservation and Management Act (MSA) in 1996 (National Oceanic and Atmospheric Administration 2007). MSA extended federal fisheries jurisdiction out to 200 nautical miles (370 km), encompassing the exclusive economic zone (EEZ), and enabled the US to limit who fishes where and for what (National Oceanic and Atmospheric Administration 2007). MSA also established eight regional fishery management councils; the North Pacific Fishery Management Council (NPFMC) is one of those eight councils and manages all federal fisheries off the coast of Alaska (Atkinson 1988, Witherell and Woodby 2005, National Oceanic and Atmospheric Administration 2007).

HISTORY

Prior to the MSA, federal jurisdiction for protecting local fisheries only covered 12 miles (19 km) offshore. Direct fisheries management was still limited and, in Alaska, the main species of concern were northern fur seals (*Callorhinus ursinus*) on the Pribilof Islands, Pacific salmon (*Oncorhynchus* spp.), Pacific halibut (*Hippoglossus stenolepis*), Pacific herring (*Clupea pallasii*), and red king crab (*Paralithodes camschaticus*) (Atkinson 1988, National Oceanic and Atmospheric Administration 2004). However, over 300 foreign-flagged vessels from Japan, the Soviet Union, South Korea, Poland, and Taiwan were fishing in waters off of Alaska (National Oceanic and Atmospheric Administration 2004). These foreign fleets were targeting other species, namely walleye pollock (*Gadus chalcogrammus*), yellowfin sole (*Limanda aspera*), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*), Greenland turbot (*Reinhardtius hippoglossoides*), and rockfish (*Sebastes* spp.); the foreign vessels would harvest up to 2.6 million tons (2.4 million metric tons) of these Alaska resources per year (National Oceanic and Atmospheric Administration 2004). Today, over half of US seafood production is caught by US vessels and fishing companies in Alaska waters (North Pacific Fishery Management Council 2016b). The Bering Sea ecosystem produces a large proportion of that seafood, and the current federal groundfish fisheries there target walleye pollock, yellowfin sole, Pacific cod, Atka mackerel (*Pleurogrammus monopterygius*), and other mixed species (North Pacific Fishery Management Council 2016b).

While federal fisheries are those in the EEZ, state-managed fisheries are anything within 3 nautical miles (5.5 km) from shore. Alaska's State Constitution establishes that renewable resources, including fisheries, must be managed on a "sustained yield basis" for the "maximum benefit of its people" (Woodby et al. 2005). The state has management authority over the salmon, herring, and shellfish fisheries and the groundfish fisheries within state waters (Woodby et al. 2005).

CONSERVATION ISSUES

Large-scale federal commercial groundfish fisheries are a relatively recent development for the US Arctic ecosystem. Between the 1950s and 1990s, the total annual removal of groundfish in Alaska waters increased from about 30,000 tons (27,000 metric tons) to over 2.2 million tons (2 million metric tons) (National Marine Fisheries Service 2004). By regulation, the US federal groundfish catches in the Bering Sea are now capped at 2.2 million tons (2 million metric tons) per year (National Marine Fisheries Service 2004). The populations of the commercially targeted groundfish species are therefore lower than what they would be without fishing, and there are both direct and indirect effects on the food web as a result of the fishery removals.

Some fishery resources are managed by international agreements and organizations. Pacific halibut is managed by the joint US/Canada International Pacific Halibut Commission (IPHC) that was established in 1923 in order to conserve the halibut resource (Bell 1969). Pacific salmon found in the high seas are protected by the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean, signed in 1992, which prohibits directed fishing of salmonids in the international waters of the North Pacific Ocean (North Pacific Anadromous Fish Commission 2003). This convention for salmonids is an agreement between the US, Canada, Japan, Russia, and Republic of Korea (North Pacific Anadromous Fish Commission 2003). Following the collapse of the walleye pollock stock in the high-seas "Donut Hole" of the central Bering Sea, an area between the EEZs of the US and Russia, the Convention on the Conservation and Management of the Pollock Resources in the Central Bering Sea was signed in 1994 in order to conserve and rebuild the pollock stock there (Bailey 2011).

Part of the successful and sustainable management of Alaska's marine resources is establishing marine protected areas (MPAs) and seasonal closures within the EEZ to conserve habitat and protect vulnerable species (Table 7.7-1).

MAPPING METHODS (MAP 7.7)

Fisheries management areas were obtained directly from the National Oceanic and Atmospheric Administration (NOAA) (National Oceanic and Atmospheric Administration 2016a, b), the managing entity for fisheries in the federal waters of Alaska. State fishery regulations were not depicted as these maps are not the appropriate scale for that information. Conservation areas in Russian waters and the Canadian Beaufort were obtained from the Marine Conservation Institute (2017) and Sasha Moiseev, WWF Russia (pers. comm.). The proposed Arctic High Seas Fisheries Moratorium was digitized based on descriptions of the interim measures in the Declaration Concerning The Prevention Of Unregulated High Seas Fishing in the Central Arctic Ocean (Regjeringen 2015).

This map also depicts the top fishing ports of Alaska, as identified by the National Marine Fisheries Service (2015).

Fish catch data are from the Alaska Fisheries Science Center (2016) Observer Groundfish Program. For this map, we selected all observed catch for all gear types from 2010–2015 and then calculated the average catch (in kilograms) for all years. Catch values were then converted to metric tons and then interpolated using the Inverse Distance Weighted (IDW) tool in ArcGIS version 10.5. A power of 2 was used and a search radius of 12 points was set as the maximum distance for interpolation.

The sea-ice data shown on this map approximate median monthly sea-ice extent. The monthly sea-ice lines are based on an Audubon Alaska (2016) analysis of 2006 to 2015 monthly sea-ice extent data from the National Snow and Ice Data Center (Fetterer et al. 2016). See Sea Ice Mapping Methods section for details.

Data Quality

Data quality and coverage through the US EEZ off Alaska is excellent. Fisheries management conservation areas are straightforward regulatory boundaries and information about management measures is readily available.

The federal groundfish fisheries catch and location are estimated and recorded by independent fisheries observers onboard vessels. The observed catch is summarized and accessible online (Alaska Fisheries Science Center 2016), however the location and amount of a small proportion of catch is deemed confidential and not released to the public.

Reviewer
- Anonymous

MAP DATA SOURCES

Management Areas: Marine Conservation Institute (2017); National Oceanic and Atmospheric Administration (2016a, b); Regjeringen (2015); Russian Federation Ministry of Agriculture (2013)

Commercial Fish Landing Ports: National Marine Fisheries Service (2015); Russian Federation Ministry of Agriculture (2013)

Observed Catch: Alaska Fisheries Science Center (2016)

Sea Ice: Audubon Alaska (2016) based on Fetterer et al. (2016)

MAP ON PAGES 298–299

TABLE 7.7-1. Fishery management conservation areas in Alaska waters established to conserve Essential Fish Habitat, protect vulnerable stocks, or minimize interactions with marine mammals. Also included are the Central Bering Sea Donut Hole, formed by US and Russian exclusive economic zones, and the proposed Arctic High Seas Fisheries Moratorium Area, which are both in international waters.

Management Area	Area Coverage		Management Action
	nm²	km²	
Alaska Seamount Habitat Protection Area (16 Seamounts)	18,283	5,330	No bottom contact gear
Alaska State Waters	150,074	43,754	No bottom trawling—with some exceptions
Aleutian Islands Coral Habitat Protection Areas (6 Areas)	380	111	No bottom contact gear or anchorage
Aleutian Islands Habitat Conservation Area	958,367	279,415	No bottom trawling
Anguniaqvia Niqiqyuam (Darnley Bay) Area of Interest	2,345	684	No bottom trawling
Arctic Closure	511,104	149,014	No commercial fishing
Arctic High Seas Fisheries Moratorium Area (Proposed)	2,804,579	817,684	No commercial fishing
Bering Sea Habitat Conservation Area	159,119	46,392	No bottom trawling
Bogoslof Groundfish Closure Area	36,957	10,775	Closed to commercial fishing for walleye pollock, Atka mackerel, and Pacific cod as part of Steller Sea Lion Protection Measures (see below)
Bowers Ridge Habitat Conservation Zone	18,122	5,284	No bottom trawling, dredging
Central Bering Sea Donut Hole	176,579	51,482	No commercial pollock fishing
Cook Inlet Trawl Closure	19,608	5,717	No bottom trawling
Gulf of Alaska Coral Habitat Protection Areas (5 Areas)	47	14	No bottom contact gear
Gulf of Alaska Slope Habitat Conservation Areas (10 Areas)	7,244	2,112	No bottom trawling
Kodiak Red King Crab Closure	7,403	2,158	No bottom trawling
Nearshore Bristol Bay	65,400	19,067	No trawling
Northern Bering Sea Research Area	211,329	61,614	No bottom trawling
Nunivak Island, Etolin Strait, and Kuskokwim Bay Habitat Conservation Area	33,466	9,757	No bottom trawling
Pribilof Islands Habitat Conservation Zone	19,582	5,709	No trawling
Red King Crab Savings Area	13,715	3,999	No bottom trawling
Southeast Alaska Trawl Closure	212,880	62,066	No trawling
St. Lawrence Habitat Conservation Area	29,006	8,457	No bottom trawling
St. Matthew Habitat Conservation Area	15,359	4,478	No bottom trawling
Steller Sea Lion Protection Measures	160,216	46,712	Closed to commercial fishing for walleye pollock, Atka mackerel, and Pacific cod; gear-specific regulations
Walrus Islands Closure	2,788	813	No commercial groundfish fishing

Sources: National Oceanic and Atmospheric Administration (2016a, b), Marine Conservation Institute (2017), and Regjeringen (2015)

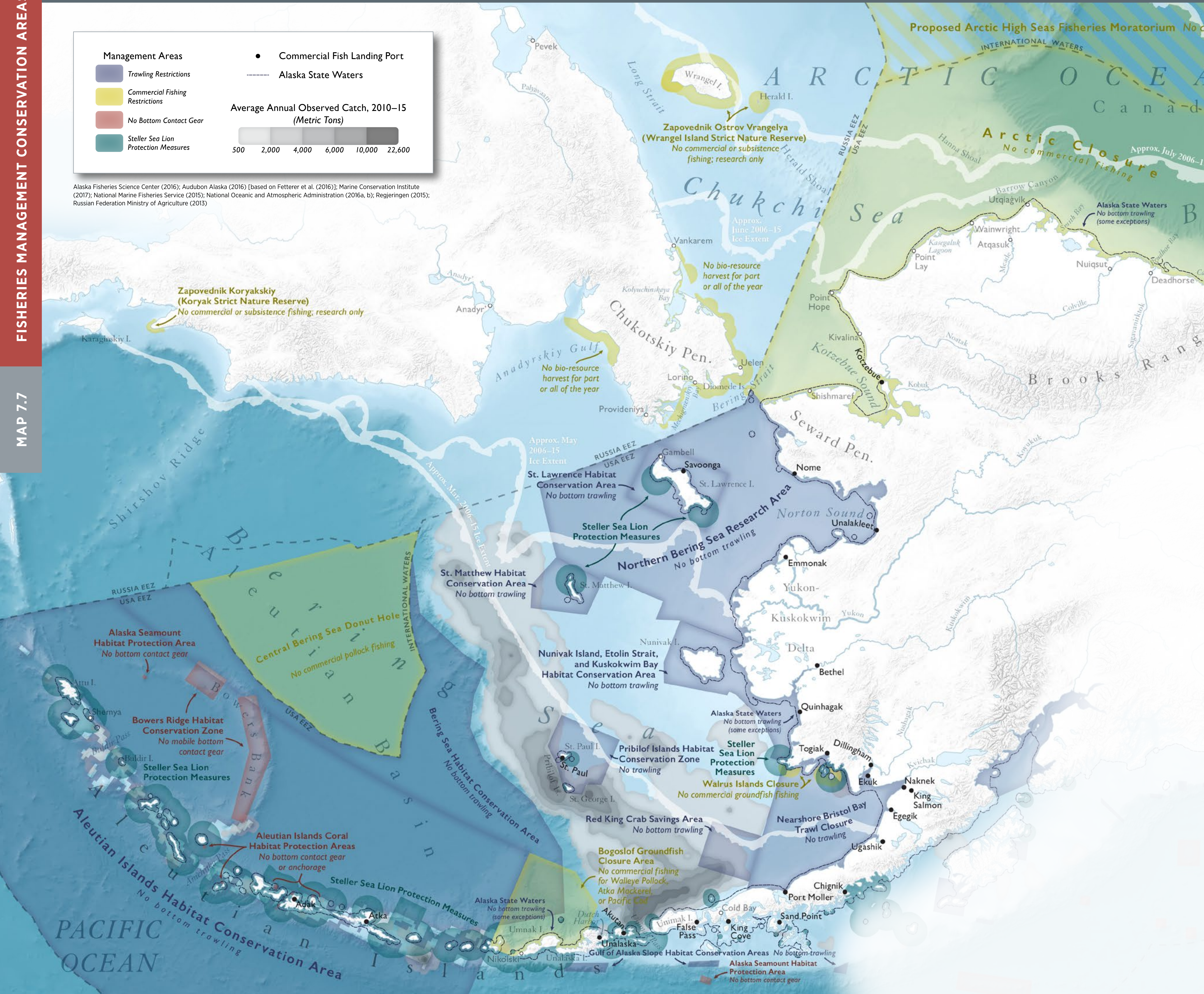
Notes:
The protected Alaska seamounts are Bowers, Brown, Chirikof, Dall, Denson, Derickson, Dickins, Giacomini, Kodiak, Marchand, Odessey, Patton, Quinn, Sirius, Unimak, and Welker.
The protected Aleutian Island coral habitats are in Adak Canyon and off Great Sitkin Island, Bobrof Island, Cape Moffett Island, Semisopochnoi Island, and Ulak Island.
The protected Gulf of Alaska coral habitats are Cape Ommaney 1, Fairweather FN1, Fairweather FN2, Fairweather FS1, and Fairweather FS2.
The conservation areas for Gulf of Alaska slope habitats are Albatross Bank and Cable, and off Cape Suckling, Kayak Island, Middleton Island East, Middleton Island West, Sanak Island, Shumagin Island, Unalaska, and Yakutat.

7.7 FISHERIES MANAGEMENT CONSERVATION AREAS MAP 7.7

Fisheries Management Conservation Areas

Map Authors: Brianne Mecum, Marilyn Zaleski, and Jon Warrenchuk
Cartographer: Daniel P. Huffman

OCEANA Audubon ALASKA



Corey Arnold

Fisheries Management Conservation Areas

Modern fishery management in Alaska began in 1976 with the Fishery Conservation and Management Act, enacted by Congress and later renamed the Magnuson-Stevens Fishery Conservation and Management Act in 1996. The Act extended federal fisheries jurisdiction out to 200 nautical miles (370 km), encompassing the exclusive economic zone (EEZ). Over half of US seafood production comes from Alaska. The Bering Sea ecosystem produces a large proportion of that seafood; up to 2.2 million tons (2 million metric tons) of groundfish are caught in the federal fisheries of the Bering Sea each year. The gray shaded areas depict the average distribution of the observed catch of federally managed groundfish. The federal groundfish fisheries target walleye pollock, yellowfin sole, Pacific cod, Atka mackerel, and other mixed species.

Part of the successful and sustainable management of Alaska's marine resources involves the establishment of marine protected areas and seasonal closures within the EEZ to conserve habitat and protect vulnerable species. Pictured are fishery management conservation areas established to conserve Essential Fish Habitat, protect vulnerable stocks, or minimize interactions with marine mammals. Also shown are protected areas including the "Donut Hole" (an international area formed by the EEZs of the US and Russia in which there is no commercial pollock fishing), the proposed Arctic High Seas Fisheries Moratorium Area in international waters, and two nature reserves in Russian waters (the Koryak Strict Nature Reserve and the Wrangel Island Strict Nature Reserve).

7.8 SUBSISTENCE MAPS ON PAGES 306–311

Subsistence

Audubon Alaska, Sandhill.Culture.Craft, and Stephen R. Braund & Associates

In this Atlas, the term "subsistence" is used in the sense that Alaska Native people predominantly use the term, which contrasts in important, although different, ways from both current federal and state legal understandings. These Alaska Native senses of the term subsistence encompass indigenous hunting, fishing, and gathering activities, "which have a deep connection to history, culture, and tradition, and which are primarily understood to be separate from commercial activities" (Raymond-Yakoubian et al. 2017). Of course, the relationships between cash, commercial activities, and subsistence practices are complex and intertwined in the economies of many northern indigenous communities (Reedy-Maschner 2009, Raymond-Yakoubian and Raymond-Yakoubian 2015). Among many Alaska Native people, there is a discomfort with the term owing to its non-indigenous roots and implications (see Satterthwaite-Phillips et al. 2016), while at the same time it has been adopted and fashioned in its own culturally unique ways. This is reflected in the deep interconnections people express between subsistence activities and other aspects of culture, reflecting the strong relationship of subsistence to the core of contemporary Alaska Native culture and identity (see Wheeler and Thornton 2005). Subsistence practices encompass a lineage of the hunting, gathering, and fishing-related traditions noted above stretching back to time immemorial.

Subsistence also has a long and complex legal and conceptual history. In Alaska, contemporary discussions about subsistence have been heavily shaped by the legacies of the Alaska Native Claims Settlement Act (ANCSA)—which created the current Native land ownership framework; the Alaska National Interest Lands Conservation Act (ANILCA)—which, among other things, guaranteed hunting and fishing rights for non-threatened species on federal lands to rural Alaskans; and State of Alaska subsistence laws (Wheeler and Thornton 2005). Framing the understandings of subsistence, and managing activities related to subsistence, are processes fraught with conflicts, as evidenced, for example, in the differing priorities associated with subsistence under federal and state mandates.

Important aspects of Alaska Native subsistence include its deep interconnections with broader indigenous cosmologies and also with traditional systems of resource management. As Gadamus and Raymond-Yakoubian (2015) have noted in regard to the Bering Strait region, communities have always had their own ways of managing resources such as subsistence-harvested animals—e.g. in terms of timing, duration, and harvest amounts—and this is in part based on their relationships with those animals. E.g. the communities of Gambell and Savoonga on St. Lawrence Island have developed ordinances relating to the take of walrus (*Odobenus rosmarus divergens*), which are based on traditional rules regarding appropriate harvest practices (Metcalf and Robards 2011).

The bodies and systems of knowledge of Alaska Native people, including traditional knowledge (TK, see e.g. Raymond-Yakoubian et al. 2017), inform their subsistence practices, as well as other aspects of indigenous life. This subsistence section of the Atlas presents a compilation of marine subsistence use areas within the Bering, Chukchi, and Beaufort Seas region from a number of studies which spatially documented TK. We were not able to obtain spatial subsistence data for many portions of the project area; lack of information for these regions is not intended to indicate that subsistence is unimportant for people in these areas, rather that we simply did not have data needed for those areas. We believe TK has substantial value and validity, and as such, in the development of this Atlas, we have attempted to gather and represent TK about marine mammal distribution, represent subsistence use areas, and highlight Alaska Native knowledge and concerns about environmental change and other issues affecting subsistence in the Bering, Chukchi, and Beaufort Seas. TK made a valuable contribution to this Ecological Atlas, yet we did not attempt to incorporate TK for all resources or regions, and do not consider our effort to incorporate TK to be comprehensive.

Subsistence whaling is important to indigenous people in many Arctic coastal communities, providing valuable food and preserving cultural heritage.

Nature Picture Library / Alamy Stock Photo

7.8 SUBSISTENCE MAPS ON PAGES 306–311

SUBSISTENCE IN THE PROJECT AREA

Many traditional values associated with subsistence practices inform these activities in and across the regions in the Atlas project area. For example, sharing and not wasting are central tenets of social life and hunting, fishing, and gathering practices (see, for example, Fienup-Riordan 1994, 2000; Magdanz et al. 2007; Raymond-Yakoubian and Raymond-Yakoubian 2015). However, species of particular importance to subsistence users vary regionally, as described below. We attempted to acquire subsistence harvest information throughout the project area, concentrating exclusively on existing, previously published datasets. The two areas in which we were able to acquire and display harvest area data (Bering Strait Region and North Slope Region) include a more robust description of subsistence practices in those regions.

North Slope Region

Iñupiat and their ancestors have inhabited areas of the North Slope for thousands of years with some of the earliest evidence for humans in Alaska dating to more than 11,000 years ago (Kunz and Reanier 1996). Today there are eight Iñupiaq communities on the North Slope including six coastal villages stretching from the Chukchi Sea community of Point Hope, located in northwest Alaska, to the Beaufort Sea community of Kaktovik, located near the border of the US and Canada. All North Slope communities consider subsistence to be a deeply rooted part of their culture, identity, and well-being. For coastal North Slope communities, marine mammals, terrestrial mammals, and non-salmon fishes comprise the bulk of subsistence harvests. Inland communities rely more on terrestrial mammals and fishes and receive marine mammals through trade and gifts with their coastal neighbors. Important species that are harvested within these groups include bowhead whale (*Balaena mysticetes*), seals, beluga whale (*Delphinapterus leucas*), and walrus (*Odobenus rosmarus divergens*) (primarily Chukchi Sea communities), caribou (*Rangifer tarandus*), whitefish (*Coregonus* spp.), cisco (*Coregonus* spp.), and char (*Salvelinus* spp.) (Braund and Burnham 1984; Stephen R. Braund and Associates and Institute of Social and Economic Research 1993a, b; Stephen R. Braund and Associates 2010, 2013a, 2014; Brown et al. 2016). Other resources, while not contributing as much in terms of pounds harvested, include migratory birds, upland game birds, salmon, and vegetation, the harvest of which help to sustain cultural practices, such as sharing, time on the land, and transmission of knowledge.

Spring (April–May) subsistence activity on the North Slope varies among communities. A common focus is on harvesting waterfowl as they migrate through the area; and, in the case of Chukchi Sea communities, spring bowhead whale hunting. Residents also harvest seals beginning in spring and continuing into summer. Fish harvests intensify over the summer (June–August). Caribou subsistence activity occurs year-round, but is particularly common during the summer months when the caribou seek relief from insects in coastal areas, and into the fall. The timing of plant and berry harvests is limited due to a brief growing period and occurs over the summer months into early fall. Fall (September–October) in the North Slope is a particularly important time for Beaufort Sea coastal communities to harvest bowhead whales; in some years Wainwright has also participated in fall whaling. Harvests commonly occur in September and October as the whales pass close to shore during their migration toward more southern waters. Some communities also participate in fall fisheries, such as Nuiqsut's Arctic cisco fishery in October and November. Winter (November–March) is the prime time for hunting and trapping furbearing animals; upland birds are also taken in early winter.

Inuvialuit Settlement Region

The Inuvialuit Settlement Region (ISR) is located in the Yukon and Northwest Territories of the western Canadian Arctic and is home to over 3,000 Inuvialuit people in 6 communities. The majority of households derive a large portion of their food and materials from subsistence harvest. Since the signing of the Inuvialuit Final Agreement with the Canadian Government in 1984, the Inuvialuit have managed their resources with conservation for future generations in mind, using the best available information to inform their annual harvest numbers. As with the people of the North Slope region, the Inuvialuit utilize available marine mammals as a subsistence resource, regularly taking beluga whales, polar bear (*Ursus maritimus*), and ice seals when conditions permit. Birds and eggs are also important food sources, as are caribou, muskoxen (*Ovibos moschatus*), grizzly bear (*Ursus arctos*), muskrat (*Ondatra zibethicus*), and furbearers such as marten (*Martes* spp.), mink (*Neovison vison*), fox (*Vulpes* spp.), and wolf (*Canis lupus*). Fish such as Dolly Varden (*Salvelinus malma*) and broad whitefish (*Coregonus nasus*) are important components of Inuvialuit subsistence take as well (Community of Aklavik et al. 2008, Community of Inuvik et al. 2008, Community of Olokhaktomiut et al. 2008, Community of Paulatuk et al. 2008, Community of Sachs Harbour et al. 2008, Community of Tuktoyaktuk et al. 2008).

