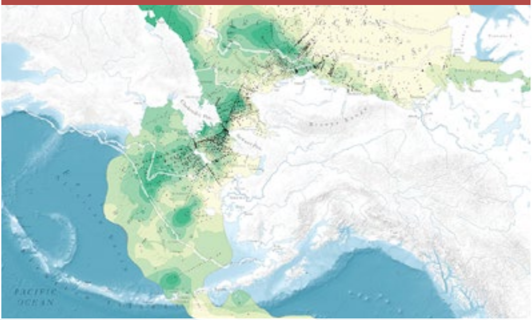
BIOLOGICAL SETTING

Celeste Leroux/Alaska Sea Grant

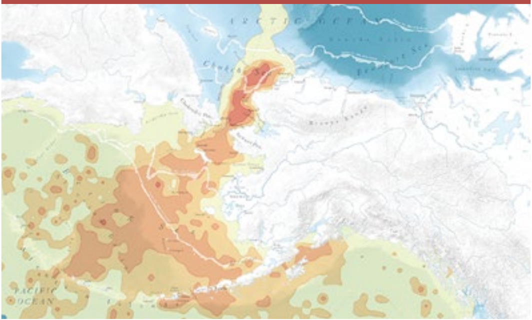
BIOLOGICAL SETTING MAP INDEX

Primary Productivity



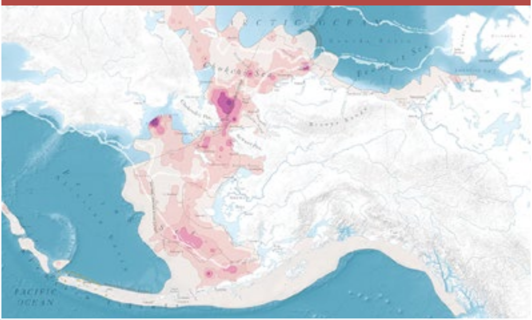
MAP 3.1 / PAGES 46–47

Zooplankton



MAP 3.2 / PAGES 50–51

Benthic Biomass



MAP 3.3 / PAGES 56–57

Snow Crab

MAP 3.4 / PAGES 62–63

Red King Crab

MAP 3.5 / PAGE 67

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.

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 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).

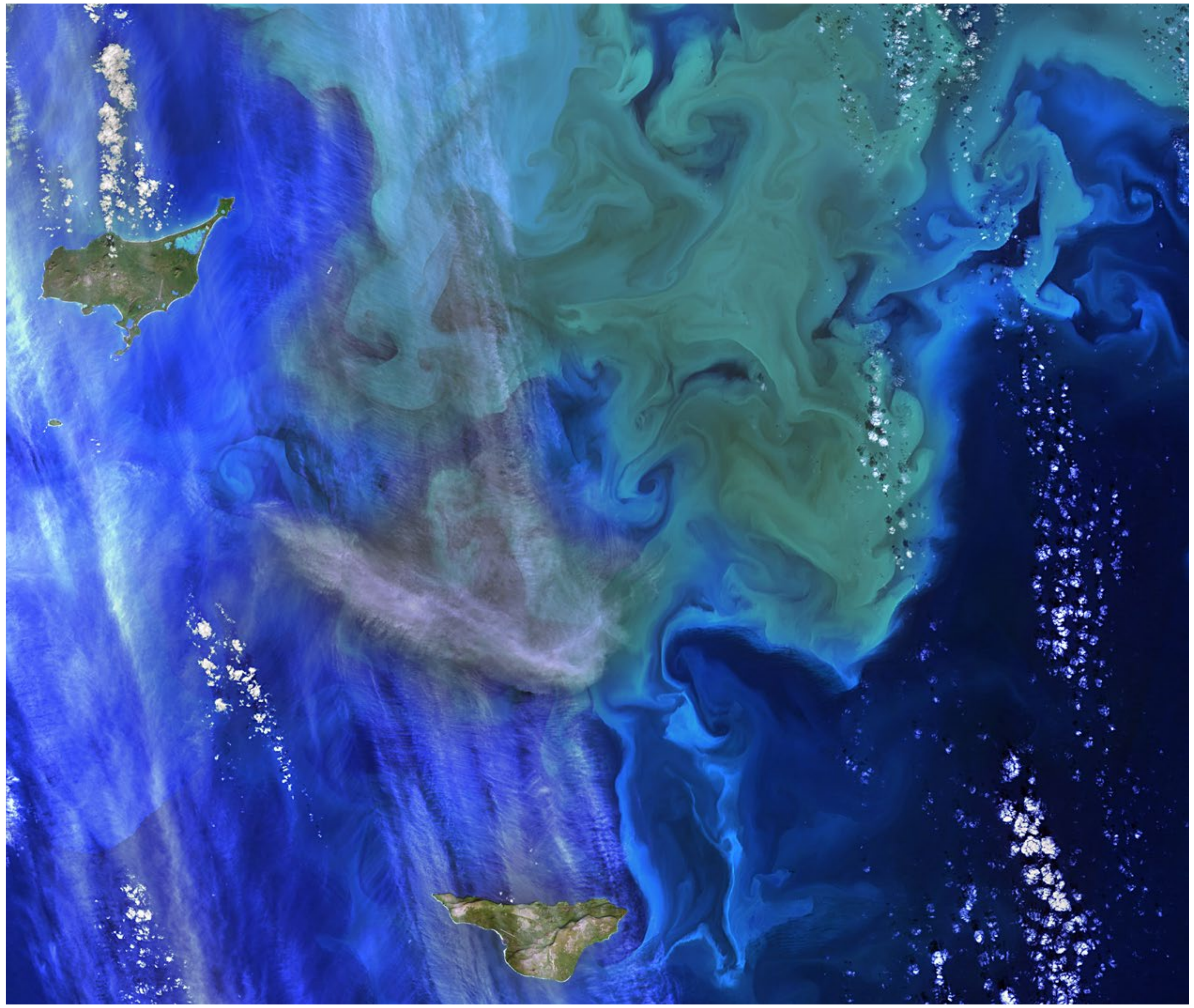
Reviewer

- 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)



