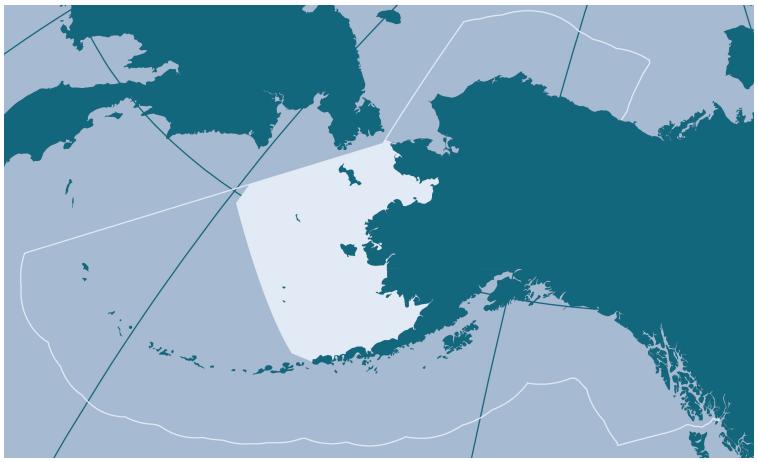
Ecosystem Status Report 2018
Eastern Bering Sea



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Eastern Bering Sea 2018 Report Card

- The eastern Bering Sea was characterized by **anomalously warm conditions** in 2018. The PDO was slightly positive with a decline to near zero in summer 2018. **~70% chance of El Niño conditions** are predicted for the winter of 2018-2019. The North Pacific Index was strongly positive from fall 2017 into 2018.
- The northern Bering Sea experienced an **unprecedented near-complete lack of sea ice** in 2018; the southeastern Bering Sea had no sea ice and **no cold pool**.
- Acoustic estimates of euphausiid density increased slightly in summer 2018 from 2016, but **remains relatively low**. The 2018 value is similar to what was observed in 2004.
- The biomass of benthic foragers **dropped in 2018** (2nd lowest value in the timeseries). The decline was due to Yellowfin sole (31%) and Northern rock sole (19%). **Northern rock sole have declined steadily since 2010**.
- The biomass of motile epifauna remains **above the long-term mean**, with an increasing trend in the past 4 years. Urchins, sand dollars, and cucumbers are above their long-term mean, with a 29% increase from 2017–2018. ***Opilio* crab increased 100% while King crab decreased 29% from 2017–2018**.
- The biomass of pelagic foragers **remains below its mean** in 2018. Similar to 2017, a large increase in Pacific herring (80%) was off-set by a decrease in Capelin (91%). Jellyfish increased 204% and Atka mackerel increased 710%. **Pollock have decreased 59% since 2014, with a 38% decrease from 2017 to 2018.**
- The biomass of fish apex predators remains at its mean, but has been **trending downwards since 2014**. This decline is driven by a **54% reduction in Pacific cod biomass** (19% decline from 2017 to 2018). Sablefish have increased since 2014 with a 173% increase from 2017 to 2018. Arrowtooth flounder biomass increased 23% from 2017 to 2018.
- The multivariate seabird breeding index remains below the long term mean, indicating that overall, **seabirds bred later and had poor reproductive success in 2018**. Some murres did well reproductively, but the number of birds breeding was low and many were late in their reproductive efforts. This pattern may reflect a mismatch in timing of breeding and prey availability and/or that only high-quality breeders attempted to nest this year.
- Northern fur seal pup production at St. Paul Island in 2018 is approximately 6% less than the 2016 estimate. Pup production has been **declining at St. Paul Island at an approximate annual rate of 4.0%** since 1998.
- Seafloor habitat disturbance due to fishing gear (pelagic and non-pelagic trawl, longline, and pot) shows **interactions have remained below the long-term average** since 2011.

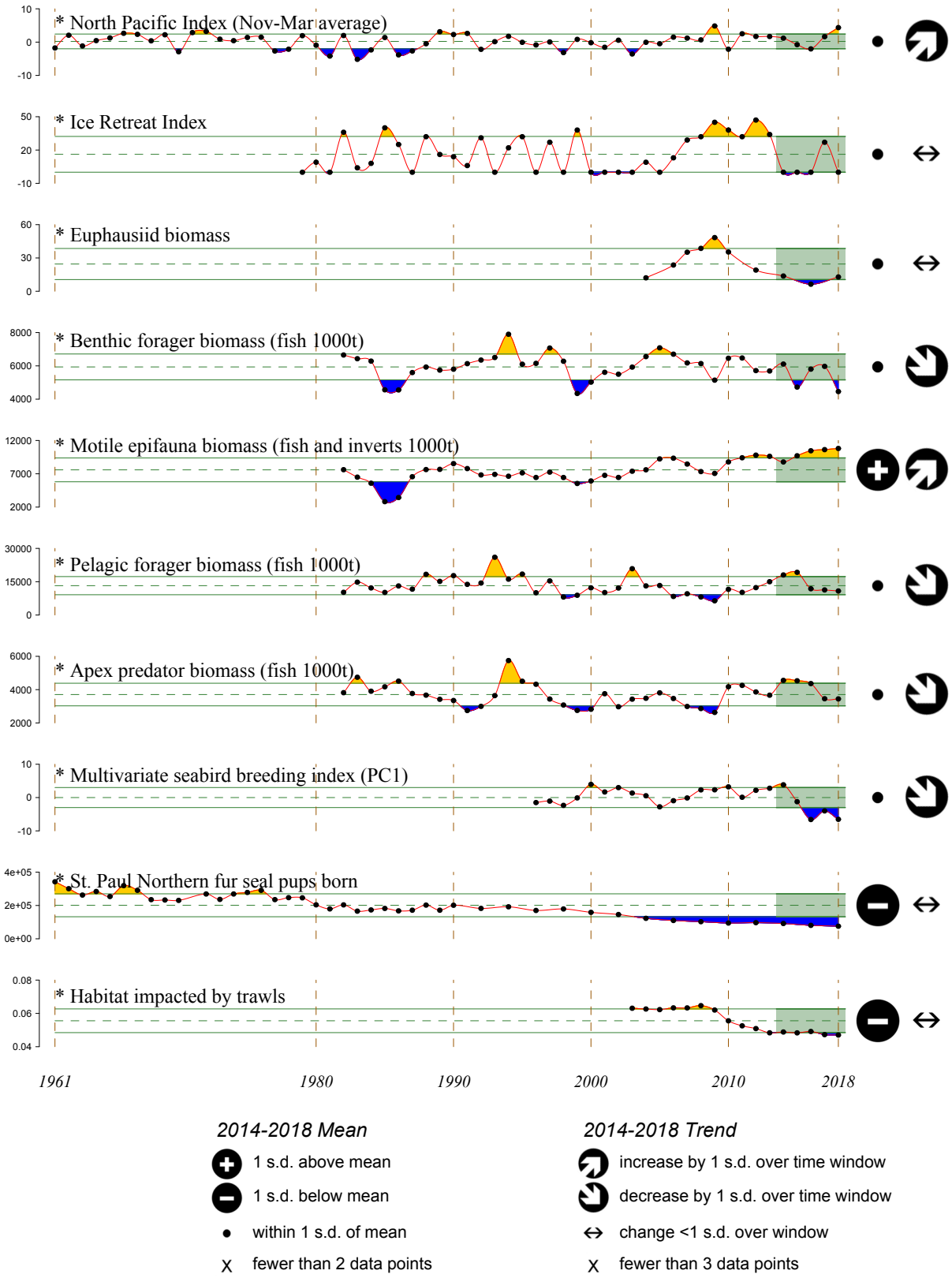

Figure 1: Eastern Bering Sea ecosystem assessment indicators; see text for descriptions.
* indicates time series updated in 2018.

Ecosystem Assessment

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The primary intent of this assessment is to summarize and synthesize climate and fishing effects (historical and future) on the eastern Bering Sea shelf and slope regions from an ecosystem perspective. The Ecosystem Status Reports of the Groundfish Stock Assessment and Fishery Evaluations (SAFE) provide the historical perspective of status and trends of ecosystem components and ecosystem-level attributes using an indicator approach. For the purposes of management, this information must be synthesized to provide a coherent view of the ecosystem effects to clearly recommend precautionary thresholds, if any, required to protect ecosystem integrity. The eventual goal of the synthesis is to provide succinct indicators of current ecosystem conditions and a prognosis of how fish stocks are expected to fare, given concurrent information on ecosystem status. To perform this synthesis, a blend of data analysis and modeling is required annually to assess current ecosystem status in the context of historical and future climate conditions.

Recap of the 2017 Ecosystem State

Some ecosystem indicators are updated to the current year (2018), while others can only be updated to the previous year (or earlier) due to the nature of the data collected, sample processing, or modeling efforts. Therefore, some of the "new" updates in each Ecosystem Status Report reflect information from the previous year. Below is a complete summary of 2017 that includes information from both previous and current indicators. The next section (Current Conditions: 2018) provides a summary of the 2018 ecosystem state based on indicators updated this year.

In 2017, sea ice extended over the eastern Bering Sea shelf and created an extensive, although narrow, cold pool over the middle domain (see p. 59). Interestingly, sea level pressure patterns set up persistent winds from the south that prevented sea ice formation in the Gulf of Anadyr creating an unusual retraction of ice extent over the northwestern shelf. As a result, the northwestern Bering Sea responded more similarly to a "warm year", whereas ice coverage over the southern middle domain lead to more moderate conditions in the southeast. Over the southeastern shelf, latent heat from the previous warm stanza (2014–2016) was off-set by the narrow, but extensive,

cold pool that resulted in average water column temperatures at mooring M2 at the southern end of the eastern Bering Sea shelf.

The narrow cold pool was centered over the middle domain while the inner domain remained anomalously warm and is thought to have acted as a wide corridor for species' movement between the southeastern and northeastern Bering Sea. Indications of a "warm year" response during 2017 in the north included observations of crab as well as adult Walleye pollock and Pacific cod in the northern Bering Sea. Genetic work conducted on Pacific cod collected in the northern Bering Sea in 2017 showed that the NBS cod grouped strongly with spawning samples from Pervenets and Pribilof canyons and Unimak Pass, suggesting population coherence across the southeastern and northern shelf regions (p. 40). While these species might typically move south during winter, the environmental cues (i.e., sea ice, cold pool) did not occur during winter 2016–2017, therefore we anticipated observations of pollock and Pacific cod, for example, from northern communities during winter 2017–2018 (see Current Conditions: 2018 below).

Productivity across the system, as indicated by zooplankton distributions, reflected increased productivity in the north with significantly higher abundances of small and large copepods near St. Matthew Island. Over the southeastern shelf, 2017 estimates of small and large copepod abundances were below that of 2016, while euphausiid abundances were comparable. Groundfish condition subsequently declined from 2016 to 2017 for all species (except Arrowtooth flounder) and may be a leading indicator of poor overwinter survival and potential for smaller stocks in 2018. Indicators demonstrated that the mean lifespan, overall length, and biomass of the groundfish community have remained relatively stable over the time series. However, these indicators are very sensitive, and small changes in mean length or mean age can be quite significant and indicative of ecosystem shifts. For example, mean length increased in 2002–2005 and again in 2014–2016. The fish community is dependent on previous year-classes that are maturing, and low recruitment during these warm stanzas results in an increase in mean length. This trend could have important consequences for the fishery.

Declines in forage fish quality and quantity have cascading effects for piscivorous-feeding seabirds and marine mammals. For example, the reproductive success of cliff-nesting seabirds at both St. Paul and St. George Islands was poor in 2017, with the exception of nearshore-feeding red-faced cormorants (*Phalacrocorax urile*). Despite the moderation of environmental conditions in 2017, seabird foraging conditions did not appear to recover. However, the number of seabirds caught incidentally in EBS fisheries in 2017 declined; northern fulmars, shearwaters, and gulls were the most common species caught (p. 162). Additionally, estimated age-1 natural mortality for pollock, Pacific cod, and Arrowtooth flounder (based on the CEATTLE model) remained at elevated levels in 2017.

Other indications of a decline in system-wide productivity include juvenile Chinook salmon (*Oncorhynchus tshawytscha*), Togiak herring, and crab stocks. First, juvenile Chinook salmon abundance in the northern Bering Sea was below the long-term average in 2017; this has important implications for abundance-based bycatch caps for Chinook in the pollock fishery because low juvenile abundance leads to reduced bycatch caps 3–4 years in the future. Second, in 2017, the abundance of Togiak herring was estimated to be 55% of the most recent 10-year aerial survey average and 59% of the most recent 20-year aerial survey average (p. 99). Lastly, in 2017, crab catches declined significantly for all species, particularly tanner crab (p. 184).

Maintaining adequate prey has important implications for upper trophic level species and other

ecosystem components. Maintaining species diversity increases ecosystem stability as species have differential responses to environmental variability. Total CPUE from the bottom trawl survey peaked in 2014 due to increased pollock catches, but declined slightly in 2015–2017. Species richness remained high along the 100m isobath while diversity was highest over the middle domain. Cooler water temperatures in 2017 resulted in a substantial southeastward shift, in contrast to a more moderate response to similar cooling in 2006.

Current Conditions: 2018

This year's assessment will highlight ecosystem conditions and responses in the northern Bering Sea (NBS) and southeastern Bering Sea (SEBS) independently, but recognizing that species responses to recent conditions (i.e., sea ice, cold pool extent, water temperatures) have emphasized the connectedness of the two regions and that they function as one ecosystem: the eastern Bering Sea.

With contributions from (in alphabetical order): Steve Barbeaux, Peter Boveng, Lyle Britt, Catie Bursch, Lauren Divine, Martin Dorn, Janet Duffy-Anderson, Lisa Eisner, Anne Hollowed, Kirstin Holsman, Jim Ianelli, Chad Jay, Dave Kimmel, Sasha Kitaysky, Bob Lauth, Kathi Lefebvre, Paul Lehman, Maggie Mooney-Seus, Carina Nichols, Emily Osborne, Jim Overland, Heather Renner, Patrick Ressler, Gay Sheffield, Phyllis Stabeno, Jeremy Sterling, Grant Thompson, Jim Thorson, and Andy Whitehouse.

Northern Bering Sea

2018 was extraordinarily different in the NBS than in the past experience of scientists visiting the region or in the oral histories of local residents.

Physical conditions

A composite of unusual weather events during the winter of 2017/2018 resulted in an unprecedented near-complete lack of sea ice in the NBS. Several climatic forces occurred that resulted in the warm conditions: (i) residual heat maintained above-average water temperatures that caused delayed freeze-up (e.g., the Chukchi remained ice-free into January 2018, ice arrived late (March) and departed early (April)), (ii) a large and persistent high-pressure system from February through April over the Aleutian Islands and southern Bering Sea, which shifted the position of the Aleutian Low Pressure System (ALPS) northwest over Siberia, and (iii) highly unusual winds from the southwest that brought warm air over the Bering Sea and prevented sea ice from forming until March.

2018 marks the lowest ice year on record for the eastern Bering Sea while the Chukchi Sea was the warmest on record. Bottom temperatures in the northern Bering Sea were 1°C to 2°C rather than <-1°C, and no cold pool formed. Historically, salinity and temperature contributed equally to the vertical stratification of the water column in the northern Bering Sea. In 2018, salinity in May was vertically uniform, with no evidence of high (>32) salinities from brine rejection. The lack of salinity structure resulted in weaker vertical stratification, permitting greater vertical mixing. Warming of the surface waters started ~May 13 and some thermal stratification began ~May 15 (data from mooring M8 located at 62.194°N 174.688°W).

Biological responses

The near-complete lack of sea ice over the northern Bering Sea shelf created an absence of ice

algae to 'seed' productivity. At St. Matthew Island, the bloom began quite late (approximately June 12; ∼1 month delay), and because stratification was weak (due to lack of salinity component), nutrients were still being mixed into the surface layer. The abundance of small copepods was similar to 2017, but the abundance of large copepods was an order of magnitude lower and abundance of juvenile euphausiids was near zero. In addition, survey scientists noted that the large copepods were predominantly *Eucalanus bungii*, which is not a lipid-rich species. In fact, estimates of lipid content for large copepods and juvenile euphausiids were low. Based on the diets of auklets and the low nesting success of thick-billed murres, which also eat large zooplankton, it seems large lipid-rich zooplankton, that are a critical component of seabird and pollock diets, were in low supply.

Bottom trawls, surface trawls, and acoustic surveys again documented the presence of Pacific cod and pollock in the NBS. When sampled in July 2018, Pacific cod were 'fat' and 'healthy' and anecdotal observations were that stomachs were 'full of *Opilio*'. Based on bottom trawl survey results, more than 50% of the overall estimated biomass of Pacific cod in the eastern Bering Sea (northern and southern components) was found in the northern Bering Sea. With half of the biomass in the northern survey area, stock assessment models for 2019 will include NBS data for the first time.

In contrast, pollock estimated biomass in the northern Bering Sea declined by 14% from 2017 to 2018. Pollock to the east of St. Lawrence Island were in 'poorer condition' while pollock sampled north of St. Lawrence Island were 'plump and healthy' (B. Lauth, pers. obs.). Initial on-board examination of pollock stomachs showed that fish were consuming polychaete worms, indicating they were feeding on the bottom. Preliminary lab-based diet analyses of Pacific cod and pollock indicated prey composition was similar to that of diets observed from the inner domain of the southeastern Bering Sea.

Ice seal distributions were dramatically impacted by the lack of sea ice over the northern Bering Sea shelf and retraction of the ice edge. In 2018, during a spring research survey, the nearest ice edge over the eastern Bering Sea shelf was between St. Lawrence Island and Norton Sound, about 375 km to the northeast of where it was found during 2014 and 2016 surveys. Ice seals (particularly ribbon seals) were unusually scarce with no evidence that they moved northeast or into Norton Sound following the ice edge; it remains unknown where they went and whether their reproduction was compromised by the lack of sea ice in their typical breeding grounds. Spotted seal pups weighed less than in recent years, indicating poor condition, and continuing a declining trend in body condition and blubber thickness from 2014 to 2016 to 2018. More walrus and bearded seals were seen than typical, likely because the survey was farther north in areas where these species are more prevalent. Walrus, which are benthic foragers, consume a wide range of prey items, but mostly clams, snails, and polychaete worms. Studies of walrus stomach contents indicate that fish are typically a very small part of their diet. Recent population modeling suggests the population has undergone as much as a 58% decline since the early 1980s. The cause of the decline is unknown, but may have been the result of the population reaching carrying capacity coupled with high walrus harvest levels in the late 1970s-early 1980s. Large numbers of dead marine mammals were found along the shorelines from north of Bering Strait, throughout Norton Sound, and on St. Lawrence Island. In July, an exceptionally large number of humpback whales was present off the north shore of St. Lawrence Island.

A seabird die-off event, unprecedented in terms of spatial and temporal scale, occurred in 2018. Large numbers of seabirds (mainly murres) washed ashore from Bering Strait southward through Norton Sound, and along the shores of St. Lawrence Island. The die-off event continued, albeit at

a slow pace, into August. On St. Matthew Island there was evidence of an earlier, year-old large die-off of seabirds. Crested auklets were reported dead from at-sea surveys. To date, starvation is the only identified cause of death.

The historical diet composition of the affected seabirds suggests that large, lipid-rich zooplankton may have been in short supply in 2018. Least and crested auklets specialize on large copepods (least auklets: *Calanus marshallae/glacialis* at St. Matthew Island and *Neocalanus plumbchrus/flemingeri* at St. Lawrence Island), euphausiids (crested auklets), and sometimes the large amphipod, *Themisto libellula*. Thick-billed murres and shearwaters take euphausiids, amphipods, and forage fish while common murres take mostly forage fish.

Concomitantly, reproductive failures and poor reproductive success (mainly murres and kittiwakes) were observed by community members, subsistence eggers, and scientists. Those birds that did nest, nested very late. On St. Lawrence Island, murre eggs that were laid late were still hatching in September. There were also indications of lower nesting success for least and crested auklets: ~30% fewer least auklet burrows were occupied, although those birds that did nest appeared to be reproducing successfully. Crested auklets that laid eggs also seemed to be doing well, though perhaps with a somewhat greater rate of egg abandonment. Community members reported very few auklets (only 20 least auklets observed) and surprisingly low numbers of puffins attending cliffs. Horned puffins were observed around the north end of Sevuokuk Mountain in late September with bill-loads of fish, perhaps reflecting very late nesting this year.

All murre reproductive effort failed north of St. Matthew Island, such that murres did not produce chicks, which is exceptional, and prior to the 2016 heatwave, widespread murre reproductive failures had not been observed. In fact, low numbers of common murres attended cliffs and very few eggs were laid (subsistence eggers reported difficulty finding eggs). Likewise, for thick-billed murres, there was very low cliff attendance and almost no eggs laid. Black-legged kittiwakes also had a near-complete reproductive failure, with <10% of nests fledging young (although not that unusual, these birds have been failing for the past 5 years). In contrast, cormorants did well. Of interest was the first observation of red-legged kittiwakes nesting on St. Matthew Island.

Harmful Algal Blooms (HABs)

As a result of warming sea surface temperatures, species of algae known to produce harmful toxins, commonly referred to as harmful algal blooms (HABs), are becoming more widespread and prevalent in the Arctic. A 2018 coordinated research effort in the Pacific Arctic Sector centered around the Bering Strait Region has made progress towards improving our baseline understanding of HABs species abundance, distribution, and toxin presence in this region. A total of six HABs oceanographic research cruises worked together to collect HABs data across the northern Bering and Chukchi Seas at more than 340 stations. Synthesized research results show concentrations of one HABs species in particular, *Alexandrium* spp., which is associated with paralytic shellfish poisoning as well as a second less abundant species, *Pseudo-nitzschia*, which is responsible for amnesiac shellfish poisoning. Research missions found no positive toxicity or significant HAB cell counts south of the strait in the northern Bering Sea (June-September), however high concentrations of HABs cells (*Alexandrium* spp.) were found in the Chukchi Sea in August and a positive toxicity test was also recorded in June.

Alexandrium spp. cells have the unique ability to form "cysts", which are a dormant phase of this species' cells that harden and rest on the seafloor until environmental conditions are right for the cell to bloom or grow. A survey of cysts in seafloor sediments found dormant cells of

Alexandrium spp. across the entire shelf of the northern Bering and Chukchi Seas. Especially high concentrations were found offshore of Ledyard Bay and some sample sites had some of the highest cyst concentrations observed in the entire global ocean.

Contributed by Emily Osborne
Program Manager, Arctic Research Program
NOAA Office of Ocean and Atmospheric Research

Local Knowledge and Traditional Knowledge
Gay Sheffield (Alaska Sea Grant Marine Advisory Agent in Nome, Alaska) recounted observations from community members in the northern Bering Sea. In Nome, large Pacific cod (1 m) were caught in crab pots and the unusual occurrence of king salmon being caught on rods from the Nome beach. There were record returns of pink and silver salmon, which came in strong and early; sockeye returns were not as great. Halibut fishing off Savoonga was 'really great'.

Subsistence hunters for crested and least auklet fledglings usually get ∼30-40/day. In 2018, a hunter stopped after he pulled 13 dead fledglings and no live ones. An Elder on St. Lawrence Island said "when there is no dirty ice, there is less food for the krill, and consequently, no food for the birds." At Sledge Island in Norton Sound, 50-70% of murres were missing from cliffs and those that were there were not laying eggs; local people were stunned and there was a complete lack of harvest. There were dead and emaciated murres, shearwaters, and crested auklets in Nome and on St. Lawrence Island.

Beginning in February, residents in shoreside communities reported walruses were harvested off St. Lawrence Island, a time when they are not typically accessible. The walruses were 'fat and in good condition'. In early June, there were reports of exceptionally high numbers (i.e., 50) of dead seals on beaches (primarily young bearded seals) along the north side of St. Lawrence Island and 48 beach-cast ice seals (bearded, ringed, and sub-adult spotted seals) near Wales. The seals appeared to have poor body condition and empty stomachs. There were also reports of seal strandings, reports of sick/dead seals out of normal range, and seals were absent or unusually scarce in the Port Clarence area.

Southeastern Bering Sea
Physical conditions
In the southeastern Bering Sea, the timing of the spring bloom was a bit late, but otherwise conditions were typical of a low-ice year with above-average water temperatures and complete lack of a cold pool. Similar to the northern Bering Sea, the southeastern shelf experienced reduced strength of water column stratification due to the lack of salinity component. These weakly stratified waters are easily disrupted by storms.

Biological responses
At mooring M2 (located at the southern end of the eastern Bering Sea shelf) a small phytoplankton bloom began May 25, approximately 1 week after stratification. While this timing is delayed, it is not unprecedented for the southeastern shelf. In early spring, small copepods and large copepods were in low abundance. Large copepod lipid values were <5% body weight (though this is not surprising) while those sampled near Unimak Pass had higher lipid values (∼10%). Evidence of increased production (phytoplankton, zooplankton, pollock) around Unimak Pass likely resulted from on-shelf flow through Bering Canyon and/or transport of Alaska Coastal Current waters from the Gulf of Alaska. During the late spring larval survey, small copepod abundances increased to one

of the highest levels recorded while large copepod abundances were similar to the historical average. However, copepod mortality may be increased due to the decreased biomass of the phytoplankton bloom and inability to sustain nauplii.

Euphausiid furcilia had very low abundances on both spring surveys, which was not unprecedented in a warm year. The acoustic survey indicated that euphausiid densities remain low; this high quality prey have become less available in 2012–2018. Thus, delayed production gave rise to a low quality zooplankton prey base over the entire shelf. Reduced energy transfer from the prey base to the top-level predators likely contributed to poor body condition and observed mortality events (i.e., seabirds and mammals).

Larval pollock production was similar to other warm years: high abundances with the distribution shifted eastward. However, the poor prey base may result in reduced growth of juvenile fish and higher overwinter mortality. Survey scientists noted that larvae 'seemed long and skinny'. It is unlikley that juvenile pollock will be able to utilize cold water refugia due to a well-mixed water column over the shelf and absence of a cold pool. The bottom trawl survey indicated that Pacific cod and pollock abundances were below the long-term mean. Pacific cod abundance was lower, but biomass was higher (fewer, larger fish). Additionally, there was no evidence of pollock recruitment, with low age-1 numbers and abundance dominated by the 2012 year class. Age-1 pollock abundance has been low since 2014.

Northern fur seal pup production at St. Paul Island was ∼6% less than 2016. Pup production has been declining at St. Paul Island at an approximate annual rate of 4.0% since 1998. Anecdotal reports suggest smaller or skinnier pups at some rookeries on St. Paul Island. The estimated St. George pup production is approximately 5% greater than 2016 with no unusual pup mortality, but shows no significant trend since 1998.

At the Pribilof Islands, seabird nesting was delayed, and/or unsuccessful. Seabird reproduction was poor, as expected for a warm year with little sea ice. For example, black-legged kittiwake reproductive success failed completely, indicating prey for these surface-foraging birds was likely not sufficient for them to successfully rear chicks. On St. George Island, common murres experienced the latest mean hatch ever recorded and thick-billed murres experienced their 2nd latest hatch date. Productivity values were mediocre and fewer birds than normal were attending cliffs or laying eggs.

Local and Traditional Knowledge

Bristol Bay

Unusual observations of adult pollock behavior were reported from community members as well as subsistence and commercial fishers from Bristol Bay in summer 2018. Sightings of pollock swimming 'with their heads out of the water' and 'behaving odd' were reported. Adult pollock were reported to have washed up on shore in high numbers, and pollock were reported to have been caught in subsistence set nets during the salmon fishery (both near Pilot Point, Ugashik River, and from the Nushagak District). "Traditionally, it is unusual to see pollock in the salmon season in Bristol Bay" (Catie Bursch, fisher, pers. comm.).

Efforts to capture the breadth of these events resulted in phone calls and emails from additional commercial fishers from Bristol Bay. Fishers reported dead fish ashore in late May in numbers that were "many, many more than other springs" (Tyler Sterling, fisher, pers. obs.). Reports continued through early July of pollock 'floating belly-up, but alive' and 'half swimming, half floating'. A local fisher who has been fishing near Pilot Point for 40 years described the events as "unusual".

"I first remember seeing pollock swimming along the surface in the shallows in early July in Nushagak district. We caught a few in our gillnet, but mostly saw them swimming. I also have a friend who setnets in Ekuk; she said they saw one swimming in the shallows near their site and heard reports of similar things from others who setnet near there. We stopped to go beachcombing along the coast between Ugashik and Egegik on July 25th. There were dead pollock dried up everywhere along the beach (I would guess a dead fish every 20 feet or so). Some of the guys I was with have fished the area for decades–they were mentioning how they had never seen anything like it." (Carina Nichols, fisher, pers. comm.).

Catie Bursch, a commercial fisher from Pilot Point, sent samples to NOAA Fisheries in Juneau, Alaska. Sample processing is still underway, but the fish were "definitely skinny compared to average weights by year/size from NOAA's bottom trawl survey" (B. Lauth, pers. comm.). Stomach contents included Caridea shrimp, gammarid amphipods, and other fish, which "seems pretty typical for Bristol Bay" (K. Aydin, pers. comm.). Stomach and intestine samples were processed for PSP toxins (i.e., saxitoxin) at the NWFSC/WARRN-West Program. All samples contained low but detectable levels of PSP, confirming that an exposure risk was present in the food web. Therefore, PSP toxins could have played a role in the unusual behaviors and mortality events observed in Bristol Bay, although it is important to note that the levels were well below the seafood safety regulatory limit and therefore were not a risk for human consumption (K. Lefebvre, pers. comm.). Samples taken for isotope and condition analyses are still being processed.

Aleut Community of St. Paul Island

The Ecosystem Conservation Office (ECO) reported that St. Paul Island community members noted how 'quiet' the cliffs were in May 2018; birds should have been returning and starting their nests. Although birds arrived around the usual time of year, they did not engage in typical nest building activities. In fact, red- and black-legged kittiwakes gathered nest-building materials a month late. Residents were unable to collect subsistence murre eggs because there were none on the cliffs during the egging season (June). Across multiple seabird species, eggs were laid a month later than usual and community members were monitoring cliffs to observe whether fledging would also occur late.

Least auklets have been declining since 2015; no auklets have been subsistence harvested in the last two years due to declining breeding colonies. Elders in St. George recall how abundant least auklets were in 1940s–1970s. Similarly, red-legged kittiwake hunting has been declining in part due to concerns about the population decline. Residents continue to take low numbers of kittiwakes for subsistence, but only to provide to Elders who request it.

In early July 2018, approximately 50 fresh-dead northern fulmars, shearwaters, and murres were collected on beach surveys. All necropsies revealed the birds died of starvation. This marks the third year that birds have washed ashore in poor body condition. Elders on both St. Paul and St. George have cited shifting prey distributions and a 'lack of food' as the reason behind declining populations. Community members continue to speak of a lack of food in both summer and winter as the cause for die-offs, population declines, and reduced productivity and fledgling success.

Subsistence fishermen have reported that they have to go out more often (spend more time on the water) and further (cover more distance from the shore) from the St. Paul harbor to catch enough halibut for their families to get through the winter. ECO continues to receive reports from subsistence fishermen that very few halibut have been caught in what used to be considered 'traditional rich fishing grounds'. Residents refer to warm water temperatures in recent years as

the reason driving a lack of food in the region: "fish have all moved north to find colder waters and sea ice".

The decline of northern fur seals is also apparent to Elders, adults, and youth. Community members comment how thin and sickly female fur seals are and Elders report 'low pup numbers' and 'no yearlings or two-year-olds returning'. These reports come from individuals who experienced the commercial harvest days. This knowledge is reflected in subsistence harvests today; harvests have a more somber tone in recent years. Subsistence harvests represent the importance of securing seal meat to provide food security for winter.

The Pribilof Islands are also experiencing crowberry (or moss berry) failure. Crowberries are a source of fiber and stored for use during the winter months when fresh foods are scarce. In 2018, a complete lack of berries occurred, potentially causing a food security issue for the community.

Please also see the Noteworthy contribution "Better Off Dead" about a rat on St. Paul Island that poses a potentially catastrophic threat to breeding seabirds (p. 40).

Contributed by Lauren Divine (Aleut Community of St. Paul Island),
with contributions from J. Erickson, G. Fratis, Sr., S. Lekanof, P. Melovidov,
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Forecasts and Predictions

Climate projections for the Chukchi Sea have impacts on the eastern Bering Sea in terms of residual heat and timing of ice formation ("freeze up"). The Chukchi Sea has been freezing up, on average, one day later each year since 1980 whereas the timing of freeze up in the northern Bering Sea has been random. Currently, the Chukchi Sea is colder than this time in 2017, which may affect the timing of freeze up and the potential for export of heat to the northern Bering Sea. If no ice forms over the eastern Bering Sea shelf this coming winter 2018–2019, summer conditions in 2019 may be much warmer due to stored heat content.

Preliminary 9-month Ecosystem Forecast for the Eastern Bering Sea:

AFSC and PMEL have produced 9-month forecasts of ocean conditions in the eastern Bering Sea as part of the Alaska region's Integrated Ecosystem Assessment (IEA) program since 2013. Forecasts made in October of each year run through July of the following year using the Bering10k ocean and plankton model forced by seasonal atmospheric predictions produced by the NOAA/NCEP Climate Forecast System (CFS).

The Bering10k regional model is based on the Regional Ocean Modeling System (ROMS) implemented at 10km resolution (Hermann et al., 2013) and includes an embedded Nutrient Phytoplankton Zooplankton (NPZ) model with euphausiids (Gibson and Spitz, 2011). The regional models were calibrated using repeated hindcasts of the region covering the period 1972–2017.

A particular metric of interest is the summer cold pool, the proportion of the summer bottom trawl survey area below a particular temperature. Figure 2 shows the cold pool with limits of ≤0°C, ≤1°C, and ≤2°C. Shown are bottom trawl survey data, Bering10k hindcast results for 1982–2018, and Bering10k 9–month ahead predictions. The most recent prediction, made in October 2018, is shown for summer (July) 2019. The Bering10K model successfully predicted a transition from

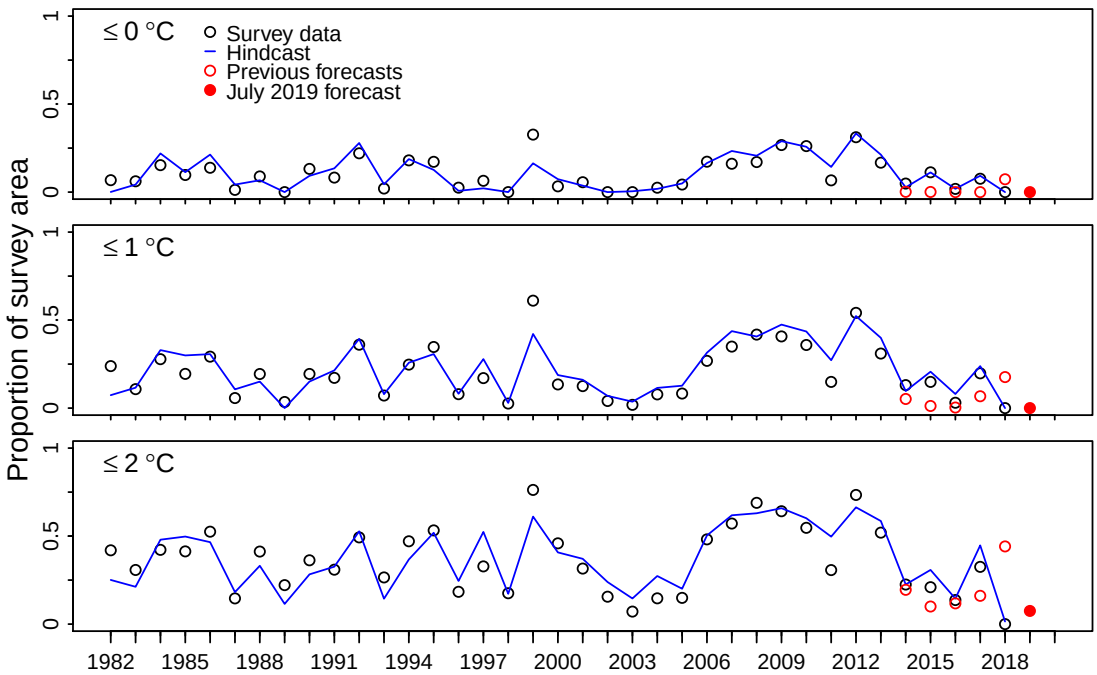

Figure 2: The eastern Bering Sea cold pool with limits of ≤0°C, ≤1°C, and ≤2°C. Shown are bottom trawl survey data, ROMS hindcast results 1982–2018, and ROMS 9–month ahead predictions. The most recent prediction, made in October 2018, is shown for summer (July) 2019.

cold to warm conditions between 2013 and 2014, and continued warm conditions were predicted successfully for three more years, through summer 2017. The prediction made in 2017 for 2018 was for cooling (returning towards average), however this prediction was substantially incorrect as anomalous atmospheric conditions (p. 59) greatly impeded the formation of ice in 2017–2018 and led to the smallest cold pool on record. The predictions for summer 2019 are for **continued warm conditions substantially similar to 2014–2018.**

Pollock Recruitment Predictions

The EBS Ecosystem Status Report includes several leading indicators of pollock recruitment that give, in some cases, contradictory results. In this section, we have summarized these predictions so that we can more easily track how they compare and how well they hold up over time. Additional research is underway to assess these indicators over longer time periods. Survival and recruitment success of juvenile pollock are driven, in part, by bottom-up processes. The abundance, species composition, and quality of zooplankton prey resources are governed by large-scale oceanographic processes and vary between warm and cold climate stanzas. For example, the abundance of large zooplankton (e.g., *Calanus marshallae*) is greater in cold years when above-average pollock recruitment to age-3 has been observed. Below we track available predictions for several recent year classes of pollock (2015–2017):

2015 year class: The 2015 pollock year class appears **slightly below-average** (Ianelli et al., 2017). Indicators that support below-average or intermediate recruitment include:

- Large zooplankton abundance was low, therefore would predict **below-average recruitment**
- Biophysical indices (chum salmon growth, temperature, predator abundance) predicted **below-average recruitment**
- Age-0 pollock diet energy density predicted **intermediate recruitment**
- Average energy content predicted **intermediate recruitment**

In contrast, the following indicators predicted above-average recruitment:

- The Temperature Change Index predicted above-average recruitment
- Surface silicic acid concentrations predicted above-average recruitment

The EBS had warm conditions in 2015, although age-0 pollock may have utilized the cold pool as a refuge which may act as a buffer against recruitment declines for this year class (Duffy-Anderson et al., 2017).

2016 year class: The 2016 pollock year class also appears **slightly below average** (Ianelli et al., 2017). Indicators that support below-average or intermediate recruitment include:

- The Temperature Change Index predicted **below-average recruitment**
- Average energy content predicted **intermediate recruitment**

In contrast, the following indicators predicted above-average recruitment:

- Surface silicic acid concentrations predicted **above-average recruitment**

2016 marked the 3rd consecutive year of above-average warmth over the eastern Bering Sea shelf and zooplankton communities appeared qualitatively and quantitatively low. However, pollock appear to have mitigated against dramatic recruitment declines. Possible mechanisms include utilizing high productivity waters associated with the strong, northerly cold pool as a refuge, or by exploiting alternative prey (i.e., euphausiids) over the southern shelf (Duffy-Anderson et al., 2017).

2017 year class: No assessment estimate available for the 2017 pollock year class.

- Average energy content predicts **average recruitment** to age-1
- The Temperature Change Index predicts **average recruitment** to age-3

Executive Summary of Recent Trends in the Eastern Bering Sea

This section contains links to all new and updated information contained in this report. The links are organized within three sections: Physical and Environmental Trends, Ecosystem Trends, and Fishing and Human Dimensions Trends.

Physical and Environmental Trends

North Pacific Trends

- The state of the North Pacific atmosphere-ocean system during 2017–2018 was similar to that during 2016-2017 (p. 50).
- Fall (Sept.–Nov.) 2017 was warmer than normal across almost the entire North Pacific Ocean with positive sea level pressure anomalies over the north central portion of the North Pacific Ocean (p. 51).
- Winter (Dec.–Feb.) 2017–2018 reflected a continuation of the previous fall's warm anomalies. Sea level pressure differentials resulted in a pattern that supported extremely strong wind anomalies from the southwest across the Bering Sea (p. 51).
- Spring (Mar.–May) 2018 sea level pressure anomaly pattern resulted in another season of warm, southwesterly flow anomalies across the Bering Sea (p. 51).
- Similar to 2016-2017, a weak La Niña developed during winter along with a weaker than normal Aleutian Low (p. 55).
- The Pacific Decadal Oscillation (PDO) was slightly positive during the past year, with a decline to near zero in the summer of 2018 (p. 55).
- Winter 2018–2019 is predicted to have ∼70% chance of a weak-moderate El Niño and warmer than normal SSTs in the North Pacific in early 2019 (p. 55).

Eastern Bering Sea Trends

- The Bering Sea experienced anomalously warm conditions in 2018. The northern Bering Sea had $>+5^{o}$C anomalies in January–April 2018 (p. 59).
- The northern Bering Sea had a near-complete lack of sea ice due to: (i) residual heat that delayed freeze-up, (ii) a large high pressure system that shifted the position of the Aleutian Low Pressure System (ALPS) northwest, and (iii) winds from the southwest that brought warm air over the Bering Sea (p. 59).

- Sea ice formation in 2018 reached an unprecedented minimum extent, with a near-complete lack of sea ice in the northern Bering Sea (p. 59).
- The cold pool for summer 2018 was nearly non-existent (p. 59).
- The predictions for summer 2019 show a lack of a cold pool based on the $\leq 0^{o}$C or $\leq 1^{o}$C definitions, and a small $\leq 2^{o}$C cold pool (similar to 2003).
- Sea surface temperature anomalies show positive anomalies in the northern Bering Sea during summer and winter for the last several years, including the warmest summer of the time series in 2018 (p. 68).
- Surface water temperatures in 2018 decreased from 2017 while bottom temperatures increased, but both were warmer than the long-term time-series mean (p. 70).
- The cold pool was the lowest areal coverage in the 37-year time-series and 2018 was the first time that bottom temperatures $<0^{o}$C were not observed within the standard bottom trawl survey area (p. 70).
- The 2018 springtime drift pattern appears favorable with consistent drift in a northerly direction. Only two years out of the past ten (2015, 2018) have drift trajectories been consistent with those that produced above-average recruitment (p. 73).

Ecosystem Trends

- Catch rates for sponges and sea anemones remained similar to estimates from 2017, which were lower than catch rates during 2010–2015. The catch rate of sea whips decreased from 2016 to 2017, but increased again in 2018 to a rate similar to 2010–2011 (p. 75).
- Rapid Zooplankton Assessments were conducted on two spring surveys in the southeastern Bering Sea during 2018. Large copepod abundances were lower in the inner domain, but similar to historical means in the middle and outer domains, with 'hot spots' near Unimak Pass and in the northwest region. Lipid content averaged 5.9% wet mass (p. 78).
- Juvenile euphausiid abundances were very low during spring 2018 and low relative to historical means with a lipid content of 3.4% wet mass (p. 78).
- A Rapid Zooplankton Assessment was conducted on one late-summer survey in the northern Bering Sea. Small copepods were abundant throughout the survey area, except at the most northern stations. Large copepods and juvenile euphausiids increased from south to north. Compared to 2007 (cold year), the 2018 abundances of small copepods were similar, abundances of large copepods were an order of magnitude lower, and abundances of juvenile euphausiids were near zero (p. 78).
- Euphausiid density, as estimated from the acoustic-trawl survey, increased slightly from 2016 to 2018, but remains low. The estimates indicate that euphausiids have become less available as prey in 2012–2018 compared to 2006–2010 (p. 88).
- Relative CPUE of jellyfishes (primarily *Chrysaora melanaster*) sampled on the bottom trawl survey increased 211% from 2017 to 2018 and was similar catch as observed in the mid 1990s and in 2009 and 2010 (p. 91).
- The abundance of smaller-sized jellyfish (*Aequorea*, *Aurelia*, *Cyanea*, and *Staurophora*) in 2018 based on surface trawl surveys was variable between the southeastern and northern Bering Sea while the abundance of larger jellyfish (*C. melanaster*) declined in both regions (p. 92).
- Larval pollock abundance has increased since 2012 with a slight decline in 2018; 'hot spots' occurred near the Alaska Peninsula and the Pribilof Islands. Pacific cod larvae show the opposite trend, with declines since 2012 and a slight uptick in 2018 with variable spatial distributions (p. 94).
- Estimated abundances of juvenile forage fish (e.g., pollock, capelin, herring, juvenile salmonids) increased in the southeastern Bering Sea relative to 2016 (driven by herring and juvenile salmonids), but decreased in the northern Bering Sea relative to 2017 (driven by herring and pollock) (p. 96).

- Togiak mature herring biomass in 2017 was estimated via aerial surveys to be 55% of the most recent 10-year average and 59% of the recent 20-year average. Due to the cyclic nature of recruitment into this population, ADF&G considers this population healthy and sustainable at current harvest levels (p. 99).
- The 2018 catch of Canadian-origin juvenile Chinook salmon in the northern Bering Sea was among the lowest observed since 2003. It is likely that the 2018 estimate will be below average, marking the 2nd consecutive year of below average abundance; this could lead to reduced bycatch caps three to four years in the future (p. 102).
- The 2018 Bristol Bay salmon inshore run of sockeye was the largest on record since 1963; inshore run sizes in 2015–2018 were above recent and long-term averages. Inshore runs to the Nushagak District 2017 and 2018 were the two highest on record. Large inshore runs in 2018 suggest these stocks experienced positive conditions at entry into the southeastern Bering Sea in summer of 2015–2016 and winter of 2016–2017 (p. 104).
- There has been a negative trend in Pacific cod condition since a peak in 2003. Condition of age-1+ pollock in 2018 was the second lowest on record and continued a decreasing trend. Length-weight residuals for most species increased or were the same from 2017 to 2018, except pollock and Alaska plaice which had lower condition in 2018 relative to 2017 (p. 107).
- In the northern Bering Sea, Pacific cod and juvenile pollock had higher than average condition in 2018. Adult pollock had lower than average condition in the northern Bering Sea, consistent with the rest of the eastern Bering Sea (p. 107).
- The climate-enhanced multispecies model (CEATTLE) estimates of age-1 predation mortality remain elevated above the long-term mean, while age-1 Pacific cod and Arrowtooth flounder mortality were at and below the long-term mean, respectively (p. 112).
- Pacific cod recruitment of the 2016 year class, as predicted by the NPI, is estimated to be higher than the median. However, the error for 2016 is the largest in the time series (p. 118).
- Regression models using large copepod abundance predict the 2016 year class will produce 3.15–3.39 billion age-3 pollock in 2019 (p. 121).
- Recruitment predictions for the 2017 year class of pollock were average based on survival to age-1 (based on energy density, p. 126) and age-3 (based on the temperature change index, p. 120).
- The 2018 relative CPUE for eelpouts decreased by 12% from 2017, but remains just above the average of the last 10 years. The poacher group CPUE decreased by 36% since 2017 to the lowest since 1987. Seastar CPUE decreased by 20% from 2017 and was just below the average of the last 10 years (p. 129).
- Crab biomass and abundance decreased in 2018 for Bristol Bay red king crab (males and females), St. Matthew Island blue king crab males, and tanner crab (males and females). Pribilof Island blue king crab (males and females) stocks remain depressed. However, snow crab biomass increased in 2018 by 60% (males and females) (p. 131).
- Seabirds showed overall poor reproductive success in 2018 at the Pribilof Islands (i.e., kittiwakes, red-faced cormorants) while murres had some reproductive success, but the number of birds breeding was low and many were late in their reproductive efforts (p. 133).
- Fur seal pup production at St. Paul Island in 2018 was approximately 6% less than in 2016. Pup production has been declining at St. Paul Island at an approximate annual rate of 4.0% since 1998. The St. George estimate is approximately 5% greater in 2018 than 2016 but shows no significant trend since 1998 (p. 136).
- The total biomass of demersal fish and invertebrates shows an apparent increase over the time series with the highest value in 2014. Total CPUE dropped substantially in 2018 but is only slightly lower than the 2010–2013 period (p. 139).

- Local species richness (species per haul) increased in 2018, but is lower than the mid-2000s. Diversity increased substantially because the distribution of biomass was more even, primarily because pollock was not as dominant as in recent years (p. 140).
- The spatial distribution of fish stocks shifted south in 2017 and 2018, but remains further north than in any other year except 2016. However, northern Bering Sea surveys in 2017 and 2018 suggested that much of the biomass occurred in the north, therefore the true center of gravity for many species likely shifted farther to the North than indicated (p. 142).
- The mean lifespan of demersal fish decreased in 2018 to 27.6 years, which is less than the long-term mean. Mean lifespan has generally been stable over the 37-year time series with no indication of a long-term trend (p. 146).
- The mean length of groundfish in 2018 was 37.6 cm, an increase of 0.5 cm from 2017, and is the highest value over the time series. Mean length shows interannual variation, but has been generally stable and trending upward since 2012 (p. 147).
- The stability of groundfish biomass increased in 2018 to 5.5. This indicator has remained generally stable since 1993 and does not exhibit a clear trend (p. 149).

Fishing and Human Dimensions Trends

- Chinook salmon caught as bycatch in the Bering Sea originate from Oregon to the Yukon River. From 2011 to 2016, the proportion of Chinook bycatch from the coastal western Alaska stock has decreased while the proportions of British Columbia and west coast U.S. fish have slightly increased (p. 152).
- Chum salmon is primarily caught as bycatch in the pollock B-season trawl fishery. Between 2011–2016, the northeast Asia and Gulf of Alaska/Pacific northwest stocks have accounted for the greatest proportions of bycatch (p. 154).
- Discard biomass in the northern Bering Sea fixed gear sector has trended upward since 2016, but remains small relative to discard biomass in the southern Bering Sea. In 2018, discards in the fixed gear sector trended lower in the southern Bering Sea and higher in the northern Bering Sea (due to freezer longline vessels targeting Pacific cod) relative to the previous 5-year period (p. 156).
- The catch of jellyfish peaked in 2014, declined in 2015 and 2016, and increased again in 2017. Catch of structural epifauna (predominantly benthic urochordate) has been steady 2011–2017. Seastars increased between 2011–2015, but have decreased in 2016 and 2017 (p. 159).
- The number of seabirds caught incidentally in EBS fisheries in 2017 was very similar to the 2007–2016 average. Northern fulmars, shearwaters, and gulls were the most common species group caught in 2017 (p. 162).
- With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling (p. 169).
- As of June 30, 2018, no BSAI groundfish stock or stock complex is subjected to overfishing, is considered to be overfished, or to be approaching an overfished condition. Only the Pribilof Islands blue king crab stock is considered overfished and subject to overfishing; the stock is in year 4 of a rebuilding plan (p. 172).
- Surplus production was high in 2014–15 and 2015–16, then dropped substantially due to a decrease in a number of species from 2016 to 2017 (p. 177).
- Landings in the EBS are predominantly from the pelagic foragers (i.e., pollock); trends in the apex predator group are driven by TAC of Pacific cod; crab stocks (motile epifauna) have trended upwards since 2003, but declined significantly in 2017, especially for tanner crab (p. 184).

- Subsistence salmon harvests in the southeastern Bering Sea reflect a downward trend; in the northern Bering Sea, household permits have increased but harvests have decreased. Subsistence halibut harvest increased in 2014–2016 in both the southeastern and northern Bering Sea (p. 180).
- Trends in ex-vessel value are closely connected to landings (see p. 184). Flatfish revenues have declined recently due to decreased prices; crab value has increased with increased landings; salmon value has increased due to stable landings and strong prices (p. 186).
- First-wholesale value varies by landings and/or prices. Pollock prices have decreased since 2013, but this has been largely offset by increased landings; Pacific cod prices dropped in 2009, but rebounded and have been stable; flatfish value decreased between 2012–2015 with decreased prices and significant supply; salmon value decreased in 2012, but rebounded in 2013 and has remained stable at 2010 levels; crab value increased with increasing prices through 2012, but has decreased slightly with reduced landings (p. 186).
- A low level of saltwater sport fishing occurs in the EBS; the number of anglers fishing has declined since the mid-1990s and is currently below 2,000 anglers (p. 190).
- Alaska is well-known for its sport fishing opportunities and draws anglers from within and from outside Alaska. In the EBS, however, saltwater recreational fishing effort is currently low and likely represents a trivial source of extraction for all functional groups (p. 192).
- The unemployment rate in EBS communities decreased to 3.1% in 2017 while the northern Bering Sea was 12.4% (p. 196).
- The 2017 population estimate of all EBS communities combined was 10,243 and the population of small communities (< 1,500) was 7,908. The EBS population has remained relatively stable overall, yet 41% of communities experienced population decline between 1990 and 2017 (p. 200).
- The 2017 population estimate of all northern Bering Sea communities was 33,620 and the population of small communities (< 1,500) was 23,778. The northern Bering Sea population has remained relatively stable with only 18% of communities experiencing population declines between 1990 and 2017 (p. 200).
- There has been a downward trend in school enrollment in the EBS (except the Lower Kuskokwim School district) with several community schools closing in rural areas, including St. George in 2018. Graduation rates for Lower Kuskokwim district consistently fall in the lower 1/3 of school districts, while the Lake and Peninsula and Pribilof school districts are consistently in the upper 1/3 (p. 205).
- Northern Bering Sea school district enrollment levels are relatively stable with very few school closures and only five schools with enrollment below 30 students out of 64 schools. However, the northern Bering Sea region has the highest dropout rates compared to other regions, with an overall average of 10% for multiple years (p. 205).

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Introduction

The goals of the Ecosystem Status Reports are to (1) provide stronger links between ecosystem research and fishery management and (2) spur new understanding of the connections between ecosystem components by bringing together the results of diverse research efforts into one document. Beginning in 2016, we split the report into four separate documents, one each for the Gulf of Alaska, Aleutian Islands, eastern Bering Sea, and the Arctic[1]. This year we present updated reports for the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea. Each report contains four main sections:

- Report Card(s)
- Ecosystem Assessment
- Executive Summary
- Ecosystem Indicators and Fishing and Human Dimensions Indicators

The purpose of the first section, the Report Card(s), is to summarize the status of the top indicators selected by teams of ecosystem experts to best represent each ecosystem. Time series of indicators are presented in figures formatted similarly to enable comparisons across indicators. Recent trends in climate and the physical environment, ecosystems, and fishing and fisheries are highlighted in bulleted lists. The selected list of indicators is intended to be revisited regularly. The eastern Bering Sea indicators were selected in 2010 and will be updated as part of the Fishery Ecosystem Plan currently being developed. The Aleutian Islands indicators were selected in 2011. The Gulf of Alaska indicators were selected in 2015.

The purpose of the second section, the Ecosystem Assessment, is to synthesize historical climate and fishing effects on Alaskan marine ecosystems using information from the Ecosystem Status and Management Indicators section and stock assessment reports. An ongoing goal is to produce ecosystem assessments utilizing a blend of data analysis and modeling to clearly communicate the current status and possible future directions of ecosystems. In 2017 we expanded the Fishing and Human Dimensions section to more broadly reflect aspects of our role in the ecosystem. In doing so, we organized this new section around a proposed set of ecosystem-scale objectives derived from U.S. legislation and current management practices.

The purpose of the third section, the Executive Summary, is to provide a concise summary of the status of marine ecosystems in Alaska for stock assessment scientists, fishery managers, and the public. Page links to sections with more detail are provided.

The purpose of the fourth section, Ecosystem Indicators and Fishing and Human Dimensions Indicators, is to provide detailed information and updates on the status and trends of ecosystem components. The indicators are broadly grouped into Ecosystem Status Indicators, organized by trophic level, and Fishing and Human Dimensions Indicators, organized around objective categories derived from U.S. legislation and current management practices. Descriptions of the Report Card indicators and "Noteworthy" items that capture unique occurrences are highlighted at the beginning. Indicators are also intended to track performance in meeting the stated ecosystem-based management goals of the NPFMC, which are:

[1] The Arctic report is under development

1. Maintain biodiversity consistent with natural evolutionary and ecological processes, including dynamic change and variability
2. Maintain and restore habitats essential for fish and their prey
3. Maintain system sustainability and sustainable yields for human consumption and non-extractive uses
4. Maintain the concept that humans are components of the ecosystem

History of the ESRs

Since 1995, the North Pacific Fishery Management Council's (NPFMC) Groundfish Plan Teams have prepared a separate Ecosystem Status (formerly Considerations) Report within the annual SAFE report. Each new Ecosystem Status Report provides updates and new information to supplement the original report. The original 1995 report presented a compendium of general information on the Gulf of Alaska, Bering Sea, and Aleutian Island ecosystems as well as a general discussion of ecosystem-based management. The 1996 edition provided additional information on biological features of the North Pacific, and highlighted the effects of bycatch and discards on the ecosystem. The 1997 edition provided a review of ecosystem-based management literature and ongoing ecosystem research, and provided supplemental information on seabirds and marine mammals. The 1998 edition provided information on the precautionary approach, essential fish habitat, effects of fishing gear on habitat, El Niño, local knowledge, and other ecosystem information. The 1999 edition again gave updates on new trends in ecosystem-based management, essential fish habitat, research on effects of fishing gear on seafloor habitat, marine protected areas, seabirds and marine mammals, oceanographic changes in 1997/98, and local knowledge.

In 1999, a proposal came forward to enhance the Ecosystem Status Report by including more information on indicators of ecosystem status and trends and more ecosystem-based management performance measures. The purpose of this enhancement was to accomplish several goals:

1. Track ecosystem-based management efforts and their efficacy
2. Track changes in the ecosystem that are not easily incorporated into single-species assessments
3. Bring results from ecosystem research efforts to the attention of stock assessment scientists and fishery managers
4. Provide a stronger link between ecosystem research and fishery management
5. Provide an assessment of the past, present, and future role of climate and humans in influencing ecosystem status and trends

Each year since 1999, the Ecosystem Status Reports have included some new contributions and will continue to evolve as new information becomes available. Evaluation of the meaning of observed changes should be in the context of how each indicator relates to a particular ecosystem component. For example, particular oceanographic conditions, such as bottom temperature increases, might be favorable to some species but not for others. Evaluations should follow an analysis framework such as that provided in the draft Programmatic Groundfish Fishery Environmental Impact Statement that links indicators to particular effects on ecosystem components.

In 2002, stock assessment scientists began using indicators contained in this report to systematically assess ecosystem factors such as climate, predators, prey, and habitat that might affect a particular stock. Information regarding a particular fishery's catch, bycatch, and temporal/spatial distribution can be used to assess possible impacts of that fishery on the ecosystem. Indicators of concern can be highlighted within each assessment and can be used by the Groundfish Plan Teams and the Council to justify modification of allowable biological catch (ABC) recommendations or time/space allocations of catch.

We initiated a regional approach to the ESR in 2010 and presented a new ecosystem assessment for the eastern Bering Sea. In 2011, we followed the same approach and presented a new assessment for the Aleutian Islands

based on a similar format to that of the eastern Bering Sea. In 2012, we provided a preliminary ecosystem assessment on the Arctic. Our intent was to provide an overview of general Arctic ecosystem information that may form the basis for more comprehensive future Arctic ecosystem assessments. In 2015, we presented a new Gulf of Alaska report card and assessment, which was further divided into Western and Eastern Gulf of Alaska report cards beginning in 2016. This was also the year that the previous Alaska-wide ESR was split into four separate report, one for the Gulf of Alaska, Aleutian Islands, eastern Bering Sea, and the Arctic[2].

The eastern Bering Sea and Aleutian Islands ecosystem assessments were based on additional refinements contributed by Ecosystem Synthesis Teams. For these assessments, the teams focused on a subset of broad, community-level indicators to determine the current state and likely future trends of ecosystem productivity in the EBS and ecosystem variability in the Aleutian Islands. The teams also selected indicators that reflect trends in non-fishery apex predators and maintaining a sustainable species mix in the harvest as well as changes to catch diversity and variability. Indicators for the Gulf of Alaska report card and assessment were also selected by a team of experts, via an online survey first, then refined in an in-person workshop.

Originally, contributors to the Ecosystem Status Reports were asked to provide a description of their contributed index/information, summarize the historical trends and current status of the index, and identify potential factors causing those trends. Beginning in 2009, contributors were also asked to describe why the index is important to groundfish fishery management and implications of index trends. In particular, contributors were asked to briefly address implications or impacts of the observed trends on the ecosystem or ecosystem components, what the trends mean and why are they important, and how the information can be used to inform groundfish management decisions. Answers to these types of questions will help provide a "heads-up" for developing management responses and research priorities.

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 3). The primary stakeholders in this case are the North Pacific Fishery Management Council. Research and development of risk analyses and management strategies is ongoing and will be referenced or included as possible.

It was requested that contributors to the Ecosystem Status Reports provide actual time series data or make them available electronically. The Ecosystem Status Reports and data for many of the time series presented within are available online at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`. These reports and data will also be available through a new NOAA-wide IEA website in early 2019.

Past reports and all groundfish stock assessments are available at: `http://www.afsc.noaa.gov/refm/stocks/assessments.htm`

If you wish to obtain a copy of an Ecosystem Considerations report version prior to 2000, please contact the Council office (907) 271-2809.

[2]The Arctic report is under development

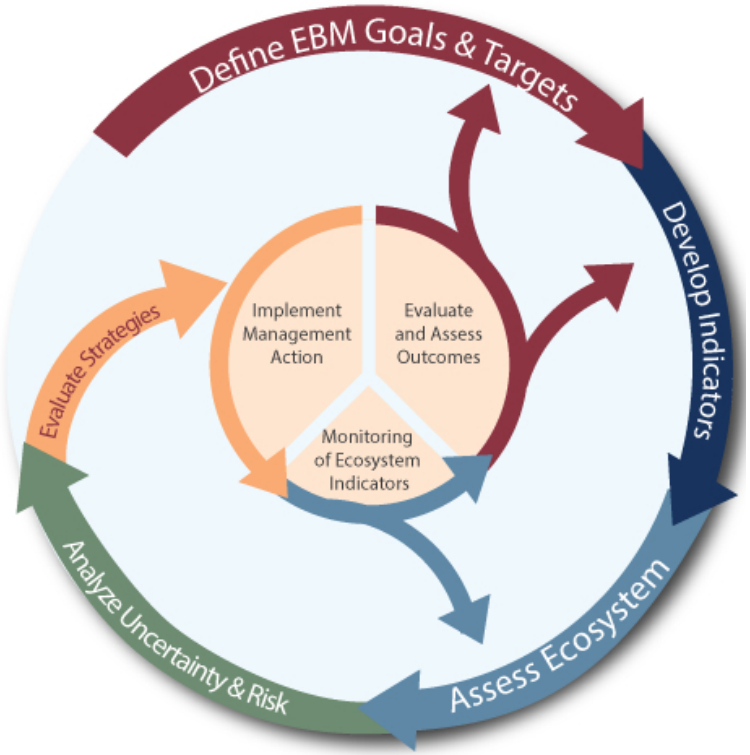

Figure 3: The IEA (integrated ecosystem assessment) process.

Ecosystem Indicators

Description of the Report Card indicators

1. The North Pacific Index (NPI) (Nov. - Mar. average): The NPI was selected as the single most appropriate index for characterizing the climate forcing of the Bering Sea. The NPI is a measure of the strength of the Aleutian Low, specifically the area-weighted sea level pressure (SLP) for the region of 30° to 65°N, 160°E to 140°W (Trenberth and Hurrell, 1994). It is relevant to the Bering Sea because the strength of the Aleutian Low relates to wintertime temperatures, with a deeper low (negative SLP anomalies) associated with a greater preponderance of maritime air masses and hence warmer conditions.

The advantageous aspects of the NPI include its systematic relationship to the primary causes of climate variability in the Northern Hemisphere, especially the El Niño-Southern Oscillation (ENSO) phenomenon, and to a lesser extent the Arctic Oscillation (AO). It may also respond to North Pacific SST and high-latitude snow and ice cover anomalies, but it is difficult to separate cause and effect. The NPI also has some drawbacks: (1) it is relevant mostly to the atmospheric forcing in winter, (2) it relates mainly to the strength of the Aleutian Low rather than its position, which has also been shown to be important to the seasonal weather of the Bering Sea (Rodionov et al., 2007), and (3) it is more appropriate for the North Pacific basin as a whole than for a specific region such as the Bering Sea shelf.

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2. Eastern Bering Sea ice retreat index: Sea ice over the southern Bering Sea (south of ∼60°N) varies greatly on all time scales (daily, annual, decadal), while the variability over the northern Bering Sea shelf is lower. We use an index of the number of days during March and April in which there was at least 20% ice cover in a 100 km box around the M2 mooring located in the southeastern portion of the shelf at 57°N and 164°W (Stabeno et al., 2012). We chose spring, because it is spring sea ice that influences the timing of the spring phytoplankton bloom, determines the extent of the cold pool, and strongly influences sea surface temperatures during summer.

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3. Euphausiid biomass: Macrozooplankton are intermediaries in the transfer of carbon from primary production to living marine resources (commercial fisheries and protected species). Understanding the mechanisms that control secondary production is an obvious goal toward building better ecosystem syntheses. In the absence of direct measurements of secondary production in the eastern Bering Sea, we rely on estimates of biomass. We use an estimate of euphausiid biomass as determined by acoustic trawls.

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4., 5., 6., 7. Description of the fish and invertebrate biomass indices: We present four guilds to indicate the status and trends for fish and invertebrates in the eastern Bering Sea: motile epifauna, benthic foragers, pelagic foragers, and apex predators. Each is described in detail below. The full guild analysis involved aggregating all eastern Bering Sea species included in a food web model (Aydin and Mueter, 2007) into 18 guilds by trophic role, habitat, and physiological status (Table 1). For each guild, time trends of biomass are presented for 1977–2018. Eastern Bering Sea biomass trends are summed stock assessment model estimates or scaled survey data, where available, for each species within the guild. If neither time series are available, the species is assumed to have a constant biomass equal to the mid-1990s mass balance level estimated in Aydin and Mueter (2007). Catch data were directly taken from the Catch Accounting System and/or stock assessments for historical reconstructions.

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Table 1: Composition of foraging guilds in the eastern Bering Sea.

Motile epifauna	**Benthic foragers**	**Pelagic foragers**	**Fish apex predators**
Eelpouts	P. cod (juv)	W. pollock (juv)	P. cod
Octopuses	Arrowtooth (juv)	W. pollock	Arrowtooth
Tanner crab	P. halibut (juv)	P. herring (juv)	Kamchatka fl. (juv)
King crabs	Yellowfin sole (juv)	P. herring	Kamchatka fl.
Snow crab	Yellowfin sole	Gr. turbot (juv)	P. halibut
Sea stars	Flathead sole (juv)	Sablefish (juv)	Alaska skate
Brittle stars	Flathead sole	P. ocean perch	Large sculpins
Other echinoderms	N. rock sole (juv)	Sharpchin rockfish	
Snails	N. rock sole	Northern rockfish	
Hermit crabs	AK plaice	Dusky rockfish	
Misc. crabs	Dover sole	Other Sebastes	
	Rex sole	Atka mackerel (juv)	
	Misc. flatfish	Atka mackerel	
	Shortraker rockfish	Misc. fish shallow	
	Thornyhead rockfish	Squids	
	Greenlings	Salmon returning	
	Other sculpins	Salmon outgoing	
		Bathylagidae	
		Myctophidae	
		Capelin	
		Eulachon	
		Sandlance	
		Other pelagic smelts	
		Other managed forage	
		Scyphozoid jellies	

4. Motile epifauna (fish and benthic invertebrates): This guild includes both commercial and non-commercial crabs, sea stars, snails, octopuses, and other mobile benthic invertebrates. Information is based on bottom trawl survey data (for more information, see p.129 and 131). There are ten commercial crab stocks in the current Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs; we include seven on the eastern Bering Sea shelf: two red king crab *Paralithodes camtschaticus* (Bristol Bay, Pribilof Islands), two blue king crab *Paralithodes platypus* (Pribilof District and St. Matthew Island), one golden king crab *Lithodes aequispinus* (Pribilof Islands), and two Tanner crab stocks (southern Tanner crab *Chionoecetes bairdi* and snow crab *C. opilio*). The three dominant species comprising the eelpout group are marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*), and shortfin eelpout (*L. brevipes*). The composition of seastars in shelf trawl catches are dominated by the purple-orange seastar (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which

is primarily an inhabitant of the outer shelf. Stock assessments for crabs have not been included to date, but could be in the future.

5. Benthic foragers (fish only): The species which comprise the benthic foragers group are the Bering Sea shelf flatfish species, juvenile Arrowtooth flounder (*Atheresthes stomias*), and the sculpins. The major species of this group are surveyed annually and have abundances estimated by statistical models, therefore our confidence in their time-trend of abundance is high.

6. Pelagic foragers (fish and squid only): This guild includes adult and juvenile Walleye pollock (*Gadus chalcogrammus*), other forage fish such as Pacific herring (*Clupea pallasi*), Capelin (*Mallotus villosus*), Eulachon (*Thaleichthys pacificus*), and Sand lance, pelagic rockfish, salmon, and squid. Information quality ranges from a sophisticated highly quantitative stock assessment for pollock (the biomass dominant in the guild) through relatively high variance eastern Bering Sea shelf survey data for forage fish, to no time series data for salmon and squid.

7. Apex predators (shelf fish only): This guild includes Pacific cod (*Gadus macrocephalus*), Arrowtooth flounder, Kamchatka flounder (*Atheresthes evermanni*), Pacific halibut (*Hippoglossus stenolepis*), Alaska skate, and large sculpins. Pacific cod and Arrowtooth flounder time series are from stock assessments, and the remaining time series are from the annual eastern Bering Sea shelf bottom trawl survey.

8. Multivariate seabird breeding index: This index represents the dominant trend among 17 reproductive seabird data sets from the Pribilof Islands that include diving and surface-foraging seabirds. The trend of the leading principal component (PC1) represents all seabird hatch timing and the reproductive success of murres and cormorants.

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9. St. Paul Northern fur seal pup production: Pup production on St. Paul was chosen as an index for pinnipeds on the eastern Bering Sea shelf because the foraging ranges of females that breed on this island are largely on the shelf, as opposed to St. George which, to a greater extent, overlap with deep waters of the Basin and slope. Bogoslof Island females forage almost exclusively in pelagic habitats of the Basin and Bering Canyon and, as such, would not reflect foraging conditions on the shelf.

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10. Habitat impacted by trawls: Fishing gear can affect habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. An estimate of the area of seafloor disturbed by trawl gear may provide an index of habitat disturbance. This new indicator uses output from the Fishing Effects (FE) model to estimate the habitat reduction of geological and biological features over the Bering Sea domain, utilizing spatially-explicit VMS data. The indicator more accurately reflects an estimate of time that gear is in contact with the substrate. Further detail on this index is reported on p. 167.

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Noteworthy (formerly Hot Topics)

We present items that are either new or otherwise noteworthy and of potential interest to fisheries managers as Noteworthy Items.