Northwest Arctic Region

In northwest Alaska, an area bordered on the north by the North Slope and on the south by the Bering Strait region, the people of the 11 communities of the Northwest Arctic Borough are predominantly Iñupiat (Satterthwaite-Phillips et al. 2016). The subsistence resources utilized in this region are very similar to the Bering Strait region, with some variations in terms of presence, abundance, and harvest opportunities and preferences for each community. For example, caribou is a highly harvested subsistence resource in the Northwest Arctic Borough (Satterthwaite-Phillips et al. 2016). Subsistence species harvested include marine mammals such as walrus, seals, whales, and polar bears; a variety of birds; and terrestrial mammals, particularly moose (*Alces alces*) and caribou in the fall.

Bering Strait Region

Spanning from above the Yukon-Kuskokwim Delta in the south to the Seward Peninsula in the north, indigenous people have lived in the Bering Strait region of Alaska for at least 10,000 years (Hoffecker and Elias 2003). Three cultural groups of indigenous people currently live in this region—Yup'ik people primarily in the southern communities, St. Lawrence Yup'ik people on St. Lawrence Island, and Iñupiat people in the more northern communities. Subsistence activities are extremely important for the cultures, economies, and well-being of the region's communities. Subsistence hunting activities include the hunting of marine mammals such as walrus, seals, whales, and polar bears; a variety of birds; and terrestrial mammals, particularly moose and caribou in the fall. Walrus are primarily hunted in the fall and spring, ice seals can be hunted year-round, and whales are hunted in the spring (Ahmasuk et al. 2008). Reindeer herding was introduced into the region beginning in the 1890s and is active today (Christie and Finnstad 2009). Subsistence fishing is undertaken for all five species of Pacific salmon (*Oncorhynchus nerka, O. tshawytscha, O. gorbuscha, O. kisutch, O. keta*) in the non-winter months, as well as for a wide variety of non-salmon fish (e.g. trout, tomcod, and Pacific halibut (*Hippoglossus stenolepis*)) at various times throughout the year; crabbing in the winter months is also a common subsistence activity (see e.g. Ahmasuk et al. 2008, Raymond-Yakoubian 2013, Raymond-Yakoubian and Raymond-Yakoubian 2015, Raymond-Yakoubian et al. 2017). The gathering of a variety of edible plants (e.g. berries, beach greens, "Eskimo potatoes," willow leaves) is a common subsistence activity in the non-winter months (Raymond-Yakoubian and Raymond-Yakoubian 2015).

Chukotka Region

On the western side of the Bering Strait, the Yup'ik, Coastal Chukchi, Chukchi, and Koryak people of the Chukotka Peninsula have thrived on locally abundant resources for millennia. Using skin boats, wooden dog sleds, harpoon heads made from walrus tusks, and seal-skin floats, the Yup'ik and Coastal Chukchi traditionally harvested gray (*Eschrichtius robustus*), bowhead, and beluga whales; ice seals; and walrus on the northern coasts of the region. Fish and seabirds also play a large role in subsistence livelihood in the area. They continue to harvest these species today, though, as with people living in other parts of the Atlas study area, the range of equipment used for subsistence has changed to include other materials, including steel harpoon points, nylon rope, and aluminum boats with outboard motors.

Further south, the Koryak and Chukchi people rely heavily on massive runs of chum and sockeye salmon, while also harvesting chicks and eggs from the numerous seabird colonies along the coast. They also harvest walrus, both at onshore haulouts and from boats. Though whales are abundant in the southern portion of the Chukotka Peninsula, they are rarely harvested there. Reindeer herding is a common practice in the area, providing a reliable protein source (Bogoslovskaya et al. 2016).

Yukon-Kuskokwim Delta Region
South of the Bering Strait region, there are 56 federally recognized tribes in the Yukon-Kuskokwim Delta region, which spans from Pastol Bay in the north to Goodnews Bay in the south. Athabascan and, predominantly, Yup'ik and Cup'ik peoples live in the communities of this region, and subsistence activities are also very important to the communities of this region. Indigenous views on human-animal relationships, which have been described for many areas of the North including the Yukon-Kuskokwim region, can be seen as one example of the significance of the interconnections between culture and subsistence resources. As Fienup-Riordan (1994, 1999, 2000) has shown, animals are seen in this region as having personhood and agency, and living in a reciprocal relationship with humans. For example, animals are often seen as being aware of human speech and behavior, and can make decisions about who will harvest them based on that knowledge (Fienup-Riordan 1994, 1999, 2000). Resources harvested by the people of this region include birds and eggs, salmon and non-salmon fish, plants, land mammals, and marine mammals such as seals, whales, and walruses (Alaska Department of Fish and Game 2017).

Aleutian/Pribilof Region
Within the 1,100 mile- (1,800 km-) long volcanic Aleutian Island chain of over 70 islands (including the Pribilof Islands to the north) are 16 tribal communities of Unangax̂ people, also referred to as Aleut people (Veltre and Smith 2010). Subsistence continues to be an important component of the culture of the region's people, with marine resources such as fish, marine invertebrates, seabirds and seabird eggs, and pinnipeds making up a substantial portion of many household diets (Veltre 2017). As this region lacks much of the snow and ice common to more northern communities within the project area, many of the resources that are only seasonally available elsewhere are available all year to the Unangax̂ people (Veltre 2017). Marine mammals such as sea otter (*Enhydra lutris*), harbor seal (*Phoca vitulina*), and Steller sea lion (*Eumetopias jubatus*) are common sources of food and materials (White 2013). Northern fur seals (*Callorhinus ursinus*) are less readily available, though they do come ashore on the Pribilof Islands to breed (National Oceanic and Atmospheric Administration 2015). Massive breeding colonies of seabirds are present in this region during the summer months, providing access to meat and eggs for subsistence hunters and their communities (US Geological Survey–Alaska Science Center 2015). The most utilized resource is fish, with many salmon and non-salmon species used throughout the year (Alaska Department of Fish and Game 2017). During the summer months, berries and terrestrial plants become abundant and are eaten fresh or preserved for the winter.

CONSERVATION ISSUES

There are a number of key contemporary issues at the intersection of subsistence, conservation, and natural resource management. One such issue is environmental change, often driven in large part by climate change. Local people have noted extensive effects of climate change on ecosystems and are feeling these impacts acutely in their communities in a variety of ways. For example, vessel traffic in the Bering, Chukchi, and Beaufort Seas has increased, also increasing the potential for environmental harm and conflicts with subsistence, which has led to urgent concern regarding gaps in regulatory and adaptive regimes addressing this increase (Arctic Council 2009; Kawerak 2015, 2016, 2017; Raymond-Yakoubian in press). Climate change has also led to concerns about the health and abundance of marine animal species, triggering management actions and potential conflicts with subsistence users and TK-holders (e.g. Raymond-Yakoubian et al. 2015, Bogoslovskaya et al. 2016). Concerns about the long-term stability of communities have also arisen due to climate change. A number of communities are seeing impacts to the infrastructural stability of their communities from erosion and flooding, and several communities have considered relocation possibilities (see e.g. Bristol Environmental and Engineering 2010, HDR with RIM First People 2016). Environmental changes and the pace of their occurrence, as exemplified by environmental patterns fluctuating outside predictable parameters, have led to deep sociocultural changes as well, creating difficulty in practicing subsistence and transmitting relevant environmental knowledge (Raymond-Yakoubian and Raymond-Yakoubian 2015).

Another key contemporary set of issues, particularly in the Bering Sea and including the Bering Strait, pertains to the impacts of commercial fisheries and fisheries management on subsistence communities. Coastal Alaska indigenous communities have expressed a desire for increased consideration of TK and subsistence concerns in policy discussions relating to commercial fisheries and fisheries management. For example, subsistence fishers in Norton Sound have noticed declines in salmon fisheries over the past five decades, and concomitantly considerable impacts to subsistence activities from diminished returns and management measures. Communities are greatly concerned about the health of fish stocks and fisheries habitat, including effects of environmental change, contaminants, and, perhaps most importantly, salmon bycatch in the Bering Sea pollock and Area M sockeye fisheries. The North Pacific Fishery Management Council (NPFMC) has taken actions to attempt to effect reductions in that bycatch (e.g. North Pacific Fishery Management Council 2015a). Increasing the use of TK, the voices of TK-holders, and the concerns of subsistence communities in federal fisheries management to the mutual benefit of communities and the conservation of fisheries resources has been a longstanding broader desire for Bering Strait and other Western Alaska subsistence communities (Raymond-Yakoubian et al. 2017). The NPFMC has recently taken steps to address this need as part of the current development of a Bering Sea Fisheries Ecosystem Plan (North Pacific Fishery Management Council 2015b, 2016).

Oil and gas exploration and extraction introduce broad-reaching impacts on subsistence throughout the project area, but particularly for North Slope subsistence harvesters who use the Chukchi and Beaufort Seas. Oil and gas exploration and production are currently underway in this region, with a strong likelihood of increased development activity in the future. The impacts of these activities on subsistence stem from changes to ecosystems and disturbance of target species through exploration techniques (such as seismic surveys, drilling, and dredging), infrastructure development, increased vessel traffic, and the threat of a catastrophic spill event through ship wreck, pipeline rupture, or accident involving drilling rigs, storage facilities, or potential future refineries. For further discussion of potential impacts due to development, see the Conservation Issues sections of the Petroleum Exploration and Development, Infrastructure, and Vessel Traffic summaries.

MAPPING METHODS MAPS (7.8.1a–7.8.2)

Subsistence information is mapped on two types of maps. Marine subsistence use areas are shown on seven maps, each pertaining to a species group. A separate map shows relative proportions of marine resources harvested by coastal communities throughout Alaska.

Harvest Areas (Maps 7.8.1a–7.8.1g)
Maps 7.8.1a–7.8.1g show marine areas where use by subsistence harvesters for marine birds and eggs, fish, marine invertebrates, polar bears, seals, walrus, and whales has been documented. Unmarked areas of the maps are areas where we could not obtain needed spatial data, where spatial data do not exist, or are areas not used for subsistence harvest; an unmarked area does not necessarily indicate non-use.

The mapped data were largely provided from two sources: Oceana and Kawerak's Bering Strait Marine Life and Subsistence Use Data Synthesis (Oceana and Kawerak 2014) and data compiled by Stephen R. Braund and Associates (2016).

Data in the Bering Strait region were compiled in Oceana and Kawerak (2014) based on subsistence data collected from TK experts from nine Bering Strait tribes during Kawerak's Ice Seal and Walrus Project in Kawerak (2013), as well as several other data sources. The data were updated based on a February 2017 workshop with Bering Strait region TK experts who reviewed Audubon Alaska's draft subsistence harvest areas maps (Audubon Alaska et al. 2017).

Kanuti National Wildlife Refuge / USFWS

The five salmon species that spawn in the Pacific Arctic are integral components of Alaska Native diet. Salmon may be smoked or dried to preserve it for use throughout the year.

Terri Stinnett Photography

With over 85% of US seabirds utilizing Alaska waters and shores to breed, bird eggs have been a consistent seasonal food source for thousands of years, and continue to be an important aspect of subsistence today.

7.8 SUBSISTENCE MAPS ON PAGES 306–311

For North Slope communities, marine subsistence harvest areas were compiled by Stephen R. Braund and Associates based on numerous data sources published between 1979 and 2014, as listed in the Map Data Sources section.

The "Extent of Marine Subsistence Harvest Areas" line shown on these maps represents the farthest offshore extent of all marine subsistence harvest-area data obtained for our project. As previously indicated, lack of data beyond this line does not necessarily indicate non-use beyond this extent.

Reported Subsistence (Harvest Map 7.8.2)
Map 7.8.2 shows the average per capita harvest of subsistence categories taken from coastal US federal subsistence regions within our project area. Data for these maps were downloaded from the Alaska Department of Fish and Game's Community Subsistence Harvest Information System (CSIS) (Alaska Department of Fish and Game 2017) for the Most Representative Year, as defined by CSIS, from each community in our project area for which a comprehensive survey has been conducted.

To get mean harvest for each subsistence category (marine invertebrates, fish, birds and eggs, land mammals, marine mammals, and vegetation), we averaged the harvested-pounds-per-capita data across each region, which were calculated by Alaska Department of Fish and Game (2017), across each federal subsistence region.

The marine mammal and fish categories are further split into subcategories: seals, whales, polar bears, walrus, and sea lions for marine mammals, and salmon and non-salmon for fish. Harvested-pounds-per-capita for these subcategories were calculated by Alaska Department of Fish and Game (2017) for each community, and we averaged each subcategory across each federal subsistence region. There are other marine mammal subcategories defined in CSIS (such as porpoises) that are not shown on our map. However harvest of these other species subcategories makes up less than 0.1% of total marine mammal pounds-per-capita harvest in the federal subsistence regions within our project area.

Data Quality
Marine subsistence data across the project area are incomplete. In a number of portions of the project area, there were limitations in the availability of spatial data. Data from some regions, though documented, sought but were unavailable for inclusion in this publication: Northwest Arctic Borough's Iñuuniaḷiqput Iḷiḷugu Nunaŋŋuanun: Documenting Our Way of Life through Maps (Satterthwaite-Phillips et al. 2016), data from community conservation plans for communities in the Inuvialuit Settlement Region of Canada (Joint Secretariat Environmental Impact Screening Committee 2008), the Bering Sea Elders Advisory Group's Northern Bering Sea: Our Way of Life (Bering Sea Elders Advisory Group 2011), data from the Bering Sea Sub-Network (available, but used different methods), and spatial harvest-area data from specific subsistence studies conducted by the Alaska Department of Fish and Game. Subsistence data collection focused exclusively on existing, previously published datasets. Of the two datasets we were able to use (for the North Slope and Bering Strait regions), both were collected using robust methods documenting subsistence use by communities. For the North Slope, these data were collected, prepared, and shared with us by Stephen R. Braund and Associates. For the Bering Strait region, our access to the data required a review workshop with their TK experts. See the Introduction Chapter sections on Use of Traditional Knowledge and Subsistence Use Datasets, and A Closer Look: Kawerak's Contribution of Traditional Knowledge. Data for the North Slope were not further reviewed by TK experts from that region.

Subsistence harvest-area data are shown only for portions of Alaska. For regions where marine subsistence data were available and are shown on our maps, polygons indicate that subsistence harvest activities occur in these areas. Unmarked areas are areas where spatial data were not available to us, where information has not been spatially documented, or are areas that are not used for subsistence harvest of a particular species. An unmarked area does not necessarily indicate non-use.

7.8 SUBSISTENCE MAPS ON PAGES 306–311

Similarly, Alaska Department of Fish and Game (2017) subsistence harvest data are available only for the Alaska portion of our project area. These data give a sense of which types of subsistence resources are used by Alaskan communities. However, data for many communities are incomplete, many have never been surveyed, and some have not been surveyed for decades. Community harvest of specific resources fluctuates over time depending on a variety of factors. The average per capita harvest data map should be viewed with these issues in mind.

Reviewers
- Bering Strait Traditional Knowledge-Holder Map Review Workshop participants
- Henry Huntington

MAP DATA SOURCES

Harvest Areas Maps

Birds: Audubon Alaska et al. (2017); Oceana and Kawerak (2014) based on Bering Straits Coastal Resource Service Area (1984), National Oceanic and Atmospheric Administration (1988), and Sobelman (1985); Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Impact Assessment Inc. (1989), Nelson (1981), Pedersen (1979, 1986), Stephen R. Braund and Associates (2003, 2010, 2013c, 2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

Fishes: Audubon Alaska et al. (2017); Oceana and Kawerak (2014) based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), Magdanz and Olanna (1986), National Oceanic and Atmospheric Administration (1988), and Raymond-Yakoubian (2013); Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Brown (1979), Impact Assessment Inc. (1989), Nelson (1981), Pedersen (1979, 1986), Pedersen and Linn (2005), Stephen R. Braund and Associates (2003, 2010, 2013b, 2013c, 2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

Marine Invertebrates: Audubon Alaska et al. (2017); Oceana and Kawerak (2014) based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), Magdanz and Olanna (1986), and National Oceanic and Atmospheric Administration (1988); Stephen R. Braund and Associates compiled based on Pedersen (1979)

Polar Bears: Audubon Alaska et al. (2017); Oceana and Kawerak (2014) based on National Oceanic and Atmospheric Administration (1988) and Sobelman (1985); Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Impact Assessment Inc. (1989), Pedersen (1979, 1986), Stephen R. Braund and Associates (2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

Seals: Audubon Alaska et al. (2017); Oceana and Kawerak (2014) based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), Kawerak (2013), Magdanz and Olanna (1986), National Oceanic and Atmospheric Administration (1988), C. Pungowiyi (pers. comm. 2008), and Sobelman (1985); Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Brown (1979), Impact Assessment Inc. (1989), Nelson (1981), Pedersen (1979, 1986), Stephen R. Braund and Associates (2003, 2010, 2013c, 2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

Walrus: Audubon Alaska et al. (2017); Oceana and Kawerak (2014) based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), Kawerak (2013), National Oceanic and Atmospheric Administration (1988), and C. Pungowiyi (pers. comm. 2008); Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Impact Assessment Inc. (1989), Nelson (1981), Pedersen (1979, 1986), Stephen R. Braund and Associates (2010, 2013c, 2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

Whales: Audubon Alaska et al. (2017); North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003); Oceana and Kawerak (2014) based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), and North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division (2003); Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Impact Assessment Inc. (1989), Nelson (1981), Pedersen (1979, 1986), Stephen R. Braund and Associates (2003, 2010, 2011, 2013c, 2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

Extent of Marine Subsistence Harvest Areas: Compiled data for all species based on all data sources listed above.

Reported Subsistence Harvest Map: Alaska Department of Fish and Game (2017)

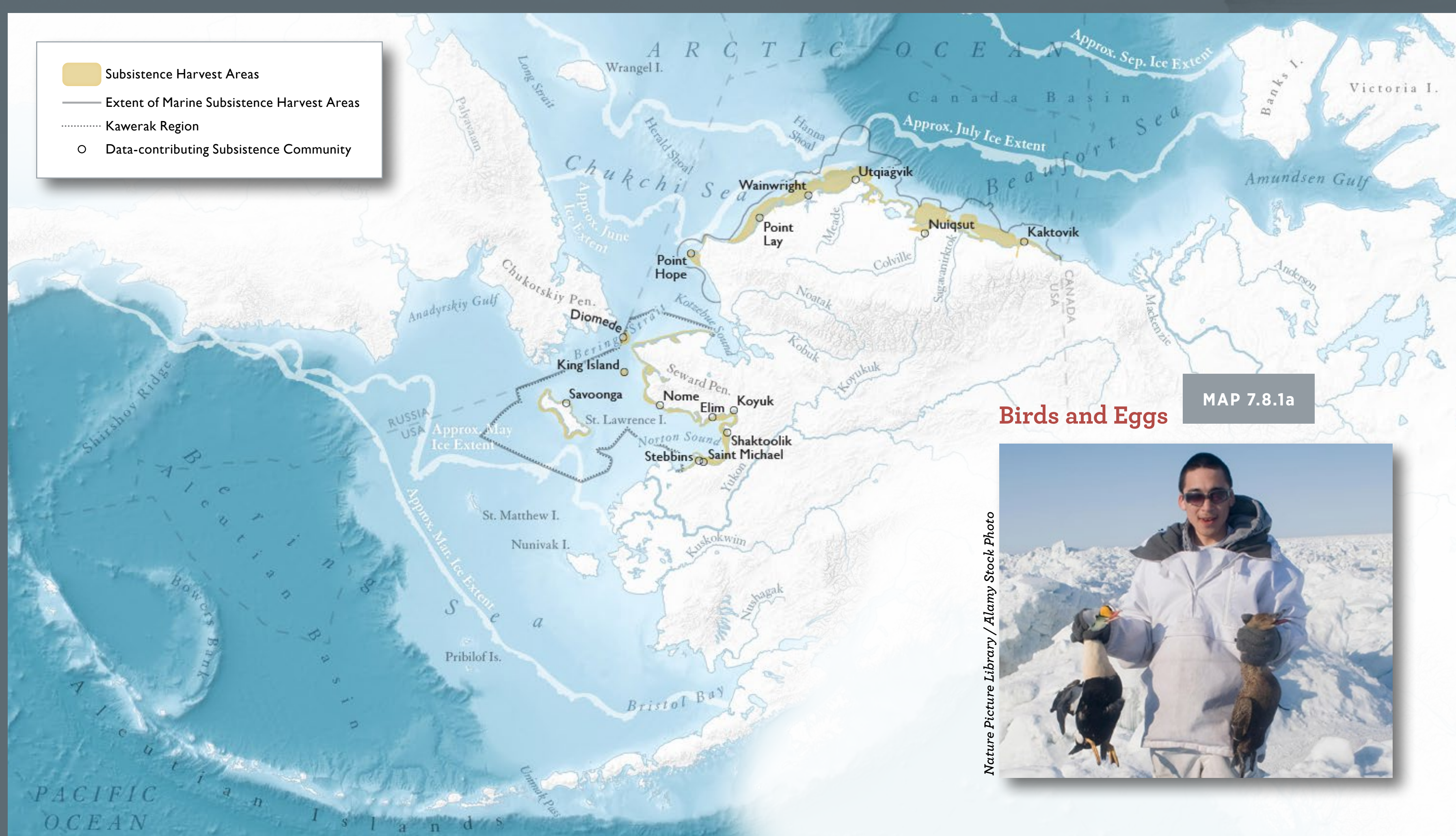
Design Pics Inc / Alamy Stock Photo

Subsistence Harvest Areas by Species

Map Authors: Erika Knight and Max Goldman
Cartographer: Daniel P. Huffman

Subsistence resources are a critical component of the cultural heritage of indigenous peoples, especially in the Arctic. This series of maps shows areas that are used to harvest specific resources in the marine environment for the North Slope and Bering Strait regions. The overall extent in which marine subsistence activities occur across all resources in those two specific regions is also shown. This map depicts subsistence only for the communities highlighted and does not attempt to describe subsistence activities outside of the extent line. Therefore, an absence of data on this map does not necessarily imply an absence of subsistence use.