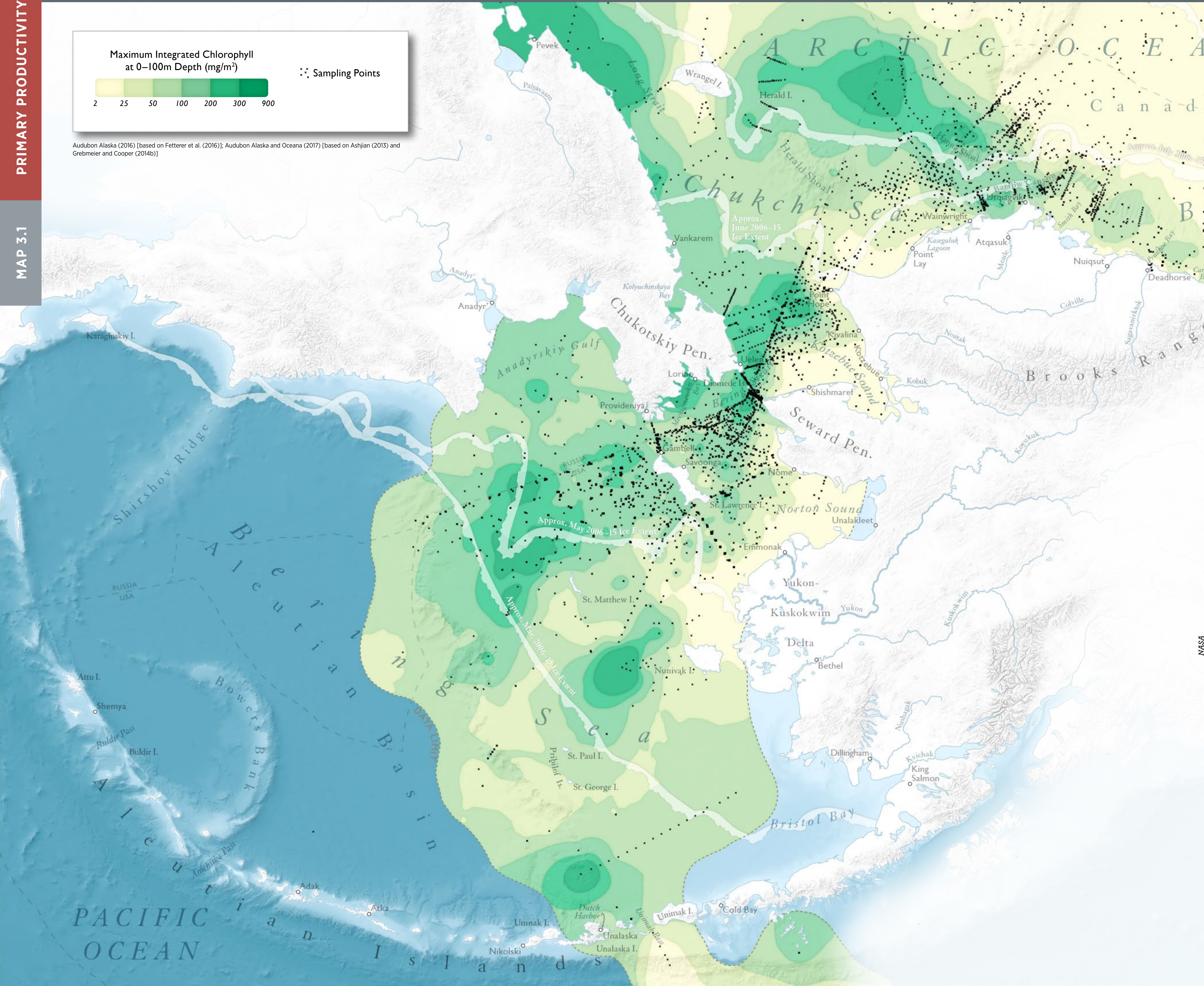
The aquamarine color is a coccolithophorid phytoplankton bloom that occurred around the Pribilof Islands in the eastern Bering Sea in 2014. Coccolithophore blooms of this size and duration are becoming more common and may be a result of changing climate conditions.

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

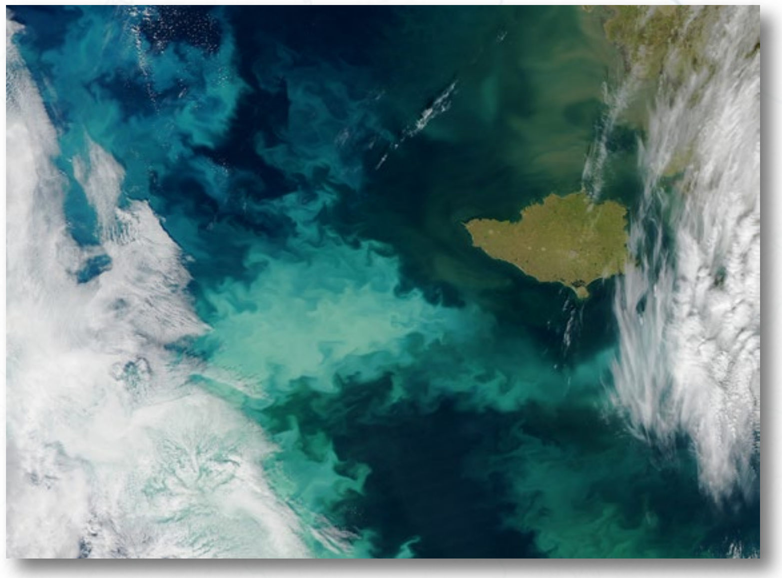
Primary Productivity

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

OCEANA Audubon ALASKA



Audubon Alaska (2016) [based on Fetterer et al. (2016)]; Audubon Alaska and Oceana (2017) [based on Ashjian (2013) and Grebmeier and Cooper (2014b)]


NASA

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).