Better Off Dead

The Ecosystem Conservation Office (ECO) of the Aleut Community of St. Paul Island maintains a rat prevention program on St. Paul Island, within the Pribilof Islands, Alaska. The rat prevention program, developed jointly by ECO and the U.S. Fish and Wildlife Service (USFWS), maintains bio-security via rodent trap stations at points of entry to St. Paul Island, including the harbor, fish processing facility, boat yard, airport, Tribal Store, and Post Office. The Pribilof Islands support a globally significant concentration of breeding seabirds and the rat prevention program was put in place to provide an early detection system to safeguard against the potentially catastrophic impacts that an established population of rats could have on breeding seabirds.

Unfortunately a rat was detected at the St. Paul fish processing facility during the last week of August 2018. ECO immediately initiated a response, via an aggressive trapping effort and deployment of motion detection cameras, and coordinated with the fish processor, the City of St. Paul, and the USFWS. ECO employees obtained photographic evidence of rat presence via the cameras in early September but were unable to capture a specimen. In consultation with ECO, the USFWS deployed a 'strike team' of rat eradication experts to the island on September 20, consisting of representatives from the USFWS, United States Department of Agriculture Wildlife Services, and Island Conservation. The team worked directly with ECO for a week and carried out increased trapping efforts, added new trapping stations, and trained ECO team members in best practices for rat eradication. Since the strike team left the island, ECO has been intensively monitoring trapping stations within the fish processing facility and the City of St. Paul. On October 21, ECO received a report that a rat had again been sighted in the fish processing facility. As a result, ECO and their partners will continue to maintain heightened rat monitoring and eradication efforts as long as the threat of a rat introduction remains.

Contributed by Lauren Divine (Aleut Community of St. Paul Island),
Marc Romano (USFWS)

Genetic Evidence for Summer Northward Movement of Pacific Cod

Changing conditions have been observed in the northern Bering Sea (NBS) region in recent years, including significant differences in the distribution of important commercial fish species from a National Marine Fisheries Service (NMFS) survey in 2010 and 2017. Significant differences in the Pacific cod (*Gadus macrocephalus*) distribution were observed from 2010 to 2017 in the NBS, a 907% increase. Concurrently, the 2017 estimate for Pacific cod in the southeastern Bering Sea declined by 37% from estimates in 2016. Hypotheses for these changes included northward movement of Pacific cod, population expansion of existing NBS populations, or movement from other regions, such as the Gulf of Alaska (which also experienced a decline in 2017) or Russia.

Researchers at the Alaska Fisheries Science Center tested these hypotheses by comparing the genetic composition (using Restriction-site Associated DNA sequencing) of a sample from the NBS in 2017 (Figure 4)

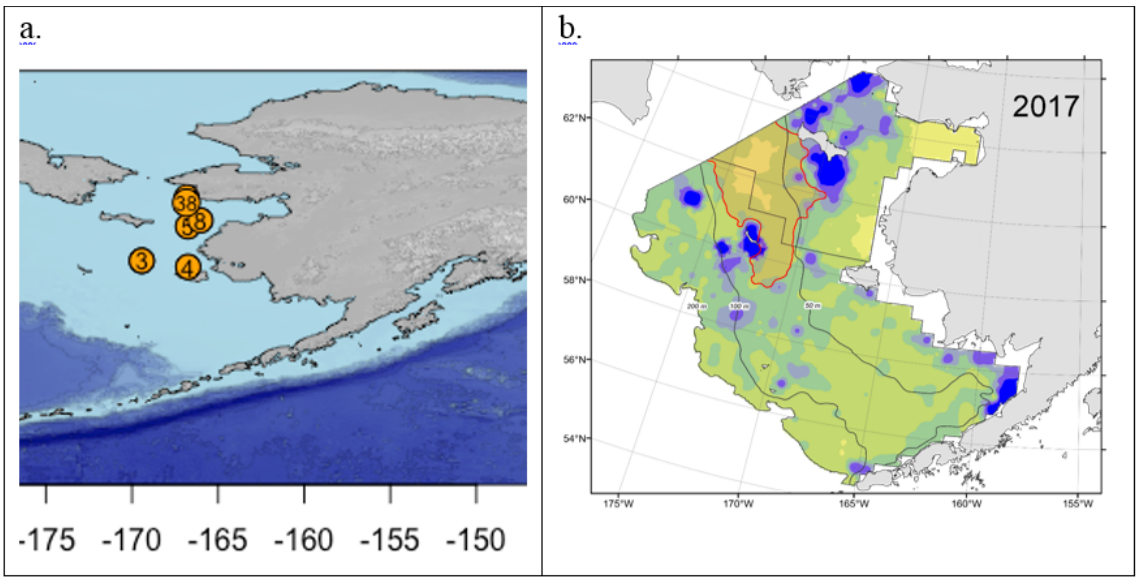

Figure 4: Sample locations with respect to Pacific cod biomass observed in 2017 in the northern Bering Sea. Sample locations and sample sizes are shown in panel a. High density observations of Pacific cod are shown in panel b, with the highest density in blue.

with that of spawning populations throughout the Bering Sea and an existing baseline from other spawning populations throughout Alaska waters. They used a method called RADseq (Restriction digest associated sequencing) that provided 3,731 Single Nucleotide Polymorphism (SNP) loci.

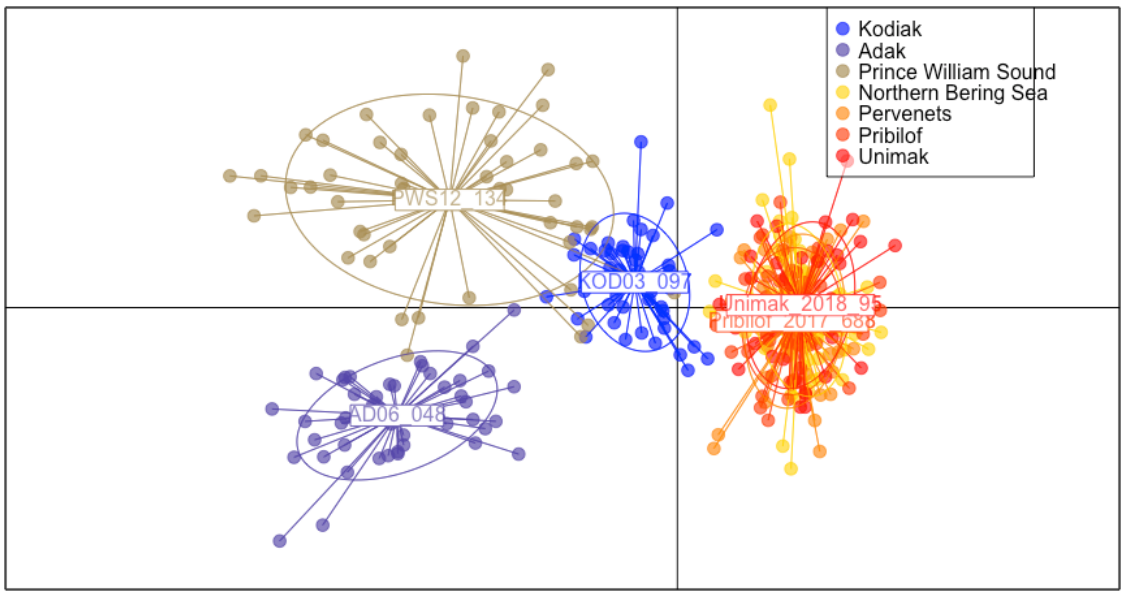

Figure 5: Discriminant analysis of principal components for samples used in the study; all samples came from spawning fish except the Norton Sound sample.

Results indicate that the sample taken in 2017 was most similar to eastern Bering Sea spawning populations (Figure 5) and not from the Gulf of Alaska or the Aleutian Islands. A DAPC (discriminant analysis of principal components) indicated that the sample from the NBS grouped strongly with spawning samples

from Pervenets and Pribilof canyons and Unimak Pass. An assignment test (Figure 6) indicated roughly equal probability that the NBS sample was from the three spawning samples from the eastern Bering Sea. It is likely that there was not enough information in the data to specify more than the NBS sample originated from eastern Bering Sea spawning stocks. Comparing observed and expected likelihood values from the assignment test indicated that the NBS sample was not from a location not sampled (i.e., Russia).

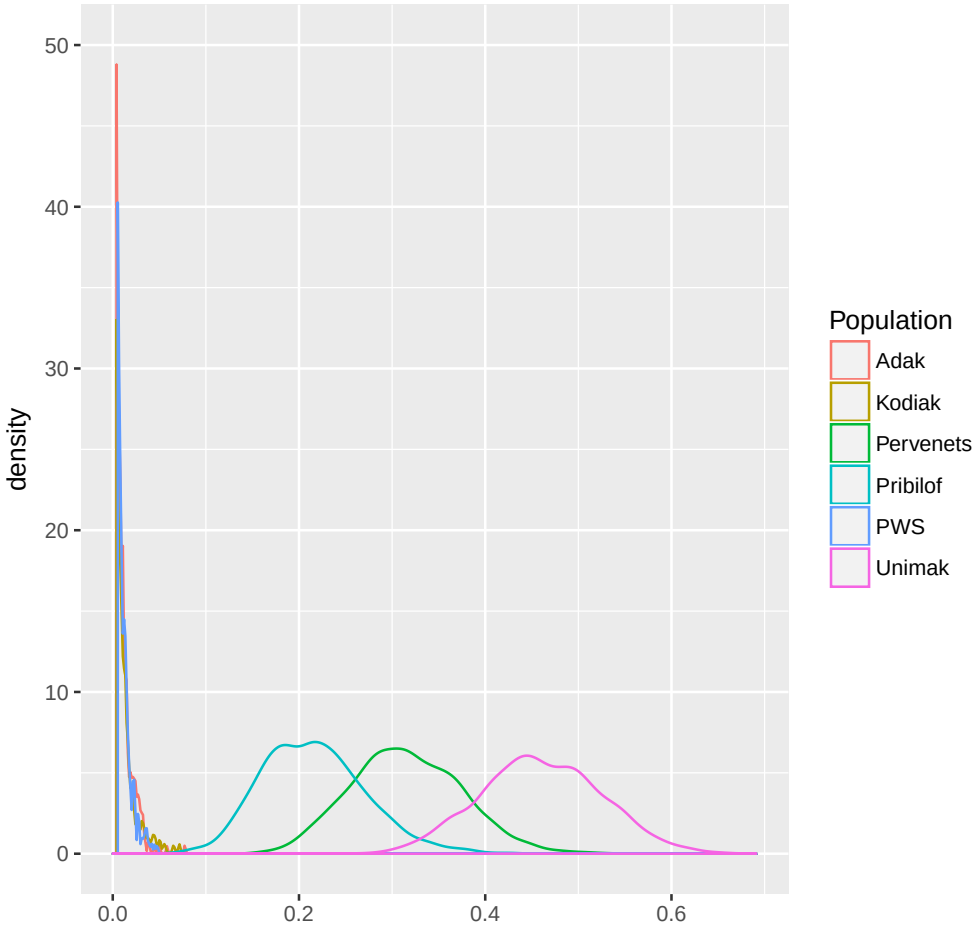

Figure 6: Assignment test results indicating that the northern Bering Sea sample of Pacific cod came from Pribilof canyon with 21% posterior probability, Pervenets canyon with 31% probability, and Unimak Pass with 46% probability.

Contributed by Ingrid Spies, Kristen Gruenthal, Lorenz Hauser, Anne Hollowed, Duane Stevenson, and Carolyn Tarpey

New Evidence of Stock Composition Differences in Pacific Herring from the Bering and Chukchi Seas

Climate warming has impacted the southern extent of sea ice in the eastern Bering Sea (EBS) leading to changes in ocean conditions and food webs. In 2018, the maximum sea ice extent was at a historical minimum in the Bering Sea. These ecosystem changes have influenced Pacific herring (*Clupea pallasii*) distribution and diet in this region (Andrews et al., 2015) and have led to further questions surrounding herring stock composition and habitat use in the eastern Bering Sea.

Pacific herring are managed as a Prohibited Species in the Federal waters of the EBS. In addition, a commercial spring sac roe fishery occurs in Togiak and smaller scale bait fisheries have occurred in Dutch Harbor and Norton Sound. The Togiak spawning population is considered the largest in Alaskan waters and makes up approximately 70% of the herring spawning biomass in the EBS (p. 99). However, while the largest spawning biomass is from Togiak (southeastern Bering Sea), the Bering Arctic Sub-Arctic Integrated Survey (BASIS) captured the largest biomass of herring in the northeastern Bering Sea. The majority of the herring captured during BASIS are thought to be juveniles leading to a new hypothesis: Is the northern Bering Sea (i.e., Norton Sound) an important nursery area for eastern Bering Sea herring populations? A pilot study

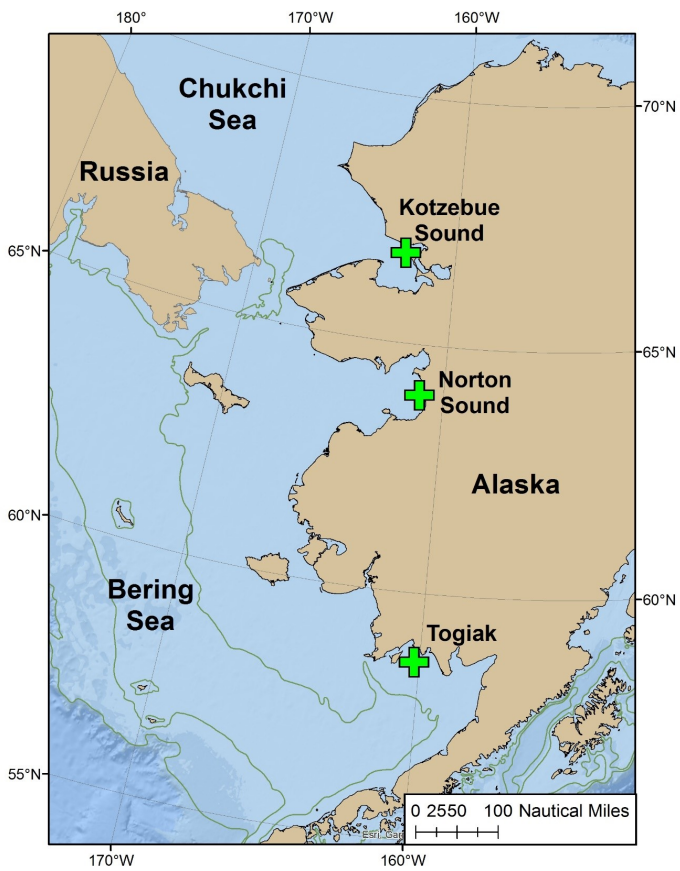

Figure 7: Map of Pacific herring collection sites in the eastern Bering and southern Chukchi Seas.

was undertaken to explore this hypothesis. Pre-spawning herring were collected from the following three regions in the Bering and Chukchi Seas: Kotzebue Sound (n=126), Norton Sound (n=50), and Togiak (n=50;

Table 2: Results of isotopic analysis.

Location	FL (mean; mm)	δ15N mean	δ15N SD	δ13C mean	δ13C SD	C:N mean	C:N SD
Kotzebue Sound	207.1	15.37	0.49	-21.41	0.66	3.99	0.83
Norton Sound	305.4	15.04	0.60	-20.49	0.63	4.55	0.21
Togiak	323.24	14.40	0.65	-20.73	0.59	4.71	0.97

Figure 7). We analyzed the samples for genetic and isotopic differences, and plan to analyze the otolith microchemistry to provide additional evidence of spawning stock differentiation. Data from 15 microsatellite loci indicate herring from Togiak and Norton Sound are genetically similar (p=0.72), but both collections significantly differ from Kotzebue Sound herring (p<0.000; Figure 8). This finding supports previous work (Grant and Utter, 1984) and emphasizes that the genetic split is north of Norton Sound. Results from the isotopic analysis from a subset of these samples indicate that the δ13C and δ15N values are consistent with known latitudinal gradients (Table 2). However, δ13C values from Kotzebue Sound are more depleted and may indicate a stronger association with nearshore environments with freshwater terrestrial input.

A better understanding of Pacific herring stock composition and habitat use for early and late life stages will provide insights into the effects of climate change on different spawning populations in the eastern Bering Sea.

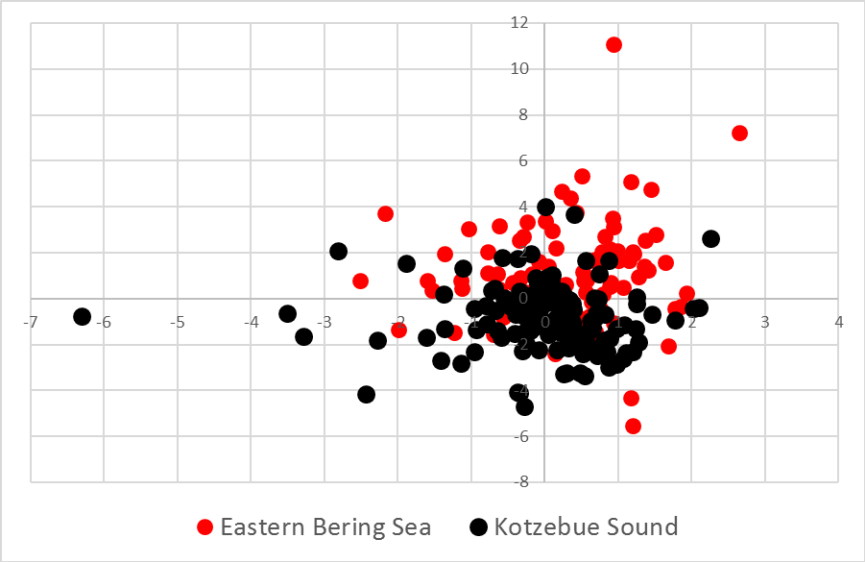

Figure 8: Principal component analysis plot of 15 microsatellite loci for herring collections from Kotzebue Sound (n=126), Norton Sound (n=50), and Togiak (n=50). Kotzebue Sound samples significantly differ from eastern Bering Sea samples (Norton Sound and Togiak).

Contributed by Alex Andrews, Sharon Wildes, and Todd Miller (NOAA/AFSC/ABL),
Sherri Dressel (ADF&G),
and Alex Whiting (Native Village of Kotzebue, Kotzebue IRA)

Seabird Mortality Events in 2018 are highest in Beringia Region

In contrast to 2017 and earlier events, reported seabird mortality events in 2018 were more heavily concentrated in the Beringia region (Figure 9). Beginning in May and extending through June 2018, the U.S. Fish and Wildlife Service (USFWS) received reports of dead and dying seabirds in the northern Bering and southern Chukchi seas, with dozens to hundreds of dead birds on various beaches. The events continued into July and expanded north to Utqiagvik in the Arctic, south to St. Paul Island in the central Bering Sea, and to the Alaska Peninsula and Lower Cook Inlet in the northern Gulf of Alaska (GOA). During USFWS seabird surveys from the northern GOA to the Beaufort Sea, 25 dead seabirds were encountered (Figure 10). This is less than the 70 dead birds encountered during 2017 surveys, but still much higher than the typical 2 birds per year (another exception being fall 2014).

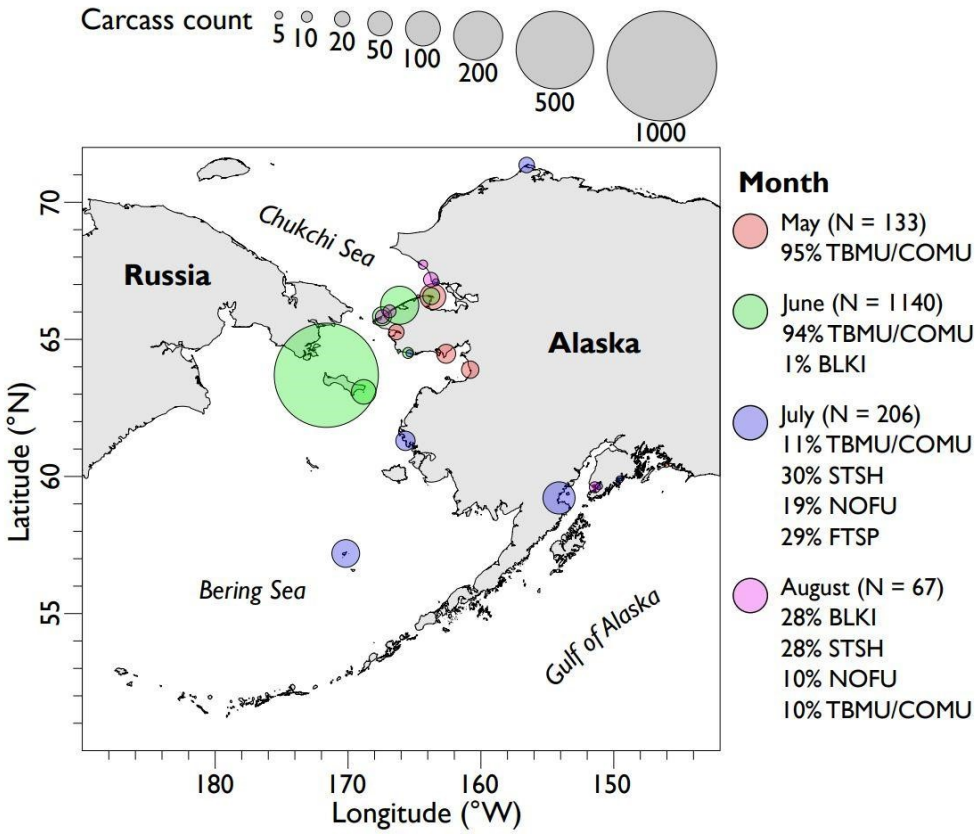

Figure 9: Dead birds counted on shore in 2018.

Contributing to mortality reports, sample collections, and response throughout Alaska were the UAF-Alaska Sea Grant, Kawerak, Inc., Aleut Community of St. Paul Island, Alaska Migratory Bird Co-management Council, National Park Service, and the Coastal Observation and Seabird Survey Team (COASST). The COASST community members continue to monitor select beaches to track this event with respect to long-term patterns.

Members of subsistence communities are greatly concerned about the cause of the die-offs and whether birds and eggs are safe to consume. To date, all bird carcasses (over 200 since 2015) sent to the USGS National Wildlife Health Center or the USGS Alaska Science Center (ASC) for examination were determined to have died of emaciation and starvation. To evaluate whether harmful algal bloom toxins may have contributed to seabird deaths, the ASC, in collaboration with NOAA and other partners, tested birds from multiple locations (including dead and apparently healthy birds from 2015–2017) for saxitoxin. They found detectable levels

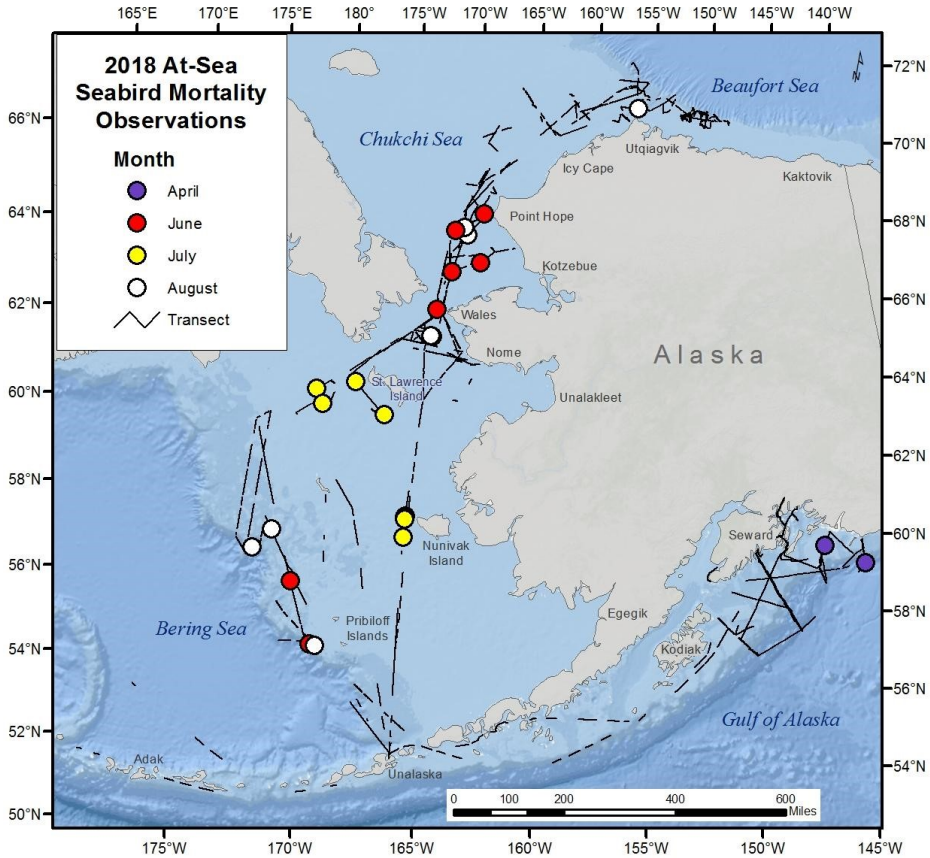

Figure 10: Dead birds counted at sea, by month, in 2018.

of saxitoxin in slightly more of the dead (45%) than apparently healthy (35%) birds tested. All saxitoxin levels were below advisory limits for human consumption of shellfish (80 ug/100 g); however, these limits do not apply to seabirds, and thus the ASC cannot advise on human harvest or consumption at this time.

This year's seabird mortality has been reported over a wide geographic region and throughout summer, with emaciation and starvation as the only identified cause of death (to date). In addition, observations at seabird breeding colonies by community members and the Alaska Maritime National Wildlife Refuge indicate lack of breeding attempts or very late and unsuccessful breeding. Together, these observations suggest that the seabird die-offs stem from a lack of food or unfavorable foraging conditions, indicating ecosystem changes that may be associated with abnormally high ocean water temperatures, particularly in the Pacific Arctic.

A 1-page information sheet on this recent die off is available at: `https://www.fws.gov/alaska/pdf/Alaska_2018_Seabird_Die-off_1Pager_VerAUG2018_FINAL.pdf`.

Contributed by: Kathy Kuletz, Liz Labunski and Robb Kaler (USFWS)
Julia Parish, Timothy Jones and Hillary Burgess (COASST)
Gay Sheffield (Alaska Sea Grant/University of Alaska, Nome)
Brandon Ahmasuk (Kawerak, Inc.) and
Sarah Schoen and Caroline Van Hemert (USGS/ASC).

Local Environmental Observer (LEO) Network

The NMFS AFSC is interested in documenting and learning from citizen science observations that may be incorporated into Ecosystem Status Reports (ESRs). We identified the LEO Network as a potential platform for tracking these observations in the 2017 ESR and were encouraged by the Council and SSC to continue exploring the utilization of this framework in future reports. Other citizen science efforts exist in Alaska, but to our knowledge these efforts are mostly project specific (e.g., bird spotting and identification) or community specific.

The LEO Network was launched in 2012 by the Alaska Native Tribal Health Consortium (ANTHC) as a tool for local observers in the Arctic to share information about climate and other drivers of environmental change (see: `https://www.leonetwork.org/en/docs/about/about`). Anyone may join the network and provide observations, and the network now spans the globe. Consultants with relevant expertise often, but not always, review the observations and provide feedback. The observations are of unusual environmental events or notable environmental changes, reported by geographic location and date, and classified by relevant category (or multiple relevant categories) such as Weather, Land, Fish, Sea Mammals, Ocean/Sea, etc. (Figure 11).

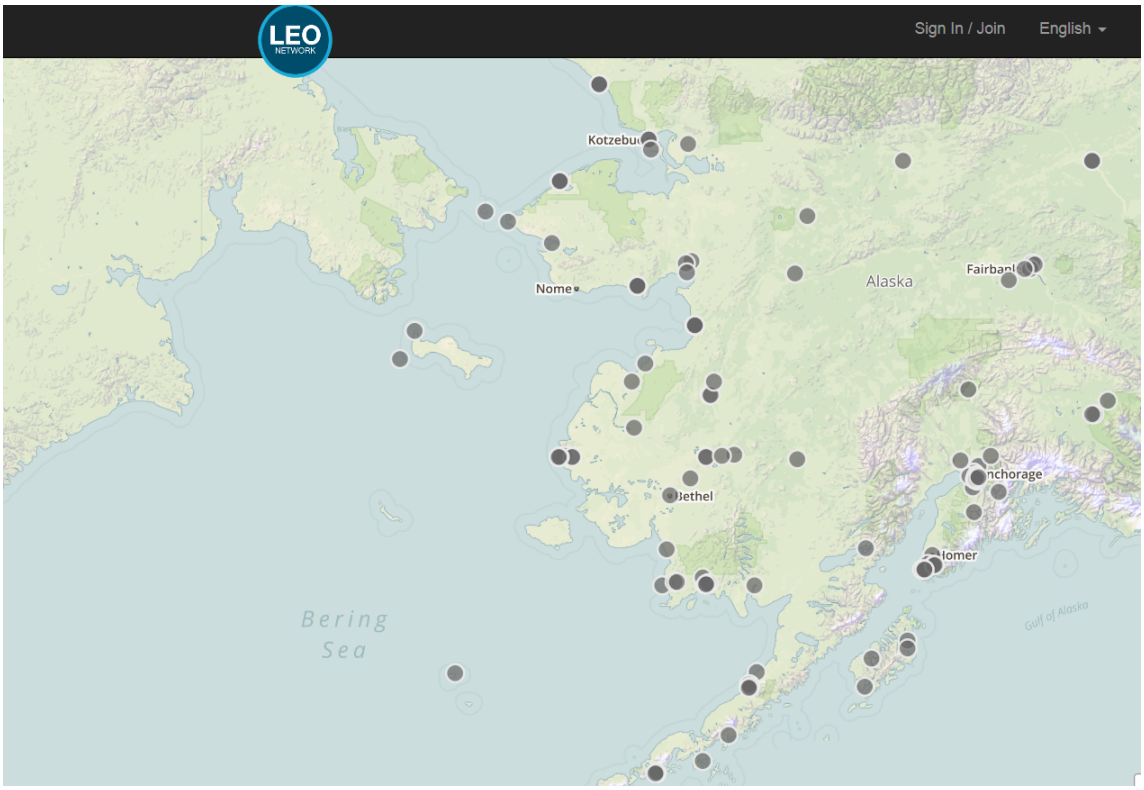

Figure 11: LEO Network observations in Alaska for 2017 and 2018 (through August 1st). Source: `https://www.leonetwork.org`.

Figure 12 shows LEO Network observations from January 1, 2017 to August 1, 2018 in the northern Bering Sea (NBS) LME with the frequency by category. These categories are based on analysis of the 38 total observations in 2017 and 2018 (through August 1st) in the NBS and are not limited to the marine environment. The observations in Figure 12 were made in 16 total communities.

Similarly to Figure 12, Figure 13 shows LEO Network observations from January 1, 2017 to August 1, 2018 in the Eastern Bering Sea (EBS) LME with the frequency by category. There were 27 total observations in

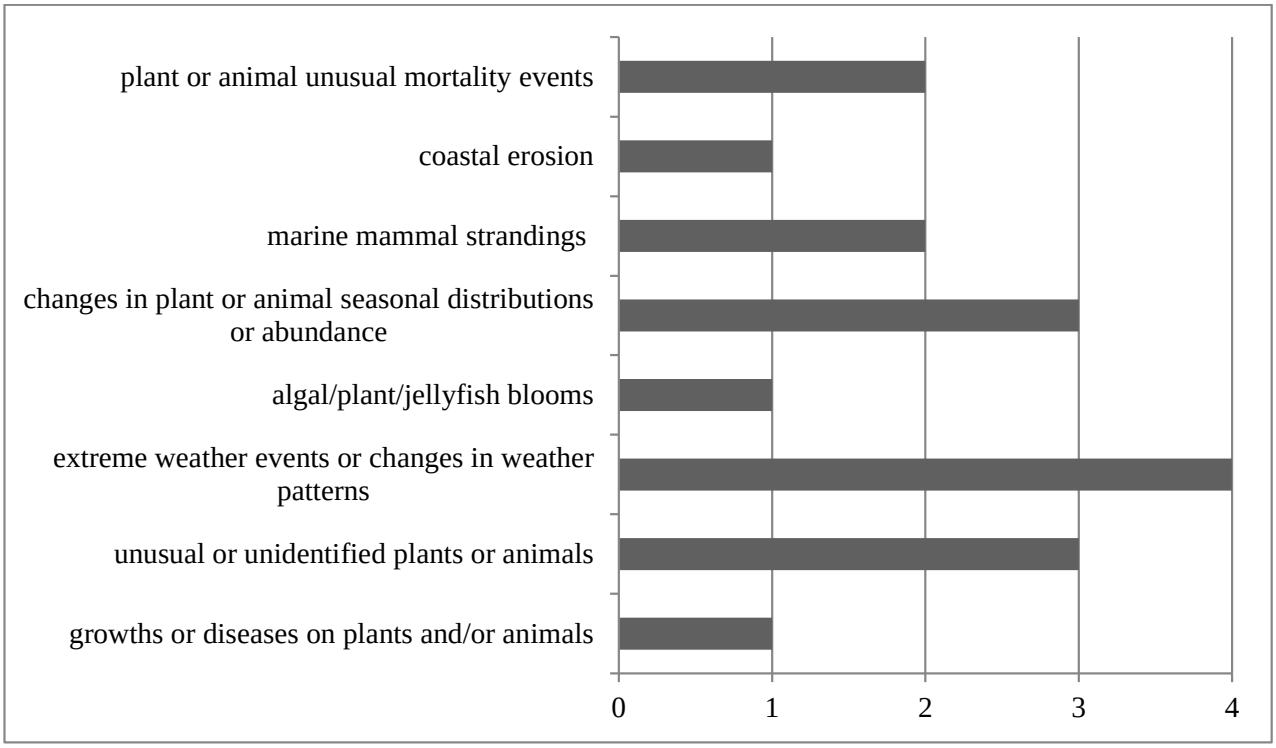

Figure 12: Distribution of 2017 and 2018 (through August 1st) LEO Network observations in NBS communities.

12 communities over this time period in the EBS.

In response to the Council's and SSC's previous comments on the use of LEO Network observations in this report, AFSC is currently developing a LEO Network project to solicit observations from community members on specific ecological questions. Alaska State agencies, non-profit organizations, universities, and U.S. federal agencies have similarly developed projects on the network to track observations specific to their area of interest, e.g., weather events, fish pathology, subsistence harvests, etc. AFSC is also actively pursuing opportunities to examine ways of incorporating local and traditional knowledge into fisheries management in the North Pacific with the Council's Bering Sea Fishery Ecosystem Plan, Social Science Planning Team, and through targeted research efforts.

Contributed by Marysia Szymkowiak

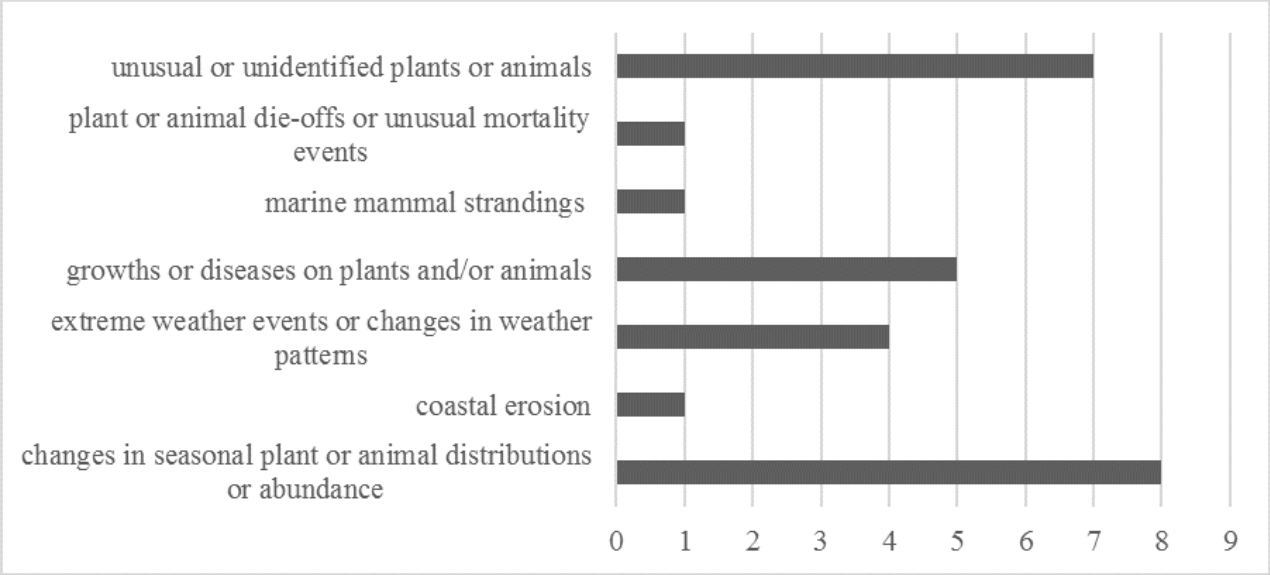

Figure 13: Distribution of 2017 and 2018 (through August 1st) LEO Network Observations in EBS communities.

Ecosystem Status Indicators

Indicators presented in this section are intended to provide detailed information and updates on the status and trends of ecosystem components. Older contributions that have not been updated are excluded from this edition of the report. Please see archived versions available at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Physical Environment

North Pacific Climate Overview

Contributed by Nick Bond (UW/JISAO)
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Contact: nicholas.bond@noaa.gov
Last updated: August 2018

Summary: *The state of the North Pacific atmosphere-ocean system during 2017-2018 was rather similar to that during 2016-17. Both winters featured La Niña and weaker than normal Aleutian lows (positive sea level pressure, SLP anomalies). The more prominent sea surface temperature (SST) anomalies during 2017-18 tended to be in the positive sense, with persistent warmth in the subtropical eastern North Pacific, increasing positive anomalies in the Bering Sea, and the expansion of warm waters off the east coast of Asia. The Pacific Decadal Oscillation (PDO) was slightly positive during the past year, with a decline to near zero in the summer of 2018. The climate models used for seasonal weather predictions are indicating about a 70% chance of a weak-moderate El Niño for the winter of 2018-19, and warmer than normal SSTs in both the western and eastern mid-latitude North Pacific in early 2019.*

Regional Highlights:

Alaska Peninsula and Aleutian Islands. The weather of this region included suppressed storminess during the fall of 2017 and the following winter of 2017/18. The regional wind anomalies were from the southwest in an overall sense. Based on synthetic data from NOAAs Global Ocean Data Assimilation System (GODAS), the Alaska Stream appears to have been relatively diffuse, as opposed to concentrated into a narrower, high velocity flow, on the south side of the eastern Aleutian Islands. The eddy activity in this region was on the low side (see Aleutian Islands Ecosystem Status Report).

Bering Sea. The Bering Sea had the least amount of sea ice in the observational record back to 1979. This can be attributed to the delayed start of winter (Being Strait was still open on 1 January) and then very mild temperatures with strong winds from the southwest, particularly in February 2018. An important consequence was a cold pool in summer 2018 of exceedingly small areal extent. The weather during summer 2018 was stormier than usual on the southeast Bering Sea shelf; at the time of this writing it is unknown if those conditions helped sustain primary production later into the warm season than usual. In the region of the M2 mooring the thermal stratification during summer 2018 was somewhat less than observed during recent years; the vertically integrated heat content was the second greatest on record, topped by 2016.

Arctic. The winter of 2017/18 was relatively warm in the Arctic, and included an extreme "heat wave" (for the season) in the central Arctic during February. The Arctic's maximum ice extent in mid-March 2018 was the 2nd lowest on record. On the other hand, the decline in sea ice coverage during the late spring and early summer of 2018 was on the slow side, primarily in association with relatively low SLP in the central Arctic and cool and cloudy weather. The west winds accompanying this circulation pattern helped maintain a wide band of ice near the coast east of Pt. Barrow. Relatively rapid losses in sea ice concentrations and coverage occurred here in late July 2018. The edge of the pack ice in the Chukchi Sea was well north of its usual

position during the summer of 2018. At the time of this writing, it appears that the minimum ice extent for the Arctic as a whole will be well below of climatological norms, but more akin to the years of 2013 and 2014 rather than the extreme minimum ice cover year of 2012.

Sea Surface Temperature and Sea Level Pressure Anomalies

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Contact: nicholas.bond@noaa.gov
Last updated: September 2018

Description of indices: The state of the North Pacific climate from autumn 2017 through summer 2018 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981–2010. The SST data are from NOAA's Optimum Interpolation Sea Surface Temperature (OISST) analysis; the SLP data are from the NCEP/NCAR Reanalysis project. Both data sets are made available by NOAA's Earth System Research Laboratory (ESRL) at `http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl`.

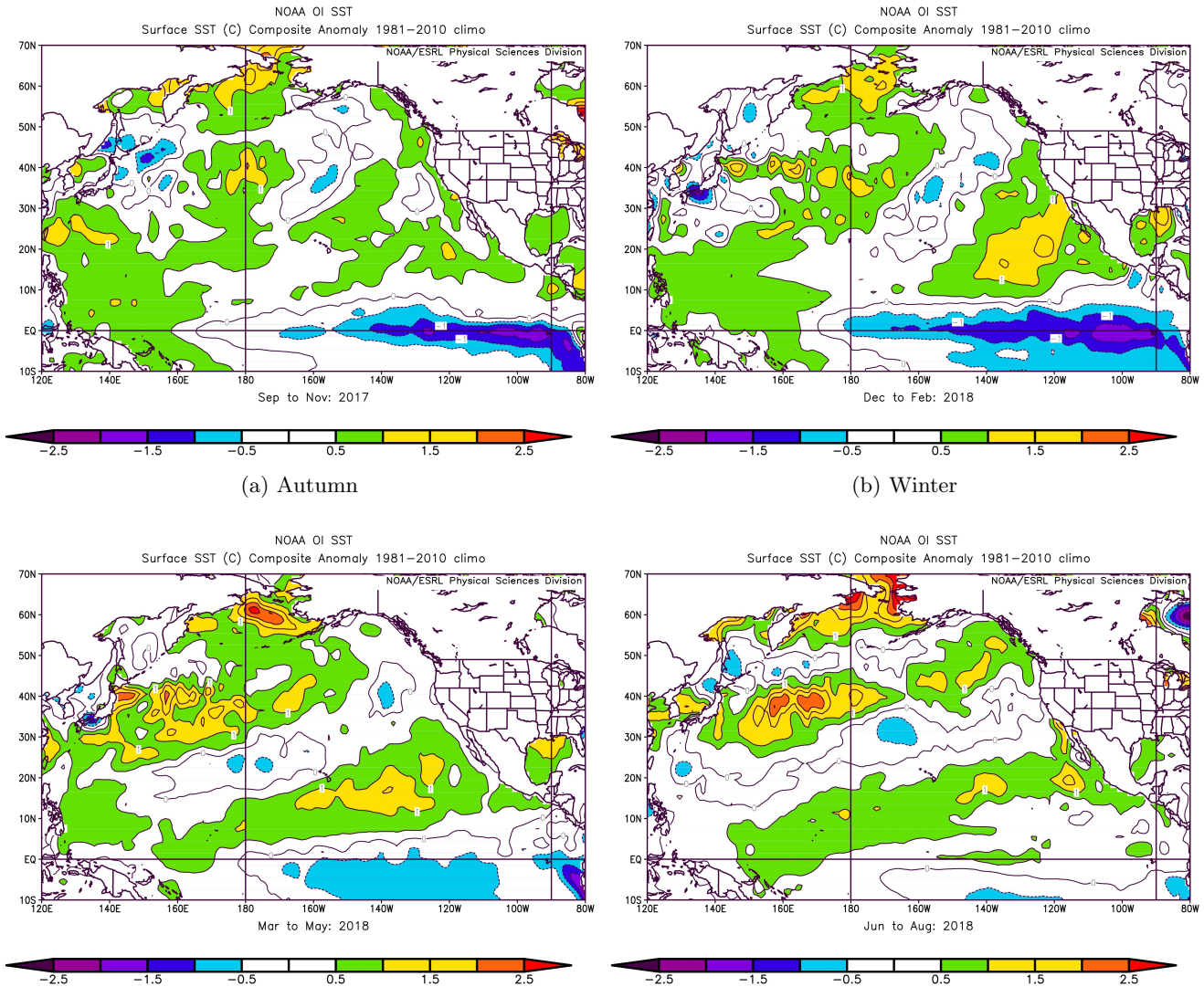
Status and trends: The eastern portion of the North Pacific ocean experienced during 2014–16 one of the most extreme marine heat waves in the observational record (Scannell et al., 2016); the interval summarized here can be considered a transition period between that event and a more climatologically normal SST distribution on the basin-scale. More detail on the evolution of the SST and SLP from a seasonal perspective is provided directly below.

The SST during the autumn (Sep–Nov) of 2017 (Figure 14a) was warmer than normal across almost the entire North Pacific Ocean. Greater positive ($> 1^{o}$C) anomalies occurred in the Chukchi Sea and northwest Bering Sea in the northern and eastern Bering Sea, resulting in a delayed onset of sea ice the following winter. The SST anomalies were negative in the eastern equatorial Pacific in association with the development of La Niña. The SLP pattern during autumn 2017 featured prominent positive anomalies over the north central portion of the North Pacific Ocean, with the greatest departures from normal over the open ocean south of the western tip of the Alaska Peninsula (Figure 15a). This SLP distribution implies an enhanced storm track along the east coast of Asia, and suppressed storminess from the Aleutians into the Gulf of Alaska (GOA).

The North Pacific atmosphere-ocean system during winter (Dec–Feb) of 2017-18 reflected to large extent a continuation of the previous fall season. The distribution of SST anomalies (Figure 14b) was quite similar, with some additional warming in the subtropical northeastern Pacific extending southwestward from southern California. The equatorial Pacific was characterized by weak/moderate La Niña conditions with the strongest negative SST anomalies well east of the dateline. The SLP during this period (Figure 15b) featured an expansion of the pattern of the season before in terms of both magnitude and area, with substantial positive anomalies from about 160°E to western North America north of about 30°N. This relatively high SLP in combination with negative SLP anomalies over the East Siberian Sea resulted in a pressure pattern that supported extremely strong wind anomalies ($\sim$3 to 4 m s^{-1}) from the southwest across the Bering Sea.

The distribution of anomalous SST in the North Pacific during spring (Mar–May) of 2018 (Figure 14c) was similar to that during the previous winter season. Exceptions were warming relative to seasonal normal in the eastern Bering Sea and in an east-west band from 25° to 40°N from Japan to the dateline. The SST anomalies in the tropical Pacific were of minor amplitude with the ending of La Niña. The SLP anomaly pattern (Figure 15c) for spring 2018 featured bands of lower than normal pressure from eastern Siberia to northwestern Alaska and higher pressure from south of the Aleutian Islands to the GOA, resulting in another season of warm, southwesterly flow anomalies across the Bering Sea. The atmospheric circulation in the northeast Pacific promoted relatively upwelling-favorable winds in the coastal GOA.

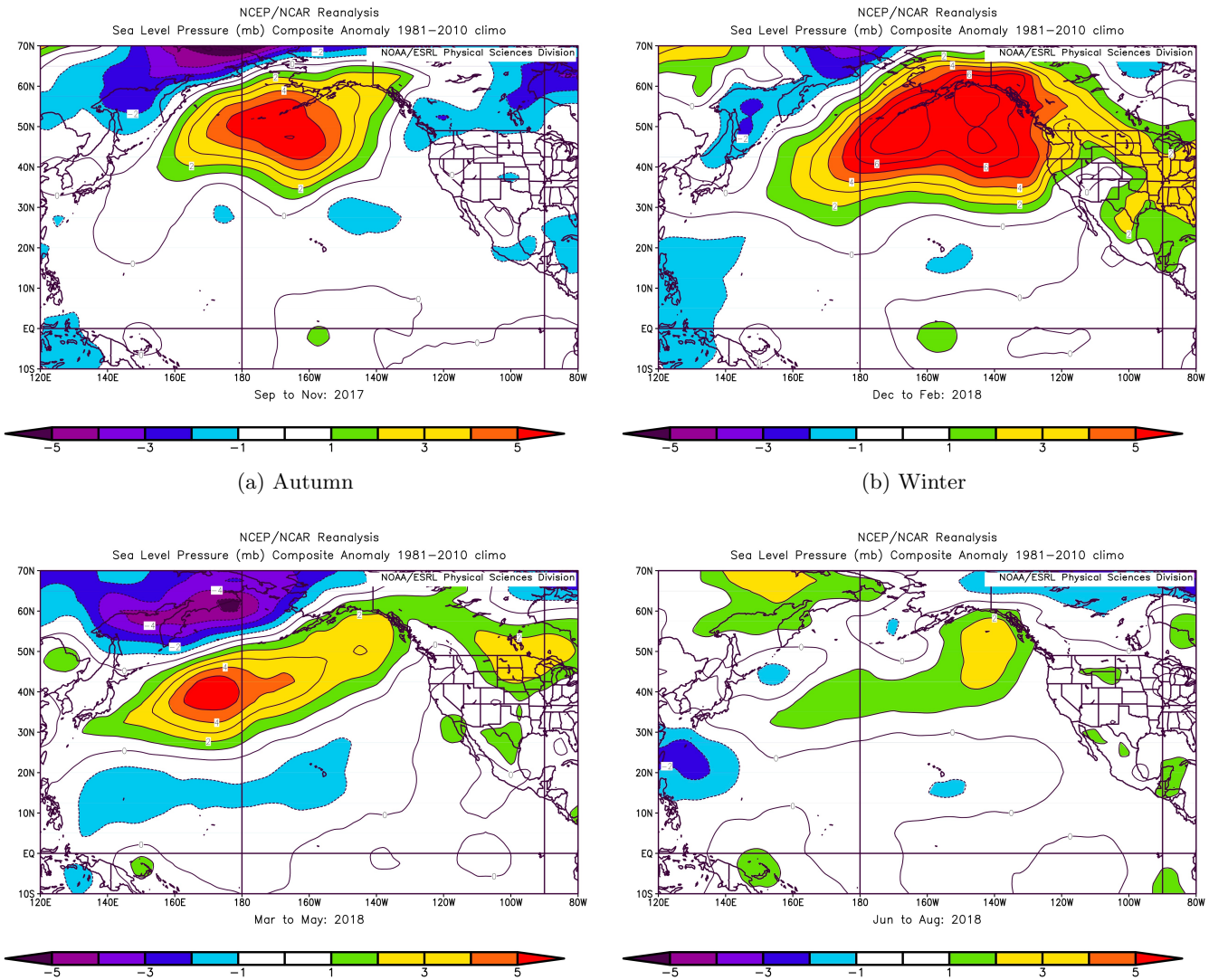
The SST anomaly pattern in the North Pacific during summer (Jun–Aug) 2018 is shown in Figure 14d. Positive anomalies continued in a broad band extending from Japan to the southeastern GOA and from the northern Bering Sea into the Chukchi Sea. In the latter area, particularly strong positive temperature anomalies (exceeding 2°C) developed in the vicinity of Bering Strait. Near normal SSTs were present along most of the west coast of North America from Vancouver Island to southern California. Warmth continued in the subtropical eastern North Pacific from Baja California to the equatorial Pacific east of the dateline, where temperatures were roughly 0.5°C above normal. The distribution of anomalous SLP (Figure 15d) during summer 2018 included mostly just weak anomalies, which is typical for the season. A band of higher than normal pressure extended from the western North Pacific north of about 30°N into the GOA. Lower pressure extended from northwestern Canada across interior Alaska into the Bering Sea.



(a) Autumn (b) Winter

(c) Spring (d) Summer

Figure 14: SST anomolies for autumn (September–November 2017), winter (December 2017–February 2018), spring (March–May 2018), and summer (June–August 2018).



(a) Autumn

(b) Winter

(c) Spring

(d) Summer

Figure 15: SLP anomolies for autumn (September–November 2017), winter (December 2017–February 2018), spring (March–May 2018), and summer (June–August 2018).

Climate Indices

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Last updated: September 2018

Description of indices: Climate indices provide an alternative means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, Pacific Decadal Oscillation (PDO) index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO), and Arctic Oscillation (AO). The time series of these indices from 2008 into spring/summer 2018 are plotted in Figure 16.

Status and trends: The North Pacific atmosphere-ocean climate system was mostly on the warm side during 2017–18. This was despite the second fall/winter in a row with a negative value for the NINO3.4 index in association with a weak/moderate La Niña event. The positive state of the PDO (indicating warmer than normal SST along the west coast of North America and cooler than normal in the central and western North Pacific) that began in early 2014 ended in 2017. This decline is consistent with the typical remote effects of ENSO, and in particular the transition from a strong El Niño in 2015–16 to the following two episodes of La Niña. The SST anomaly distribution during spring and summer of 2018 has a minimal projection on the characteristic pattern of the PDO. The NPI was strongly positive from fall 2017 into 2018 due to the relatively high SLP in the region of the Aleutian low. A positive sense for the NPI commonly accompanies La Niña, its magnitude from late 2017 into 2018 was greater than might be expected.

The NPGO became strongly negative in 2017, and stayed negative into 2018 (February is the latest month for which this index is available). This index has undergone an overall decline from positive values during the period of 2008 to 2012. The AO represents a measure of the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the Pacific and Atlantic Ocean at a latitude of roughly 45°N. It was in a near-neutral state during the last half of 2017 with a transition to a positive state in spring 2018 that has continued into summer. A consequence has been relatively low pressure in the Arctic during early summer.

Seasonal Projections from the National Multi-Model Ensemble (NMME)

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Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figures 17. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.

Status and trends: First, the projections from a year ago are reviewed qualitatively. From an overall perspective, the SST forecasts were essentially correct with respect to their basin-scale patterns of negative and positive SST anomalies. The NMME forecasts included an under-prediction of the magnitudes of some of the more prominent anomalies. In particular, Alaskan waters generally ended up warmer than forecast,

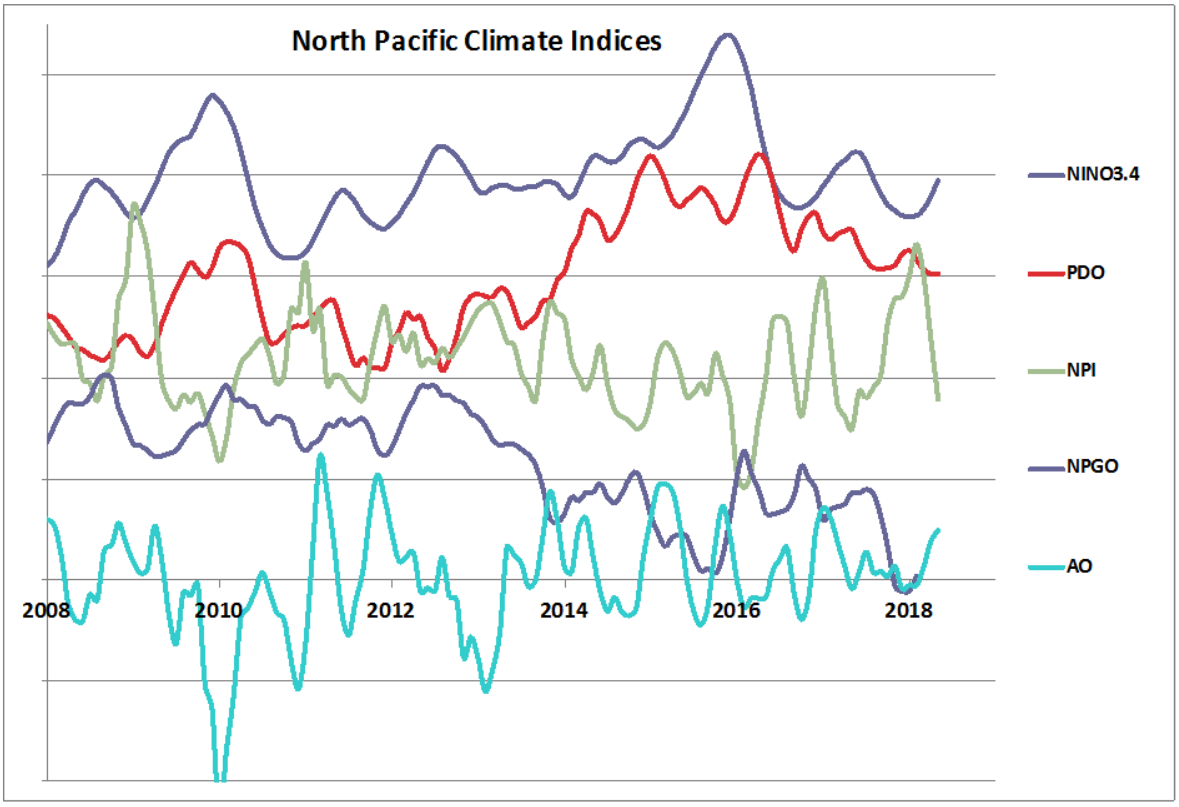


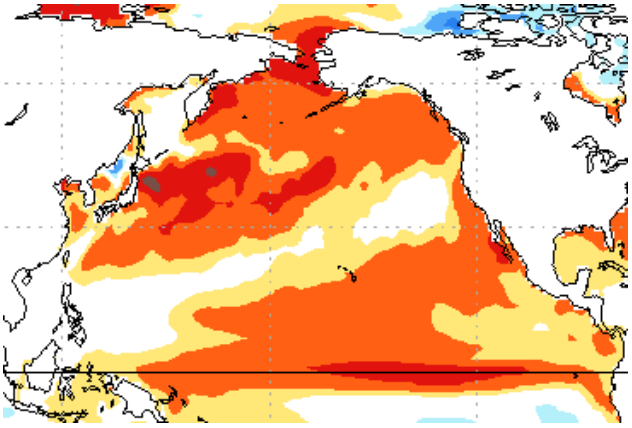
Figure 16: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices for 2008–2018. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Earth Systems Laboratory at `http://www.esrl.noaa.gov/psd/data/climateindices/`.

especially the Bering Sea shelf during late winter and early spring 2018 where there was much less sea ice than suggested by the model forecasts made during September 2017.

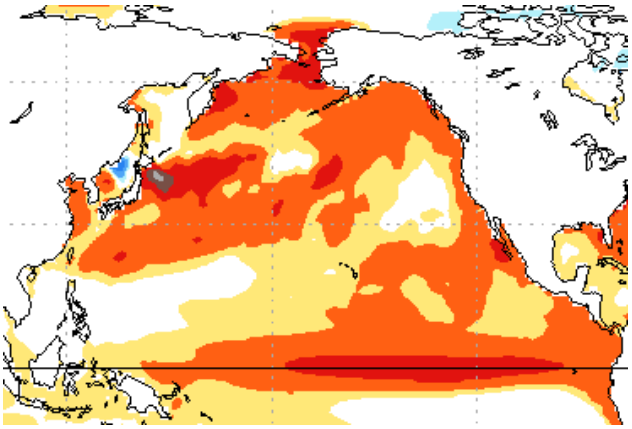
These NMME forecasts of three-month average SST anomalies indicate a continuation of warm conditions across virtually all of the North Pacific through the end of the year (Oct–Dec 2018) with a reduction in the longitudinal extent of cooler than normal temperatures offshore of the Pacific Northwest (Figure 17a). The magnitude of the positive anomalies is projected to be greatest (exceeding 1°C) north of the Kuroshio Extension in the western North Pacific and in the northern portion of the Bering Sea. Positive SST anomalies are projected in the central and eastern equatorial Pacific. The ensemble model average is strong enough to constitute El Niño of weak to moderate magnitude. As of early September 2018, the probabilistic forecast provided by NOAA's Climate Prediction Center (CPC) in collaboration with the International Research Institute for Climate and Society (IRI) for the upcoming fall through winter indicates about a 70% chance of

El Niño, and otherwise equatorial SSTs in the neutral category. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2018–February 2019 (Figure 17b) and February–April 2019 (Figure 17c). There is moderate but by no means a complete consensus among the models that the Aleutian low will be deeper than normal (negative SLP anomalies) during the latter portion of the winter of 2018–2019. This is a common remote response to El Niño, and tends to result in relatively warm late winter and early spring weather for Alaska that is liable to be enhanced by the effects of the warmth of the waters surrounding Alaska. For the period of February–April 2019, the models are projecting little noticeable decline in the magnitude of the equatorial Pacific temperature anomalies even though El Niño often weakens during the boreal spring. The positive SST anomalies along the west coast of North America that are indicated in Figure 17c commonly occur after El Niño winters.

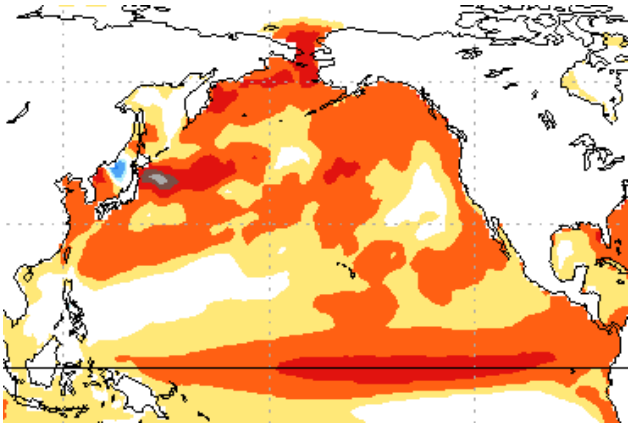
Implications: The PDO has also generally been positive during these kinds of periods in the past, but the predicted warmth in both the western and eastern portions of the mid-latitude North Pacific does not resemble the characteristic pattern of the PDO. An important implication is that the PDO is liable to be ill-suited for characterizing the state of the North Pacific in early 2019.



(a) Months OND



(b) Months DJF



(c) Months FMA

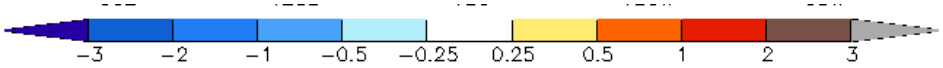


Figure 17: Predicted SST anomalies from the NMME model for OND (1 month lead), DJF (3 month lead), and JFM (4 month lead) for the 2017–2018 season.

Eastern Bering Sea Climate - FOCI

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Last updated: October 2018

Summary. After 3 consecutive warm years (2014–2016), followed by moderate climate conditions over the eastern Bering Sea in 2017, anomalously warm conditions returned in 2018. For example, air temperatures in the northern Bering Sea experienced > +5°C anomalies January through April 2018. Several climatic forces occurred that resulted in the warm conditions: (i) residual heat maintained above-average water temperatures that caused delayed freeze-up (e.g., the Chukchi remained ice-free into December 2017), (ii) a large and persistent high pressure system from February through April over the Aleutian Islands and southern Bering Sea, which shifted the position of the Aleutian Low Pressure System (ALPS) northwest over Siberia, and (iii) highly unusual winds from the southwest that brought warm air over the Bering Sea and prevented sea ice from forming. The southern Bering Sea shelf experienced conditions typical of above-average temperature years, while the northern Bering Sea experienced an unprecedented near-complete lack of sea ice.

Air temperatures Slightly positive near surface air temperature anomalies occurred over the southeastern Bering Sea shelf (+ 1-3°C) during spring (January–April) 2018, while strongly positive temperature anomalies persisted over the northern Bering Sea (+ 6-8°C) (Figure 18 top). By summer, temperature anomalies over the southeastern shelf were 0-+1°C while over the northern shelf, temperature anomalies subsided to 1-2°C (Figure 18 bottom). Continued warm conditions are predicted based on the PDO pattern.

Sea level pressure patterns showed weak gradients over the eastern Bering Sea during June–August, indicating weak winds following the contours of geopotential heights (Figure 19). Gradients in sea level pressure parallel the Alaska Peninsula, with increasing pressures to the east and into the central Gulf of Alaska. This high pressure system resulted in above-average warm temperatures and dry conditions over much of Alaska during summer 2018. Long-term surface air temperatures measured on St. Paul Island (Figure 20) also reflect the recent years' continued warm anomalies. The St. Paul temperature anomalies have been on the positive side since April 2014 for every single month. In 2018, four new records were set for the warmest temperature anomalies since 1980: February, March, April, and May 2018.

Sea ice. Seasonal sea ice is a defining characteristic of the Bering Sea shelf. The presence of sea ice influences the timing of the spring bloom and bottom temperatures throughout the year. Over the time series, years with less sea-ice coverage occurred in 2001–2005 and 2014–2016, and years with more extensive sea ice coverage occurred in 2007–2013 (excluding 2011). Moderated conditions in 2017 resulted in a more southerly extent of sea ice over the Bering Sea shelf (more similar to 2006, although a narrow cold pool). Note the unusual feature of the 2017 and 2018 sea ice boundary retreating into the Gulf of Anadyr (Figure 21).

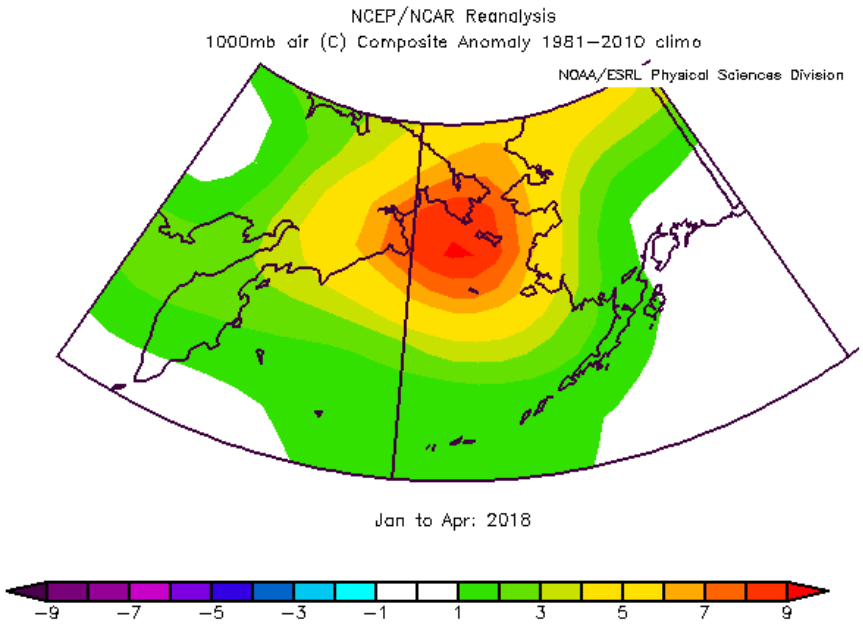
For the ice season 2017–2018, significant amounts of sea ice did not arrive in the Bering Sea until December (Figure 22). The areal extent largely increased until early February, when winds shifted and the northern Bering Sea was impacted by strong, warm southerly winds. These winds persisted until approximately 10 March 2018. Wind direction then reversed and the system was dominated by cold northerly winds for approximately one month. These winds forced the ice southward, but water conditions were particularly warm (>1°C) and limited the advance of sea ice. Maximum ice extent occurred in mid-March. The maximum areal ice extent was approximately half of the historical mean and sea ice was limited to the eastern shelf (Figure 21). For the first time in the satellite era, sea ice did not reach St. Matthew Island at any point during the winter. This is the lowest maximum ice extent in the satellite era. Without the cooling effect of melting sea ice, the ocean temperatures remained well above freezing, even on the northern shelf.

Predictions for winter 2018–2019 include late ice arrival in the Bering Sea, similar to what occurred in 2017.

However, the extreme low ice that occurred in 2018 was equally a result of the strong southerly winds in February and early March. While such wind conditions could happen again in 2019, it is not expected. Historically, the mean wind direction during the winter contains a southward (i.e., winds out of the north) component.

Ocean temperatures. The cold pool (Figure 23), defined by bottom temperatures <2°C, influences not only near-bottom biological habitat, but also the overall thermal stratification and ultimately the mixing of nutrient-rich water from depth into the euphotic zone during summer. The cold pool extent for summer 2018 was nearly non-existent, reflecting the very low sea ice extent.

Depth-averaged temperatures. Moorings have been deployed at the M2 site (56.9°N, 164.05°W) since 1995. The depth-averaged temperatures show the annual range (Figure 24), with maximum temperatures occurring in September and minimum temperatures occurring in winter months. The Bering Sea has had periods of years with low ice extent resulting in warm ocean conditions (2001–2005) and extensive ice/cold ocean conditions (2007–2013). More recently, 2014–2016 were warm years with low ice extent. 2017 had more extensive ice that resulted in average water temperatures. Even though 2018 was the lowest ice extent on record, the depth-averaged temperatures at M2 were only second warmest on record. The warmest temperatures occurred in 2016, which followed the warmest (at that time) year on record.



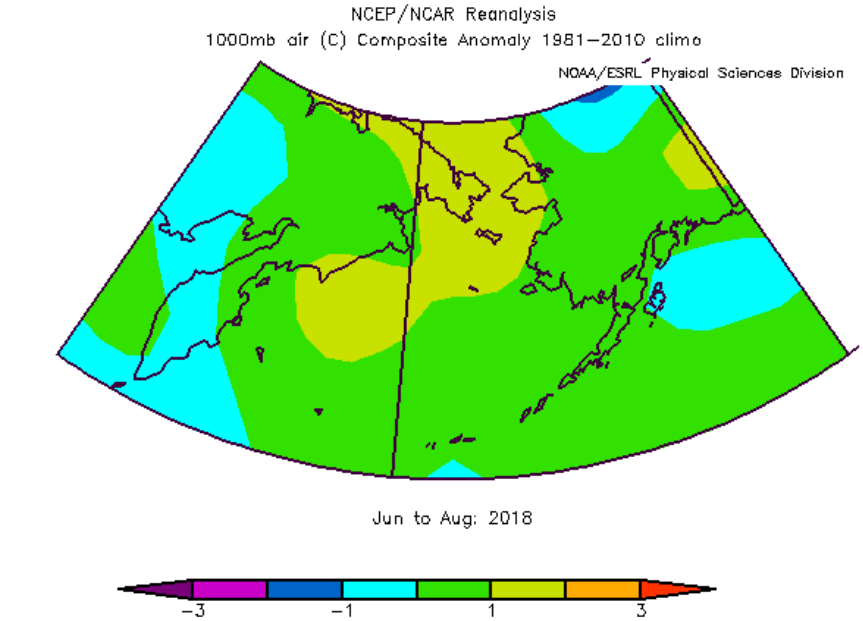


Figure 18: Near surface positive air temperature anomalies over the southeastern Bering Sea for January–April (top) and June–August (bottom) 2018.