Michael Cameron / NOAA



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KAWERAK, INC. OCEANA Audubon ALASKA

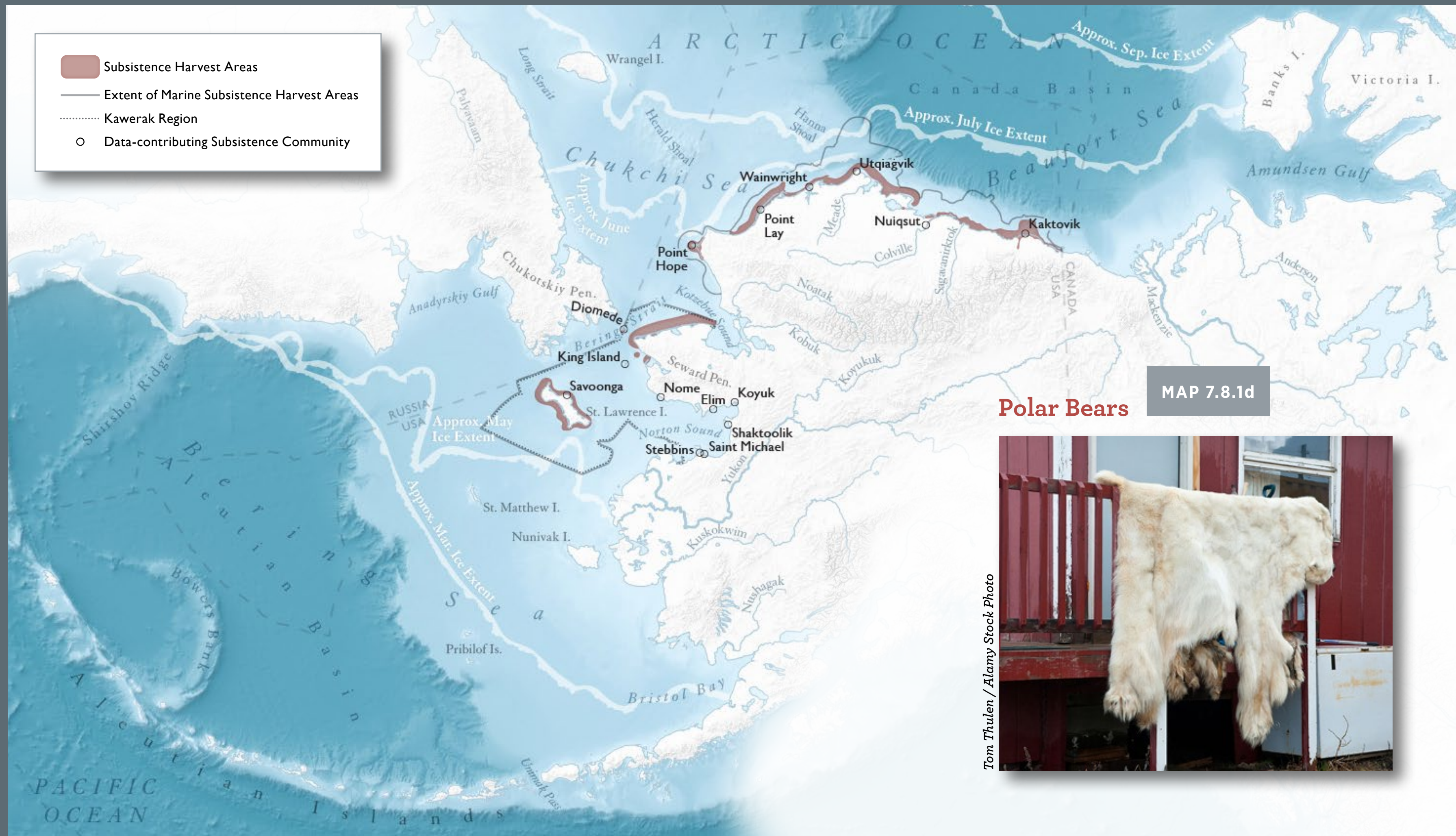
Audubon Alaska et al. (2017); Oceana and Kawerak (2014) [based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), Magdanz and Olanna (1986), National Oceanic and Atmospheric Administration (1988), and Raymond-Yakoubian (2013)]; Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Brown (1979), Impact Assessment Inc. (1989), Nelson (1981), Pedersen (1979, 1986), Pedersen and Linn (2005), Stephen R. Braund and Associates (2003, 2010, 2013b, 2013c, 2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

Audubon Alaska et al. (2017); Oceana and Kawerak (2014) [based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), Magdanz and Olanna (1986), and National Oceanic and Atmospheric Administration (1988)]; Stephen R. Braund and Associates compiled based on Pedersen (1979)

Subsistence Harvest Areas by Species

Map Authors: Erika Knight and Max Goldman
Cartographer: Daniel P. Huffman

KAWERAK, INC. OCEANA Audubon ALASKA



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Audubon Alaska et al. (2017); Oceana and Kawerak (2014) [based on Bering Straits Coastal Resource Service Area (1984), Jorgenson (1984), Kawerak (2013), National Oceanic and Atmospheric Administration (1988), and C. Pungowiyi (pers. comm. 2008)]; Stephen R. Braund and Associates compiled based on Braund and Burnham (1984), Impact Assessment Inc. (1989), Nelson (1981), Pedersen (1979, 1986), Stephen R. Braund and Associates (2010, 2013c, 2014, 2017), and Stephen R. Braund and Associates and Institute of Social and Economic Research (1993a)

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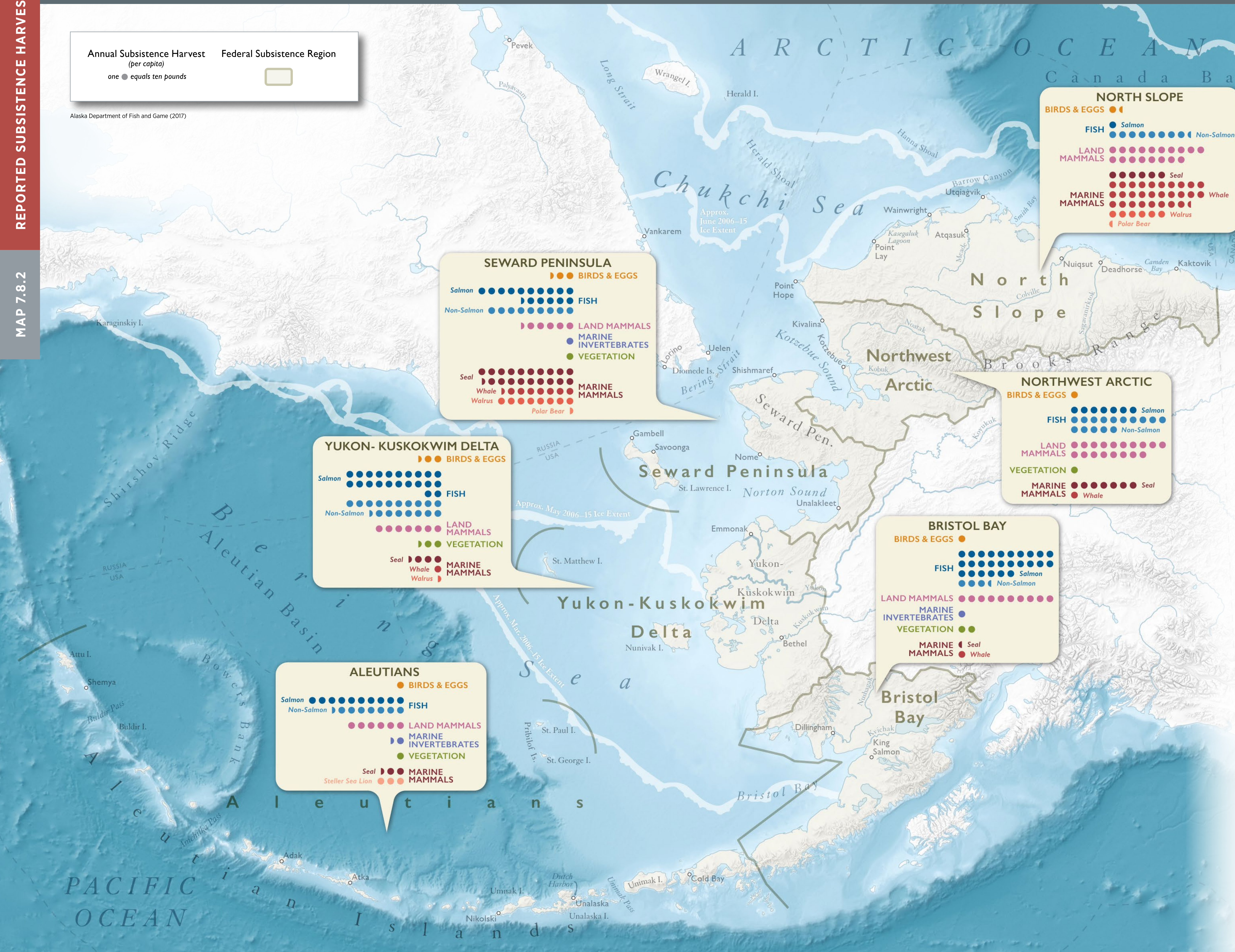
Reported Subsistence Harvest

Map Authors: Erika Knight , Melanie Smith, and Max Goldman
Cartographer: Daniel P. Huffman

Audubon ALASKA



Milo Burcham

Reported Subsistence Harvest

Many Arctic communities consider subsistence to be a deeply rooted part of their culture, identity, and well-being. For coastal communities, the bulk of subsistence harvests are composed of marine mammals, terrestrial mammals, and fishes; inland communities rely more on terrestrial mammals and fishes, and receive marine mammals from their coastal neighbors through trade and gifts. Important marine species harvested within these groups include bowhead whales, beluga whales, seals, walrus, salmon, whitefish, cisco, and char. Other resources, while not contributing as much in terms of pounds harvested, include marine invertebrates, migratory birds, upland game birds, and vegetation. These resources help to sustain cultural practices, such as sharing, time on the land, and the transmission of knowledge. This map shows the average per capita harvest of subsistence resources taken from US federal subsistence regions within our project area.

A Closer Look: The Legal Framework for US Arctic Marine Resource Protection

Susan Culliney

International and domestic laws intersect in the legal landscape of the Bering, Chukchi, and Beaufort Seas, mirroring the Arctic's multi-faceted marine ecology. Before notions of Western law took hold in Arctic waters, the indigenous people of the Arctic coastal waters navigated the marine environment and held a tapestry of beliefs about right and wrong. An in-depth analysis of these concepts is beyond the scope of this writing, but bears consideration in present-day decisions on how Arctic marine laws should operate. Present day laws applicable to this marine landscape touch on ownership, wildlife conservation, resource extraction, pollution prevention and cleanup, and climate change.

JURISDICTION AND OWNERSHIP

There are eight Arctic nations, but only five that touch the Bering, Chukchi, and Beaufort Seas: Canada, the US, Russia, Greenland, and Norway. Other nations may utilize these seas or be affected by activities that happen there. Jurisdiction determines which nation holds decision-making power on all manner of Arctic topics, particularly authority over exploitable resources. The jurisdiction question is one sure to be implicated more and more strongly as once-inaccessible resources, such as fisheries, shipping lanes, and petroleum are uncovered by receding ice.

Early in European wayfaring history, Hugo Grotius' 1609 "freedom of the seas" doctrine held that seafarers should be granted free passage through all marine waters. But as nations grew in awareness and ability to extract their nearshore marine resources, governments tacked away from free seas toward domestic ownership of nearshore waters and submerged lands. While some nations initially used a highly practical 3 nautical mile (5.6 km) "cannon shot" rule to measure their national waters, the 200-nautical-mile (370-km) buffer of authority (the exclusive economic zone, or EEZ) used by the US eventually prevailed in the United Nations Convention on the Law of the Sea (UNCLOS), which still operates today. UNCLOS also dictates ownership of the submerged continental shelf, well beyond 200 nautical miles, the exact extent of which can be geologically technical.

As Arctic ice recedes, potentially revealing new petroleum reserves, disputes over continental shelf ownership could arise. The US has not officially ratified UNCLOS, but UNCLOS represents such strong international norms that the US is effectively held to its strictures under the notion of customary law. Within US territorial waters, the State of Alaska has authority over the first 3 nautical miles (5.5 km) of the ocean under the Submerged Lands Act of 1953. Many coastal US states work cooperatively with the federal government under the Coastal Zone Management Act to issue a plan for sustainable development and environmental protection. The State of Alaska presently has no Coastal Zone Management Plan, after the most recent plan expired in 2011 without a replacement.

MARINE SPECIES PROTECTIONS

Arctic marine wildlife species have long benefitted from a generally remote and unspoiled habitat. This isolation and integrity is rapidly changing, however, with an uptick in vessel traffic, development activities, and climate change. A number of legal protections conserve or regulate harvest of Arctic marine wildlife species. The Convention on Biological Diversity (CBD) aims to conserve biodiversity for humanity's benefit. The Conservation of Arctic Flora & Fauna (CAFF) is the working group under the Arctic Council that reports on Arctic wildlife, habitat, and ecosystem health and issues guidelines. Domestically, the US Endangered Species Act (ESA) safeguards biodiversity by conserving species, designating critical habitat, requiring process when development overlaps with species or their habitat, and limiting take to prescribed activities. In the Arctic marine environment, several species including polar bears (*Ursus maritimus*) and Spectacled Eiders (*Somateria fischeri*) are listed under the ESA.

Arctic birds are additionally afforded protection through several treaties calling for migratory bird conservation. The US has existing treaty obligations from the early 1900s with the United Kingdom, Mexico, Japan, and Russia to conserve the migratory birds shared between nations. In the US, the 1918 Migratory Bird Treaty Act puts US treaty obligations within American borders into effect, by broadly proscribing any take of migratory birds.

Arctic marine mammals are legally protected under other international treaties. The bowhead whale (*Balaena mysticetus*) is the only Arctic species protected by the 1973 Convention on the International Trade in Endangered Species (CITES), which aims to prevent wildlife exploitation by prohibiting international trade in the animal or its parts. The 1973 Agreement on the Conservation of Polar Bears, signed by Canada, Denmark, Norway, the US, and Russia in 1973 regulates hunting and requires participant nations to conserve polar bear habitat and denning sites. The International Whaling Commission presently bans whaling under the 1946 International Convention for the Regulation of Whaling, with an exception for aboriginal harvest, including bowhead whales in Arctic indigenous communities. Marine mammals under US jurisdiction are also granted conservation protections by the 1972 Marine Mammal Protection Act.

International fisheries regimes play an important role for fish stock conservation in the Bering Sea, but do not operate in the Chukchi and Beaufort Seas due to international agreement against commercial fishing in the high Arctic. In 2015, the five Arctic marine nations signed a non-binding "Declaration Concerning the Prevention of Unregulated High Seas Fishing in the Central Arctic Ocean," to halt commercial fishing in the international waters of the Chukchi and Beaufort until scientists can ascertain which fish species are present there, and their population numbers and trends. However, in the Bering Sea, regulated fisheries exist and generally abide by the zones set out by UNCLOS. A coastal nation has exclusive authority to manage fisheries within its EEZ. Outside the EEZ, international jurisdiction takes over; authority over stocks that "straddle" or migrate through the EEZ is framed by the United Nations Convention on Straddling Stocks and Highly Migratory Stocks, though this law only provides customary norms as it has not officially taken effect.

REDUCING IMPACTS AND RISK

In addition to focus on biodiversity and species, the Arctic marine legal regime includes laws that aim to conserve wildlife by reducing threats. Ship traffic through the three seas brings disturbance to wildlife in the form of pollution, collisions, and noise (see the Vessel Traffic summary for more information). Another working group of the Arctic Council, the Protection of the Arctic Marine Environment (PAME), issues guidelines to address impacts to wildlife from offshore activities, such as development and tourism. The International Maritime Organization (IMO) is an arm of the United Nations that puts international vessel traffic treaties into effect and sets parameters on shipping. The IMO gains its authority from several international laws including the 1972 London Convention, and the 1973 International Convention for the Prevention of Pollution from Ships, which regulates dumping of waste and pollution at sea. The IMO recently finalized the Polar Code, which constrains Arctic ship operators to specifications on vessels, discharge, and voyage routes with marine mammal concentrations in mind.

Designating some marine areas as off-limits to certain activities can be a powerful conservation tool. The National Wildlife Refuge System in the US and the Strict Nature Reserves in Russia set aside certain marine areas for wildlife. The IMO may designate "Particularly Sensitive Sea Areas," which place limits on vessel traffic. Although no PSSAs exist in the Arctic Ocean, Arctic shipping routes may make this designation more applicable. In the US, the Coast Guard may conduct a Port Access Route Study (PARS), under the Ports and Waterways Safety Act to determine best routes, and may simultaneously identify Areas to be Avoided (ATBAs) in order to reduce ship strikes with marine wildlife. Setting areas off-limits to oil and gas operations benefits wildlife by reducing noise and avoids placing an oil spill in the midst of ecologically rich zones (though marine oil spills outside these areas do not respect designated boundaries). Under the US Outer Continental Shelf Lands Act, which regulates petroleum lease sales in the Pacific, Atlantic, and Arctic Oceans, the US Department of Interior may choose to defer areas from leasing or not to hold lease sales at all, thereby giving certain areas a temporary reprieve; more permanent protections can come in the form of Presidential "withdrawals" from further leasing. Critical habitat designation under the ESA and Essential Fish Habitat designation under the Magnuson-Stevens Act are two additional designation tools that aim to reduce threats to habitat that vulnerable species rely on. For a more in-depth discussion of conservation area designations, see the Conservation Areas summary.

A changing climate affects ecosystems around the globe, yet perhaps nowhere more dramatically than in the polar oceans. Climate laws generally do not implicate ocean protection in detail, but rather work to reduce carbon emissions, which are well-known contributors to the changes that are coming, and already seen, in our Arctic marine ecosystems. The United Nations Framework Convention on Climate Change (UNFCCC) forms the structure for further protocols and accords, such as the Paris Agreement in 2016, which, for the first time in a UNFCCC Agreement, notes the importance of oceans in climate regulation. The US is a party to the UNFCCC, but not the Paris Agreement. The US Clean Power Plan was created to address obligations under the Paris Agreement, and is slated to be managed by the Environmental Protection Agency, but now faces uncertainty as the US retracts their agreement on the Paris Climate Accord.

The legal landscape is constantly shifting in response to political and societal pressures. Meanwhile, the Arctic is slated to undergo massive transformations in ice cover, sea level rise, and wildlife species ranges. The fate of Arctic jurisdiction and prohibitions will likely run parallel to those ecological changes in the coming years and decades, as nations necessarily need to update the rules that govern what happens in the waters of the Bering, Chukchi, and Beaufort Seas. However, one basic tenet will persist: humans are unavoidably tied to natural resources in the Arctic and other natural environments.

Corey Arnold

7.9 THE LEGAL FRAMEWORK FOR US ARCTIC MARINE RESOURCE PROTECTION

MAP ON PAGES 318–319

Conservation Areas

Melanie Smith, Susan Culliney, and Nils Warnock

The Bering, Chukchi, and Beaufort Seas encompass some of the world's most productive marine ecosystems. Among Arctic regions, these seas are a major hotspot of biological activity. The Bering Sea is known for its extremely high abundance of salmon and seabirds, as well as whales and seals. The US Fish and Wildlife Service (2008) estimated that seabird nesting along the Bering Sea coast accounts for 87% of the seabirds in the US. The Bering Sea provides about half of US fisheries production by weight, as well as the largest sockeye salmon (*Oncorhynchus nerka*) fishery in the world (Overland and Stabeno 2004, McDowell Group 2015). Shared between the Bering and Chukchi Seas, the Bering Strait is one of the world's most productive regions, both in terms of primary productivity (Springer and McRoy 1993) and abundant wildlife populations. The northern Bering Sea and the Chukchi Sea are regions of very high benthic biomass as well, which feeds species such as gray whales (*Eschrichtius robustus*) that migrate here in the summer from as far south as Mexico—the longest known marine mammal migration for any species (Lee 2015). In the Russian Chukchi Sea, Wrangel Island is known for its globally significant densities of denning polar bears (*Ursus maritimus*) and hauled out Pacific walrus (*Odobenus rosmarus divergens*) (UNESCO World Heritage Convention 2004, Rode et al. 2015). The Beaufort Sea provides high densities of various zooplankton, which attracts large groups of bowhead whales (*Balaena mysticetus*) in late summer and fall (Clarke et al. 2017). Home to many globally significant populations of Arctic species, these seas are deserving of careful management and thoughtful conservation measures. In the US, a number of marine mammal, bird, and salmon co-management councils (a cooperative partnership between Alaska Native and federal representatives) along with area protections make up the conservation measures for managing these Arctic seas. (Note that the following information regarding conservation presents a US-centric synopsis of the tools used for conservation designation, with reference to some similar Russian and Canadian designations.)

Amongst the array of state, national, and international conservation laws, conservation area designation can be a powerful tool for safeguarding ecological values like those in the Arctic Ocean (also see *A Closer Look:* The Legal Framework for US Arctic Marine Resource Protection). But drawing lines around specific acres and limiting allowable commercial use within those borders has historically met with limited interest in the Arctic Ocean. Part of the relative lack of appeal is for practical reasons. For instance, fishing laws in the Bering Sea operate according to the zones described in the United Nations Convention on the Law of the Sea; but until recently the sea-ice coverage in the Chukchi and Beaufort Seas had rendered commercial fishing essentially impracticable, and therefore, international fishing regimes largely moot (Pew Charitable Trusts 2012, Canada et al. 2015). Similarly, vessel traffic was not prominent in recent decades due to prohibitively harsh conditions.

Yet, today, interest in developing the Arctic is high. With a changing climate comes greater access and discovery of natural resources, and with those pressures, a greater need for conservation.

SETTING

Corresponding to the associated map, the sections below outline the foremost types of conservation designations for area protections in the Bering, Chukchi, and Beaufort Seas.

Strict Nature Reserves, Wilderness, and National Parks

Russia designates a level of protection greater than the highest form of protection in the US or Canada. Strict nature reserves (called "zapovedniks" in Russian) are similar to designated Wilderness in the US, but "human visitation, use, and impacts are strictly controlled and limited" (International Union for the Conservation of Nature 2017). In the US, designated Wilderness allows human visitation, but does not allow development or motorized use. National parks allow limited development and encourage visitation, while other uses are restricted, such as hunting. National preserves are areas within national parks that may allow extractive uses and/or hunting depending on their enabling legislation.

Strict nature reserves include Wrangel Island and Koryaksky in Russia. Wilderness areas that are adjacent to marine areas in the US include parts of the Arctic and the Alaska Maritime National Wildlife Refuges, and, in Canada, include an area with similar restrictions called the Banks Island Migratory Bird Sanctuary. National parks bordering marine areas include the Bering Land Bridge National Park and Preserve in the US; Beringia National Park in Russia; and Ivvavik, Aulavik, and Tuktut Nogiat National Parks in Canada.

National Wildlife Refuges

US national wildlife refuges are one of the most common and well-known conservation area designations. First conceived by President Teddy Roosevelt in 1903, and codified into law in 1966, the National Wildlife Refuge System acts to "administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans" (16 U.S.C. 668dd(a)(2)). The Alaska Maritime National Wildlife Refuge as it is known today was established in 1980 by the landmark Alaska National Interest Lands Conservation Act (ANILCA). But the Refuge has its origins from the turn of the 20th Century. ANILCA drew together 11 smaller refuges, some of them established by President Teddy Roosevelt in the early 1900s, comprising about 3 million acres (12,000 km^2), and also added 1.9 million acres (7,700 km^2). Today, the Alaska Maritime National Wildlife Refuge encompasses 47,300 miles (76,100 km) of Alaska coastline, and has among its enumerated purposes "to conserve fish and wildlife populations and habitats in their natural diversity"; to provide subsistence opportunities; and to provide a scientific research program (Pub. L. 96-487 Sec. 303(1)(B)). Within the borders of the refuge designation, managers implement conservation programs, such as rat control to benefit nesting seabirds; fishing and hunting and recreation are allowed; and some areas designated as wilderness are subject to more restrictive rules on access and use.

Energy Development Restrictions

Although specific to only one type of development restriction, the Outer Continental Shelf Lands Act (OCSLA), the US law dictating offshore oil-and-gas leasing, can result in significant conservation area protection. OCSLA requires the Bureau of Ocean Energy Management (BOEM) to write five-year agency plans outlining where, when, and how lease sales will occur for the federal outer continental shelf, or OCS. Within these plans, the agency may "defer" sensitive areas where lease sales will not occur for that five-year time period, or may leave entire planning areas out of the plan, thereby effectively pausing leasing for the five-year time period. Beyond the planning process, Section 12(a) of OCSLA allows presidents to "from time to time, withdraw from disposition" any of the unleased federal outer continental shelf.

Past presidents, such as President Clinton in 1998, have used the Section 12(a) withdrawal tool to create temporary withdrawals that came with a pre-determined expiration date. Between 2014 and 2016, President Obama withdrew, without expiration date, 32 million acres (129,429 km^2) in Bristol Bay; 25 million acres (101,171 km^2) in the Bering Sea; 10 million acres (40,469 km^2) covering Hanna Shoal and the Chukchi Corridor (a 25-mile [40-km] coastal buffer important for migrating birds and mammals); and 115 million acres (465,388 km^2) in the Chukchi and Beaufort Seas. But the true permanent nature of these indefinite withdrawals remains unresolved.

In May 2017, President Trump issued an Executive Order revoking the recent OCSLA 12a withdrawal in the Bering Seas. President Trump's Executive Order also modified President Obama's Chukchi and Beaufort withdrawals to leave only National Marine Sanctuaries designated as of July 14, 2008, which had the effect of deleting those earlier Arctic withdrawals. Whether President Obama had the authority to implement "permanent" withdrawals, and correspondingly, whether President Trump now has the authority to undo his predecessor's withdrawals, will eventually be subject to statutory interpretation by the federal courts (League of Conservation Voters et al. v. Trump 2017).

