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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

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*

Pass (Logerwell et al. 2010, Goddard et al. 2014, National Oceanic and Atmospheric Administration 2016a).

Pacific sand lance along with several species of pricklebacks, 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 pricklebacks (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).

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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.

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.

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)

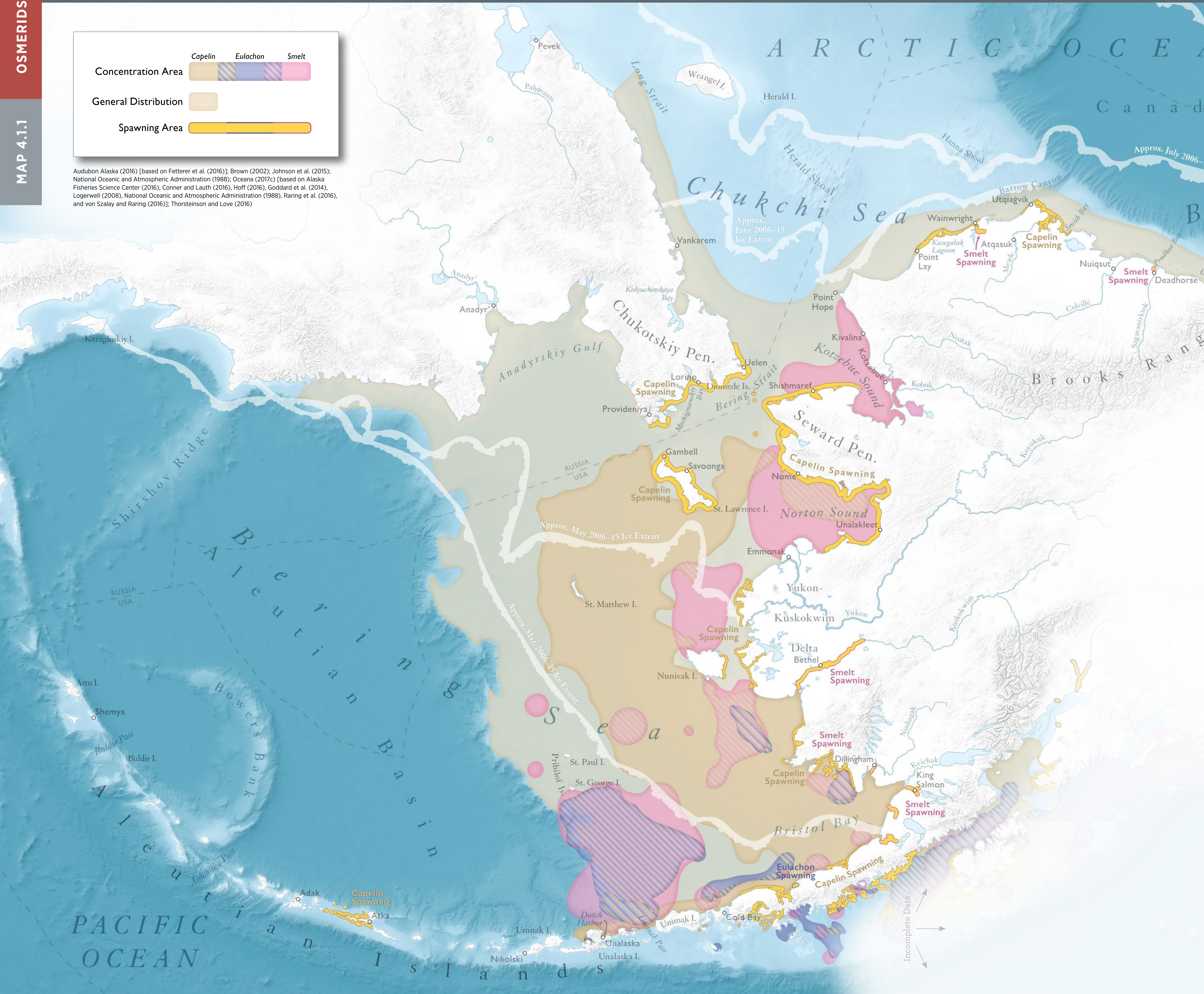
School of capelin.