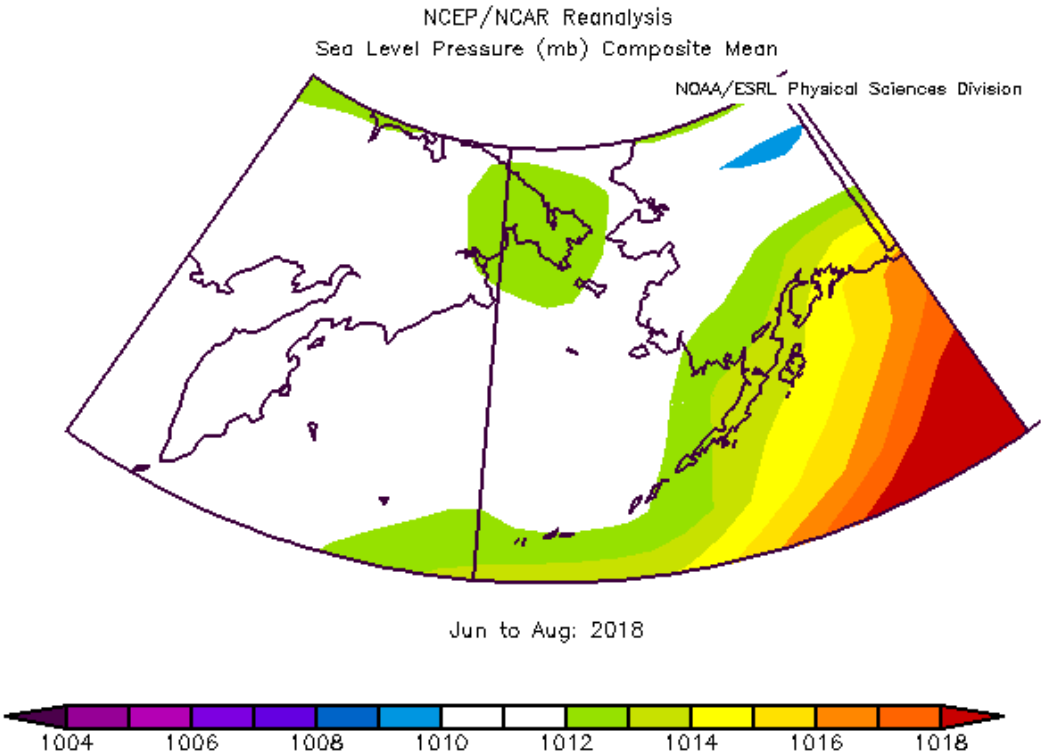


Figure 19: Moderate positive sea level pressure anomaly over the greater Bering Sea for June–August 2018.

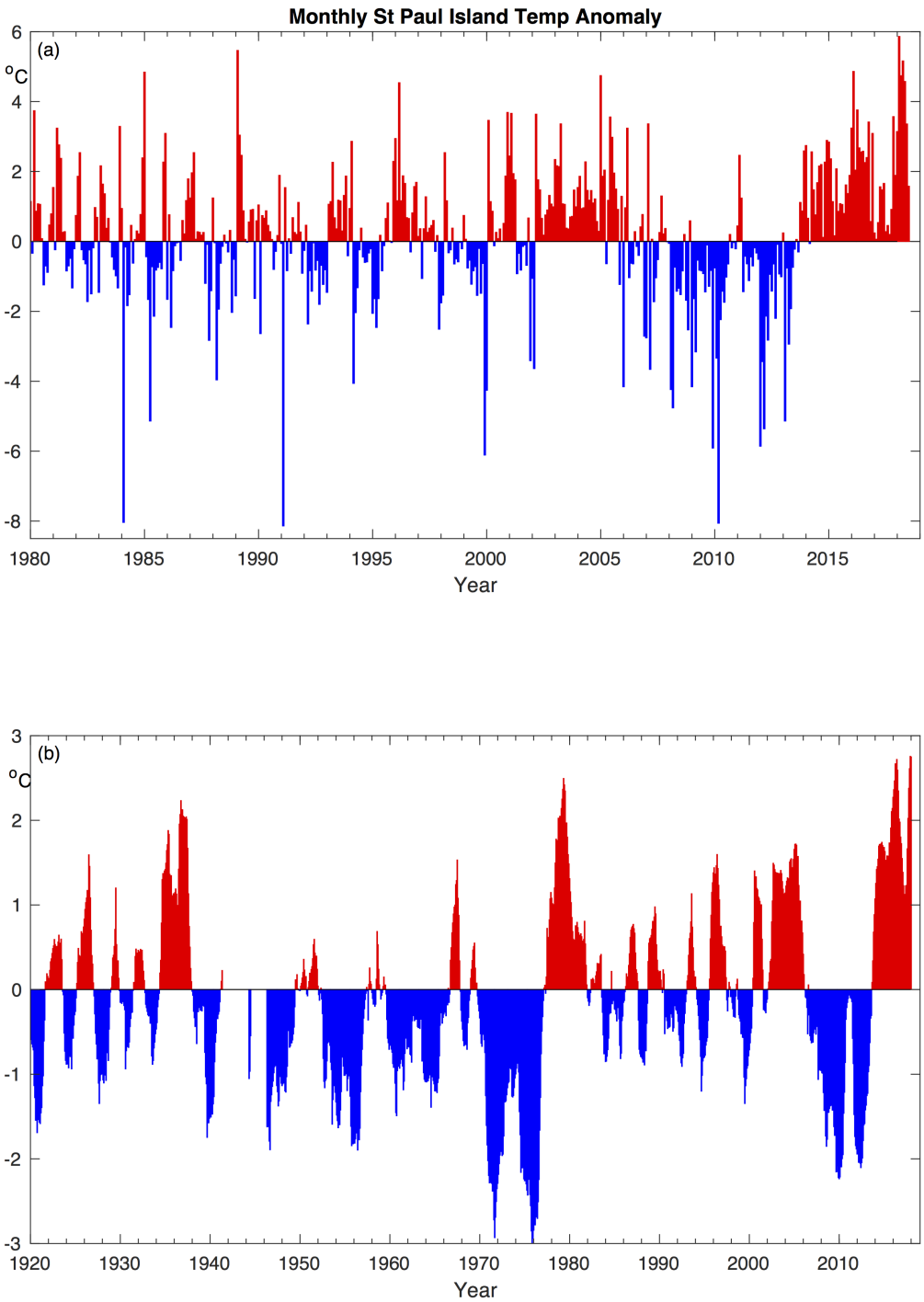


Figure 20: Mean monthly surface air temperatures anomalies at St. Paul (Pribilof Islands). (a) Unsmoothed 1980–2018 and (b) smoothed by 13-month running averages, January 1920 through August 2018. The base period for calculating anomalies is 1981–2010.

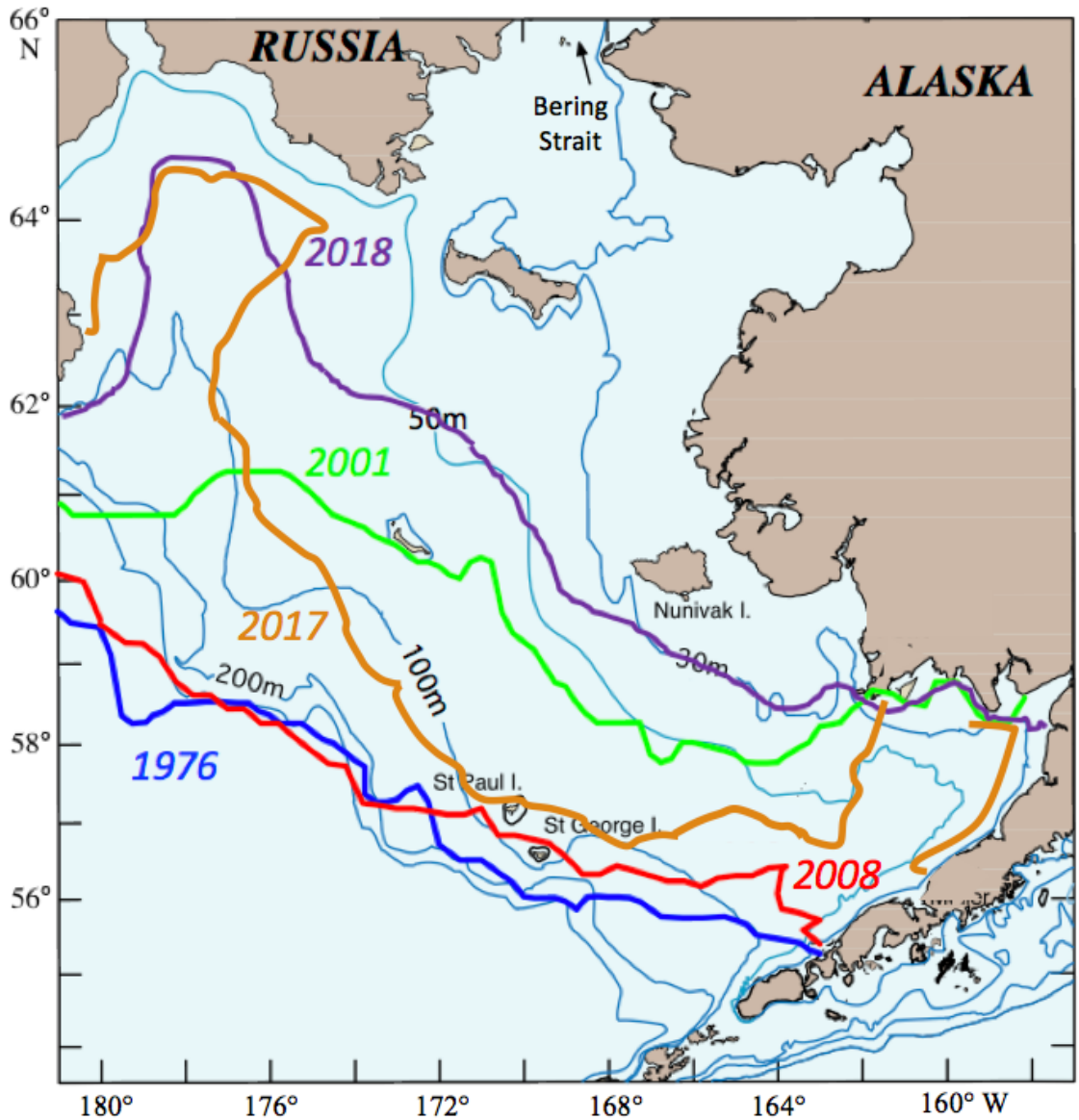


Figure 21: Maximum sea-ice extent for 2018 (purple) and for selected other years in the southeastern Bering Sea.

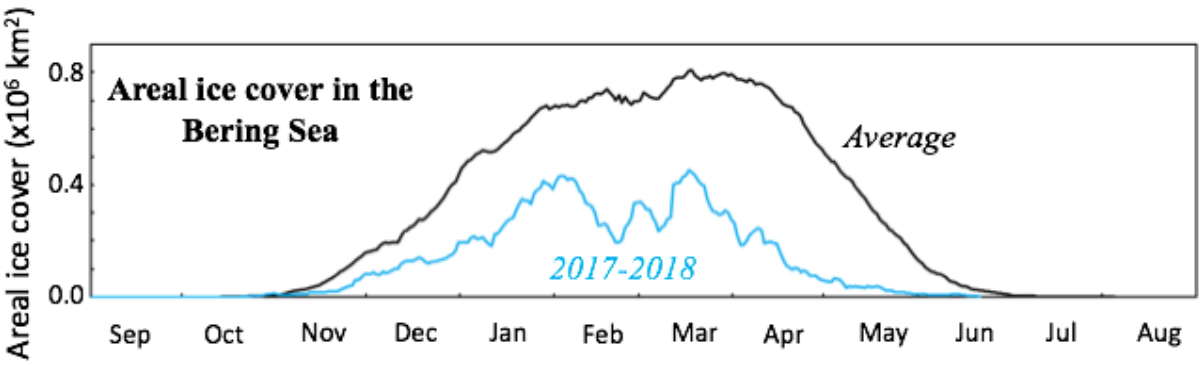


Figure 22: Areal sea-ice extent in the Bering Sea for 2017–2018. Data are from Multisensor Analyzed Sea Ice Extent–Northern Hemisphere (ASIE-NH; `https://nsidc.org/data/masie`). The black line is the long-term mean.

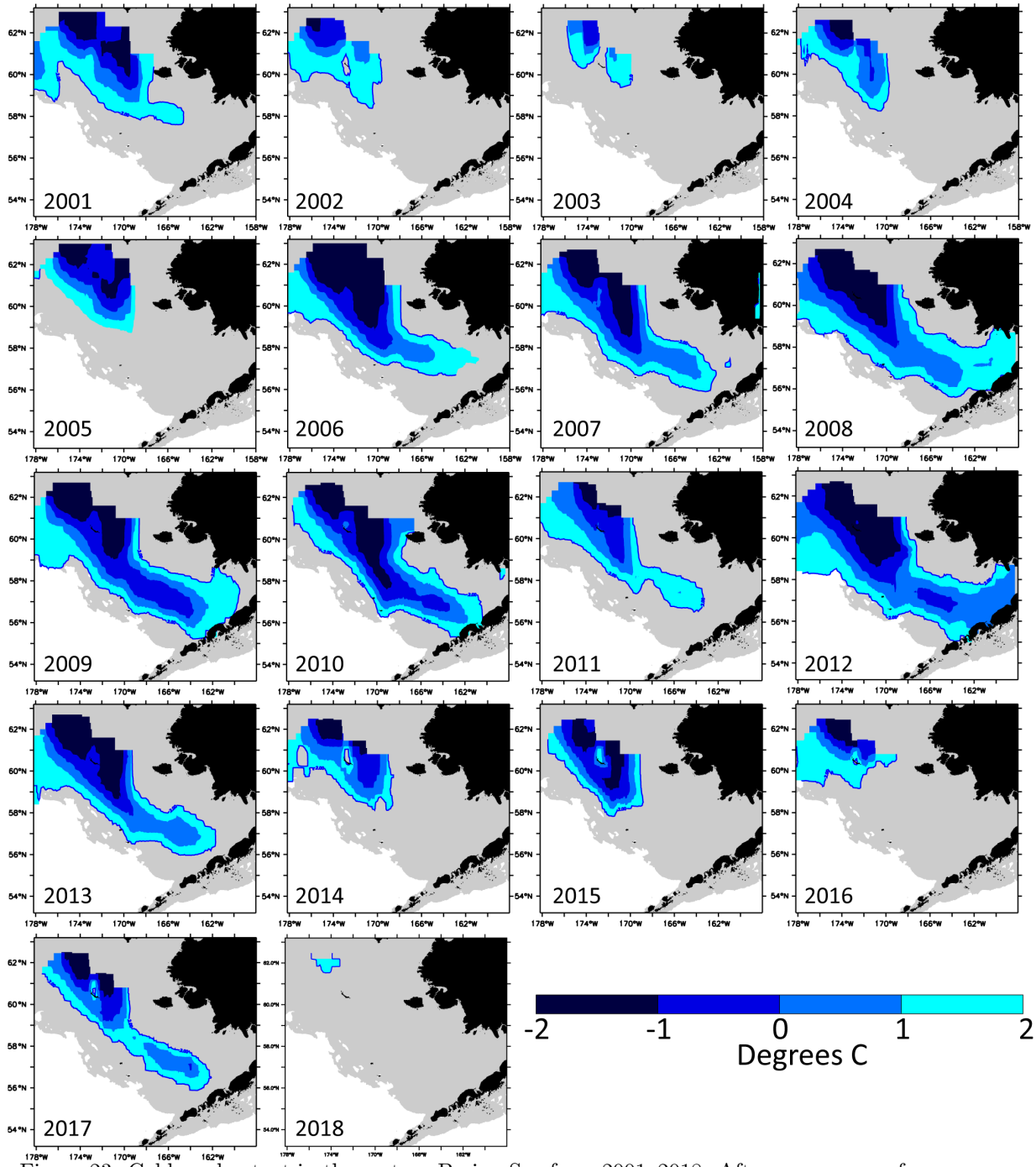


Figure 23: Cold pool extent in the eastern Bering Sea from 2001–2018. After a sequence of warm years from 2014–2016, moderate thermal conditions and a more extensive cold pool occurred in 2017. In 2018, the cold pool was nearly non-existent.

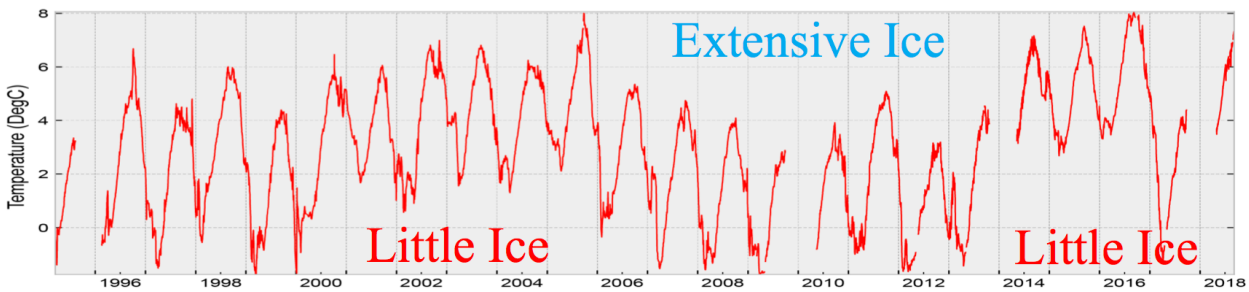


Figure 24: Depth-averaged temperature at M2 mooring. Note warm years of 2001–2005, cold years of 2007–2013, and warm years of 2014–2016 and 2018.

Satellite-derived Sea Surface Temperatures for Alaska Fishery Management Areas in the Bering Sea

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Last updated: October 2018

Description of indicator: Sea surface temperature (SST) is often used to explore relationships between commercial fisheries and environmental dynamics. During interpretation of fishery and ecological data, the question often arises, "Was it a cold year or a warm year?" Using satellite data, this ecosystem indicator provides a transparent and simple method by which to evaluate sea surface temperature anomalies across spatial scales that are not limited to the location of a single buoy or data collected during seasonal surveys.

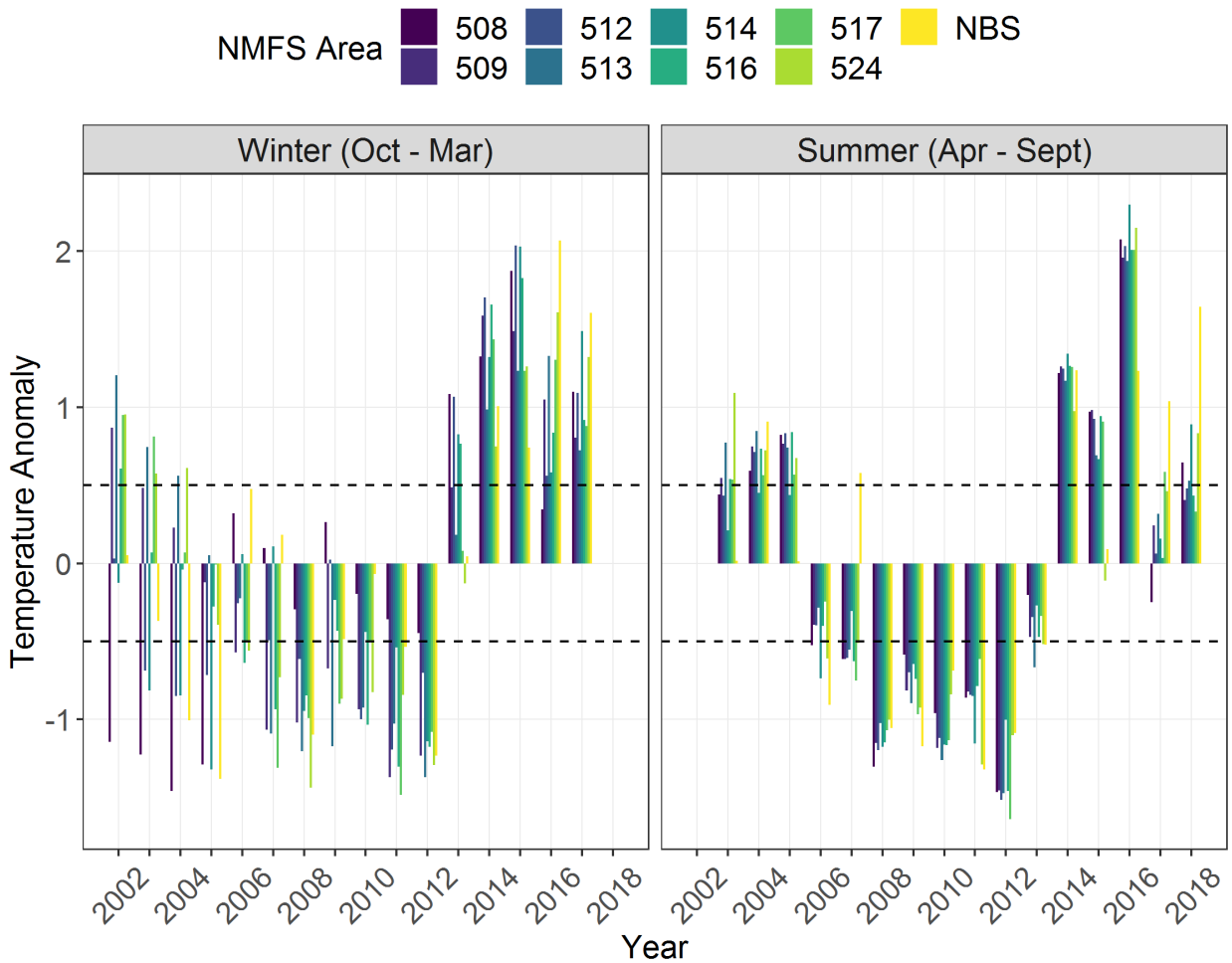

Figure 25: Seasonal sea surface temperature anomalies by NMFS area for the Bering Sea. Data were unavailable for summer 2002 and winter 2018, so these portions of their respective figures are omitted.

A common limitation of SST records derived from satellites has been missing data as a result of cloud cover. Using the NASA multi-scale ultra-high resolution (MUR) SST dataset however, a combination of collection modalities creates a gap-free blend of data (`https://mur.jpl.nasa.gov/InformationText.php`). Data are available at the daily level for the North Pacific from mid–2002 to present and can be downloaded from the

NOAA Coast Watch West Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/`) where they are searchable as "Multi-scale ultra-high resolution (MUR) SST Analysis fv04.1, Global, 0.01°, 2002–present, daily." More than 24 billion individual daily temperature records were downloaded (October 1, 2002–September 30, 2018) and the data were averaged daily by Alaska Department of Fish and Game (ADF&G) groundfish statistical areas (also called stat6 areas; `www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByFishery.statmaps`), yielding about 10 million temperature records (a daily record for each of the 1,736 statistical areas). More detailed methods are available online (`github.com/jordanwatson/ERDDAP`).

As an ecosystem indicator for the Bering Sea, the daily average temperatures were calculated by month for the statistical areas falling within each of the NMFS areas (`https://alaskafisheries.noaa.gov/maps`) in the eastern and northern Bering Sea and anomalies were calculated (Figure 25). Monthly anomalies were aggregated by winter (October–March) and summer (April–September). In Figure 25, winter 2002 refers to October–December 2002 and January–March 2003. Horizontal dashed lines in Figure 25 are provided as a reference.

Status and trends: The satellite derived time series of summer sea surface temperatures demonstrates a general spatial coherence across NMFS areas and years. During winter, there was a greater degree of spatial variability in temperature anomalies in the earlier years (when summer temperatures were anomalously warm) with some NMFS areas demonstrating negative anomalies and others revealing positive anomalies. Most notable perhaps is the sustained positive anomalies in northern Bering Sea temperatures during both summer and winter for the last several years, including the warmest summer of the time series in 2018.

Factors influencing observed trends: The trends illustrated here are consistent with generally accepted warm and cold year anomalies for the eastern Bering Sea. The NMFS areas (e.g., 508, 512, 514) with negative anomalies during the otherwise warm early years of the time series include nearshore waters that may be more heavily influenced by cold terrestrial temperatures during the winter, accounting for some of the disparity between these areas and the other NMFS areas.

Implications: The importance of these observations lies with extensive Bering Sea research focused on understanding how warm or cold stanzas may affect Bering Sea prey quality, predator-prey dynamics, northward range shifts of commercial species, and the responses of fishers themselves. This sea surface temperature contribution provides context for further examining bottom-up dynamics within the Bering Sea ecosystem.

For researchers that study fishery effects directly, the daily SST data described here are being linked to fish ticket data in AKFIN so that landings information will be explicitly associated with the temperature of the ADF&G statistical areas in which the fish were reported to have been caught.

Summer Bottom and Surface Temperatures - Eastern Bering Sea Shelf

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Last updated: October 2018

Description of indicator: Survey operations for the annual AFSC eastern Bering Sea shelf bottom trawl survey in 2018 started on 3 June and ended on 31 July.

Status and trends: Surface temperature mean for the 2018 eastern Bering Sea shelf decreased from the 2017 estimate, while bottom temperature mean increased from the 2017 estimate, but both were still warmer than the long-term time-series mean (Figure 26). The 2018 mean surface temperature was 7.5°C, which was 0.3°C lower than 2017 and 0.9°C above the time-series mean (6.6°C). The mean bottom temperature was 4.3°C, which was 1.4°C higher than 2017, and 1.8°C above the time-series mean (2.5°C). The 'cold pool', defined as the area where bottom temperatures are <2°C, was confined to a very small part of standard EBS survey area (Figure 27). Moreover, it was the lowest areal coverage of the cold pool in the 37-year EBS shelf time-series and the first time that bottom temperatures <0°C were not observed within the standard EBS survey area (Figure 28).

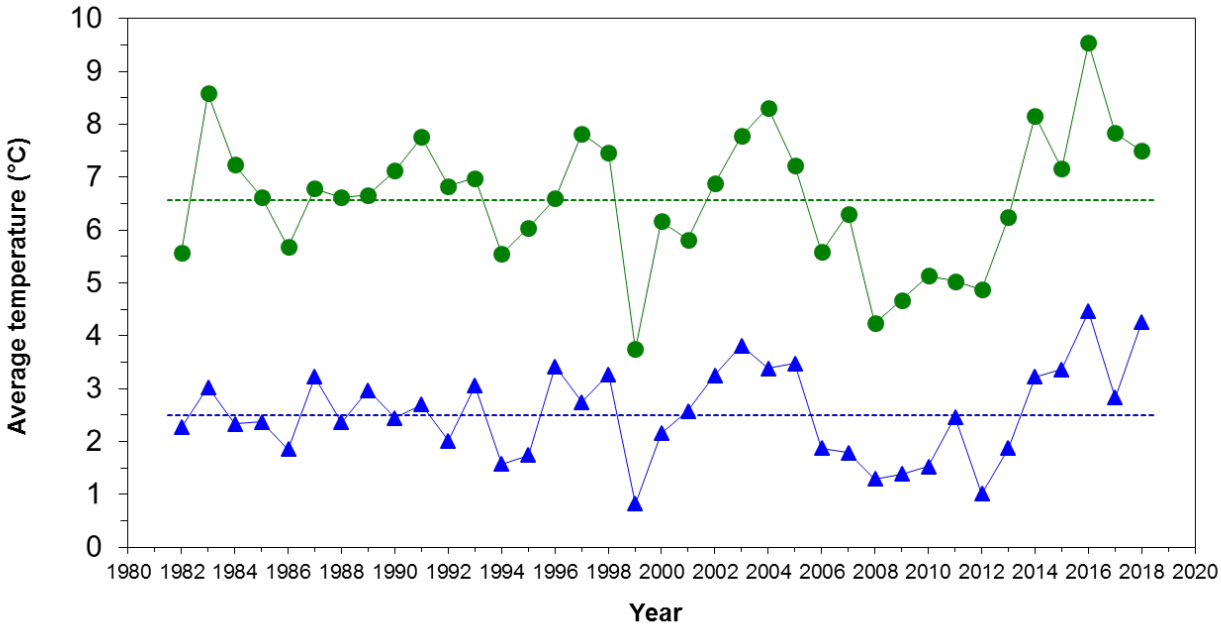

Figure 26: Average summer surface (green circles) and bottom (blue triangles) temperatures (°C) of the eastern Bering Sea shelf collected during the standard bottom trawl surveys from 1982–2018. Water temperature samples from each station were weighted by the proportion of their assigned stratum area. Dotted lines represent the time-series mean for 1982-2018.

Factors influencing observed trends: Warm and cold years are the result of interannual variability in climatic conditions that affect the extent, timing, and retreat of sea ice on the eastern Bering Sea shelf. During warmer than average years, seasonal sea ice generally does not extend as far down the shelf and retreats earlier in the spring.

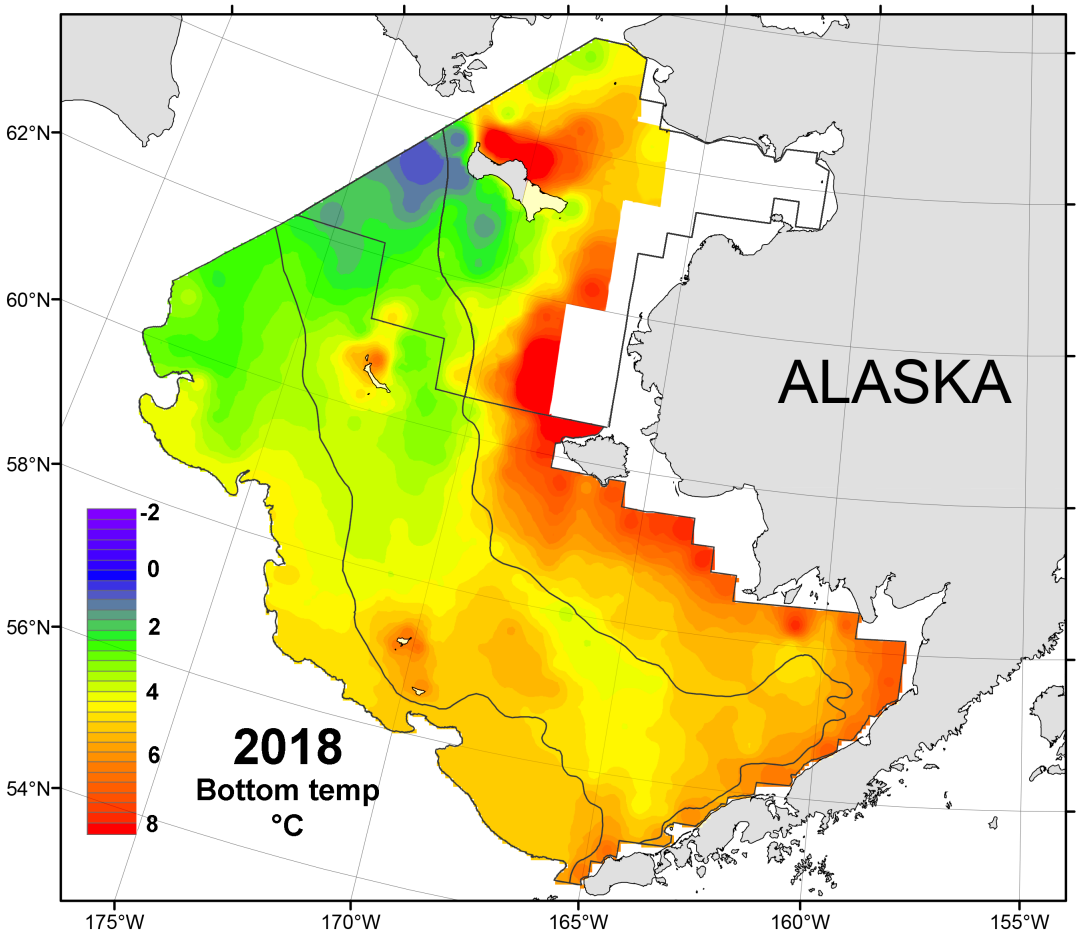

Figure 27: Map showing the near-bottom temperatures from the 2018 eastern Bering Sea shelf bottom trawl survey.

Implications: The relatively large interannual fluctuations in bottom temperature on the EBS shelf affect the spatial and temporal distribution of groundfishes and the structure and ecology of the marine community (Kotwicki and Lauth, 2013; Mueter and Litzow, 2008; Spencer, 2008). The timing of phytoplankton and subsequent zooplankton blooms are also affected by the extent of sea ice and timing of its retreat which in turn can affect survival and recruitment in larval and juvenile fishes as well as the energy flow in the system (Hunt et al., 2002; Coyle et al., 2011; Coyle and Gibson, 2017).

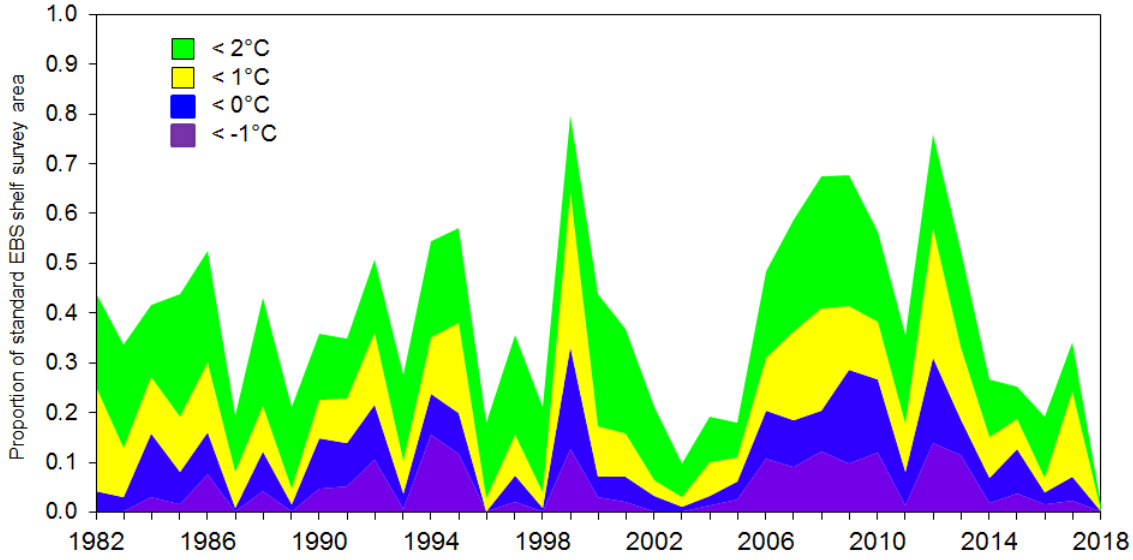

Figure 28: Proportion of the standard eastern Bering Sea shelf survey area where bottom temperatures were <2°C, <1°C, <0°C, and <-1°C for the 37-year time series.

Eastern Bering Sea Winter Spawning Flatfish Recruitment and Wind Forcing

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Last updated: October 2018

Description of indicator: Wilderbuer et al. (2002, 2013) summarized a study examining the recruitment of winter-spawning flatfish in relation to decadal atmospheric forcing, linking favorable recruitment to the direction of wind forcing during spring. OSCURS model time series runs indicated in-shore advection to favorable nursery grounds in Bristol Bay during the 1980s. The pattern changed to off-shore in the 1990–97 time series coinciding with below-average recruitment for Northern rock sole (*Lepidopsetta polyxystra*), Arrowtooth flounder (*Atheresthes stomias*), and Flathead sole (*Hippoglossoides elassodon*) relative to the 1980s. Favorable springtime winds were present again in the early 2000s which also corresponded with improved recruitment. The time series is updated through 2018 and shown for 2010 through 2018 in Figure 29.

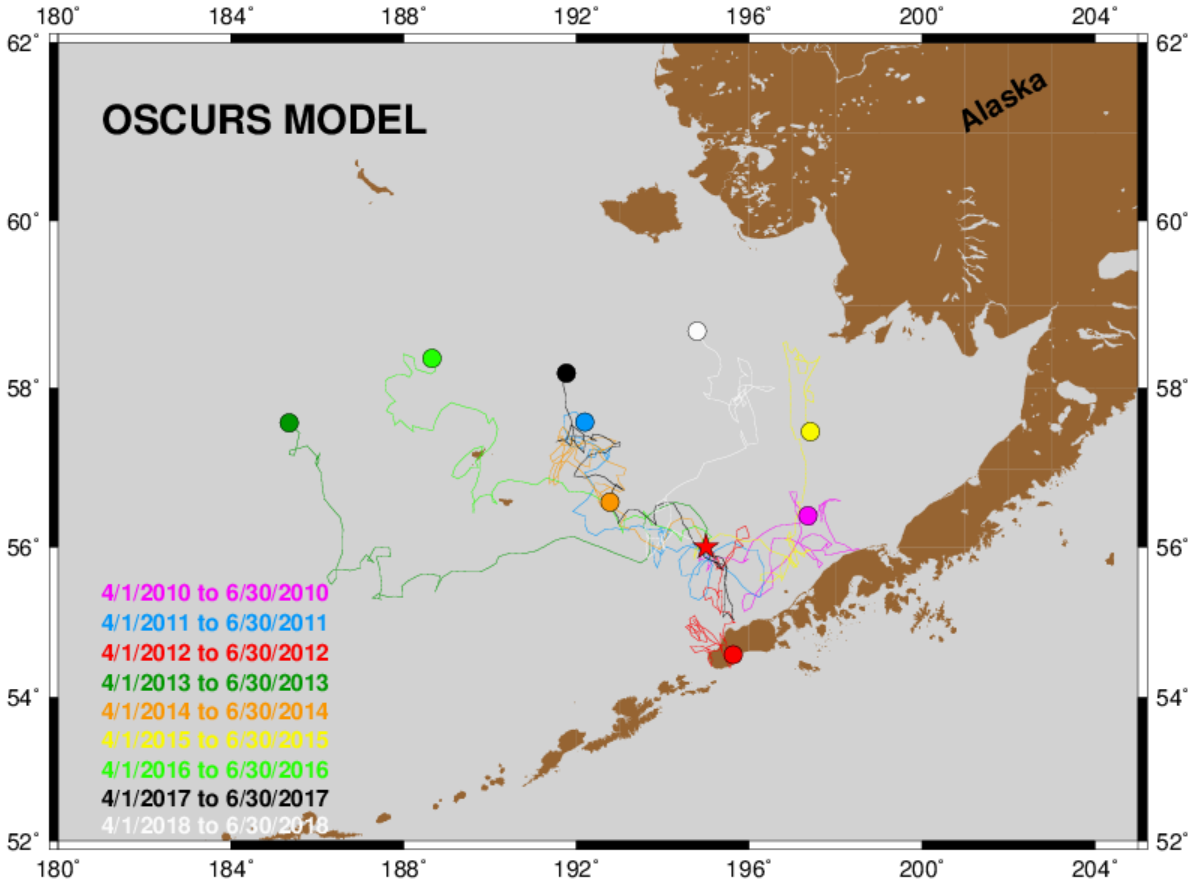

Figure 29: OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56°N, 164°W from April 1–June 30 for 2010–2018.

Status and trends: The 2018 springtime drift pattern appears favorable with consistent drift in a northerly direction during the 90-day period of the index. 2017 was mixed where winds during the first 60 days of the 90-day drift index were unfavorable off-shore winds that changed to a northerly on-shore direction in the last 30 days of the index. This causes some difficulty in interpretation of drift patterns but may be more consistent with years of below-average recruitment for winter-spawning flatfish. Only two years out of the past ten have OSCURS trajectories that are consistent with those which produced above-average recruitment in the original analysis (2015, 2018). The 2018 north-northeast drift pattern suggests that larvae may have been advected to favorable, near-shore areas of Bristol Bay by the time of their metamorphosis to a benthic form of juvenile flatfish. Preliminary estimates of Northern rock sole recruitment in recent years are consistent with this larval drift hypothesis. For Arrowtooth flounder and Flathead sole, the correspondence between the springtime drift pattern from OSCURS and estimates of year class strength have weakened since the 1990s. Arrowtooth flounder produced year classes of average strength during some off-shore drift years, suggesting that this species may have different timing for spawning, larval occurrence, and settlement preferences than Northern rock role. In the case of Flathead sole, the 2001 and 2003 year-classes appear stronger than the weak recruitment that has persisted since the 1990s.

Implications: The 2018 springtime drift pattern appears to be consistent with years when above-average recruitment occurred for Northern rock sole, Arrowtooth flounder, and Flathead sole. Wind patterns in 2008 and 2015 may promote average to above-average recruitment. 2010 featured a mixture of wind direction as there were strong northerly winds for part of the spring but also southerly winds that would suggest increased larval dispersal to Unimak Island and the Alaska Peninsula.

Habitat

Structural Epifauna - Eastern Bering Sea Shelf

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Last updated: October 2018

Description of indicator: Groups considered to be structural epifauna include: sea whips, corals, anemones, and sponges. Corals are rarely encountered on the eastern Bering Sea shelf so they were not included here. Relative CPUE by weight was calculated and plotted for each species group by year for 1982–2018. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (± 1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: Relative catch rates for both sponges and sea anemones remained similar to estimates from 2017, which were lower than the catch rates during 2010–2015, and sea whip estimates increased from 2017 to a catch rate similar to that seen in 2010–2011. These trends should be viewed with caution, however, because the quality and specificity of their field identifications and their enumeration have varied over the time series (Stevenson and Hoff, 2009; Stevenson et al., 2016). Moreover, the identification of trends is uncertain given the large variability in relative CPUE (Figure 30).

Factors influencing observed trends: Further research in several areas would benefit the interpretation of structural epifauna trends including systematics and taxonomy of Bering Sea shelf invertebrates; survey gear selectivity; and the life history characteristics of the epibenthic organisms captured by the survey trawl.

Implications: Understanding the trends as well as the distribution patterns of structural epifauna is important for modeling habitat to develop spatial management plans for protecting habitat, understanding fishing gear impacts and predicting responses to future climate change (Rooper et al., 2016); however, more research on the eastern Bering Sea shelf will be needed to determine if there are definitive links.

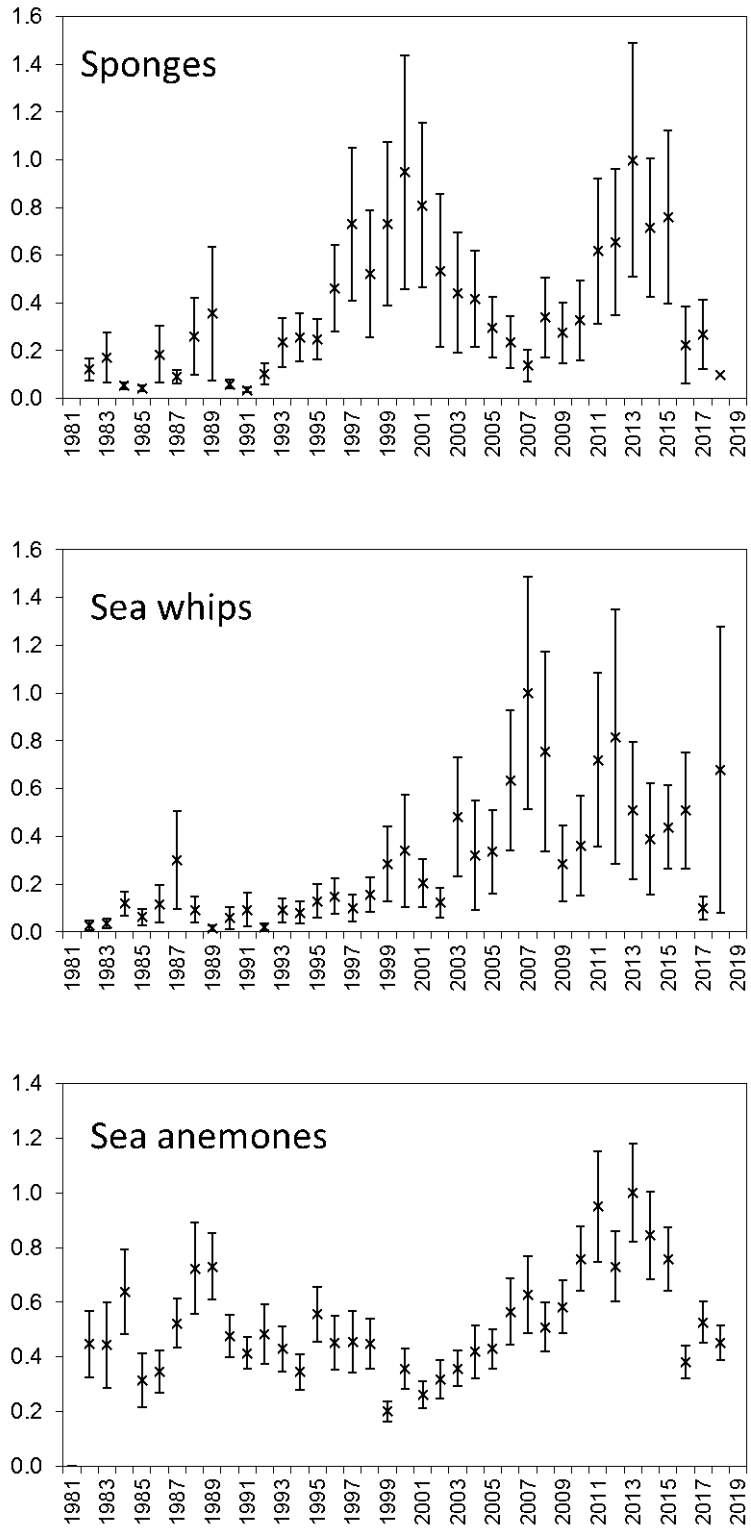

Figure 30: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for benthic epifauna during the May to August time period from 1982–2018.

Primary Production

There are no updates to Primary Production indicators in this year's report. See the contribution archive for previous indicators at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Zooplankton

Rapid Zooplankton Assessment for 2018 – Distribution, Abundance, and Lipid Content – and Historical Time Series

Contributed by David Kimmel[1], Jesse Lamb[1], Nissa Ferm[1], Corey Fugate[2], and Colleen Harpold[1]
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Last updated: October 2018

Description of indicator: In 2015, EcoFOCI implemented a method for an at-sea Rapid Zooplankton Assessment (RZA) to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20/60 cm oblique bongo tows from 10m from bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories are small copepods (< 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp., and *Oithona* spp.), large copepods (> 2 mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids (< 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 μm mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 μm mesh, 60 cm bongo net. In 2016, the method was refined and personnel counted a minimum of 100 organisms per sample at sea to improve zooplankton estimates. Other more rare zooplankton taxa were present but were not sampled effectively with the on-board sampling method. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1+ years post survey).

Southeastern Bering Sea
The 70m isobath transect and Unimak Box were sampled 29 April–10 May 2018 and sampling occurred along the 70m isobath and around the M5 mooring. The spring larval survey occurred from 14 May–1 June 2018 over the SEBS shelf. To provide comparison to yearly RZA data, long-term time-series for the inner, middle, and outer domains were developed from archived data. The mean spring abundance of each RZA category was plotted for the southern inner, middle, and outer shelf of the Bering Sea (Ortiz et al., 2012) and represented primarily April and May as the months with the greatest sampling frequency. Plotted on the time-series were the RZA estimates from the corresponding location and year, presented as an annual mean.

Northern Bering Sea
For the first time since the implementation of the RZA, the NBS survey was sampled 27 August–18 September 2018. As this was the initial sampling, comparisons to previous years are not possible.

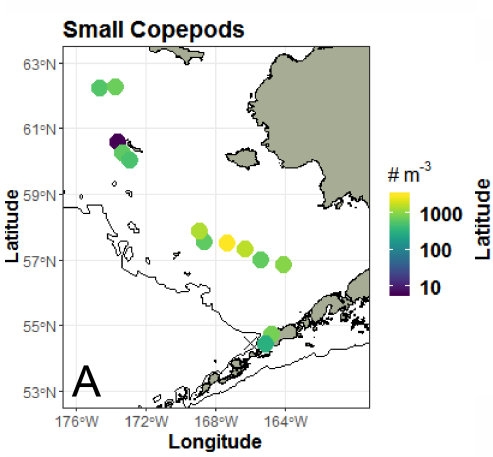
Lipid Content
Another new addition for this year is the inclusion of percent lipid content for large copepods and larval/juvenile euphausiids. Samples were collected at sea during the RZA and lipid content was determined using a modified calorimetric method (Van Handel, 1985). All lipid values reported are in terms of wet mass. Lipid content data provides further context to zooplankton abundances by acting as a proxy for energy content.

Southeastern Bering Sea
Status and trends:
All RZA categories had very low abundances along the 70m isobath (Figure 31A, C, and E), with the exception of the Unimak Pass region where large copepods had higher abundance. Small copepod abundances increased substantially during the spring larval survey (Figure 31B) and were at a high abundance along

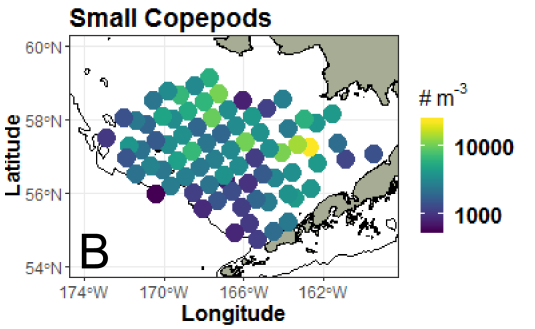
the middle shelf historically (Figure 32). Large copepods also were in higher abundance during the spring larval survey as compared to the 70 m isobath survey. Large copepods were more abundant in the northwest portion of the sampling grid (Figure 31D). From the time-series perspective, large copepod abundances were lower in the inner shelf, but similar to historical means in the middle and outer shelves (Figure 33). Finally, larval and juvenile euphausiid numbers were very low in both surveys (Figure 31E and F). Abundances were also very low compared to the historical measures across the southeastern Bering Sea. However, near zero euphausiid larval/juvenile abundances are not uncommon in spring (Figure 34). Lipid content for both large copepods and euphausiids averaged 5.93% and 3.43% of wet mass, respectively (Figure 35).

Factors influencing observed trends: Two factors may explain the observed patterns in 2018: temperature and the late arrival of the spring bloom. The lack of ice cover in the Bering Sea during 2018 resulted in elevated temperatures and a spring bloom that did not begin until the spring larval survey, though it is usually encountered during the 70 m isobath survey. Warm and cold year "stanzas" influence zooplankton population dynamics in the Bering Sea (Eisner et al., 2014; Kimmel et al., 2018). Small and large copepod abundances were low in the first survey (Figure 31A and C), but increased substantially during the spring larval survey (Figure 31B and D). The combination of increased phytoplankton production observed during the spring larval survey and temperatures increasing copepod growth rates resulted in population growth, particularly among the smaller copepods. The result was historical abundances that were high for small copepods (Figure 32) and near average for large copepods (Figure 33). Less is understood about fluctuations in larval/juvenile euphausiid numbers, which were low on both surveys (Figure 31E and F). However, based on historical sampling, some euphausiid larvae/juveniles should have been present in the southeastern Bering Sea as reproduction for *Thysanoessa raschii* and *T. inermis* usually beings in March/April (Smith, 1991). Compared to historical numbers, abundances were low across the shelf (Figure 34). Lipid content (Figure 35) was low for both large copepods and euphausiids; however, lipid values are generally lower for large copepods during the spring as lipid content increases later in the year and in the copepodite 5 stage for *Calanus*.

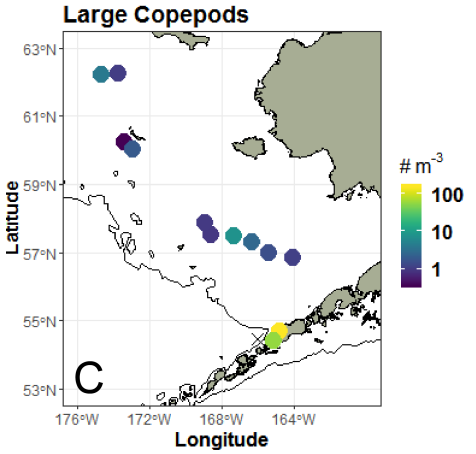
Implications: Smaller copepods form the prey base for larval to early juvenile Walleye pollock (*Gadus chalcogrammus*) during spring (Figure 31A and B). The high abundances of small copepods indicate good forage for larval and juvenile pollock early in the year. The warm temperatures increase copepod secondary production rates and trophic transfer is generally favorable during warm springs (Kimmel et al., 2018). Low abundances of large copepods are less critical in the spring, but very important later in the year (Hunt et al., 2011). Large copepod abundances were high along the southeastern Bering Sea shelf during the spring larval survey (Figure 31D) and higher large copepod abundances in spring are usually associated with reduced large copepod abundances during fall (Eisner et al., 2014; Kimmel et al., 2018). This suggests that juvenile pollock will not encounter larger, lipid-rich copepods in the fall. It has been hypothesized that euphausiids may compensate for a lack of copepods during fall (Duffy-Anderson et al., 2017), however 2018 data indicated a lack of euphausiid presence on the shelf (Figure 31E and F) and abundances much lower than in recent years (Figure 34). It is less clear how the spring euphausiid numbers relate to fall abundances of adults, therefore predicting the presence of euphausiids in fall is not possible with these data.



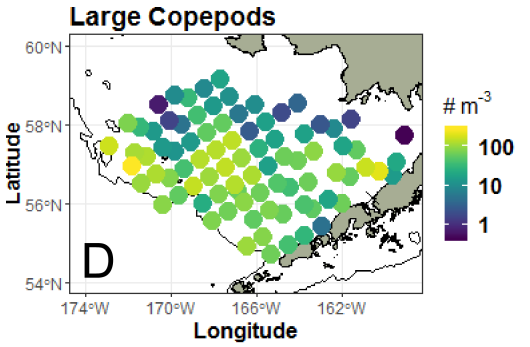
(a) Small Copepods (<2mm) 70 m isobath survey



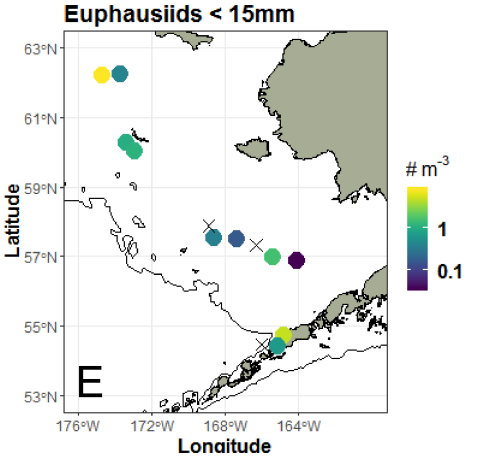
(b) Small Copepods (<2mm) Spring larval survey



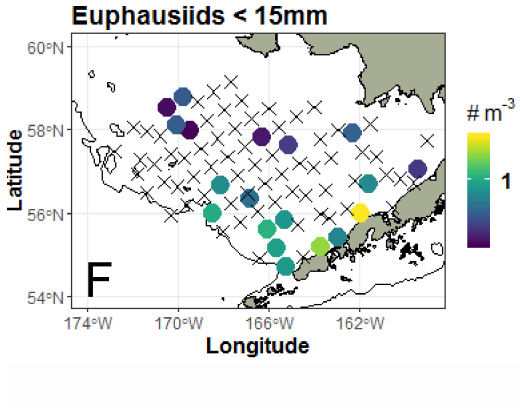
(c) Large Copepods (>2mm) 70 m isobath survey



(d) Large Copepods (>2mm) Spring larval survey



(e) Euphausiids (<15mm) 70 m isobath survey



(f) Euphausiids (<15mm) Spring larval survey

Figure 31: Maps show the abundance of small copepods, large copepods, and euphausiid larvae/juveniles as estimated by the Rapid Zooplankton Assessment during the 70 m isobath survey (left) and spring larval survey (right) in 2018. Note all maps have different abundance scales (No. m^{-3}). X indicates a sample with abundance of zero individuals m^{-3}.

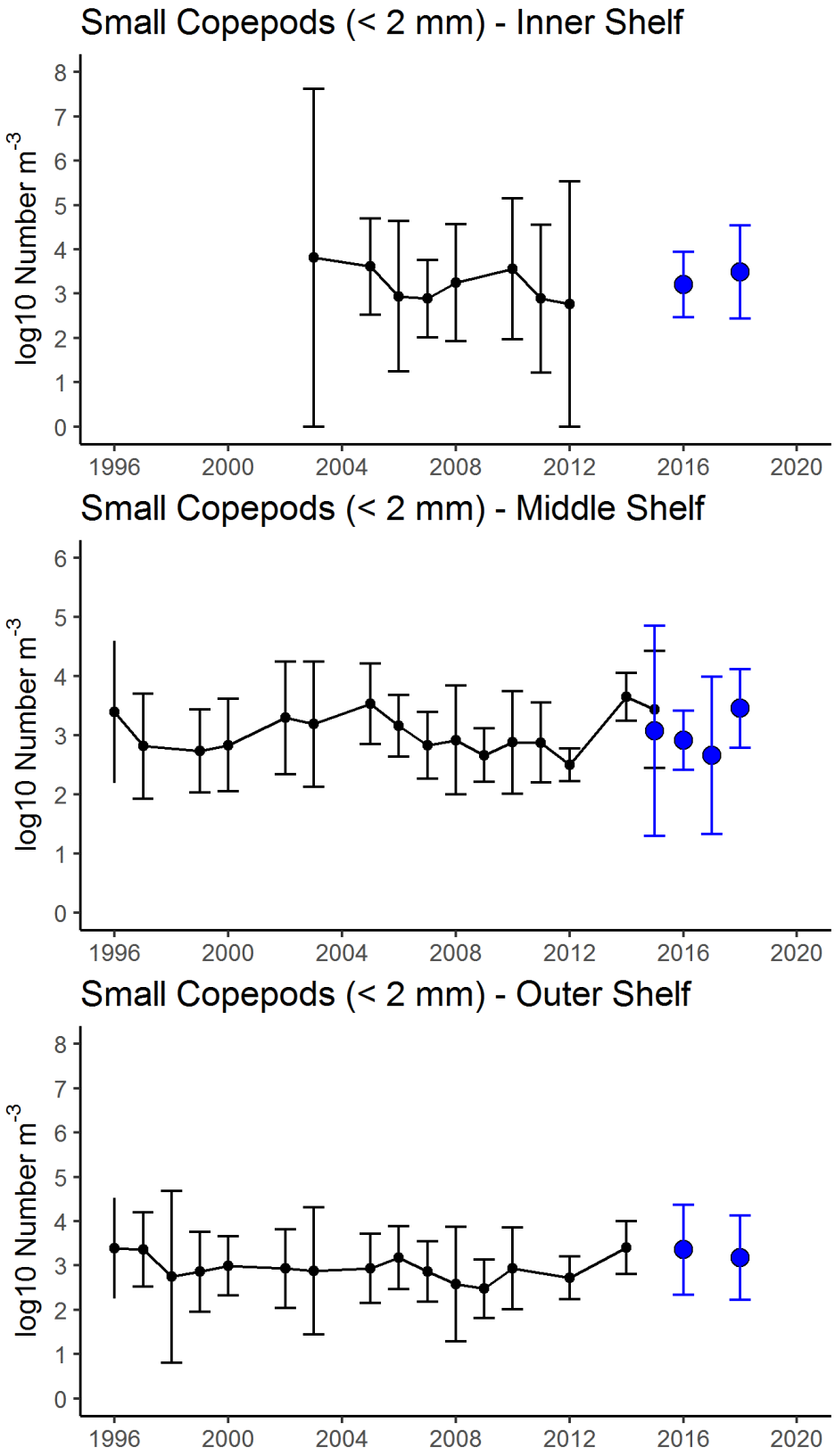


Figure 32: Annual mean abundance of small (<2 mm) copepods in the southeastern region of the Bering Sea (Ortiz et al., 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.

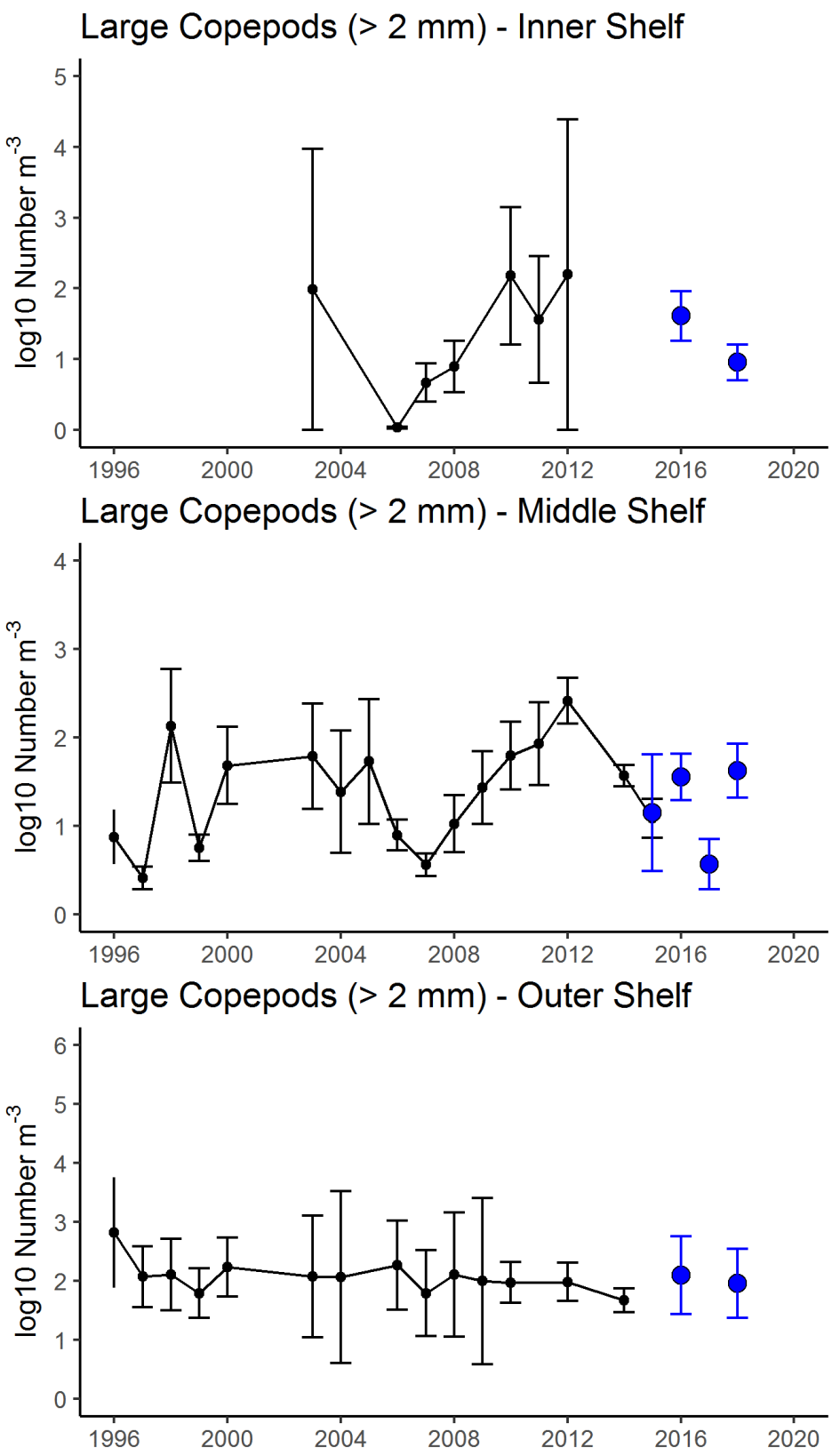


Figure 33: Annual mean abundance of large (>2 mm) copepods in the southeastern region of the Bering Sea (Ortiz et al., 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.

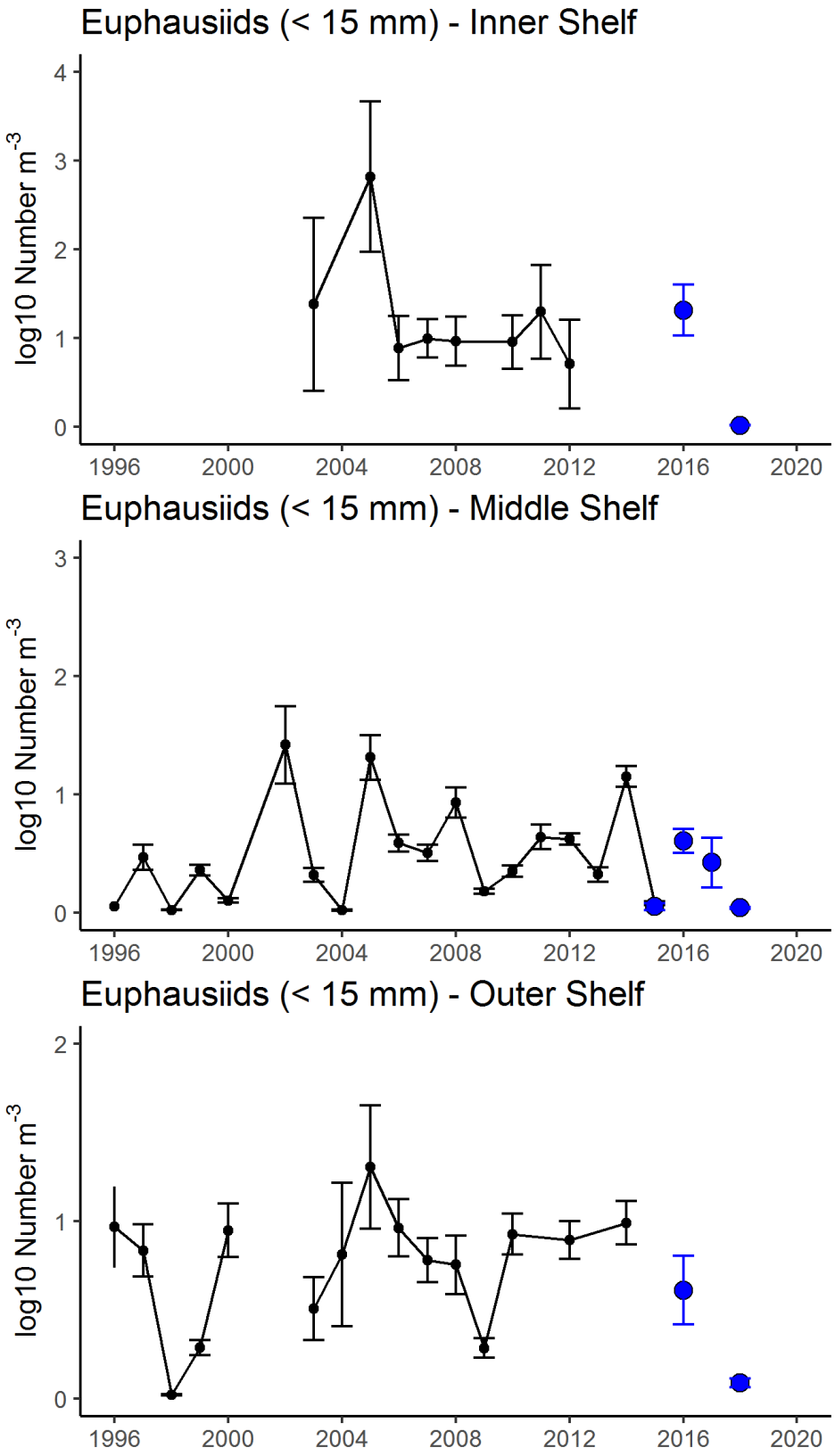
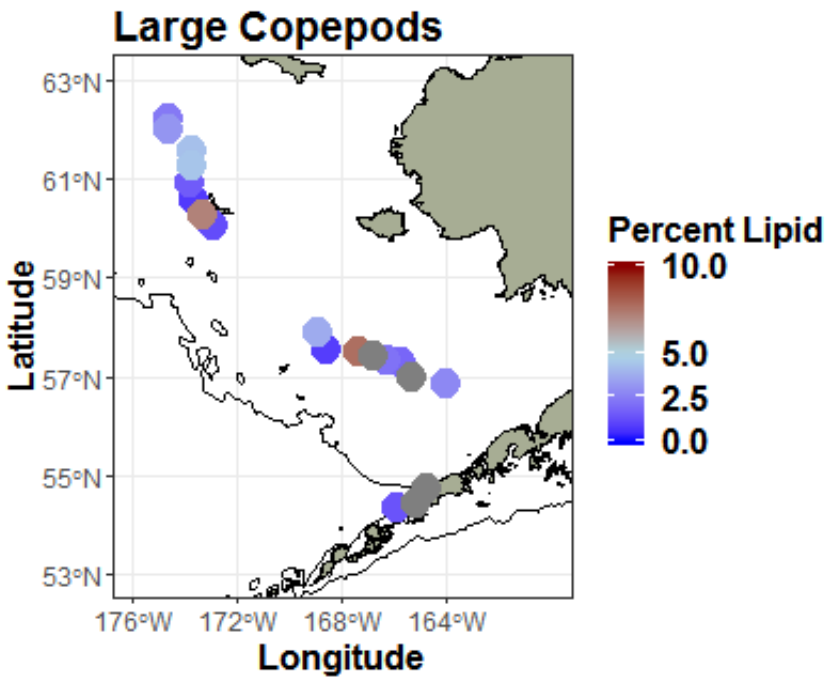


Figure 34: Annual mean abundance of euphausiids in the southeastern region of the Bering Sea (Ortiz et al., 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.



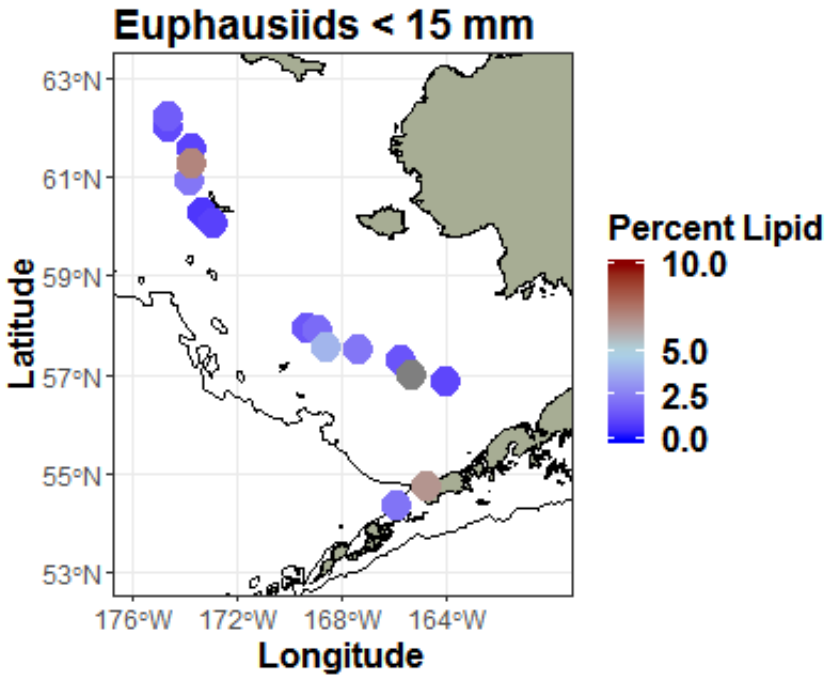


Figure 35: Maps show the percent lipid of large copepods (top) and euphausiid larvae/juveniles (bottom) as measured during the Rapid Zooplankton Assessment on the 70 m isobath survey.