Vessel Traffic Restrictions

The US Coast Guard is responsible for US-based/flagged vessels and international vessels going to or from a port or place out to 200 nautical miles (370 km) in US waters, while the International Maritime Organization (IMO) sets standards and requirements for vessels on international voyages. An Area to Be Avoided (ATBA) is one type of conservation designation related to shipping. ATBAs are most often established to avoid human casualties in areas where navigation is particularly hazardous or to protect national and international recognized habitat and species from ship source pollution.

The Aleutian Islands Risk Assessment, conducted from 2010–2015, recommended five ATBAs to reduce the potential for groundings, which would apply to vessels making transoceanic voyages (Nuka Research and Planning Group 2015). The US Coast Guard delineated the ATBAs, which were subsequently adopted by the IMO and went into effect January 1, 2016, "to reduce the risk of marine casualty and resulting pollution, protect the fragile and unique environment of the Aleutian Islands, and facilitate the ability to respond to maritime emergencies" (US Coast Guard 2014).

The Ports and Waterways Safety Act (33 U.S.C. 1223(c)) requires the US Coast Guard to conduct a Port Access Route Study (PARS) before establishing new or adjusting existing vessel traffic separation schemes or fairways. Between 2001 and 2016, the US Coast Guard conducted a PARS for the eastern Bering Sea, which recommended four new ATBAs and a recommended route, to protect safety, and cultural and environmental resources (US Coast Guard 2016). These measures will be recommended to the IMO for adoption, to apply to domestic and international vessels 400 gross tons and above.

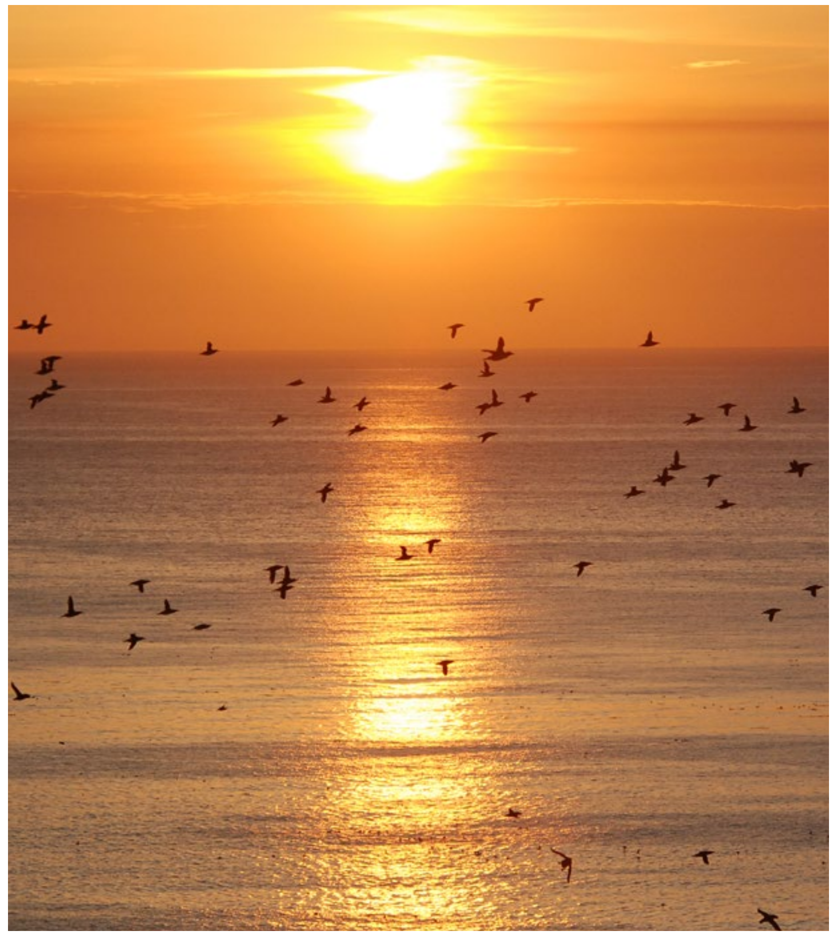
Critical Habitat and Essential Fish Habitat

Another well-known conservation area tool is the critical habitat designation under the US Endangered Species Act (ESA) (16 U.S.C. §§ 1531–1544). When a species is listed as endangered or threatened under the Act, critical habitat is designated concurrently (§ 1533(a)(3)(A)). The Act defines critical habitat as the area "essential to the conservation of the species" (§ 1532(4)), taking into account the best available science, and impacts to economic and national security (§ 1533(b)(2)). A federal action, including permitting, that overlaps with the presence of a listed species or its critical habitat triggers a Section 7 consultation process. This process ensures the action does not jeopardize the species or result in destruction or adverse modification to designated critical habitat (§ 1536). The US Fish and Wildlife Service manages Section 7 consultation for terrestrial species plus polar bears and walrus, and National Marine Fisheries Service does so for all other marine species. Critical habitat designation may seem to imply similar protections as a national wildlife refuge; but in fact is not as strict, in that federal actions will typically move forward, albeit with some limits or mitigation measures in place from the consultation process (§ 1536(b)(3)(A)).

The Magnuson-Stevens Act (MSA) is another legal vehicle for implementing place-based conservation measures. The MSA grants authority to eight regional fishery management councils to write fisheries management plans. These plans typically include designations of Essential Fish Habitat (EFH) (Section 303(a)(7) of the Magnuson-Stevens Act), as areas that are necessary to fish during stages in their life cycles. EFH areas receive special consideration in the form of impact studies, fishing restrictions, and actions to conserve and enhance the designated habitat. There are fishery management plans in place for crab, groundfish, salmon, and scallop fisheries that occur in the Bering Sea (e.g. North Pacific Fishery Management Council 2011). Collectively, these plans identify areas as EFH for numerous species. The current fishery management plan operating in the Arctic Management Area, by contrast, prohibits commercial fishing and therefore does not designate any areas of EFH (North Pacific Fishery Management Council 2009).

Eric Chandler

MAP ON PAGES 318–319



Tasha DiMarzio

Marine Protected Areas

In the US, marine protected areas, or MPAs, "come in a variety of forms and are established and managed by all levels of government...MPAs may be established to protect ecosystems, preserve cultural resources such as shipwrecks and archaeological sites, or sustain fisheries production" (National Oceanic and Atmospheric Administration 2017c). In Alaska, most MPAs are related to commercial fishing restrictions or closures, and do not restrict other activities. Fishing-related MPAs are covered under the Fisheries Management Conservation Areas map (Map 7.7) and summary in this chapter, and are not included here. There are two MPAs in the Canadian Beaufort Sea with more sweeping regulations to prohibit activities that disturb, damage, or destroy marine organisms or habitat. For example, the Anguniaqvia Niqiqyuam MPA (Map 7.7), established in late 2016, protects species including Arctic char (*Salvelinus alpinus*), cod, beluga whales (*Delphinapterus leucas*), polar bears, and birds such as Thick-billed Murres (*Uria lomvia*) (CBC News 2016). In Russia, an MPA surrounds the Wrangel Island Strict Nature Reserve, which prohibits exploration and extraction of minerals, building pipelines, discharge of waste, disturbance of wildlife, fishing, and hunting. Currently, Alaska does not have any designated marine sanctuaries (National Oceanic and Atmospheric Administration 2017c), and is the only coastal US state that does not participate in the Coastal Zone Management Act program (National Oceanic and Atmospheric Administration Office for Coastal Management 2017b).

International Designations

World Heritage Sites are nominated and designated by the United Nations Education, Scientific and Cultural Organization's (UNESCO's) World Heritage Convention based on ten ecological and biological criteria that establish outstanding international importance. In 2004, the Natural System of Wrangel Island Reserve was established as a World Heritage Site. The site, including Wrangel Island, Herald Island, and the immediate surrounding waters, was listed because of the exceptionally high animal and plant biodiversity values of the region, including the world's largest population of Pacific walrus and the highest density of polar bear dens (UNESCO World Heritage Convention 2004).

The Ramsar Convention, also called the *Convention on Wetlands of International Importance especially as Waterfowl Habitat*, is an international treaty of which Russia, Canada, and the US are contracting parties to promote the wise use of wetlands through national land-use planning (Matthews 2013). Established in 1994, Parapolskiy Dol, part of the Koryaksky Strict Nature Reserve, is a Ramsar Site located on the main migratory bird flyway from Southeast Asia to Chukotka. In Canada, the Old Crow Flats Important Bird Area, identified based on the 500,000 waterfowl that breed there in the summer, is a Ramsar Site established in 1982 (Bird Studies Canada 2017). In 1986, Izembek Lagoon was designated as a Ramsar Site, the only one in the Alaska Arctic region, because of its extensive eelgrass beds (*Zostera marina*) and globally important concentrations of Pacific Black Brant (*Branta bernicla nigricans*), Steller's Eider (*Polysticta stelleri*), Emperor Goose (*Chen canagica*), and Steller sea lion (*Eumetopias jubatus*), among other fish and wildlife populations (Andrew 1986).

In 2010, a group of 34 invited Arctic marine experts from several nations, representing academia, government agencies, indigenous knowledge, and non-governmental organizations came together to identify marine areas of international conservation importance. The workshop, held by the Natural Resources Defense Council (NRDC) and the International Union for the Conservation of Nature (IUCN), identified "Ecologically and Biologically Significant Areas," better known as EBSAs (see Speer and Laughlin 2011). The criteria for EBSAs, developed under the United Nations Convention on Biological Diversity, include:

- uniqueness or rarity;
- special importance for life-history stages of species;
- importance for threatened, endangered or declining species and/or habitat;
- vulnerability, fragility, sensitivity, or slow recovery;
- biological productivity;
- biological diversity;
- and naturalness.

Importance of an area for subsistence or cultural heritage was also considered. The Pacific Arctic region (northern Bering, Chukchi, Beaufort, and East Siberian Seas) stood out as a hotspot of Holarctic, and even global, proportions, spurring the organizers to create a higher-level category of "super EBSAs" to convey the international significance of the region. While the EBSAs in the region included a vast majority of the continental shelf waters, as well as some off-shelf areas, the super EBSAs highlighted four areas: St. Lawrence Island, Bering Strait, Chukchi/Beaufort coasts, and Wrangel Island (Speer and Laughlin 2011). These qualifying areas have not yet been designated as EBSAs, but do enjoy some level of protection through various other means described above. Another important resource for conservation areas, many of these places had been previously recognized in the Arctic Council's Arctic Marine Shipping Assessment (AMSA) IIC report which identified Arctic marine areas of heightened ecological and cultural significance.

ECOLOGICAL ROLE

Often, a marine hotspot for one species also hosts a number of other species. As an example, seabird congregations, such as Important Bird Areas (IBAs), are regarded as good indicators of areas of marine productivity for multiple taxa (Lascelles et al. 2012, Ronconi et al. 2012, Smith et al. 2014). The US Coast Guard-recommended Bering Strait ATBA, which is a globally significant Important Bird Area, is also a concentration area for Pacific walrus, bowhead whales, and a major migration bottleneck for Arctic Ocean species. Hanna Shoal, long recognized in administrative decisions as an area worthy of protection (though its current and ongoing status may depend on future agency and judicial decisions), is a hotspot best known for the late-summer high density of Pacific walrus. The Shoal has a high density of benthic biomass that also attracts bearded seals (*Erignathus barbatus*) and gray whales, as well as high pelagic productivity that attracts Ivory Gulls (*Pagophila eburnea*), bowhead and beluga whales, and polar bears.

Marine conservation areas are designated to restrict certain classes of activities, such as bottom trawling, usually in response to potential threats to areas of biological productivity, and aim to promote resilience and protect biological resources from harm. The ecological role of MPAs and other marine conservation measures has been studied in recent years. As advances in marine protection have increased, scientists have assessed the success of these areas in conserving species. Although conservation success is difficult to measure, a study of coral reef health within fisheries-restricted MPAs found that coral cover declined in non-protected areas, while cover stayed constant in protected areas. The same study found that the benefits of MPAs appear to increase with the number of years since establishment (Selig and Bruno 2010). Another study found that MPAs provide larval connectivity among protected and unprotected sites (Christie et al. 2010). Various types of marine conservation areas appear to be most effective when they have been established long term (>10 years), they are of substantial size (>25,000 acres; [100 km^2]), and are well enforced (Halpern and Warner 2002, Selig and Bruno 2010, Edgar et al. 2014).

CONSERVATION ISSUES

Conservation takes many forms—not only as protected areas, but also in management practices. As described further in the Subsistence summary, Native people have been self-regulating their own sustainable use of natural resources for centuries before government regulations were put in place. Today, through cooperative agreement, a number of co-management councils, made up of Alaska Native organizations together with NOAA and USFWS, make informed decisions about marine mammal population management and harvest. These include the Alaska Beluga Whale Committee, the Alaska Eskimo Whaling Commission, the Aleut Marine Mammal Commission, the Alaska Native Harbor Seal Commission, the Eskimo Walrus Commission, the Ice Seal Committee, the Indigenous People's Council for Marine Mammals, the Traditional Council of St. George Island, and the Tribal Government of St. Paul (National Oceanic and Atmospheric Administration 2017a).

Currently, commercial fishing is closed in the US Chukchi and Beaufort Seas, and is regarded as well-managed in the Bering Sea (see the Fisheries Management Conservation Areas map and summary).

Offshore energy development is unlikely in the Bering Sea in the near future, but is developing in the Beaufort Sea, and recently explored in the Chukchi Sea. Effectively responding to an oil spill is extremely difficult in Arctic marine waters (National Research Council 2014), making conservation of key areas and prevention standards for the industry of utmost importance (Audubon Alaska et al. 2016). Furthermore, decisions made outside the border of a conservation area can have serious impacts to the wildlife habitat found within. For instance, an oil spill occurring in lower priority wildlife habitat does not respect the lines drawn on a map that delineate critical seabird habitat. For more information on the risks of oil spills, see the Vessel Traffic and Petroleum Exploration and Development summaries.

Increasing vessel traffic is a concern for this region. The narrow, 53-mile-wide (85-km-wide) Bering Strait is the only marine connection between the Pacific and Arctic Oceans. Around 12 million seabirds nest in colonies along the coasts of Alaska and Chukotka in the Bering Strait region (Seabird Information Network 2011), while millions more marine birds and mammals migrate, forage, molt, breed, and raise young there. Currently less than 500 transits pass through each year, but projections are for nearly 2,000 transits by 2025. Unimak Pass, in contrast, is a major global shipping route that sees more than 5,000 transits annually, and has the highest density of foraging pelagic birds of any area of Alaska (Smith et al. 2014). See *A Closer Look:* Unimak Pass and Bering Strait Vessel Traffic for more information. Both passes have globally significant populations of birds and marine mammals—a major concern if an accident or spill were to occur. Identifying and formalizing ATBAs, routes, and other ship-routing measures is a straightforward and effective way to reduce these risks (covered in detail in the Vessel Traffic summary).

As noted above under Ecological Role, conservation areas contribute to ecosystem resilience. Under a changing climate, the conservation of key areas becomes even more important. Protection of productive ecosystem features, such as upwellings, canyons, shoals, lagoons, leads/polynyas, and shelf breaks, can reduce risks to species by maintaining processes that exhibit climate resilience (e.g. physical features that stimulate continued productivity over time), and allowing space for adaptation to coming changes. Founded on this idea, World Wildlife Fund's RACER program identified several such areas for the Chukotka Peninsula and Beaufort Sea (Christie and Sommerkorn 2012). Many areas that are key to the ecological functioning today, and in the future, are not yet under conservation designation. As we continue to study and understand the Arctic, and to develop its resources, forward-looking conservation measures are warranted.

The placement of conservation area designations and the legal mechanisms needed to achieve those protections will always be subject to some change over time. Some areas, due to their physical geographies and a convergence of ecological factors, will consistently rise to the top as important areas. Other areas may be more important over time in a changing climate. Legal mechanisms and designations that are not used today may be picked up in the future or new designations may be created that do not currently exist, likely when awareness and need reach a critical threshold, or when an event or disaster underscores their necessity. Even designations that today merely recognize the importance of an area can be built upon with additional layers of protection and management. Some of the nation's strongest environmental laws came about following a period of great environmental crisis. The period following the Santa Barbara Channel oil spill gave rise to a marine sanctuary designation around the Channel Islands, founding of Earth Day, and the beginnings of the National Environmental Policy Act that today require our federal government to carefully consider environmental impacts before moving ahead with any major action. Similarly, new types of designations conceived by local communities, which address human concerns related to the conservation and sustainable use of resources, may gain increasing traction in the future. The protection to a particular conservation area is, in the end, only as strong as our society's interest and political willpower in protecting that area and the natural resources found within its borders.

MAPPING METHODS (MAP 7.10)

Conservation areas were derived from the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) working group (2017a). CAFF classifies protections into multiple categories that translate measures across international borders. We mapped the following designations together: Ia—Strict Nature Reserves; Ib—Wilderness Areas; II, III, and V—National Park, National Monument, or Similar; IV—National Wildlife Refuge or Habitat/Species Management Area; VI and Other—Protected Area with Sustainable Use of Natural Resources or MPAs. Ramsar Sites and World Heritage Sites were also downloaded from CAFF (2017c). ATBAs were digitized from the Aleutian Islands Risk Assessment and the eastern Bering Sea PARS (Nuka Research and Planning Group 2015, US Coast Guard 2016). Oil and gas withdrawals were from Bureau of Ocean Energy Management (2016b). The mapped program areas were published in BOEM's 2017–2022 OCS Oil and Gas Leasing Proposed Final Program (Bureau of Ocean Energy Management 2016a). The GIS data were downloaded from Bureau of Ocean Energy Management (2016b) and were current as of April 2017. In May 2017, President Trump wrote an Executive Order retracting the Chukchi and Beaufort Sea withdrawals, among others. The legality of the president's action to reverse withdrawals is under review, therefore the areas under legal review were left on the map and labeled as contested.

MAP DATA SOURCES

Arctic Boundary: Conservation of Arctic Flora and Fauna (2017b)

Areas to be Avoided: Nuka Research and Planning Group (2015); US Coast Guard (2016)

Conservation Areas: Conservation of Arctic Flora and Fauna (2017a)

Oil and Gas Withdrawals: Bureau of Ocean Energy Management (2016a, b)

World Heritage and Ramsar Sites: Conservation of Arctic Flora and Fauna (2017c)

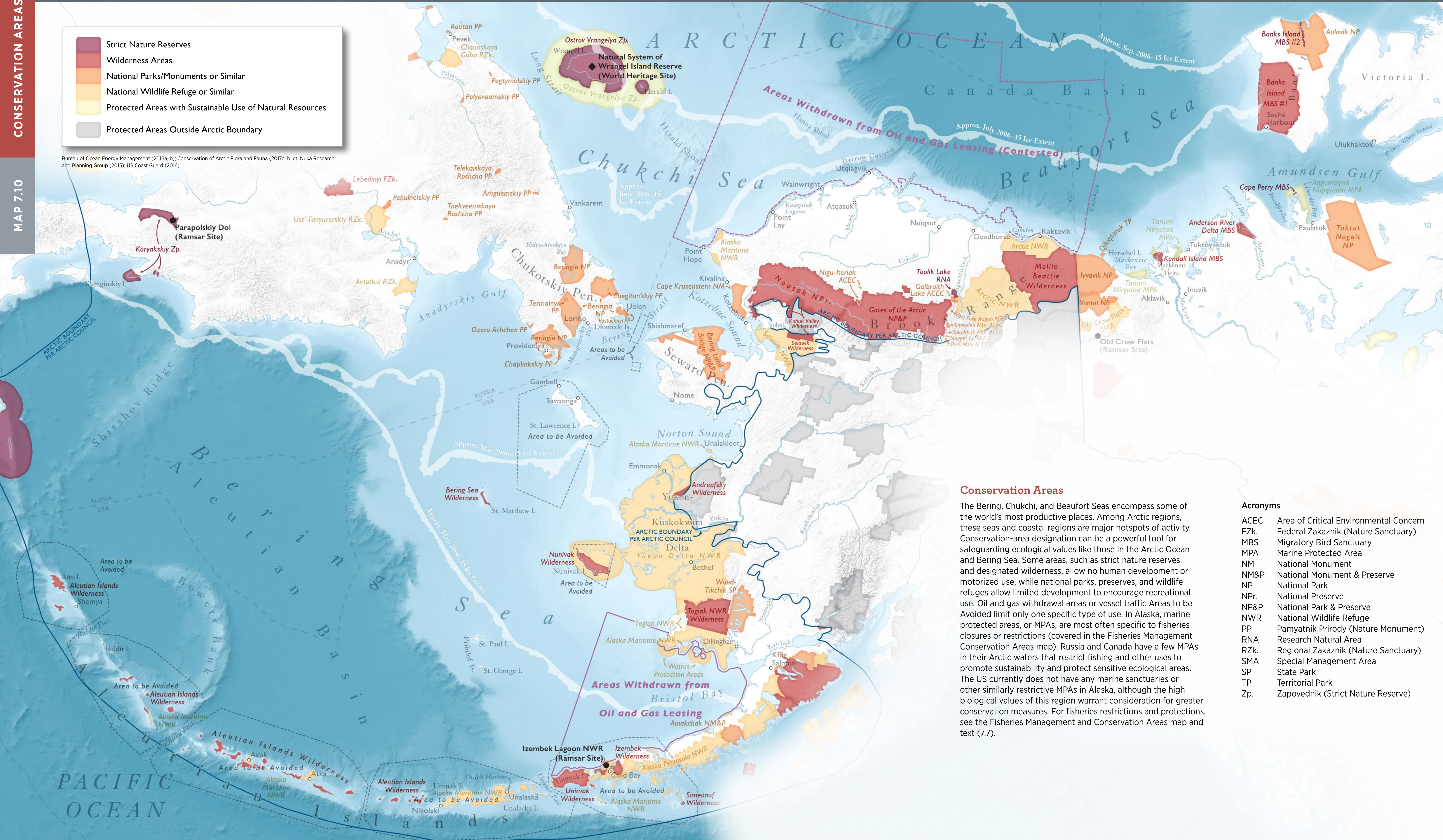
7.10 CONSERVATION AREAS

MAP ON PAGES 318–319

Conservation Areas

Map Authors: Melanie Smith and Erika Knight
Cartographer: Daniel P. Huffman

Audubon ALASKA



Conservation Areas

The Bering, Chukchi, and Beaufort Seas encompass some of the world's most productive places. Among Arctic regions, these seas and coastal regions are major hotspots of activity. Conservation-area designation can be a powerful tool for safeguarding ecological values like those in the Arctic Ocean and Bering Sea. Some areas, such as strict nature reserves and designated wilderness, allow no human development or motorized use, while national parks, preserves, and wildlife refuges allow limited development to encourage recreational use. Oil and gas withdrawal areas or vessel traffic Areas to be Avoided limit only one specific type of use. In Alaska, marine protected areas, or MPAs, are most often specific to fisheries closures or restrictions (covered in the Fisheries Management Conservation Areas map). Russia and Canada have a few MPAs in their Arctic waters that restrict fishing and other uses to promote sustainability and protect sensitive ecological areas. The US currently does not have any marine sanctuaries or other similarly restrictive MPAs in Alaska, although the high biological values of this region warrant consideration for greater conservation measures. For fisheries restrictions and protections, see the Fisheries Management and Conservation Areas map and text (7.7).

Acronyms

ACEC	Area of Critical Environmental Concern
FZk.	Federal Zakaznik (Nature Sanctuary)
MBS	Migratory Bird Sanctuary
MPA	Marine Protected Area
NM	National Monument
NM&P	National Monument & Preserve
NP	National Park
NPr.	National Preserve
NP&P	National Park & Preserve
NWR	National Wildlife Refuge
PP	Pamyatnik Prirody (Nature Monument)
RNA	Research Natural Area
RZk.	Regional Zakaznik (Nature Sanctuary)
SMA	Special Management Area
SP	State Park
TP	Territorial Park
Zp.	Zapovednik (Strict Nature Reserve)

REFERENCES

Ahmasuk, A., E. Trigg, J. Magdanz, and B. Robbins. 2008. Bering Strait Region Local and Traditional Knowledge Pilot Project: A Comprehensive Subsistence Use Study of the Bering Strait Region. North Pacific Research Board Final Report #643. Kawerak, Inc., Nome, AK.