G. Parsons / iStock

Osmerids

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

OCEANA Audubon ALASKA



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

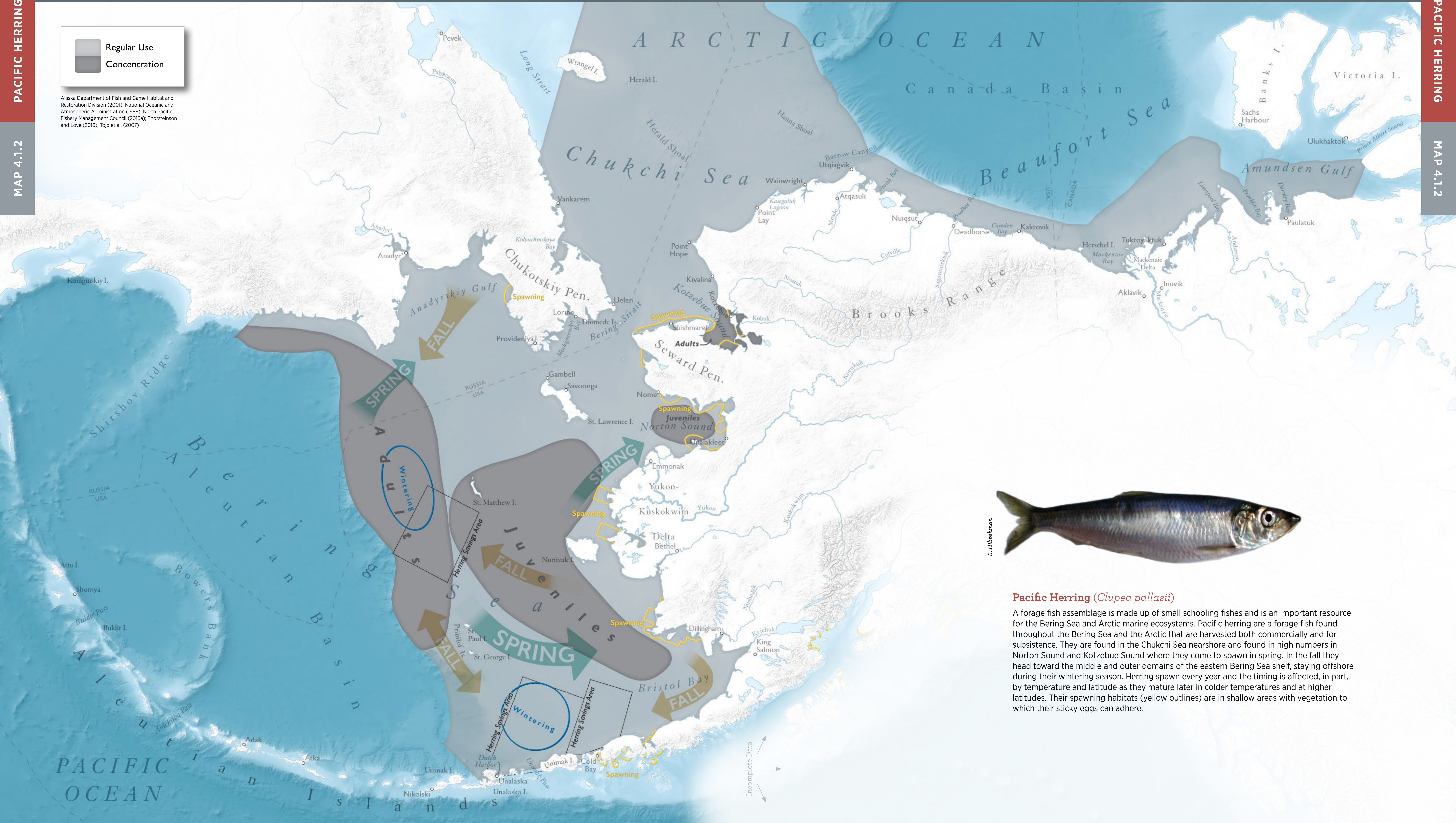
Capelin, Eulachon, and Smelt (Family *Osmeridae*)

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 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



Alaska Department of Fish and Game Habitat and Restoration Division (2001); National Oceanic and Atmospheric Administration (1988); North Pacific Fishery Management Council (2016a); Thorsteinson and Love (2016); Tojo et al. (2007)

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)