Northern Bering Sea
Status and trends:
Small copepods were abundant throughout the survey region (Figure 36A), with the exception of very low abundances at the most northern stations. Conversely, large copepods (Figure 36B) displayed a range of low to higher abundance from south to north, with highest abundances found at the most northern stations. It is also worth noting that the majority of large copepods enumerated were *Eucalanus bungii*, which is not a lipid-rich species. Lipid values for large copepods averaged 8.12% overall (Figure 37). As lipid values for copepods are normally reported as % of dry mass (Lee et al., 2006), we are unable to assess this lipid content value for copepods as we lack comparison data. Larval and juvenile euphausiids (Figure 36C) displayed a similar gradient as large copepods, with low to higher abundances from south to north, with the exception that they were only found in water with a depth of at least 25 meters. Lipid values were low for euphausiids, averaging 1.61% overall. For context, total lipid as percent of wet mass for *Thysanoessa raschii* reported from the SEBS during the last cold stanza ranged between 2.4% and 5.9% (Harvey et al., 2012). Lastly, the highest abundances for large copepods and euphausiids occurred within close proximity to St. Lawrence Island (Figure 36B and C). The station just north of St. Lawrence Island was the only station where adult euphausiids were caught (not shown), but note that adult euphausiids are not well sampled by the bongo nets.

Implications: The conditions in the Northern Bering Sea were similar to those found in the spring in the southeastern Bering Sea (i.e., warm temperatures), which would suggest that both the factors and implications for the southeastern Bering Sea could apply to this region, as well. We are unable to report on any multi-year trends as this is the first time the RZA has been conducted in the region, however, a previous study was conducted during the relatively cold year of 2007 (Eisner et al., 2013). Compared to 2007, the 2018 abundances of small copepods are similar, with abundances of large copepods almost an order of magnitude lower, and abundances of larval and juvenile euphausiids multiple orders of magnitude lower. The lack of larger, lipid-rich copepods and euphausiids (Figure 36) could affect the body condition and survival of overwintering groundfish within the region.

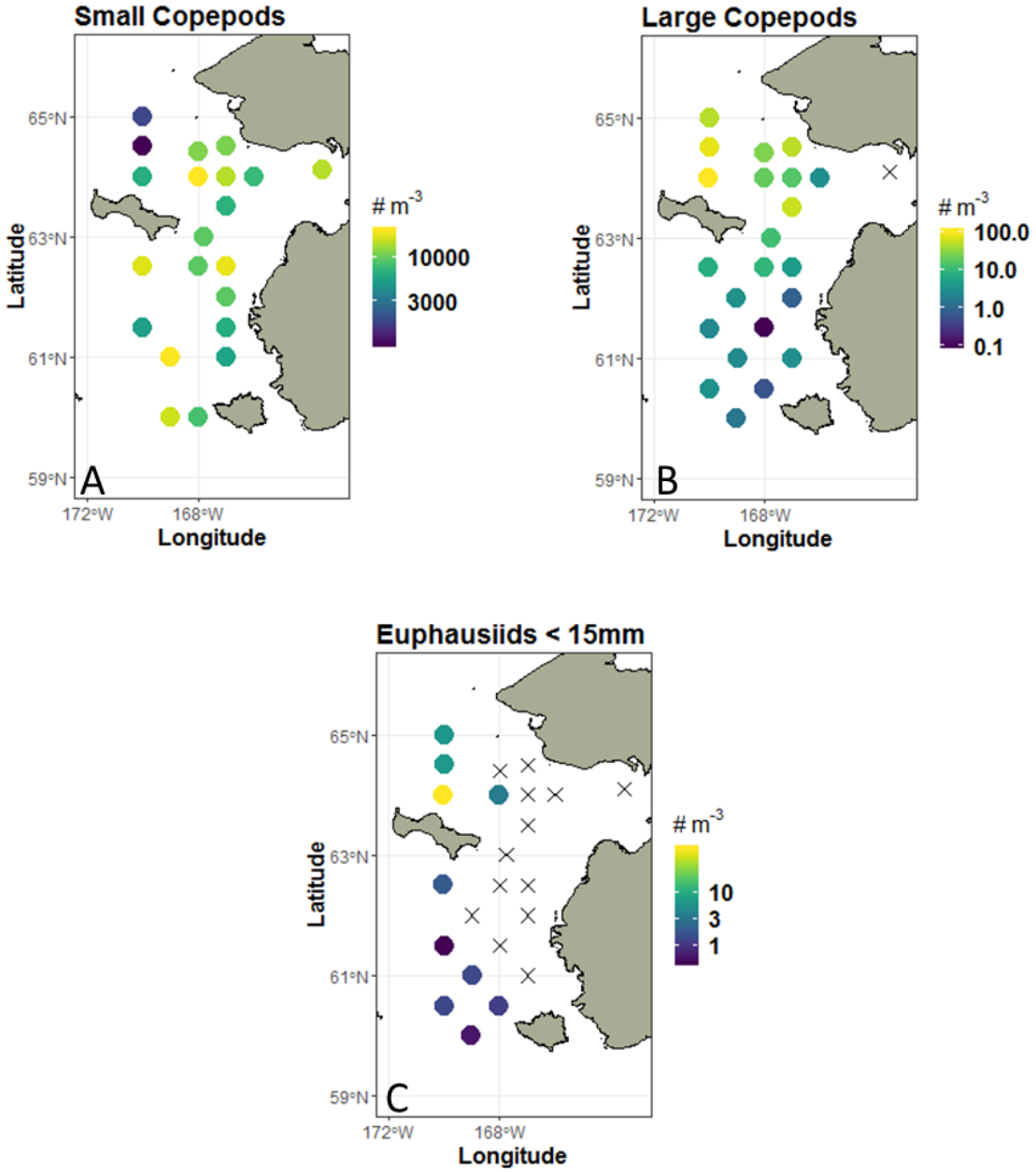


Figure 36: Maps show the abundance of small copepods, small copepods, and euphausiid larvae/juveniles as estimated by the Rapid Zooplankton Assessment during the Northern Bering Sea survey. Note all maps have different abundance scales (No. m^{-3}). X indicates a sample with abundance of zero individuals m^{-3}.

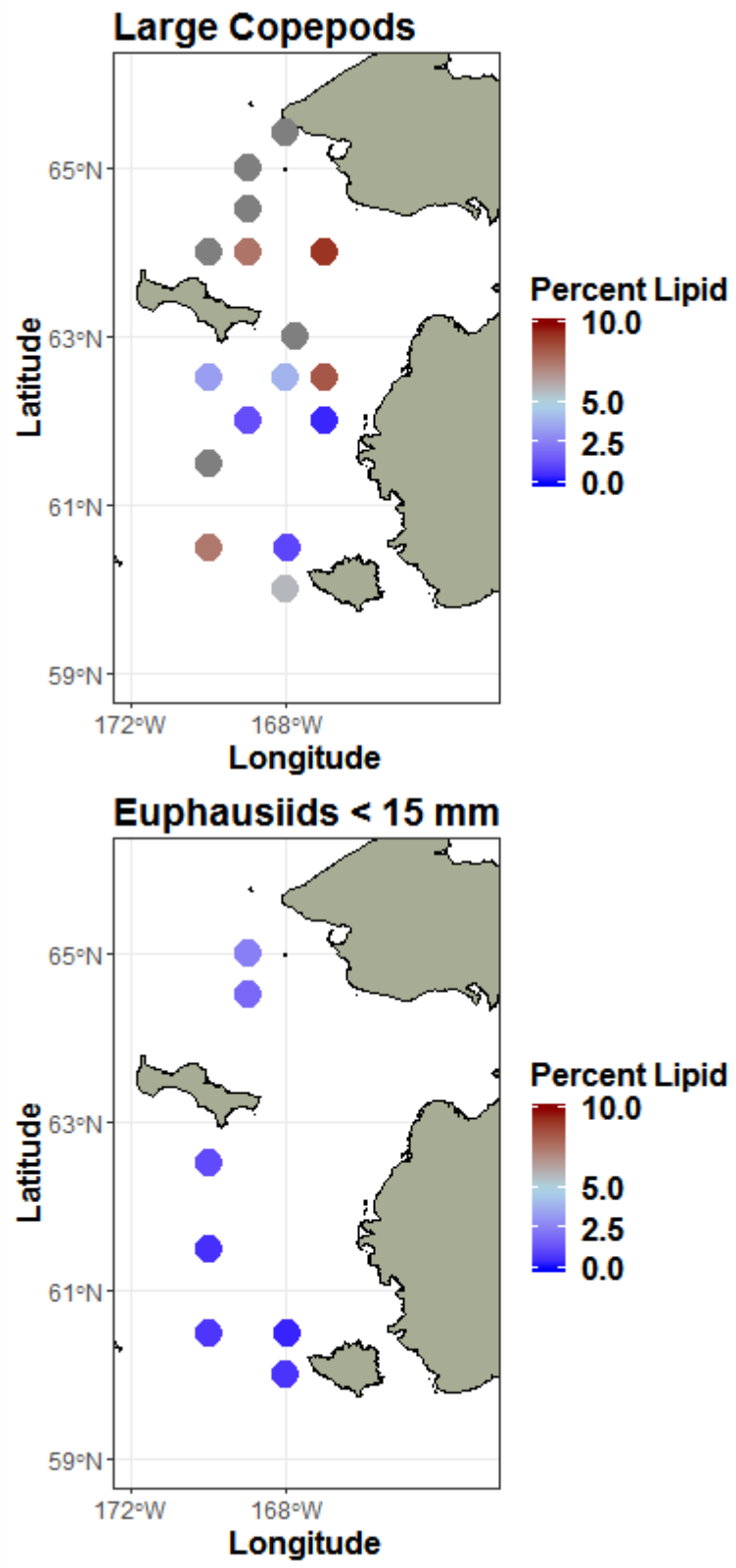


Figure 37: Maps show the percent lipid of large copepods (top) and euphausiid larvae/juveniles (bottom) as measured during the Rapid Zooplankton Assessment on the NBS survey.

Eastern Bering Sea Euphausiids ('Krill')

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Last updated: October 2018

Description of indicator: Ressler et al. (2012) developed a survey of the abundance and biomass of euphausiids on the middle and outer shelf of the eastern Bering Sea using acoustic and Methot trawl data from 2004–2010 surveys of midwater Walleye pollock (*Gadus chalcogrammus*, e.g., Honkalehto and McCarthy (2015)). The method has been used to estimate an index of euphausiid abundance on a biennial schedule since that time. Acoustic backscatter classified as euphausiids (Figure 38) was used to compute the numerical density (no. m^3) of euphausiids in 0.5 nmi intervals along acoustic-trawl survey transects; these values were then averaged over the water column and across the surveyed area to produce annual averages (Figure 39). Because few trawl samples were available in the early years of the times series, the parameter used to convert euphausiid backscatter to numerical density (target strength; Smith et al. (2013)) was modeled using the average of length and species composition from samples collected 2004–2016 (length and species composition from trawl samples collected in 2018 are not yet available). There is large uncertainty about the absolute abundance of euphausiids in the eastern Bering Sea (Hunt et al., 2016), but the relative trends in the index presented here are probably robust. Error bars on annual values indicate 95% confidence intervals computed from geostatistical estimates of relative estimation error due to sampling variability (Petitgas, 1993).

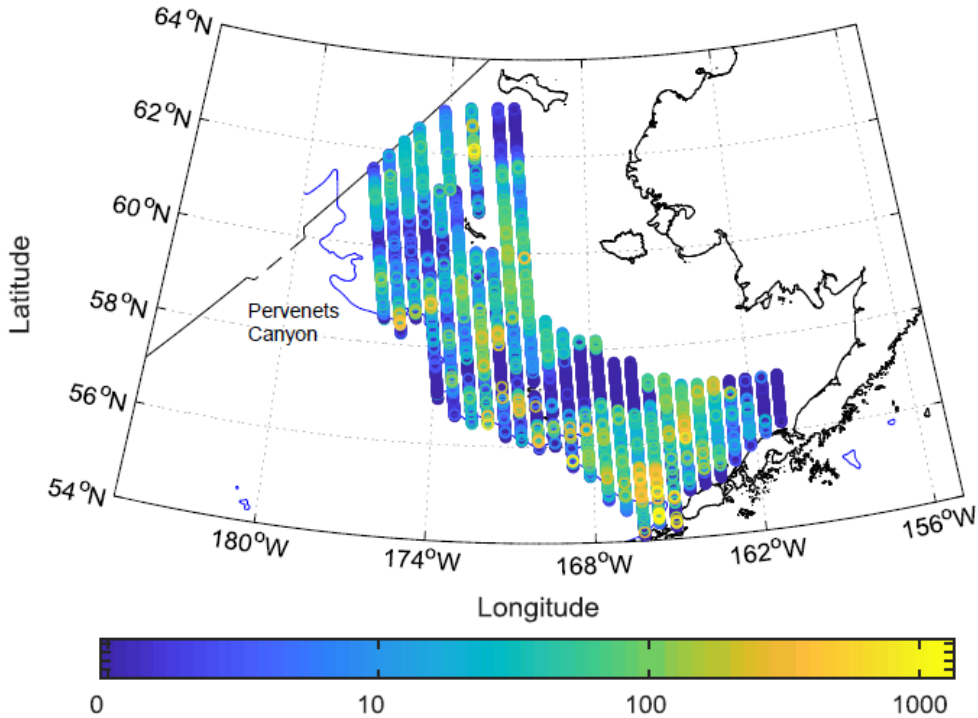

Figure 38: Spatial distribution of acoustic backscatter density (s_A at 120 kHz, m^2 nmi^{-2}) attributed to euphausiids in the 2018 NOAA/AFSC eastern Bering Sea summer acoustic-trawl survey. Note that areas north of St. Matthew Island are not typically surveyed but were included this year as part of a 'northern extension' of the pollock survey, and that the typically sampled shelf area near Pervenets Canyon was not sampled this year.

Since the previous update to this index, a) euphausiid backscatter observations from the 2018 acoustic-trawl survey of pollock and b) euphausiid length and species composition from net tows conducted during the 2016 acoustic-trawl survey were added to the analysis. The addition of these new data changed the absolute abundance given in previous reports, but the temporal pattern in the time series remained the same. Net catches from euphausiid layers in 2004–2016 were dominated numerically by euphausiids (mean 87%) of average length between 18 and 20 mm; *Thysanoessa inermis* dominated species composition on the outer shelf, and *T. raschii* dominated inshore. These observations of length and species composition are consistent with what is known from the literature (Smith, 1991; Coyle and Pinchuk, 2002). There is some indication that euphausiids were smaller in 2004–2009 and in 2016 (by 1-2 mm), and that there was an increase in relative abundance of *T. spinifera* in 2016 compared to other years in the time series. Overall though, no radical changes in length or species composition of euphausiid scattering layers have been indicated. (De Robertis et al., 2010) advocated the use of a mean normal deviate (z-score) of the frequency response to judge the quality of the multifrequency backscatter classification process used here, where a value of 1 indicates that the frequency response is within 1 standard deviation of the known response for a given class of acoustic targets. For euphausiids, this value has averaged 0.87 (range 0.75–1.15) from 2004–2018; the 2018 value was 0.85, indicating consistent performance of the method.

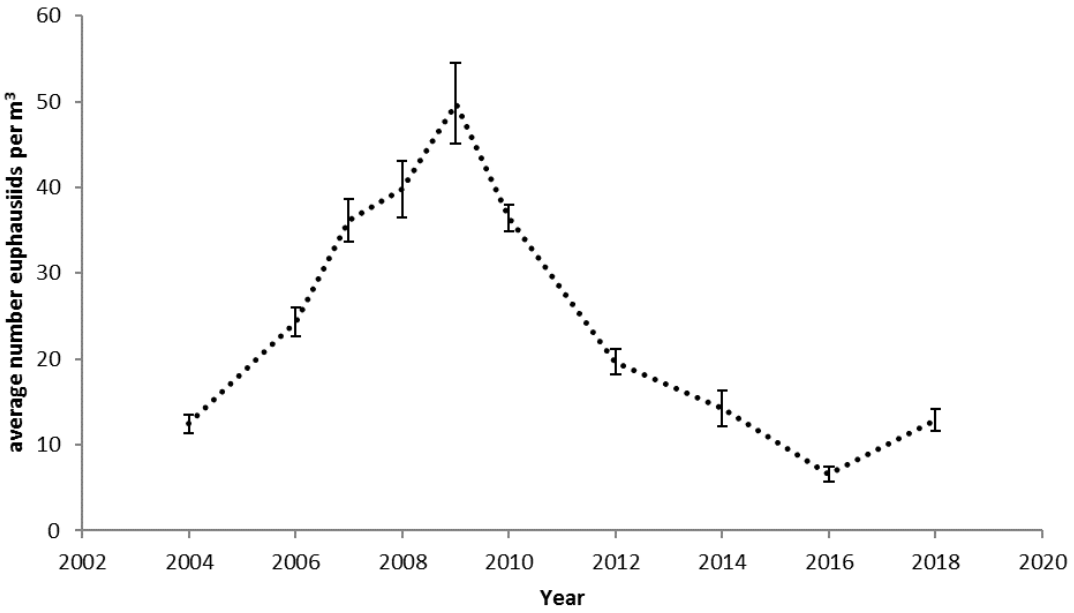

Figure 39: Acoustic estimate of average euphausiid abundance (no. m^3) from NOAA-AFSC EBS summer acoustic-trawl surveys. Error bars are approximate 95% confidence intervals computed from geostatistical estimates of sampling error (Petitgas, 1993).

Status and trends: Summertime euphausiid density increased on the eastern Bering from 2004–2009, then subsequently declined 2010 through 2016, when the lowest value in the time series was reported. Euphausiid density increased slightly in summer 2018 from 2016, but remains relatively low. The 2018 value is similar to what was observed in 2004, a year with very low euphausiid densities according to data from many sources (reviewed in Hunt et al. (2016)).

Factors influencing observed trends: Factors controlling annual changes in euphausiid abundance in the north Pacific are not well understood; possible candidates include bottom-up forcing by temperature and food supply, and top-down control through predation (Hunt et al., 2016). When factors including temperature, pollock abundance, primary production, and spatial location have been considered in spatially-explicit multiple regression models, temperature has been the best predictor, with increases in euphausiid abundance associated with cold temperatures in the eastern Bering Sea (Ressler et al., 2014), but not in

the Gulf of Alaska (Simonsen et al., 2016). The summers of 2014–2018 have been unusually warm on the Bering Sea shelf, with 2018 being particularly warm in the northern Bering Sea (see Overland contribution p. 59, see Lauth contribution p. 70) and in the acoustic-trawl survey area (McCarthy et al., in prep.). The biomass of eastern Bering Sea pollock (an abundant predator of euphausiids) has recently been above the historical mean (Ianelli et al., 2017), though euphausiid abundance has not been strongly correlated with pollock biomass in multiple regression models of euphausiid biomass in either the eastern Bering Sea or the Gulf of Alaska (Ressler et al., 2014; Simonsen et al., 2016).

Annual values of this index are computed using all available survey data, including those collected in the Russian EEZ with permission in some years, or north of the typical acoustic-trawl survey area in 2018. In 2018, there was a 2-week delay in survey execution during July, and after the survey continued some areas in the northwest near Pervenets Canyon were ultimately not sampled, both due to vessel mechanical problems (McCarthy et al., in prep.; Figure 38).

Implications: Euphausiids are food for many species of both ecological and commercial importance in the eastern Bering Sea, including walleye pollock (Aydin and Mueter, 2007). The data presented here suggest that euphausiid prey have become less available in 2012–2018 compared to 2006–2010, perhaps at a level of availability comparable to 2004, which data from many sources suggest was a year with very low euphausiid densities (reviewed in Hunt et al. (2016)).

Jellyfish

Jellyfishes - Eastern Bering Sea Shelf

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Contact: bob.lauth@noaa.gov
Last updated: October 2018

Description of indicator: The time series for jellyfishes (primarily *Chrysaora melanaster*) relative CPUE by weight was updated for 2018 (Figure 40). Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error. **Status and trends:** The

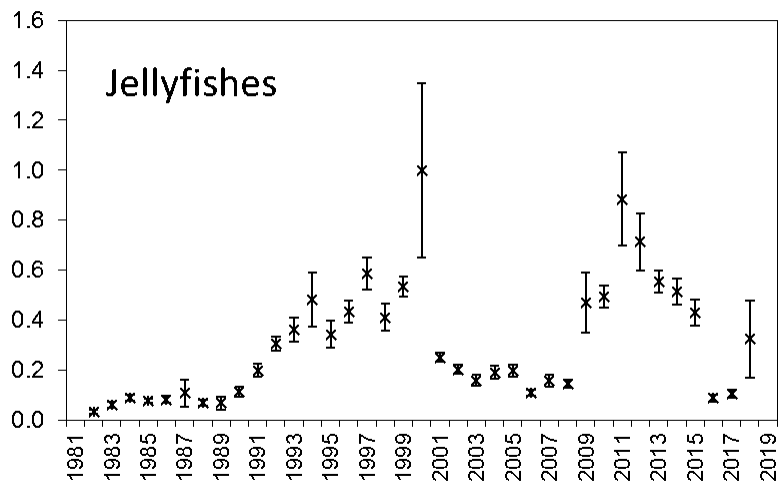

Figure 40: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for jellyfish during the May to August time period from 1982–2018.

relative CPUE for jellyfishes in 2018 increased by 211% from 2017, returning the 2018 estimate within a similar catch range as observed in the mid 1990's and in 2009 and 2010. The low CPUE values observed during 2016 and 2017 were within the range of those observed during the first nine years of the time series (1982–1991). There was a period of increasing biomass of jellyfishes throughout the 1990's (Brodeur et al., 1999) followed by a second period of relatively low CPUE from 2001–2008 and then a second period with relatively higher CPUE values from 2009–2015.

Factors influencing observed trends: The fluctuations in jellyfish biomass and their impacts on forage fish, juvenile Walleye pollock (*Gadus chalcogrammus*), and salmon in relation to other biophysical indices were investigated by Cieciel et al. (2009) and Brodeur et al. (2002, 2008). Ice cover, sea-surface temperatures in the spring and summer, and wind mixing all have been shown to influence jellyfish biomass and affect jellyfish sensitivity to prey availability (Brodeur et al., 2008).

Implications: Jellyfish are pelagic consumers of zooplankton, larval and juvenile fishes, and small forage fishes. A large influx of pelagic consumers such as jellyfish can decrease zooplankton and small fish abundance, which in turn can affect higher trophic levels causing changes to the community structure of the ecosystem.

Temporal Trends in the Abundance of Jellyfish in the Eastern Bering Sea, 2004–2018

Contributed by Kristen Cieciel, Ellen Yasumiishi, and Andrew Dimond
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Last updated: October 2018

Description of indicator: Jellyfish were sampled using a trawl net towed in the upper 25m of the eastern Bering Sea during the Alaska Fisheries Science Center's Bering Arctic Subarctic Integrated Surveys (BASIS) during late summer, 2004–2018. Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes; since 2016 a staggered systematic grid has been used in the southeastern Bering Sea making trawl station distance approximately 60 nautical miles longitudinally. Area swept was estimated from horizontal net opening and distance towed.

Jellyfish catch was estimated in kilograms. Surveys were not conducted in the south (<60°N) during 2013 and 2015 and north (≥60°N) during 2008 so abundance was not estimated for these years and regions. All jellyfish medusae caught in the surface trawl (top 18-20m of the water column) are sorted by species and subsampled for bell diameter and wet weight. Five species are commonly caught with the surface trawl: *Aequorea* sp., *Chrysaora melanaster*, *Cyanea capillata*, *Aurelia labiata*, and *Staurophora mertensi*.

Abundance was estimated for each jellyfish species and region (north >59.9°N, and south <59.9°N) using the VAST package (version 1.5.0) for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 1.1456 and R software version 3.3.0 (Team, 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015); Thorson and Kristensen (2016); Thorson et al. (2016*a*,*b*) to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 50 knots. Parameter estimates were within the upper and lower bounds.

Status and trends: In 2018, jellyfish abundance was about 25% lower than 2016 during the late summer survey in the eastern Bering Sea. Abundance of jellyfish was generally higher in the south than in the north, but trends in abundance were similar (Figure 41), except for the high abundances in 2014, due to *Chrysaora*. *Chrysaora* was the most abundant species until reaching a low level in 2018, when *Aequorea* dominate. 2014 was a peak abundance year for *Chrysaora*. *Aequorea* catches were high in 2016 and 2018. In the north, the relative abundance during 2018 compared to 2017 increased for *Aequorea*, *Cyanea*, and *Staurophora* and decreased for *Aurelia* and *Chrysaora*. In the south, the relative abundance was high and increased for *Aequorea* and *Aurelia*, and was low and declined for *Staurophora* and *Chrysaora* in 2018 relative to 2016. *Chrysaora* appears to be returning to lower levels similar to 2004–2007.

Factors causing observed trends: Shifts in abundance of single large sized jellyfish in cold years to multiple smaller sized species in warm years indicate that there could possibly be a shift to multiple taxa present in the future during warm stanzas. The cause for the shifts in biomass and distribution do not seem to rely solely on physical ocean factors (temperature and salinity). These shifts could also be a result of environmental forcing earlier in the growing season or during an earlier life history stage (polyp), which may influence large medusae biomasses and abundances (Purcell et al., 2009). Jellyfish are predators of zooplankton and may compete for food with other zooplanktivores such as small fish, birds, and marine mammals.

Implications: Significant increases in jellyfish biomass may redirect energy pathways in the eastern Bering Sea food web through jellyfish predation on zooplankton and larval fish, and could result in limiting carbon transfer to higher trophic levels (Condon et al., 2011).

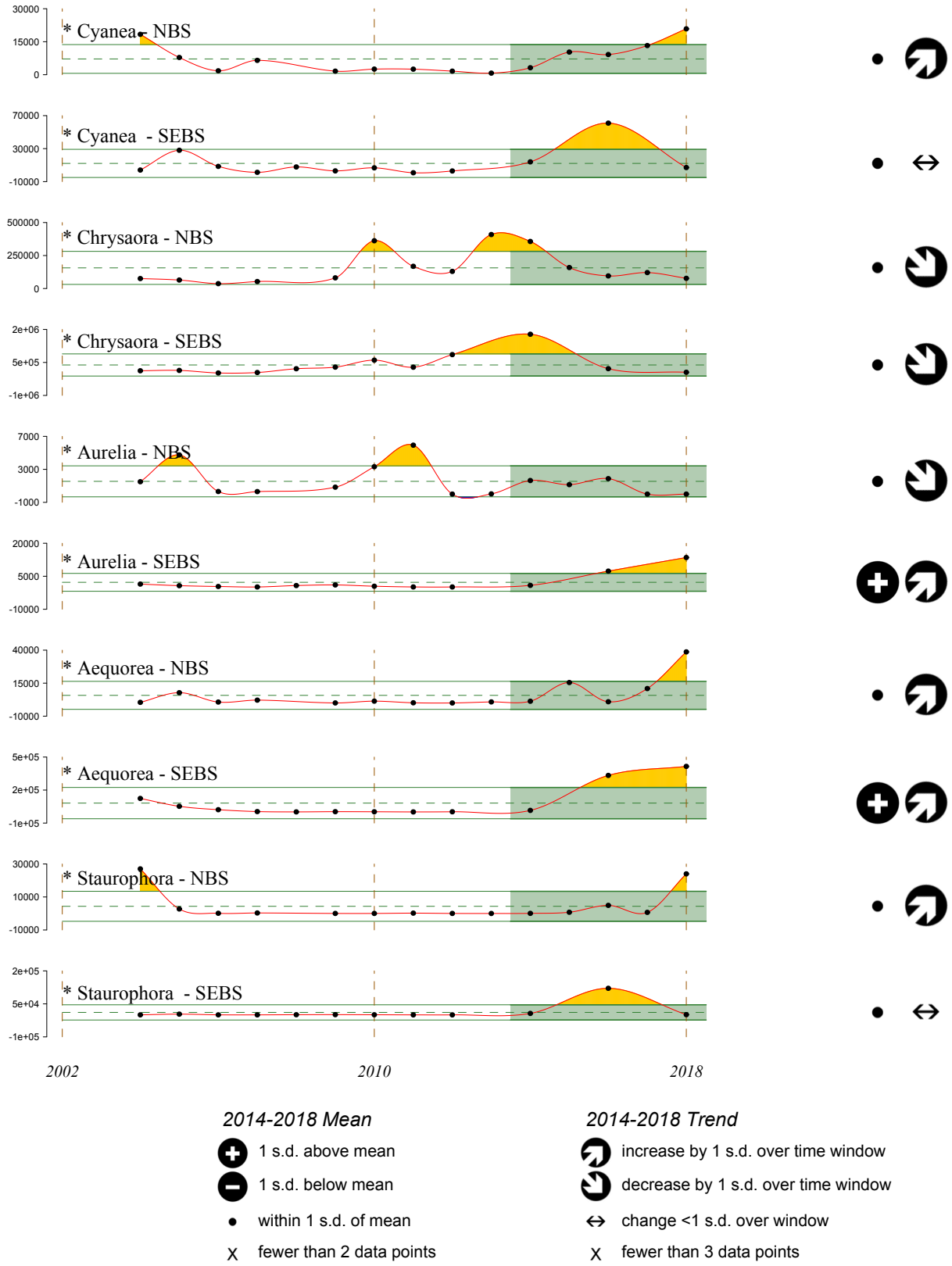

Figure 41: Index of abundance (metric tonnes) ± 1 standard deviation for jellyfish in the eastern Bering Sea during late summer, 2004–2018.

Ichthyoplankton

Abundance and Distribution of Larval Fishes in the Southeastern Bering Sea 2012–2018

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Last updated: September 2018

Description of indicator: The southeastern Bering Sea shelf ichthyoplankton survey is conducted biannually in the late spring to assess the abundance and spatial distribution of early life stages of fishes. Prior to 2016 the spatial coverage of the survey varied. In 2016 a new sampling grid was implemented so that the area surveyed would be consistent among years allowing for improved time series and calculation of indices of larval fish abundance. Ichthyoplankton were sampled using a paired 60-cm bongo array with 505μm mesh nets. Tows were conducted to 10 meters off bottom or 300 meters maximum depth. A Sea-Bird FastCat CTD was mounted above the bongo array to acquire gear depth, temperature, and salinity profiles.

Larval fish abundance (number/10m^2) for 2012–2016 was calculated from the number of larvae counted at the Plankton Sorting and Identification Center in Szczecin, Poland and standardized by the volume of water filtered during a tow. The abundance of larvae in 2018 was estimated at sea by counting the number of larvae collected in the bongo codend and standardizing by volume filtered. Model-based estimates of mean larval abundance (number/10m^2) were produced using the VAST package (version 4.0.0; Thorson et al. (2015)). Model selection supported a lognormal-Poisson distribution for the data, and a spatial resolution of 107 knots was used (equal to the least number of stations sampled in any year).

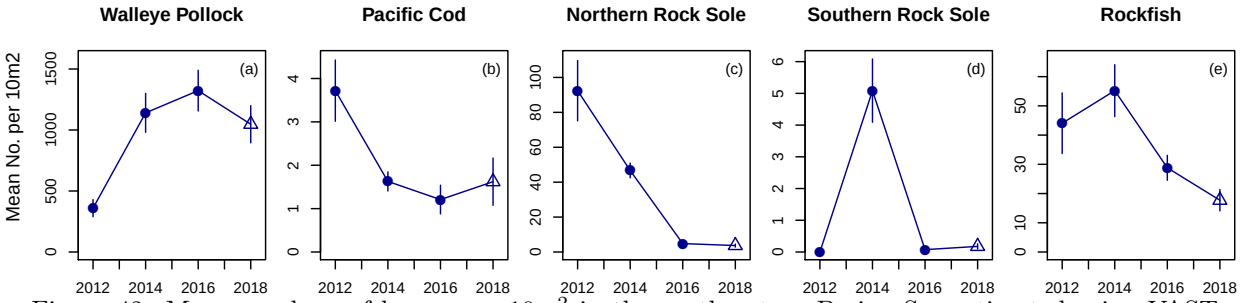

Figure 42: Mean numbers of larvae per 10m^2 in the southeastern Bering Sea estimated using VAST. Open triangles indicate estimates based on at-sea counts of larvae. Errors bars indicate ± 1 SD.

Status and trends: Temporal abundance and spatial distribution of fish larvae varied by species and year. Walleye pollock (*Gadus chalcogrammus*) were the most abundant larvae of the five species examined for this report, and their abundance increased from near the end of the last cold stanza (2012) through 2016 in the current warm stanza that began in 2014 (Figure 42a). Walleye pollock larvae were distributed throughout the area surveyed with high abundances near the Alaska Peninsula and the Pribilof Islands (Figure 43). The abundance of Pacific cod (*G. macrocephalus*) larvae dramatically declined from near the end of the cold stanza to the start of the warm stanza, and remained low through 2018 (Figure 42b). Pacific cod larvae distribution varied greatly among years. In 2012 they were most abundant in the northern most area surveyed, and in the warm years of 2016 and 2018 their distribution had shifted mostly south to near the Alaska Peninsula (Figure 44). Similar to Pacific cod, the relative abundance of Northern rock sole (*Lepidopsetta polyxystra*) larvae also significantly declined between the warm and cold stanzas and remained low through 2018 (Figure 42c). These larvae were abundant throughout the area surveyed in 2012 and 2014, and in 2016 and 2018 they were distributed in northern and southern clusters (not shown). Southern rock

sole (*L. bilineata*) larvae were the least abundant of all the species examined. This species was not present in the survey area in 2012, were most abundant in 2014 and present at very low levels in 2016 and 2018 (Figure 42d). Larvae were sparsely distributed across the southeastern Bering Sea shelf (present at one station in 2016 and three stations in 2018), except for 2014 when they were clustered east of the Pribilof Islands (not shown). Rockfish (*Sebastes* spp.) larvae showed a general decline in relative abundance from 2012 to 2018 (Figure 42e). They were present on the outer domain and along the shelf break and this pattern was consistent among years (not shown).

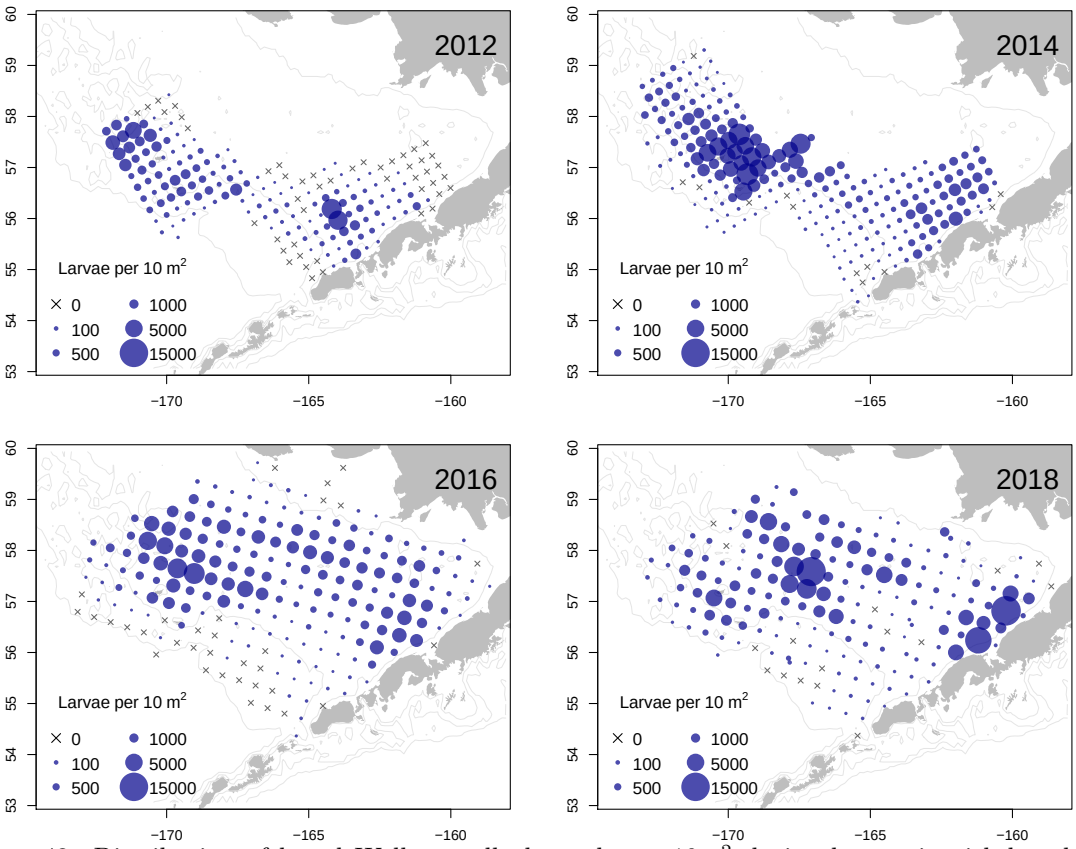

Figure 43: Distribution of larval Walleye pollock catch per 10m^2 during late-spring ichthyoplankton surveys in the southeastern Bering Sea, 2012–2018.

Factors influencing observed trends: Interannual variation in ocean temperature in early spring can shift phenology of fishes and the timing of the spring bloom that is also important for the production of prey for fish larvae. This can lead to a mismatch between fish larvae and their prey resulting in poor larval survival. In addition, changes in the timing of spawning can affect whether larvae are in the study region during the survey. The abundance of three out of the five species of fish larvae examined (Pacific cod, Northern rock sole, and Rockfish) declined when conditions on the southeastern Bering Sea shelf changed from cold to warm. Pacific cod and Northern rock sole larvae showed the most marked decline in abundance during this time. However, Northern rock sole recruitment is typically higher in warmer years relative to cold years, a pattern which is linked to differential use of a northern nursery area (Cooper and Nichol, 2016), highlighting the importance of settlement processes for this stock. The low abundance of Pacific cod larvae in recent warm years could indicate poor production or survival, but could also indicate a shift in phenology, as larger and older larvae become more capable swimmers and are able to evade the sampling gear. Further investigation of larval size will be needed to address this. Walleye pollock was the only species that showed higher abundance during the warm stanza. For Walleye pollock the effects of warm ocean temperatures may not be apparent until after their first winter (Hunt et al., 2011). Southern rock sole is at the northern most

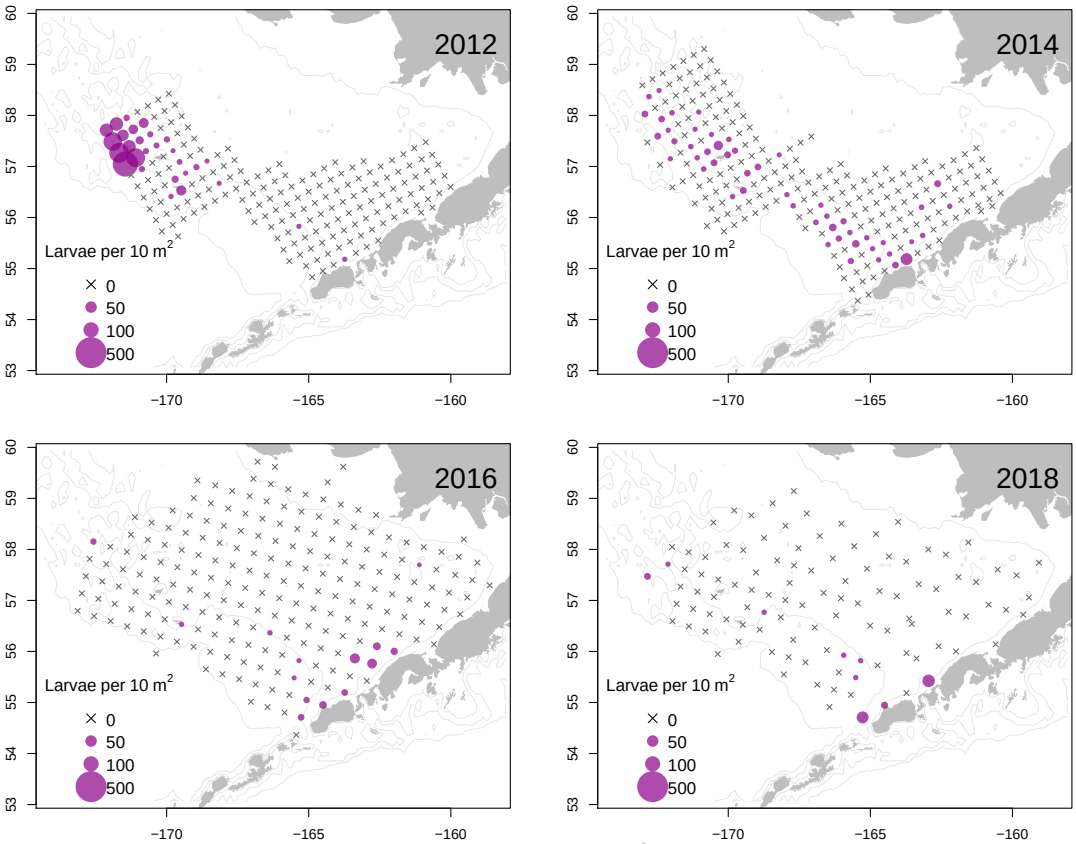

Figure 44: Distribution of larval Pacific Cod catch per 10m^2 during late-spring ichthyoplankton surveys in the southeastern Bering Sea, 2012–2018.

extent of its range in the Bering Sea and this may account for its low abundance.

Implications: Ichthyoplankton surveys can provide early-warning indicators for ecosystem conditions and recruitment patterns in marine fishes. In 2018, larval abundance declined or stayed roughly level for the five studied species relative to 2016, reflecting a continuation of warm conditions on the southeastern Bering Sea shelf. Ongoing research is focused on the importance of larval phenology, condition, geographic distribution, and overlap with prey for eventual recruitment success.

Forage Fish

Temporal Trends in the Abundance of Forage Fish in the Eastern Bering Sea, 2002–2018

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Last updated: October 2018

Description of indicator: Fish were sampled using a trawl net towed in the upper 25m of the eastern Bering Sea during the Alaska Fisheries Science Center's Bering Arctic Subarctic Integrated Surveys (BASIS) during late summer, 2002–2018. Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes; since 2016 a staggered systematic grid has been used in the southeastern Bering Sea making trawl station distance approximately 60 nautical miles longitudinally. Area swept was estimated from horizontal net opening and distance towed.

Fish catch was weighed in kilograms at each station. Surveys were not conducted in the south (<60°N) during 2013, 2015, and 2017; and north (≥60°N) during 2008 so no estimates of abundance were made for these years or regions. Eight species were commonly caught with the surface trawl: age-0 Walleye pollock (*Gadus chalcogrammus*), Capelin (*Mallotus villosus*), Pacific herring (*Clupea pallasii*), juvenile Chinook salmon (*Oncorhynchus tshawytscha*), juvenile chum salmon (*O. keta*), juvenile pink salmon (*O. gorbuscha*), juvenile coho salmon (*O. kisutch*), and juvenile sockeye salmon (*O. nerka*); for this analysis all non-Chinook salmon have been pooled into a juvenile salmon group. Biomass was calculated for each species or group and compared in the northern and southeastern regions of the Bering Sea. Few Chinook salmon were captured in the south so we did not estimate abundance for these fish.

Abundance was estimated for each species or group using the VAST package (version 1.5.0, cpp version) for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 1.1456 and R software version 3.3.0 (Team, 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015); Thorson and Kristensen (2016); Thorson et al. (2016*a*,*b*) to estimate indices of abundance for stock assessments. We specified a gamma or normal distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 50 knots (model estimated central locations between stations). We used the Poisson delta link model. Parameter estimates were within the upper and lower bounds.

Status and trends: In 2018, the abundance of pelagic fish species increased in the southeastern Bering Sea relative to 2016 and decreased in the northern Bering Sea relative to 2017. In the north, juvenile non-Chinook salmon (primarily pink and chum salmon) were the only fish group that was above average in 2018, while herring and capelin were below average and age-0 pollock was around the mean. In the south, the model-estimated relative abundance of juvenile salmon and herring were both above the average, while capelin was below average and age-0 pollock was near the mean (Figure 45). Warm and cold year occurrences were observed in the normalized time series of abundance of fish in pelagic waters. Capelin were typically more abundant during cold years, whereas herring were typically more abundant during warm years. Juvenile salmon abundances were higher during the recent warm stanza (2014–2018), but not during the earlier 2002–2005 warm stanza. Age-0 pollock also occurred in higher abundances during warm years than cold years.

Factors influencing observed trends: Non-Chinook juvenile salmon had relatively high abundances in both the northern and southeastern Bering Sea during 2018, indicating favorable conditions for juvenile pink and chum salmon survival. Lower abundances of pollock, capelin, herring, and juvenile Chinook salmon in the north indicate poor environmental conditions for the growth and survival in the eastern Bering Sea during summer or movement out of the survey area.

Age-0 pollock did not appear in large biomasses in pelagic waters of the northern or southeastern Bering Sea during late summer 2018 relative to 2002–2017. Age-0 pollock may have lowered abundance, deeper distribution (e.g., off the shelf), or be distributed outside the survey area.

Implications: Lower abundances of forage fish in the north and higher abundances in the south during 2018 indicate differential productivity of pelagic waters in the eastern Bering Sea. Declining trends in four of five forage fish groups in the north coincide with warmer than average water temperature in 2018, indicating overall unfavorable conditions with the exception of juvenile pink and chum salmon. There was little evidence of shifts in distribution northward based on changes in abundance.

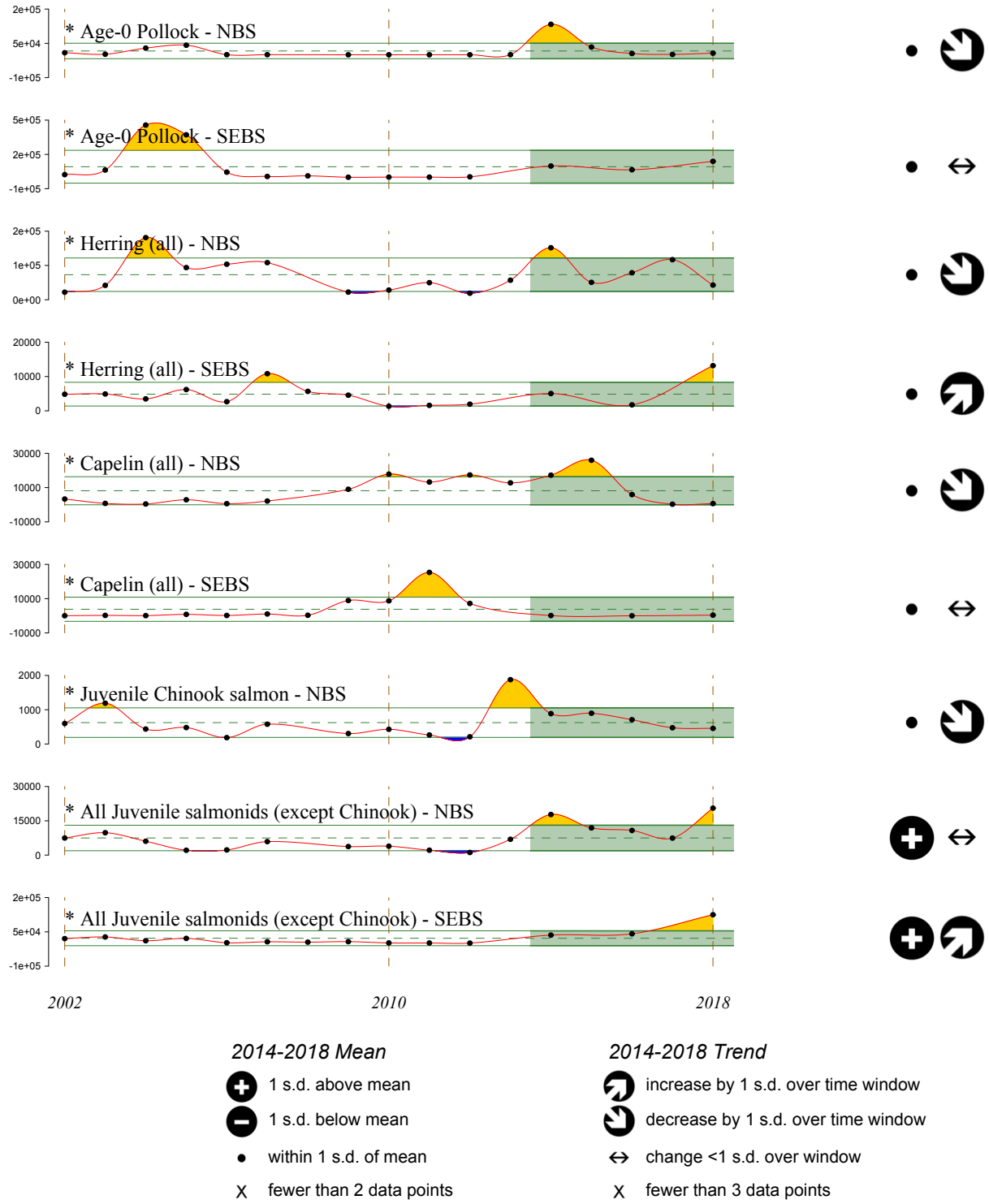

Figure 45: Relative abundance (metric tonnes) of forage fish in pelagic waters of the eastern Bering Sea during late summer, 2002–2018.

Togiak Herring Population Trends

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Last updated: October 2018

Description of indicator: The biomass of mature Pacific herring (*Clupea pallasii*) occurring in the Togiak District of Bristol Bay has been tracked through aerial surveys since the late 1970s using methods described by Lebida and Whitmore (1985). Generally, the peak aerial survey biomass estimate during the days when the commercial fishery is open, harvest prior to the peak aerial survey biomass, and the peak aerial survey biomass after the commercial fishery is closed are combined to provide the survey estimate of mature herring biomass. An age-structured analysis (ASA) model is then used to forecast herring biomass in Togiak District of Bristol Bay for setting the State of Alaska commercial guideline harvest level for the spring sac roe fishery and the Dutch Harbor bait fishery (Funk et al., 1992; Funk and Rowell, 1995). The data used in the ASA model includes aerial survey estimates of biomass weighted by a confidence score (confidence depends primarily on visibility conditions, aerial survey coverage, and number of surveys), age composition and weight-at-age information collected from the fishery, and harvest from both the seine and gillnet fisheries. Recruitment of Togiak herring to the fishery begins around age-4 and fish are believed to be fully recruited into the fishery around age-8.

Togiak Bay herring is the largest herring spawning stock in Alaskan waters and thought to comprise approximately 70% of the eastern Bering Sea (EBS) herring spawning biomass (from Port Heiden/Port Moller to Norton Sound). Due to reduced market demands for herring and State of Alaska budget cuts, Togiak Bay herring is the only mature herring stock in the EBS area that is currently monitored, surveyed, and assessed on an annual basis.

The annual forecasted biomass of mature Togiak herring, combined with long-term average aerial survey biomass estimates from other herring stocks in the EBS, provides the basis for establishing the prohibited species catch (PSC) limit for groundfish fisheries in the EBS per Amendment 16A of the Bering Sea/Aleutian Islands Groundfish Fishery Management Plan. The annual PSC limit is set at 1% of the annual biomass of mature EBS herring and is apportioned among trawl fishery categories. Attainment of any apportionment triggers closure of Herring Savings Areas to that fishery. If the NOAA Regional Administrator determines that the PSC limit of herring is attained, the Herring Savings Areas may be closed for the remainder of the year or season. This is important because if high herring PSC triggers Savings Area closures, the fleet may be forced to move from an area of high herring and low salmon PSC, to an area of low herring and high salmon PSC.

Status and trends: Togiak mature herring biomass as estimated by the ASA model increased from a low of 63,500 short tons in 1980 to over 400,000 short tons from 1985 to 1987 (Figure 46), due to large age-4 recruitments in 1981 and 1982 (Figure 47). The biomass then declined through the mid-1990s and has remained stable since that time. The large biomasses estimated by the model during the late 1980s have considerable uncertainty due to the poor aerial survey conditions and confidence scores during that time. In 2017 we observed 90,268 tons on our aerial survey which is 55% of the most recent 10-year aerial survey average and 59% of the most recent 20-year aerial survey average (G. Buck, unpubl. data). However, the ASA estimated biomass in 2016 and 2017 was considerably greater than aerial survey estimates because of the low confidence ranking of the surveys during these years and the contribution of the age-composition information.

An active sac roe fishery is conducted on this population with gillnet and purse seine gear. A small spawn on kelp quota is allowed but has not been utilized since 2003. The sac roe fishery has harvested an average of 21,046 tons in recent years (2008–2017; G. Buck, unpubl. data).

Factors causing observed trends: Herring recruitment is both highly variable and cyclic with large recruitment events occurring roughly every 8 to 10 years in this population. We believe fish from the

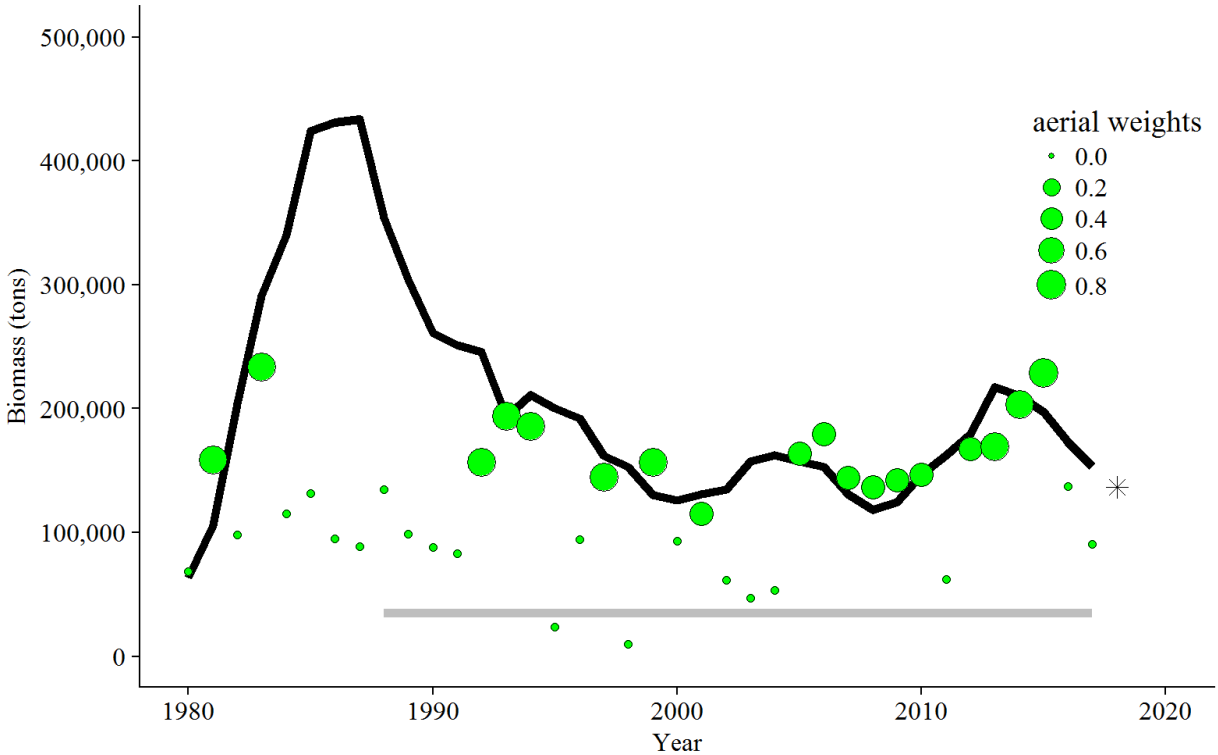

Figure 46: Aerial survey-estimated biomass plus pre-peak catch that were included in the model (green points), model-estimated mature biomass (black solid line), and model-estimated mature biomass forecast (black star). The size of the green points reflects the confidence weighting of each aerial survey estimate in the model based on weather, number of surveys, quality of surveys, and timing of surveys relative to the spawn (ranging from 0=no confidence to 1=perfect confidence). The gray line denotes the threshold.

most recent large recruitment event began to show up in the commercial harvest around 2009 at age-4. Williams and Quinn (2000) demonstrate that herring populations in the North Pacific are closely linked to environmental conditions, particularly water temperature. Tojo et al. (2007) demonstrate how the complex reproductive migration of EBS herring is related to temperature and the retreat of sea ice and how it has changed since the 1980s. We believe that closer examination of environmental conditions such as sea surface temperature, air temperature, and EBS ice coverage may increase our understanding of the recruitment processes at play in this population.

Implications: Togiak herring are an important forage fish for piscivorous fish, seabirds, and marine mammals as well as the basis for a directed herring sac roe fishery and the Dutch Harbor bait fishery. The cyclic nature of recruitment into this population has implications for predators and prey of herring as well as the fishery. The Alaska Department of Fish and Game considers this population healthy and sustainable at current harvest levels.

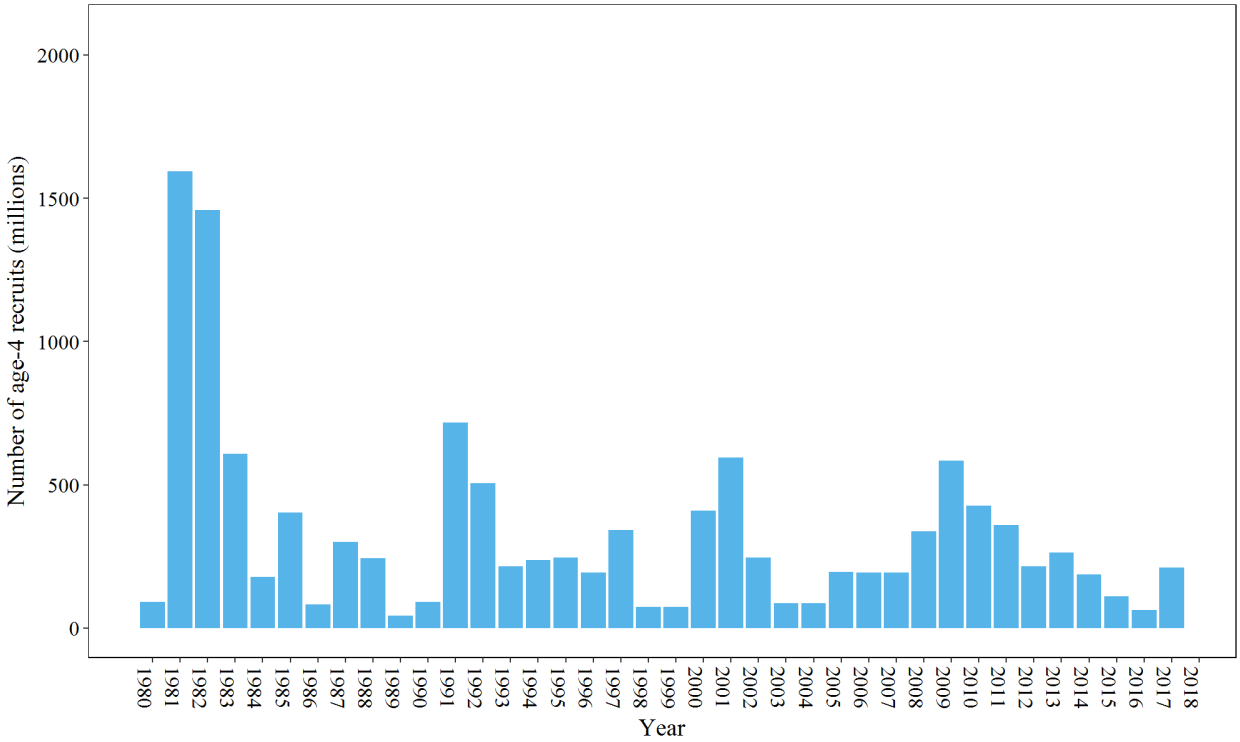

Figure 47: Model estimates of age-4 recruit strength (numbers of age-4 mature and immature fish).

Salmon

Juvenile Chinook Salmon Abundance in the Northern Bering Sea

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Last updated: October 2018

Description of indicator: An index of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) abundance was constructed for the Canadian-origin (Upper Yukon) stock group of the Yukon River, 2003–2017. Juvenile (first year at sea) abundance is estimated during late-summer (typically September) during surface trawl and oceanographic surveys in the northern Bering Sea. Estimates are based on trawl catch-per-unit-effort data, estimates of genetic stock composition, and mixed layer depth. Abundance for the Canadian-origin stock group have ranged from 0.6 million to 2.8 million juveniles with an overall average of 1.6 million juvenile Chinook salmon from 2003–2017 (Figure 48).

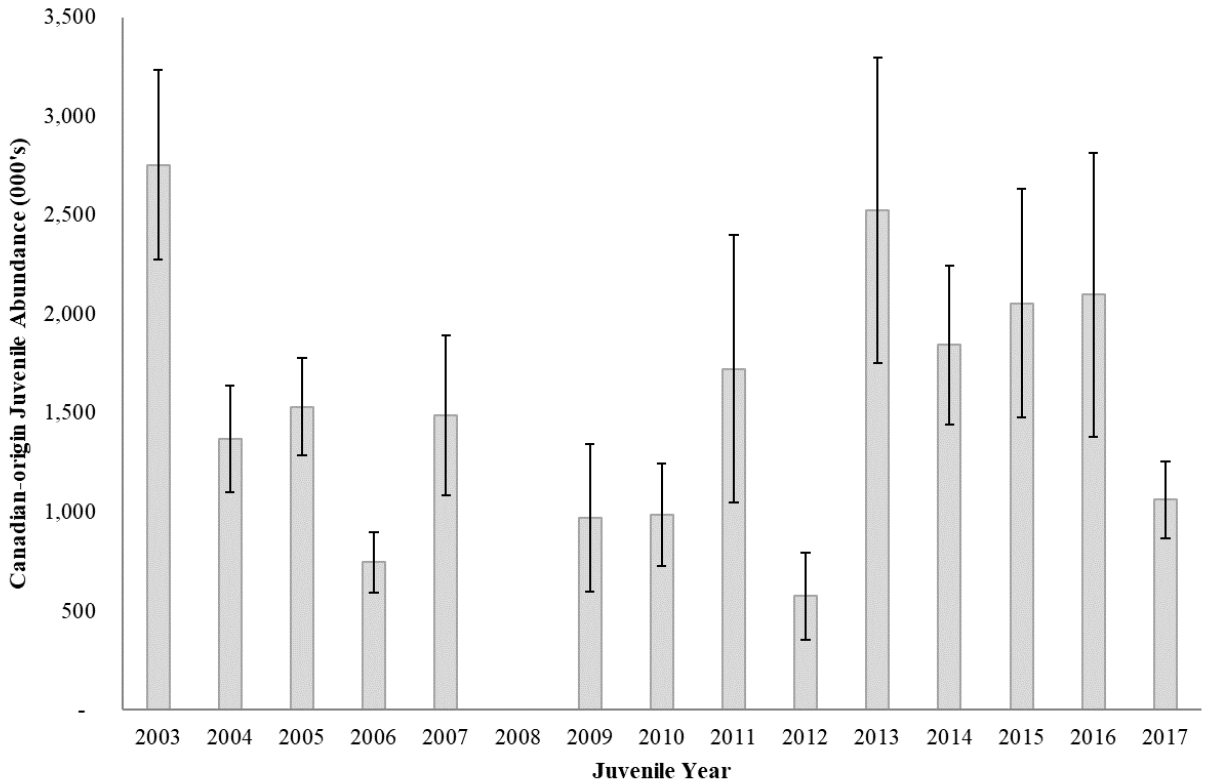

Figure 48: Juvenile abundance estimates for the Canadian-origin stock group of Chinook salmon in Yukon River, 2003–2017. Error bar range is one standard deviation above and below juvenile abundance estimates.

Status and trends: Although the 2017 juvenile abundance estimates have been finalized, data complications during the 2018 survey have prevented us from completing preliminary estimates for 2018. However, the 2018 catch of juvenile Chinook during the survey were among the lowest observed since 2003. It is likely that the 2018 estimate will be below average, marking the second consecutive year of below average juvenile Chinook salmon abundance in the northern Bering Sea.

Factors influencing observed trends: Changes in the early life-history (freshwater and early marine) survival, as indicated by the number of juveniles-per-spawner (Figure 49, is the primary factor impacting juvenile abundance in the northern Bering Sea. Estimates of juveniles-per-spawner in 2017 is the lowest we have observed since 2003. Juvenile abundance reflects both spawner abundance and the number of juveniles-per-spawner, and spawner abundance was also the highest we have observed since 2003.

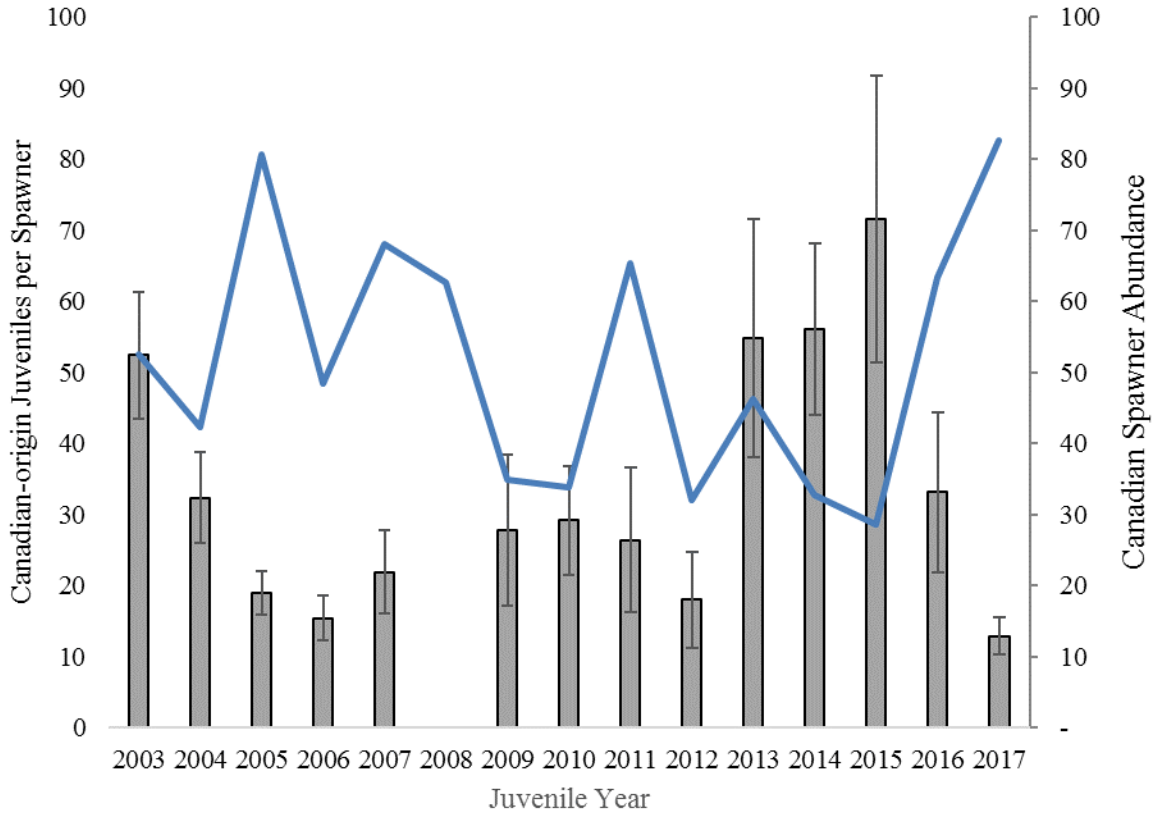

Figure 49: Estimated number of juveniles-per-spawner and spawner abundance for the Canadian-origin stock group of Chinook salmon in the Yukon River, 2003–2017. Error bar range is one standard deviation above and below juvenile abundance estimates.

Implications: Juvenile abundance of the Canadian-origin stock group is significantly correlated (r=0.84; Figure 50) with adult returns, indicating that much of the year-to-year variability in their survival occurs during their early life stages (freshwater and initial marine). The Canadian-origin stock group of Chinook salmon is the largest stock group of Chinook salmon in the Yukon River and has a complex management framework, directed by both domestic and international (US/Canada) management policies and decisions. Juvenile abundance has been used over the last five years to assist the pre-season fisheries management decisions in the Yukon River. Juvenile abundance also has important implications for anticipating implementation of bycatch caps based on adult abundance of Chinook salmon in the eastern Bering Sea pollock fishery. Assuming juvenile abundance continues to reflect future abundance, the abundance of immature and adult life-history stages of Yukon River Chinook salmon will be expected to decline over the next few years.

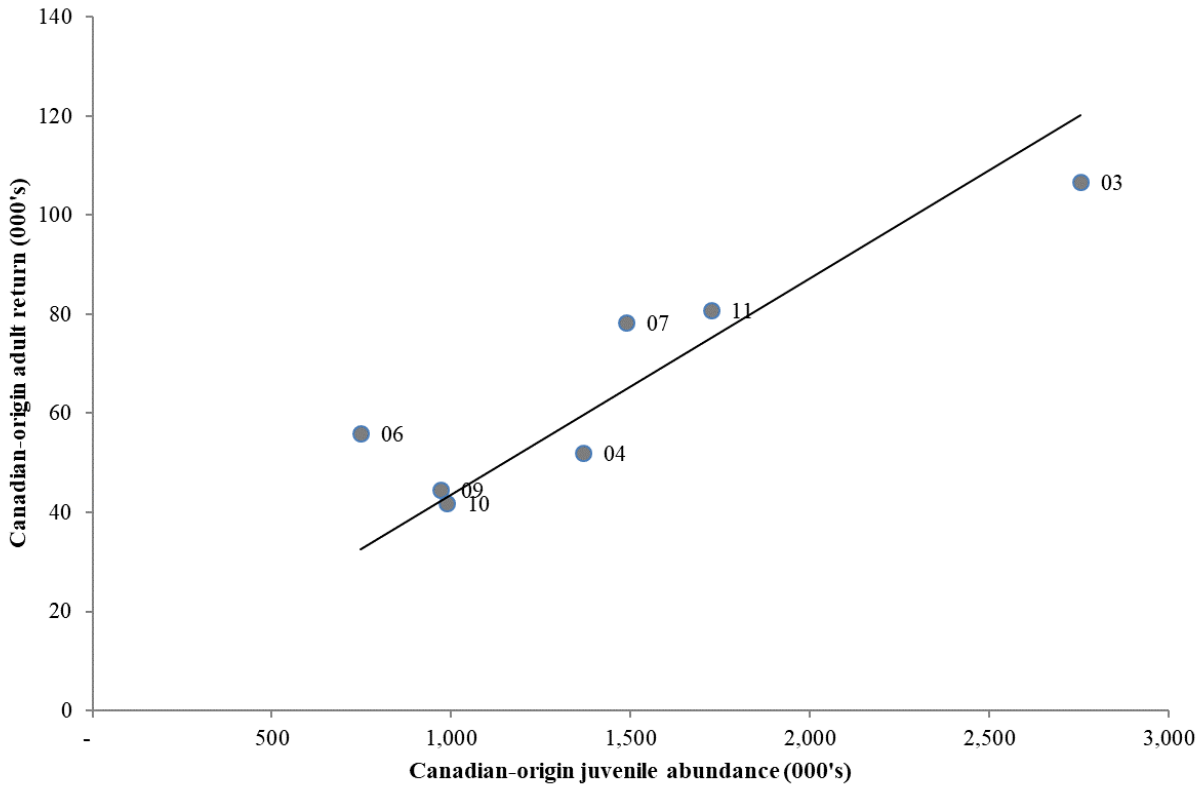

Figure 50: The relationship between juvenile abundance and adult abundance for the Canadian-origin stock group of Chinook salmon in the Yukon River for juvenile years 2003-2011. Adult abundance is the number of returning adults and only includes years where all juveniles have returned to the Yukon River. Adult returns and juvenile data from 2005 are not included because genetic proportion data were unavailable for apportionment.