Alaska Department of Fish and Game. 2017. Community Subsistence Information System: Harvest Information. Alaska Department of Fish and Game, Juneau, AK. Accessed online at http://www.adfg.alaska.gov/sb/CSIS/.

Alaska Department of Natural Resources. 2009. Cook Inlet Areawide Oil and Gas Lease Sale: Final Finding of the Director. Alaska Department of Natural Resources, Anchorage, AK.

______. 2017. Office of Project Management and Permitting. Alaska Department of Natural Resources, Anchorage, AK. Accessed online 17 Apr 2017 at http://dnr.alaska.gov/commis/opmp/.

Alaska Department of Transportation and Public Facilities. 2016a. Ferry Terminals in Alaska. Alaska Department of Transportation and Public Facilities, Juneau, AK.

______. 2016b. Public Ports and Harbors in Alaska. Alaska Department of Transportation and Public Facilities, Juneau, AK.

Alaska Energy Authority. 2017a. Bulk Fuel Upgrade Program Factsheet. Alaska Energy Authority, Anchorage, AK.

______. 2017b. Rural Power System Upgrade (RPSU) Factsheet. Alaska Energy Authority, Anchorage, AK.

Alaska Fisheries Science Center. 2016. AFSC/FMA: Web Map Observer Groundfish Data, Alaska, 1993–2015. Alaska Fisheries Science Center Fisheries Monitoring and Analysis Division, Seattle, WA. Accessed online at http://www.afsc.noaa.gov/FMA/spatial_data.htm.

Alaska Marine Highway System. 2016a. 2015 Annual Traffic Volume Report. Alaska Marine Highway System, Department of Transportation and Public Facilities, Ketchikan, AK.

______. 2016b. Ferry Routes. Alaska Department of Transportation and Public Facilities, Alaska Marine Highway System, Juneau, AK.

Alaska Oil and Gas Association. 2015. Alaska Oil and Gas Association Fact Sheet: Cook Inlet Oil & Gas Production. Alaska Oil and Gas Association, Anchorage, AK.

Alaska Oil and Gas Conservation Commission. 2004. 2004 Annual Pool Statistics—Prudhoe Bay Unity, Prudhoe Oil Pool. Alaska Oil and Gas Conservation Commission, Anchorage, AK. Accessed online 17 Apr 2017 at http://doa.alaska.gov/ogc/annual/2004/oil_pools/prudoe%20bay%20-%20oil/prudhoe%20bay,%20prudhoe%20bay/1_Oil_1.html.

______. 2016. Oil and Gas Information System. Alaska Oil and Gas Conservation Commission, Anchorage, AK. Accessed online at http://doa.alaska.gov/ogc/publicdb.html.

Amundsen, R. and G. Hansen. 1908. *The Northwest Passage*. Volume 2. E. P. Dutton and Company, New York, NY.

Andrew, J. 1986. Proposal for the Designation of Izembek Lagoon as a Wetland of International Importance Under Ramsar Convention. US Fish and Wildlife Service Realty Division, Anchorage, AK.

Arctic Council. 2009. Arctic Marine Shipping Assessment 2009 Report. Arctic Council, Tromsø, Norway.

Ashton, G. V., E. I. Riedlecker, and G. M. Ruiz. 2008. First non-native crustacean established in coastal waters of Alaska. *Aquatic Biology* 3:133–137.

Atkinson, C. E. 1988. Fisheries Management: An Historical Overview. *Marine Fisheries Review* 50:111–123.

Audubon Alaska. 2016. Monthly Sea Ice Approximate 2006–2015 Medians GIS File. Audubon Alaska, Anchorage, AK.

______. 2017. Vessel Traffic GIS File. Audubon Alaska, Anchorage, AK.

Audubon Alaska, Kawerak, and Sandhill.Culture.Craft. 2017. Traditional Knowledge-Holder Map Review Workshop. February 21–22, 2017. Nome, AK.

Audubon Alaska, Oceana, Ocean Conservancy, Pew Charitable Trusts, and World Wildlife Fund. 2016. A Synthesis of Important Areas in the US Chukchi and Beaufort Seas: The Best Available Data to Inform Managment Decisions. Audubon Alaska, Anchorage, AK.

Auerbach, N. A., M. D. Walker, and D. A. Walker. 1997. Effects of roadside disturbance on substrate and vegetation properties in Arctic tundra. *Ecological Applications* 7:218–235.

Bailey, K. M. 2011. An empty donut hole: The great collapse of a North American fishery. *Ecology and Society* 16:28.

Bancroft, H. H., A. Bates, I. Petroff, and W. Nemos. 1886. *History of Alaska: 1730–1885*. Volume 33. A. L. Bancroft and Company, San Francisco, CA.

Barringer, F. 2006. Large Oil Spill in Alaska Went Undetected for Days. New York Times, March 15.

Barton, K. 2016. Crews Connect Inuvik to Tuktoyaktuk Highway in the Middle. CBC News, April 8.

Bax, N., A. Williamson, M. Aguero, E. Gonzalez, and W. Geeves. 2003. Marine invasive alien species: A threat to global biodiversity. *Marine Policy* 27:313–323.

Becker, M. S. and W. H. Pollard. 2015. Sixty-year legacy of human impacts on a high Arctic ecosystem. *Journal of Applied Ecology* 53:876–884.

Bell, F. H. 1969. Agreements, Conventions, and Treaties Between Canada and the United States of America with Respect to the Pacific Halibut Fishery. Report of the International Pacific Halibut Commission No. 50. International Pacific Halibut Commission, Seattle, WA.

Bennett, M. 2016a. The Sudden Closure of Canada's Only Deepwater Arctic Port. The Maritime Executive, August 7.

Bennett, M. M. 2016b. Discursive, material, vertical, and extensive dimensions of post-Cold War Arctic resource extraction. *Polar Geography* 39:258–273.

Bering Sea Elders Advisory Group. 2011. The Northern Bering Sea: Our Way of Life. Bering Sea Elders Group and Alaska Marine Conservation Council, Anchorage, AK.

Bering Straits Coastal Resource Service Area. 1984. *Bering Straits Coastal Resource Service Area*. Volume 1–Resource Inventory. Northern Resource Management, Anchorage, AK.

Bernton, H. 1987. Oil Spill Halts Harvest of Seafood in Alaska. Washington Post, July 15.

Bhattarai, P. R. and S. Thompson. 2016. Optimizing an off-grid electrical system in Brochet, Manitoba, Canada. *Renewable and Sustainable Energy Reviews* 53:709–719.

Bird Studies Canada. 2017. IBACanada: Old Crow Flats Site Summary. Bird Studies Canada, Port Rowan, Canada. Accessed online 20 May at http://www.ibacanada.ca/site.jsp?siteID=YK001.

Bogoslovskaya, L. S., I. V. Slugin, I. A. Zagrebin, and I. Krupnik. 2016. *Maritime Hunting Culture of Chukotka: Traditions and Modern Practices*. Shared Beringian Heritage Program, US Department of the Interior, Anchorage, AK.

Born, E. W., F. F. Riget, R. Dietz, and D. Andriashek. 1999. Escape responses of hauled out ringed seals (*Phoca hispida*) to aircraft disturbance. *Polar Biology* 21:171–178.

Bornstein, J. M., J. Adams, B. Hollebone, T. King, P. V. Hodson, and R. S. Brown. 2014. Effects-driven chemical fractionation of heavy fuel oil to isolate compounds toxic to trout embryos. *Environmental Toxicology and Chemistry* 33:814–824.

Boute, A. 2016. Off-grid renewable energy in remote Arctic areas: An analysis of the Russian Far East. *Renewable and Sustainable Energy Reviews* 59:1029–1037.

Braund, S. R. and D. Burnham. 1984. Subsistence economics and marine resource use patterns, *In Proceedings of a Synthesis Meeting: Barrow Arch Environment and Possible Consequences of Planned Offshore Oil and Gas Development*. Prepared by LGL Ecological Research Associates, Inc. Prepared for Minerals Management Service and National Oceanic and Atmospheric Administration, Girdwood, AK.

Bristol Environmental and Engineering. 2010. Shishmaref Relocation Plan Update: Final. Prepared for Shishmaref Erosion and relocation Coalition and Kawerak, Inc., Anchorage, AK.

Brown, C., N. Braem, M. Kostick, A. Trainor, L. Slayton, D. Runfola, E. Mikow, H. Ikuta, C. McDevitt, J. Park, and J. Simon. 2016. Harvests and Uses of Wild Resources in 4 Interior Alaska Communities and 3 Arctic Alaska Communities. Technical Paper No. 426. Alaska Department of Fish and Game Division of Subsistence, Fairbanks, AK.

Brown, W. 1979. Nuiqsut Paisanich: Nuiqsut Heritage, a Cultural Plan. Prepared for the Village of Nuiqsut and the North Slope Borough Planning Commission on History and Culture, Anchorage, AK.

Bureau of Land Management. 2014. Final Supplemental Environmental Impact Statement for the Alpine Satellite Development Plan for the Proposed Greater Mooses Tooth One Development Project. Department of the Interior, Anchorage, AK.

Bureau of Ocean Energy Management. 2012. ION Geophysical 2012 Seismic Survey: Beaufort Sea and Chukchi Sea, Alaska. Bureau of Ocean Energy Management, Alaska OCS Region, Anchorage, AK.

______. 2015. Chukchi Sea Planning Area Oil and Gas Lease Sale 193 Final Second Supplemental Environmental Impact Statement. Bureau of Ocean Energy Management, Anchorage, AK.

______. 2016a. 2017–2022 Outer Continental Shelf Oil and Gas Leasing Proposed Final Program. Bureau of Ocean Energy Management, Washington, DC.

______. 2016b. Alaska Cadastral Data. Bureau of Ocean Energy Management, Washington, DC. Accessed online at http://www.boem.gov/Oil-and-Gas-Energy-Program/Mapping-and-Data/Alaska.aspx.

Burger, A. E. and D. M. Fry. 1993. Effects of oil pollution on seabirds in the northeast Pacific, *In The Status, Ecology, and Conservation of Marine Birds of the North Pacific*. K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey eds., pp. 254–263. Canadian Wildlife Service, Ottawa, Canada. Accessed online at http://pacificseabirdgroup.org/psg-publications/symposia/the-status-ecology-and-conservation-of-marine-birds-of-the-north-pacific/.

Burke, J. 2012. Fuel Delivery to Nome, Alaska: A Mission of Economics or Humanitarianism? Alaska Dispatch News, January 18.

Byrd, G. V. and L. Daniel. 2008. Bird Species Found Oiled, December 2004–January 2005, at Unalaska Island Following the M/V Selendang Ayu Oil Spill. US Fish and Wildlife Service Alaska Maritime National Wildlife Refuge, Homer, AK.

Caelus Energy. 2017. Smith Bay Project. Caelus Energy LLC, Dallas, TX. Accessed online 13 June 2017 at http://caelusenergy.com/smith-bay-project/.

Calder, R. S. D., A. T. Schartup, M. Li, A. P. Valberg, P. H. Balcom, and E. M. Sunderland. 2016. Future impacts of hydroelectric power development on methylmercury exposures of Canadian indigenous communities. *Environmental Science and Technology* 50:13115–13122.

Calef, G. W., E. A. DeBock, and G. M. Lortie. 1976. The reaction of barren-ground caribou to aircraft. *Arctic* 29:201–212.

Canada, the Kingdom of Denmark, the Kingdom of Norway, the Russian Federation, and the United States of America. 2015. Declaration Concerning the Prevention of Unregulated High Seas Fishing in the Central Arctic Ocean, signed in Oslo 16 July 2015. Accessed online at https://www.regjeringen.no/globalassets/departementene/ud/vedlegg/folkerett/declaration-on-arctic-fisheries-16-july-2015.pdf.

Canadian Electricity Association. 2016. Power for the Future: Electricity Map. Canadian Electricity Association, Ottawa, Canada. Accessed online at http://powerforthefuture.ca/electricity-411/electricity-map/.

Carbon Monitoring for Action. 2016. Carbon Monitoring for Action (CARMA) Power Plant Database. Carbon Monitoring for Action, Washington, DC. Accessed online at http://carma.org/dig/show/carbon+plant.

Carlton, J. T. 2001. The scale and ecological consequences of biological invasions in the world's oceans, *In Invasive Species and Biodiversity Management*. O. T. Sandlund, P. J. Schei, and A. Viken eds., pp. 195–211. Springer Netherlands, Dordrecht, Netherlands.

CBC News. 2015a. Hydro-Quebec to Clean Up 13,500-litre Diesel Spill in Inukjuak. CBC News, September 18.

______. 2015b. Ivujivik Fuel Spill Will Not Harm Ocean, Says Hydro-Quebec. CBC News, August 6.

______. 2016. New Marine Protected Area Established in Beaufort Sea's Darnley Bay. CBC News, November 16.

Charpentier, R. R. and D. L. Gautier. 2011. US Geological Survey Circum-Arctic Resource Appraisal (CARA)—Introduction and summary of organization and methods, *In Arctic Petroleum Geology*. A. M. Spencer, A. F. Embry, D. L. Gautier, A. V. Stoupakova, and K. Sørensen eds., pp. 145–150. Geological Society of London, London, United Kingdom.

Charpentier, R. R., T. R. Klett, and E. D. Attanasi. 2008. Database for Assessment Unit-Scale Analogs (Exclusive of the United States). US Geological Survey Open-File Report 2007-1404. US Geological Survey, Reston, VA.

Christie, A. and G. Finnstad. 2009. Reindeer in the "Great Land": Alaska's red meat industry. *Journal of Agricultural and Food Information* 10:354–373.

Christie, M. R., B. N. Tissot, M. A. Albins, J. P. Beets, Y. Jia, D. M. Ortiz, S. E. Thompson, and M. A. Hixon. 2010. Larval Connectivity in an Effective Network of Marine Protected Areas. *PLoS ONE* 5:e15715.

Christie, P. and M. Sommerkorn. 2012. RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience. World Wildlife Fund, Global Arctic Programme, Ottawa, Canada.

Citta, J. J., L. T. Quakenbush, S. R. Okkonen, M. L. Druckenmiller, W. Maslowski, J. Clement-Kinney, J. C. George, H. Brower, R. J. Small, C. J. Ashjian, L. A. Harwood, and M. P. Heide-Jørgensen. 2015. Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012. *Progress in Oceanography* 136:201–222.

Clarke, J. T., A. A. Brower, M. C. Ferguson, and A. L. Willoughby. 2017. Distribution and Relative Abundance of Marine Mammals in the Eastern Chukchi and Western Beaufort Seas, 2015. Annual Report, OCS Study BOEM 2017-019. National Oceanic and Atmospheric Administration, National Marine Mammal Laboratory, Alaska Fisheries Science Center, Seattle, WA.

Clarke, J. T., M. C. Ferguson, C. Curtice, and J. Harrison. 2015. Biologically important areas for cetaceans within US waters—Arctic region. *Aquatic Mammals* 41:2–16.

Community of Aklavik, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Aklavik Inuvialuit Community Conservation Plan. Community of Aklavik, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Aklavik, Canada.

Community of Inuvik, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Inuvik Inuvialuit Community Conservation Plan. Community of Inuvik, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Inuvik, Canada.

Community of Olokhaktomiut, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Olokhaktomiut Inuvialuit Community Conservation Plan. Community of Olokhaktomiut, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Olokhaktomiut, Canada.

Community of Paulatuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Paulatuk Inuvialuit Community Conservation Plan. Community of Paulatuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Paulatuk, Canada.

Community of Sachs Harbour, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Sachs Harbour Inuvialuit Community Conservation Plan. Community of Sachs Harbour, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Sachs Harbour, Canada.

Community of Tuktoyaktuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat. 2008. Tuktoyaktuk Inuvialuit Community Conservation Plan. Community of Tuktoyaktuk, Wildlife Management Advisory Council (NWT), and Joint Secretariat, Tuktoyaktuk, Canada.

Connors, P. G., C. S. Connors, and K. G. Smith. 1981. *Shorebird Littoral Zone Ecology of the Alaskan Beaufort Coast*. University of California, Bodega Marine Laboratory, Bodega Bay, CA.

Conservation of Arctic Flora and Fauna. 2017a. Arctic Protected Areas, 2017. CAFF Arctic Biodiversity Data Service, Akureyri, Iceland. Accessed online at https://www.abds.is/.

______. 2017b. Boundary for Conservation of Arctic Flora and Fauna (CAFF) Working Group of the Arctic Council. CAFF Arctic Biodiversity Data Service, Akureyri, Iceland. Accessed online at https://www.abds.is/.

______. 2017c. Distribution of Ramsar and World Heritage Sites within the CAFF Boundary, 2016. CAFF Arctic Biodiversity Data Service, Akureyri, Iceland. Accessed online at https://www.abds.is/.

Cott, P. A., A. Schein, B. W. Hanna, T. A. Johnston, D. D. MacDonald, and J. M. Gunn. 2015. Implications of linear developments on northern fishes. *Environmental Reviews* 23:177–190.

Cronin, M. A., W. B. Ballard, J. D. Bryan, B. J. Pierson, and J. D. McKendrick. 1998. Northern Alaska oil fields and caribou: A commentary. *Biological Conservation* 83:195–208.

Davis, R. W., T. M. Williams, J. A. Thomas, R. A. Kastelein, and L. H. Cornell. 1988. The effects of oil contamination and cleaning on sea otters (*Enhydra lutris*). II. Metabolism, thermoregulation, and behavior. *Canadian Journal of Zoology* 66:2782–2790.

de Rivera, C. E., B. P. Steves, P. W. Fofonoff, A. H. Hines, and G. M. Ruiz. 2011. Potential for high-latitude marine invasions along western North America. *Diversity and Distributions* 17:1198–1209.

DeMarban, A. 2017a. Explorer Plans First Test of Fracking Potential in North Slope Shale. Alaska Dispatch News, April 23.

______. 2017b. Fuel Spill Discovered in Northern Alaska Village After Storm. Alaska Dispatch News, January 11.

Derksen, D. V., W. D. Eldridge, and M. W. Weller. 1982. Habitat ecology of Pacific Black Brant and other geese moulting near Teshekpuk Lake, Alaska. *Wildfowl* 33:39–57.

Dlouhy, J. A. 2017. Trump Weighing Eni's Arctic Drilling Bid in Post-Obama Pivot. Bloomberg, March 16.

Drachev, S. S., N. A. Malyshev, and A. M. Nikishin. 2010. Tectonic history and petroleum geology of the Russian Arctic shelves: An overview. *Petroleum Geology Conference Series 2010* 7:591–619.

Drewitt, A. L. and R. H. Langston. 2008. Collision effects of wind-power generators and other obstacles on birds. *Annals of the New York Academy of Sciences* 1134:233–266.

Ebbert, S. E. and G. V. Byrd. 2002. Eradications of invasive species to restore natural biological diversity on Alaska Maritime National Wildlife Refuge, *In Turning the Tide: The Eradication of Invasive Species*. C. R. Veitch and M. N. Clout eds., pp. 102–109. IUCN Invasive Species Specialist Group, Gland, Switzerland and Cambridge, United Kingdom.

Edgar, G. J., R. D. Stuart-Smith, T. J. Willis, S. Kininmonth, S. C. Baker, S. Banks, N. S. Barrett, M. A. Becerro, A. T. F. Bernard, J. Berkhout, C. D. Buxton, S. J. Campbell, A. T. Cooper, M. Davey, S. C. Edgar, G. Forsterra, D. E. Galvan, A. J. Irigoyen, D. J. Kushner, R. Moura, P. E. Parnell, N. T. Shears, G. Soler, E. M. A. Strain, and R. J. Thomson. 2014. Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506:216–220.

Environmental Protection Agency. 1999. BP Exploration [Alaska] Pleads Guilty To Hazardous Substance Crime Will Pay $22 Million, Establish Nationwide Environmental Management System. Environmental Protection Agency, Washington, DC. Accessed online at https://yosemite.epa.gov/opa/admpress.nsf/016bcfb1deb9fecd85256aca005d74df/5d61856989631e20852567f6004bbbff?OpenDocument.

exactEarth. 2017. AIS Shipping Data, 2014–2016. Cambridge, Canada.

Exxon Valdez Oil Spill Trustee Council. 2014. *Exxon Valdez* Oil Spill Restoration Plan: 2014 Update, Injured Resources and Services. Exxon Valdez Oil Spill Trustee Council, Anchorage, AK.

Fay, G., A. V. Melendez, and C. West. 2013. Alaska Energy Statistics 1960–2011. Institute of Social and Economic Research, University of Alaska Anchorage, Anchorage, AK.

Fechhelm, R. G. 1999. The effect of new breaching in a Prudhoe Bay causeway on the coastal distribution of humpback whitefish. *Arctic* 52:386–394.

Fechhelm, R. G., L. R. Martin, B. J. Gallaway, W. J. Wilson, and W. B. Griffiths. 1999. Prudhoe Bay causeways and the summer coastal movements of Arctic cisco and least cisco. *Arctic* 52:139–151.

Felix, N. A. and M. K. Raynolds. 1989. The effects of winter seismic trails on tundra vegetation in northeastern Alaska, USA. *Arctic and Alpine Research* 21:188–202.

Ferguson, M. C., J. Waite, C. Curtice, J. Clarke, and J. Harrison. 2015. Biologically important areas for cetaceans within US waters—Aleutian Islands and Bering Sea region. *Aquatic Mammals* 41:79–93.

Fetterer, F., K. Knowles, W. Meier, and M. Savoie. 2016. Sea Ice Index, Version 2. National Snow and Ice Data Center, Boulder, CO.

Fienup-Riordan, A. 1994. *Boundaries and Passages: Rule and Ritual in Yup'ik Eskimo Oral Tradition*. University of Oklahoma Press, Norman, OK.

______. 1999. Yaqulget qaillun pilartat (what the birds do): Yup'ik Eskimo understandings of geese and those who study them. *Arctic* 52:1–22.

______. 2000. *Hunting Tradition in a Changing World: Yup'ik Lives in Alaska Today*. Rutgers University Press, London, United Kingdom.

Forgey, P. 2012. "Fracking" for oil likely to grow in Alaska. Juneau Empire, March 23.

Furness, R. W., H. M. Wade, and E. A. Masden. 2013. Assessing vulnerability of marine bird populations to offshore wind farms. *Journal of Environmental Management* 119:56–66.

Gadamus, L. and J. Raymond-Yakoubian. 2015. A Bering Strait indigenous framework for resource management: Respectful seal and walrus hunting. *Arctic Anthropology* 52:87–101.

Gautier, D. L., K. J. Bird, R. R. Charpentier, A. Grantz, D. W. Houseknecht, T. R. Klett, T. E. Moore, J. K. Pitman, C. J. Schenk, J. H. Schuenemeyer, K. Sørensen, M. E. Tennyson, Z. C. Valin, and C. J. Wandrey. 2009. Assessment of Undiscovered Oil and Gas in the Arctic. *Science* 324:1175–1179.

George, J. C., L. M. Philo, K. Hazard, D. Withrow, G. M. Carroll, and R. Suydam. 1994. Frequency of killer whale (*Orcinus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort Seas stock. *Arctic* 47:247–255.

Girard, M. and C. Dumont. 1996. Varying mercury exposure with varying food source in a James Bay Cree community. *Arctic Medical Research* 55:69–74.

Grantz, A., P. E. Hart, and V. A. Childers. 2011. Chapter 50: Geology and tectonic development of the Amerasia and Canada Basins, Arctic Ocean. *Geological Society Memoir* 35:771–799.