4.2 WALLEYE POLLOCK
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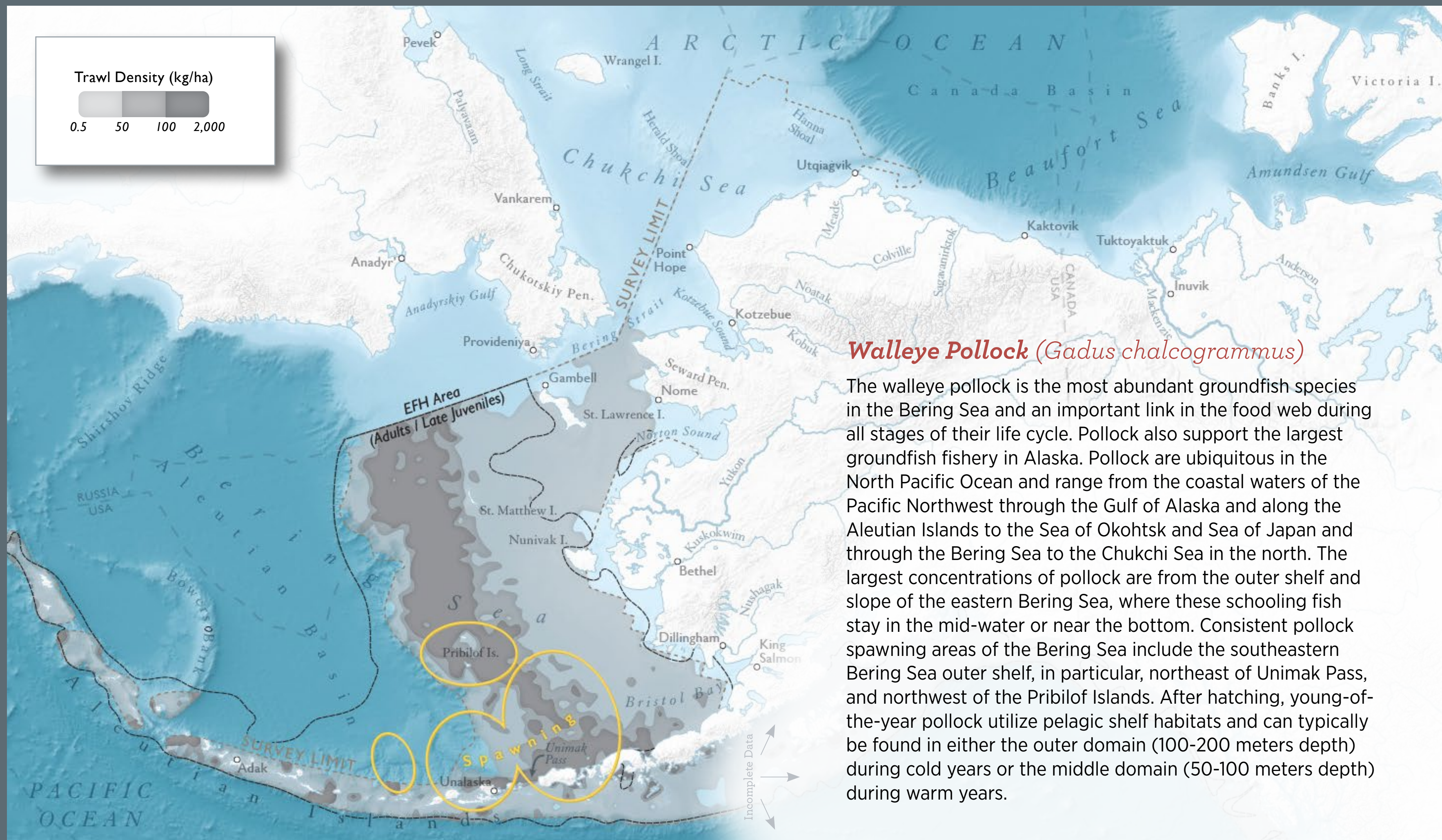
Walleye Pollock

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).