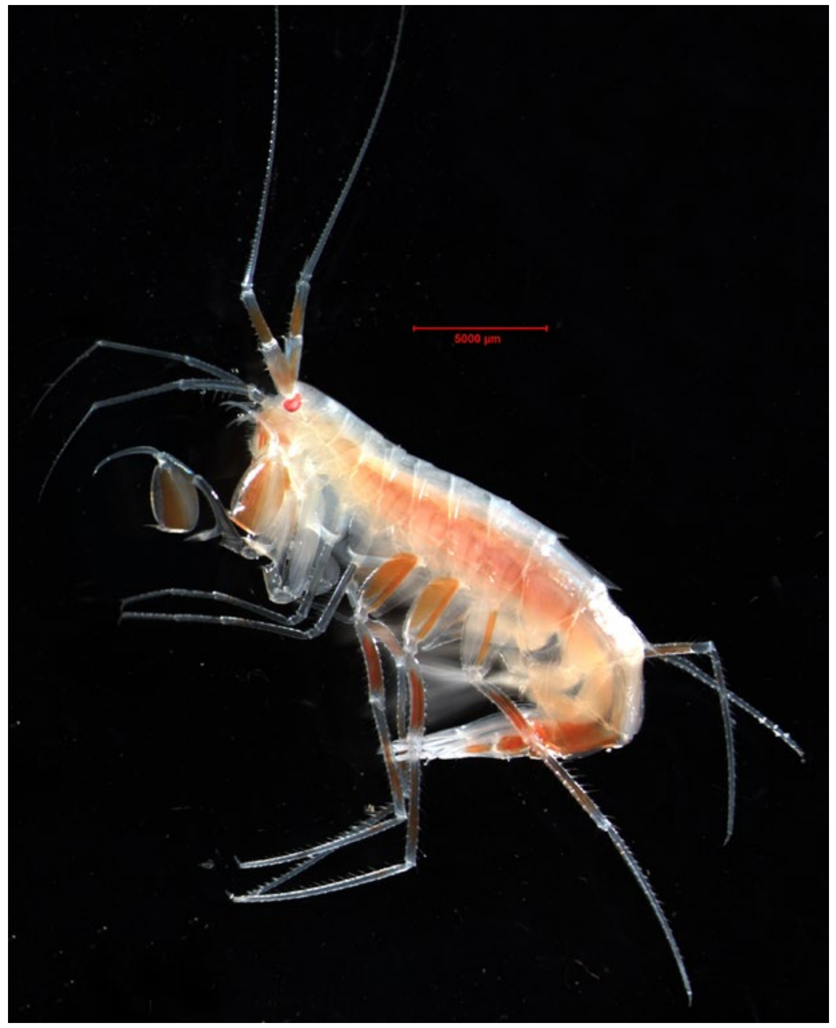
Zooplankton distribution changes over time and is strongly influenced by ocean conditions, ice coverage, and phytoplankton blooms (Hunt et al. 2002, Coyle et al. 2008, Ohashi et al. 2013, Sigler et al. 2016). Late sea-ice retreats, caused by a colder winter/spring, lead to early spring phytoplankton 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 (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.


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.

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)