Grantz, A., R. A. Scott, S. S. Drachev, T. E. Moore, and Z. C. Valin. 2010. Sedimentary Successions of the Arctic Region. AAPG Datapages. Accessed online at http://www.datapages.com/gis-map-publishing-program/gis-open-files/geographic/sedimentary-successions-of-the-arctic-region-by-grantz-et-al-2010.

Grebmeier, J. M., B. A. Bluhm, L. W. Cooper, S. L. Danielson, K. R. Arrigo, A. L. Blanchard, J. T. Clarke, R. H. Day, K. E. Frey, R. R. Gradinger, M. Kędra, B. Konar, K. J. Kuletz, S. H. Lee, J. R. Lovvorn, B. L. Norcross, and S. R. Okkonen. 2015a. Ecosystem characteristics and processes facilitating persistent macrobenthic biomass hotspots and associated benthivory in the Pacific Arctic. *Progress in Oceanography* 136:92–114.

Grebmeier, J. M., L. W. Cooper, C. A. Ashjian, B. A. Bluhm, R. B. Campbell, K. E. Dunton, J. Moore, S. Okkonen, G. Sheffield, J. Trefry, and S. Y. Pasternak. 2015b. Pacific Marine Arctic Regional Synthesis (PacMARS) Final Report. North Pacific Research Board, Anchorage, AK.

Grebmeier, J. M., L. W. Cooper, H. M. Feder, and B. I. Sirenko. 2006. Ecosystem dynamics of the Pacific-influenced northern Bering and Chukchi Seas in the Amerasian Arctic. *Progress in Oceanography* 71:331–361.

Griffiths, W. B., R. G. Fechhelm, B. J. Gallaway, L. R. Martin, and W. J. Wilson. 1998. Abundance of selected fish species in relation to temperature and salinity patterns in the Sagavanirktok Delta, Alaska, following construction of the Endicott Causeway. *Arctic* 51:94–104.

Hall, B. D., V. L. St. Louis, K. R. Rolfhus, R. A. Bodaly, K. G. Beaty, M. J. Paterson, and K. A. Peech Cherewyk. 2005. Impacts of reservoir creation on the biogeochemical cycling of methyl mercury and total mercury in boreal upland forests. *Ecosystems* 8:248–266.

Hall, J. D. 2008. Oooguruk Project Offshore Alaska. Offshore, August 1.

Halpern, B. S. and R. R. Warner. 2002. Marine reserves have rapid and lasting effects. *Ecology Letters* 5:361–366.

HDR with RIM First People. 2016. Shaktoolik Strategic Management Plan. Prepared for the State of Alaska Department of Commerce, Community, and Economic Development on behalf of the Community of Shaktoolik, Shaktoolik, AK.

Heim, K. C., M. S. Wipfli, M. S. Whitman, C. D. Arp, J. Adams, and J. A. Falke. 2015. Seasonal cues of Arctic grayling movement in a small Arctic stream: The importance of surface water connectivity. *Environmental Biology of Fishes* 99:49–65.

Herrmann, V. 2017. The Geographies of Energy Poverty: Where North and South Intersect. Center for Circumpolar Security Studies, The Arctic Institute, Washington, DC.

Hilcorp Alaska. 2015. Liberty Development Project: Development and Production Plan Revision 1. Hilcorp Alaska, LLC, Anchorage, AK.

______. 2016. Northstar: A Little Island of Firsts. Hilcorp Alaska, LLC, Anchorage, AK.

Hillmer-Pegram, K. 2014. A Synthesis of Existing, Planned, and Proposed Infrastructure and Operations Supporting Oil and Gas Activities and Commercial Transportation in Arctic Alaska. University of Alaska Fairbanks, Fairbanks, AK.

Hird, M. J. 2016. The DEW Line and Canada's Arctic waste: Legacy and futurity. *Northern Review* 42:23–45.

Hobson, M. K. 2015. Electricity: A Renewable Energy Success Story Above the Arctic Circle. E&E News, October 20.

______. 2017. Scrap of Beaufort Still Open to Drilling is in High Demand. E&E News, January 17.

Hoffecker, J. and S. Elias. 2003. Environment and archeology in Beringia. *Evolutionary Anthropology* 12:34–49.

Holthus, P., C. Clarkin, and J. Lorentzen. 2013. Emerging Arctic opportunities. *Proceedings of the Marine Safety and Security Council* 70:10–13.

Houseknecht, D. W. and K. J. Bird. 2006. Oil and Gas Resources of the Arctic Alaska Petroleum Province. US Geological Survey Professional Paper 1732-A. US Geological Survey, Reston, VA.

Hulley, C. C. 1953. *Alaska, 1741–1953*. Binfords and Mort, Portland, OR.

Hunt, G. L. and P. J. Stabeno. 2005. Oceanography and ecology of the Aleutian Archipelago: Spatial and temporal variation. *Fisheries Oceanography* 14:292–306.

Huntington, H. P., R. Daniel, A. Hartsig, K. Harun, M. Heiman, R. Meehan, G. Noongwook, L. Pearson, M. Prior-Parks, and M. Robards. 2015. Vessels, risks, and rules: Planning for safe shipping in Bering Strait. *Marine Policy* 51:119–127.

Impact Assessment Inc. 1989. Point Lay Case Study. Alaska OCS Social and Economic Studies Program, Technical Report No. 139. OCS Study MMS 89-0093. US Department of the Interior, Minerals Management Service, Anchorage, AK.

Indigenous and Northern Affairs Canada. 2016. Oil and Gas Rights Digital Files. Indigenous and Northern Affairs Canada. Accessed online at http://www.aadnc-aandc.gc.ca/eng/110010003629 8/1100100036301.

International Council on Clean Transportation. 2015. A 10-Year Projection of Maritime Activity in the US Arctic Region. US Committee on the Marine Transportation System, Washington, DC.

International Maritime Organization. 2016. International Code for Ships Operating in Polar Waters (Polar Code). London, United Kingdom.

International Union for the Conservation of Nature. 2017. Protected Areas, Category 1a: Strict Nature Reserves. International Union for the Conservation of Nature. Accessed online 20 May 2017 at https://www.iucn.org/theme/protected-areas/about/protected-areas-categories/category-ia-strict-nature-reserve.

Janssen, N. A. H., M. E. Gerlofs-Nijland, T. Lanki, R. O. Salonen, F. Cassee, G. Hoek, P. Fischer, B. Brunekreef, and M. Krzyzanowski. 2012. Health Effects of Black Carbon. World Health Organization, Copenhagen, Denmark.

Jay, C. V., A. S. Fischbach, and A. A. Kochnev. 2012. Walrus areas of use in the Chukchi Sea during sparse sea ice cover. *Marine Ecology Progress Series* 468:1–13.

Jenssen, B. M. 1994. Review article: Effects of oil pollution, chemically treated oil, and cleaning on thermal balance of birds. *Environmental Pollution* 86:207–215.

Joint Secretariat Environmental Impact Screening Committee. 2008. ISR Community Conservation Plan Data. Inuvik, Canada.

Joling, D. 2015. Alaska Deepwater Port Proposed for Vessels in Arctic Waters. Alaska Dispatch News, February 19.

Jorgenson, J. C., J. M. V. Hoef, and M. Jorgenson. 2010. Long-term recovery patterns of Arctic tundra after winter seismic exploration. *Ecological Applications* 20:205–221.

Jorgenson, J. G. 1984. Effects of Renewable Resource Harvest Disruptions on Socioeconomic and Sociocultural Systems: Norton Sound. Social and Economic Studies Program Technical Report No. 90. Minerals Management Service, Anchorage, AK.

Kawerak. 2013. Seal and Walrus Harvest and Habitat Area for Nine Bering Strait Region Communities. Kawerak Social Science Program, Nome, AK.

______. 2015. Bering Strait Voices on Arctic Shipping: Workshop Report. September 16–17, 2014. Kawerak Marine Program, Nome, AK.

______. 2016. Bering Strait Voices on Arctic Shipping: Moving Forward to Protect Alaska Native Ways of Life and the Natural Resources We Rely On. January 25–26, 2016. Kawerak Marine Program, Nome, AK.

______. 2017. Bering Strait Voices Vision for Action Summit Report. October 12–14, 2016. Kawerak Marine Program, Nome, AK.

Kohlhoff, D. W. 2011. *Amchitka and the Bomb: Nuclear Testing in Alaska*. University of Washington Press, Seattle, WA.

Kolak, J. J. 2011. Chapter 2. Geological context, *In An Evaluation of the Science Needs to Inform Decisions on Outer Continental Shelf Energy Development in the Chukchi and Beaufort Seas, Alaska. US Geological Survey Circular 1370*. L. Holland-Bartels and B. Pierce eds., pp. 13–40. US Geological Survey, Reston, VA.

Kondolf, G. M. 1994. Geomorphic and environmental effects of instream gravel mining. *Landscape and Urban Planning* 28:225–243.

Kujawinski, P. 2016. The Road to the Top of the World. New York Times, February 11.

Kunz, M. and R. Reanier. 1996. The Mesa Site, Iteriak Creek, *In American Beginnings: The Prehistory and Paleoecology of Beringia*. F. West ed., pp. 497–504. University of Chicago Press, Chicago, IL.

Lackenbauer, P. W. and M. Farish. 2007. The Cold War on Canadian soil: Militarizing a northern environment. *Environmental History* 12:920–950.

Ladd, C., G. L. Hunt, C. W. Mordy, S. A. Salo, and P. J. Stabeno. 2005a. Marine environment of the eastern and central Aleutian Islands. *Fisheries Oceanography* 14:22–38.

Ladd, C., J. Jahncke, G. L. Hunt, K. O. Coyle, and P. J. Stabeno. 2005b. Hydrographic features and seabird foraging in Aleutian passes. *Fisheries Oceanography* 14:178–195.

Lascelles, B. G., G. M. Langham, R. A. Ronconi, and J. B. Reid. 2012. From hotspots to site protection: Identifying marine protected areas for seabirds around the globe. *Biological Conservation* 156:5–14.

League of Conservation Voters et al. v. Trump. 2017. Complaint for Declaratory and Injunctive Relief, No. 3:17-cv-00101 (District of Alaska, May 3, 2017).

Lee, J. 2015. A Gray Whale Breaks the Record for Longest Mammal Migration. National Geographic, Washington, DC. Accessed online at http://news.nationalgeographic.com/2015/04/150414-gray-whale-pacific-migration-endangered-ocean-animal-science/.

Lidji, E. 2010. Big Risk, Bigger Rewards: Two Newcomers with Two Strategies. Petroleum News, February 14.

______. 2014. Explorers 2014: Caelus Energy Takes Over Pioneer Assets in Alaska. Petroleum News, July 20.

Lockard, D. 2016. Bulk Fuel Tank Farm Conditions in Rural Alaska. Alaska Energy Authority, Fairbanks, AK.

Magdanz, J. and A. Olanna. 1986. Subsistence Land Use in Nome. Technical Paper No. 148. Alaska Department of Fish and Game, Division of Subsistence, Juneau, AK.

Magdanz, J., S. Tahbone, A. Ahmasuk, D. Koester, and B. Lewis. 2007. Customary Trade and Barter in Fish in the Seward Peninsula Area, Alaska. Technical Paper 328. Alaska Department of Fish and Game Division of Subsistence, Juneau, AK.

Malyshev, N. A., V. V. Obmetko, A. A. Borodulin, E. M. Barinova, and B. I. Ikhsanov. 2011. Tectonics of the sedimentary basins in the Russian sector of the Chukchi Sea. *In* Proceedings of the International Conference on Arctic Margins VI. Fairbanks, AK.

Marine Conservation Institute. 2017. MPAtlas. Marine Conservation Institute, Seattle, WA. Accessed online at www.mpatlas.org.

Masden, E. A., D. T. Haydon, A. D. Fox, R. W. Furness, R. Bullman, and M. Desholm. 2009. Barriers to movement: Impacts of wind farms on migrating birds. *ICES Journal of Marine Science* 66:746–753.

Matthews, G. V. T. 2013. The Ramsar Convention on Wetlands: Its History and Development. Ramsar Convention Bureau, Gland, Switzerland.

McDowell Group. 2015. The Economic Value of Alaska's Seafood Industry. Alaska Seafood Marketing Institute and McDowell Group, Juneau, AK.

Melendez, A. V. and G. Fay. 2012. Energizing Alaska: Electricity Around the State. Institute of Social and Economic Research, University of Alaska-Anchorage, Anchorage, AK.

Metcalf, V. and M. Robards. 2011. Tribal Marine Mammal Ordinances of St. Lawrence Island, *In 27th Lowell Wakefield Fisheries Symposium*. Anchorage, AK.

Miller, E. L., A. Grantz, and S. L. Klemperer. 2002. Tectonic Evolution of the Bering Shelf, Chukchi Sea, Arctic Margin and Adjacent Landmasses. Geological Society of America Special Paper 360, Boulder, CO.

Mizroch, S. A., D. W. Rice, D. Zwiefelhofer, J. Waite, and W. L. Perryman. 2009. Distribution and movements of fin whales in the North Pacific Ocean. *Mammal Review* 39:193–227.

Moore, S. E. and J. T. Clarke. 2002. Potential impact of offshore human activities on gray whales (*Eschrichtius robustus*). *Journal of Cetacean Research and Management* 4:19–25.

Moore, S. E. and D. P. DeMaster. 1998. Cetacean habitats in the Alaskan Arctic. *Journal of Northwest Atlantic Fishery Science* 22:55–69.

Moore, S. E., R. R. Reeves, B. L. Southall, T. J. Ragen, R. S. Suydam, and C. W. Clark. 2012. A new framework for assessing the effects of anthropogenic sound on marine mammals in a rapidly changing Arctic. *BioScience* 62:289–295.

Moore, S. E. and P. J. Stabeno. 2015. Synthesis of Arctic Research (SOAR) in marine ecosystems of the Pacific Arctic. *Progress in Oceanography* 136:1–11.

Morkill, A. 2006. Shipwrecks, Spills and Seabirds: Wildlife at Risk on the Alaska Maritime National Wildlife Refuge, *In The Selendang Ayu Oil Spill: Lessons Learned, Conference Proceedings*. R. Brewer ed., pp. 19–32. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, AK.

Mosbech, A. and D. Boertmann. 1999. Distribution, abundance and reaction to aerial surveys of post-breeding king eiders (*Somateria spectabilis*) in western Greenland. *Arctic* 52:188–203.

Munilla, I., J. M. Arcos, D. Oro, D. Álvarez, P. M. Leyenda, and A. Velando. 2011. Mass mortality of seabirds in the aftermath of the Prestige oil spill. *Ecosphere* 2:1–14.

Nahrgang, J., P. Dubourg, M. Frantzen, D. Storch, F. Dahlke, and J. P. Meador. 2016. Early life stages of an Arctic keystone species (*Boreogadus saida*) show high sensitivity to a water-soluble fraction of crude oil. *Environmental Pollution* 218:605–614.

National Energy Board. 2014. Wells GIS File. National Energy Board, Calgary, Canada.

National Marine Fisheries Service. 2004. Programmatic Supplemental Environmental Impact Statement for the Alaska Groundfish Fisheries Implemented Under the Authority of the Fishery Management Plans for the Groundfish Fishery of the Gulf of Alaska and the Groundfish of the Bering Sea and Aleutian Islands Area. National Marine Fisheries Service, Juneau, AK and Seattle, WA.

______. 2015. Fisheries of the United States, 2014. National Oceanic and Atmospheric Administration, Silver Spring, MD.

______. 2016a. Fisheries of the United States. National Oceanic and Atmospheric Administration, Silver Spring, MD.

______. 2016b. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. National Oceanic and Atmospheric Administration, Silver Spring, MD.

National Oceanic and Atmospheric Administration. 1988. Bering, Chukchi, and Beaufort Seas Coastal and Ocean Zones: Strategic Assessment Data Atlas. National Oceanic and Atmospheric Administration, Rockville, MD.

______. 2002. Final Restoration Plan and Environmental Assessment for the M/V Kuroshima Oil Spill. National Oceanic and Atmospheric Administration Damage Assessment Center, Seattle, WA.

______. 2004. History of Alaska Groundfish Fisheries and Management Practices. Alaska Groundfish Fisheries Programmatic Supplemental Environmental Impact Statement. National Oceanic and Atmospheric Administration, Juneau, AK.

______. 2007. Magnuson-Stevens Fishery Conservation and Management Act, as Amended Through January 12, 2007. National Oceanic and Atmospheric Administration.

______. 2015a. Northern Fur Seals NMML Research—Distibution and US Breeding Sites. National Marine Mammal Laboratory, Anchorage, AK. Accessed online at http://www.afsc.noaa.gov/nmml/alaska/nfs/smallfsrange.php.

______. 2015b. Northern Fur Seals NMML Research—Distibution and U.S. Breeding Sites. National Marine Mammal Laboratory, Accessed online at http://www.afsc.noaa.gov/nmml/alaska/nfs/smallfsrange.php.

______. 2016a. Essential Fish Habitat (EFH) Mapper GIS Shapefiles. National Oceanic and Atmospheric Administration, Seattle, WA. Accessed online at http://www.habitat.noaa.gov/protection/efh/efhmapper/index.html.

______. 2016b. North Pacific EFH Areas Protected From Fishing GIS shapefiles. National Oceanic and Atmospheric Administration, Seattle, WA. Accessed online at http://www.habitat.noaa.gov/protection/efh/newInv/.

______. 2016c. Reinitiation Quintillion Subsea Cable Project and NMF's IHA Issuance, 2016. NMFS Consultation Number AKR-2016-9590. National Oceanic and Atmospheric Administration, Juneau, AK.

______. 2017a. Co-management of Marine Mammals in Alaska. National Oceanic and Atmospheric Administration, Seattle, WA. Accessed online 6 June 2017 at https://alaskafisheries.noaa.gov/pr/comanagement.

______. 2017b. Coastal Zone Management Programs. Accessed online 15 May 2017 at https://coast.noaa.gov/czm/mystate/#alaska.

______. 2017c. What is a marine protected area? National Oceanic and Atmospheric Administration. Accessed online 11 May 2017 at http://oceanservice.noaa.gov/facts/mpa.html.

National Petroleum Council. 2015. Arctic Potential: Realizing the Promise of US Arctic Oil and Gas Resources. National Petroleum Council, Washington, DC.

National Research Council. 2000. *Toxicological Effects of Methylmercury*. National Academies Press, Washington, DC.

______. 2003. *Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope*. National Academy Press, Washington, DC.

______. 2014. Responding to Oil Spills in the US Arctic Marine Environment. National Academy of Sciences, Washington, DC.

Natural Resources Canada. 2011. Status of Remote/Off-grid Communities in Canada. Natural Resources Canada, Quebec, Canada.

Nelson, R. K. 1981. Harvest of the Sea: Coastal Subsistence in Modern Wainwright. North Slope Borough Coastal Management Program, Barrow, AK.

Nihoul, J. C. J., P. Adam, P. Brasseur, E. Deleersnijder, S. Djenidi, and J. Haus. 1993. Three-dimensional general circulation model of the northern Bering Sea's summer ecohydrodynamics. *Continental Shelf Research* 13:509–542.

Nolan, M. 2005. An Annotated Bibliography of Research Related to the Possible Long-term Impacts of Pumping Water from Tundra Ponds for the Creation of Ice Roads. Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks, AK.

North Pacific Anadromous Fish Commission. 2003. Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean. North Pacific Anadromous Fish Commission, Vancouver, Canada.

North Pacific Fishery Management Council. 2009. Fishery Management Plan for Fish Resources of the Arctic Management Area. North Pacific Fishery Management Council, Anchorage, AK.

______. 2011. Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs, Appendix D.3. North Pacific Fishery Management Council, Anchorage, AK.

______. 2015a. Bering Sea Salmon Bycatch Final Motion, April 11, 2015. North Pacific Fishery Management Council, Anchorage, AK.

______. 2015b. Motion on C7. Bering Sea Fishery Ecosystem Plan. December 2015. North Pacific Fishery Management Council, Anchorage, AK.

______. 2016a. Bering Sea FEP Next Steps: Update for Ecosystem Committee, February 2, 2016. North Pacific Fishery Management Council, Anchorage, AK.

______. 2016b. Stock Assessment and Fishery Evaluation Report for the Groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands Area: Economic Status of the Groundfish Fisheries Off Alaska, 2015. North Pacific Fishery Management Council, Anchorage, AK.

North Slope Borough. 2014. Oil and Gas Technical Report: Planning for Oil & Gas Activities in the National Petroleum Reserve—Alaska. North Slope Borough Department of Planning and Community Services, Barrow, AK.

North Slope Borough Department of Planning and Community Services: Geographic Information Systems Division. 2003. Bowhead Whale Subsistence Sensitivity Map. Barrow, AK.

Northern Alaska Environmental Center. 2010. Red Dog Mine Factsheet. Northern Alaska Environmental Center, Fairbanks, AK.

Northwest Territories Transportation. 2015. NWT Transportation Strategy 2015–2040. Northwest Territories Transportation, Yellowknife, Canada.

Nowacek, D. P., C. W. Clark, D. Mann, P. J. O. Miller, H. C. Rosenbaum, J. S. Golden, M. Jasny, J. Kraska, and B. L. Southall. 2015. Marine seismic surveys and ocean noise: Time for coordinated and prudent planning. *Frontiers in Ecology and the Environment* 13:378–386.

Nowacek, D. P., L. H. Thorne, D. W. Johnston, and P. L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37:81–115.

Nuka Research and Planning Group. 2015. Aleutian Islands Risk Assessment: Recommending an Optimal Response System for the Aleutian Islands Summary Report. Nuka Research and Planning Group, LLC, Seldovia, AK.

______. 2016. Bering Sea Vessel Traffic Risk Analysis. Nuka Research and Planning Group, LLC, Seldovia, AK.

Nuka Research and Planning Group and Cape International. 2006. Vessel Traffic in the Aleutians Subarea. Nuka Research and Planning Group, LLC and Cape International, Inc., Seldovia, AK.

Nussbaum, A. 2017. A Father of Fracking Seeks to Emulate Shale Boom in Alaska. Bloomberg, March 9.

Oceana and Kawerak. 2014. Bering Strait Marine Life and Subsistence Use Data Synthesis. Oceana and Kawerak, Juneau, AK.

Organization of the Petroleum Exporting Countries. 2017. Monthly Oil Market Report. Organization of the Petroleum Exporting Countries. Accessed online 17 Apr 2017 at http://www.opec.org/opec_web/en/publications/338.htm.

Overland, J. E. and P. J. Stabeno. 2004. Is the climate of Bering Sea warming and affecting the ecosystem? *EOS* 85:309–316.

Patenaude, N. J., W. J. Richardson, M. A. Smultea, W. R. Koski, G. W. Miller, B. Würsig, and C. R. Greene. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. *Marine Mammal Science* 18:309–335.

Pedersen, S. 1979. Regional Subsistence Land Use, North Slope Borough, Alaska. Anthropology and Historic Preservation, Cooperative Park Studies Unit, University of Alaska Fairbanks and Conservation and Environmental Protection, North Slope Borough, Fairbanks and Barrow, AK.

______. 1986. Nuiqsut Subsistence Land Use Atlas, 1986 Update. Alaska Department of Fish and Game Division of Subsistence, Fairbanks, AK.

Pedersen, S. and A. Linn, Jr. 2005. Kaktovik 2000–2002 Subsistence Fishery Harvest Assessment. Final Report to US Fish and Wildlife Service Office of Subsistence Management, Anchorage, AK.

Peng, C., X. Zhao, and G. Liu. 2015. Noise in the sea and its impacts on marine organisms. *International Journal of Environmental Research and Public Health* 12:12304–12323.

Peterson, C. H., S. D. Rice, J. W. Short, D. Esler, J. L. Bodkin, B. E. Ballachey, and D. B. Irons. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. *Science* 302:2082–2086.

Pew Charitable Trusts. 2012. The International Waters of the Central Arctic Ocean: Protecting Fisheries in an Emerging Ocean. Pew Charitable Trusts.

Piatt, J. F., C. J. Lensink, W. Butler, M. Kendziorek, and D. R. Nysewander. 1990. Immediate impact of the 'Exxon Valdez' oil spill on marine birds. *Auk* 107:387–397.