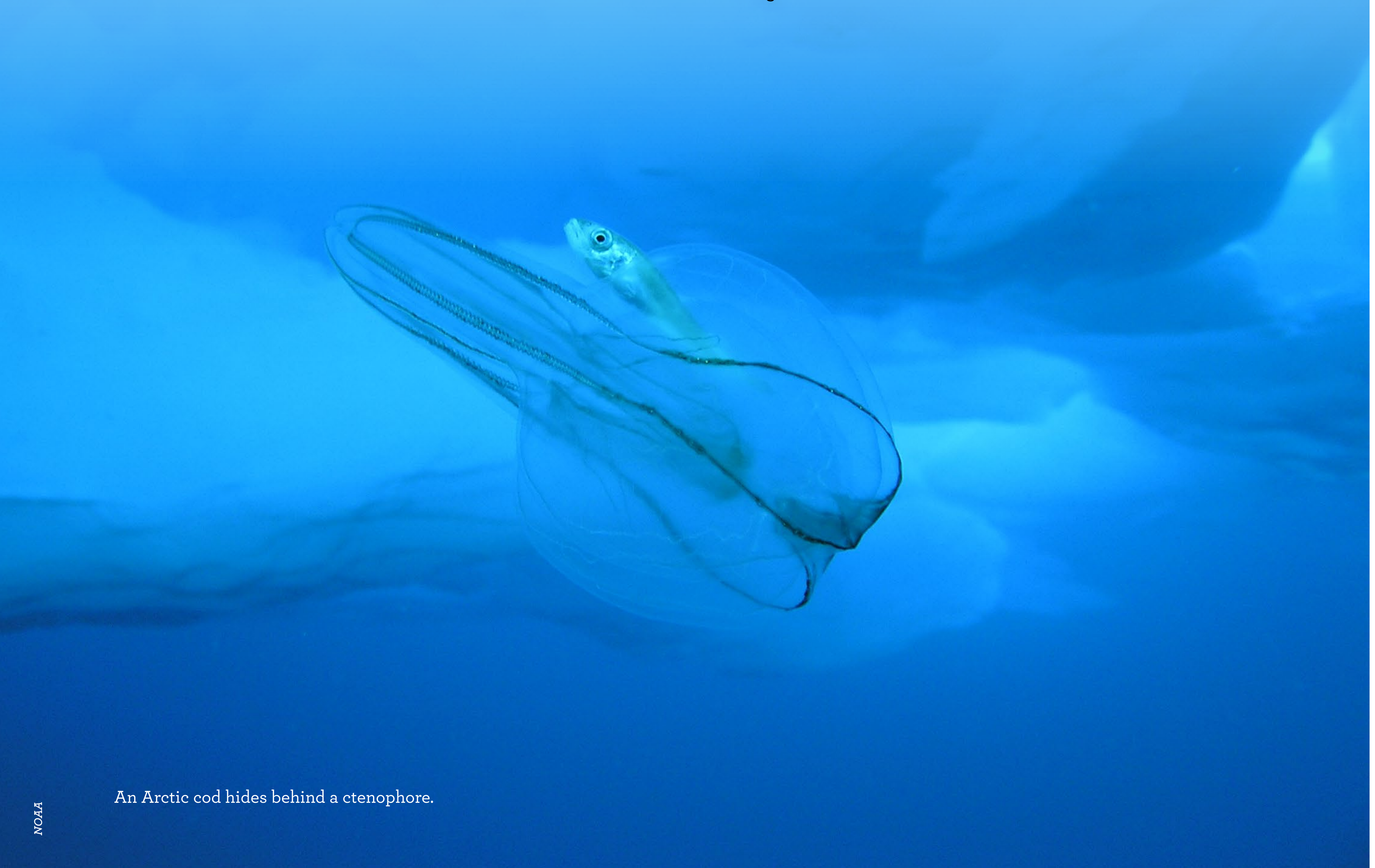
CONSERVATION ISSUES

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

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

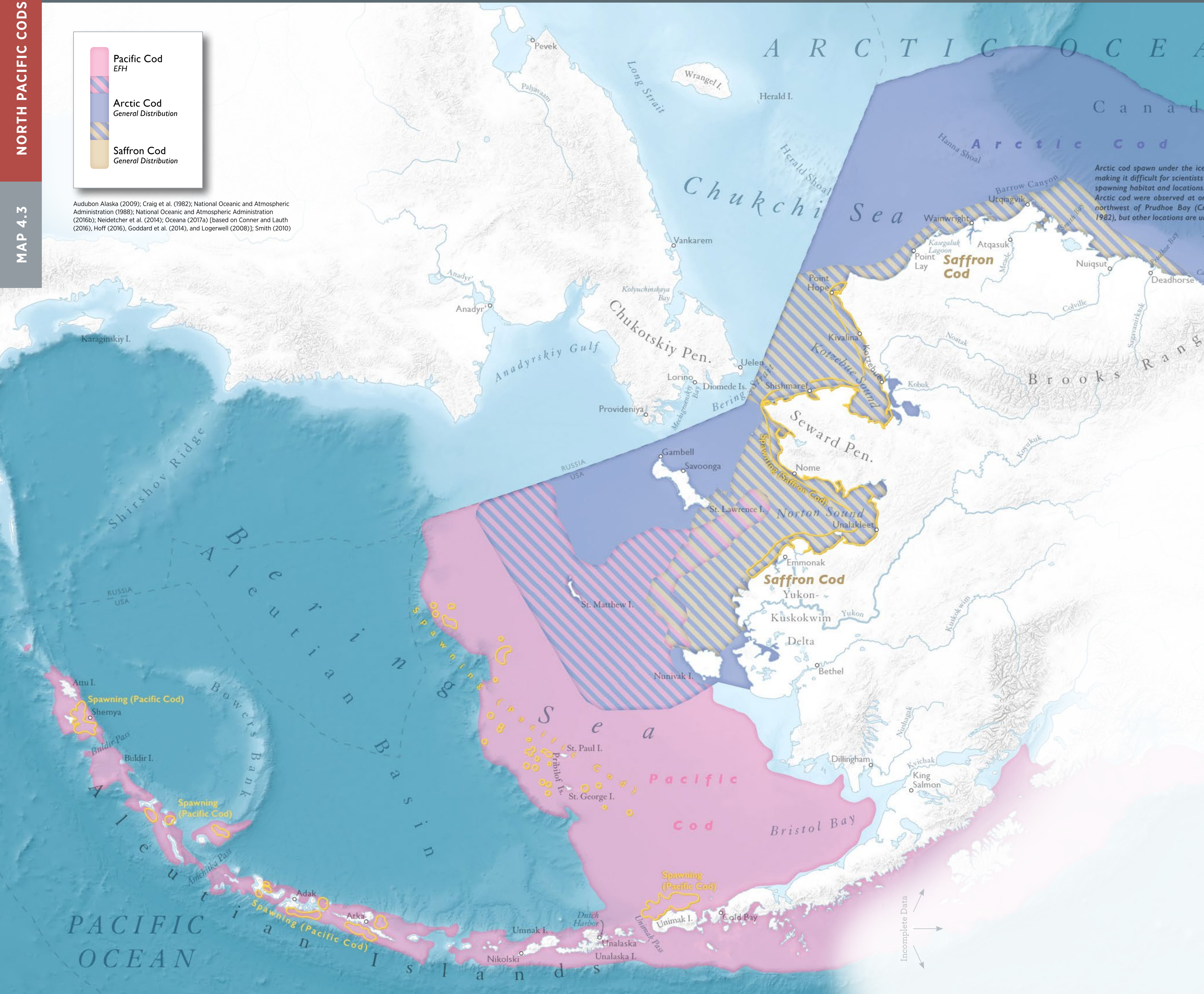
Juvenile gadids have more muted coloring, but they are still distinguishable between species based on their mouth shape, chin barbel size, and proportion of eye diameter to head depth.