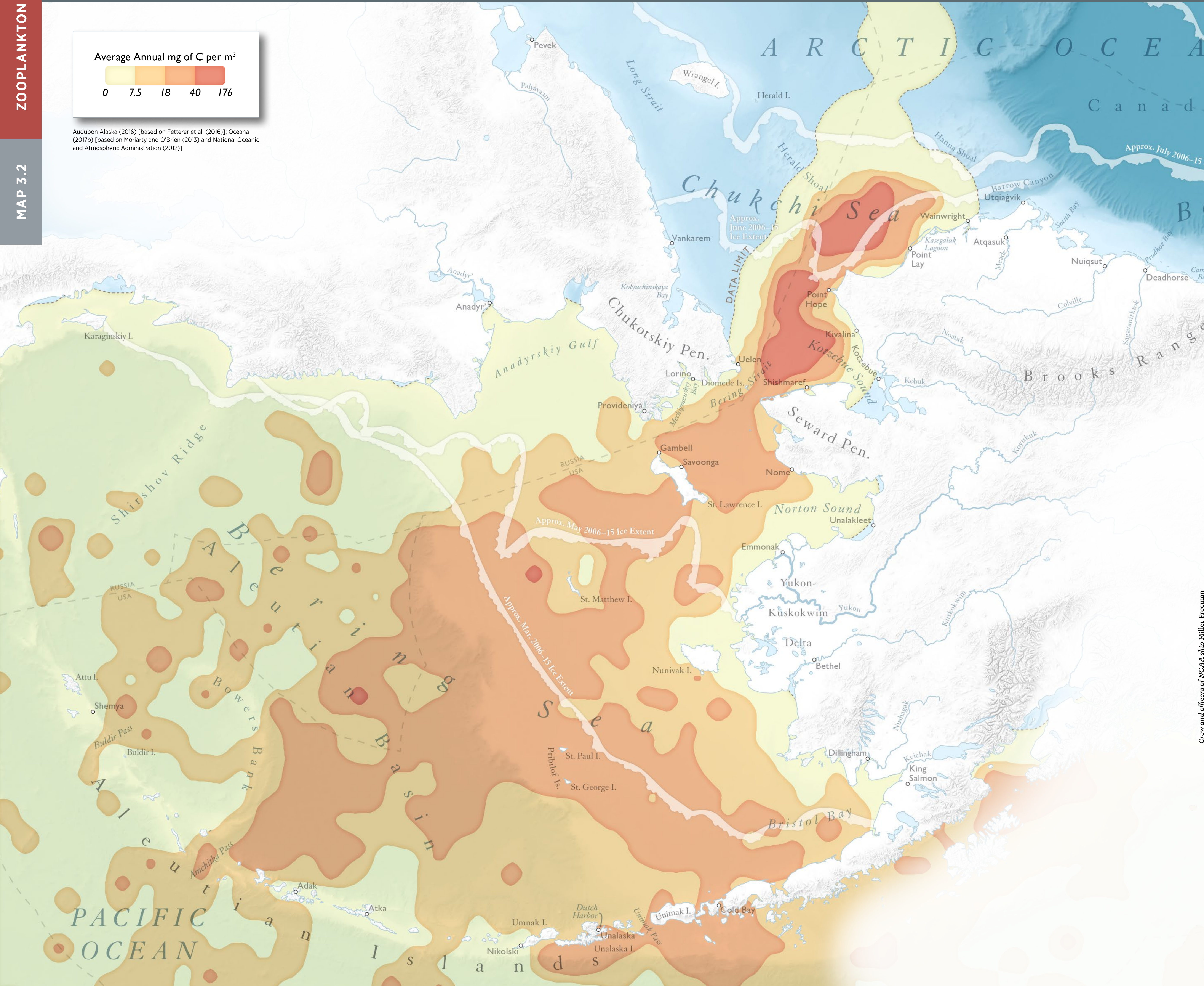

Eric Vance / US Environmental Protection Agency

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)]

Herschel I. Tuktoyaktuk Mackenzie Bay Mackenzie Delta Aklavik Inuvik Amundsen Gulf Paulatuk Ulukhaktok Prince Albert Sound Victoria I. Banks I. Sachs Harbour

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

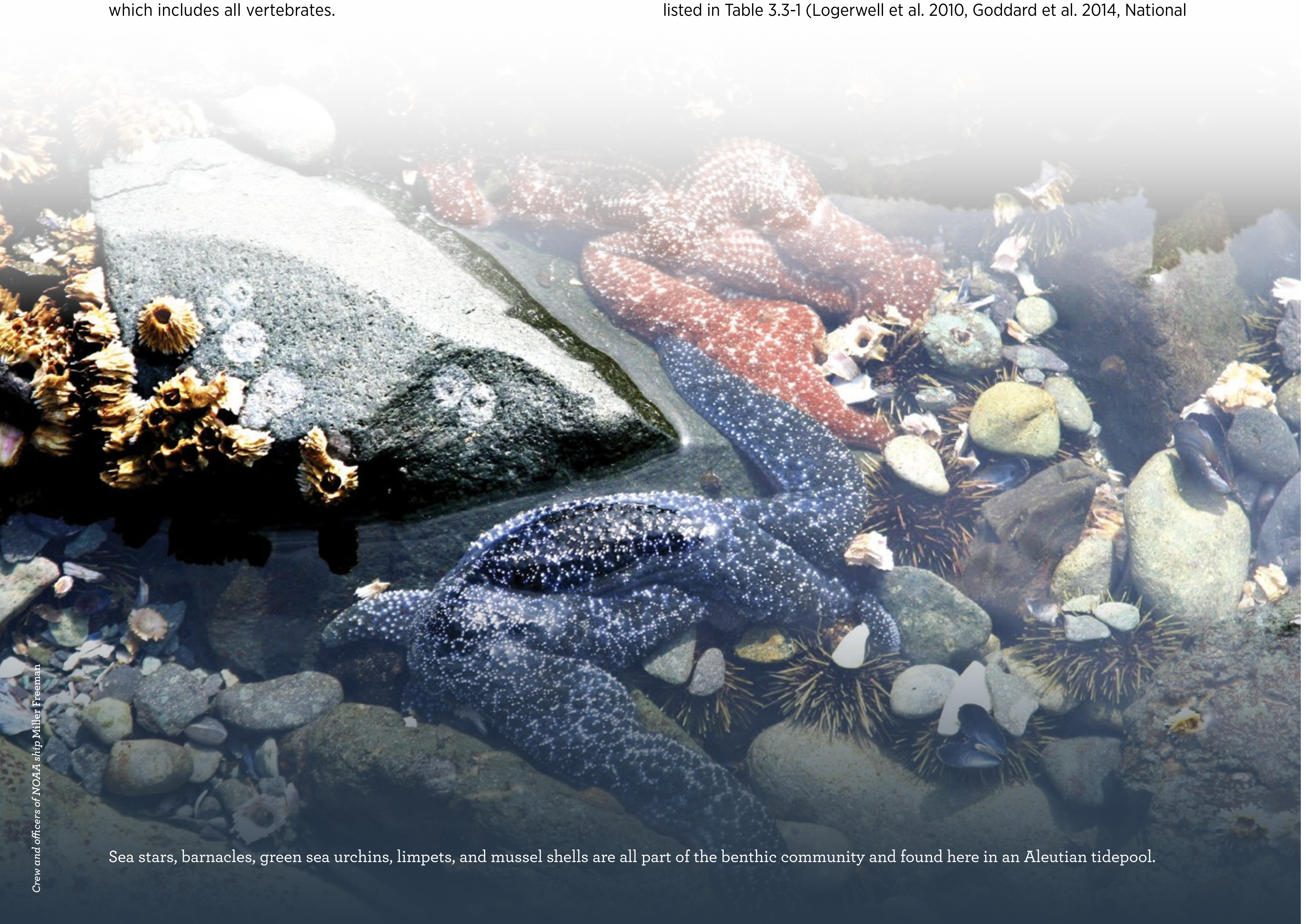
Benthic invertebrates live on or in the seafloor. Some benthic invertebrates form structures that become habitats, others live in the substrate, and some are mobile and travel on the surface of the seafloor. Benthic invertebrates comprise a large proportion of the total marine biomass and species diversity 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