Pollon, C. 2017. What Will It Take to Get Canada's Arctic Off Diesel? Reveal, February 22.

Price, M. E. 1979. A Moment in History: The Alaska Native Claims Settlement Act. *UCLA-Alaska Law Review* 8:89–101.

Ramanathan, V. and G. Carmichael. 2008. Global and regional climate changes due to black carbon. *Nature Geoscience* 1:221–227.

Raymond-Yakoubian, B., L. Kaplan, M. Topkok, and J. Raymond-Yakoubian. 2015. "The World has Changed": Iŋalit Traditional Knowledge of Walrus in the Bering Strait. North Pacific Research Board Project 1013 Final Report (Revised). Kawerak, Inc. Social Science Program, Nome, AK.

Raymond-Yakoubian, B. and J. Raymond-Yakoubian. 2015. "Always taught not to waste": Traditional Knowledge and Norton Sound/Bering Strait Salmon Populations. 2015 Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative Project 1333 Final Product. Kawerak Inc, Nome, AK.

Raymond-Yakoubian, J. 2013. When the Fish Come, We Go Fishing: Local Ecological Knowledge of Non-salmon Fish Used for Subsistence in the Bering Strait Region. Kawerak, Inc., Nome, AK.

______. In press. Arctic vessel traffic and indigenous communities in the Bering Strait region of Alaska, *In Sustainable Shipping in the Changing Arctic*. Springer.

Raymond-Yakoubian, J., B. Raymond-Yakoubian, and C. Moncrieff. 2017. The incorporation of traditional knowledge into Alaska federal fisheries management. *Marine Policy* 78:132–142.

Raynolds, M. K., D. A. Walker, K. J. Ambrosius, J. Brown, K. R. Everett, M. Kanevskiy, G. P. Kofinas, V. E. Romanovsky, Y. Shur, and P. J. Webber. 2014. Cumulative geoecological effects of 62 years of infrastructure and climate change in ice-rich permafrost landscapes, Prudhoe Bay Oilfield, Alaska. *Global Change Biology* 20:1–14.

Reedy-Maschner, K. 2009. Entangled livelihoods: Economic integration and diversity in the western Arctic. *Alaska Journal of Anthropology* 7:135–146.

Reeves, R., C. Rosa, J. C. George, G. Sheffield, and M. Moore. 2012. Implications of Arctic industrial growth and strategies to mitigate future vessel and fishing gear impacts on bowhead whales. *Marine Policy* 36:454–462.

Regjeringen. 2015. Declaration Concerning The Prevention Of Unregulated High Seas Fishing in the Central Arctic Ocean. Regjeringen, Oslo, Norway.

Reimers, E. and J. E. Colman. 2006. Reindeer and caribou (*Rangifer tarandus*) response towards human activities. *Rangifer* 26:55–71.

Rein, L. 2014. US Postal Service losing Tens of Millions Annually Subsidizing Shipments to Alaska. Washington Post, June 28.

Renewable Energy Alaska Project. 2016. Renewable Energy Atlas of Alaska. Renewable Energy Alaska Project, Anchorage, AK.

Renner, M., G. L. Hunt, Jr, J. F. Piatt, and G. V. Byrd. 2008. Seasonal and distributional patterns of seabirds along the Aleutian Archipelago. *Marine Ecology Progress Series* 357:301–311.

Renner, M. and K. J. Kuletz. 2015. A spatial-seasonal analysis of the oiling risk from shipping traffic to seabirds in the Aleutian Archipelago. *Marine Pollution Bulletin* 101:127–136.

Richardson, W. J. 1995. *Marine Mammals and Noise*. Academic Press, San Diego, CA.

Richardson, W. J., K. J. Finley, G. W. Miller, R. A. Davis, and W. R. Koski. 1995. Feeding, social and migration behavior of bowhead whales, *Balaena mysticetus*, in Baffin Bay vs. the Beaufort Sea—regions with different amounts of human activity. *Marine Mammal Science* 11:1–45.

Robertson, J. O., G. V. Chilingarian, and S. Kumar. 1989. *Surface Operations in Petroleum Production, II*. Elsevier, Amsterdam, Netherlands.

Rocque, D. 2006. Impacts of Oil Spills on Unalaska Island Marine Mammals, *In The Selendang Ayu Oil Spill: Lessons Learned, Conference Proceedings*. R. Brewer ed., pp. 42–46. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, AK.

Rode, K. D., R. R. Wilson, E. V. Regehr, M. St. Martin, D. C. Douglas, and J. Olson. 2015. Increased land use by Chukchi Sea polar bears in relation to changing sea ice conditions. *PLoS ONE* 10:e0142213.

Rolland, R. M., S. E. Parks, K. E. Hunt, M. Castellote, P. J. Corkeron, D. P. Nowacek, S. K. Wasser, and S. D. Kraus. 2012. Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society of London B: Biological Sciences* 279:2363–2368.

Ronconi, R. A., B. G. Lascelles, G. M. Langham, J. B. Reid, and D. Oro. 2012. The role of seabirds in Marine Protected Area identification, delineation, and monitoring: Introduction and synthesis. *Biological Conservation* 156:1–4.

Ropeik, A. 2014. 10 Years On, Selendang Ayu Spill's Legacy Still Evolving. Alaska Public Media, December 12.

Rosneft. 2016. Geographic Outreach. Rosneft, Moscow, Russia. Accessed online at https://www.rosneft.com/.

Russian Federation Ministry of Agriculture. 2013. On the Approval of Fishing Rules for the Far Eastern Fisheries Basin. October 21, 2013. Registered by the Ministry of Justice of Russia on January 23, 2014, Registration No. 31100, Moscow, Russia.

Satterthwaite-Phillips, D., C. Krenz, G. Gray, and L. Dodd. 2016. Iñuuniaļiqput Iļiļugu Nunaŋŋuanun: Documenting Our Way of Life through Maps. Northwest Arctic Borough, Kotzebue, AK.

Schartup, A. T., P. H. Balcom, A. L. Soerensen, K. J. Gosnell, R. S. Calder, R. P. Mason, and E. M. Sunderland. 2015. Freshwater discharges drive high levels of methylmercury in Arctic marine biota. *Proceedings of the National Academy of Sciences* 112:11789–11794.

Seabird Information Network. 2011. North Pacific Seabird Data Portal. Accessed online at http://axiom.seabirds.net/maps/north-pacific-seabirds/.

Selig, E. R. and J. F. Bruno. 2010. A global analysis of the effectiveness of marine protected areas in preventing coral loss. *PLoS ONE* 5:e9278.

Serumgard, K. and M. Krause. 2013. Ice ops: Mission execution in the evolving Arctic. *Proceedings of the Marine Safety and Security Council* 70:22–25.

Sherwood, K. W., J. Larson, C. D. Comer, J. D. Craig, and C. Reitmeier. 2006. North Aleutian Basin OCS Planning Area Assessment of Undiscovered Technically-Recoverable Oil and Gas. US Minerals Management Service, Alaska OCS Region, Anchorage, AK.

Shindell, D. and G. Faluvegi. 2009. Climate response to regional radiative forcing during the twentieth century. *Nature Geoscience* 2:294–300.

Smith, M. A., N. J. Walker, C. M. Free, M. J. Kirchhoff, G. S. Drew, N. Warnock, and I. J. Stenhouse. 2014. Identifying marine Important Bird Areas using at-sea survey data. *Biological Conservation* 172:180–189.

Sobelman, S. 1985. The Economics of Wild Resource Use in Shishmaref, Alaska. Technical Paper No. 112. Juneau, AK.

Speer, L. and T. L. Laughlin. 2011. IUCN/NRDC Workshop to Identify Areas of Ecological and Biological Significance or Vulnerability in the Arctic Marine Environment—Workshop Report. NRDC and IUCN, La Jolla, CA.

Spencer, A. M., A. F. Embry, D. L. Gauthier, A. V. Stoupakova, and K. Sørensen. 2011. An overview of the petroleum geology of the Arctic, *In Arctic Petroleum Geology*. A. M. Spencer, A. F. Embry, D. L. Gautier, A. V. Stoupakova, and K. Sørensen eds., pp. 1–15. Geological Society of London, London, United Kingdom.

Springer, A. M. and C. P. McRoy. 1993. The paradox of pelagic food webs in the northern Bering Sea—III: Patterns of primary production. *Continental Shelf Research* 13:575–599.

Springer, A. M., C. P. McRoy, and M. V. Flint. 1996. The Bering Sea green belt: Shelf-edge processes and ecosystem production. *Fisheries Oceanography* 5:205–223.

St. Louis, V. L., C. A. Kelly, É. Duchemin, J. W. M. Rudd, and D. M. Rosenberg. 2000. Reservoir surfaces as sources of greenhouse gases to the atmosphere: A global estimate. *BioScience* 50:766–775.

Stabeno, P. J., R. K. Reed, and J. M. Napp. 2002. Transport through Unimak Pass, Alaska. *Deep Sea Research Part II: Topical Studies in Oceanography* 49:5919–5930.

Stabeno, P. J., J. D. Schumacher, and K. Ohtani. 1999. The physical oceanography of the Bering Sea, *In Dynamics of the Bering Sea: A Summary of Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea*. T. R. Loughlin and K. Ohtani eds., pp. 1–28. North Pacific Marine Science Organization (PICES), University of Alaska Sea Grant AK-SG-99-03, Fairbanks, AK.

Stephen R. Braund and Associates. 2003. Field Interviews Conducted for US Department of the Interior, Bureau of Land Management 2004 Alpine Satellite Development Plan Final Environmental Impact Statement. Stephen R. Braund and Associates, Anchorage, AK.

______. 2010. Subsistence Mapping of Nuiqsut, Kaktovik, and Barrow. MMS OCS Study No. 2009-003. Bureau of Ocean Energy Management, Anchorage, AK.

______. 2011. Nuiqsut Subsistence Monitoring Project: Results of 2009 Hunter Interviews. Prepared for ConocoPhillips Alaska, Inc., Anchorage, AK.

______. 2013a. COMIDA: Impact Monitoring for Offshore Subsistence Hunting, Wainwright and Point Lay, Alaska. OCS Study BOEM 2013-211. Bureau of Ocean Energy Management, Alaska OCS Region, Anchorage, AK.

______. 2013b. Nuiqsut Subsistence Monitoring Project: Results of Year 4 Hunter Interviews. Prepared for ConocoPhillips Alaska, Inc., Anchorage, AK.

______. 2013c. Subsistence Use Area and Traditional Knowledge Studies: Anaktuvuk Pass, Barrow, and Nuiqsut. Foothills West Transportation Access Environmental Studies. Prepared for Three Parameters Plus, Inc. and the Alaska Department of Transportation and Public Facilities, Anchorage, AK.

______. 2014. Subsistence Use Areas and Traditional Knowledge Study for Point Lay, Alaska: 1997–2006. Prepared for the North Slope Borough Department of Wildlife Management, Barrow, AK.

______. 2017. Unpublished data from North Slope Borough key informant subsistence mapping project, Barrow and Wainwright. Stephen R. Braund and Associates, Anchorage, AK.

Stephen R. Braund and Associates and Institute of Social and Economic Research. 1993a. North Slope Subsistence Study: Barrow 1987, 1988, and 1989. Minerals Management Service Report MMS 91-0086. Stephen R. Braund and Associates and Institute of Social and Economic Research, Anchorage, AK.

______. 1993b. North Slope Subsistence Study: Wainwright, 1988 and 1989. Technical Report No. 147. Prepared for Minerals Management Service, Alaska OCS Region, Social and Economic Studies, Anchorage, AK.

Troy, D. M. 2000. Shorebirds, *In The Natural History of an Arctic Oilfield*. J. Truett and S. R. Johnson eds., pp. 277–303. Academic Press, San Diego, CA.

Turcotte, C. and B. Sainte-Marie. 2009. *Biological synopsis of the Japanese skeleton shrimp (Caprella mutica)*. Fisheries and Oceans Canada, Regional Science Branch, Quebec, Canada.

Ummel, K. 2012. CARMA Revisited: An Updated Database of Carbon Dioxide Emissions from Power Plants Worldwide. Center for Global Development, Washington, DC.

UNESCO World Heritage Convention. 2004. Natural System of Wrangel Island Reserve. UNESCO World Heritage Centre, United Nations. Accessed online 15 May 2017 at http://whc.unesco.org/en/list/1023.

US Army Corps of Engineers and Alaska Department of Transportation and Public Facilities. 2013. Alaska Deep-Draft Arctic Port System Study. US Army Corps of Engineers and State of Alaska Department of Transportation and Public Facilities, Anchorage, AK.

US Coast Guard. 2014. Routeing Measures and Mandatory Ship Reporting Systems: Establishment of Five Areas to be Avoided in the Region of the Aleutian Islands Submitted by the United States. US Coast Guard Sub-Comittee on Navitagation, Communications and Search and Rescue, Washington, DC.

______. 2016. Preliminary Findings: Port Access Route Study: In the Chukchi Sea, Bering Strait, and Bering Sea. US Coast Guard 17th District, Juneau, AK.

US Department of Transportation. 2016a. Air Carrier Summary Data: T-100 Market (All Carriers). US Department of Transportation, Bureau of Transportation Statistics, Washington, DC.

______. 2016b. Aviation Support Tables: Master Coordinate. US Department of Transportation, Bureau of Transportation Statistics, Washington, DC.

US Energy Information Administration. 2016. Power Plants. US Department of Energy, Energy Information Administration, Washington, DC.

______. 2017a. Alaska State Energy Profile. US Department of Energy, Washington, DC.

______. 2017b. Short-term Energy and Summer Fuels Outlook. US Department of Energy, Washington, DC. Accessed online 17 Apr 2017 at https://www.eia.gov/outlooks/steo/marketreview/crude.cfm.

US Fish and Wildlife Service. 2008. Seabirds Overview. US Fish and Wildlife Service, Anchorage, AK. Accessed online 15 July 2013 at http://alaska.fws.gov/mbsp/mbm/seabirds/seabirds.htm.

US Geological Survey—Alaska Science Center. 2015. North Pacific Pelagic Seabird Database (NPPSD) Version 2.0 US Geological Survey, Anchorage, AK.

US Postal Service Office of Inspector General. 2011. Alaska Bypass: Beyond Its Original Purpose. Risk Analysis Research Center, United States Postal Service, Arlington, VA.

Veltre, D. W. 2017. Unangax̂: Coastal People of Far Southwestern Alaska. Kendall Hunt Publishing, Dubuque, IA. Accessed online 5/31 2017 at http://www.apiai.org/culture-history/history/.

Veltre, D. W. and M. A. Smith. 2010. Historical overview of archaeological research in the Aleut region of Alaska. *Human Biology* 82:487–506.

Verzhbitsky, V. E., S. D. Sokolov, M. I. Tuchkova, E. M. Frantzer, A. Little, and L. I. Lobkovsky. 2012. The South Chukchi Sedimentary Basin (Chukchi Sea, Russian Arctic): Age, structural pattern, and hydrocarbon potential, *In Tectonics and Sedimentation: Implications for Petroleum Systems*. D. Gao ed., pp. 267–290. American Association of Petroleum Geologists, Tulsa, OK.

Vistnes, I. and C. Nellemann. 2007. The matter of spatial and temporal scales: A review of reindeer and caribou response to human activity. *Polar Biology* 31:399–407.

Walker, D. A. and K. R. Everett. 1987. Road dust and its environmental impact on Alaskan taiga and tundra. *Arctic and Alpine Research* 19:479–489.

Walker, D. A., P. J. Webber, E. F. Binnian, K. R. Everett, N. D. Lederer, E. A. Nordstrand, and M. D. Walker. 1987. Cumulative impacts of oil fields on northern Alaskan landscapes. *Science* 238:757–761.

Wheeler, P. and T. Thornton. 2005. Subsistence research in Alaska: A thirty year retrospective. *Alaska Journal of Anthropology* 3:69–103.

White, J. L. 2013. Subsistence in Alaska, *In Native Voices Rising*. L. T. Delgado ed., pp. 38–51. Common Counsel Foundation and Native Americans in Philanthropy, Oakland, CA and Minneapolis, MN.

Williams, T. J., W. L. Quinton, and J. L. Baltzer. 2013. Linear disturbances on discontinuous permafrost: Implications for thaw-induced changes to land cover and drainage patterns. *Environmental Research Letters* 8:025006.

Wilson, R. R., L. S. Parrett, K. Joly, and J. R. Dau. 2016. Effects of roads on individual caribou movements during migration. *Biological Conservation* 195:2–8.

Witherell, D. and D. Woodby. 2005. Application of Marine Protected Areas for sustainable production and marine biodiveristy off Alaska. *Marine Fisheries Review* 67:1–27.

Woodby, D., D. Carlile, S. Siddeek, F. Funk, J. H. Clark, and L. Hulbert. 2005. Commercial Fisheries of Alaska. Special Publication. Alaska Department of Fish and Game, Juneau, AK.

World Bank. 2017. Commodity Markets. The World Bank Group, Washington, DC. Accessed online 17 Apr 2017 at http://www.worldbank.org/en/research/commodity-markets.

Worrall, D. M. 1991. Tectonic History of the Bering Sea and the Evolution of Tertiary Strike-Slip Basins of the Bering Shelf. *Geological Society of America Special Papers* 257:1–127.

Young, O. R. 1992. *Arctic Politics: Conflict and Cooperation in the Circumpolar North*. Dartmouth College Press, Hanover, NH.

Zerbini, A. N., M. F. Baumgartner, A. S. Kennedy, B. K. Rone, P. R. Wade, and P. J. Clapham. 2015. Space use patterns of the endangered North Pacific right whale *Eubalaena japonica* in the Bering Sea. *Marine Ecology Progress Series* 532:269–281.

Zerbini, A. N., N. A. Friday, D. M. Palacios, J. M. Waite, P. H. Ressler, B. K. Rone, S. E. Moore, and P. J. Clapham. 2016. Baleen whale abundance and distribution in relation to environmental variables and prey density in the Eastern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography* 134:312–330.

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CONSERVATION SUMMARY

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The chapters in this Ecological Atlas collectively tell a story relating the physical, biological, ecological, and human use patterns of the Bering, Chukchi, and Beaufort Seas. The three seas comprise an Arctic marine ecosystem characterized by both dynamic and enduring features, which together support high productivity and globally important wildlife populations. At the same time, the region is experiencing and anticipating imminent changes from climate warming and development. The significance of this region lies not only in its productivity and what the ocean provides for the people who live here and elsewhere, but also in the impact the Arctic has on global systems. We are learning more and more that the Arctic affects global weather patterns, temperatures, ocean circulation patterns, and is increasingly influencing global trade, energy extraction, and tourism.

A key feature of these three seas is the extraordinary productivity and impressive abundance of wildlife. As illustrated in Chapter 2 (Physical Setting), this marine ecosystem is highly dynamic in nature—driven by an ever-shifting ice edge and the productivity that blooms along this moving feature; strong currents and winds that move water masses and pelagic resources; and the fish, birds, and mammals that follow the advancing and retreating ice. We learn in Chapter 5 (Birds) that some 87% of US seabirds flock to the Bering Sea to nest (US Fish and Wildlife Service 2008). For instance, the Diomede Islands in the Bering Strait make up one of the largest seabird colonies in the world, estimated at over 5.5 million birds (Seabird Information Network 2011). Chapter 4 (Fishes) details many fish species, and explains that the Bering Sea provides about half of US fisheries production by weight and boasts the largest sockeye salmon (*Oncorhynchus nerka*) fishery in the world (Overland and Stabeno 2004, McDowell Group 2015). By measure of primary productivity, the southern Chukchi Sea is one of the most productive marine systems in the world (Springer and McRoy 1993); primary productivity is mapped out in Chapter 3 (Biological Setting). Barrow Canyon, where the Beaufort and Chukchi Seas meet, attracts high densities of many species of marine mammals and birds, and is particularly renowned for the large groups of bowhead whales (*Balaena mysticetus*) that frequent the area to feed on the proliferation of krill (Citta et al. 2015), described in Chapter 6 (Mammals). Wrangel Island has one of the highest densities of polar bear (*Ursus maritimus*) dens and Pacific walrus (*Odobenus rosmarus divergens*) haulouts in the world, designating it a World Heritage Site (UNESCO World Heritage Convention 2004, Rode et al. 2015), as described under Conservation Areas in Chapter 7 (Human Uses). These and countless other impressive environmental phenomena make the Pacific Arctic a globally significant region for many species of fish, birds, marine mammals, and the food web they rely on.

Looking from shore out into places such as Norton Bay, Kotzebue Sound, or Barrow Canyon, one sees dynamic ice and wildlife patterns shifting daily. Yet viewing this system over a longer time period—weeks to months to years—reveals patterns of stability. One begins to see that certain areas consistently provide productive foraging, abundant wildlife, and subsistence opportunities; areas of recurring productivity shift and cycle, yet tend to persist. Continuing to watch for many years uncovers a grander weather and climate cycle, the Pacific Decadal Oscillation, which intermittently delivers warmer or cooler decades, affecting the distribution of fish, birds, and mammals. Looking out even further in time, observation on the scale of multiple decades allows one to realize that beneath this intricate dynamism lies a trend of intense climate warming, which is shifting the very foundations of this ever-changing seascape, making it difficult to quantify what is normal and what is new.

A CHANGING CLIMATE

Currently, the Arctic climate is changing rapidly due to global warming. This change shows itself in the increasingly thin sea ice, the open-water season arriving far earlier and lasting longer, rescheduled hunting trips due to enduring storms, more frequent winter warm spells, and the forced relocations of villages away from the coast due to seawater inundation. Talk to the people of the Arctic coast, and it is in their stories comparing the past to the present. Climate change is the new normal, a daily reality to work with. In a place that characteristically experiences great shifts and changes, the people, wildlife, and ecosystems are resilient and adaptive. But it remains to be seen how far the pendulum can swing before the new normal is too far from the old normal, and systems—both ecological and social—break down.

With a warmer Arctic, ecological impacts will be widespread, and while some are already occurring or are reasonably foreseeable, many others are difficult or impossible to predict (Arctic Climate Impact Assessment 2004). Reduction in sea ice cover is a major change to the Arctic as it functions today. Aside from the Aleutian Islands and the Aleutian Basin, the Bering, Chukchi, and Beaufort Seas are seasonally ice-covered. Sea ice shapes the functioning of this ecosystem throughout the food chain and across all species and is greatly affected by changes in climate. The ice influences the timing, extent, and abundance of primary productivity, which in turn influences the distribution and abundance of zooplankton and fish, and in turn the distribution and concentration of upper trophic species (Sigler et al. 2011). To some species, sea ice is a necessary platform for hunting, resting, and breeding. For others, openings in the ice provide foraging opportunities and breathing holes. Other species encounter the ice as an obstacle or barrier to movement. Loss of sea ice drives ecological changes from the base of the food chain to higher trophic levels (Grebmeier et al. 2006). Forage resources may decrease, increase, redistribute to new areas, or become available at different times. Scientists have predicted that the Arctic Ocean will be nearly ice-free in summer by the 2030s (Wang and Overland 2009, 2012).

By virtue of their adaptations for living in this harsh and dynamic region, Arctic species are incredibly resilient. Yet even these hardy species are already experiencing the pressure from changing climate and habitat. In this fundamentally different Arctic marine future, there will be climate winners and losers. Some species will increase in abundance; others may become threatened or even extirpated. Species will see their habitat expand, shift, shrink, or possibly disappear; some will adapt in place, others will migrate. Certain enduring features in the Arctic will continue to provide vital habitat areas to Arctic wildlife species. By making sure to protect those key places, managers can give fish and wildlife a better chance to persist and adapt as the region undergoes unprecedented change.

PRESSURE POINTS

Climate change is at the forefront of the threats to the Arctic, but it is certainly not alone. Sea ice has acted as a barrier to year-round shipping and vessel traffic pressure. Retreating ice brings greater access and increased vessel traffic, which comes with associated risks: shipwrecks, chemical spills or leaks, and ship strikes and noise disturbance to wildlife.