4.3
NORTH PACIFIC CODS
MAP ON PAGES 88–89

North Pacific Cods

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

OCEANA Audubon ALASKA



NOAA

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).

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).

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

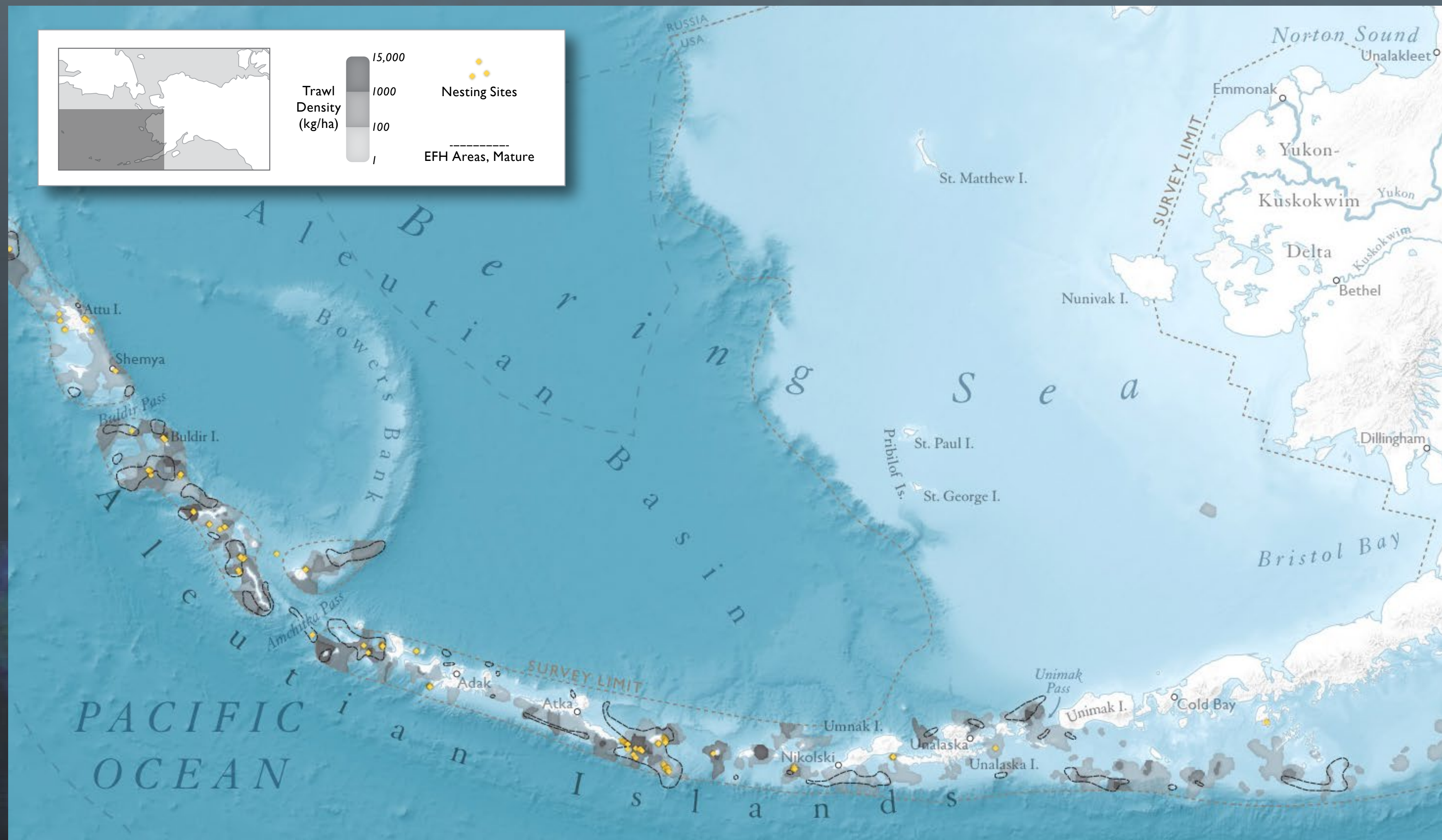
Relative Abundance: Oceana (2017b) based on Conner and Lauth (2016), Hoff (2016), Goddard et al. (2014), Logerwell (2008), Raring et al. (2016), and von Szalay and Raring (2016)