Temporal Trend in the Annual Inshore Run Size of Bristol Bay Sockeye Salmon (*Oncorhynchus nerka*)

Contributed by Curry J. Cunningham[1], Gregory Buck[2], Katie Sechrist[2], Jordan Head[2]
[1]Auke Bay Laboratories, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[2]Alaska Department of Fish and Game, Anchorage, Alaska
Contact: curry.cunningham@noaa.gov
Last updated: September 2018

Description of indicator: The annual abundance of adult sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay, Alaska is enumerated by the Alaska Department of Fish and Game (ADF&G). The total inshore run in a given year is the sum of catches in five terminal fishing districts plus the escapement of sockeye to nine major river systems. Total catch is estimated based on the mass of fishery offloads and the average weight of individual sockeye within time and area strata. Escapement is the number of fish successfully avoiding fishery capture and enumerated during upriver migration toward the spawning grounds, or through post-season aerial surveys of the spawning grounds (Elison et al., 2018). Although there have been slight changes in the location and operation of escapement enumeration projects and methods over time, these data provide a consistent index of the inshore return abundance of sockeye salmon to Bristol Bay since 1963.

Status and trends: The 2018 Bristol Bay salmon inshore run of 63.0 million sockeye is the largest on record

since 1963 and is 55.8% higher than the recent 10-year average of 40.4 million sockeye, and 98.0% higher than the 1963–2017 average of 31.8 million sockeye. The temporal trend in Bristol Bay sockeye salmon run size indicates a large increase during the recent 4-year period, with inshore run sizes in 2015–2018 above recent and long-term averages (Figure 51). Also of note, inshore runs to the Nushagak District in 2018 and 2017 are the first and second highest on record since 1963, which at 33.5 and 20.0 million sockeye, respectively, were 395.4% and 196.1% higher than the 1963–2018 average of 6.8 million sockeye (Figure 52).

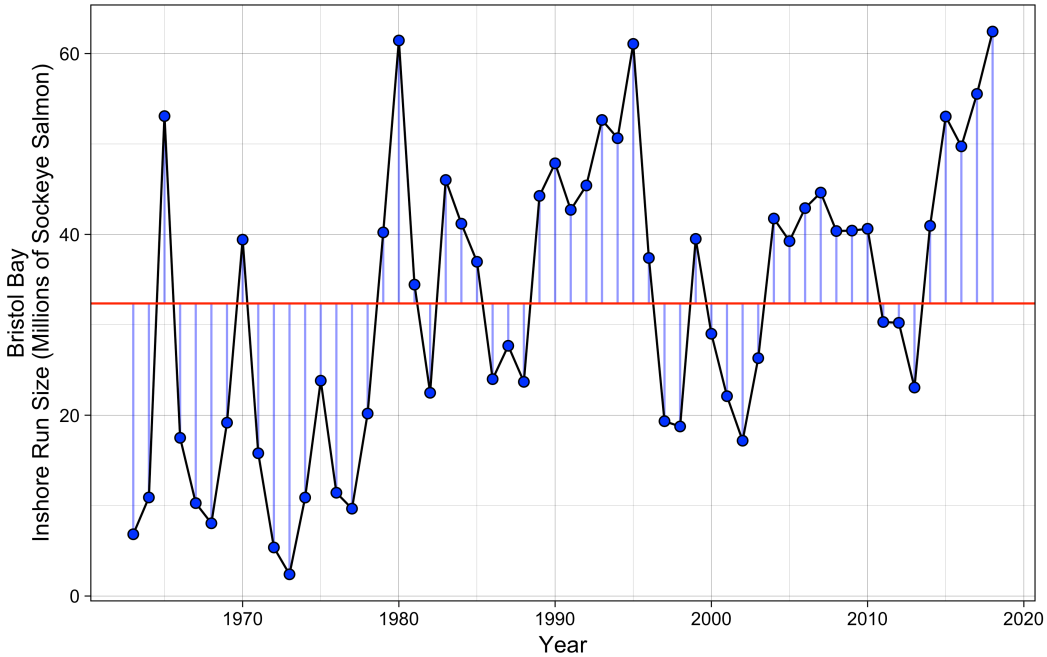

Figure 51: Annual Bristol Bay sockeye salmon inshore run size 1963–2018. Red line is the time series average of 32.4 million sockeye.

Factors influencing observed trends: The return abundance of Bristol Bay sockeye salmon is positively correlated with the Pacific Decadal Oscillation (Hare et al., 1999), specifically with Egegik and Ugashik district run sizes increasing after the 1976/1977 regime shift. The abundance and growth of Bristol Bay sockeye salmon has also been linked to the abundance of pink salmon (*Oncorhynchus gorbuscha*) in the North Pacific (Ruggerone and Nielsen, 2004; Ruggerone et al., 2016).

Implications: The high inshore run of Bristol Bay sockeye salmon in 2018 and the preceding 3-year period indicate positive survival conditions for these stocks while in the ocean. Given evidence that the critical period for sockeye salmon survival occurs during the first summer and winter at sea (Beamish and Mahnken, 2001; Farley et al., 2007, 2011) and the predominant age classes observed for Bristol Bay stocks are 1.2, 1.3, 2.2, and 2.3 (European designation: years in freshwater–years in the ocean), the large 2018 Bristol Bay sockeye salmon inshore run suggests these stocks experienced positive conditions at entry into the southeastern Bering Sea in the summer of 2015–2016 and winter of 2016–2017.

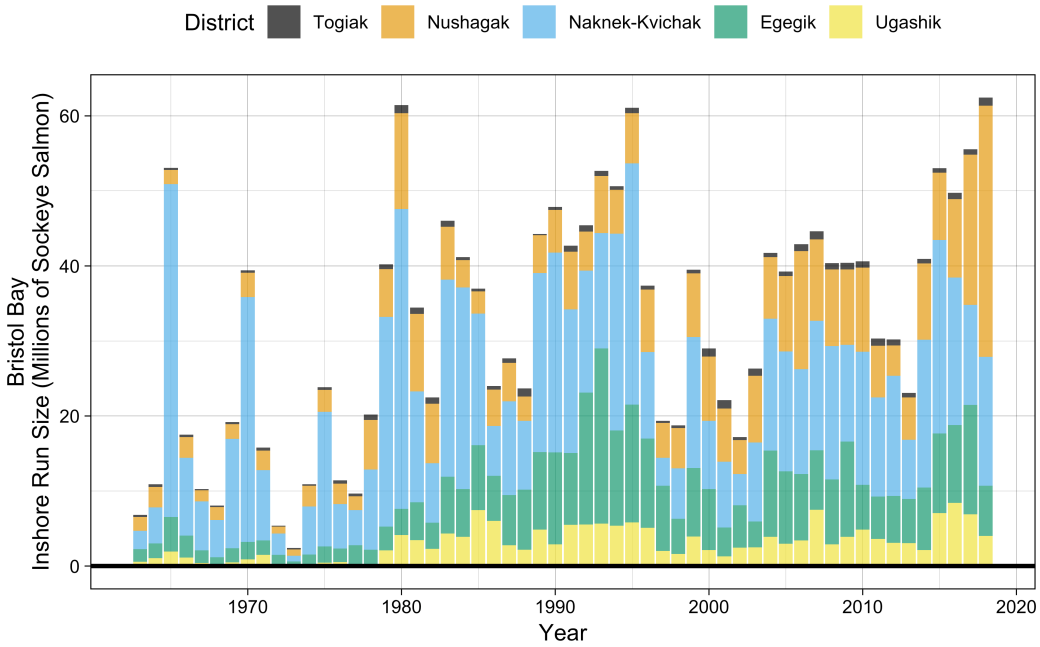

Figure 52: Annual Bristol Bay sockeye salmon inshore run size 1963–2018 by commercial fishing district.

Groundfish

Eastern Bering Sea Groundfish Condition

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Last updated: October 2018

Description of indicator: Length-weight residuals are an indicator of somatic growth (Brodeur et al., 2004) and, therefore, a measure of fish condition. Fish condition is an indicator of how heavy a fish is per unit body length, and may be an indicator of ecosystem productivity. Positive length-weight residuals indicate fish are in better condition (i.e., heavier per unit length); whereas, negative residuals indicate fish are in poorer condition (i.e., lighter per unit length). Fish condition may affect fish growth and subsequent survival (Paul et al., 1997; Boldt and Haldorson, 2004).

The AFSC eastern Bering Sea shelf bottom trawl survey data was utilized to acquire lengths and weights of individual fish for Walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), Arrowtooth flounder (*Atheresthes stomias*), Yellowfin sole (*Limanda aspera*), Flathead sole (*Hippoglossoides elassodon*), Northern rock sole (*Lepidopsetta polyxystra*), and Alaska plaice (*Pleuronectes quadrituberculatus*) (Figure 53). Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 82 and 90 are included in the analyses but they are not sampled in every year of the time series.

Length-weight relationships for each of the seven species were estimated with a linear regression of log-transformed values over all years where data was available (during 1982–2018). Additionally, length-weight relationships for age 1+ walleye pollock (length from 100–250 mm) were also calculated independent from the adult life history stages. Predicted log-transformed weights were calculated and subtracted from measured log-transformed weights to calculate residuals for each fish. Length-weight residuals were averaged for the entire EBS and for the strata sampled in the summer survey. Temporal and spatial patterns in residuals were examined.

Status and trends: Length-weight residuals have varied over time for all species with a few notable patterns (Figure 54). Residuals for all species where there was data were negative in 1999, a cold year in the Bering Sea. Residuals became positive or more positive in 2002 for five of the seven species examined. Flatfish residuals were generally positive from 2002 to 2004 or 2005 depending on species. Age-1 pollock and Pacific cod residuals were positive from 2001 to 2004 or 2005. In 2008, all species except Flathead sole and pollock had negative residuals. There has been a distinct negative trend in Pacific cod since a peak value in 2003. Condition of pollock older than age-1 in 2018 was the second lowest on record and continued a decreasing trend. Age-1 pollock and older pollock were not well correlated in most years. Length-weight residuals for most species increased or were the same from 2017 to 2018. The exceptions were pollock and Alaska plaice which had lower condition in 2018 relative to 2017.

In the northern Bering Sea, two species (pollock and cod) have been sampled consistently when these survey strata are completed. The existing time series for these species is shown in (Figure 54). In 2018, Pacific cod and juvenile pollock both had higher than average condition in the northern Bering Sea (relative to the entire Bering Sea fish population). Adult pollock had lower than average condition in the northern Bering Sea, consistent with the rest of the eastern Bering Sea (Figures 54 and 55).

Spatial trends in residuals were also apparent for some species (Figure 56). Generally, fish were in better

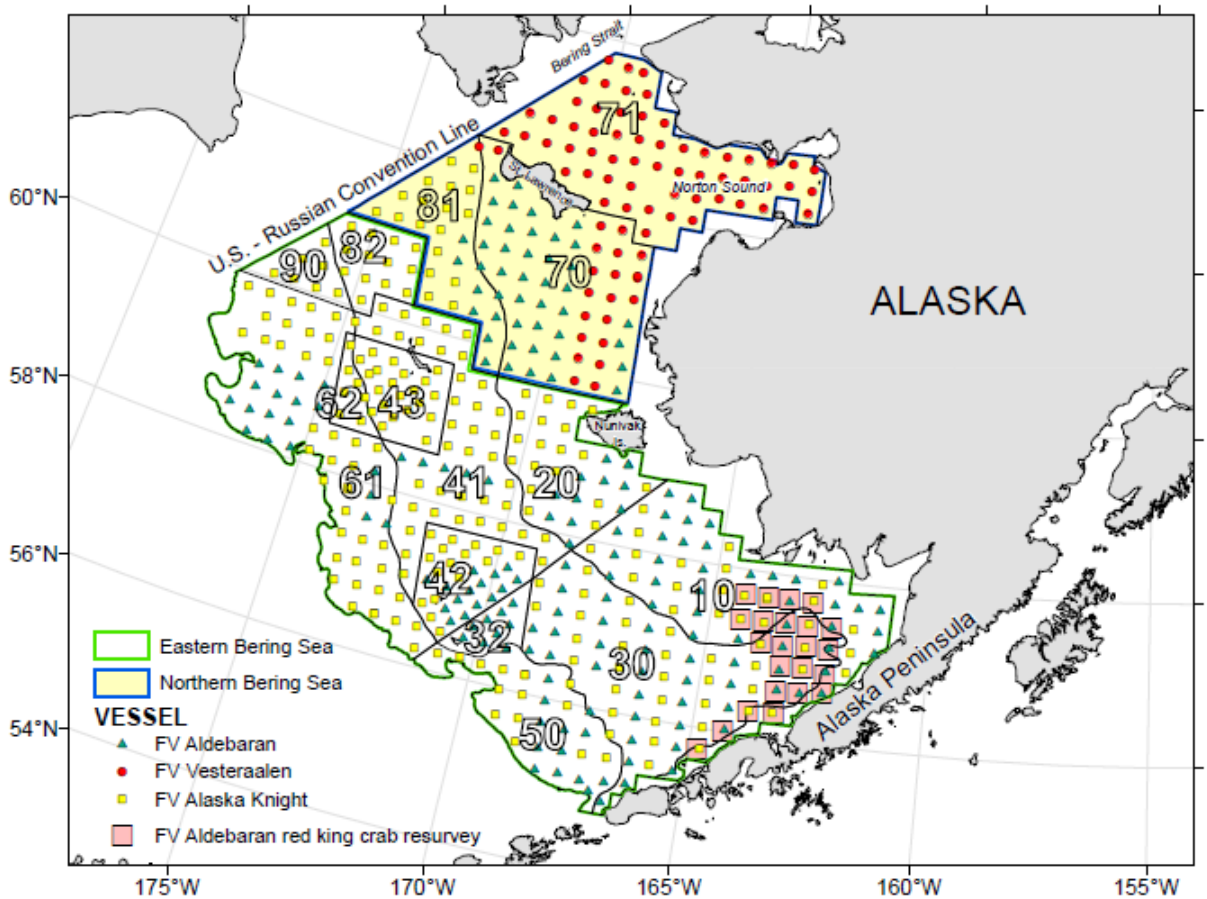

Figure 53: NMFS summer bottom trawl survey strata (from Lauth (2011)). Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 70, 71, and 81 were combined into northern Bering Sea stratum (identified as NBS). Note that strata 70, 71, 81, 82, and 90 are not standard survey strata and they are not sampled in every year.

condition on the outer shelf and to the north (strata 50, 60, 82, and 90). For all species except Yellowfin sole (which did not occur in outer shelf strata), residuals were almost always positive on the northern outer shelf (strata 60, 82, and 90). For Yellowfin sole, residuals were positive in the outermost shelf strata in which they occurred (stratum 40) except in 1999. In addition to having positive residuals on the outer shelf, gadids tended to have negative residuals on the inner shelf. Pollock residuals were generally positive in strata 50 and 60 and negative in strata 10, 20, and 40. Pacific cod residuals were generally positive in strata 60-90 and negative in strata 10 and 20. In 2018, cod residuals were highest in strata 60-90. Spatial patterns in flatfish residuals were also apparent but varied among species. Alaska plaice residuals were almost always negative in stratum 40. Flathead sole residuals were often positive in strata 40.

Factors influencing observed trends: One potential factor causing the observed temporal variability in length-weight residuals is temperature. The year 1999 was a particularly cold year in the Bering Sea and also a year of negative length-weight residuals for all groundfish examined (where data existed). Despite the abundant large crustacean zooplankton and relatively high microzooplankton productivity present in 1999 (Hunt et al., 2008), the spatial distribution of some groundfish species is affected by temperatures and a cold year may, therefore, have affected the spatial overlap of fish and their prey. Cold temperatures may

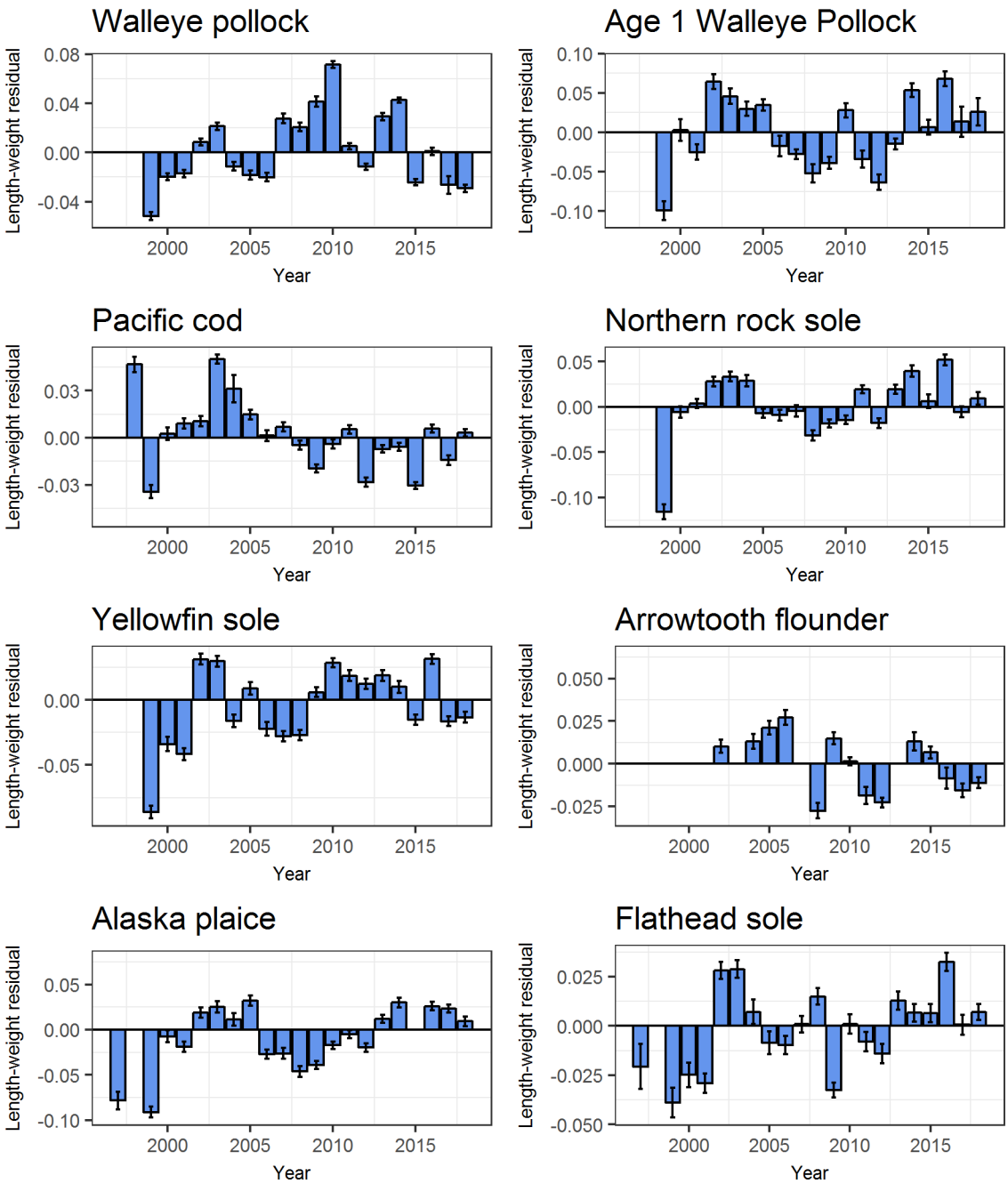

Figure 54: Length-weight residuals for seven eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997–2018.

have also affected fish energy requirements and prey productivity. Conversely, the continuing warmer than normal 2016 temperatures across the Bering Sea shelf may have resulted in negative trends for length-weight residuals.

Other factors that could affect length-weight residuals include survey sampling timing and fish migration. The date of the first length-weight data collected annually varied from late May to early June (except 1998, where the first data available was collected in late July). Also, the bottom trawl survey is conducted

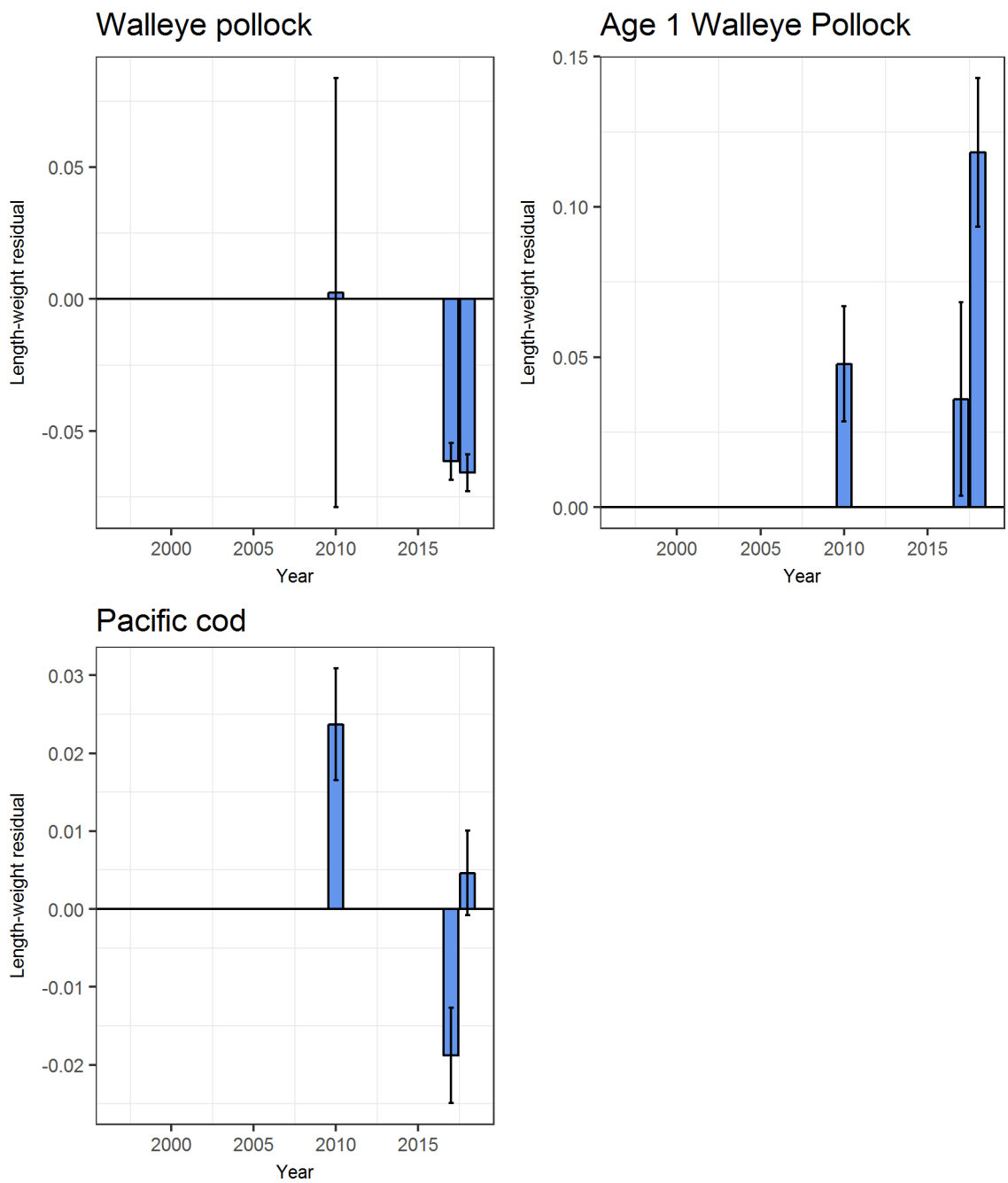

Figure 55: Length-weight residuals for two eastern Bering Sea groundfish sampled in the Northern Bering Sea strata during the summer bottom trawl survey (2010, 2017, and 2018).

throughout the summer months, and as the summer progresses, we would expect fish condition to improve. Since the survey begins on the inner shelf and progresses to the outer shelf, the higher fish condition observed on the outer shelf may be due to the fact that they are sampled later in the summer. We also expect that some fish will undergo seasonal and, for some species, ontogenetic migrations through the survey months. For example, seasonal migrations of pollock occur from overwintering areas along the outer shelf to shallow waters (90–140 m) for spawning (Witherell, 2000). Pacific cod concentrate on the shelf edge and upper slope (100–250 m) in the winter, and move to shallower waters (generally <100 m) in the summer (Witherell,

Figure 56: Length-weight residuals for seven eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997–2018, by survey strata (10–90). NMFS summer bottom trawl survey strata are shown in the top left panel. Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40; stratum 82 is listed as stratum 80.

2000). Arrowtooth flounder are distributed throughout the continental shelf until age 4, then, at older ages, disperse to occupy both the shelf and the slope (Witherell, 2000). Flathead sole overwinter along the outer shelf, and move to shallower waters (20–180 m) in the spring (Witherell, 2000). Yellowfin sole concentrate on the outer shelf in the winter, and move to very shallow waters (<30 m) to spawn and feed in the summer

(Witherell, 2000). How these migrations affect the length-weight residuals is unknown at this time.

Implications: A fish's condition may have implications for its survival. For example, in Prince William Sound, the condition of Pacific herring prior to the winter may in part determine their survival (Paul and Paul, 1998). The condition of Bering Sea groundfish, may therefore partially contribute to their survival and recruitment. In the future, as years are added to the time series, the relationship between length-weight residuals and subsequent survival can be examined further. It is likely, however, that the relationship is more complex than a simple correlation. Also important to consider is the fact that condition of all sizes of fish were examined and used to predict survival. Perhaps, it would be better to examine the condition of juvenile fish, not yet recruited to the fishery, or the condition of adult fish and correlations with survival.

Multispecies Model Estimates of Time-varying Natural Mortality

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Last updated: October 2018

Description of indicator: We report trends in age-1 total mortality for Walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), and Arrowtooth flounder (*Atheresthes stomias*) from the eastern Bering Sea. Total mortality rates are based on residual mortality inputs (M1) and model estimates of annual predation mortality (M2) produced from the multi-species statistical catch-at-age assessment model (known as CEATTLE; Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics). See Appendix 1 of the BSAI pollock stock assessment for 2019, Holsman et al. (2016), Holsman and Aydin (2015), Ianelli et al. (2016), and Jurado-Molina et al. (2005) for more information.

Status and trends: Estimated age-1 natural mortality (i.e., M1+M2) for pollock, Pacific cod, and Arrowtooth flounder peaked in 2016. At 1.67 yr^{-1} age-1 mortality estimated by the model was greatest for pollock and lower for Pacific cod and Arrowtooth flounder, with total age-1 natural mortality stable at around 0.67 and 0.62 yr^{-1}. In 2018, for the fourth year in a row, pollock natural mortality remained slightly elevated relative to the long-term mean (Figure 57), while Pacific cod and Arrowtooth flounder mortality were at and below the long-term mean, respectively.

The total biomass of each species consumed by the predators in the model reflects patterns in age-1 natural mortality. In 2018, the total biomass of pollock consumed increased slightly from 2017 and was above average. Meanwhile, Pacific cod and Arrowtooth flounder biomass consumed was near and below the long-term means, respectively. While pollock and Pacific cod estimates were within the 95% CI, estimates of Arrowtooth flounder consumed were below the 95% CI for the long-term mean (Figures 58 & 59).

Factors influencing observed trends: Temporal patterns in natural mortality reflect annually varying changes in predation mortality that primarily impact age 1 fish (but also impact ages 2 and 3 fish in the model). Pollock are primarily consumed by older conspecifics, and pollock cannibalism accounts for 59% (on average) of total age-1 predation mortality on average, with the exception of the years 2006–2008 when predation by Arrowtooth flounder exceeded cannibalism as the largest source of predation mortality of age-1 pollock; Figure 60).

Combined annual predation demand (annual ration) of pollock, Pacific cod, and Arrowtooth flounder in 2018 was 6.63 million tons, down slightly from the 7.67 million t annual average during the warm years of 2014–2016. Pollock represent approximately 81% of the model estimates of combined prey consumed with a long term average of 5.2 million tons of pollock consumed annually by all three predators in the model (Figure 61).

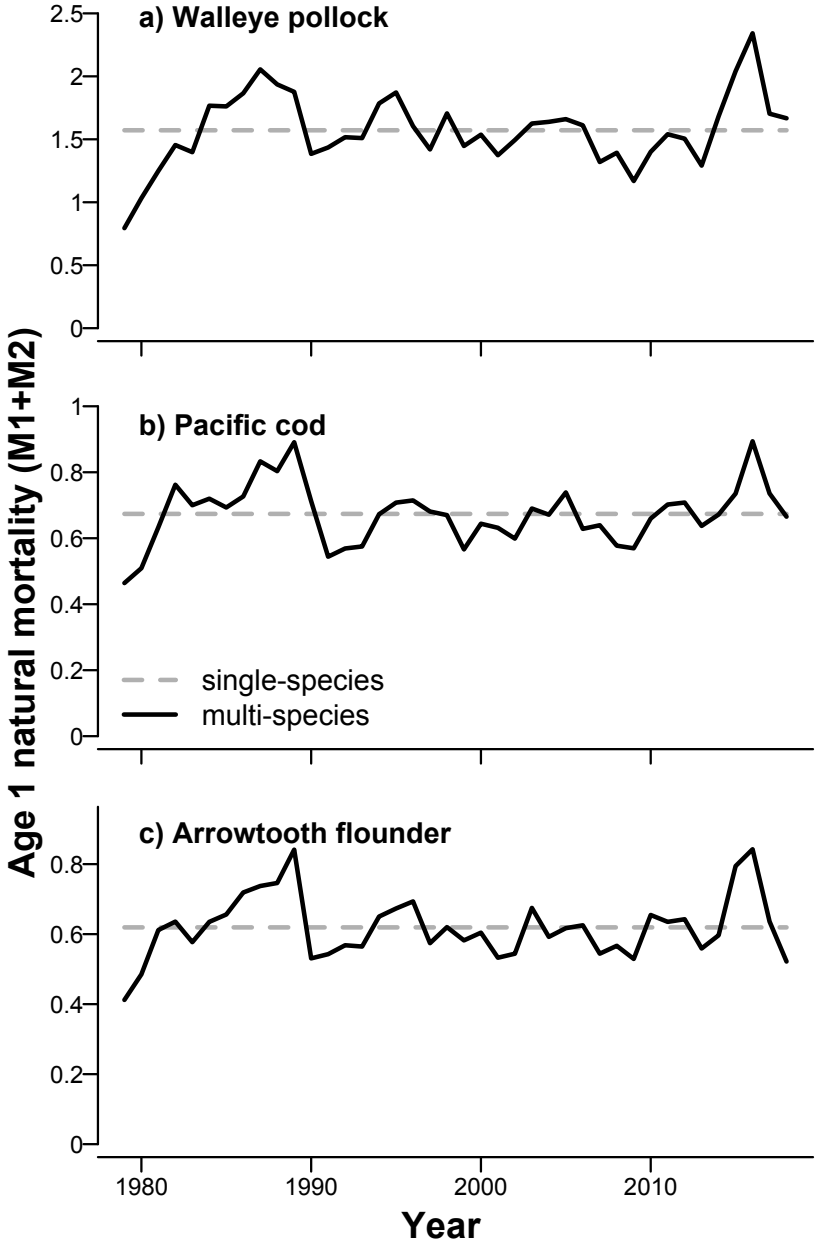

Figure 57: Annual variation in total mortality ($M1_{i1} + M2_{i1,y}$) for age-1 pollock (a), Pacific cod (b), and Arrowtooth flounder (c) from the single-species models (dashed gray line) and the multi-species models with temperature (black line). Updated from Holsman and Aydin (2015); more model detail can be found in Appendix 1 of the BSAI pollock stock assessment for 2019.

Implications: We find evidence of continued elevated rates of predation mortality on age-1 pollock, while Pacific cod and Arrowtooth flounder predation rates appear to be much lower than in previous years. This pattern may reflect higher metabolic (and energetic) demand of predators under warm conditions combined with maturing large 2010–2012 age classes of pollock and Pacific cod that have increased predator demand in the EBS (Holsman and Aydin, 2015; Spencer et al., In press; Hunsicker et al., 2013; Zador et al., 2011). This pattern may also explain and reflect low model estimates of recruitment of EBS pollock and Pacific cod

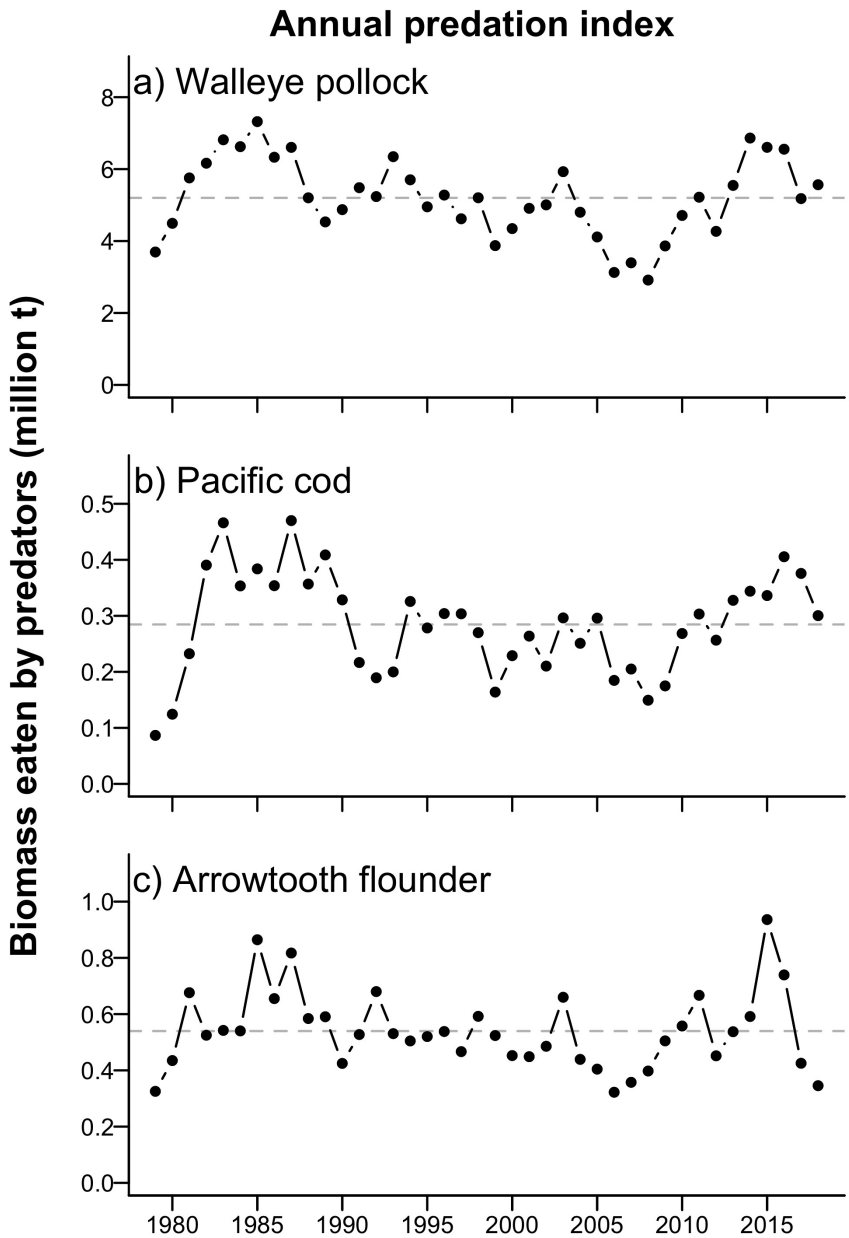

Figure 58: Multispecies estimates of prey species biomass consumed by all predators in the model a) total biomass of pollock consumed by predators annually b) total biomass of Pacific cod consumed by predators annually, c) total biomass of Arrowtooth flounder consumed by predators annually. Gray lines indicate 1979–2018 mean estimates for each species.

in recent years.

Between 1980 and 1993, relatively high natural mortality rates reflect patterns in combined annual demand for prey by all three predators that was highest in the mid 1980's (collectively 8.11 million t per year), and in recent years (collectively 7.41 million t per year). The peak in predation mortality of age-1 pollock in 2006 corresponds to the maturation of a large age class of 5–7 year old pollock and 2 year old Pacific cod

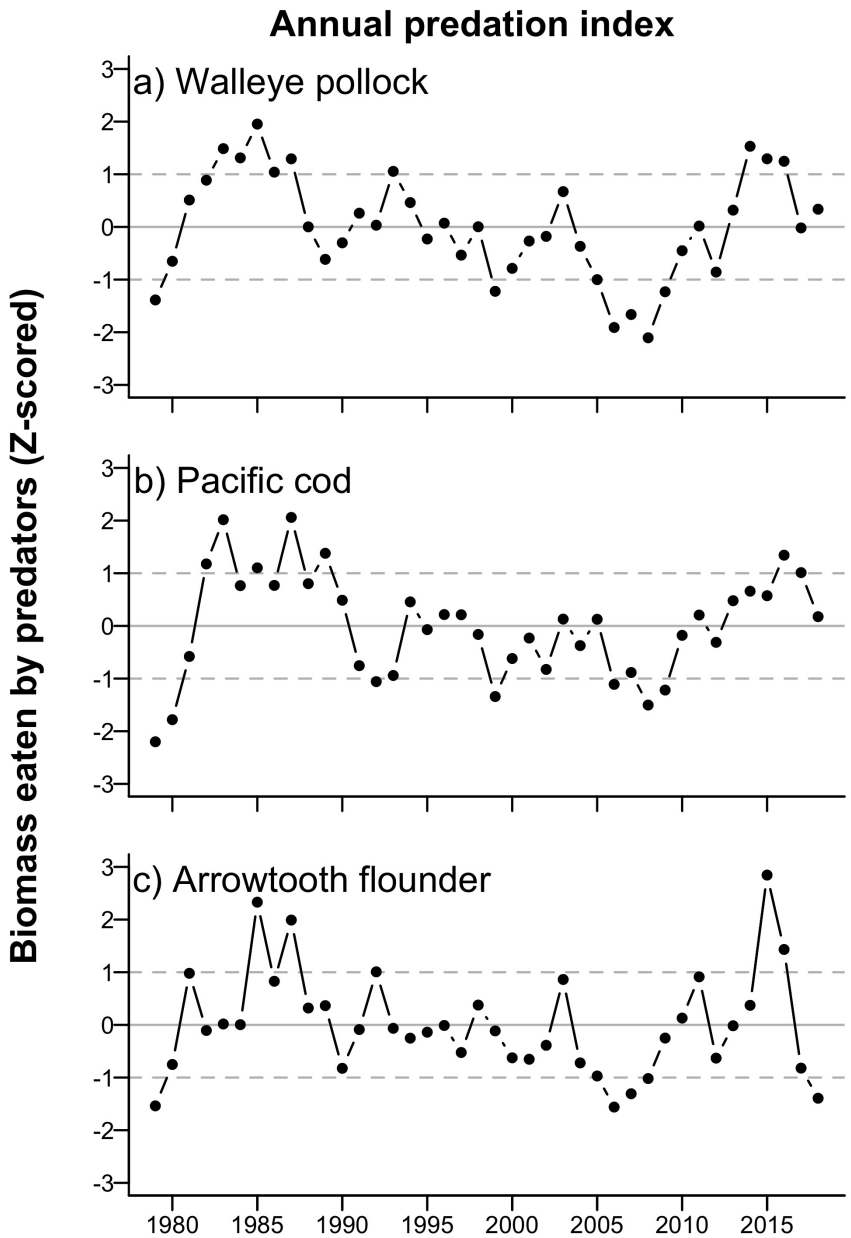

Figure 59: Multispecies estimates of prey species biomass consumed by all predators in the model Z-score scaled to the mean and standard deviation for each species a) total biomass of pollock consumed by predators annually b) total biomass of Pacific cod consumed by predators annually, c) total biomass of Arrowtooth flounder consumed by predators annually. Gray lines indicate 1979–2018 mean estimates and 1 SD for each species.

that dominated the age composition of the two species in 2006. Similarly, the recent peaks in mortality in 2016 reflect maturation of the large 2012 year class of pollock.

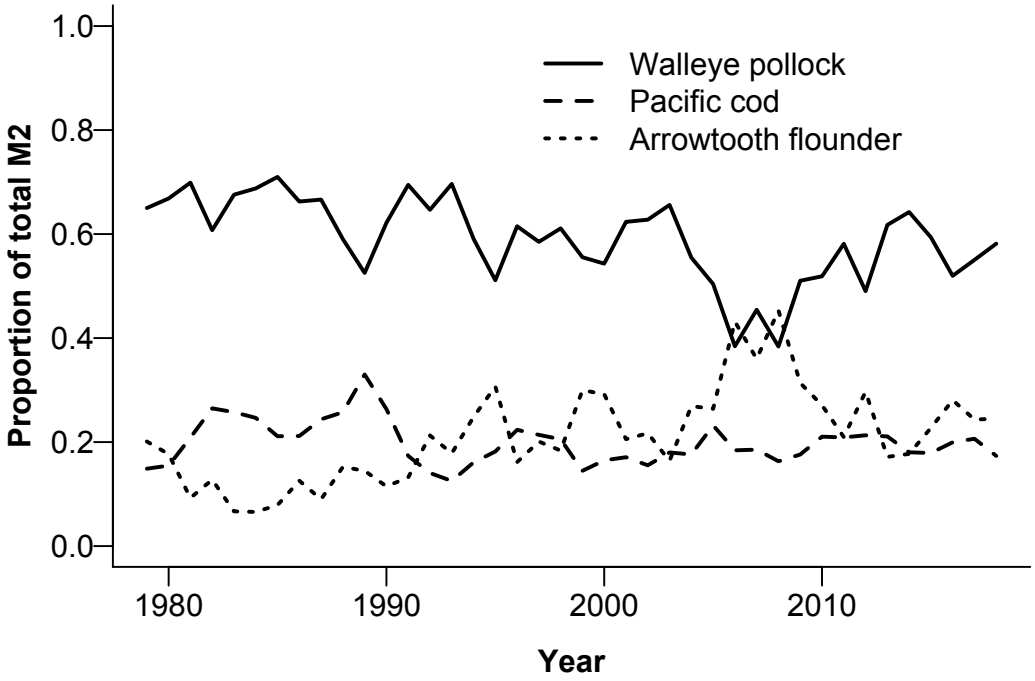

Figure 60: Proportion of total predation mortality for age-1 pollock from pollock (solid), Pacific cod (dashed), and Arrowtooth flounder (dotted) predators across years. Updated from Holsman et al. (2016); more model detail can be found in Appendix 1 of the BSAI pollock stock assessment for 2019.

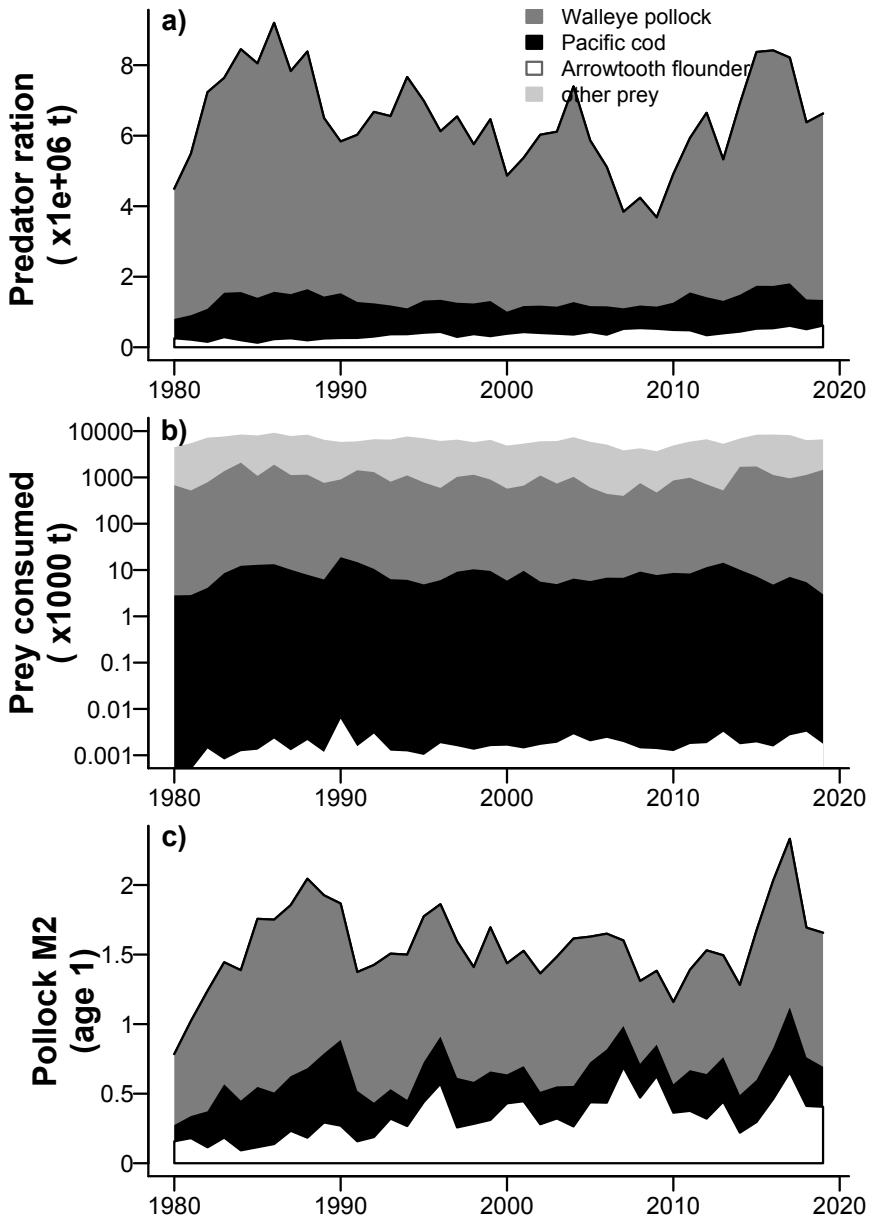

Figure 61: Multispecies estimates of annual predator demand for prey, prey consumed, age-1 natural mortality of pollock a) Combined total predator ration (tons; all three predators combined) over time grouped by predator. b) Total prey consumed by all three predators combined (note the log scale). c) Pollock predation mortality (M2; age-1 only) consumed by each predator species.

Groundfish Recruitment Predictions

Age-0 Recruitment of Pacific Cod (*Gadus macrocephalus*) in the Southeastern Bering Sea as Predicted by the Average of the North Pacific Index from October through December

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Last updated: September 2018

Description of indicator: The North Pacific Index (NPI) was developed by Trenberth and Hurrell (1994), and represents the area-weighted sea level pressure over the region 30°N–65°N, 160°E–140°W. Monthly values of the NPI since January 1899 are reported at `https://climatedataguide.ucar.edu/sites/default/files/npindex_monthly.txt`. Specifically, the indicator used in this analysis is the average of the monthly NPI values from October–December in each year.

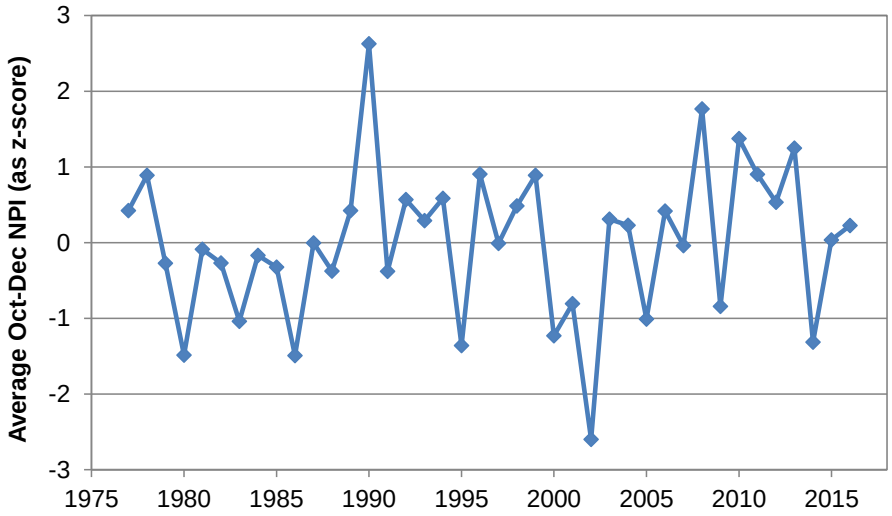

Figure 62: Average North Pacific Index (NPI) between October–December. The z-score is calculated as the average Oct.–Dec. NPI minus the mean of the time series divided by the standard deviation of the time series.

In the 2012 assessment of the eastern Bering Sea (EBS) stock of Pacific cod (*Gadus macrocephalus*) (Thompson and Lauth, 2012), annual log-scale recruitment deviations (from the mean) estimated by the assessment model were regressed against each of several environmental indices summarized by Zador et al. (2011). The highest univariate correlation was obtained for the spring–summer NPI. Further investigations were conducted with monthly NPI data from the website referenced above. The best univariate model obtained in the 2012 analysis was a linear regression of recruitment deviations from 1977–2011 against the October–December average NPI (from the same year). Vestfals et al. (2014) also noted a positive correlation between Pacific cod recruitment and the NPI, although not the October–December average NPI in particular.

Status and trends: The 2017 assessment of the EBS stock of Pacific cod (Thompson, 2017) presented the 1977–2016 time series shown in Figure 62. The trend depends on the range of years considered. If the regression starts in 2014 or 2015, the trend is positive; if the regression starts anywhere from 2006 through 2013, the trend is negative; and if the regression starts anywhere from 1991 through 2005, the trend is

positive.

In each assessment since 2012, the regression analysis has been updated. The regression in the 2017 assessment (Thompson, 2017) resulted in a correlation of 0.53 (R^2=0.28). The time series, regression line, and 95% confidence interval from the 2017 regression are shown in Figure 63. According to this regression, the probability of the 2016 year class being higher than the median for the time series is 56%. However, the datum for 2016 (magenta diamond in Figure 63) falls quite a bit below the predicted value from the regression. In fact, the error for 2016 is the largest (in absolute value) in the time series. The data for 2015 (red diamond in Figure 63) and 2016 mark the only two times in the last 12 years (cohorts) that the sign of the difference from the mean estimated by the assessment model differs from the sign predicted by the regression.

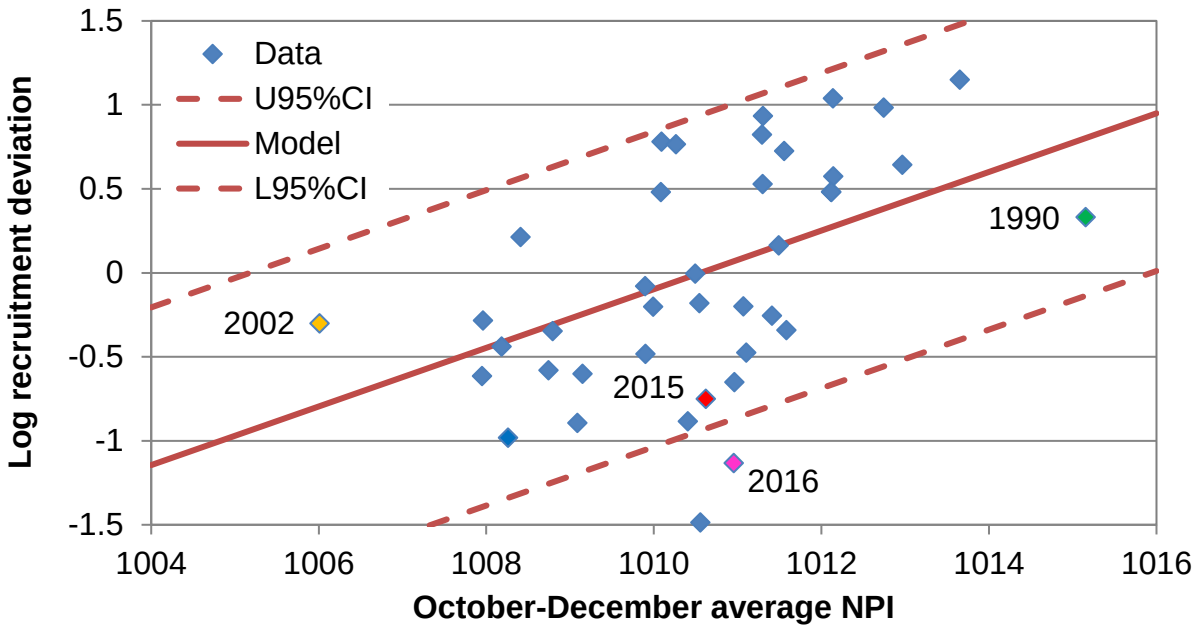

Figure 63: Estimated log recruitment deviations of age-0 Pacific cod versus same-year October–December average of the North Pacific Index, with regression line and 95% confidence interval.

Factors influencing observed trends: Two years, 1990 and 2002 (yellow and green diamonds in Figure 63), turned out to be far more influential than any other year in determining the magnitude of the estimated slope, and both of these influences were negative. In other words, the positive slope is not due to the influence of outliers; if anything, the outliers are making the relationship appear less strong than would be the case without them.

Circulation patterns over the EBS shelf vary with large-scale climate drivers such as the Pacific Decadal Oscillation (see p. 55). The strength of the Bering Slope Current is correlated with the NPI (Vestfals et al., 2014) with higher NPI values related to weaker along-shelf transport. The positive relationship between the NPI and Pacific cod recruitment may indicate that weaker circulation leads to better retention of age-0 fish in suitable nursery habitats (Vestfals et al., 2014).

Implications: Potential uses of the estimated relationship in the context of fishery management are: 1) as an independent means of corroborating initial estimates of year class strength, which are not made until the year class reaches age-1 (the first age at which the fish show up in the EBS shelf bottom trawl survey); 2) as a determinant of year class strength within the stock assessment model itself; and 3) in the event that the average October–December NPI can be forecast into the future, as a means of forecasting future year class strengths.

Pre- and Post-Winter Temperature Change Index and the Recruitment of Bering Sea Pollock

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Last updated: August 2018

Description of indicator: The temperature change (TC) index is a composite index for the pre-and post-winter thermal conditions experienced by Walleye pollock (*Gadus chalcogrammus*) from age-0 to age-1 in the southeastern Bering Sea (Martinson et al., 2012)). The TC index (year t) is calculated as the difference in the average monthly sea surface temperature in June (t) and August (t-1) (Figure 64) in an area of the southern region of the eastern Bering Sea (56.2°N to 58.1°N by 166.9°W to 161.2°W). Time series of average monthly sea surface temperatures were obtained from the NOAA Earth System Research Laboratory Physical Sciences Division website. Sea surface temperatures were based on NCEP/NCAR gridded reanalysis data (Kalnay et al. (1996), data obtained from `http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl`). Less negative values represent a cool late summer during the age-0 phase followed by a warm spring during the age-1 phase for pollock.

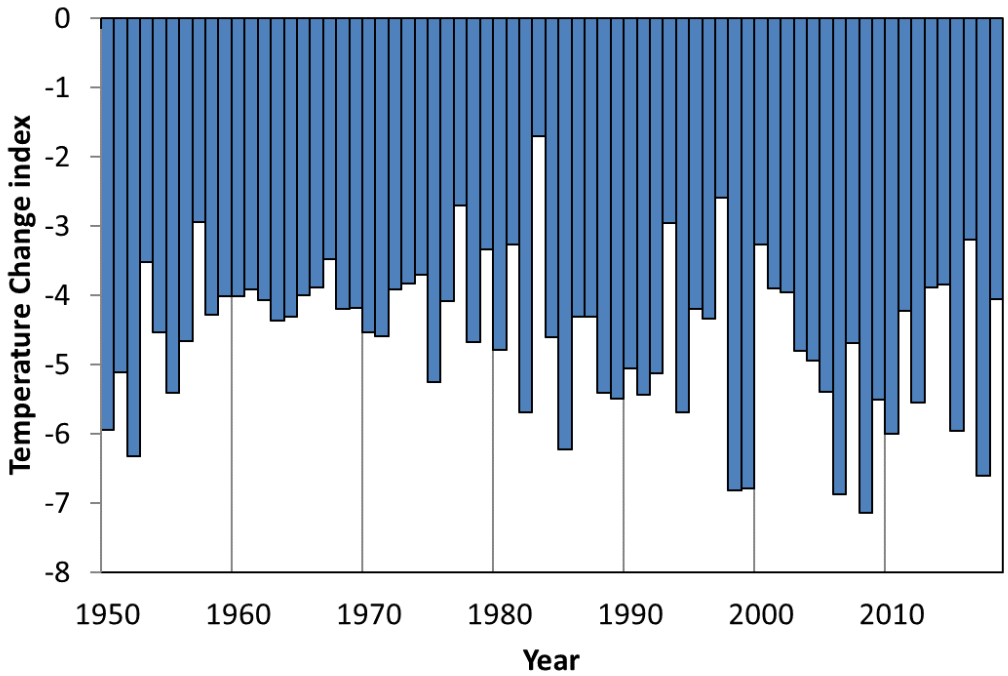

Figure 64: The Temperature Change index values from 1949 to 2018. Values represent the differences in sea temperatures on the southeastern Bering Sea shelf experienced by the 1948–2017 year classes of pollock. Less favorable conditions (more negative values) represent a warm summer during the age-0 life stage followed by a relatively cool spring during the age-1 life stage. More favorable conditions (less negative values) represent a cool summer during the age-0 life stage followed by a relatively warm spring during the age-1 life stage.

Status and trends: The 2018 TC index value is -4.06, higher than the 2017 TC index value of -6.61, indicating improved conditions for pollock survival from age-0 and age-1 from 2017 to 2018, respectively. The

Table 3: Pearson's correlation coefficient relating the Temperature Change index to subsequent estimated year class strength of pollock. Bold values are statistically significant ($p < 0.05$).

	Correlations					
	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6
1964–2017	**0.35**	**0.35**	**0.33**	0.27	0.23	0.21
1996–2017	0.38	0.40	**0.44**	0.39	0.36	0.41

decrease in expected survival is due to the larger difference in sea temperature from late summer (warmer) to the following spring (cooler). However, both the late summer sea surface temperature (10.67°C) in 2017 and spring sea temperatures (6.61°C) in 2018 were warmer than the long-term average of 9.8°C in late summer and 5.2°C in spring since 1949. The TC index was positively correlated with subsequent recruitment of pollock to age-1 through age-4 from 1964 to 2018, but not significantly correlated for the shorter period (1997–2018) (Table 3).

Factors causing observed trends: According to the original Oscillating Control Hypothesis (OCH), warmer spring temperatures and earlier ice retreat led to a later oceanic and pelagic phytoplankton bloom and more food in the pelagic waters at an optimal time for use by pelagic species (Hunt et al., 2002). The revised OCH indicated that age-0 pollock were more energy-rich and have higher over wintering survival to age-1 in a year with a cooler late summer (Coyle et al., 2011; Heintz et al., 2013). Therefore, the colder, later summers during the age-0 phase followed by warmer spring temperatures during the age-1 phase are assumed favorable for the survival of pollock from age-0 to age-1. The 2017 year class of pollock experienced a warm to average summer during the age-0 stage and a warm to average spring in 2018 during the age-1 stage indicating slightly above average conditions for over wintering survival from age-0 to age-1.

Implications: The 2018 TC index value of -4.06 was slightly above the long-term average of -4.61, therefore we expect average recruitment of pollock to age-3 in 2020 from the 2017 year class. The 2017 TC index value of -6.16 was below the long-term average, therefore we expect lower than average recruitment of pollock to age-3 in 2019 from the 2016 year class. The 2016 TC index value of -3.19 was above the long-term average, therefore we expect slightly above average recruitment of pollock to age-3 in 2018 from the 2015 year class. The 2015 TC index value of -5.96 was below the long-term average, therefore we expect slightly below average recruitment of pollock to age-3 in 2017 from the 2014 year class (Figure 65).

Large copepod abundance (observed and modeled) as an indicator of pollock recruitment to age-3 in the southeastern Bering Sea

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Last updated: August 2018

Description of indicator: Interannual variations in large copepod abundance were compared to age-3 walleye pollock (*Gadus chalcogrammus*) abundance (billions of fish) for the 2002–2016 year classes on the southeastern Bering Sea shelf, south of 60°N, < 200 m bathymetry. The large copepod index sums the abundances of *Calanus marshallae/glacialis* (copepodite stage 3 (C3)-adult), *Neocalanus* spp. (C3-adult), and *Metridia pacifica* (C4-adult), taxa typically important in age-0 pollock diets (Coyle et al., 2011; Siddon et al., 2013*a*; Strasburger et al., 2014). Zooplankton samples were collected with oblique bongo tows over the water column using 60 cm/505 μm mesh nets for 2002–2011, and 20 cm/153 μm mesh or 60 cm/505

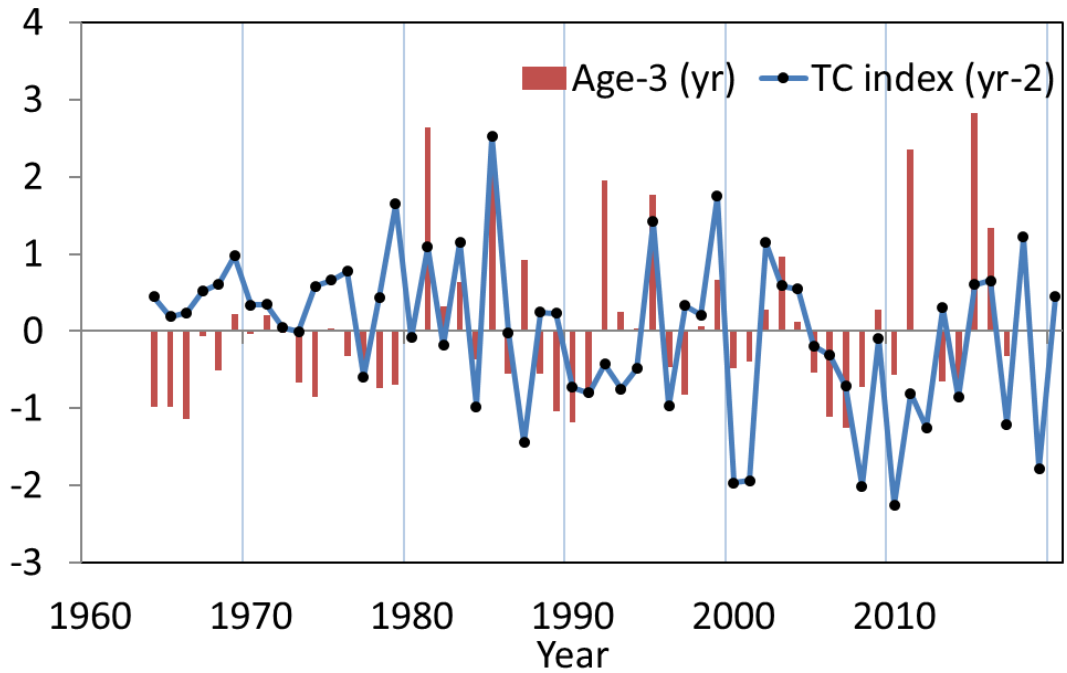

Figure 65: Normalized time series values of the temperature change index (t-2) from 1964–2020 indicating conditions experienced by the 1961–2017 year classes of pollock during the summer age-0 and spring age-1 life stages. Normalized values of the estimated abundance of age-3 Walleye pollock in the southeastern Bering Sea from 1964–2017 (t) for the 1961–2014 year classes. Age-3 Walleye pollock estimates are from Table 28 in Ianelli et al. (2017). The TC index indicates above average conditions for the 2015 and 2017 year class and below average conditions for the 2016 year classes of pollock.

μm nets, depending on taxa and stage for 2012–2016. Data were collected on the Bering Arctic Subarctic Integrated Survey (BASIS) fishery oceanography surveys during mid-August to late September, for four warm years (2002–2005) followed by one average (2006), six cold (2007–2012), and three warm (2014–2016) using methods in Eisner et al. (2014). Zooplankton data was not available for 2013. Age-3 pollock abundance was obtained from the stock assessment report for the 2002–2014 year classes (Ianelli et al., 2017). Two estimates of large copepod abundances were calculated, the first using observed means among stations of abundance data (number m^2) and the second using the means estimated from the geostatistical model, Vector Autoregressive Spatial Temporal (VAST) package version 4-2-0 (Thorson et al., 2015). We specified 50 knots, a log normal distribution, and the delta link function between probability or encounter and positive catch rate in VAST.

Status and trends: Positive significant linear relationships were found between observed and VAST modeled mean abundances of large copepods collected during the age-0 stage of pollock and stock assessment estimates of these same pollock at age-3 for the 2002–2014 year classes (Figure 66). The stronger relationship using the VAST package compared to observed means among stations ($R^2 = 0.69$ vs $R^2 = 0.47$) appears to be partially due to the VAST package filling in data for survey areas missed in some years (e.g., 2008).

Fitted means and standard errors of the age-3 pollock abundances were estimated from the linear regression model using means of large copepods from observed data and from the VAST model, and compared to the pollock stock assessment estimates from Ianelli et al. (2017) (Figure 67). Our regression models using observed means among stations predict an abundance of 2.83 and 3.39 billion age-3 pollock with a standard error of 1.35 and 1.24 billion for the 2015 and 2016 year classes, respectively. Likewise, estimates using VAST predict an abundance of 2.77 and 3.15 billion age-3 pollock with a standard error of 0.96 and 0.91 billion for the 2015 and 2016 year classes, respectively.

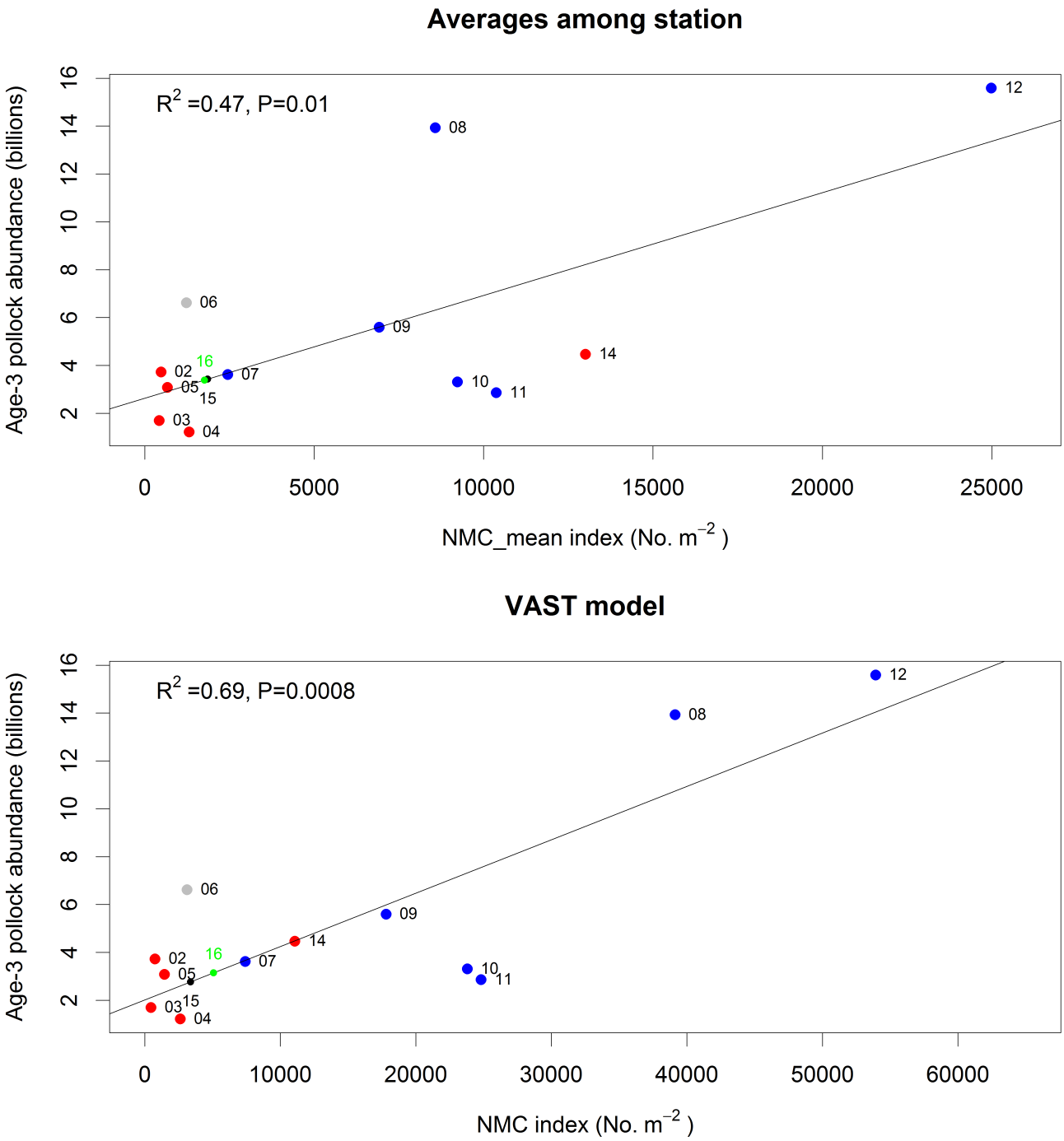

Figure 66: Linear relationships between observed (top) or VAST (bottom) estimated mean abundance of large copepods during the age-0 life stage of pollock and the estimated abundance of these pollock at age-3 pollock from Ianelli et al. (2017). Points are labeled with pollock year class. Red points are warm (low ice) years, blue are cold (high ice) years, gray is an average year, and black and green are estimates from the linear regressions for 2015 and 2016 year classes, respectively. No zooplankton data were available for 2013.

Factors influencing observed trends: Increases in sea ice extent and duration were associated with increases in large zooplankton abundances on the southeastern shelf (Eisner et al., 2014, 2015), increases

in large copepods and euphausiids in pollock diets (Coyle et al., 2011), and increases in age-0 pollock lipid content (Heintz et al., 2013). The increases in sea ice and associated ice algae and phytoplankton blooms may provide an early food source for large crustacean zooplankton reproduction and growth (Baier and Napp, 2003; Hunt et al., 2011). These large zooplankton taxa contain high lipid concentrations (especially in cold, high ice years) which in turn increases the lipid content in their predators such as age-0 pollock and other fish that forage on these taxa. Increases in energy density (lipids) in age-0 pollock allow them to survive their first winter (a time of high mortality) and eventually recruit into the fishery. Accordingly, a strong relationship has been shown for energy density in age-0 fish and age-3 pollock abundance (Heintz et al., 2013).