The Arctic is also vulnerable to the effects of hydrocarbon extraction and transportation. The petroleum products extracted from the Arctic are at least partly traceable to the very carbon emissions indirectly causing such profound changes to climate and sea ice. But the direct impacts of seeking, extracting, and transporting petroleum products in the Arctic marine environment can also cause severe impacts to surrounding habitat and wildlife. The associated activities of constructing infrastructure, moving people and materials to and from job sites, and providing for the transportation of products in pipelines or barges, all add up to substantial activity in a remote region of the world. The wells, rigs, pipelines, roads, airports, power plants, rig platforms, and artificial islands can have an impact on nearby seabirds and marine mammals. Even with comprehensive planning for mitigating a spill event, drilling in the Arctic is inherently risky, the stakes are high, and response is very challenging.

In addition to biological value for the wildlife that inhabit the Bering, Chukchi, and Beaufort Seas, this region is a place with many human values, both contemporary and ancient. Indigenous communities are facing challenges to food security and their traditional ways of life, and stand to be most immediately and directly affected by the changing climate. Researchers and scientists have an interest in surveying the environment, and the knowledge they gain plays an important role in understanding the ecosystem and contributing to sound management decisions. Industry also has a financial stake in what occurs in the Arctic, whether drilling for oil or seeking safer shipping routes. Finally, the Arctic also is a region of enormous personal significance even for those who may never visit, or personally see a polar bear or sea ice. All of these voices merit attention and consideration. Sustainable management of this region should consider various perspectives, and integrate information across disciplines and geographies to implement sustainable actions that account for cumulative effects.

KEY CONSERVATION THEMES AND MANAGEMENT IMPLICATIONS

This Ecological Atlas represents a data-rich foundation upon which to understand the complex dynamics of the Arctic marine ecosystem and the social, cultural, and economic relationships that depend upon it. Through the study of physical influences, species natural history, and human uses, we begin to see the spatial patterns that point to special places in the Arctic Ocean—Unimak Pass, Bering Strait, Barrow Canyon, Wrangel Island, and MacKenzie Bay, to name a few. We also have learned key lessons from considering this compilation of data holistically.

Frequently, management agencies do not have the dedicated staff or funding to pull together a transboundary resource like this one, or the jurisdiction to engage in data gathering or planning beyond their respective missions. However, a holistic perspective is vital to understanding the larger context of decisions and to assessing cumulative effects. Over the past four decades, Audubon Alaska, with many partners, has promoted the conservation of bird, mammal, and fish populations in and around Alaska for present and future generations. Through this latest Ecological Atlas, we have worked to examine ecological patterns, share interdisciplinary knowledge, inform sustainable management of natural resources, and inspire an appreciation for this spectacular place. While we created this Ecological Atlas with the assistance of many people, most prominently our collaborators at Oceana, as well as the many agencies, organizations, and individuals who contributed data, expertise, and review, we recognize that our partners represent diverse backgrounds and may interpret data presented in the atlas differently. We offer the following observations and recommendations for managing the Bering, Chukchi, and Beaufort Seas. However, we emphasize that the following key themes and recommendations presented below reflect Audubon Alaska's background, experience, and viewpoints. They do not necessarily represent the views of any of the other authors, editors, data stewards, reviewers, or agencies who contributed to this effort.

CONNECTING THE NINE CONSERVATION AND MANAGEMENT THEMES

1. The Bering, Chukchi, and Beaufort Seas region is a major hotspot of productivity.
2. This ecosystem is dynamic and highly seasonal, and especially driven by sea ice.
3. Certain enduring features consistently contribute to ecosystem function and resiliency.
4. The areas critical to ecosystem function are interconnected.
5. Climate change is shifting sea ice patterns and species ranges, and requires adaptation to a new normal condition.
6. There is intensifying development interest in the Arctic, requiring a better understanding of cumulative impacts at regional scales.
7. Among what we currently know, there are a number of outstanding data gaps and uncertainties.
8. The synthesizing, publishing, and sharing of spatial data greatly enhances understanding and decision-making abilities.
9. Managers should integrate the best available data across disciplines and broad geographic and temporal scales to assess cumulative effects and implement sustainable actions.

1

PRODUCTIVITY

The Bering, Chukchi, and Beaufort Seas region is a major hotspot of productivity.

CONSERVATION THEME	PRODUCTIVITY	MANAGEMENT IMPLICATIONS
This ecosystem has a great richness and abundance of species that live here year-round, or travel great distances to feed here during the summer months. This is one of the most productive areas in the world for phytoplankton, zooplankton, invertebrates, fish, birds, and mammals.		Management of this region should recognize and protect this productivity and preserve the significant global value to wildlife. Resource use and development decisions should incorporate and integrate the stewardship responsibility for migratory species that belong to multiple nations at different times of year.
Example: Globally, seabird numbers are thought to be in steep decline, down 70% since 1950 among the world's monitored populations (Paleczny et al. 2015). The US, and particularly Alaska, supports the largest number of breeding seabird species of any nation, as well as the second-highest number of endemic breeding seabird species, and the third-highest number of species of conservation concern (Croxall et al. 2012).		**Example:** Having a significant proportion of the world's seabird abundance and diversity, Alaska bears a great responsibility for the stewardship of seabird habitat and populations. Concentration areas for marine birds should be thoughtfully managed, especially in Important Bird Areas. Conserving only 27 of the 865 bird colonies in this region protects three-quarters of all colonial nesting seabirds in the project area—about 25 million individuals (Table 5.1-1). Those sites, of which many are already incorporated into the Alaska Maritime National Wildlife Refuge (Maps 5.1 and 7.10), deserve the highest possible protection from harm.

2

DYNAMISM

This ecosystem is dynamic and highly seasonal, and especially driven by sea ice.

CONSERVATION THEME		MANAGEMENT IMPLICATIONS
The seasonally advancing or retreating ice edge influences the timing, extent, and abundance of primary productivity, which in turn influences the abundance of zooplankton and fish, and the distribution and concentration of upper trophic species.	DYNAMISM	The dynamic, shifting nature of sea ice means that the location of Arctic marine species' habitat constantly shifts as the sea-ice margin advances and retreats over the course of a year. Static management boundaries are not ideal; creative new conservation approaches should be considered.
Example: For polar bears (*Ursus maritimus*), sea ice is a necessary platform for many life functions, which may include travel, foraging, resting, breeding, and denning (Summary 6.1). These bears have evolved to live on this shifting habitat and to thrive on food resources (mainly seals) that also live among the drifting pack ice.		**Example:** The US Fish and Wildlife Service designated critical habitat for polar bears effective in 2011 (Figure 6.1-3). This designation included various components of habitat, including sea-ice habitat, which encompassed much of the US portion of the marine ecosystem because the location of this habitat is constantly shifting. The designation has been contentious, in part because of the all-encompassing spatial extent of critical habitat.

3

ENDURING FEATURES

Certain enduring features consistently contribute to ecosystem function and resiliency.

CONSERVATION THEME		MANAGEMENT IMPLICATIONS
As evidenced throughout this atlas, wildlife abounds across the Bering, Chukchi, and Beaufort Seas. Certain areas have additional ecological significance due to underlying bathymetry and the biological and physical processes that drive productivity, supporting a high density or diversity of wildlife.	ENDURING FEATURES	The high biological values of this region warrant consideration for enhanced conservation measures. Responsible agencies should identify ecological hotspots that are key to ecosystem functioning today, as well as project which areas exhibit resiliency and will continue to be important in the future (e.g. Christie and Sommerkorn 2012). Governments should protect those key areas from harm, in the form of conservation areas and/or by instituting best management practices that protect the resources at stake.
Example: The Nushagak and Kvichak River systems, and their marine counterpart, Bristol Bay, are a global hotspot of productivity for salmon (Map 4.7). These anadromous fish facilitate an immense terrestrial-marine nutrient exchange that is a foundational building block of the regional ecology (Summary 4.7). This region fuels the largest sockeye salmon fishery in the world, and provides $1.5 billion dollars annually to the US economy (Knapp et al. 2013).		**Example:** Conservation organizations, fishermen, tribal entities, and government agencies identified Bristol Bay as an area of critical ecological importance to Alaska's commercial salmon fisheries. In 2014, the North Aleutian Basin, which includes Bristol Bay, was withdrawn from oil and gas leasing by then President Obama to safeguard its unique biological values (Map 7.3).

4

INTERCONNECTION

The areas critical to ecosystem function are interconnected.

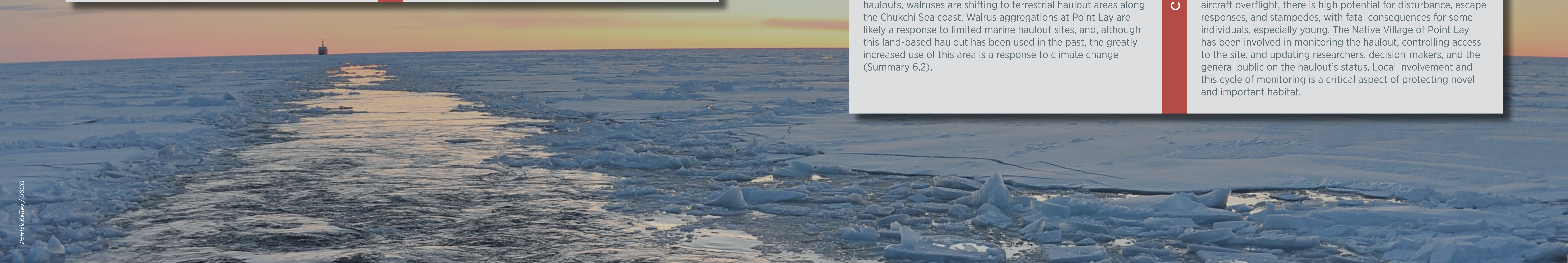
CONSERVATION THEME		MANAGEMENT IMPLICATIONS
Components of the marine ecosystem—from water masses and nutrients, phytoplankton and fishes, to birds and mammals—travel among these three seas. Even the terrestrial and marine environments are linked by physical processes such as freshwater runoff and by wildlife such as anadromous fish and birds. Upper-trophic-level species such as birds, marine mammals, and people rely on productivity of lower trophic levels such as zooplankton, benthic biomass, and fish.	INTERCONNECTEDNESS	Because of the connectivity inherent in the Arctic marine ecosystem, even localized impacts can resonate across a much broader area. Management decisions should consider connectivity and cumulative effects among key sites and at regional scales. Migratory birds, for example, travel long distances to and from other continents, and reduced breeding success in the Arctic would affect species abundance throughout their range.
Example: Migratory birds such as the Spectacled Eider (*Somateria fischeri*) utilize a series of seasonally important habitats. The entire global population overwinters in a recurrent polynya south of St. Lawrence Island before dispersing across discrete breeding locations on the North Slope of Alaska, Siberia, and the Yukon-Kuskokwim Delta (Map 5.4.2). Nutrients acquired during foraging near the Bering shelf break are redistributed to terrestrial nesting sites and marine staging areas, linking the Bering Sea with coastal wetlands, the Chukchi Sea, and Russian waters.		**Example:** The US Fish and Wildlife Service designated critical habitat for the Spectacled Eider based not only on the heavily concentrated wintering area, but also breeding areas in the Yukon-Kuskokwim Delta and molting areas in Ledyard Bay and in Norton Sound (Map 5.4.2). Aligning protections across a broader geography, as the US Fish and Wildlife Service has done with Spectacled Eider critical habitat, highlights the biological connections among distant sites.

5

CLIMATE CHANGE

Climate change is shifting sea ice patterns and species ranges, and requires adaptation to a new normal condition.

CONSERVATION THEME		MANAGEMENT IMPLICATIONS
Experts predict that climate change will have major effects on physical, ecological, social, and economic systems around the world over the next century. Climate is a fundamental aspect of the ecology and natural history of species, and ecological impacts will be widespread. Some impacts—such as loss of sea ice and a shift from a benthic-driven to pelagic-driven food web—are already occurring or reasonably foreseeable (Grebmeier et al. 2006). However, many other impacts are difficult or impossible to predict, such as whether ice-obligate species will redistribute, develop novel behaviors to continue to persist, or simply become extirpated.	CLIMATE CHANGE	Climate change is a reality in Arctic Alaska and requires agencies to acknowledge Arctic warming and shifting patterns, and to conduct studies, anticipate impacts, and fund mitigation efforts. In particular, adaptive management based on an iterative process of planning, implementation, monitoring, and adaptation is of paramount importance to effectively respond to uncertain changes. Beyond the scope of this Ecological Atlas, but most importantly, governments should set limits on carbon emissions and reduce greenhouse gases to abate further damage to the Arctic ecosystem and coastal communities.
Example: In the absence of ice floes traditionally used as haulouts, walruses are shifting to terrestrial haulout areas along the Chukchi Sea coast. Walrus aggregations at Point Lay are likely a response to limited marine haulout sites, and, although this land-based haulout has been used in the past, the greatly increased use of this area is a response to climate change (Summary 6.2).		**Example:** Because hauled out walrus are highly responsive to aircraft overflight, there is high potential for disturbance, escape responses, and stampedes, with fatal consequences for some individuals, especially young. The Native Village of Point Lay has been involved in monitoring the haulout, controlling access to the site, and updating researchers, decision-makers, and the general public on the haulout's status. Local involvement and this cycle of monitoring is a critical aspect of protecting novel and important habitat.



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6

DEVELOPMENT INTEREST

There is intensifying development interest in the Arctic, requiring a better understanding of cumulative impacts at regional scales.

DEVELOPMENT INTEREST

CONSERVATION THEME	MANAGEMENT IMPLICATIONS
There is interest in using the Arctic for many different activities including for natural resource extraction, shipping, and tourism. Main pressure points on the ecosystem include fishing, vessel traffic, energy extraction, and climate change, each of which poses a variety of threats.	Agencies should work together domestically and internationally to adequately understand, plan for, and address major threats and cumulative impacts of development at regional scales.
Example: Vessel traffic and offshore hydrocarbon extraction pose risks of oil spills, ship strikes, noise-based disturbance, discharges and emissions, and aquatic invasions (Summaries 7.3 and 7.5). In particular, a large oil spill like *Deepwater Horizon* or *Exxon Valdez* could be catastrophic to some wildlife species or populations, and may greatly impact food security for nearby communities. Due in part to the long distance from the nearest response station, the US is not adequately prepared to respond to a major oil spill in ice-covered Arctic and subarctic waters.	**Example:** Especially in newly seasonally ice-free areas, the US Coast Guard and other similar agencies should establish vessel traffic routing, speed restrictions, Areas to be Avoided, and other measures to mitigate negative effects of increasing shipping and be prepared for accidents and spills (Map 7.5.3m). Prior to permitting offshore oil and gas production, the US and other nations should develop adequate response capabilities (Figure 7.5-1).

7

DATA GAPS

Among what we currently know, there are a number of outstanding data gaps and uncertainties.

DATA GAPS

CONSERVATION THEME	MANAGEMENT IMPLICATIONS
The Arctic is very much a region still being discovered. Despite technological advances, there are significant hurdles to a comprehensive understanding of Arctic ecology, including limited baseline data, short field seasons, challenging international coordination, and a combination of broad species ranges and logistically, financially, or physically inaccessible locations. Areas such as the Aleutian Basin and Canada Basin are little studied, often leaving gaps in species distribution that may or may not reflect actual lack of use. Data gaps similarly preclude precise species population estimates, a foundation of sustainable management. Climate change introduces significant uncertainty in how population dynamics and distributions will respond in the years and decades ahead.	Data gathering and monitoring are the foundation for informed management decisions. Sufficient funding is essential for agencies to continue to conduct science, and provide long-term datasets to develop our knowledge and aid management decisions. The US, Russia, and Canada should increase international cooperation regarding species management and conservation. More complete documentation of traditional knowledge through the use of appropriate social science methods in cooperation with communities would fill data gaps and improve knowledge. Furthermore, when data gaps or scientific uncertainty exist, management decisions should be informed by the precautionary principle that a new action with the potential for causing harm bears the burden of proof, and a protective action can be taken given plausible but uncertain risks.
Example: Successful management of fisheries in the Chukchi and Beaufort Seas relies on balancing somewhat limited scientific understanding with the varying perspectives of numerous user groups and political entities. As fish ranges expand due to climate change, economically viable commercial fishing may become possible in the Arctic Ocean. However, the absence of definitive stock estimates and other key biological data make it challenging to define sustainable catch limits, harvest timing and duration, and acceptable catch methods (Summary 7.7).	**Example:** Both the US and international communities have taken proactive steps toward sustainable management of emerging Arctic fisheries. The Arctic Fishery Management Plan, implemented in 2009, closed the US Arctic to commercial fishing (Map 7.7). This decision was reaffirmed by a landmark international agreement from the five Arctic-bounding nations passed in July 2015 banning commercial fishing until a more complete scientific understanding is gained. Together, these agreements preclude ecologically damaging harvest practices and protect novel fish populations until research demonstrates that these stocks can support sustainable commercial fishing.

8

DATA SYNTHESIS

The synthesizing, publishing, and sharing of spatial data greatly enhances understanding and decision-making abilities.

DATA SYNTHESIS

CONSERVATION THEME	MANAGEMENT IMPLICATIONS
Ecological data are inherently spatial. Environmental processes are tied to places—the physical features, climate, and interactions that set the biological stage. Maps make such data visually accessible, bringing ideas together to help people understand spatial context, patterns, and relationships. The process of bringing together ecological data across broad scales also identifies data quality and data gaps and the need for greater knowledge.	Ecosystem-based management requires synthesizing spatial data across larger regions to understand the ecological patterns and broader context. Natural resource management requires decisions about where activities will take place and what may be affected. Agencies should continue and also enhance a culture of data synthesis, publishing, sharing, and cross-disciplinary collaboration to promote understanding and sustainable management.
Example: The Aerial Survey of Arctic Marine Mammals (ASAMM) documents the distribution and relative abundance of whales and other marine mammals. Formerly focused on surveying the fall migration of bowhead whales (Map 6.7d) in the Beaufort Sea, ASAMM dates back to 1979 with expanded species, geographic, and temporal coverage in more recent years (National Oceanic and Atmospheric Administration 2015). The survey serves as a baseline for pre-development conditions and for studying trends in distribution and abundance over time.	**Example:** ASAMM is a National Oceanic and Atmospheric Administration (NOAA) and Bureau of Ocean Energy Management (BOEM) cooperative effort. The survey occurs annually during the summer and fall in the Chukchi and Beaufort Seas in areas of potential energy exploration, development, and production. NOAA and BOEM compile, analyze, and report data annually, and make those data easily available. ASAMM has provided much-needed data to planning processes related to offshore energy development.

9

INTEGRATED ASSESSMENT

Managers should integrate the best available data across disciplines and broad geographic and temporal scales to assess cumulative effects and implement sustainable actions.

INTEGRATED ASSESSMENT

CONSERVATION THEME	MANAGEMENT IMPLICATIONS
Synthesizing data across time and space reveals important patterns, and cross-disciplinary study lends useful connections. Integrated assessment succeeds by comprehensively evaluating actions across disciplines, stakeholder groups, and broad geographic and temporal scales. With this information, managers are better equipped to make sound decisions and succeed at long-term conservation goals.	Decision-makers need to comprehensively assess the cumulative effects of decisions—changes to the environment that are caused by an action in combination with other past, present and future human actions. To this end, agencies should collaborate more seamlessly across missions and jurisdictions, and continue to work with tribes on co-management. An understanding of cumulative effects should be applied to design mitigation, monitoring, and adaptation strategies and ultimately to implement sustainable actions.
Example: The Arctic Council's 2009 Arctic Marine Shipping Assessment (AMSA) brought together people and knowledge from various disciplines to holistically assess the future of Arctic vessel traffic. AMSA reported on the last few hundred years of shipping history as well as changing conditions (e.g. sea ice) looking 15 years ahead. The effort covered the circumpolar Arctic, while including regional and local perspectives. The report focused on geography, history, governance, current uses, future scenarios, human dimensions, environmental impacts, and infrastructure.	**Example:** AMSA resulted in recommendations for enhancing marine safety, protecting Arctic people and the environment, and building Arctic marine infrastructure. The report recommended identification of areas of heightened ecological and cultural significance, and found that the release of oil into the Arctic marine environment is the most significant threat from Arctic shipping.

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REFERENCES

Arctic Climate Impact Assessment. 2004. Impacts of a Warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press, Cambridge, UK.

Christie, P. and M. Sommerkorn. 2012. RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience. World Wildlife Fund, Global Arctic Programme, Ottawa, Canada.

Citta, J. J., L. T. Quakenbush, S. R. Okkonen, M. L. Druckenmiller, W. Maslowski, J. Clement-Kinney, J. C. George, H. Brower, R. J. Small, C. J. Ashjian, L. A. Harwood, and M. P. Heide-Jørgensen. 2015. Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012. *Progress in Oceanography* 136:201-222.

Croxall, J. P., S. H. M. Butchart, B. Lascelles, A. J. Stattersfield, B. Sullivan, A. Symes, and P. Taylor. 2012. Seabird conservation status, threats, and priority actions: A global assessment. *Bird Conservation International* 22:1-34.

Grebmeier, J. M., L. W. Cooper, H. M. Feder, and B. I. Sirenko. 2006. Ecosystem dynamics of the Pacific-influenced northern Bering and Chukchi Seas in the Amerasian Arctic. *Progress in Oceanography* 71:331-361.

Knapp, G., M. Guettabi, and S. Goldsmith. 2013. The Economic Importance of the Bristol Bay Salmon Industry. University of Alaska Institute of Social and Economic Research, Anchorage, AK.

McDowell Group. 2015. The Economic Value of Alaska's Seafood Industry. Alaska Seafood Marketing Institute, Juneau, AK.

National Oceanic and Atmospheric Administration. 2015. Aerial Survey of Arctic Marine Mammals, 1979-2014 (ASAMM; including the Historical BWASP and COMIDA Databases). NOAA Fisheries, Alaska Fisheries Science Center, National Marine Mammal Labratory, Anchorage, AK. Accessed online December 2015 at http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php.

Overland, J. E. and P. J. Stabeno. 2004. Is the climate of Bering Sea warming and affecting the ecosystem? *EOS* 85:309-316.

Paleczny, M., E. Hammill, V. Karpouzi, and D. Pauly. 2015. Population trend of the world's monitored seabirds, 1950-2010. *PLoS ONE* 10:1-11.

Rode, K. D., R. R. Wilson, E. V. Regehr, M. St. Martin, D. C. Douglas, and J. Olson. 2015. Increased land use by Chukchi Sea polar bears in relation to changing sea ice conditions. *PLoS ONE* 10:e0142213.

Seabird Information Network. 2011. North Pacific Seabird Data Portal. Accessed online at http://axiom.seabirds.net/maps/north-pacific-seabirds/.

Sigler, M. F., M. Renner, S. L. Danielson, L. B. Eisner, R. R. Lauth, K. J. Kuletz, E. A. Logerwell, and G. L. Hunt, Jr. 2011. Fluxes, fins, and feathers: Relationships among the Bering, Chukchi, and Beaufort Seas in a time of climate change. *Oceanography* 24:250-265.

Springer, A. M. and C. P. McRoy. 1993. The paradox of pelagic food webs in the Northern Bering Sea—III: Patterns of primary production. *Continental Shelf Research* 13:575-599.

UNESCO World Heritage Convention. 2004. Natural System of Wrangel Island Reserve. UNESCO World Heritage Centre, United Nations. Accessed online 15 May 2017 at http://whc.unesco.org/en/list/1023.

US Fish and Wildlife Service. 2008. Seabirds Overview. US Fish and Wildlife Service, Anchorage, AK. Accessed online July 15 2013 at http://alaska.fws.gov/mbsp/mbm/seabirds/seabirds.htm.

Wang, M. and J. E. Overland. 2009. A sea ice free summer Arctic within 30 years? *Geophysical Research Letters* 36:L07502.

______. 2012. A sea ice free summer Arctic within 30 years: An update from CMIP5 models. *Geophysical Research Letters* 39:L18501.

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