Nesting Sites: Lauth et al. (2007b)

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

Atka Mackerel

OCEANA Audubon ALASKA



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

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

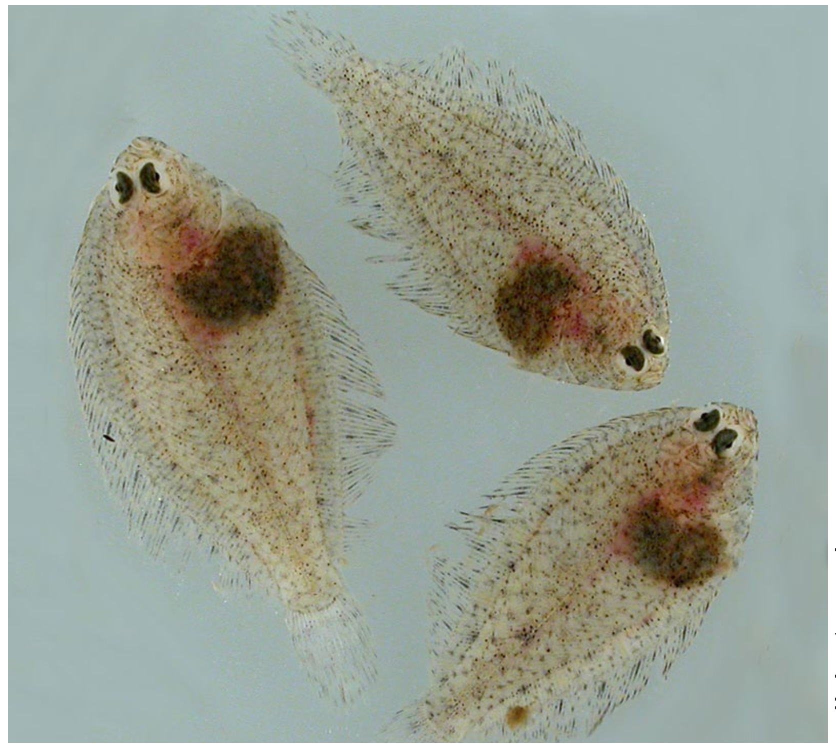
Yellowfin sole range along the continental shelf in waters generally less than 330 feet (100 m) deep from the Beaufort and Chukchi Seas up north to British Columbia in the south and along the Asian coast off South Korea (Wilderbuer et al. 1992). They occur in higher densities on sandy areas of the shelf (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).

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)