Implications: Our results suggest that decreases in the availability of large copepod prey during the first year at sea in 2015 and 2016 were not favorable for age-0 pollock overwinter survival and recruitment to age-3. If the relationship between large copepods and age-3 pollock remains significant in our analysis, the index can be used to predict the recruitment of pollock three years in advance of recruiting to age-3, from zooplankton data collected three years prior. This relationship also provides further support for the revised oscillating control hypothesis that suggests as the climate warms, reductions in the extent and duration of sea ice could be detrimental to large crustacean zooplankton and subsequently to the pollock fishery in the southeastern Bering Sea (Hunt et al., 2011).

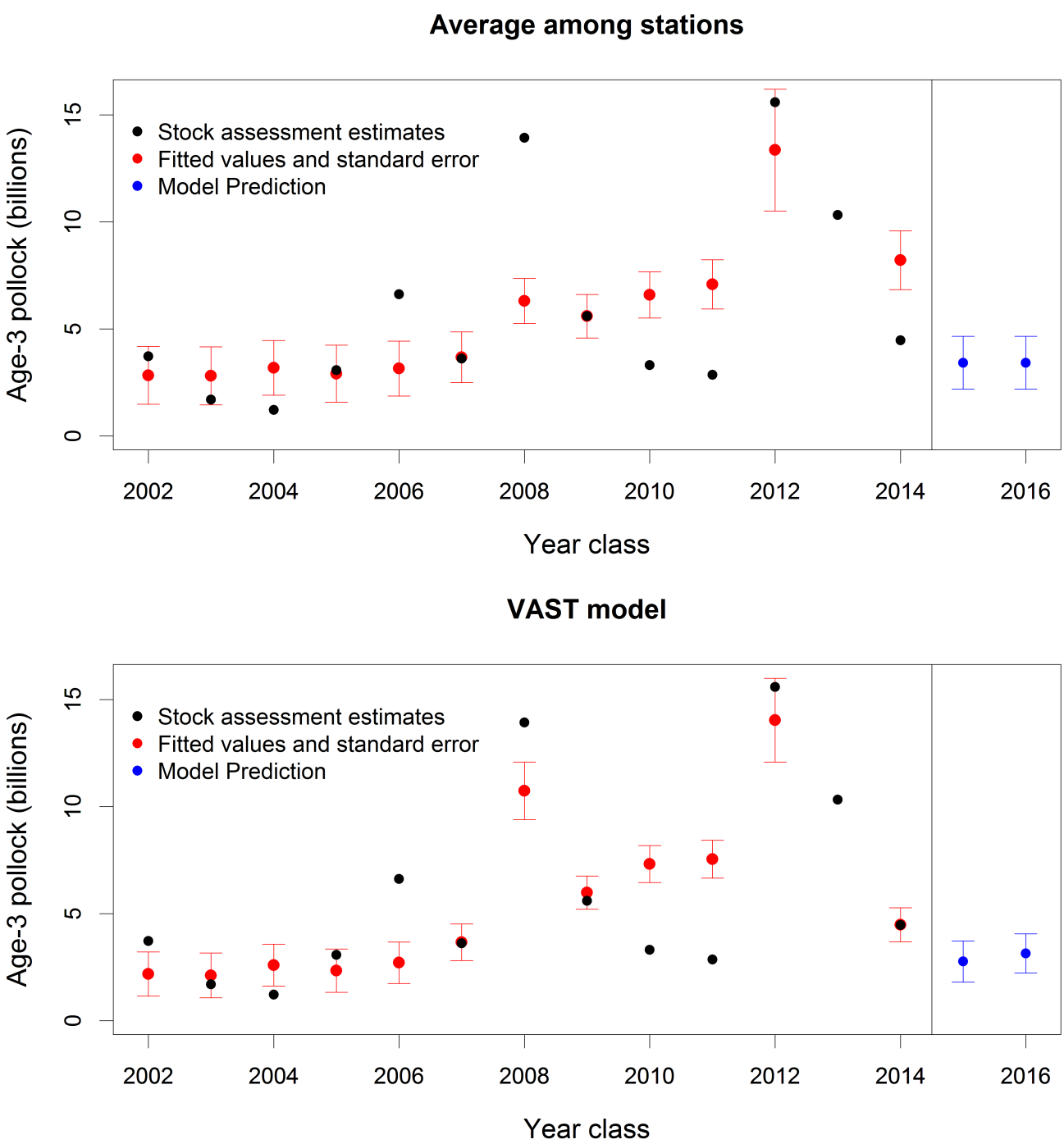

Figure 67: Fitted means and standard errors (red) of the age-3 pollock abundance estimated from the linear regression models using means of large copepods from observed data (top) and VAST model (bottom), and pollock stock assessment estimates (black) from Ianelli et al. (2017). Predicted estimates of age-3 pollock for 2015 and 2016 year classes (recruited into fishery as age 3's in 2018 and 2019, respectively) are shown in blue.

Fall Energetic Condition of Age-0 Walleye Pollock Predicts Survival and Recruitment Success

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Last updated: October 2018

Description of indicator: Average Energy Content (AEC; kJ/fish) is the product of the average individual mass and average energy density of age-0 Walleye pollock (*Gadus chalcogrammus*) collected during the late-summer BASIS survey in the southeastern Bering Sea (SEBS). Fish were collected from surface trawls in all years except 2015 when oblique (water column) trawls were used. The average individual mass is calculated by dividing the total mass by the total number of age-0 pollock caught in each haul. The average energy density is estimated in the laboratory from multiple (2–5) fish within ± 1 standard deviation of the mean length (see Siddon et al. (2013*a*) for detailed methods). The haul-specific energy value is weighted by catch to estimate average energy density per station. The product of the two averages represents the average energy content for an individual age-0 pollock in a given year.

We relate AEC to the number of age-1 recruits per spawner (R/S) using the index of adult female spawning biomass as an index of the number of spawners. Relating the AEC of age-0 pollock to year class strength from the age-structured stock assessment indicates the energetic condition of pollock prior to their first winter predicts their survival to age-1.

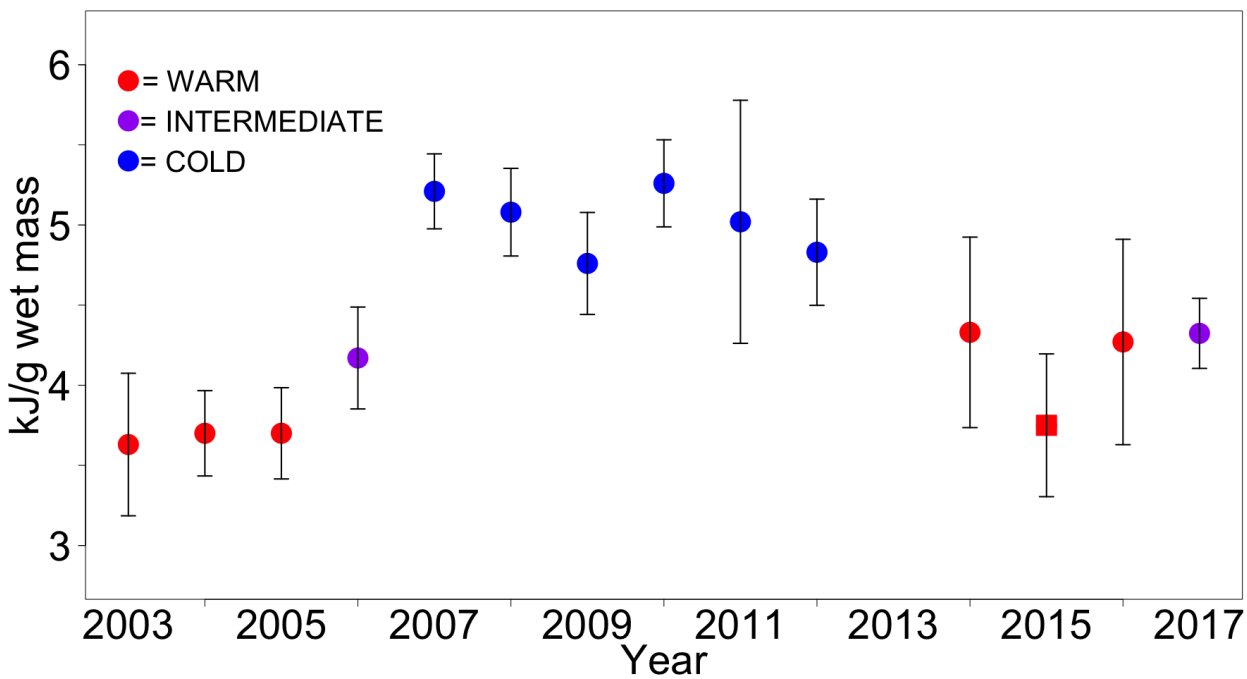

Figure 68: Average energy density (kJ/g) of age-0 Walleye pollock (*Gadus chalcogrammus*) collected during the late-summer BASIS survey in the eastern Bering Sea 2003–2017. Fish were collected with a surface trawl in all years except in 2015 when an oblique trawl was used.

Status and trends: Energy density (kJ/g), mass (g), and standard length (SL; mm) of age-0 pollock have been measured annually since 2003 (except 2013 when no survey occurred). Over that period, energy density has varied with the thermal regime in the SEBS. Between 2003 and 2005 the SEBS experienced warm

conditions characterized by an early ice retreat. Thermal conditions in 2006 were intermediate, indicating a transition, and ice retreated much later in the years 2007-2013 (i.e., cold conditions). Warm conditions returned in 2014 through 2016 while 2017 was moderate (i.e., intermediate).

The transition between warm and cold conditions is evident when examining energy density over the time series (Figure 68). Energy density was at a minimum in 2003 (3.63 kJ/g) and increased to a maximum of 5.26 kJ/g in 2010. In contrast, the size (mass or length) of the fish has been less influenced by thermal regime. The AEC of age-0 pollock in warm years between 2003–2017 accounts for 74% of the variation in age-1 recruits per spawner, but only 9% in cold years between 2003–2017 (Figure 69).

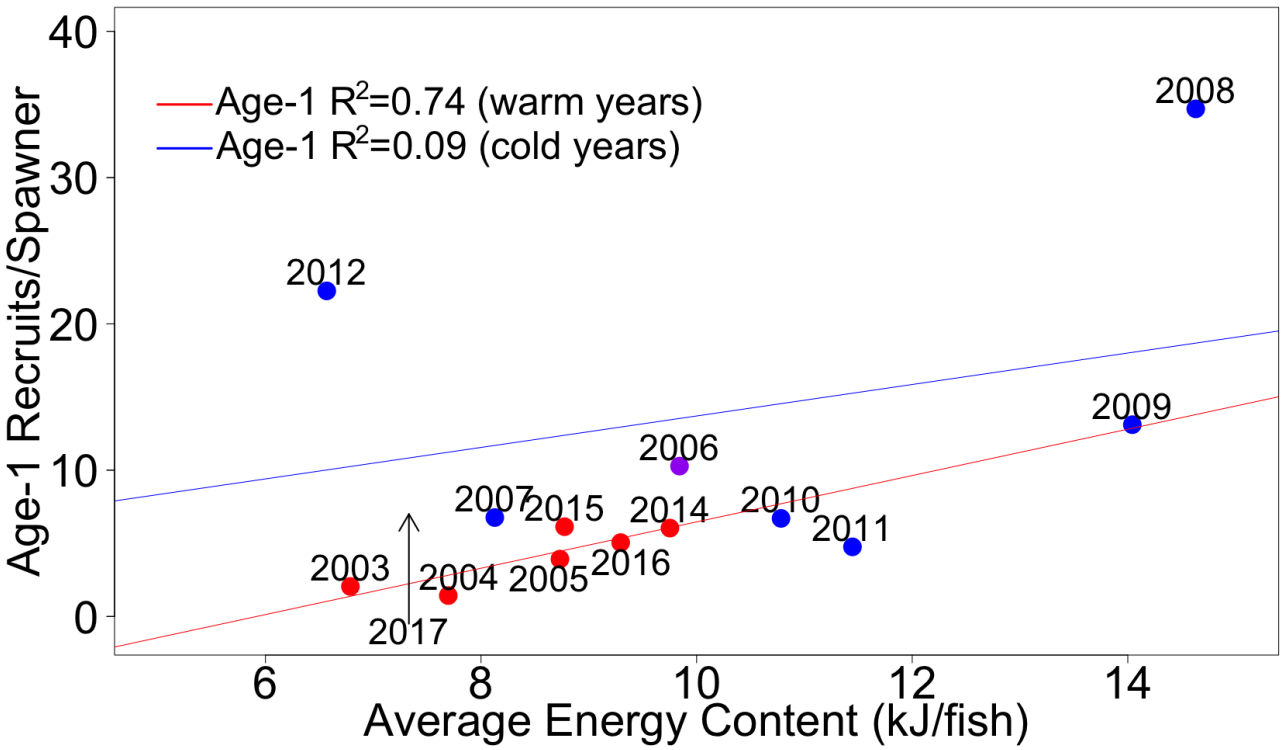

Figure 69: Relationship between average energy content (AEC) of individual age-0 Walleye pollock (*Gadus chalcogrammus*) and the number of age-1 recruits per spawner from the 2017 stock assessment (Ianelli et al., 2017). Fish were collected with a surface trawl in all years except in 2015 when an oblique trawl was used.

Factors influencing observed trends: The AEC of age-0 pollock integrates information about size and energy density into a single index, therefore reflecting the effects of size dependent mortality over winter (Heintz et al., 2010) as well as prey conditions during the age-0 period. Late summer represents a critical period for energy allocation in age-0 pollock (Siddon et al., 2013*a*) and their ability to store energy depends on water temperatures, prey quality, and foraging costs (Siddon et al., 2013*b*).

Prey availability for age-0 pollock differs between warm and cold years with cold years having greater densities of large copepods (e.g., *Calanus marshallae*) over the SEBS shelf (Hunt et al., 2011; Coyle et al., 2011). Zooplankton taxa available in cold years are generally higher in lipid content, affording age-0 pollock a higher energy diet than that consumed in warm years. Lower water temperatures also optimize their ability to store lipid (Kooka et al., 2007).

Implications: The model fit under warm years suggests that bottom-up processes (i.e., higher metabolic demands, poor prey quality and quantity) have a strong impact on survival and subsequent recruitment success of age-0 pollock. The model fit under cold years suggests survival and recruitment success are more

variable and likely the result of a suite of processes, including bottom-up and top-down pathways. 2017 was a moderate year in the southeastern Bering Sea in terms of thermal conditions, with an extensive, yet narrow cold pool. As such, it is difficult to predict the success of the 2017 year-class, but evidence from 2006 recruitment success suggests the 2017 year-class will have average success.

Benthic Communities and Non-target Fish Species

Miscellaneous Species - Eastern Bering Sea Shelf

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Last updated: October 2018

Description of indicator: "Miscellaneous" species fall into three groups: eelpouts (Zoarcidae), poachers (Agonidae), and sea stars (Asteroidea). The three species comprising the eelpout group are the wattled eelpout (*Lycodes palearis*) and shortfin eelpout (*L. brevipes*) and to a lesser extent the marbled eelpout (*L. raridens*). The biomass of poachers is dominated by a single species, the sturgeon poacher (*Podothecus acipenserinus*) and to a lesser extent the sawback poacher (*Leptagonus frenatus*). The composition of sea stars in shelf trawl catches are dominated by the purple-orange sea star (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. Relative CPUE by weight was calculated and plotted for each species or species group by year for 1982–2018. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (± 1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: The 2018 relative CPUE for eelpouts decreased by 12% from 2017, but the 2018 estimate was just above the average of the estimates over the last 10 years. The poacher group CPUE decreased by 36% since 2017, by 55% since 2016, and by 66% since 2015. The 2018 poacher estimate ranked as the lowest since 1987. Only during a single three year time period from 1984 to 1986, were poacher estimates lower. The sea stars as a group decreased by 20% from 2017 to 2018, and the 2018 CPUE was just below the CPUE average of the last 10 years (Figure 70).

Factors causing observed trends: Determining whether these trends represent real responses to environmental change or are simply an artifact of standardized survey sampling methodology (e.g., temperature dependent catchability) will require more specific research on survey trawl gear selectivity relative to interannual differences in bottom temperatures and on the life history characteristics of these epibenthic species.

Implications: Eelpouts have important roles in the energy flow within benthic communities. For example, eelpouts are a common prey item of Arrowtooth flounder (*Atheresthes stomias*). However, it is not known at present whether these changes in CPUE are related to changes in energy flow.

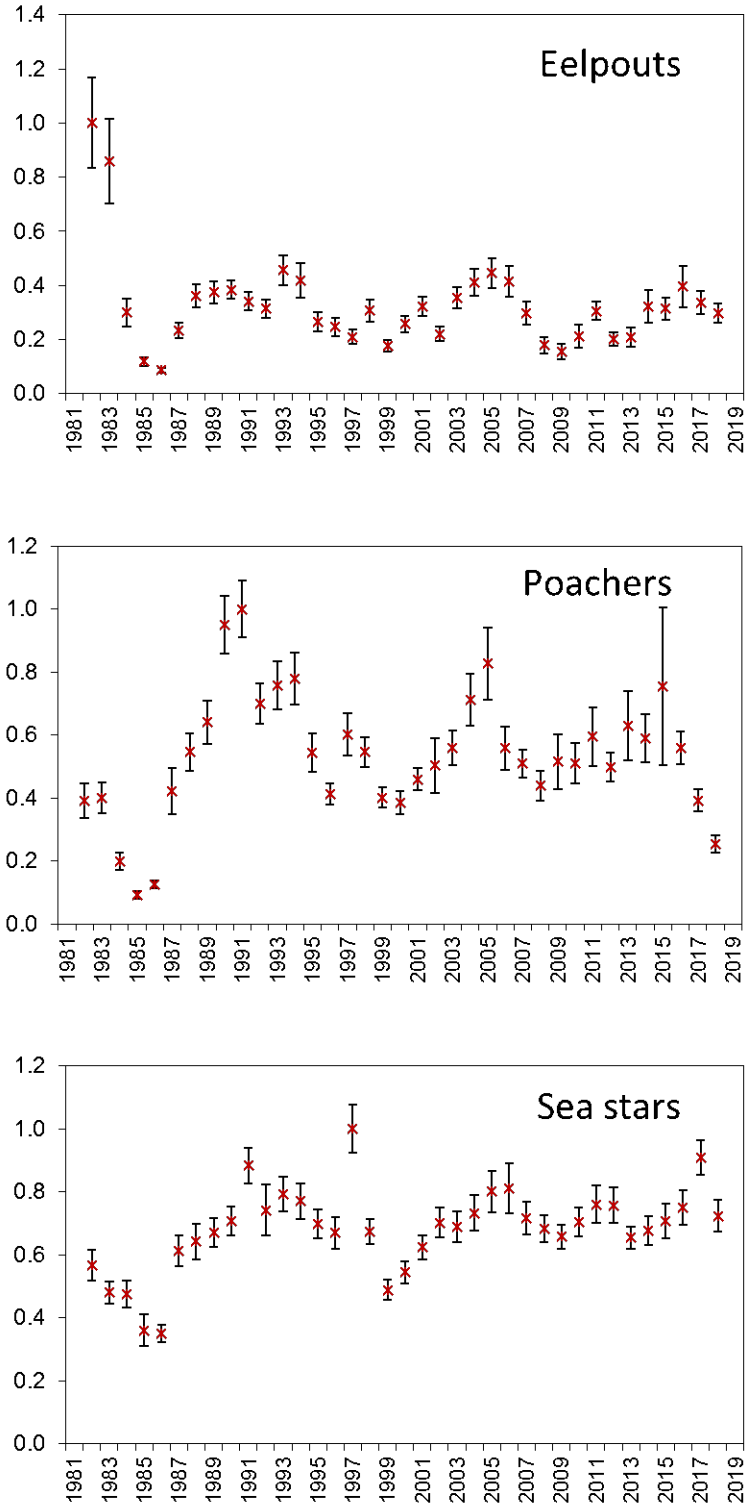

Figure 70: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for miscellaneous fish species during the May to August time period from 1982–2018.

Eastern Bering Sea Commercial Crab Stock Biomass Indices

Contributed by Robert Foy, Christie Lang, Jon Richar
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Last updated: October 2018

Description of indicator: This indicator is the commercial crab species biomass time series in the eastern Bering Sea. The eastern Bering Sea bottom trawl survey has been conducted annually since 1975 by the Resource Assessment and Conservation Engineering Division of the Alaska Fisheries Science Center, National Marine Fisheries Service. The purpose of this survey is to collect data on the distribution and abundance of crab, groundfish, and other benthic resources in the eastern Bering Sea. The data provided here include the time series of results from 1998 to the present. In 2018, 375 total stations were sampled on the eastern Bering Sea shelf from 3 June to 31 July. The trends in crab biomass may be indicative of trends in benthic production or benthic response to environmental variability. The commercial crab biomass also indicates trends in exploited resources over time.

Status and trends: The historical trends of commercial crab biomass and abundance are highly variable (Figure 71). In 2018, there was an overall decrease in biomass and abundance in red king, blue king, and Tanner crab stocks. Bristol Bay red king crab mature males declined by 43% in 2018, continuing a 71% decline since 2014 and reaching a 35-year low. Bristol Bay red king crab mature females also declined 53% in 2018 reaching a 22-year low. The St. Matthew blue king crab adult male stock continued a four year decline to the lowest levels observed for this stock. Female blue king crab biomass is not adequately sampled during this survey due to a nearshore distribution around St. Matthew Island. Tanner crab male and female biomass declined by 20-30%, respectively, in 2018 due mostly to declines in the eastern portion of the stock. The declining trend has continued since 2014 following previous cycles in biomass for this stock. The western portion of the stock, however, has been increasing or stable in recent years. The snow crab stock biomass increased in 2018 with a 60% increase in both mature males and females. The stock had declined to all-time lows in 2016 but increased recruitment has led to an increase that is expected to continue. Pribilof Islands crab stocks remain extremely depressed with variable survey biomass due to trawl survey limitations due to habitat and the contagious crab distribution.

Factors influencing observed trends: Environmental variability and exploitation affect trends in commercial crab biomass over time. Recent modeling analyses suggest that environmental variability is largely driving inter-annual variability in crab stock recruitment.

Implications: The implications of the observed variability in crab stocks are dramatic inter-annual and inter-decadal variability in benthic predators and ephemeral (seasonal) pelagic prey resources when crab are in larval stages in the water column or as juveniles in the benthos. Although it is unclear at what life stage crab stock variability is determined, it is likely that environmental variability affecting larval survival and changes in predation affecting juvenile survival are important factors. As such, the environmental conditions affecting larval crab may also be important for larval demersal groundfish and the availability of crab as prey may be important for demersal fish distributions and survival.

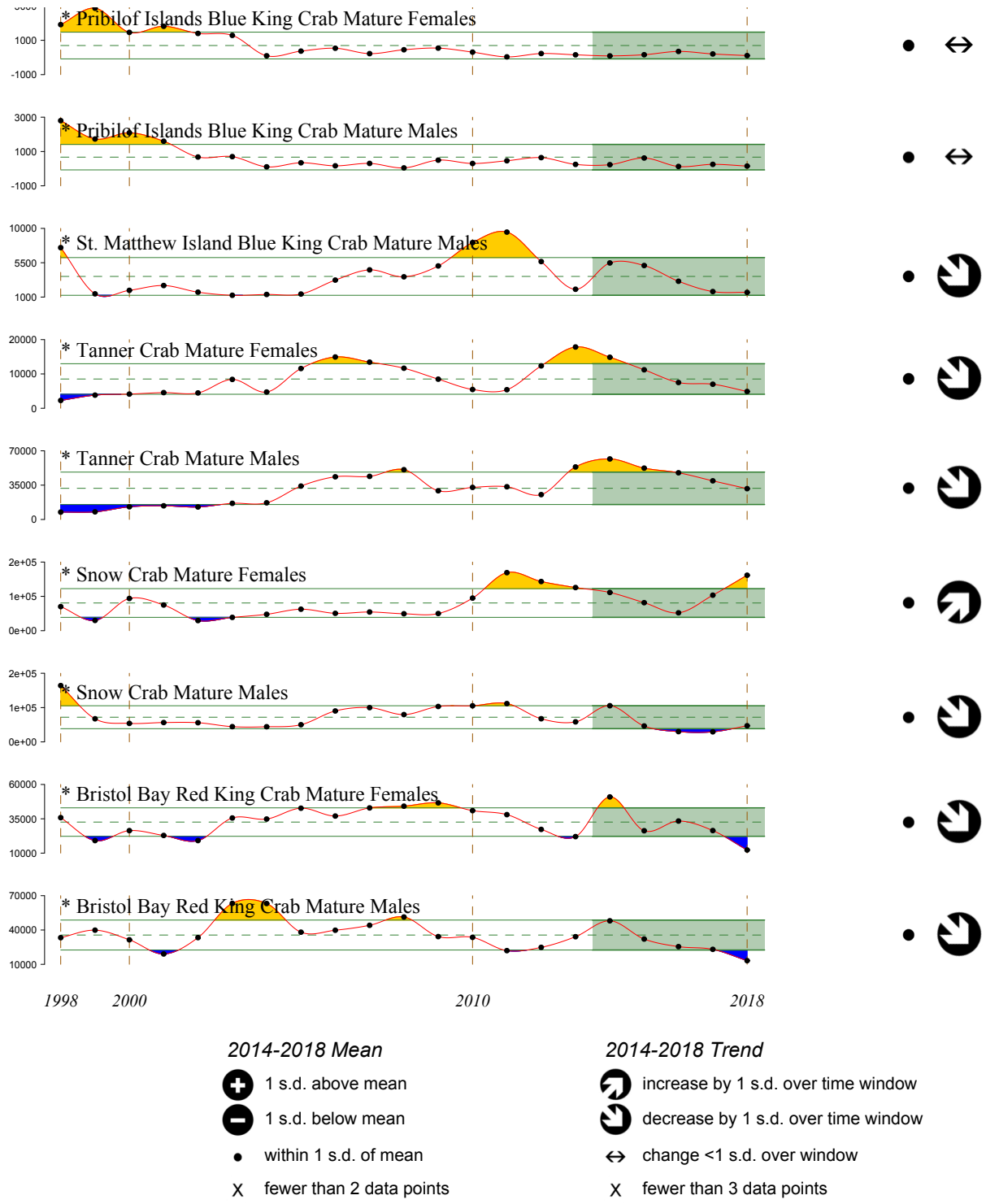

Figure 71: Historical biomass for commercial crab stocks caught on the National Marine Fisheries Service eastern Bering Sea bottom trawl surveys (1998–2018).

Seabirds

Seabird Monitoring Summary from Alaska Maritime National Wildlife Refuge

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Last updated: October 2018

Description of indicator: The Alaska Maritime National Wildlife Refuge has monitored seabirds at colonies around Alaska in most years since the early- to mid-1970s. Time series of annual breeding success and phenology (among other parameters) are available from over a dozen species at eight Refuge sites in the Gulf of Alaska, Aleutian Islands, and Bering and Chukchi Seas (see Figure 72) . Monitored colonies in the eastern Bering Sea include St. Paul and St. George Islands. Here, we focus on cliff-nesting, primarily fish-eating species: black-legged kittiwake (*Rissa tridactyla*), red-legged kittwake (*R. brevirostris*), common murre (*Uria aalge*), thick-billed murre (*U. lomvia*), and red-faced cormorants (*Phalacrocorax urile*). Reproductive success is defined as the proportion of nest sites with eggs (or just eggs for murres, as they do not build nests) that fledged a chick.

Status and trends: Both kittiwake species and red-faced cormorants showed overall poor reproductive success in 2018 at both St. Paul and St. George Islands (Figure 73). This was the fourth consecutive year of poor reproduction for both black-legged and red-legged kittiwakes. Thick-billed murres and common murres at both islands had some reproductive success (0.34–0.50) but far fewer than normal birds showed up to breed. As a result, while reproductive success was comparable to the long-term mean, total production of murre chicks for both colonies was likely low. Mean hatching dates were late across the board for those species that successfully hatched chicks. During a brief August visit to other Bering Sea colonies, both kittiwakes and murres had extremely low production at all sites. In contrast, cormorants appeared to be doing well at other sites.

Factors influencing observed trends: Poor reproductive success is presumed to be linked to warm sea temperatures although the mechanism is unclear. In general, these species appear to be experiencing negative responses to the marine heat wave in the Northeast Pacific over the past few years, with widespread reproductive failures, die-offs, and low attendance at breeding colonies. Kittiwakes began to fail during the first year of the heatwave in 2015, and continued to do so through 2018. Murres did not show negative responses to the marine heat wave until 2016, and although reproductive success improved in 2018, low breeding attendance and late hatching suggest that some reproductive parameters are still being impacted. Although murres are able to buffer reproductive success in poor conditions to some degree (Burger and Piatt, 1990), kittiwakes appear to be more susceptible. While it is not uncommon for kittiwakes to fail to fledge any chicks, complete or near complete failure of both species at both islands for more than two years in a row has only been detected for one other time period (1982–85).

Implications: Reproductive activity of central-place foraging seabirds can reflect ecosystem conditions at multiple spatial and temporal scales. For piscivorous species that feed at higher trophic levels, continued reduced reproductive success may indicate that the ecosystem has not yet shifted back from warm conditions and/or there is a lagged response of the prey. Despite environmental changes returning back to more neutral conditions, seabird foraging conditions do not appear to have completely recovered in the eastern Bering Sea. While increased reproductive success of murres in the Pribilofs during 2018 suggests that some improvement in foraging conditions for those species occurred (particularly later in the season), the low number of breeding birds of all species monitored remains a concern.

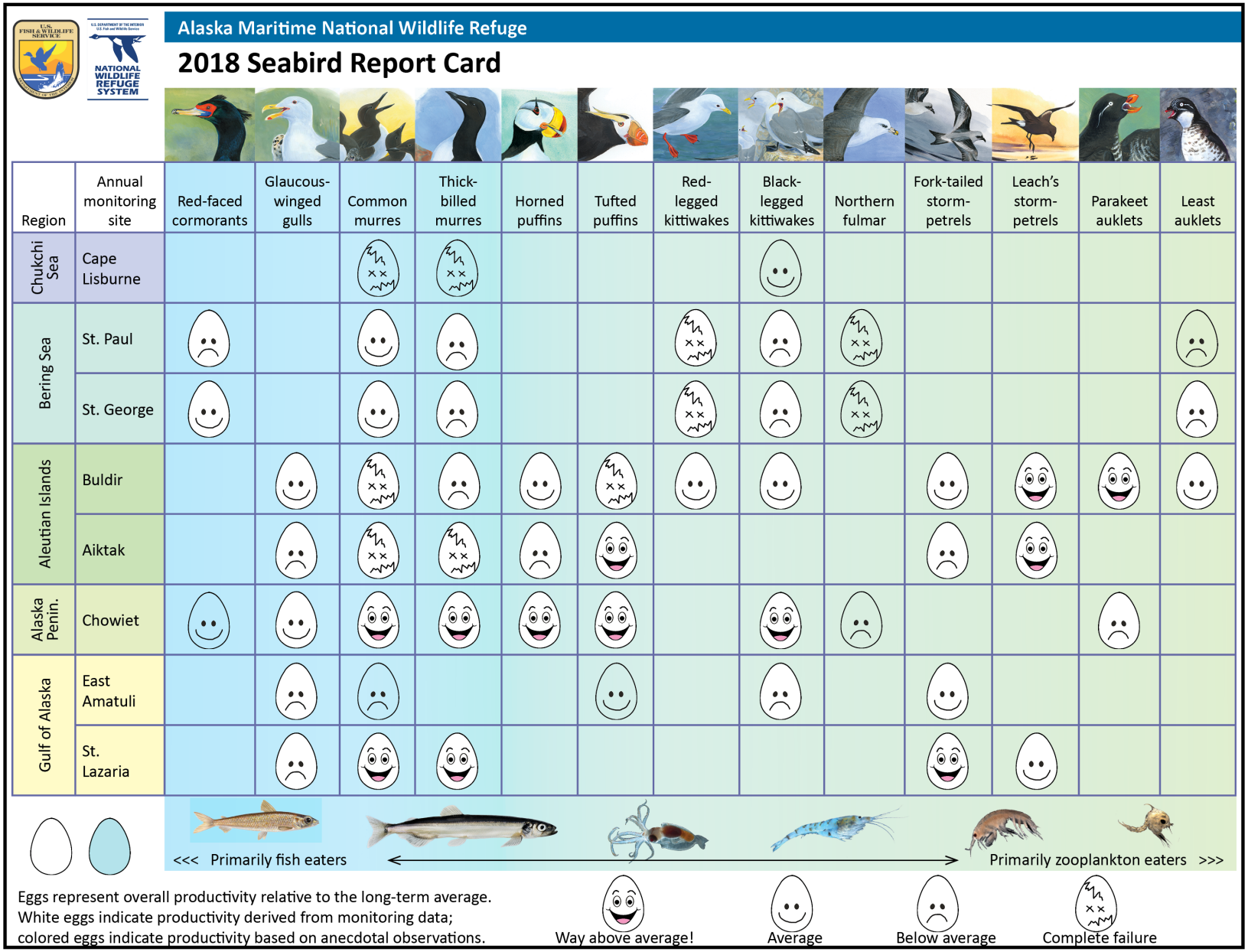

Figure 72: Report Card.

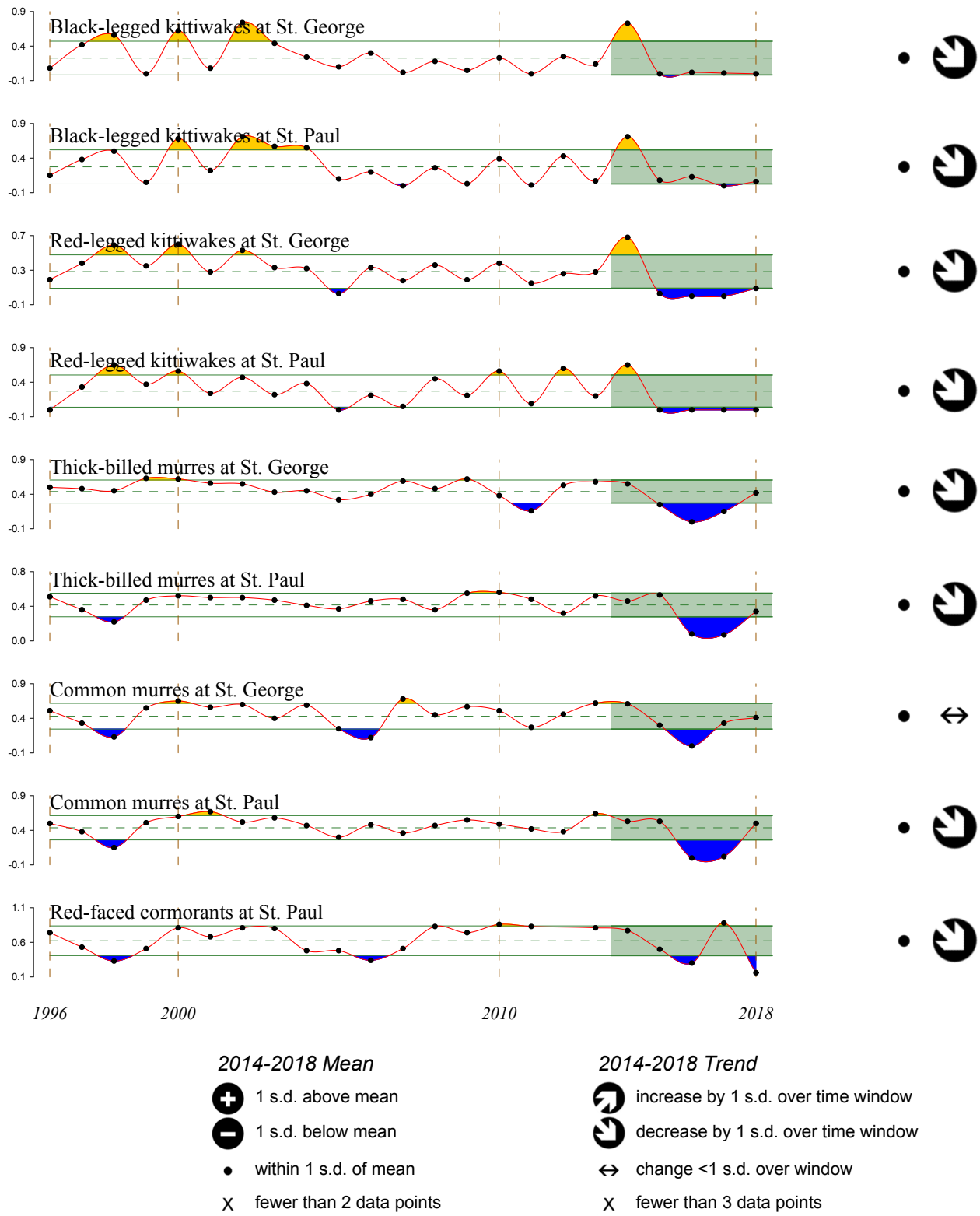

Figure 73: Reproductive success of five seabird species at St. George and St. Paul Islands between 1996–2018.

Marine Mammals

The Marine Mammal Protection Act requires stock assessment reports to be reviewed annually for stocks designated as strategic, annually for stocks where there is significant new information available, and at least once every 3 years for all other stocks. Each stock assessment includes, when available, a description of the stock's geographic range, a minimum population estimate, current population trends, current and maximum net productivity rates, optimum sustainable population levels and allowable removal levels, as well as estimates of annual human-caused mortality and serious injury through interactions with commercial fisheries and subsistence hunters. The most recent (2017) Alaska Marine Mammal stock assessment was released in June 2018 and can be downloaded at `https://repository.library.noaa.gov/view/noaa/18114`.

Northern Fur Seal (*Callorhinus ursinus*) Pup Production in the Bering Sea

Contributed by Rod Towell, Rolf Ream, John Bengtson, Michael Williams, and Jeremy Sterling
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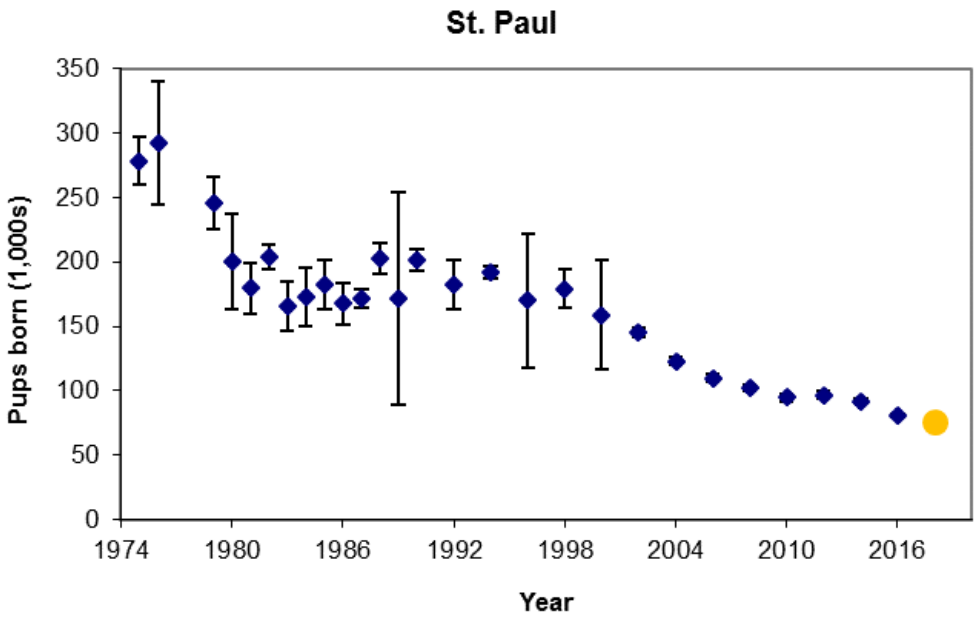
Last updated: October 2018

Description of indicator: The northern fur seal (*Callorhinus ursinus*) ranges throughout the North Pacific Ocean from southern California north to the Bering Sea and west to the Okhotsk Sea and Honshu Island, Japan. Breeding in the U.S. is restricted to only a few sites: the Pribilof Islands and Bogoslof Island in Alaska, and San Miguel and the Farallon Islands off California (Muto et al., 2016). Two separate stocks of northern fur seals are recognized within U.S. waters: an Eastern Pacific stock (Pribilof and Bogoslof Islands) and a California stock.

Northern fur seals were listed as depleted under the Marine Mammal Protection Act (MMPA) in 1988 because population levels had declined to less than 50% of levels observed in the late 1950s, with no compelling evidence that carrying capacity had changed (NMFS, 2007). Fisheries regulations were implemented in 1994 (50 CFR 679.22(a) (6)) to create a Pribilof Islands Area Habitat Conservation Zone (no fishing with trawl permitted), in part to protect northern fur seals. Under the MMPA, this stock remains listed as "depleted" until population levels reach at least the lower limit of its optimum sustainable population (estimated at 60% of carrying capacity). A Conservation Plan for the northern fur seal was written to delineate reasonable actions to protect the species (NMFS, 2007). Pup production of northern fur seals on Pribilof and Bogoslof Islands is estimated by the Marine Mammal Laboratory biennially using a mark-recapture method (shear-sampling) on 1-2 month old pups. The most recent pup production estimate for the Pribilof Islands was conducted during August 2018; pup production on Bogoslof Island was assessed in August 2015.

Status and trends: At this time, only draft estimates are available for northern fur seal pup production on the Pribilof Islands of St. Paul and St. George. Approximately 75,500 fur seal pups were born on St. Paul Island and approximately 21,500 fur seal pups were born on St. George Island. The 2018 estimated production for St. Paul Island is approximately 6% less than the 2016 estimate. The St. George estimate is approximately 5% greater in 2018 than 2016. Trend wise, this indicates a continued decline in pup production on St. Paul Island and a leveling to slightly increasing trend on St. George Island (Figure 74). Using the draft estimates for 2018, pup production has been declining since 1998 at an approximate annual rate of 4.0% on St. Paul Island and shows no significant trend on St. George Island over the same time period.

Since 2002, pup production has been lower than was estimated in 1921 on St. Paul Island and in 1918 on St. George Island, when the populations were recovering at 8% annually from a pelagic harvest that ended in the early 20th century. On a positive note, St. George Island pup production has shown an increase for three consecutive estimates over a 6 year period.



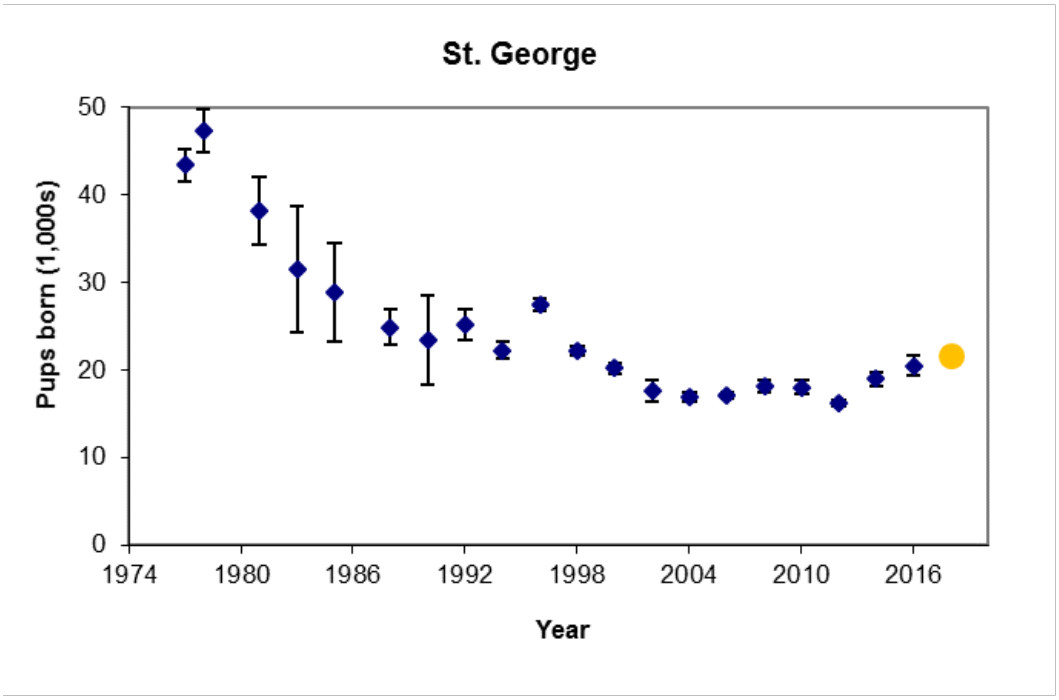


Figure 74: Estimated number of northern fur seal pups born on the Pribilof Islands 1975–2018. Error bars are approximate 95% confidence intervals. Note that St. Paul Island estimates do not include pups born on Sea Lion Rock. The 2018 point estimate in the figure is large to highlight that it is a preliminary estimate.

Factors influencing observed trends: While overall pup production has declined on the Pribilof Islands, it has increased on Bogoslof Island. The last Bogoslof survey occurred in August 2015 at which time pup

production had increased at approximately 10.1% (SE=1.08) per year since 1997. This rate is faster than what could be expected from a completely closed population of fur seals, indicating that at least some of the increase is due to immigration. However, recent volcanic activity (December 2016 to September 2017) likely impacted the northern fur seal population and pup production on Bogoslof Island. Steller sea lion and harbor seal aerial surveys did detect numerous fur seals and sea lions on Bogoslof Island in 2018. Additionally, declines observed on the Pribilof Islands are much greater than the increase in numbers on Bogoslof Island, indicating that the decline on the Pribilof Islands cannot be explained by emigration alone.

Implications: Differences in trends between the largely shelf-foraging Pribilof fur seals and the pelagic-foraging Bogoslof fur seals likely reflect differences in their summer foraging conditions. These populations mix across the North Pacific Ocean during the migration and presumably encounter similar conditions during these fall, winter, and spring months.

Ecosystem or Community Indicators

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys on the Eastern Bering Sea Shelf, 1982–2018

Contributed by Franz Mueter[1] and Robert Lauth[2]
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[2]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2018

Description of indicator: The index provides a measure of the overall biomass of demersal and benthic fish and invertebrate species. We obtained catch-per-unit-effort (CPUE in kg ha) of fish and major invertebrate taxa for each successful haul completed during standardized bottom trawl surveys on the eastern Bering Sea shelf (EBS), 1982–2018. Total CPUE for each haul was computed as the sum of the CPUEs of all fish and major invertebrate taxa. To obtain an index of average CPUE by year across the survey region, we modeled log-transformed total CPUE (N = 13,714 hauls) as a smooth function of depth, Julian Day, and location (latitude/longitude) with year-specific intercepts using Generalized Additive Models following Mueter and Norcross (2002). Hauls were weighted based on the area represented by each station. The CPUE index does not account for gear or vessel differences, which are confounded with interannual differences and may affect results prior to 1988.

Status and trends: Total log(CPUE) in the EBS shows an apparent, but not statistically significant, increase over the entire time series with the highest observed value in the time series occurring in 2014. Total CPUE declined after 2014 and dropped sharply between 2017 and 2018. Estimated means prior to 1988 may be biased due to unknown gear effects and because annual differences are confounded with changes in mean sampling date, which varied from as early as June 15 in 1999 to as late as July 16 in 1985. On average, sampling occurred about a week earlier since the 2000s compared to the 1980s.

Factors influencing observed trends: Commercially harvested species accounted for approximately 95% of survey catches. Fishing is expected to be a major factor determining trends in survey CPUE, but environmental variability is likely to account for a substantial proportion of the observed variability in CPUE through variations in recruitment, growth, and distribution. The increase in survey CPUE in the early 2000s primarily resulted from increased abundances of Walleye pollock (*Gadus chalcogrammus*) and a number of flatfish species (Arrowtooth flounder, *Atheresthes stomias*; Yellowfin sole, *Limanda aspera*; Rock sole, *Lepidopsetta bilineata*; and Alaska plaice, *Pleuronectes quadrituberculatus*) due to strong recruitments in the 1990s. Decreases in 2006–2009 and subsequent increases are largely a result of fluctuations in pollock recruitment and abundance. Models including bottom temperature suggest that, in the EBS, CPUE is greatly reduced at low temperatures ($< 1^{o}$C) as evident in reduced CPUEs in 1999 and 2006–2009, when the cold pool covered a substantial portion of the shelf. Overall, there is a moderate positive relationship between average bottom temperatures and CPUE in the same year (r=0.49, p=0.025), but not in the following years. The reduction in CPUE during cold periods is likely due to a combination of actual changes in abundance, temperature-dependent changes in catchability of certain species (e.g., flatfish, crab), and changes in distribution as a result of the extensive cold pool displacing species into shallower (e.g., red king crab) or deeper (e.g., arrowtooth flounder) waters. The large decrease in 2018 was primarily due to a decrease in the CPUE of walleye pollock, as well as that of Pacific cod and most flatfish species, except arrowtooth flounder (which increased).

Implications: This indicator can help address concerns about maintaining adequate prey for upper trophic level species and other ecosystem components. Relatively stable or increasing trends in the total biomass of demersal fish and invertebrates, together with a relatively constant size composition of commercial species, suggest that the prey base has remained stable over recent decades, but displays substantial fluctuations

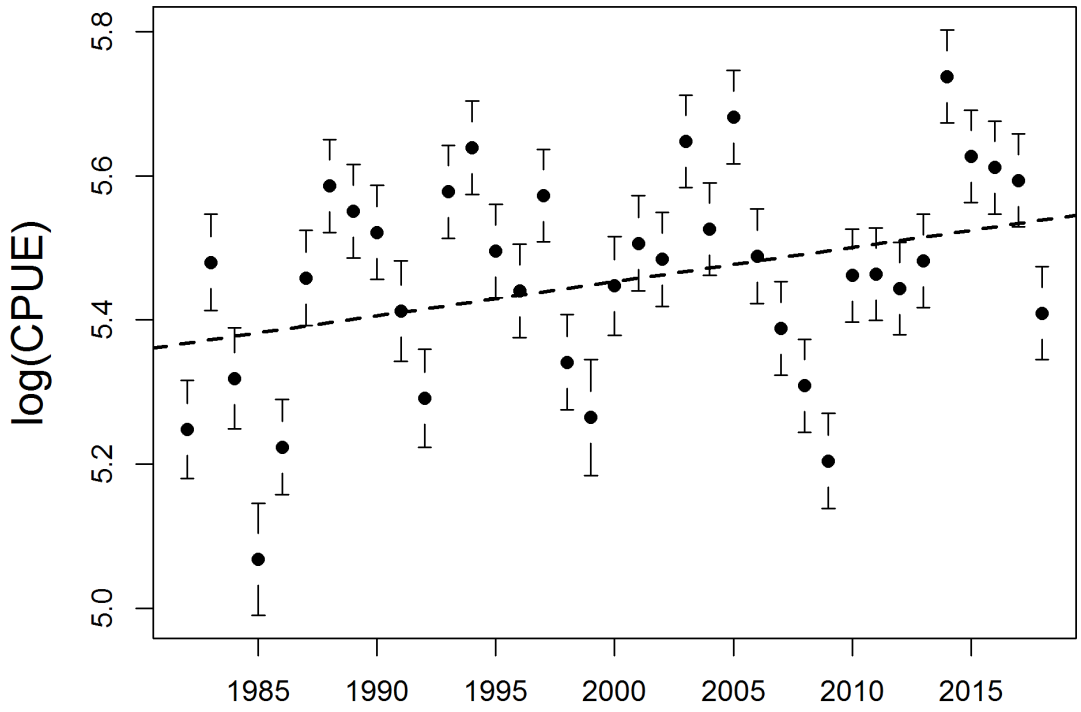

Figure 75: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2018 in the Bering Sea with approximate pointwise 95% confidence intervals and linear time trend. Estimates were adjusted for differences in depth, day of sampling, and sampling locations among years. Gear differences prior to 1988 were not accounted for. The linear time trend based on generalized least squares regression assuming 1st order auto-correlated residuals was not statistically significant at the 95% significance level (t=1.332, p=0.191).

over time, largely as a result of variability in walleye pollock biomass.

Average Local Species Richness and Diversity of the Eastern Bering Sea Groundfish Community

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Last updated: October 2018

Description of indicator: Indices of local species richness and diversity are based on standard bottom trawl surveys in the eastern Bering Sea (EBS). We computed the average number of fish and major invertebrate taxa per haul (richness) and the average Shannon index of diversity (Magurran, 1988) by haul based on CPUE (by weight) of each taxon. Indices for the EBS were based on 45 fish and invertebrate taxa that were consistently identified throughout all surveys since 1982 (Table 1 in Mueter and Litzow (2008), excluding Arctic cod *Boreogadus saida* because of unreliable identification in early years). Indices were com-

puted following Mueter and Norcross (2002). Briefly, annual average indices of local richness and diversity were estimated by first computing each index on a per-haul basis, then estimating annual averages with confidence intervals across the survey area using a Generalized Additive Model that accounted for the effects of variability in sampling locations (latitude/longitude), depth, and date of sampling. In addition to trends over time, we mapped average spatial patterns for each index across the survey region.

Status and trends: Species richness and diversity on the EBS shelf have undergone significant variations from 1982 to 2018 (Figure 76). The average number of species per haul increased by one to two species per haul from 1995 to 2004, remained relatively high through 2011 and both richness and diversity decreased through 2014, followed by an increase in both indices through 2018, with a particularly large increase in Shannon diversity from 2015 to 2018. Richness tends to be highest along the 100 m isobath, while diversity tends to be highest on the middle shelf (Figure 77). Local richness is lowest along the slope and in the northern part of the survey region, while diversity is lowest in the inner domain.

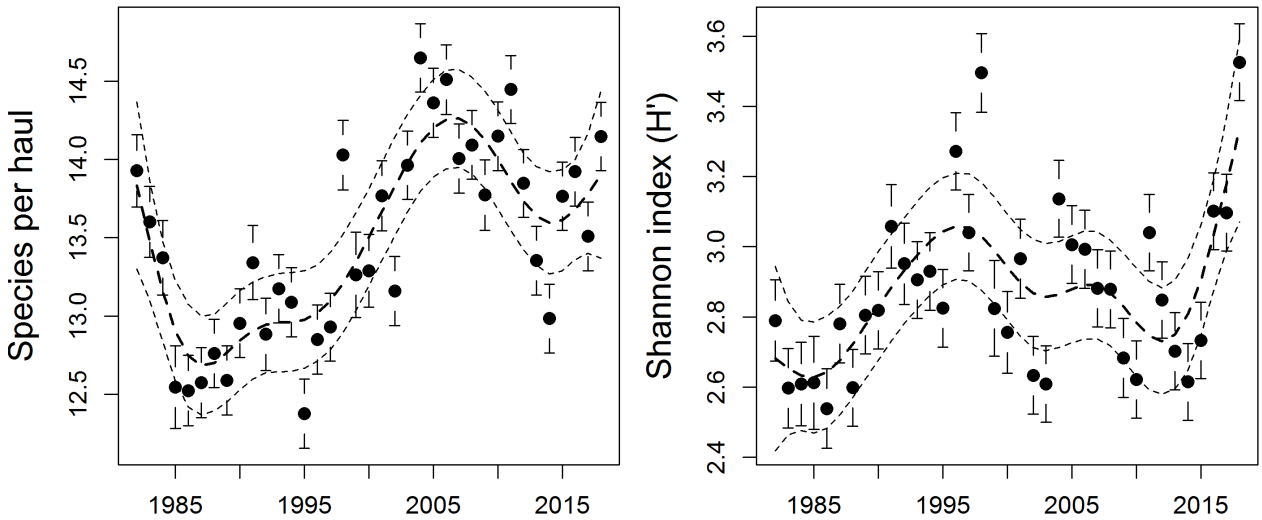

Figure 76: Model-based annual averages of local species richness (left, average number of species per haul), and species diversity (Shannon index, right) in the Eastern Bering Sea, 1982–2018, based on 45 fish and invertebrate taxa collected by standard bottom trawl surveys with pointwise 95% confidence intervals (bars) and loess smoother with 95% confidence band (dashed/dotted lines). Model means were adjusted for differences in depth, date of sampling, and geographic location.

Factors influencing observed trends: Local richness and diversity reflect changes in the spatial distribution, abundance, and species composition that may be caused by fishing, environmental variability, or climate change. If species are, on average, more widely distributed in the sampling area, the number of species per haul increases. Spatial shifts in distribution from year to year can cause high variability in local species richness in certain areas, for example along the 100m contour. These shifts appear to be the primary drivers of changes in species richness over time. Local species diversity is a function both of how many species are caught in a haul and how evenly CPUE is distributed among these species, hence time trends (Figure 76) and spatial patterns (Figure 77) in species diversity differ from those in species richness. The large increase in diversity in 2018 was associated with a moderate increase in species richness and a decrease in the dominance of walleye pollock, which made up 30-43% of total biomass in recent years, but only 23% in 2018.

Implications: There is evidence from many systems that diversity is associated with ecosystem stability, which depends on differential responses to environmental variability by different species or functional groups

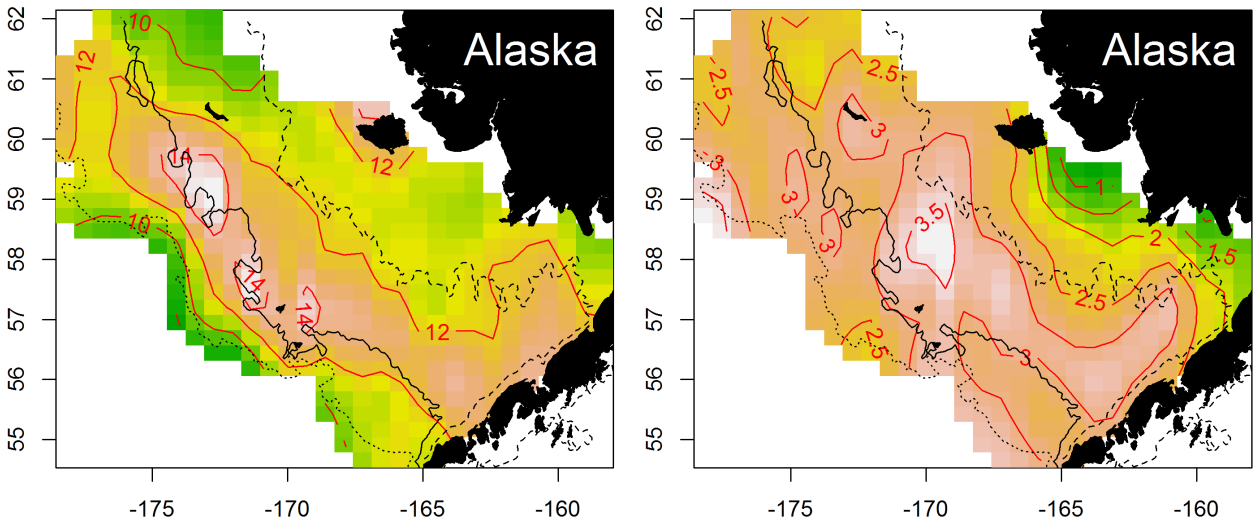

Figure 77: Average spatial patterns in local species richness (left, number of taxa per haul) and Shannon diversity in the Eastern Bering Sea. The 50m (dashed), 100m (solid), and 200 m (dotted) depth contours are shown. Note highest richness along 100 m contour, highest diversity on middle shelf.

(e.g., McCann, 2000). To our knowledge, such a link has not been established for marine fish communities. In the EBS, local species richness may be particularly sensitive to long-term trends in bottom temperature as the cold pool extent changes (Mueter and Litzow, 2008) and may provide a useful index for monitoring responses of the groundfish community to projected climate warming.

Spatial Distribution of Groundfish Stocks in the Bering Sea

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Last updated: October 2018

Description of indicator: We provide indices of changes in the spatial distribution of groundfish on the eastern Bering Sea shelf. The first index provides a simple measure of the average North-South displacement of major fish and invertebrate taxa from their respective centers of gravity (e.g., Woillez et al., 2009) based on AFSC-RACE bottom trawl surveys for the 1982–2018 period. Annual centers of gravity for each taxon were computed as the CPUE-weighted mean latitude across 285 standard survey stations that were sampled each year and an additional 58 stations sampled in all but one survey year. Each station (N=343) was also weighted by the approximate area that it represents. Initially, we selected 46 taxa as in Table 1 of Mueter and Litzow (2008). Taxa that were not caught at any of the selected stations in one or more years were not included, resulting in a total of 39 taxa for analysis. In addition to quantifying N-S shifts in distribution, we computed CPUE and area-weighted averages of depth to quantify changes in depth distribution. Because much of the variability in distribution is likely to be directly related to temperature variability, we removed linear relationships between changes in distribution and temperature by regressing distributional shifts on annual mean bottom temperatures. Residuals from these regressions are provided as an index of temperature-

adjusted shifts in distribution.

Status and trends: Both the latitudinal and depth distribution of the demersal community on the eastern Bering Sea shelf show strong directional trends over the last three and a half decades, indicating significant distributional shifts to the North and into shallower waters (Figure 78). The distribution shifted slightly to the south and deeper in recent cold years (2006–2013) and has shifted back to the North and shallower since 2014 with a substantial shift to the Northwest (along the main axis of the shelf) in 2016. The distribution shifted back towards the South in 2017 and 2018, but remains further north than in any other year besides 2016. Strong shifts in distribution remain evident even after adjusting for linear temperature effects (Figure 78). The center of gravity of most individual species shifted to the Northwest along the shelf and/or to the Northeast onto the shelf in 2016, the warmest year in the survey time series (Figure 79). Cooler temperatures in 2017 appeared to result in an immediate and substantial southeastward shift, in contrast to a more moderate response to similar cooling in 2006. In spite of a return to higher bottom temperatures in 2018, the overall center of gravity shifted only marginally to the North. However, northern Bering Sea surveys in 2017 and 2018 suggested that much of the biomass of fishes in both of these years occurred in the northern Bering Sea (Figure 80). Therefore the true center of gravity for many species likely shifted further to the North than indicated by the index.

Factors influencing observed trends: Many populations shift their distribution in response to temperature variability. Such shifts may be the most obvious response of animal populations to global warming (Parmesan and Yohe, 2003). However, distributional shifts of demersal populations in the Bering Sea are not a simple linear response to temperature variability (Mueter and Litzow (2008); Figure 78). The reasons for strong residual shifts in distribution that are not related to temperature changes remain unclear but could be related to density-dependent responses (Spencer, 2008) in combination with internal community dynamics (Mueter and Litzow, 2008). Unlike groundfish in the North Sea, which shift to deeper waters in response to warming (Dulvy et al., 2008), the Bering Sea groundfish community shifted to shallower waters during warm periods (Figure 78) because of the retreat of the cold pool from the middle shelf that allows subarctic species to expand from the outer shelf into shallower shelf regions.

Implications: Changes in distribution have important implications for the entire demersal community, for other populations dependent on these communities, for the fishing industry, and for stock assessments. The demersal community is affected because distributional shifts change the relative spatial overlap of different species, thereby affecting trophic interactions among species (Hunsicker et al., 2013; Spencer et al., 2016) and, ultimately, the relative abundances of different species. Upper trophic level predators, for example fur seals and seabirds on the Pribilof Islands and at other fixed locations, are affected because the distribution and hence availability of their prey changes. Fisheries are directly affected by changes in the distribution of commercial species, which alters the economics of harvesting because fishing success within established fishing grounds may decline and travel distances to new fishing grounds may increase (Haynie and Pfeiffer, 2013). Finally, stock assessments are affected by shifts outside the standard survey area, such as the substantial redistribution of Pacific cod into the northern Bering Sea in 2018 and the apparent redistribution of much of the overall biomass in the Bering Sea to the northern Bering Sea shelf as evident in decreasing densities in the south and increasing densities in the north (Figure 80).

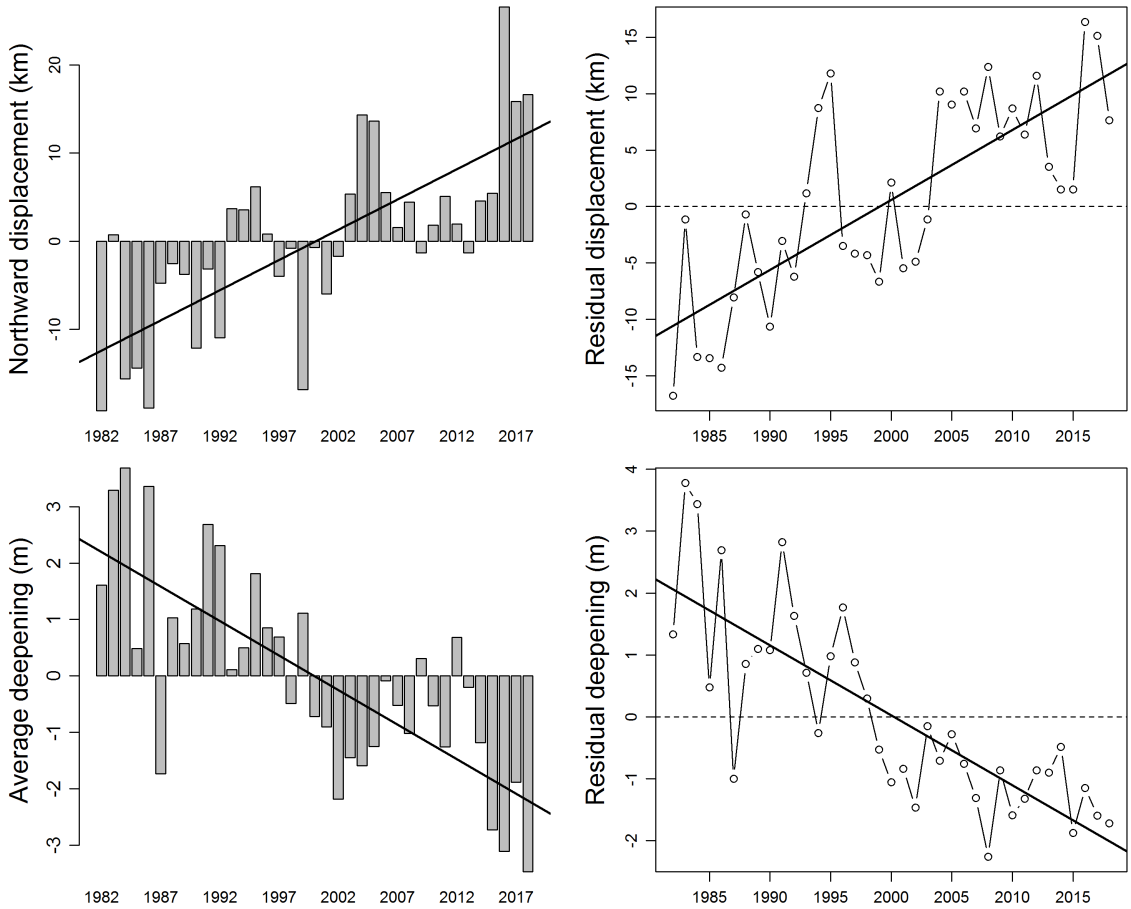

Figure 78: Left: Distributional shifts in latitude (average northward displacement in km from species-specific mean latitudes) and shifts in depth distribution (average vertical displacement in m from species-specific mean depth, positive indices indicate deeper distribution). Right: Residual displacement from species-specific mean latitude (top) and species-specific mean depth (bottom) after adjusting the indices on the left for linear effects of mean annual bottom temperature on distribution. Residuals were obtained by linear regression of the displacement indices on annual average temperature (Northward displacement: $R^2 = 0.24$, t = 4.72, p<0.001; depth displacement: $R^2 = 0.25$, t = -4.57, p<0.001). Solid lines denote linear regressions over time (Northward displacement: $R^2 = 0.38$, t = 3.50, p=0.001; Residual northward displacement: $R^2 = 0.54$, t = 4.63, p<0.001; depth displacement: $R^2 = 0.74$, t = -5.77, p<0.001; residual depth displacement: $R^2 = 0.63$, t = -7.78, p<0.001).

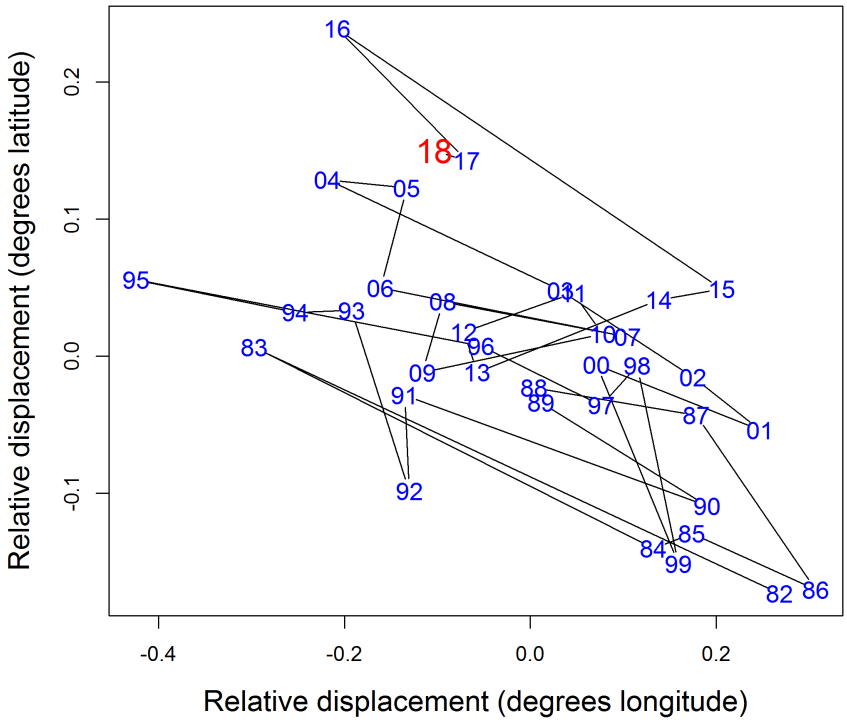

Figure 79: Average North-South and East-West displacement across 39 taxa on the eastern Bering Sea shelf relative to species-specific centers of distribution.

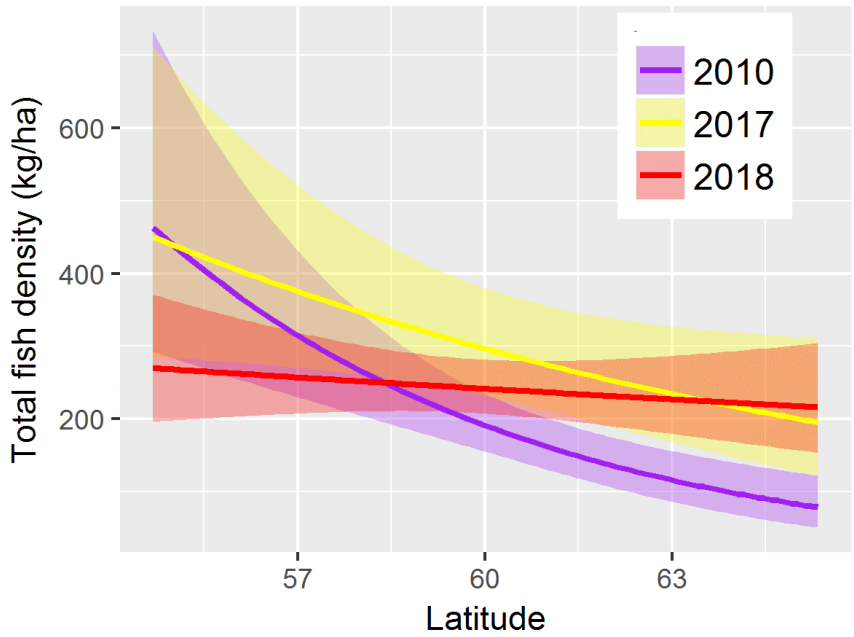

Figure 80: Estimated average fish density along the 50m isobath from the Alaska Peninsula in the south to the Bering Strait in the North. Estimates are based on generalized additive models of log(catch-per-unit-effort) as a function of latitude and depth by year with an exponential autocorrelation structure.