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)

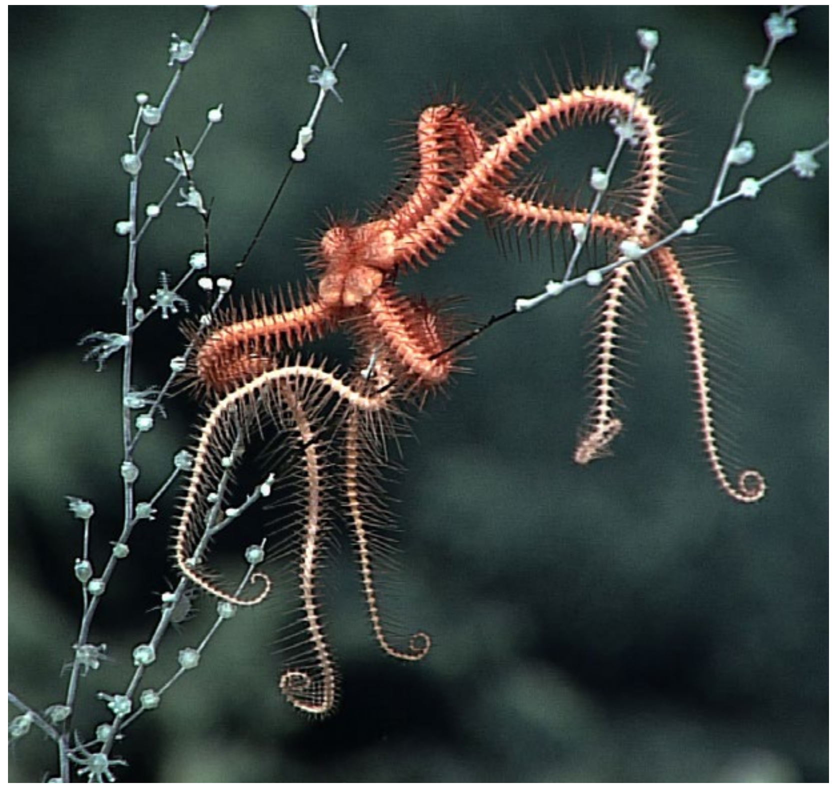
A trawl survey database was created by combining multiple bottom trawl surveys which employed consistent methodologies and sampled waters within the US exclusive economic zone (EEZ) of the Bering Sea (Conner and Lauth 2016, Hoff 2016), Aleutian Islands (Raring et al. 2016), Gulf of Alaska (von Szalay 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 i^{th} dataset, (X_{ij}) is the average value for grid cell j for the i^{th} dataset, and (X_{ij}) and (σ_i) are the overall mean and overall standard deviation of all the calculated grid cell average values for the i^{th} 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

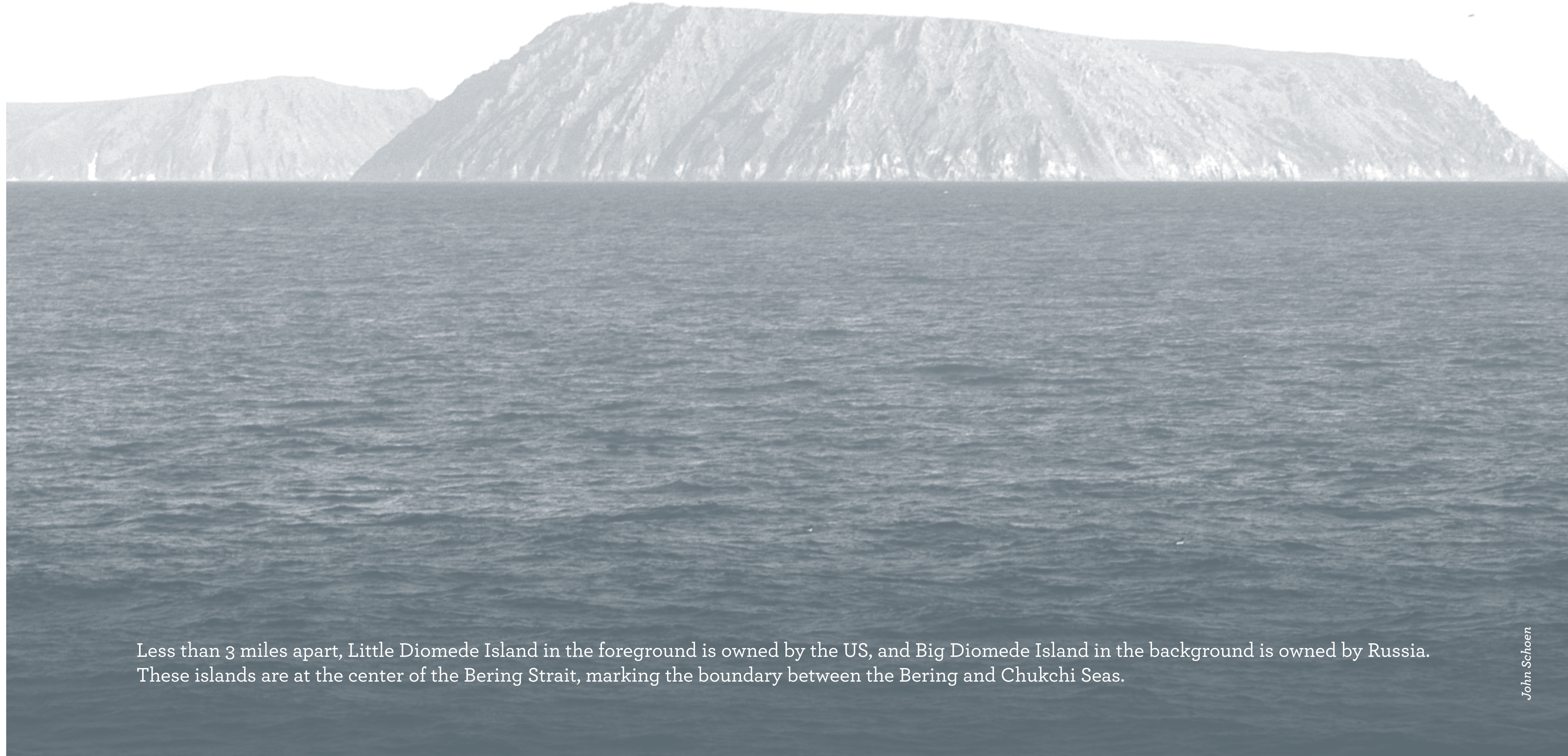
- Robert Stone
- Cynthia Yeung
- Jacqueline Grebmeier