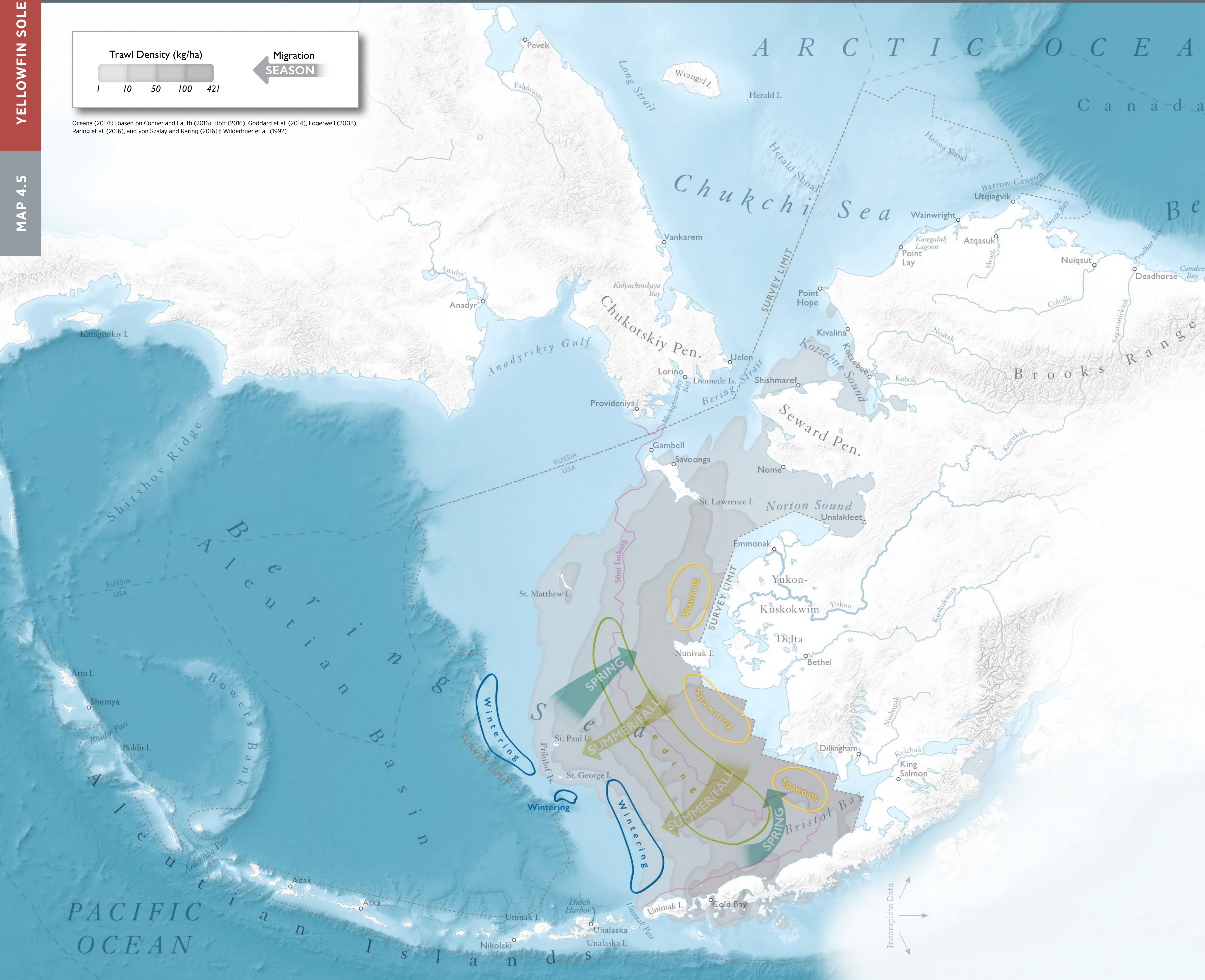
R. Hibpshman

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.

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.

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).

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)

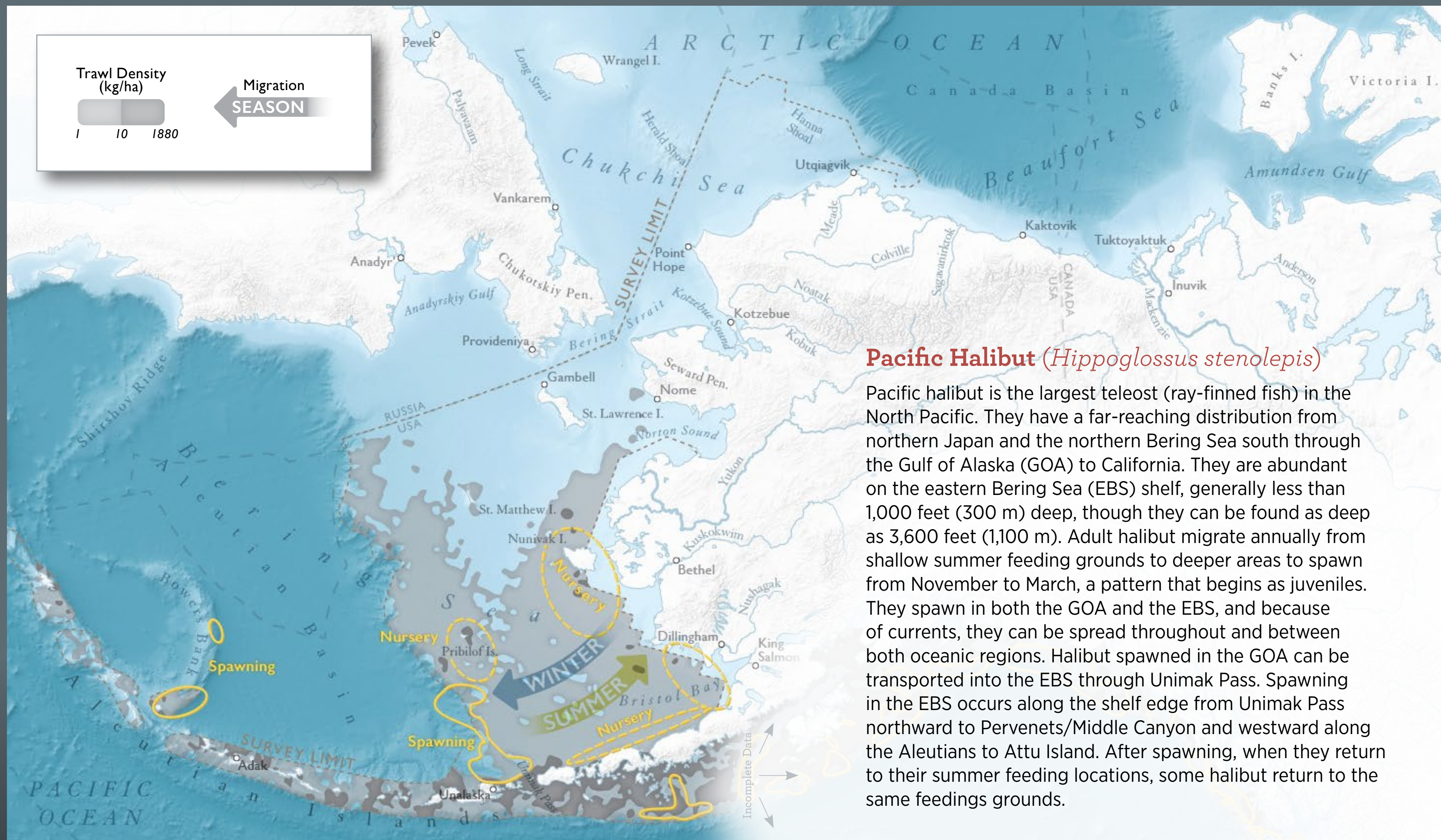
Spawning Areas: St-Pierre (1984)