Mean Lifespan of the Fish Community

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Last updated: September 2018

Description of indicator: The mean lifespan of the community is defined by Shin et al. (2010) as "a proxy for the mean turnover rate of species and communities" and is intended to reflect ecosystem stability and resistance to perturbations. The indicator for mean lifespan of the groundfish community is modeled after the method for mean lifespan presented in Shin et al. (2010). Lifespan estimates of groundfish species regularly encountered during the NMFS/AFSC annual summer bottom trawl survey of the southeastern Bering Sea were retrieved from the AFSC Life History Database (`https://access.afsc.noaa.gov/reem/LHWeb/Index.php`). The groundfish community mean lifespan is weighted by biomass indices calculated from the bottom trawl survey catch data.

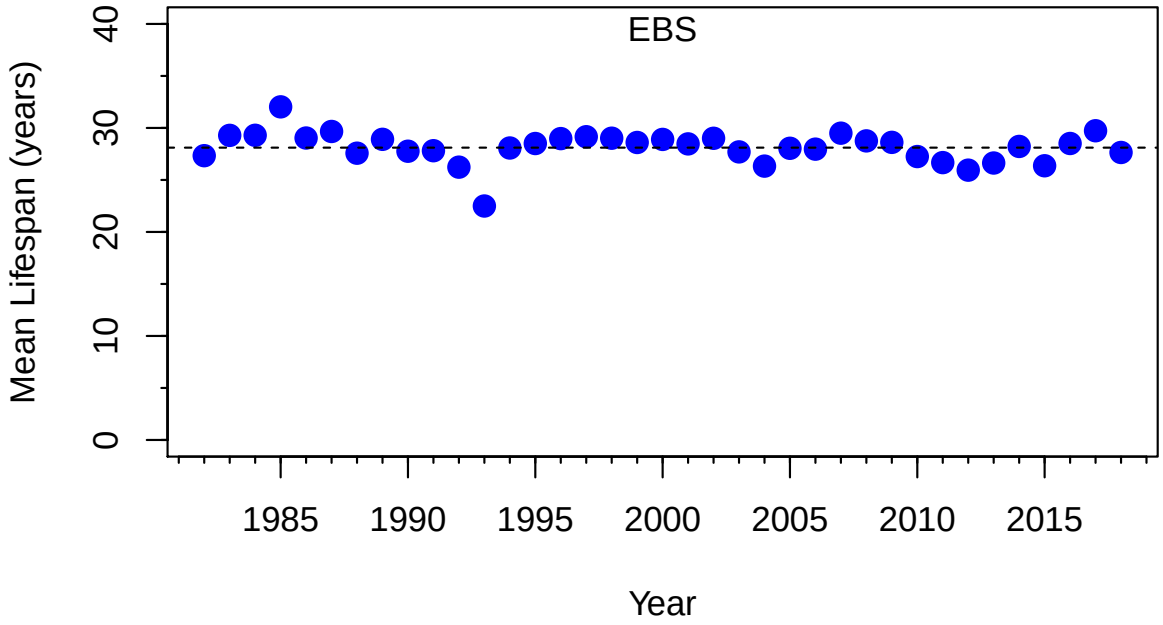

Figure 81: The mean lifespan of the southeastern Bering Sea demersal fish community, weighted by biomass indices calculated from the NMFS/AFSC annual summer bottom trawl survey.

This indicator specifically applies to the portion of the demersal groundfish community that is efficiently sampled by the trawling gear used by NMFS during this survey at the standard survey sample stations (for survey details see Conner and Lauth (2016)). Species that are infrequently encountered or not efficiently caught by the bottom trawl gear are excluded from this indicator (e.g., sharks, grenadiers, myctophids, pelagic smelts). This is a change from last year's method for this indicator, therefore the results presented

here are different from last year's results.

Status and trends: The mean lifespan of the southeastern Bering Sea demersal fish community in 2018 is 27.6 years. This is down from 29.7 years in 2017 and is less than the long-term mean of 28.1 years (Figure 81). Mean groundfish lifespan has generally been stable over the 37-year time series with only a small amount of year-to-year variation, and shows no indication of a long-term trend. The slope of a trendline was not significantly different from zero.

Factors influencing observed trends: Fishing can affect the mean lifespan of the groundfish community by preferentially targeting larger, older fishes, leading to decreased abundance of longer-lived species and increased abundance of shorter-lived species (Pauly et al., 1998). Interannual variation in mean lifespan can be influenced by the spatial distribution of species and the differential selectivity of species and age classes to the trawling gear used in the survey. Strong recruitment events or periods of weak recruitment could also influence the mean community lifespan by altering the relative abundance of species and age classes.

Implications: The groundfish mean lifespan has been stable over the time series of the summer bottom trawl survey. There is no indication that longer-lived species have decreased in relative abundance or are otherwise being replaced by shorter lived-species. Species that are short-lived are generally smaller and more sensitive to environmental variation than larger, longer-lived species (Winemiller, 2005). Longer-lived species help to dampen the effects of environmental variability, allowing populations to persist through periods of unfavorable conditions and to take advantage when favorable conditions return (Berkeley et al., 2004; Hsieh et al., 2006).

Mean Length of the Fish Community

Contributed by George A. Whitehouse[1] and Geoffrey M. Lang[2]
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Last updated: September 2018

Description of indicator: The mean length of the groundfish community tracks fluctuations in the size of groundfish over time. This size-based indicator is thought to be sensitive to the effects of commercial fisheries because larger predatory fish are often targeted by fisheries and their selective removal would reduce mean size (Shin et al., 2005). Fish lengths are routinely recorded during the NMFS bottom trawl survey of the southeastern Bering Sea, which has occurred each year since 1982. Mean lengths are calculated for groundfish species (or functional groups of multiple species; e.g., eelpouts) from the length measurements collected during the trawl survey. The mean length for the groundfish community is calculated with the species mean lengths, weighted by biomass indices (Shin et al., 2010) calculated from the bottom-trawl survey catch data.

This indicator specifically applies to the portion of the demersal groundfish community that is efficiently sampled with the trawling gear used by NMFS during the summer bottom-trawl survey of the southeastern Bering Sea (EBS) at the standard survey sample stations (for survey details see Conner and Lauth (2016)). Species that are infrequently encountered or not efficiently caught by the bottom-trawling gear are excluded from this indicator (e.g., sharks, grenadiers, myctophids, pelagic smelts). This is a change from last year's method for this indicator, therefore the results presented here are different from last year's results.

Species (or functional groups) infrequently sampled for lengths (less than five times over the time series) are excluded from this indicator (e.g., capelin, eulachon, greenlings). A total of 22 species are included in this indicator. Eleven species had their lengths sampled in all 37 years of the time series. Another eleven species were sampled between 11 and 34 times over the time series. In those years where lengths were not sampled

for a species we replaced with a long term mean for that species. This is another change in methods from last year.

Status and trends: The mean length of the EBS groundfish community in 2018 was 37.6 cm. This is up half a cm from 2017 and is the highest value over the time series. Since 1982, the mean length has shown variation from year to year but has been generally stable, and has been trending upward since 2012 (Figure 82). A trendline over the time series has a positive slope (p = 0.014) indicating a slow increase over time.

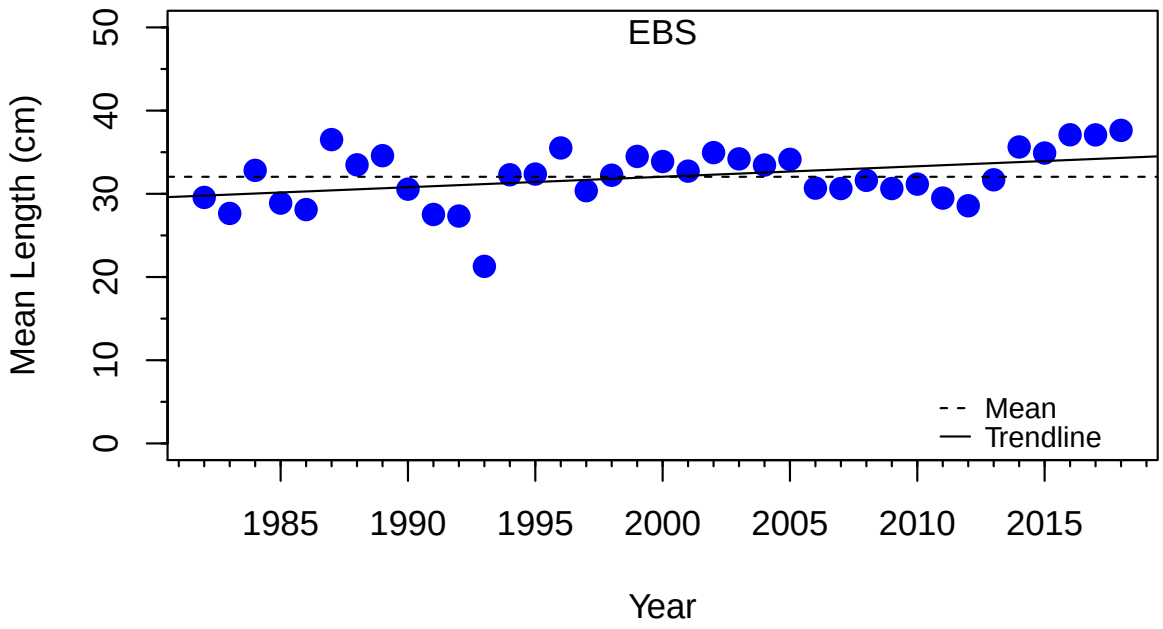

Figure 82: Mean length of the groundfish community sampled during the NMFS/AFSC annual summer bottom-trawl survey of the southeastern Bering Sea (1982–2018). The groundfish community mean length is weighted by the relative biomass of the sampled species. The dashed line represents the mean of the time series (1982–2018) and the solid line is a trendline with slope = 0.126.

Factors influencing observed trends: This indicator is specific to the fishes that are routinely caught and sampled during the NMFS summer bottom trawl survey. The estimated mean length can be biased if specific species-size classes are sampled more or less than others, and is sensitive to spatial variation in the size distribution of species. Changes in fisheries management or fishing effort could also affect the mean length of the groundfish community. Modifications to fishing gear, fishing effort, and targeted species could affect the mean length of the groundfish community if different size classes and species are subject to changing levels of fishing mortality. The mean length of groundfish could also be influenced by fluctuations in recruitment, where a large cohort of small forage species could reduce mean length of the community. Environmental factors could also influence fish growth and mean length by afffecting the availability and quality of food, or by direct temperature effects on growth rate.

Walleye pollock is a biomass dominant component of this ecosystem and year-to-year fluctuations in their mean size and biomass have a noticeable effect on this indicator. In 1993 their biomass index was above average but their mean size was the fifth lowest of the time series. This contributes to 1993 having the lowest

index value over the time series. Years where this indicator attained its highest values (1987, 2016–2018) generally correspond to years of above average mean size and/or biomass index for pollock; except 2018 where pollock mean size was average but their biomass index was below average. The groundfish mean size in 2018 was buoyed by other prominent groundfish such as Yellowfin sole and Pacific cod which had above average mean length.

Implications: The mean length of the groundfish community in the EBS has been stable over the bottom trawl time series (1982–2018) with some interannual variation. A trendline indicates a slight increase in mean size over time and there is no evidence from this indicator that an external pressure is reducing the groundfish community mean size.

Stability of Groundfish Biomass

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Last updated: September 2018

Description of indicator: The stability of the groundfish community total biomass is measured with the inverse biomass coefficient of variation (1 divided by the coefficient of variation of total groundfish biomass (1/CV[B])). This indicator provides a measure of the stability of the ecosystem and its resistance to perturbations. The variability of total community biomass is thought to be sensitive to fishing and is expected to increase with increasing fishing pressure (Blanchard and Boucher, 2001). This metric is calculated following the methods presented in Shin et al. (2010). The CV is calculated as the mean total groundfish biomass index over the previous 10 years divided by the standard deviation over the same time span. The biomass index for groundfish species was calculated from the catch of the NMFS/AFSC annual summer bottom trawl survey of the southeastern Bering Sea. Since 10 years of data are required to calculate this metric, the indicator values start in 1991, the tenth year in the trawl survey time series (1982–2018). This metric is presented as an inverse, so as the CV increases the value of this indicator decreases, and if the CV decreases the value of this indicator increases.

This indicator specifically applies to the portion of the demersal groundfish community that is efficiently sampled by the trawling gear used by NMFS during this survey at the standard survey sample stations (for survey details see Conner and Lauth (2016)). Species that are infrequently encountered or not efficiently caught by the bottom trawl gear are excluded from this indicator (e.g., sharks, grenadiers, myctophids, pelagic smelts). This is a change from last year's method for this indicator, therefore the results presented here are different from last year's results.

Status and trends: The state of this indicator in 2018 was 5.5, which is up from 5.2 in 2016. 1/CV[B] peaked in 1992 at 7.6 and reached a low of 3.9 in 2002. After a decrease from 1992 to 1993 near the start of this time series, this indicator has remained generally stable to the present and does not exhibit a clear trend (Figure 83). Since 1991, the mean value for this metric is 5.1. The slope of a trendline was not significantly different from zero.

Factors influencing observed trends: Fishing is expected to influence this metric as fisheries can selectively target and remove larger, long-lived species affecting population age structure (Berkeley et al., 2004; Hsieh et al., 2006). Larger, longer-lived species can become less abundant and be replaced by smaller shorter-lived species (Pauly et al., 1998). Larger, longer-lived individuals help populations to endure prolonged periods of unfavorable environmental conditions and can take advantage of favorable conditions when they return (Berkeley et al., 2004). A truncated age-structure could lead to higher population variability (CV) due to increased sensitivity to environmental dynamics (Hsieh et al., 2006). Interannual variation in this metric could also be influenced by interannual variation in species abundance in the trawl survey catch or patchy spatial distribution for some species. This metric, as calculated here with trawl survey data,

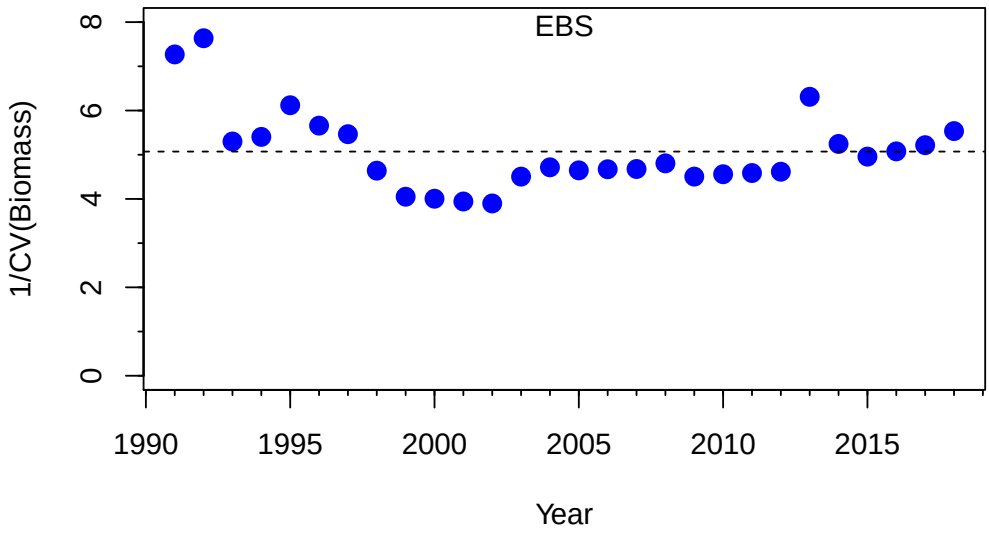

Figure 83: The stability of groundfish in the southeastern Bering Sea represented with the metric 1/CV[B]. Ten years of data are required to calculate this metric, so this time series begins in 1991 after the tenth year of the NMFS/AFSC annual summer bottom trawl survey.

reflects the stability of the groundfish community that is represented in the catch data of the annual summer bottom trawl survey.

The high values for this indicator at the start of the time series are indicative of stable groundfish biomass with a relatively low CV. Low values for this indicator from 1998–2002 are the result of the previous ten years including years of both relatively high groundfish biomass and years of low biomass. In 2013 there was a sharp increase in this indicator which was the result of the previous ten years having relatively stable biomass (i.e., low CV) and because the relatively high biomass year of 2003 was now outside the ten year window. Collectively this resulted in an abrupt one year drop in CV and peak in this indicator. In general, year-to-year variation in this indicator is the result of interannual variation of the groundfish biomass index.

Implications: The measure 1/CV[B] indicates that the southeastern Bering Sea groundfish community is stable over the time period examined here. For the duration of the trawl survey time series this indicator is generally stable and there is no indication of a trend or driving influence on the stability of the groundfish community.

Disease Ecology Indicators

There are no updates to Disease Ecology indicators in this year's report. See the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Fishing and Human Dimensions Indicators

Indicators presented in this section are intended to provide a summary of the status of several ecosystem-scale indicators related to fishing and human economic and social well-being. These indicators are organized around objective categories derived from U.S. legislation and current management practices (see Table 1 for a full list of objective categories and resulting indicators):

- Maintaining diversity
- Maintaining and restoring fish habitats
- Sustainability (for consumptive and non-consumptive uses)
- Seafood production
- Profits
- Recreation
- Employment
- Socio-cultural dimensions

The indicators presented are meant to represent trends in different aspects of the general management objective, but some indicators are better proxies than others. For example, seafood production is a fairly good proxy for the production of seafood to regional, national, and international markets but ex-vessel and wholesale value are imperfect proxies for harvesting and processing sector profits. This suite of indicators will continue to be revised and updated to provide a more holistic representation of human/environment interactions and dependencies.

Maintaining Diversity: Discards and Non-Target Catch

Stock Compositions of Chinook Salmon Bycatch in Bering Sea Trawl Fisheries

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Last updated: August 2018

Description of indicator: Chinook salmon (*Oncorhynchus tshawytscha*) is a highly migratory species that is caught as bycatch in trawl fisheries in the Bering Sea and the Gulf of Alaska (Schnaittacher et al., 2013). This economically and culturally valuable species is designated as prohibited species catch, with a suite of bycatch mitigation measures, including hard caps that can result in fishery closures (Stram and Ianelli, 2014). Chinook salmon caught in the Bering Sea originate from as far south as Oregon and as far north as the Yukon River, so identifying sources of Chinook salmon caught as bycatch is critical for conservation and management of domestic and US/Canada transboundary stocks.

Observers from the North Pacific Groundfish Observer Program monitor 100% of the trips targeting walleye pollock (*Gadus chalcogrammus*) in the Bering Sea each year (Faunce, 2015), and the Genetics Program at the Auke Bay Laboratories analyzes Chinook salmon bycatch samples for genetic stock identification (Guthrie et al., 2018). Catches are apportioned to reporting groups (West Coast U.S., British Columbia (BC), Coastal Southeast Alaska (Coast SE AK), Copper River, Northeast Gulf of Alaska, Northwest Gulf of Alaska (NW GOA), North Alaska Peninsula, Coastal Western Alaska, Middle Yukon River, Upper Yukon River, and

Russia). We present the proportional composition of the bycatch for each of these reporting groups (Figure 84).

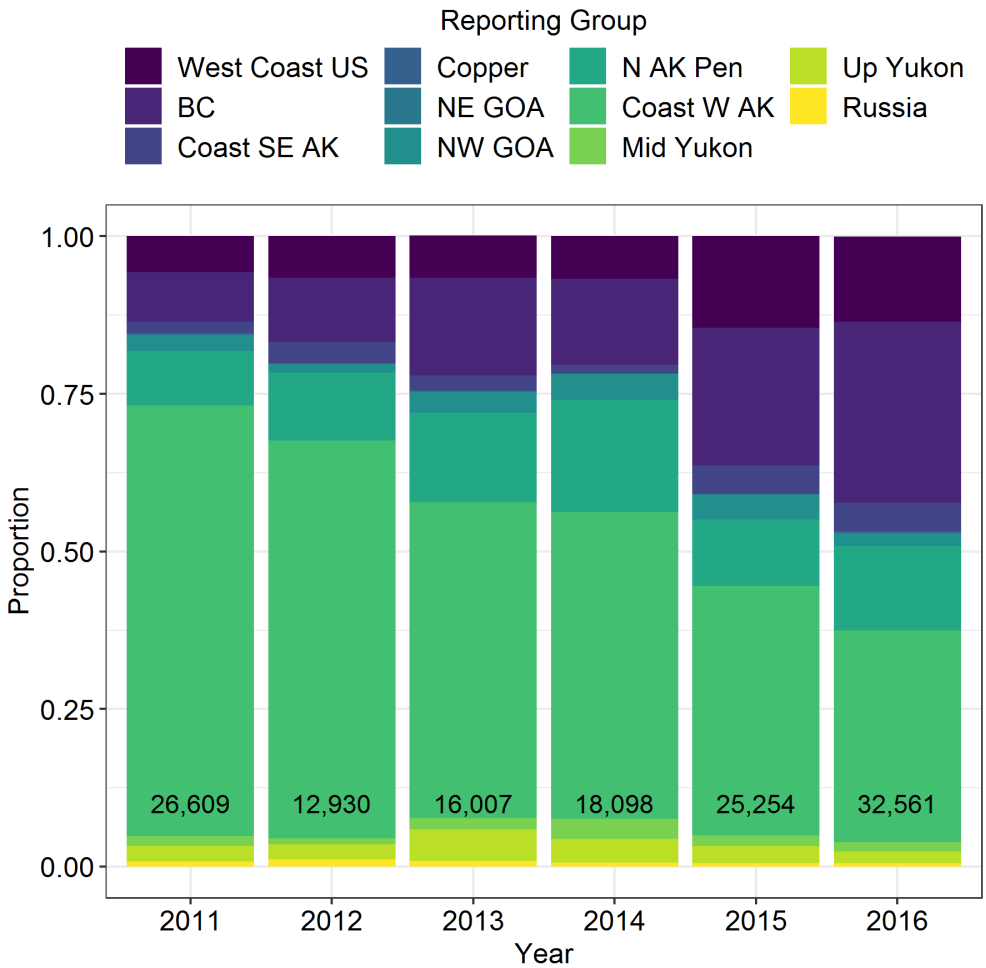

Figure 84: Stock composition (proportion) of Chinook salmon bycatch by year from the Bering Sea pollock trawl fishery with total numbers of Bering Sea trawl fishery catches of Chinook salmon provided in the lower portion of each bar.

Status and trends: For most of the stocks, the proportion of bycatch has been relatively stable throughout the short time series, but the proportion of the most dominant stock, coastal western Alaska, has decreased while the proportions of British Columbia and west coast U.S. fish have increased slightly.

Data have only been collected in a reproducible and consistent manner for a few years, so a description of trends is fairly limited at this point. However, as we move forward, these data establish a baseline with which to compare changes in the future.

Factors influencing observed trends: Several factors are likely to be driving the observed compositions of bycatch. First, increased survival of stocks from British Columbia and the west coast U.S. may account for some of the increase in the more southern populations. Second, during the recent warm years, in particular 2015 and 2016, the pollock fleet concentrated much of its effort farther south in the Bering Sea (Watson and Haynie, 2018). With more of the fishing effort focused closer to Unimak Pass and warm conditions potentially driving more southern fish northward into the Bering Sea, this may account for some of the shift in composition. These factors may also account for some of the increase in total numbers of Chinook salmon

caught in the most recent years as well.

Implications: Understanding the dynamics of Chinook salmon bycatch in trawl fisheries is critical to groundfish management because Chinook represent a prohibited species catch that can drive fisher behavior and lead to significant economic impacts on the fleet. A shift in compositions could be indicative of a change in timing of either Chinook migration patterns or fishing patterns (Watson and Haynie, 2018), both of which could be related to environmental changes. Alternatively, a change in genetic stock structure could be indicative of a change in population dynamics (e.g., higher or lower juvenile mortality) of a particular stock, altered hatchery production scales or schedules, or the recovery or failure of dominant regional runs. Any such factors could affect groundfish fleets or salmon fisheries and may warrant further investigation.

Stock Compositions of Chum Salmon Bycatch in Bering Sea Trawl Fisheries

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Last updated: August 2018

Description of indicator: Chum salmon (*Oncorhynchus keta*) is a highly migratory species that is caught as bycatch in trawl fisheries in the Bering Sea and the Gulf of Alaska (Schnaittacher et al., 2013). Chum salmon is primarily caught as bycatch in the Bering Sea trawl fishery for walleye pollock (*Gadus chalcogrammus*). Chum salmon is an economically and culturally valuable species and it is designated as prohibited species catch in the trawl fisheries, with a suite of bycatch mitigation measures, including industry-managed rolling hotspot closures (Little et al., 2015). Chum salmon caught in the Bering Sea originate from as far east as Japan and as far south as Washington, and include fish from western Alaska (Urawa et al., 2009; Whittle et al., 2018). Notably, chum salmon from western Alaska are an important part of subsistence catches and thus, identifying origins of chum salmon caught as bycatch is critical for managing the impacts of bycatch on particular stocks.

Observers from the North Pacific Groundfish Observer Program monitor 100% of the trips targeting walleye pollock in the Bering Sea each year. During these trips, they enumerate all and genetically sample 1 in 30 chum salmon caught as bycatch. The Genetics Program at the Auke Bay Laboratories analyzes chum bycatch samples for genetic stock identification (Whittle et al., 2018), apportioning catches to reporting groups (southeast Asia, northeast Asia, western Alaska, upper-middle Yukon River, southwest Alaska, and eastern Gulf of Alaska/Pacific northwest). We present the proportional composition of the bycatch for each of these reporting groups (Figure 85).

Status and trends: Stock composition has varied inter-annually during this short time series (2011–2016), with northeast Asia and GOA/Pacific northwest stocks alternately accounting for the greatest proportions of bycatch in each year. The next largest contributions to the bycatch have typically come from southeast Asia and western Alaska stocks of chum salmon. Upper-Middle Yukon and southwest Alaska stocks have accounted for less than 10% of the bycatch in each of the years. The majority of chum salmon are caught in the pollock fishery during the B-season (June–October) and most of these have been caught east of 170°W. See Whittle et al. (2018) for further descriptions of temporal and spatial strata in stock compositions.

Data have only been collected in a reproducible and consistent fashion for a few years, so a description of trends is fairly limited at this point. However, as we move forward, these data establish a baseline from which to compare changes in the future.

Factors influencing observed trends: Work is on-going to understand the spatial and temporal dynamics of chum salmon bycatch. Fishing fleets actively seek to avoid salmon bycatch so trends in the composition may be confounded by the behaviors of fishers, which also vary as a function of pollock abundance and water temperature (Watson and Haynie, 2018). Additionally, chum salmon run sizes vary by region so a full

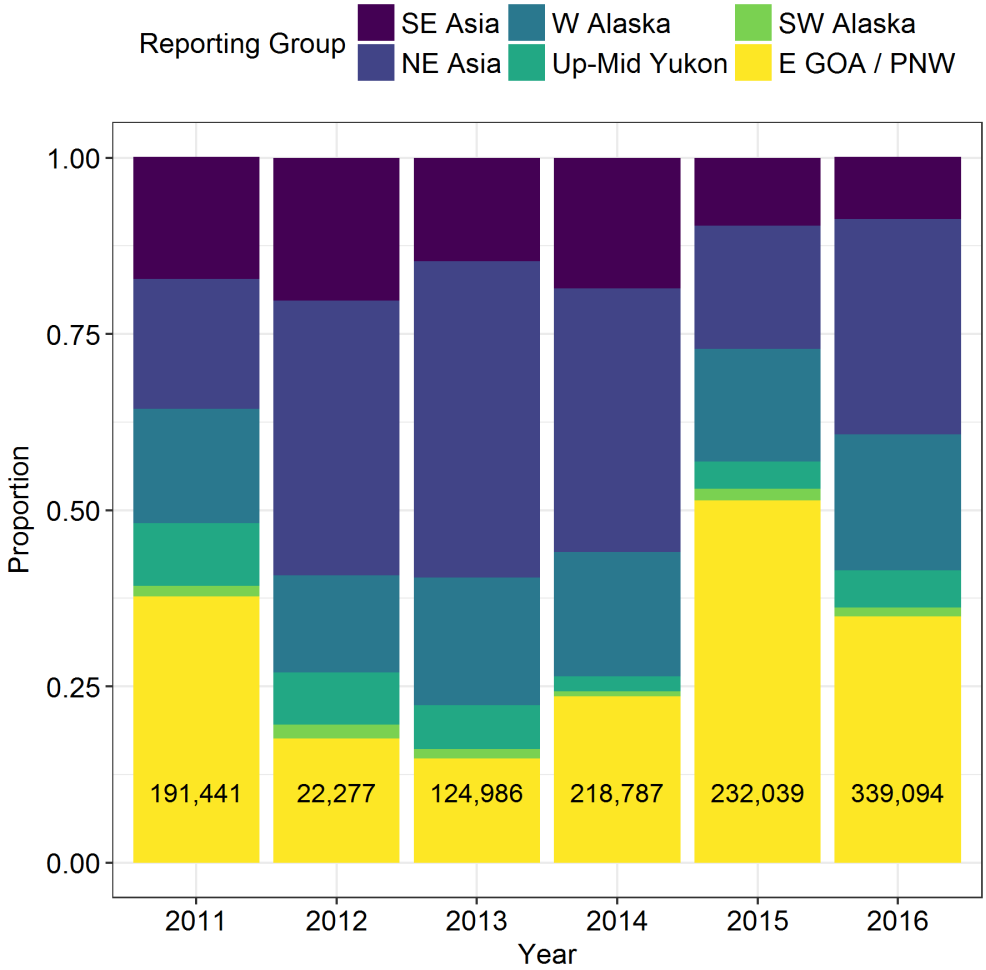

Figure 85: Stock composition (proportion) of chum salmon bycatch by year from the Bering Sea pollock trawl fishery with total numbers of chum salmon caught provided in lower portion of each bar.

understanding how variability in stock composition may vary by year will rely upon a standardization of bycatch proportions to the numbers of fish that may be encountered by fishers.

Implications: Understanding the dynamics of chum salmon bycatch in trawl fisheries is critical to groundfish management because chum salmon represent a prohibited species catch that can drive fisher behavior and lead to significant economic impacts to the fleet. The coarse spatial resolution of the reporting groups makes it difficult to resolve the impacts of chum salmon bycatch on individual stocks. However, because chum salmon are of great importance to subsistence users in western Alaska, the broader impacts of the trawl fishery may be inferred to some extent using these data. A shift in stock compositions could be indicative of a change in timing of either chum migration patterns or fishing patterns, both of which could be related to environmental changes. Alternatively, a change in genetic stock structure could be indicative of a change in population dynamics (e.g., higher or lower juvenile mortality) of a particular stock, different run sizes, or the recovery or failure of dominant regional runs. Any such factors could affect groundfish fleets or salmon fisheries and may warrant further investigation.

Time Trends in Groundfish Discards

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Last updated: September 2018

Description of indicator: Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Region's blend data, while estimates for 2003 and later come from the Alaska Region's Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards. Discard rates as shown here are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area-gear-target sector. Where rates are described below for species or species groups, they represent the total discarded weight of the species/species group divided by the total catch weight of the species/species group for the relevant area-gear-target sector. These estimates include only catch of FMP-managed groundfish species within the FMP groundfish fisheries: not included are groundfish discards in the halibut fishery and discards of non-groundfish species, such as forage fish and species managed under prohibited species catch (PSC) limits.

Status and trends: Figure 86 shows annual FMP groundfish discards (biomass and percentage of total FMP groundfish catch biomass) by sector (fixed gear, pollock trawl, and non-pollock trawl) and region (all EBS, northern EBS, and southern EBS). Figure 87 shows weekly discard biomass across the entire EBS by sector for the previous 5 years plus the current year (2018) to date. Since 1993 discard rates of groundfish in federally-managed Alaskan groundfish fisheries have generally declined in both pollock and non-pollock trawl fisheries in the eastern Bering Sea (EBS). Discard rates in the EBS pollock trawl sector declined from 20% to about 1% in 1998 and have remained at or below this level. Rates in the non-pollock trawl sector have declined from a high of 50% in 1994 and have remained below 8% since 2011. Discard rates and volumes in the fixed gear (hook-and-line and pot) sector trended upward from 2010 to 2016, reaching the highest annual discard biomass (26.7K metric tons) over the entire time series before declining in 2017. Discard biomass in the northern Bering Sea fixed gear sector has trended upward since 2016, though remains small relative to discard biomass in the southern Bering Sea. To date in 2018, discards in the fixed gear sector are trending lower in the southern Bering Sea and higher in the northern Bering Sea relative to the previous 5-year period.

Factors influencing observed trends: Discards of groundfish may occur for economic or regulatory reasons. Economic discards include discards of lower value and unmarketable fish in order to maximize harvest or production value. Regulatory discards are those required by regulation, such as discards of species where harvest has reached the allowable catch limit and which may no longer be retained. Mechanisms used in North Pacific groundfish fisheries for reducing discards include:

- Limited access privilege programs (LAPPs), which allocate catch quotas and may reduce economic discards by removing the "race for fish"
- In-season closure of fisheries once target or bycatch species quotas are reached
- Minimum retention and utilization standards for certain fisheries
- Maximum retainable amounts (MRAs) specifying the amounts of non-target species that harvesters may retain relative to other groundfish species that remain open to directed fishing. MRAs reduce regulatory discards by allowing for limited retention of species harvested incidentally in directed fisheries.

In the EBS, management and conservation measures aimed at reducing bycatch have contributed to an overall decline in groundfish discards since the early 1990ss (NPFMC, 2016; NPFMC, 2017). Pollock roe

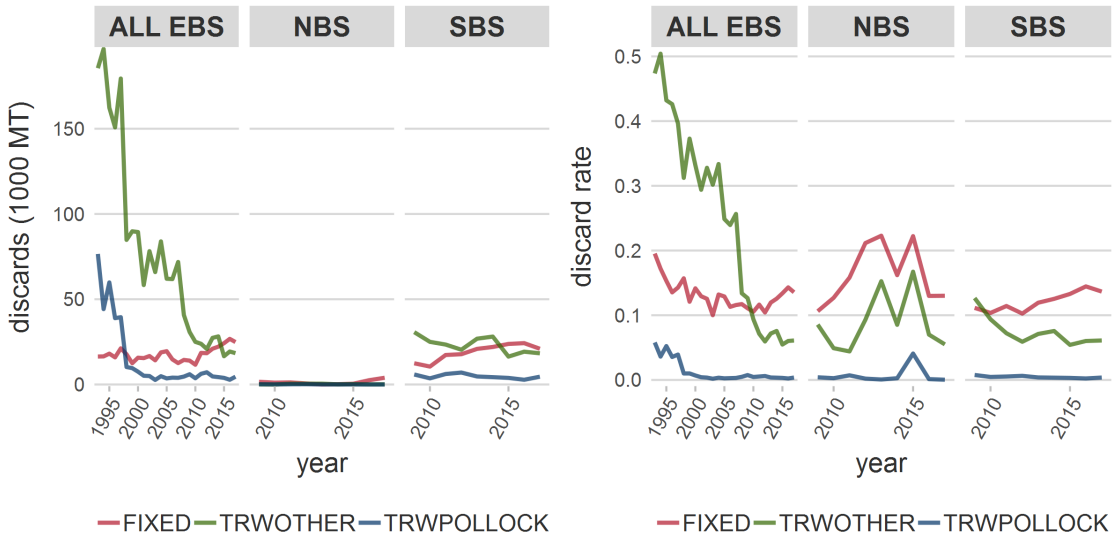

Figure 86: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear, pollock trawl, and non-pollock trawl sectors, 1993–2017, for the EBS and northern and southern EBS subregions (data by subregion available only for 2009 and forward). Discard rates are calculated as total discard weight of FMP groundfish divided by total retained and discarded weight of FMP groundfish for the sector (includes only catch counted against federal TACs).

stripping, wherein harvesters discard all but the the highest value pollock product, was prohibited in 1991 (56 Federal Register 492). Throughout the 1990s, declines in total catch and discard of non-pollock groundfish in the pollock fishery coincided with the phasing out of bottom trawl gear in favor of pelagic gear, which allows for cleaner pollock catches (Graham et al., 2007). Full retention requirements for pollock and Pacific cod were implemented in 1998 for federally-permitted vessels fishing for groundfish (62 Federal Register 63880). Between 1997 and 1998 annual discard rates for cod fell from 13% to 1% in the non-pollock trawl sector and from 50% to 3% in the trawl pollock sector; pollock discards also declined significantly across both trawl gear sectors. In the trawl pollock fishery, discards of pollock have remained at nominal levels since passage of the American Fisheries Act, which established a sector-based LAPP and implemented more comprehensive observer requirements for the fishery in 2000.

Low retention rates in the non-AFA trawl catcher processor (head and gut) fleet prompted Amendments 79 and 80 to the BSAI Groundfish FMP in 2008 (NPFMC, 2016). Amendment 79 established a Groundfish Retention Standard (GRS) Program with minimum retention and utilization requirements for vessels at least 125 feet LOA; industry-internal monitoring of retention rates has since replaced the program. Amendment 80 expanded the GRS program to all vessels in the fleet and established a cooperative-based LAPP with fixed allocations of certain non-pollock groundfish species. In combination with the GRS program, these allocations are intended to remove the economic incentive to discard less valuable species caught incidentally in the multi-species fishery. In 2013, NMFS revised MRAs for groundfish caught in the BSAI arrowtooth flounder fishery, including an increase from 0 to 20 percent for pollock, cod, and flatfish (78 Federal Register 29248). Groundfish discard rates in the trawl flatfish fishery fell from 23% to 12% between 2007 and 2008 and have continued on a gradual decline since then.

Since 2003 across all Bering Sea sectors combined, discard rates for species groups historically managed together as the "other groundfish" assemblage (skate, sculpin, shark, squid, and octopus) have ranged from 65% to 80%, with skates representing the majority of discards by weight. In the fixed gear sector other groundfish typically account for at least 70% of total groundfish discards annually. Fluctuations in discard volumes and rates for these species may be driven by changes in market conditions and in fishing behavior within the directed fisheries in which these species are incidentally caught. For example, low octopus catch

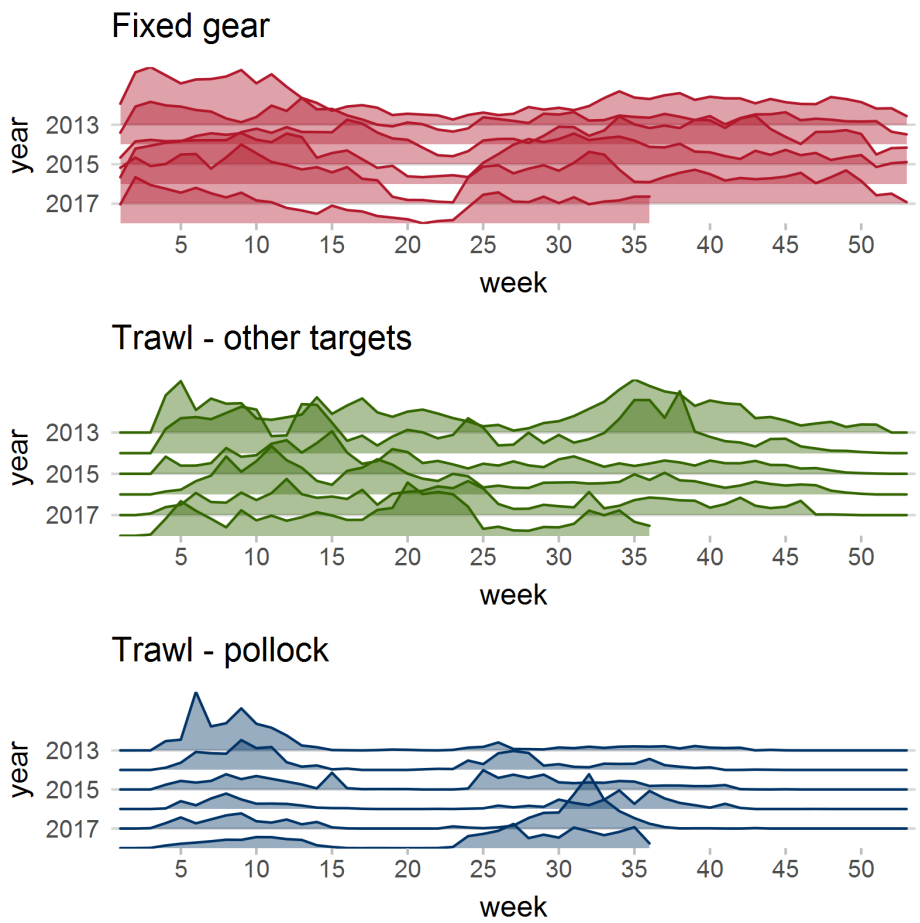

Figure 87: Total biomass of FMP groundfish discarded in the EBS by sector and week of the fishing season, 2013–2018 (data for 2018 is shown through week 36). Plotted heights are not comparable across fisheries.

from 2007–2010 may be attributable to lower processor demand for food-grade octopus and decreases in cod pot-fishing effort stemming from declines in cod prices (Conners et al., 2016).

The upward trend in discards in the northern Bering Sea since 2016 is primarily attributable to increased fishing in the region by freezer longline vessels targeting Pacific cod.

Implications: Minimizing fishery discards is recognized as an ecological, economic, and moral imperative in various multilateral initiatives and in National Standard 9 of the Magnuson-Stevens Fishery Conservation and Management Act (Alverson (1994); FAO, 1995; Karp et al. (2011)). Fishery bycatch adds to the total human impact on biomass without providing a benefit to the Nation and as such are seen as "contrary to responsible stewardship and sustainable utilization of marine resources" (Kelleher, 2005). Bycatch may constrain the utilization of target species and increases the uncertainty around total fishing-related mortality, making it more difficult to assess stocks, define overfishing levels, and monitor fisheries for overfishing (Alverson, 1994; Clucas, 1997; Karp et al., 2011). Although ecosystem effects of discards are not fully understood, discards of whole fish and offal have the potential to alter energy flow within ecosystems and have been observed to result in changes to habitat (e.g., oxygen depletion in the benthic environment) and community structure (e.g., increases in scavenger populations) (Queirolo et al., 1995; Alverson, 1994; Catchpole et al., 2006; Zador and Fitzgerald, 2008). Monitoring discards and discard rates provides a means of assessing the efficacy of measures intended to reduce discards and increase groundfish retention and utilization.

Time Trends in Non-Target Species Catch

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Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the Eastern Bering Sea (EBS). In previous years we included the catch of "other" species, "non-specified" species, and forage fish in this contribution. However, stock assessments have now been developed or are under development for all groups in the "other species" category (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), some of the species in the "non-specified" group (giant grenadier, other grenadiers), and forage fish (e.g., capelin, eulachon, Pacific sand lance, etc.), therefore we no longer include trends for these species/groups here (see AFSC stock assessment website at `http://www.afsc.noaa.gov/refm/stocks/assessments.htm`). Invertebrate species associated with habitat areas of particular concern, previously known as HAPC biota (seapens/whips, sponges, anemones, corals, and tunicates) are now referred to as structural epifauna. Starting with the 2013 Ecosystem Considerations Report, the three categories of non-target species we continue to track here are:

1. Scyphozoan jellyfish
2. Structural epifauna (seapens/whips, sponges, anemones, corals, tunicates)
3. Assorted invertebrates (bivalves, brittle stars, hermit crabs, miscellaneous crabs, sea stars, marine worms, snails, sea urchins, sand dollars, sea cucumbers, and other miscellaneous invertebrates).

Total catch of non-target species is estimated from observer species composition samples taken at sea during fishing operations, scaled up to reflect the total catch by both observed and unobserved hauls and vessels operating in all FMP areas. Catch since 2003 has been estimated using the Alaska Regions Catch Accounting System. This sampling and estimation process does result in uncertainty in catches, which is greater when observer coverage is lower and for species encountered rarely in the catch.

For this contribution the catch of non-target species/groups from the Bering Sea includes the reporting areas 508, 509, 512, 513, 514, 516, 517, 521, 523, 524, and 530 (`https://alaskafisheries.noaa.gov/sites/default/files/fig1.pdf`). In previous years this contribution included reporting areas 518 and 519 as part of the Bering Sea. Starting with the 2017 contribution, reporting areas 518 and 519 are now considered part of the Aleutian Islands. This change has made this contribution consistent with the spatial boundaries used for the ecosystem assessments in this report.

Status and trends: The catch of Scyphozoan jellyfish has fluctuated over the last seven years and peaked in 2014 (Figure 88). Highs in jellyfish catch in 2011 and 2014 were followed by sharp drops the following year to catches less than half the size. The catch of jellyfish in 2014 is more than double the catch in 2015 and is more than five times the catch in 2016, which is the lowest over the time period examined. The catch in 2017 is more than double the catch in 2016. Jellyfish are primarily caught in the pollock fishery.

The catch of structural epifauna has been relatively steady from 2011 to 2017 (Figure 88). Benthic urochordata, anemones, and sponge comprised the majority of the structural epifauna catch from 2011–2017. Sponge were the dominant component of the structural epifauna catch in 2011 and were primarily caught in non-pelagic trawls. Benthic urochordate caught in non-pelagic trawls were the dominant component of the

structural epifauna catch in 2012, 2015, 2016, and 2017. In 2013 and 2014, anemones caught in the Pacific cod fishery were the dominant part of the structural epifauna catch.

Sea stars comprise the majority of the assorted invertebrates catch in all years (2011-2017) and are primarily caught in flatfish fisheries (Figure 88). The catch of assorted invertebrates has generally trended upward from 2011–2015, and has decreased slightly in 2016 and 2017.

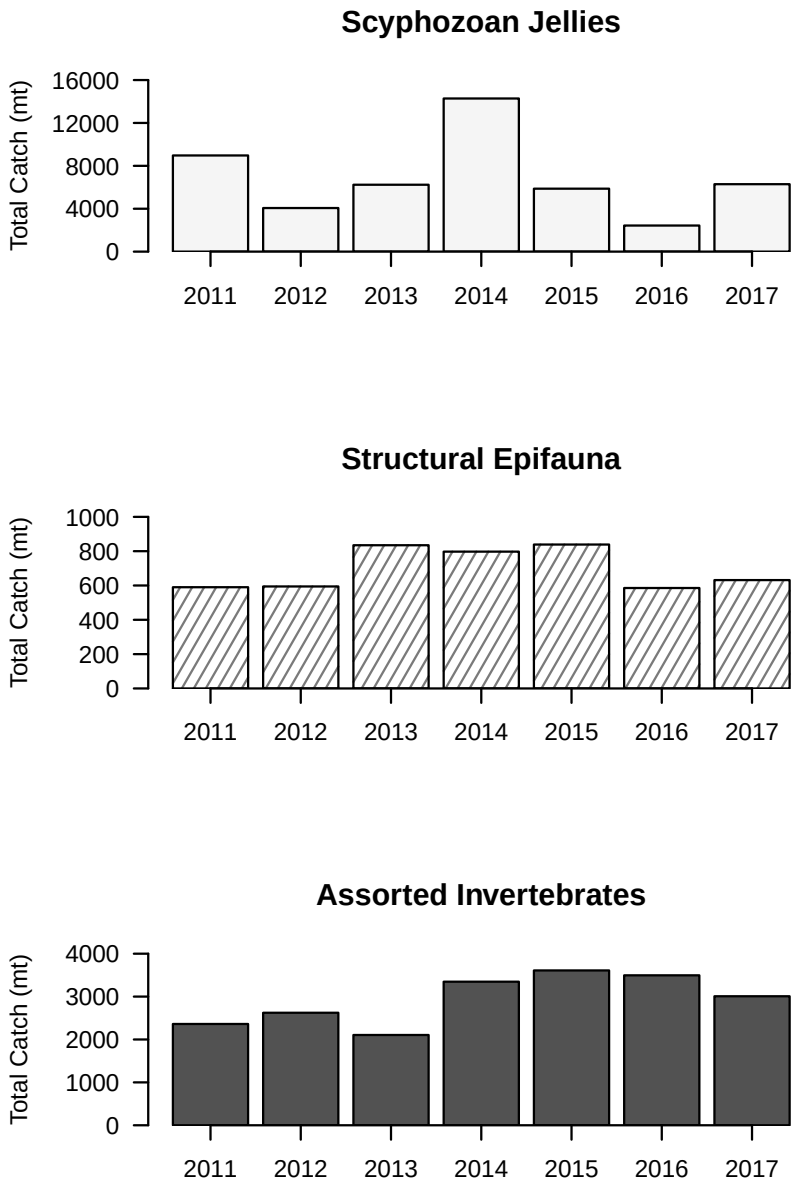

Figure 88: Total catch of non-target species (tons) in eastern Bering Sea groundfish fisheries (2011–2017). **Please note the different y-axis scales** between the species groups.

Factors influencing observed trends: The catch of non-target species may change if fisheries change, if ecosystems change, or both. Because non-target species catch is unregulated and unintended, if there have been no large-scale changes in fishery management in a particular ecosystem, then large-scale signals in the non-target catch may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish in the EBS are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, sea ice phenology, wind-mixing, ocean currents, and prey abundance (Brodeur et al., 2008).

Implications: The catch of structural epifauna species and assorted invertebrates is very low compared with the catch of target species. Structural epifauna species may have become less available to the EBS fisheries (or the fisheries avoided them more effectively) since 2005. The lack of a clear trend in the catch of scyphozoan jellies may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries. Abundant jellyfish may have a negative impact on fishes as they compete with planktivorous fishes for prey resources (Purcell and Arai, 2001), and additionally, jellyfish may prey upon the early life history stages (eggs and larvae) of fishes (Purcell and Arai, 2001; Robinson et al., 2014).

Seabird Bycatch Estimates for Groundfish Fisheries in the Eastern Bering Sea, 2007–2017

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Last updated: August 2018

Description of indicator: This report provides estimates of the numbers of seabirds caught as bycatch in commercial groundfish fisheries operating in federal waters of the U.S. Exclusive Economic Zone of the eastern Bering Sea for the years 2007 through 2017. Estimates of seabird bycatch from earlier years using different methods are not included here. Fishing gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic trawl. These numbers do not apply to gillnet, seine, or troll fisheries. Data collection on the Pacific halibut longline fishery began in 2013 with the restructured observer program, although some small amounts of halibut fishery information were collected in previous years when an operator had both halibut and sablefish individual fishing quota (those previous years of halibut data, from 2007–2012, are not included in the data presented in this report).

Estimates are based on two sources of information: (1) data provided by NMFS-certified Fishery Observers deployed to vessels and floating or shoreside processing plants (AFSC, 2011), and (2) industry reports of catch and production. The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2010, 2014). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. It is also used for the provision of estimates of non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. The CAS produces estimates based on these two current data sets, which may have changed over time. Changes in the data from one reporting year to another are due to errors that were discovered during observer debriefing, through additional data quality checks, and use of data for analysis, or issues with the data that come to light. Examples of the possible changes in the underlying data are include: changes in species identification, deletion of data sets where data collection protocols were not properly followed, and changes in the landing or at-sea production reports where data entry errors were found.

Table 4: **Estimated** seabird bycatch in eastern Bering Sea groundfish fisheries for all gear types, 2007 through 2017. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Unidentified Albatrosses	0	0	0	0	0	0	0	13	0	0	0
Short-tailed Albatross	0	0	0	15	5	0	0	11	0	0	0
Laysan Albatross	2	7	14	16	30	48	19	17	30	18	33
Black-footed Albatross	18	7	5	9	2	0	1	9	2	0	0
Northern Fulmar	3,158	2,132	7,215	1,933	5,416	3,115	2,901	715	2,484	5,182	3,844
Shearwaters	2,821	1,185	571	571	160	527	197	119	363	3,212	999
Storm Petrels	1	0	0	0	0	0	0	0	0	0	0
Gulls	717	1,348	911	721	1,654	836	421	586	941	605	372
Kittiwakes	10	0	16	0	6	5	3	4	12	5	22
Murres	6	6	13	102	14	6	3	47	0	58	10
Puffins	0	0	0	9	0	0	0	0	0	10	0
Auklets	0	3	0	0	0	7	4	99	19	29	34
Other Alcids	0	0	105	0	0	0	0	0	0	0	0
Cormorants	0	0	0	0	0	0	0	0	3	0	0
Other Birds	0	0	136	0	0	0	0	0	0	0	63
Unidentified Birds	461	267	501	253	378	308	275	78	160	283	268
Grand Total	7,194	4,955	9,487	3,629	7,665	4,852	3,824	1,698	4,014	9,402	5,645

Status and trends: The numbers of seabirds estimated to be caught incidentally in the eastern Bering Sea fisheries in 2017 decreased from 2016, and were very similar to the 2007–2016 average of 5,672 (Table 4, Figure 89). In the eastern Bering Sea fisheries, 2016 had an unusually large number of shearwaters caught incidentally; the 2017 seabird bycatch estimates were closer to what is normally seen in this region. Northern fulmars, shearwaters, and gulls were the most common species group caught incidentally in the eastern Bering Sea fisheries in 2017. No short-tailed albatross or black-footed albatross were caught, and an average number of Laysan albatross were caught incidentally. The estimated numbers of birds caught incidentally in the eastern Bering Sea exceeded that in the Gulf of Alaska and the Aleutian Islands, combined, as has been the case in all years in this time series (Figure 89). However, the number of albatross caught incidentally in the eastern Bering Sea is less than that in the Gulf of Alaska and in the Aleutian Islands, as has been the case in all years in this time series (Figure 90).

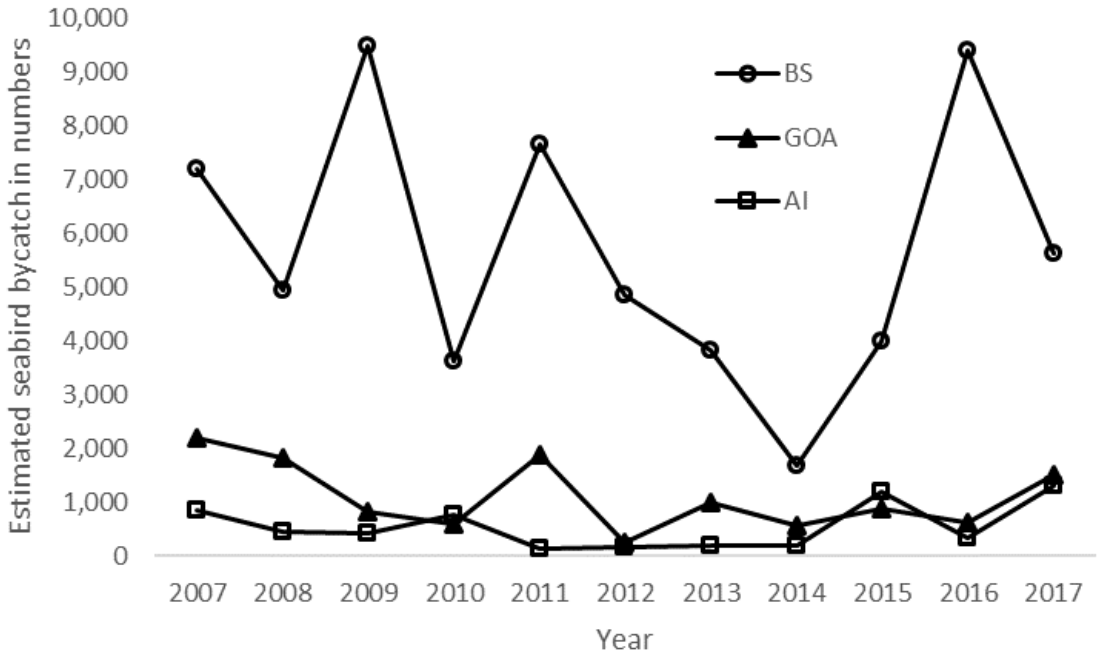

Figure 89: Total estimated seabird bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007–2017.

Factors influencing observed trends: There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. For example, a marked decline in overall numbers of birds caught after 2002 reflected the increased use of seabird mitigation devices. A large portion of the freezer longline fleet adopted these measures in 2002, followed by regulation requiring them for the rest of the fleet beginning in February 2004. Since 2002, seabird bycatch estimates have varied annually but have not returned to the level seen prior to the use of seabird mitigation devices. Since 2004, work has continued on developing new and refining existing mitigation gear (Dietrich and Melvin, 2008).

The longline fleet has traditionally been responsible for about 90% of the overall seabird bycatch in Alaska, as determined from the data sources noted above. However, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates may be downward biased. For example, the 2010 estimate of trawl-related seabird mortality is 823, while the additional observed mortalities (not included in this estimate and not expanded to the fleet) were 112 (S. Fitzgerald, pers. comm.). Observers now record the additional mortalities they see on trawl vessels and the AFSC Seabird Program has contracted an analyst to work on how these additional numbers can be folded into an overall estimate. The challenge to further reduce seabird bycatch is great

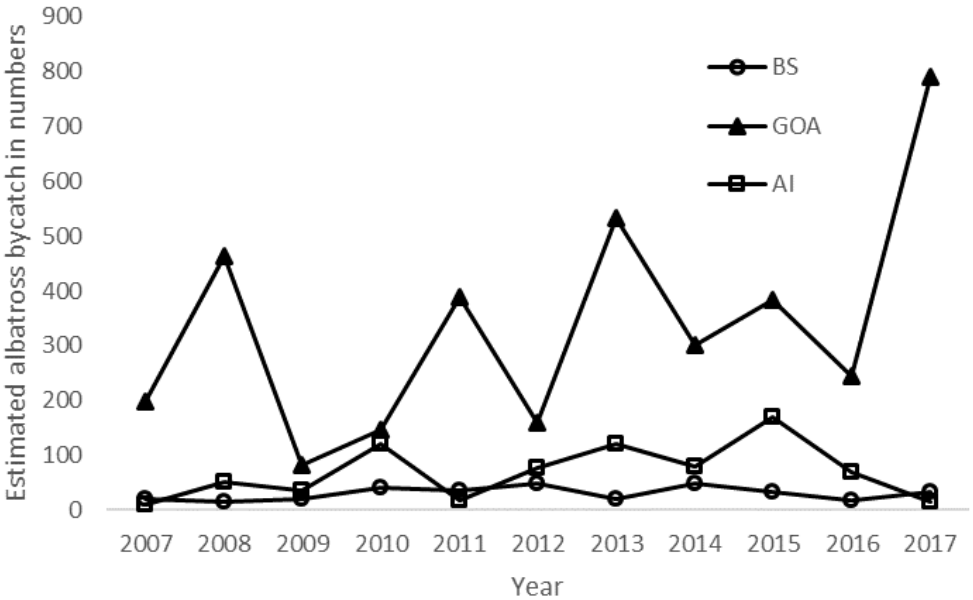

Figure 90: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007–2017.

given the rare nature of the event. For example, (Dietrich and Fitzgerald, 2010) found in an analysis of 35,270 longline sets from 2004 to 2007 that the most predominant species, northern fulmar, only occurred in 2.5% of all sets. Albatross, a focal species for conservation efforts, occurred in less than 0.1% of sets. However, given the vast size of the fishery, the total estimated bycatch can add up to hundreds of albatross or thousands of fulmars (Eich et al., 2017).

Implications: Estimated seabird bycatch decreased from 2016 to 2017 in the eastern Bering Sea, but 2016 had an unusually large number of shearwaters caught incidentally; the 2017 seabird bycatch estimates were closer to what is normally seen in that region. Estimated seabird bycatch increased from 2016 to 2017 in the Aleutian Islands, primarily attributed to increased numbers of shearwaters. Estimated seabird bycatch also increased from 2016 to 2017 in the Gulf of Alaska but that was primarily attributed to increased numbers of black-footed albatross and northern fulmar. These differences indicate localized changes in the three different regions regarding seabird distribution, fishing effort, and/or seabird prey supply, all of which could impact bycatch.

The effects of the "Warm Blob" that resulted in an extreme marine heat wave from 2014–2016, appeared to be moderating and dissipating in 2017 (Zador and Yasumiishi, 2017). The warm temperatures caused variability in prey availability for seabirds. Over the last few years, seabird die-offs appear to have increased, presumably linked to the extreme marine heat wave from 2014–2016. Numerous seabirds have been reported dead, in poor body condition, or in reproductive failure (Zador and Yasumiishi (2017); Siddon and Zador (2017), K. Kuletz, pers comm.). These seabirds include northern fulmars, murres, storm petrels, short-tailed shearwaters, black-legged kittiwakes, auklets, gulls, and horned puffins. Examined birds ultimately died of starvation or drowning, but underlying factors contributing to the die-off have yet to be determined (K. Kuletz, pers comm.).

It is difficult to determine how seabird bycatch numbers and trends are linked to changes in ecosystem components, because seabird mitigation gear is used in the longline fleet. There does appear to be a link between poor ocean conditions and the peak bycatch years, on a species-group basis. Fishermen have noted in some years that the birds appear starved and attack baited longline gear more aggressively. From year to year, broad changes in total seabird bycatch for all regions combined, up to 5,746 birds per year, occurred between 2007 and 2017. This probably indicates changes in food availability rather than drastic changes

in how well the fleet employs mitigation gear. A focused investigation of this aspect of seabird bycatch is needed and could inform management of poor ocean conditions if seabird bycatch rates (reported in real time) were substantially higher than normal.

Maintaining and Restoring Fish Habitats

Area Disturbed by Trawl Fishing Gear in Alaska

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Last updated: October 2018

Description of indicator: Fishing gear can impact habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. This indicator uses output from the Fishing Effects (FE) model to estimate the area of geological and biological features disturbed across Alaska's Large Marine Ecosystems, utilizing spatially-explicit VMS data. The time series for this indicator is available since 2003, when widespread VMS data became available.

Status and trends: The percent of area disturbed due to commercial fishing interactions (pelagic and non-pelagic trawl, longline, and pot) decreased steadily from 2008 to the present in the Bering Sea, with slightly decreasing or steady trends in the Gulf of Alaska and Aleutian Islands (Figures 91 and 92).

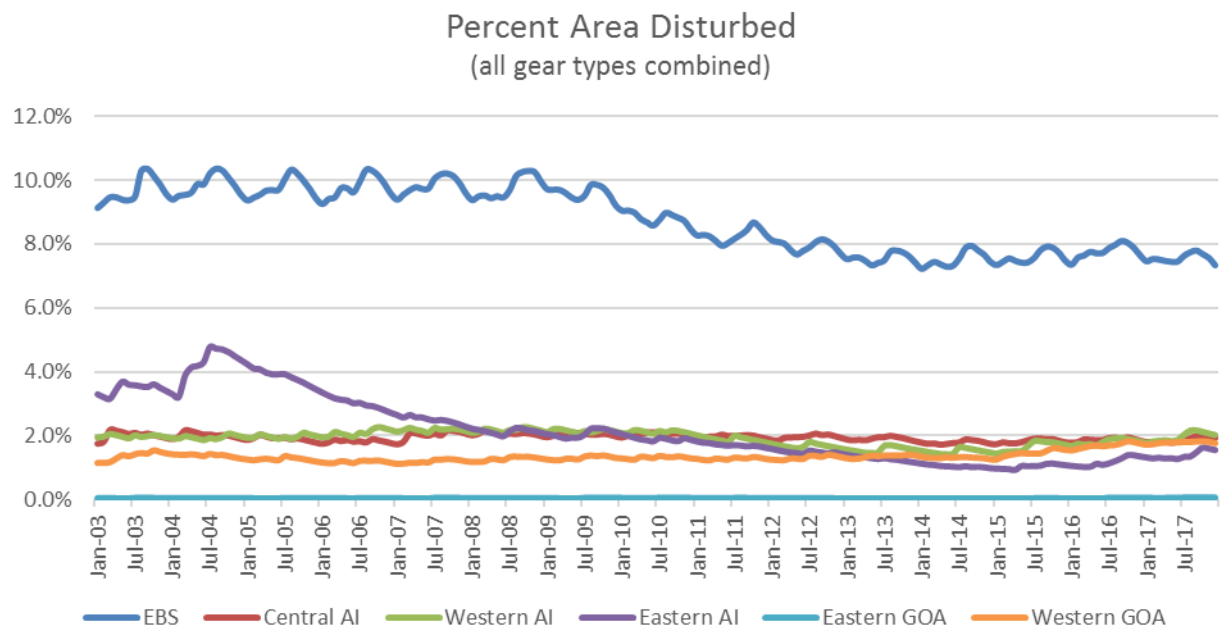

Figure 91: Percent habitat reduction, all gear types combined, from 2003 through 2017.

Factors influencing observed trends: Trends in seafloor area disturbed can be affected by numerous variables, such as fish abundance and distribution, management actions (e.g., closed areas), changes in the structure of the fisheries due to rationalization, increased technology (e.g., increased ability to find fish), markets for fish products, and changes in vessel horsepower and fishing gear. Intensive fishing in an area can result in a change in species diversity by attracting opportunistic fish species which feed on animals that have been disturbed by fishing activity, or by reducing the suitability of habitat used by some species. It is possible that increased effort in fisheries that interact with both living and non-living bottom substrates could result in increased habitat loss/degradation due to fishing gear effects. The footprint of habitat damage varies with gear (type, weight, towing speed, depth of penetration), the physical and biological characteristics of the

areas fished, recovery rates of living substrates in the areas fished, and management changes that result in spatial redistribution of fishing effort.

Between 2003 and 2008, variability in area disturbed was driven largely by the seasonality of fishing in the Bering Sea. In 2008, Amendment 80 was implemented, which allocated BSAI Yellowfin sole, Flathead sole, Rock sole, Atka mackerel, and Aleutian Islands Pacific ocean perch to the head and gut trawl catcher processor sector, and allowed qualified vessels to form cooperatives. The formation of cooperatives reduced overall effort in the fleet while maintaining catch levels. In 2010, trawl sweep gear modifications were implemented on non-pelagic trawls in the Bering Sea, resulting in less gear contacting the seafloor and less habitat impact. Trawl sweep modifications were implemented in the Gulf of Alaska in 2014.

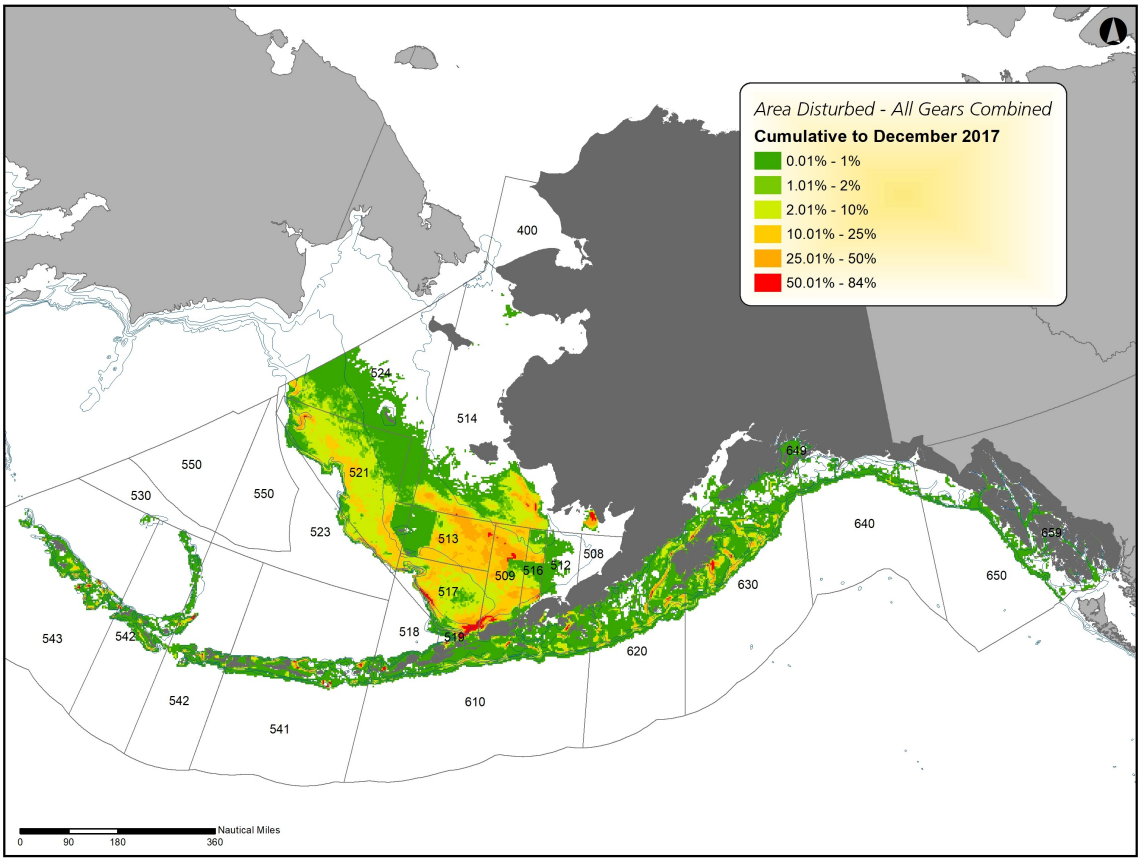

Figure 92: Map of percentage area disturbed per grid cell for all gear types. Effects are cumulative, and consider impacts and recovery of features from 2003 to 2017.

Implications: The effects of changes in fishing effort on habitat are largely unknown, althouth our ability to quantify those effects has increased greatly with the development of a Fishing Effects model as a part of the 2015 EFH Review (`ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/TM_NMFS_AFKR/TM_NMFS_FAKR_15.pdf`). The 2005 EFH FEIS, 2010 EFH Review, and 2015 EFH Review concluded that fisheries do have long term effects on habitat, and these impacts were determined to be minimal and not detrimental to fish populations or their habitats. These previous EFH analyses indicated the need for improved fishing effects model parameters. With the FE model, our ability to analyze fishing effects on habitat has grown exponentially. Vessel Monitoring System data provides a much more detailed treatment of fishing intensity, allowing better assessments of the effects of overlapping effort and distribution of effort between and within

grid cells. The development of literature-derived fishing effects database has increased our ability to estimate gear-specific susceptibility and recovery parameters. The distribution of habitat types, derived from increased sediment data availability, has improved. The combination of these parameters has greatly enhanced our ability to estimate fishing impacts.

New methods and criteria were developed to evaluate whether the effects of fishing on EFH are more than minimal and not temporary on managed fish stocks in Alaska. Criteria were developed by and reviewed by the Council and its advisory committees in 2016, and stock assessment authors in 2017. In April 2017, based on the analysis with the FE model, the Council concurred with the Plan Team consensus that the effects of fishing on EFH do not currently meet the threshold of more than minimal and not temporary, and mitigation action is not needed at this time.