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)



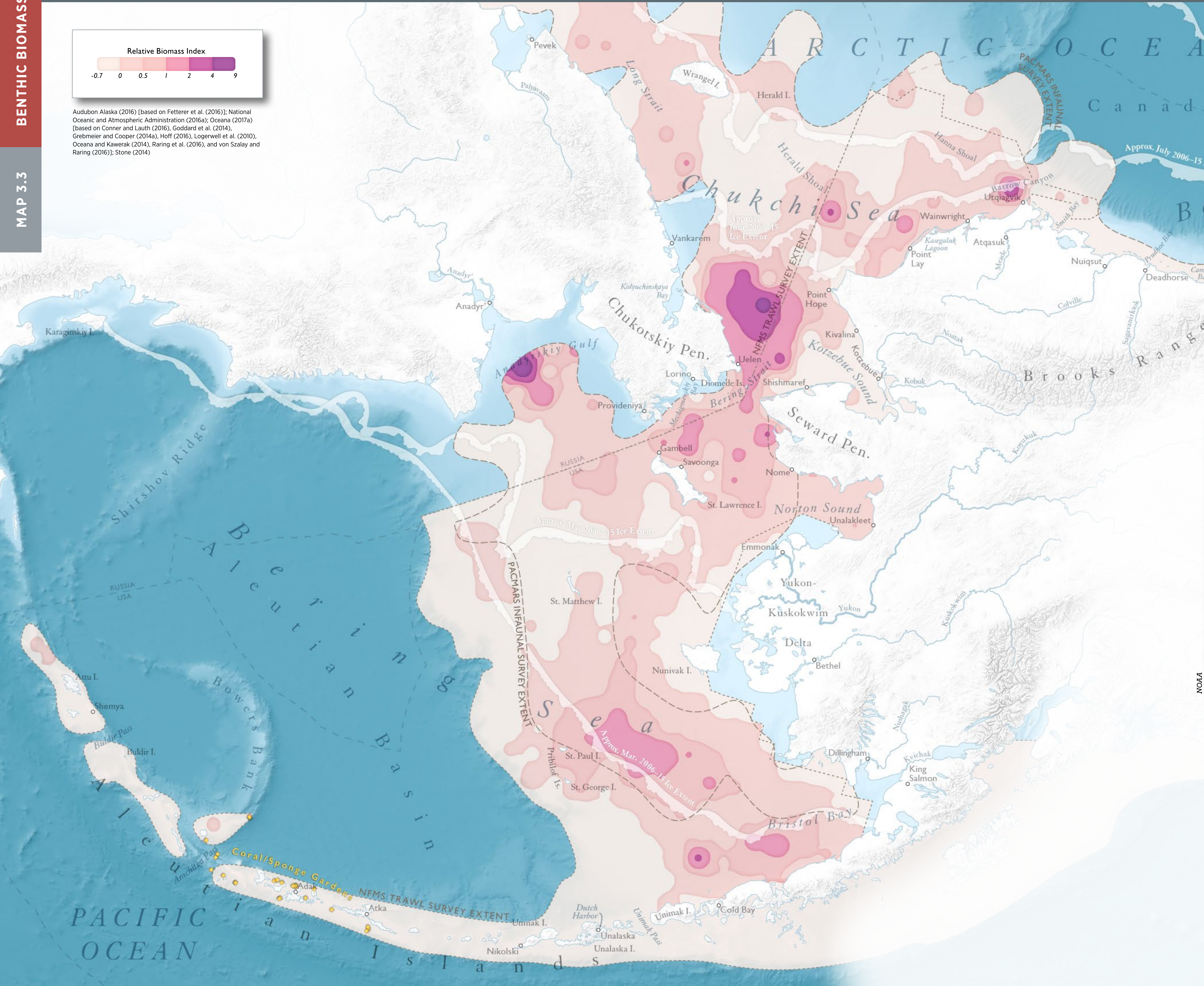
Less than 3 miles apart, Little Diomede Island in the foreground is owned by the US, and Big Diomede Island in the background is owned by Russia. These islands are at the center of the Bering Strait, marking the boundary between the Bering and Chukchi Seas.

John Schoen

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.

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).