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)

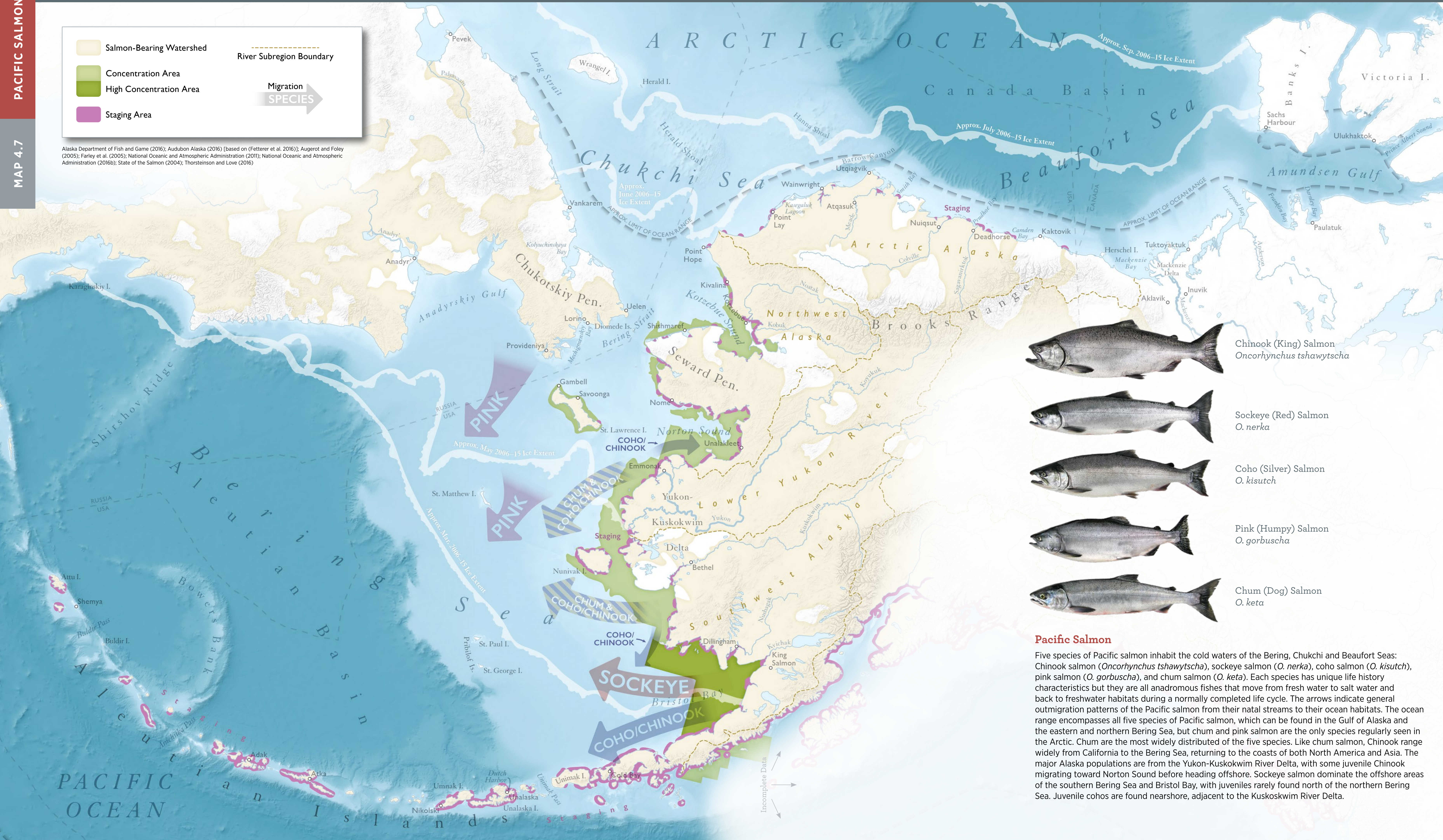
Pink salmon are also commonly known as "humpy" salmon due the the large hump they develop as they approach fresh water to spawn.

John Schoen

Pacific Salmon

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

OCEANA Audubon ALASKA



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.

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