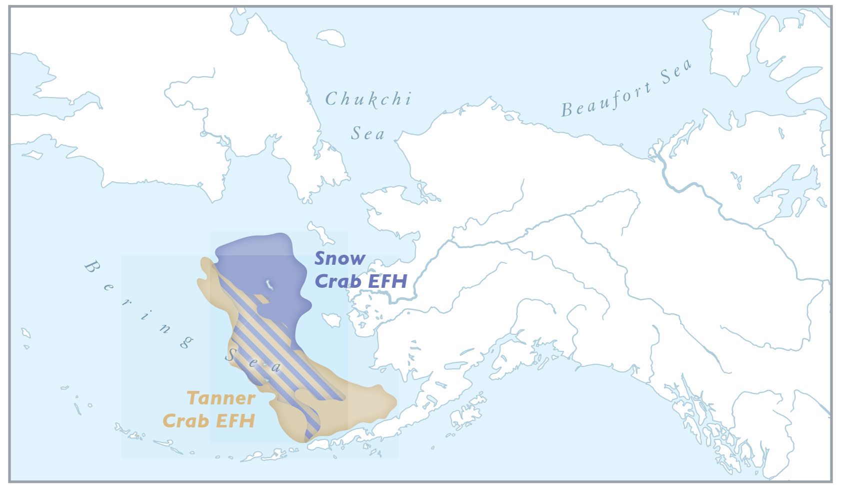


FIGURE 3.4-1. Snow crab and Tanner crab Essential Fish Habitats, showing overlapping distributions which offer opportunities for hybridization. Figure adapted from National Oceanic and Atmospheric Administration (2016b).

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]

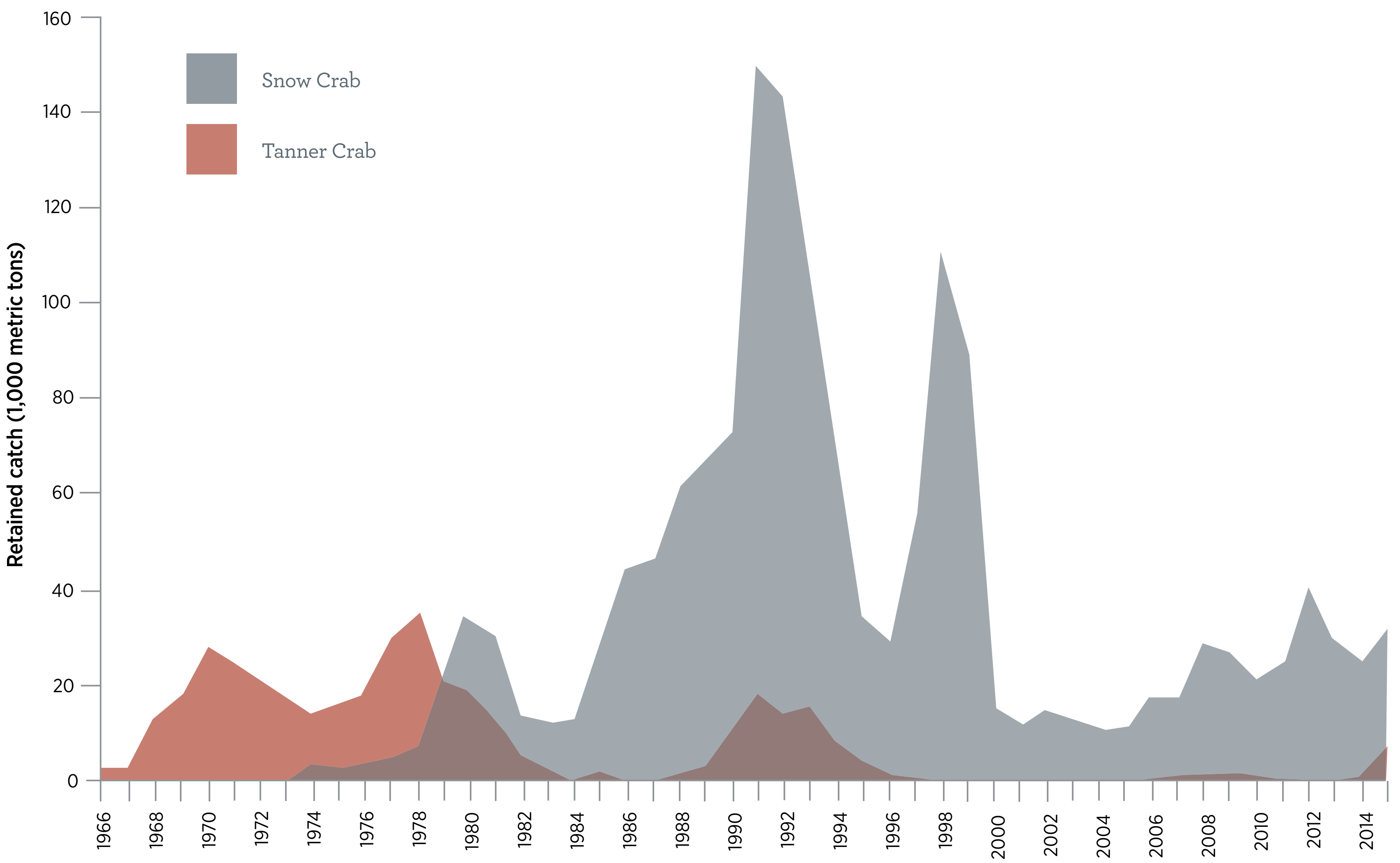
Sources: [1] North Pacific Fishery Management Council (2016); [2] Conan et al. (1989) and Comeau et al. (1999)

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).



Derek Keats / Creative Commons - CC BY 2.0

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.

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


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)

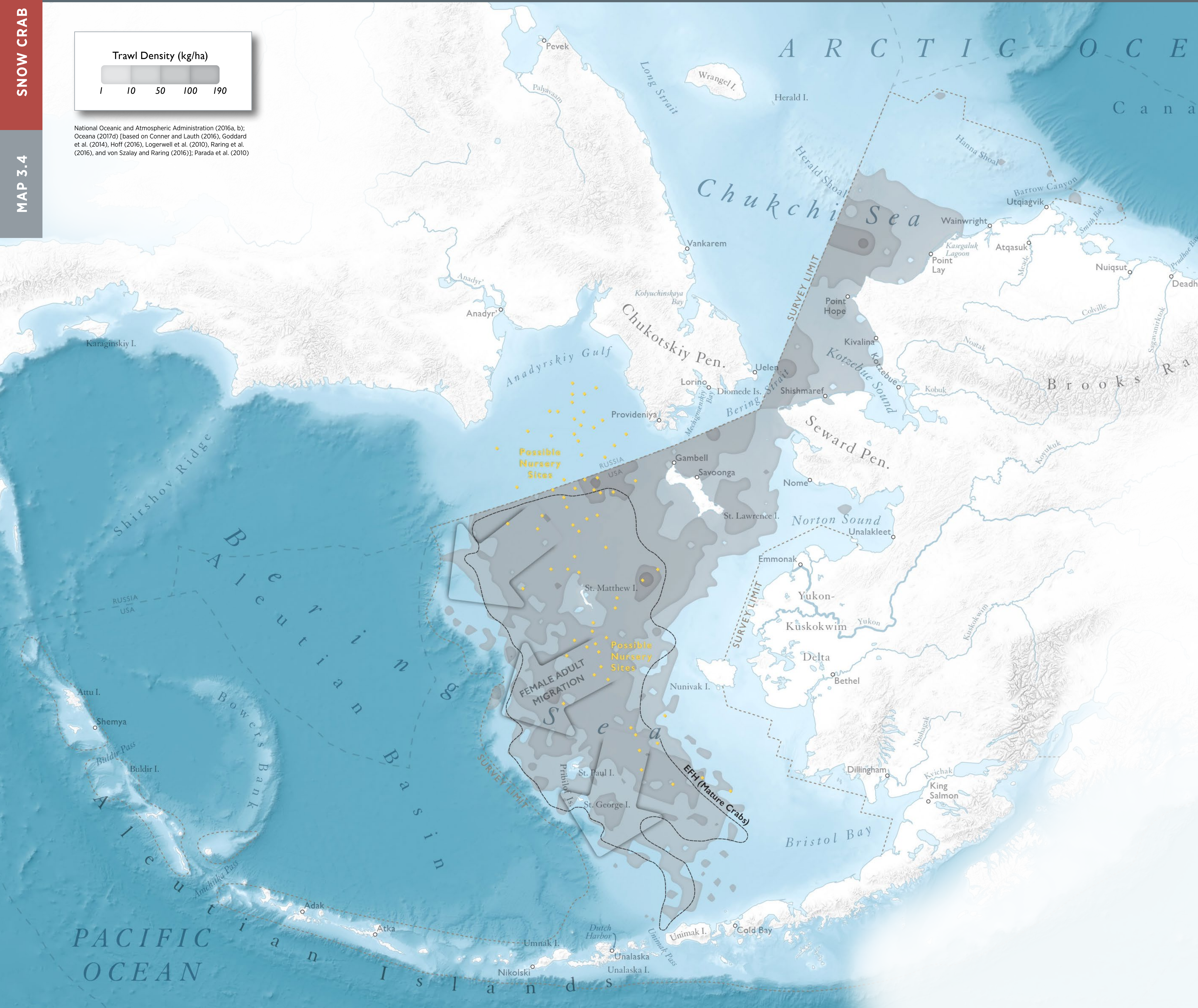
Essential Fish Habitat: National Oceanic and Atmospheric Administration (2016b)

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

Snow Crab

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

OCEANA Audubon ALASKA



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)


R. Hibpshman

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.

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 (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).

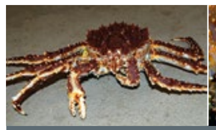
David Csepp / NOAA

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

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).

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.

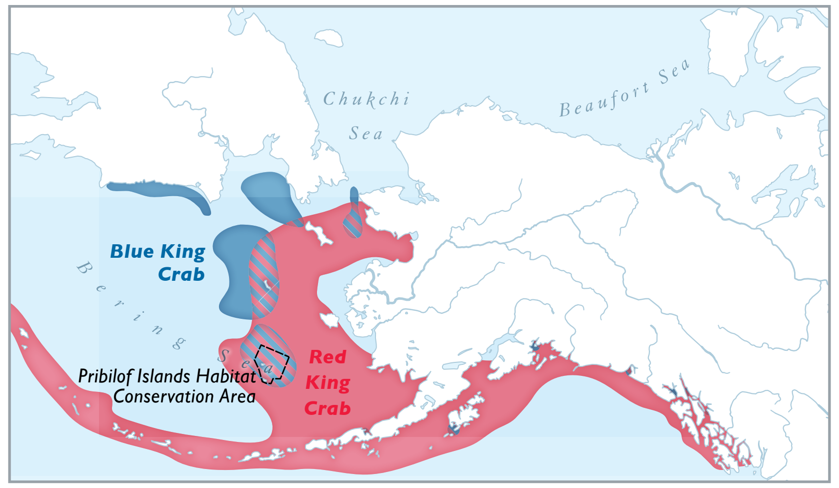


FIGURE 3.5-1. Red king crab and blue king crab Essential Fish Habitat, showing overlap including around the Pribilof Islands. Interactions with blue king crabs precipitated the establishment of the Pribilof Islands Habitat Conservation Zone. Figure adapted from National Oceanic and Atmospheric Administration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

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

Corey Arnold

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