Although the impacts of fishing across the domain are very low, it is possible that localized impacts may be occurring. The issue of local impacts is an area of active research.

Areas Closed to Bottom Trawling in the BSAI and GOA

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Last updated: October 2018

Description of indicator: Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Figure 93, Table 5). Some of the trawl closures are in effect year-round while others are seasonal. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high.

Status and trends: Additional measures to protect the declining western stocks of the Steller sea lion began in 1991 with some simple restrictions based on rookery and haulout locations; in 2000 and 2001 more specific fishery restrictions were implemented. In 2001, over 90,000 nm^2 of the Exclusive Economic Zone (EEZ) of Alaska was closed to trawling year-round. Additionally, 40,000 nm^2 were closed on a seasonal basis. State waters (0-3 nmi) are also closed to bottom trawling in most areas. A motion passed the North Pacific Management Council in February 2009 which closed all waters north of the Bering Strait to commercial fishing as part of the development of an Arctic Fishery management plan. This additional closure adds 148,300 nm^2 to the area closed to bottom trawling year round.

In 2010, the Council adopted area closures for Tanner crab east and northeast Kodiak Island. Federal waters in Marmot Bay are closed year round to vessels fishing with nonpelagic trawl gear. In two other designated areas, Chiniak Gully and ADF&G statistical area 525702, vessels with nonpelagic trawl gear can only fish if they have 100% observer coverage. To fish in any of the three areas, vessels fishing with pot gear must have minimum 30% observer coverage.

Implications: With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling. For additional background on fishery closures in the U.S. EEZ off Alaska, see Witherell and Woodby (2005).

Steller Sea Lion closure maps are available here:
`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/atka_pollock.pdf`
`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/pcod_nontrawl.pdf`
`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/cod_trawl.pdf`

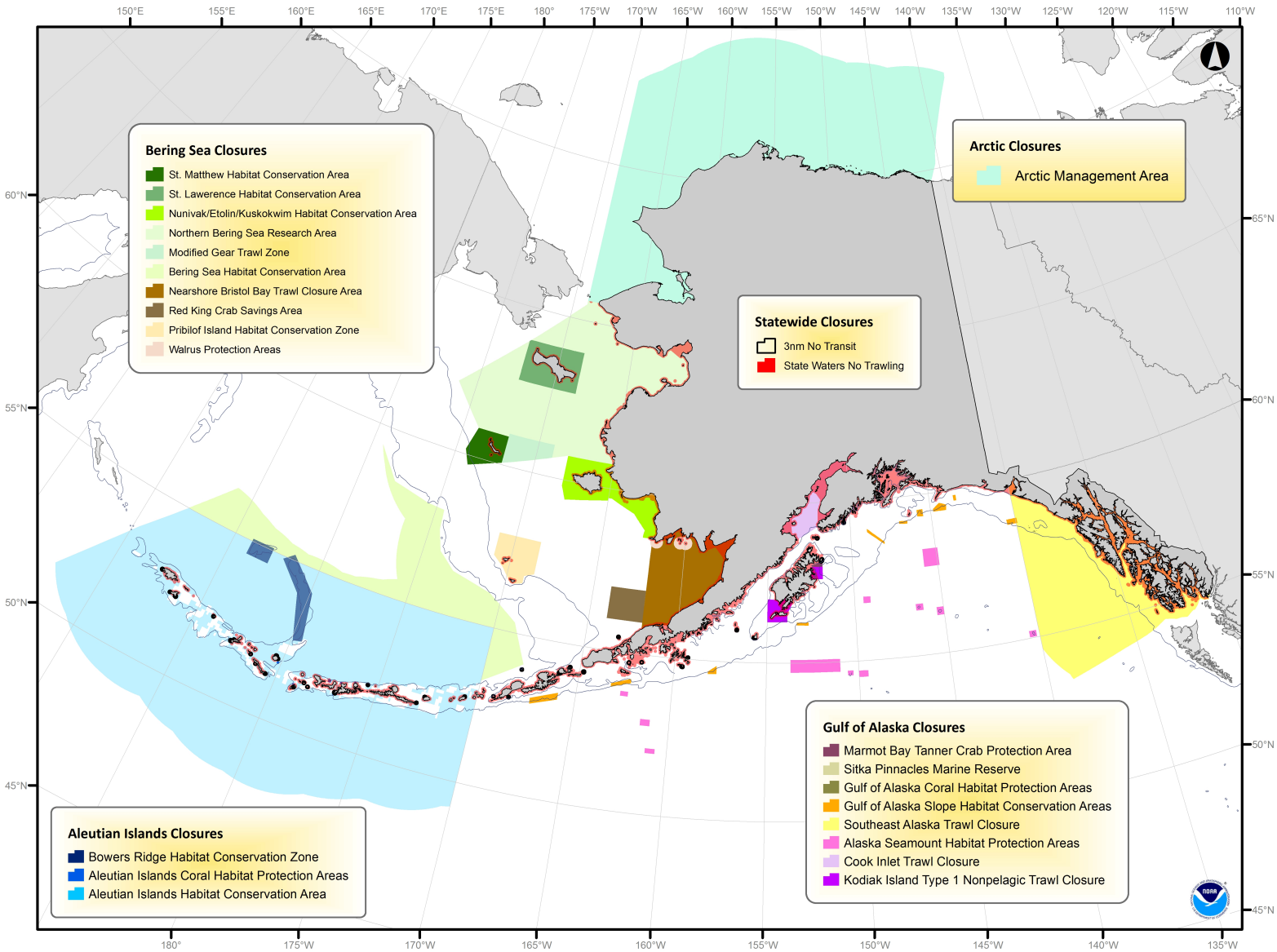

Figure 93: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Table 5: Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2017. LLP= License Limitation Program; HCA = Habitat Conservation Area; HCZ = Habitat Conservation Zone.

Area	Year	Location	Season	Area size	Notes
BSAI	1995	Area 512	year-round	8,000 nm^2	closure in place since 1987
		Area 516	3/15-6/15	4,000 nm^2	closure in place since 1987
		Chum Salmon Savings Area	8/1-8/31	5,000 nm^2	re-closed at 42,000 chum salmon
		Chinook Salmon Savings Area	trigger	9,000 nm^2	closed at 48,000 Chinook salmon
		Herring Savings Area	trigger	30,000 nm^2	trigger closure
		Zone 1	trigger	30,000 nm^2	trigger closure
		Zone 2	trigger	50,000 nm^2	trigger closure
		Pribilofs HCA	year-round	7,000 nm^2	
		Red King Crab Savings Area	year-round	4,000 nm^2	pelagic trawling allowed
		Walrus Islands	5/1-9/30	900 nm^2	12 mile no-fishing zones
		SSL Rookeries	seasonal ext.	5,100 nm^2	20 mile extensions at 8 rookeries
	1996	Nearshore Bristol Bay Trawl Closure	year-round	19,000 nm^2	expanded area 512 closure
		C. opilio bycatch limitation zone	trigger	90,000 nm^2	trigger closure
	2000	Steller Sea Lion protections			
		Pollock haulout trawl exclusion zones for EBS, AI * areas include GOA	* No trawl all year	11,900 nm^2	
			No trawl (Jan-June)*	14,800 nm^2	
			No Trawl Atka Mackerel restrictions	29,000 nm^2	
	2006	Essential Fish Habitat			
		AI Habitat Conservation Area	No bottom trawl all year	279,114 nm^2	
		AI Coral Habitat Protection Areas	No bottom contact gear all year	110 nm^2	
		Bowers Ridge Habitat Conservation Zone	No mobile bottom tending fishing gear	5,286 nm^2	
	2008	Northern Bering Sea Research Area	No bottom trawl all year	66,000 nm^2	
		Bering Sea HCA	No bottom trawl all year	47,100 nm^2	
		St. Matthews HCA	No bottom trawl all year	4,000 nm^2	
		St. Lawrence HCA	No bottom trawl all year	7,000 nm^2	
		Nunivak/Kuskokwim Closure Area	No bottom trawl all year	9,700 nm^2	
Arctic	2009	Arctic Closure Area	No Commercial Fishing	148,393 nm^2	
GOA	1995	Kodiak King Crab Protection Zone Type 1	year-round	1,000 nm^2	red king crab closures, 1987
		Kodiak King Crab Protection Zone Type 2	2/15-6/15	500 nm^2	red king crab closures, 1987
		SSL Rookeries	year-round	3,000 nm^2	10 mile no-trawl zones
	1998	Southeast Trawl Closure	year-round	52,600 nm^2	adopted as part of the LLP
		Sitka Pinnacles Marine reserve	year-round	3.1 nm^2	
	2000	Pollock haulout trawl exclusion zones for GOA* areas include EBS, AI	No trawl all year	11,900 nm^2*	
			No trawl (Jan-June)	14,800 nm^2	
	2006	Essential Fish Habitat			
		GOA Slope Habitat Conservation Area	No bottom trawl all year	2,100 nm^2	
		GOA Coral Habitat Protection Measures	No bottom tending gear all year	13.5 nm^2	
		Alaska Seamount Habitat Protection Measures	No bottom tending gear all year	5,329 nm^2	
	2010	Marmot Bay Tanner Crab Protection Area	No bottom trawl all year	112 nm^2	

Sustainability (for consumptive and non-consumptive uses)

Fish Stock Sustainability Index and Status of Groundfish, Crab, Salmon, and Scallop Stocks

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Last updated: July 2018

Description of indicator: The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of fish stocks selected for their importance to commercial and recreational fisheries (`http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`). The FSSI will increase as overfishing is ended and stocks rebuild to the level that provides maximum sustainable yield. The FSSI is calculated by awarding points for each fish stock based on the following rules:

1. Stock has known status determinations:
   (a) overfishing level is defined = 0.5
   (b) overfished biomass level is defined = 0.5
2. Fishing mortality rate is below the "overfishing" level defined for the stock = 1.0
3. Biomass is above the "overfished" level defined for the stock = 1.0
4. Biomass is at or above 80% of the biomass that produces maximum sustainable yield (B_{MSY}) = 1.0 (this point is in addition to the point awarded for being above the "overfished" level)

The maximum score for each stock is 4.

In the Alaska Region, there are 36 FSSI stocks and an overall FSSI of 144 would be achieved if every stock scored the maximum value, 4. Over time, the number of stocks included in the FSSI has changed as stocks have been added and removed from Fishery Management Plans (FMPs). Prior to 2015 there were 35 FSSI stocks and maximum possible score of 140. To keep FSSI scores for Alaska comparable across years we report the FSSI as a percentage of the maximum possible score (i.e., 100%).

Additionally, there are 29 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement. None of the non-FSSI stocks are known to be subject to overfishing, be overfished, or to be approaching an overfished condition. For more information on non-FSSI stocks see the Status of U.S. Fisheries webpage.

Within the BSAI region there are 22 FSSI stocks. The assessment for sablefish is based on aggregated data from the GOA and BSAI regions. In FSSI contributions prior to 2017, the sablefish FSSI score was included among BSAI species. Starting with last years contribution sablefish was removed from the BSAI FSSI contribution and placed in the GOA FSSI contribution (see the Gulf of Alaska Ecosystem Considerations Report). With few exceptions, groundfish species (or species

Table 6: Summary of status for the 22 FSSI stocks in the BSAI, updated through June 2018.

BSAI FSSI (22 stocks)	Yes	No	*Unknown*	*Undefined*	N/A
Overfishing	0	22	0	0	0
Overfished	1	21	0	0	0
Approaching Overfished Condition	0	21	0	0	1

complex) in the BSAI are managed as single stocks and not separately for the Bering Sea and Aleutian Islands. As such, the FSSI scores are reported for the BSAI as a whole. At this time it is not practical to report FSSI separately for the Bering Sea or Aleutian Islands.

Status and trends: As of June 30, 2018, no BSAI groundfish stock or stock complex is subjected to overfishing, is considered to be overfished, or to be approaching an overfished condition (Table 6). Among BSAI crab stocks, the Pribilof Islands blue king crab stock is considered to be overfished but is not subject to overfishing. This stock is in year 4 of a rebuilding plan.

The current overall Alaska FSSI is 135 out of a possible 144, or 93.75%, based on updates through June 2018 and is the highest score observed over the time period examined (Figure 94). FSSI increased 2.5 points from last years score and is the net result of increased scores for two king crab stocks in the EBS and a lower score for snow crab in the EBS. The overall Alaska FSSI has generally trended upwards from 80% in 2006 to 93.75% in 2018.

The BSAI groundfish FSSI score is 56 out of a maximum possible 56, and BSAI king and tanner crabs are 28 out of a possible 32. The overall Bering Sea/Aleutian Islands score is 84 out of a maximum possible score of 88 (Table 7). Since 2006 the BSAI overall FSSI has increased from 74% up to 95.45% in 2018 (Figure 95).

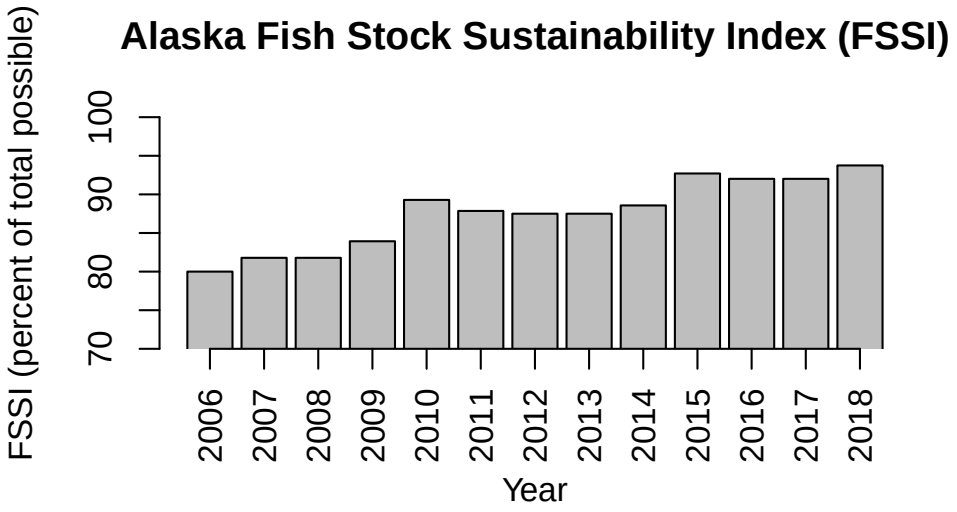

Figure 94: The trend in overall Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2018. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 on it is 144. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Factors influencing observed trends: The overall trend in Alaska FSSI has been positive over the duration examined here (2006-2018). The increase in overall score in 2018 is the net result of increased scores for two king crab stocks in the EBS and a decreased score for EBS snow crab. All other FSSI scores for individual stocks of crabs and groundfish are unchanged. In the EBS, the Pribilofs Islands blue king crab stock gained a point by no longer being subject to overfishing. The primary driver of decline for this stock is thought to be changes in environmental conditions that negatively affect reproduction. Two and a half points were gained for the Aleutian Islands golden king crab stock by defining the overfished state (0.5), determining the stock biomass was above the overfished level (1.0), and by having biomass greater than 80% of B_{MSY} (1.0). A point was lost for the snow crab biomass falling below 80% of B_{MSY} (-1.0). The net result of these changes is an overall increase of 2.5 points from last year. The only other stock in the EBS with an FSSI less than 4 is Saint Matthews Island blue king crab which loses a point for having biomass less than 80% of B_{MSY}.

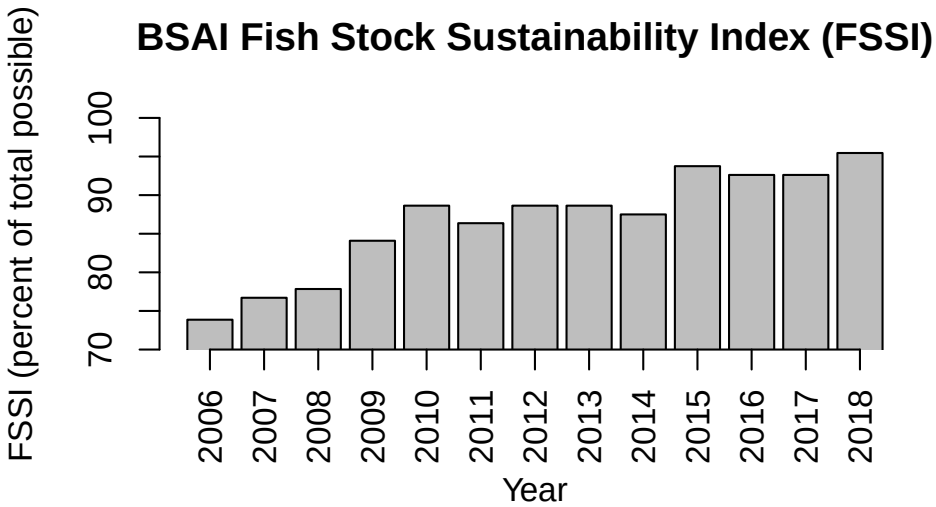

Figure 95: The trend in FSSI from 2006 through 2018 for the BSAI region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Implications: The majority of Alaska groundfish fisheries appear to be sustainably managed. No stocks in the BSAI are subject to overfishing and only a single crab stock is considered to be overfished (Pribilof Islands blue king crab). No other stocks or stock complexes in the BSAI are known to be approaching an overfished condition.

Table 7: BSAI FSSI stocks under NPFMC jurisdiction updated through June 2018 adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`. See Box A for endnotes and definition of stocks and stock complexes.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/B_{MSY}	FSSI Score
Blue king crab - Pribilof Islands[a]	No	Yes	N/A	Continue rebuilding	Year 4 of plan	0.09	2
Blue king crab - Saint Matthews Island	No	No	No	N/A	N/A	0.57	3
Golden king crab - Aleutian Islands	No	No	No	N/A	N/A	1.18	4
Red king crab - Bristol Bay	No	No	No	N/A	N/A	0.93	4
Red king crab - Norton Sound	No	No	No	N/A	N/A	1.29	4
Red king crab - Pribilof Islands	No	No	No	N/A	N/A	1.64	4
Snow crab - Bering Sea	No	No	No	N/A	N/A	0.60	3
Southern Tanner crab - Bering Sea	No	No	No	N/A	N/A	2	4
BSAI Alaska plaice	No	No	No	N/A	N/A	2.03	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.41	4
BSAI Arrowtooth Flounder	No	No	No	N/A	N/A	2.67	4
BSAI Blackspotted and Rougheye Rockfish[b]	No	No	No	N/A	N/A	0.90	4
BSAI Flathead Sole Complex[c]	No	No	No	N/A	N/A	2.07	4
BSAI Rock Sole Complex[d]	No	No	No	N/A	N/A	1.66	4
BSAI Skate Complex[e]	No	No	No	N/A	N/A	1.99	4
BSAI Greenland halibut	No	No	No	N/A	N/A	1.15	4
BSAI Northern rockfish	No	No	No	N/A	N/A	1.92	4
BS Pacific cod	No	No	No	N/A	N/A	1.56	4
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.72	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	1.02	4
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.88	4
BSAI Yellowfin sole	No	No	No	N/A	N/A	1.83	4

Box A. Endnotes and stock complex definitions for FSSI stocks listed in Table xx, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/`

(a) A new rebuilding plan for this stock was implemented January 1, 2015 but does not specify a target rebuilding date because it is not known when the stock is expected to rebuild. There is no directed fishing for the blue king crab-Pribilof Islands and the majority of blue king crab habitat is closed to bottom trawling, and beginning in 2015 there is a prohibition on directed cod pot fishing in the Pribilof Islands Habitat Conservation Zone (PIHCZ). For this stock to rebuild, the stock would likely require multiple years of above average recruitment and/or a change in environmental conditions to increase larval productivity around the Pribilof Islands.

(b) BSAI Blackspotted and Rougheye Rockfish consists of Blackspotted Rockfish and Rougheye Rockfish. An assessment of the combined species provides the overfished determination, and the OFL is based on the combined-species assessment.

(c) Flathead Sole Complex consists of Flathead Sole and Bering Flounder. Flathead Sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

(d) Rock Sole Complex consists of Northern Rock Sole and Southern Rock Sole (NOTE: These are two distinct species, not two separate stocks of the same species). Northern Rock Sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

(e) The Skate Complex consists of Alaska Skate, Aleutian Skate, Bering Skate, Big Skate, Butterfly Skate, Commander Skate, Deepsea Skate, Mud Skate, Okhotsk Skate, Roughshoulder Skate, Roughtail Skate, Whiteblotched Skate, and Whitebrow Skate. Alaska Skate is assessed and is the indicator species for this complex.

Total Annual Surplus Production and Overall Exploitation Rate of Groundfish, Bering Sea

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Last updated: October 2018

Description of indicator:

Total annual surplus production (ASP) of 9 groundfish stocks on the eastern Bering Sea (EBS) shelf from 1979–2016 was estimated by summing annual production across major commercial groundfish stocks for which assessments were available (Table 8). These species represent at least 80% of the total catch in bottom trawl surveys. Annual surplus production in year t can be estimated as the change in total adult groundfish biomass across species from year t (Bt) to year t+1 ($Bt+1$) plus total catches in year t (Ct):

$$ASPt = \Delta Bt + Ct = Bt + 1 - Bt + Ct$$

All estimates of B and C are based on 2017 stock assessments. An index of total exploitation rate within each region was obtained by dividing the total groundfish catch across the major commercial species by the estimated combined biomass at the beginning of the year:

$$ut = Ct/Bt$$

Table 8: Species included in computing annual surplus production in the BSAI management area.

Stock (*BSAI unless otherwise indicated*)
EBS Walleye Pollock (*Gadus chalcogrammus*)
EBS Pacific Cod (*Gadus macrocephalus*)
Yellowfin Sole (*Limanda aspera*)
Greenland Turbot (*Reinhardtius hippoglossoides*)
Arrowtooth Flounder (*Atheresthes stomias*)
Alaska Plaice (*Pleuronectes quadrituberculatus*)
Pacific Ocean Perch (*Sebastes alutus*)
Northern Rockfish (*S. polyspinus*)
Atka Mackerel (*Pleurogrammus monopterygius*)

Status and trends: The resulting indices suggest high variability in groundfish production in the eastern Bering Sea (Figure 96). Surplus production was lowest in the late 1980s, mid-1990s, from 2004–2007, and in 2016. Total exploitation rates for these groundfish species ranged from 6.7–14.4% (Figure 96). Overall exploitation rates were highest following periods of low surplus production in the late 1980s and mid-2000s. Trends in annual surplus production in the eastern Bering Sea are largely driven by variability in walleye pollock. Therefore, ASP for the Bering Sea was also computed after excluding walleye pollock (Figure 97). The results suggest variable aggregate surplus production of all non-pollock species ranging from a high of about 1 million tons

in 1979, due to strong recruitment of a number of species, to a low of less than 200,000 t in a number of years. Annual non-pollock surplus production has been moderately high between 300,000 and 600,000 t in the most recent time period.

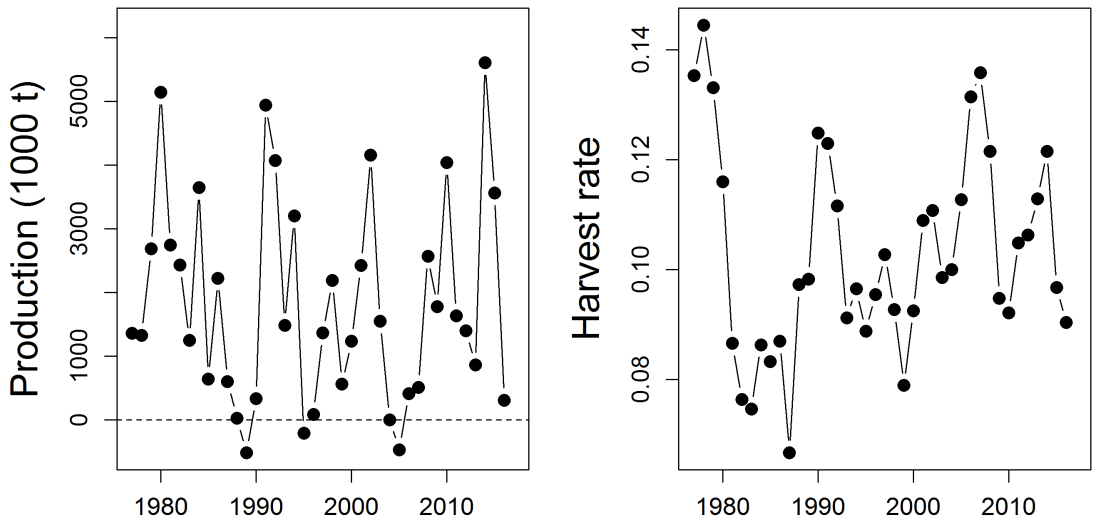

Figure 96: Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Bering Sea/Aleutian Islands (left) and total harvest rate (total catch/beginning-of-year biomass, each summed across the major groundfish species in Table 8).

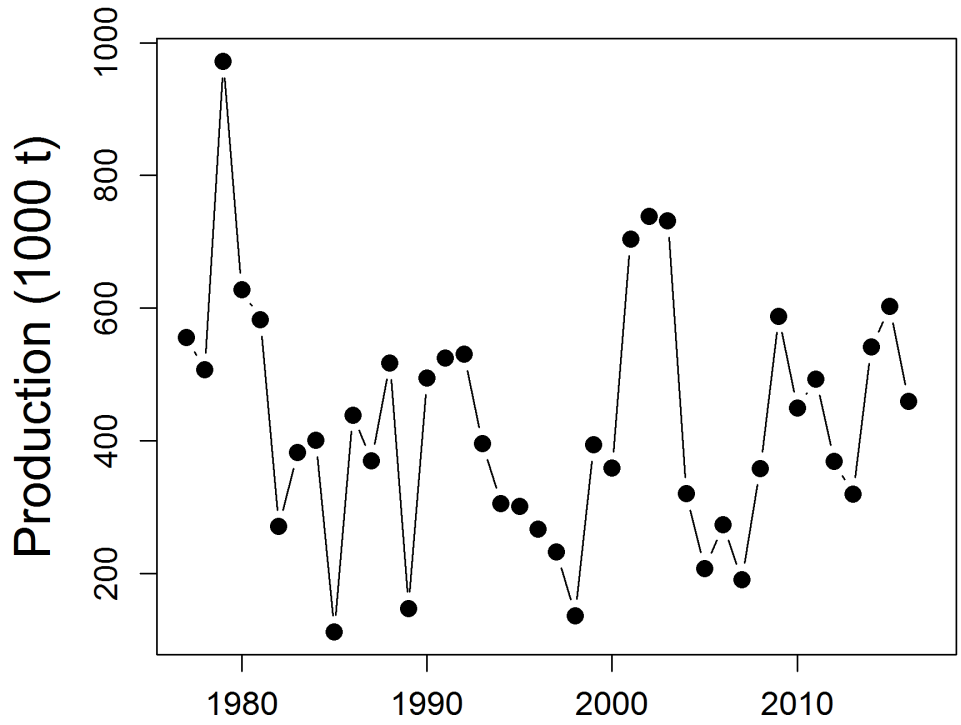

Figure 97: Total annual surplus production (change in biomass plus catch) in the Bering Sea across the major groundfish species in Table 8, excluding walleye pollock.

Factors influencing observed trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e. mortality from all non-fishery sources) during a given year. It is highest during periods of increasing total biomass and lowest during periods of decreasing biomass (e.g., 2004–2007). In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Theory suggests that surplus production of a population will decrease as biomass increases much above B_{MSY}, which is the case for many species in the BSAI management area. Exploitation rates are primarily determined by management and reflect a relatively precautionary management regime with rates that have averaged about 10% for the species in Table 8 combined.

Implications: Under certain assumptions, aggregate surplus production can provide an estimate of the long-term maximum sustainable yield of these groundfish complexes (Mueter and Megrey (2006), Figure 98). Although there is relatively little contrast in total biomass over time, it appears that biomass was generally above the level that would be expected to yield maximum surplus production under a Graham-Schaefer model fit to aggregate ASP (Figure 98). The estimated maximum sustainable yield for the groundfish complex encompassing the 9 stocks in Table 8 was 2.0 million tons.

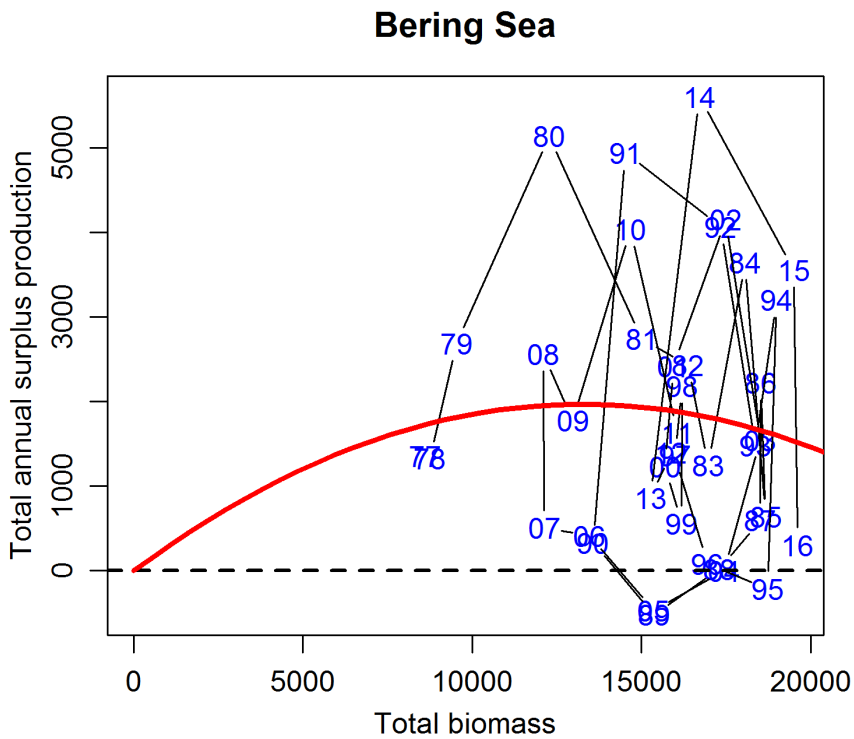

Figure 98: Estimated annual aggregated surplus production against total biomass of major commercial species with fitted Graham-Schaefer curve. Units on both axes are in 1000 t.

Seafood Production

Salmon and Halibut Subsistence Trends in the Southeastern and Northern Bering Sea

Contributed by Sarah P. Wise[1] and Kim Sparks[1,2]
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Last updated: August 2018

Description of indicator: Subsistence uses of wild resources are defined as "noncommercial, customary, and traditional uses" for a variety purposes including nutritional, trade, and cultural purposes (ADFG, 2018). Harvest data were collected from The Alaska Department of Fish and Game Division of Subsistence for years 1990 to 2016 (ADFG, 2018). ADF&G reports that 1994 was the first year data from all subsistence fisheries was available and comparable to current collections. Subsistence data is largely collected from household surveys. On average, rural Alaskans harvest 155 pounds of fish per person per year (Fall et al., 2017). For these reasons, subsistence harvests of two focal species–salmon and halibut–were considered informative.

In the Southeastern Bering Sea (SEBS) coastal region salmon, halibut, smelt, dolly varden, pike, shrimp, and crab are harvested for subsistence and contribute to the mixed subsistence and cash economy as well as a cultural practice (The Bering Sea Elders Group 2011, Huntington et al. (2013)). Reliance on a diverse range of subsistence foods is considered very high (Krieg et al., 2015). In some areas of the SEBS, an estimated 56 of the subsistence harvest (in pounds) is salmon and 9% other fishes (ibid).

In the Northern Bering Sea (NBS) coastal region marine mammals, salmon, and shellfish are harvested for subsistence and contribute to the mixed subsistence and cash economy, as well as a cultural practice (The Bering Sea Elders Group 2011, Fall et al. (2013); Huntington et al. (2013)). Gear used varies depending on area and time of season, but can include drift gillnets, set gillnets, fish wheels, and rod and reel. Subsistence foods are diverse and make up a substantial portion of household nutrition (Fall et al., 2013). Recent research shows environmental changes are directly affecting subsistence harvest patterns (ibid).

Status and trends:
Southeastern Bering Sea
Salmon
ADF&G data reflect a downward trend in subsistence harvest, however species harvest is variable (see Figures 99 and 100). The historical average since 1990 is 310,717 salmon with the most recent total salmon subsistence harvest in 2016 estimated at 111,413 fish. Chinook salmon is particularly important to SEBS communities, with the Bristol Bay Management Area harvesting the largest percentage of subsistence Chinook (41%), followed by the Kuskokwim Management Area (21%) in 2014. Data from 2001–2003 is suspect, and should not be interpreted as a sudden decline. Due to data error for years 2001–2003, those data are unreliable and should not be considered in broader analysis.

Southeastern Bering Sea

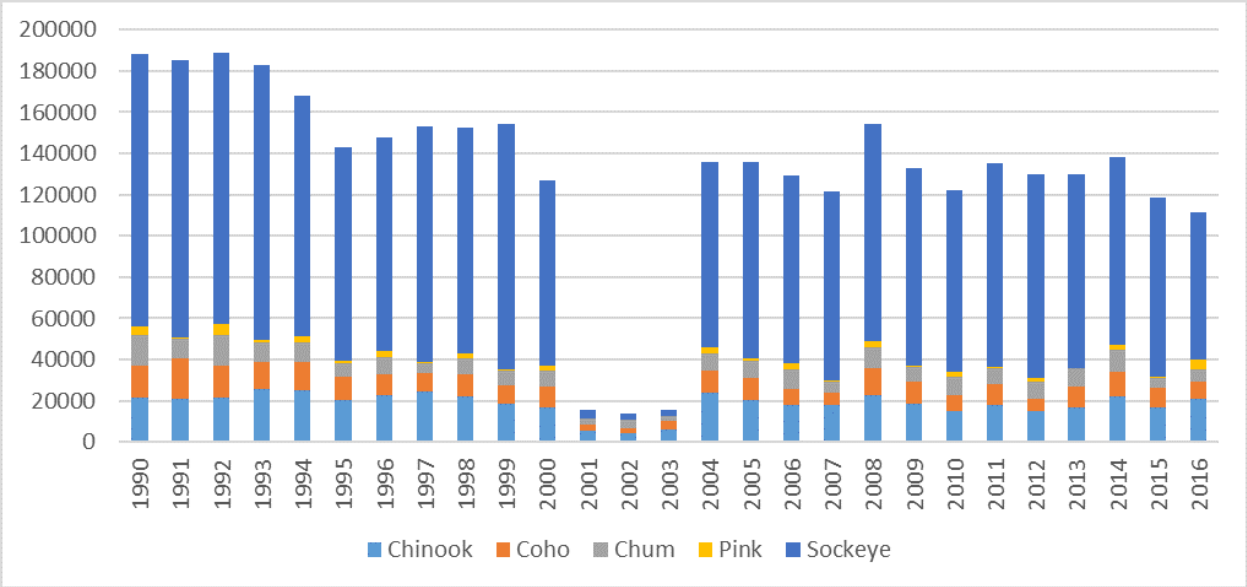

Figure 99: Subsistence salmon harvests between 1990–2016 (SEBS).

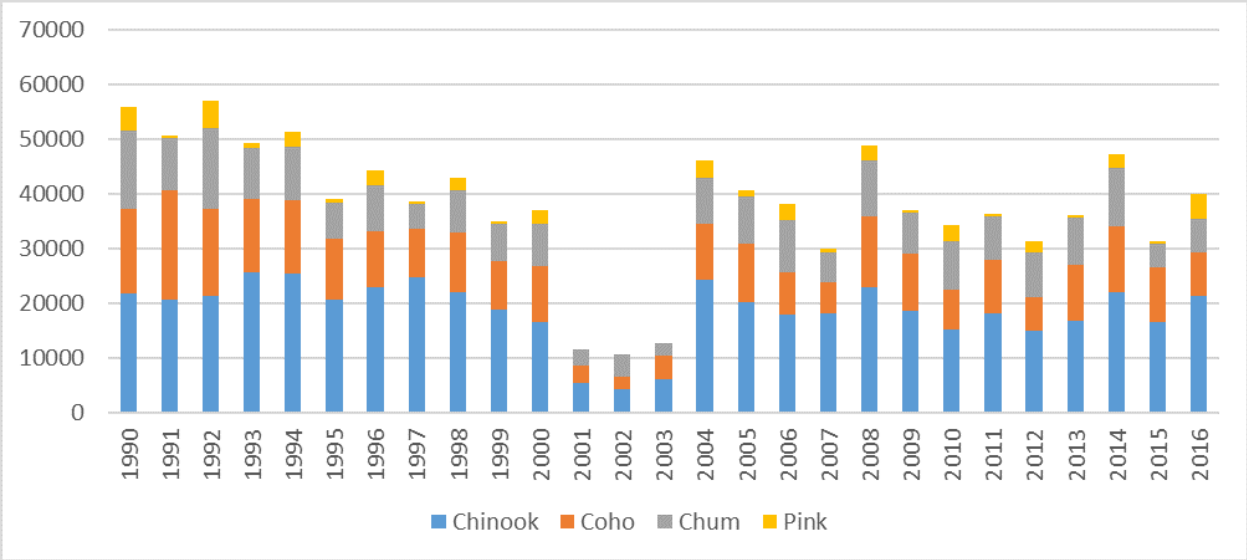

Figure 100: Subsistence salmon harvests without sockeye between 1990–2016 (SEBS)

Halibut

According to the ADF&G, statewide subsistence halibut harvest (in pounds) declined substantially between the years 2004 to 2012, with a slight uptick in 2014–2016. There were approximately 8,847 subsistence permits issued in the whole of Alaska, harvesting an estimated 36,467 halibut in 2016. The SEBS region represented just 1% of the total halibut pounds harvested in 2016; however pounds of halibut subsistence harvest declined from 2007 to 2012, with a slight increase in 2014 and 2016 (Figure 101). The number of SHARC permits issued has also substantially declined from 465 permits in 2003 to 75 permits in 2016.

Northern Bering Sea

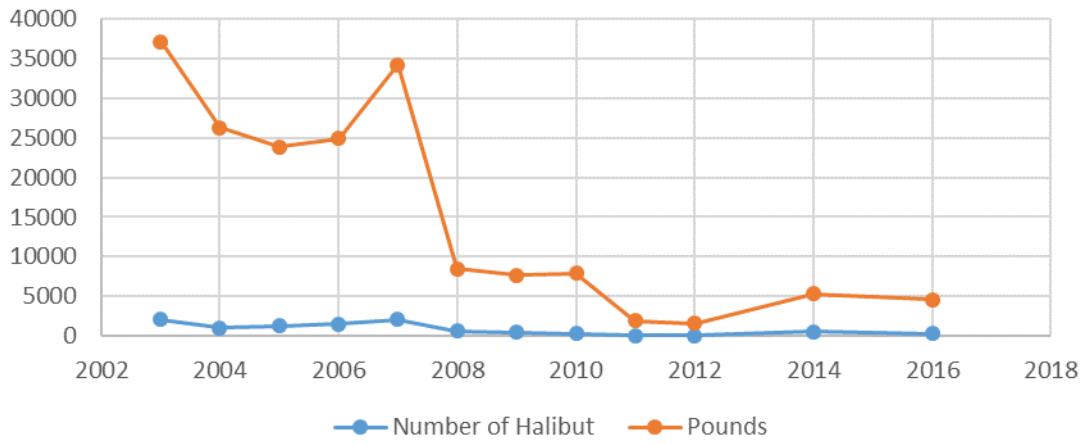

Figure 101: Estimated subsistence harvests of halibut in SEBS, 2003–2012, 2014, & 2016 (lbs. net weight).

Salmon

All five species of salmon are present in the NBS, however Chinook, chum, and coho comprise the majority of salmon harvests in the Yukon River drainage system (ADFG, 2018). ADF&G records report an increase in household permits in the NBS, however the data reflect a downward trend in subsistence harvest, particularly in Chinook salmon (see Figure 102). The historical average since 1990 is 414,417 salmon, with the most recent total salmon subsistence harvest in 2016 estimated at 372,074 fish. The 2014 estimate for Chinook subsistence harvest is the lowest estimate on record for the NBS.

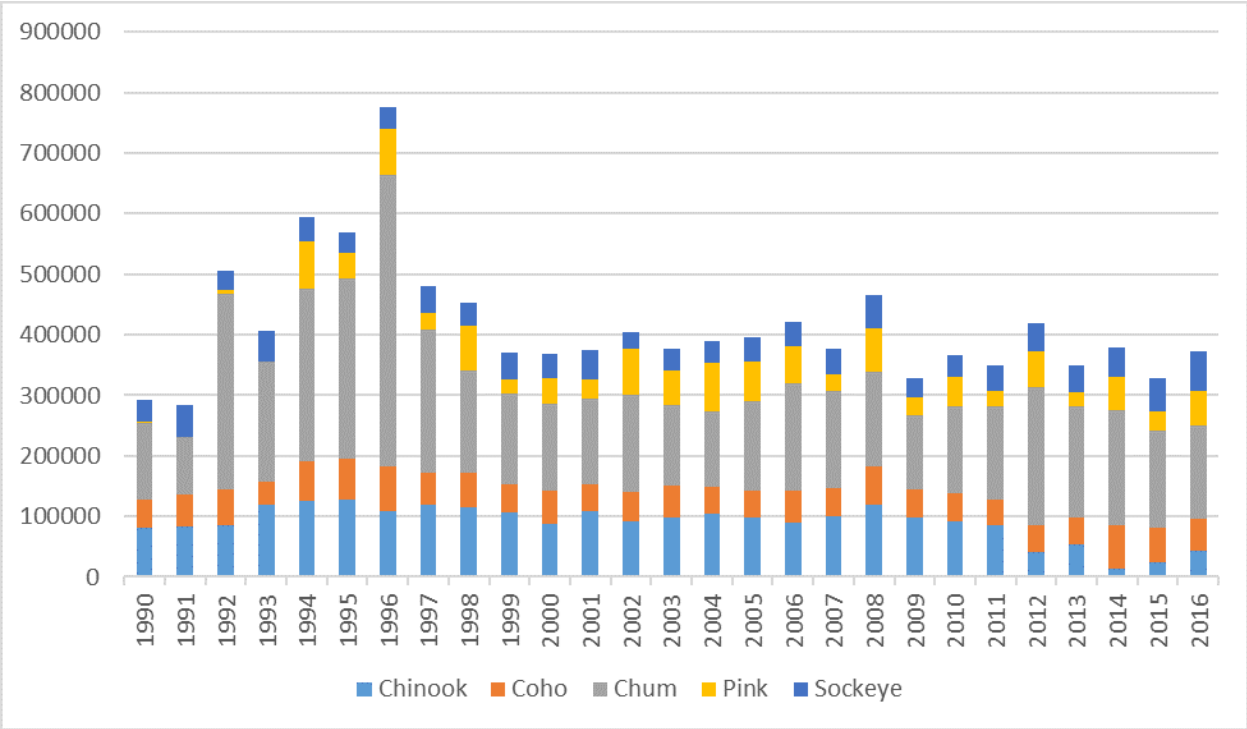

Figure 102: Subsistence salmon harvests between 1990–2016 (NBS).

Northern Bering Sea
Halibut
The NBS region represented 5% of the total halibut pounds harvested in 2016. In the NBS pounds of halibut subsistence harvest substantially declined from 2006 to 2012; the increase from 2012–2016 is due to an increase in two communities (Figure 103). The number of SHARC permits issued has also substantially declined from 809 permits in 2003 to 217 permits in 2006.

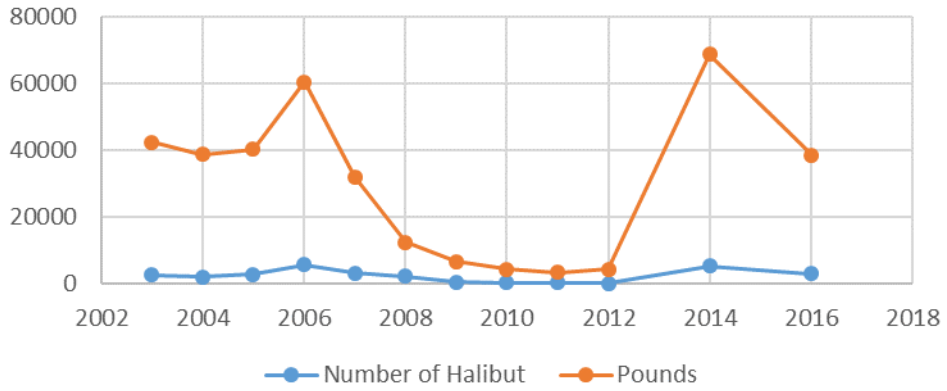

Figure 103: Estimated subsistence harvests of halibut in NBS, 2003–2012, 2014, & 2016 (lbs. net weight).

Factors influencing observed trends: The EBS is undergoing dramatic environmental change including diminishing sea ice and increased temperatures, seasonal climate variations, and fluctuations in species abundance and mobility. Additionally, socio-economic pressures such as rising fuel and food costs are affecting subsistence patterns (Fall et al., 2013).

Salmon harvests are closely monitored and documented regularly. Variations in salmon harvest suggest a decrease in available targeted species due to the continued reliance on subsistence fisheries. All salmon species do not return to every watershed every year and pink salmon return to spawn every other even numbered year (ADFG, 2018). The decrease in Chinook salmon is consistent across SEBS and NBS. Additional research into the drivers of the decline is necessary.

The reasons for the decline in subsistence halibut harvest are complex, and in large part related to participation in the survey and methodology (Fall and Lemons, 2015). Due to budgetary constraints, data collection efforts were reduced in size and scope, which is consistent with the decrease in reported harvests, suggesting that some of the decrease in halibut harvest is a result of a lower participation in the survey. Non-renewal of SHARCs, low survey participation rates, and the lack of follow-up field work indicate halibut harvest may be under estimated (Fall and Lemons, 2015). In 2014, an effort was made to follow up with non-participants in some regions to complete the survey, increasing the reported harvest estimates.

Implications: Food security among subsistence users is a growing concern. Changing environmental conditions are affecting fish movement, health, and abundance, directly affecting the people relying on subsistence fisheries to survive. Subsistence fishing and hunting represent a major source of food security and cultural identity for many Alaskans. Rural households rely on subsistence resources as a primary source of nutrition during the winter when other sources of food may be unavailable or prohibitively expensive (Loring and Gerlach, 2009). Equally important, subsistence practices represent a way of life which supports community bonds of sharing and inter reliance, and

reinforces community connections to land and a shared heritage (Holen, 2014; Picou et al., 1992).

Economic Indicators in the Eastern Bering Sea Ecosystem – Landings

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Last updated: October 2018

Description of indicator: Landings are a baseline metric for characterizing commercial economic production in the eastern Bering Sea. Landings are the retained catch of fish and are plotted here by functional group (Figure 104). While many species comprise a functional group, it is the handful of species that fishermen target that dominate the economic metrics in each group. The primary target species in the apex predators' functional group are Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), Sablefish (*Anoplopoma fimbria*), and Arrowtooth flounder (*Atheresthes stomias*). The primary target species in the pelagic foragers' functional group are Walleye pollock (*Gadus chalcogrammus*), Atka mackerel (*Pleurogrammus monopterygius*), and Pacific ocean perch (*Sebastes alutus*). The primary target species in the benthic foragers' functional group are Yellowfin sole (*Limanda aspera*), Rock sole (*Lepidopsetta bilineata*), and Flathead sole (*Hippoglossoides elassodon*). The primary target species in the salmonid functional group are Chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*), and pink (*O. gorbuscha*) salmon. The primary target species in the motile epifauna functional group are king, bairdi, and snow crab. Because of significant differences in the relative scale of landings across functional group, landings are plotted on a log scale.

Status and trends: Landings in the eastern Bering Sea are predominantly from the pelagic forager functional group. The primary species landed within this group is pollock whose landings are an order of magnitude larger that of any other species or functional group. Trends in the landings of the apex predator functional group are primarily driven by TAC levels in the Pacific cod stock which has remained slightly higher since 2011 than before. Landings were increasing up to 2008 in the flatfish fisheries which make up the benthic foragers functional group. Total flatfish catches are well below their respective TACs and stocks remain healthy. EBS salmon landings have remained largely stable from 2004–2017 with a temporary decline from 2011–2013. Landings in the crab stocks which comprise the motile epifauna group have trended up gradually since 2003 largely reflecting an increased catch of tanner crab. In 2017 crab catches declined significantly for all species, particularly tanner crab resulting in the significant decline in the index displayed in Figure 104.

Factors influencing observed trends: Between 2008–2010 conservation-based reductions in the pollock Total Allowable Catch (TAC) resulted in reduced landings for the pelagic forager functional group. In 2008 Amendment 80 to the BSAI groundfish FMP was implemented rationalizing the major flatfish fisheries which resulted in significant reductions in bycatch. Total catch of the groundfish that comprise the pelagic forager, apex predators, and benthic foragers' functional groups in the Bering Sea is capped at 2 million metric tons. The sum of the Allowable Biological Catches (ABC)

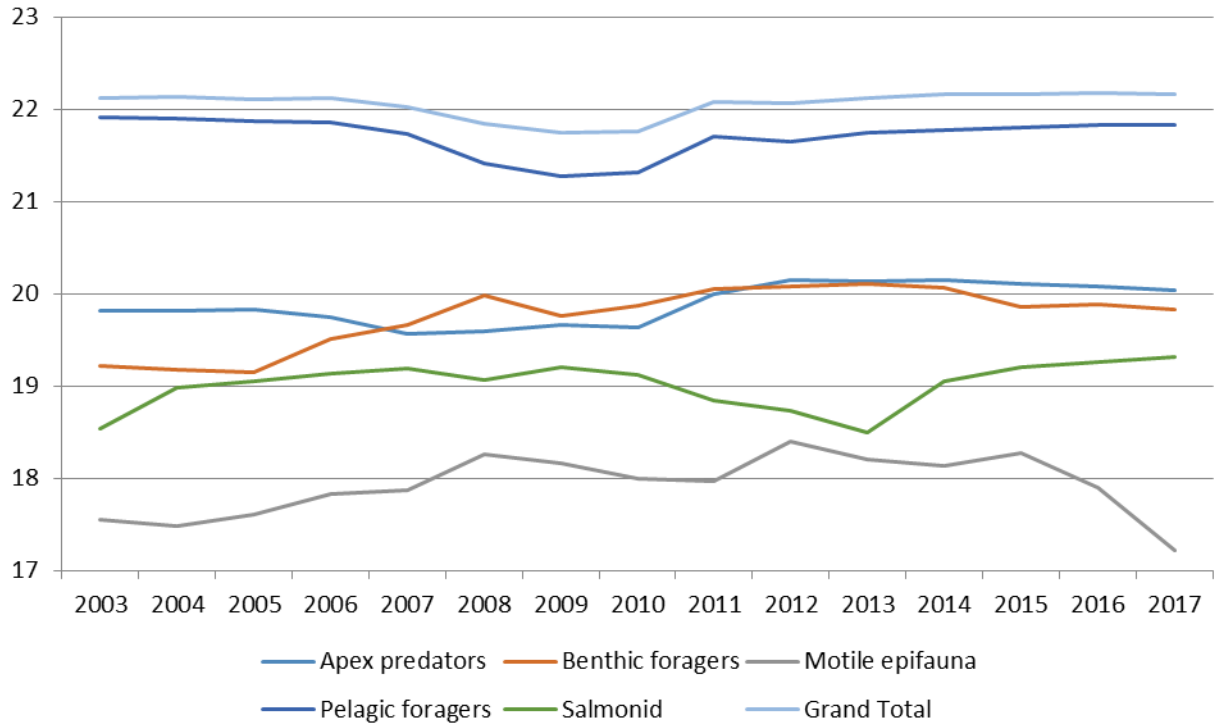

Figure 104: Eastern Bering Sea landings by functional group (log pounds).

for these groups are typically above the cap and TACs are reduced from the ABC through negotiations at the North Pacific Fishery Management Council to meet the cap requirement. This cap system influences interpretation of trends in landings relative to their underlying stocks as changes in landings may not be the direct result of changes in biomass.

Implications: Landings depict one aspect of the raw stresses from harvesting imposed on the eastern Bering Sea ecosystem's functional group through fishing. This information can be useful in identifying areas where harvesting may be impacting different functional groups in times where the functional groups within the ecosystem might be constrained. What is clear from Figure 104 is that pelagic foragers have been by far the largest share of total landings over the 2003–2017 period, while motile epifauna represent the smallest, and declining, share. Monitoring the trends in landings stratified by ecosystem functional group provides insight on the fishing-related stresses on ecosystems. The ultimate impact that these stresses have on the ecosystem cannot be discerned from these metrics alone and must be viewed within the context of what the ecosystem can provide.

Profits

Economic Indicators in the Eastern Bering Sea Ecosystem – Value and Unit Value

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Last updated: October 2018

Description of indicator: Three plots are used to characterize economic value in an ecosystem context for the eastern Bering Sea. Ex-vessel value is the un-processed value of the retained catch (Figure 105). Ex-vessel value can informally be thought of as the revenue that fishermen receive from the catch.

First-wholesale value is the revenue from the catch after primary processing by a processor (Figure 106). First-wholesale value is a more comprehensive measure of value to the fishing industry as it includes ex-vessel value as well as the value-added revenue from processing which goes to processing sector.

The first-wholesale value to total catch unit value is the ratio of value to biomass extracted as a result of commercial fish harvesting (Figure 107). The measure of biomass extracted in this index includes retained catch, discards, and prohibited species catch. This metric answers the question: "how much revenue is the fishing industry receiving per-unit biomass extracted from the ecosystem?" The first-wholesale to total catch unit value is analogous to a volumetrically weighted average price across functional groups which is inclusive of discards. However, discards represent a relatively small fraction of total catch. Because of the comparatively larger volume and value from pelagic foragers' the unit value index is more heavily weighted towards this group.

Figures 105 and 106 are plotted by functional group. While many species comprise a functional group, it is the handful of species that fishermen target that dominate the economic metrics in each group. The primary target species in the apex predators' functional group are Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), Sablefish (*Anoplopoma fimbria*), and Arrowtooth flounder (*Atheresthes stomias*). The primary target species in the pelagic foragers' functional group are Walleye pollock (*Gadus chalcogrammus*), Atka mackerel (*Pleurogrammus monopterygius*), and Pacific ocean perch (*Sebastes alutus*). The primary target species in the benthic foragers' functional group are Yellowfin sole (*Limanda aspera*), Rock sole (*Lepidopsetta bilineata*), and Flathead sole (*Hippoglossoides elassodon*). The primary target species in the salmonid functional group are Chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*), and pink (*O. gorbuscha*) salmon. The primary target species in the motile epifauna functional group are king, bairdi, and snow crab. Because of significant differences in the relative scale of value across functional group, value is plotted on a log scale.

Status and trends: Ex-vessel value is the revenue from landings, consequently trends in ex-vessel value and landings are closely connected. Ex-vessel value is highest in the pelagic forager functional group because of the volume of landings in the pollock fishery. Benthic forager flatfish revenues were increasing from 2000–2008 with increase landings volume but recent declines in value have been

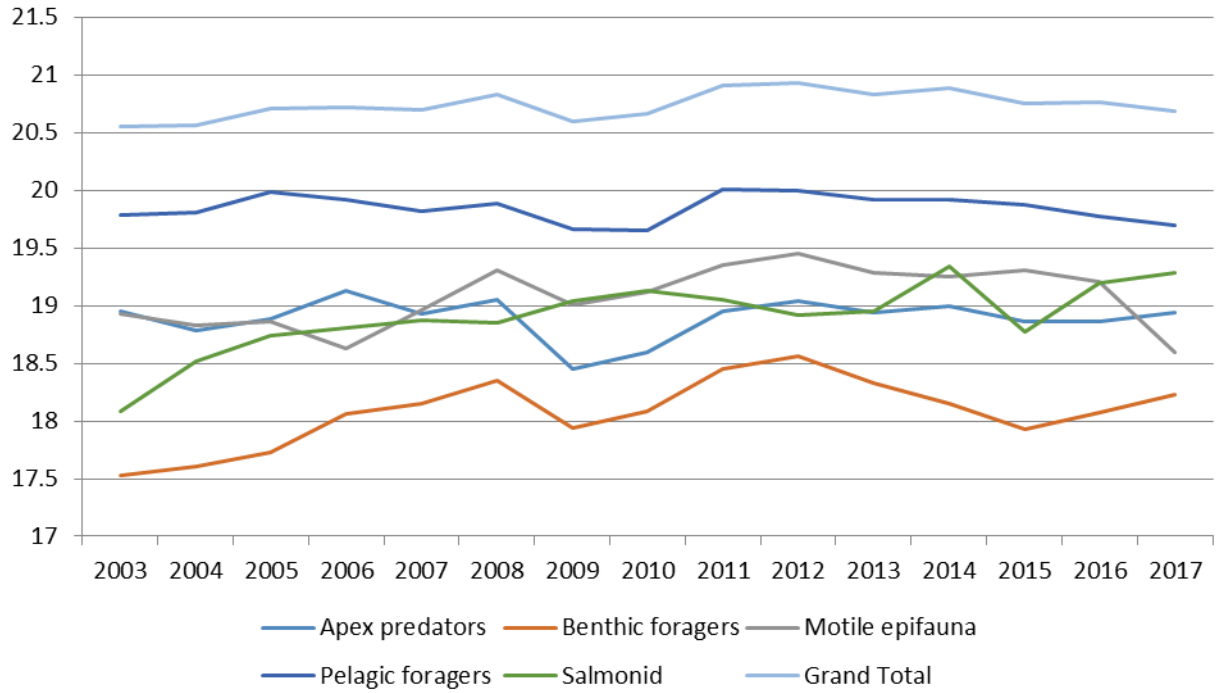

Figure 105: Eastern Bering Sea real ex-vessel value by functional group (log 2016 dollars).

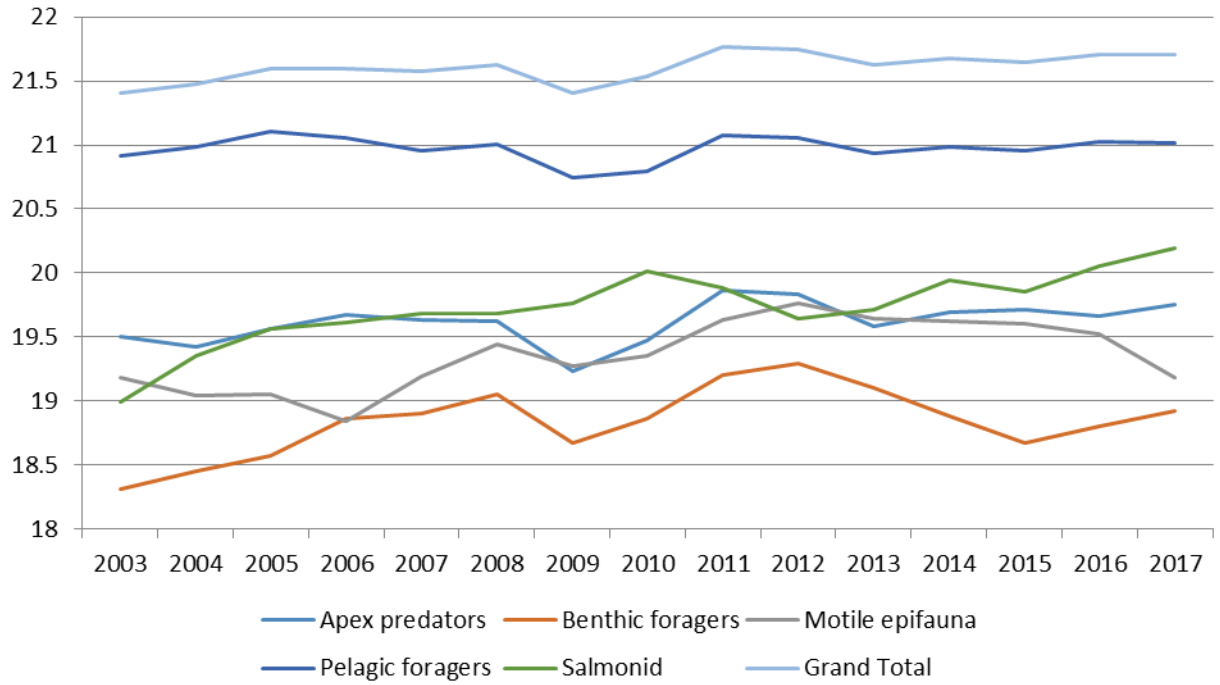

Figure 106: Eastern Bering Sea real first-wholesale value by functional group (log 2016 dollars).

the result of decreased prices. Value in the motile epifauna group has been increasing with crab landings. The generally increasing trend in salmon value is the result of generally stable landings and strong prices.

Differences in the relative level of the indices between the landings and ex-vessel value in Figure 105 reflect differences in the average prices of the species that make up the functional group. Hence, landings of benthic forager flatfish may be larger than salmon, but salmon ex-vessel value is higher because it commands a higher price.

First-wholesale value was generally increasing for each of the functional groups up to about 2008–2010 with stable or increasing landings and gradually increasing prices. After this, variation in landings or in prices have had differential impacts. The value of the pelagic forager group shows a gradual increasing trend as result of relatively stable landings with the exception of 2008–2009 when landings were low. Since 2013 prices for pollock have decreased as global pollock supply has been high, but increased landings have had the combined effect of marginal increases in value. First-wholesale value dipped in the apex predator group with a decrease in Pacific cod prices in 2009, prices rebounded after but have shown subsequent volatility and landings have generally increased. Benthic forager first-wholesale value decreased from 2012 to 2015 with decreases in flatfish prices as demand for these products plateaued with significant supply. Decreased landings in 2012 brought down salmon value but a price increase buoyed value in 2013 as landings continued to decline after which landing and value have remained at roughly 2010 levels. Value in the motile epifauna group continued to increase with increasing crab prices through 2012 but has since stabilized and value has decreased slightly with marginal reductions in landing.

The unit value index increased from 2003–2008 with generally increasing prices across all functional groups. Pollock prices fell somewhat in 2013 with significant global pollock supply. Salmon and motile epifauna prices also rose in 2010 and have shown significant volatility since. Apex predator prices dipped in 2009, rebounded in 2010–2011, declined in 2013, and have since leveled out. Benthic forager prices declined through 2009, increased from 2009–2012, and decreased after before leveling out in 2014. The cumulative effect of these price changes is that the first-wholesale unit value index increased to 2008, was relatively volatile at this high level through 2012, then decreased somewhat in 2013 and has vacillated at approximately that level since.

Factors influencing observed trends: The reduction in revenue from 2008–2010 was the result of conservation based reductions in the pollock Total Allowable Catch (TAC). Supply reductions in the pollock fishery which began in 2008 resulted in increased first-wholesale prices which account for the significant increase in the 2008 unit value and the relatively high level maintained through 2012. In recent years, increasing global supply has put downward pressure on minimally processed whitefish product prices which has filtered through to ex-vessel market. As a result, revenue has decreased since 2013 in the pelagic forager and apex predator groups despite strong landings.

Ex-vessel prices are influenced by a multitude of potential factors including demand for processed products, the volume of supply (both from the fishery and globally), the first-wholesale price, inflation, fishing costs, and bargaining power between processors and fishermen. However, annual variation in the ex-vessel prices tends to be smaller than variations in catch and short to medium term variation in the landings and ex-vessel revenue indices appear similar. The long-term general increasing trend is the result of increasing value in the first-wholesale market as well as inflation.

First-wholesale value is the revenue from the sale of processed fish. Some fish, in particular pollock and Pacific cod, are processed in numerous product forms which can influence the generation of revenue by the processing sector. Level shifts in the relative location of the first-wholesale indices compared to the ex-vessel indices are influenced by differences in the amount and types of value-added processing that is done in each functional group.

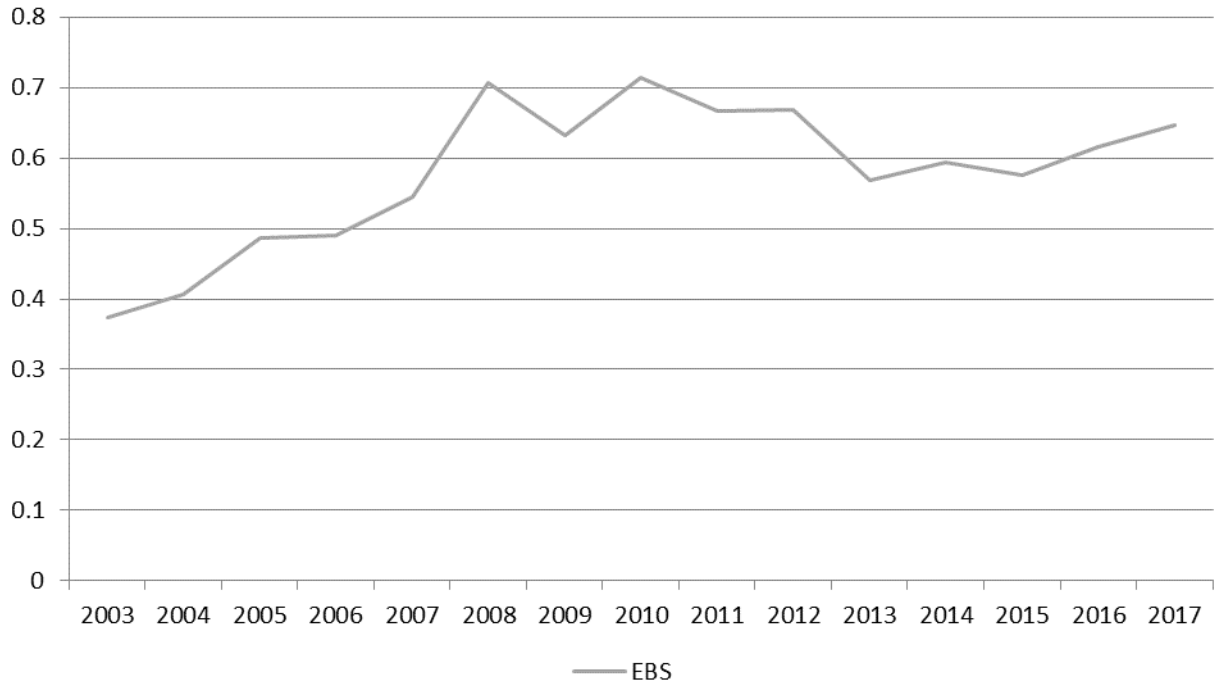

Figure 107: Real first-wholesale to total catch unit value in the Eastern Bering Sea (2016 dollars).

Implications: The economic metrics displayed here provide perspective on how the human component of the ecosystem utilizes and receives value from the eastern Bering Sea and the species within that ecosystem. Ex-vessel and first-wholesale value metrics area measure of the ultimate value from the raw resources extracted and how humans add value to the harvest for their own uses. In contrast to the landings metrics that are heavily dominated by the pelagic forager functional group, ex-vessel and first wholesale revenues are more evenly distributed across functional groups, which indicates the importance of the groups with lower landings and higher prices to the fishing sector.

Situations in which the value of a functional group is decreasing but catches are increasing indicate that the per-unit value of additional catch to humans is declining. This information can be useful in identifying areas where fishing effort could be reallocated across functional groups in times where the functional groups within the ecosystem might be constrained while maintaining value to the human component of the ecosystem. Monitoring the economic trends stratified by ecosystem functional group provides insight on the fishing related stresses on ecosystems and the economic factors that influence observed fishing patterns. The ultimate impact that these stresses have on the ecosystem cannot be discerned from these metrics alone and must be viewed within the context of what the ecosystem can provide.

Recreation

Saltwater Recreational Fishing Participation in the Eastern Bering Sea: Number of Anglers and Fishing Days

Contributed by Daniel K. Lew[1] and Jean Lee[1,2]
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[2]Alaska Fisheries Information Network, Pacific States Marine Fisheries Commission
Contact: Dan.Lew@noaa.gov
Last updated: August 2018

Description of indicator: Federal fisheries management objectives include managing healthy ecosystems in part to provide recreational fishing opportunities. We use saltwater fishing participation to represent trends in recreational fishing in Alaska. The magnitude of recreational saltwater fishing participation is captured by (a) the days fished and (b) the number of anglers. The Alaska Department of Fish and Game (ADF&G) conducts an annual survey of anglers to collect information on participation, catch, and harvest (e.g., Jennings et al. (2015); Romberg (2016))[3]. Annual estimates of the total number of saltwater anglers are available from 1996 to 2016. Estimates of the total number of saltwater fishing days are available from 1981 through 2016. For the purposes of this indicator, ADF&G Sport Fishing Areas R-Z comprise the EBS (see `http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=main.home`).

Status and trends: In the EBS, the total number of days fished has remained under 30,000, reflecting the low level of saltwater sport fishing that occurs in the region. Since the mid-1990s, there have only been two years with more than 15,000 fishing days in saltwater. In recent years, the annual fishing days has been just shy of 10,000 fishing days (Figure 108). The annual number of saltwater anglers fishing in the EBS has declined overall since the mid-1990s and is currently below 2,000 anglers.

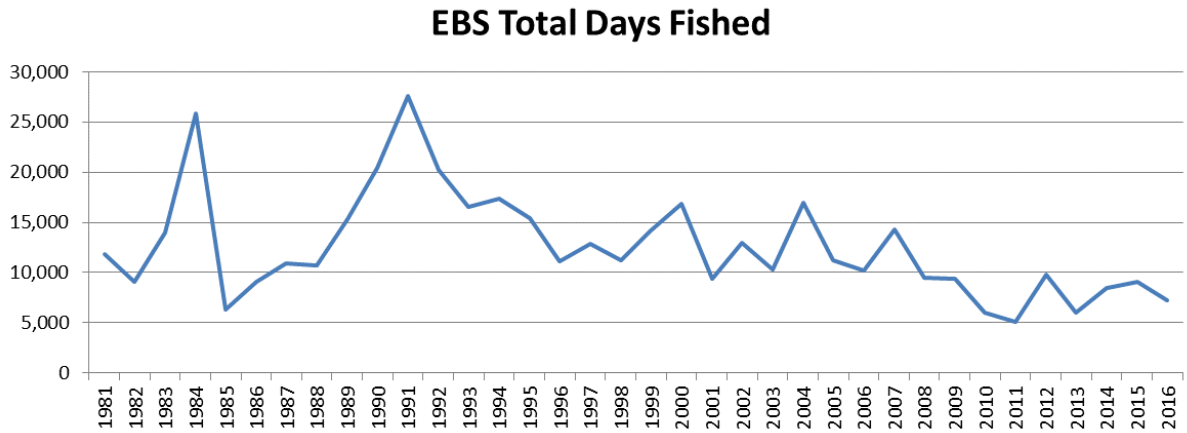

Figure 108: The total number of days fished in saltwater in the eastern Bering Sea.

[3]ADFG Division of Sport Fish Alaska Sport Fishing Survey database. Public data available at `https://www.adfg.alaska.gov/sf/sportfishingsurvey/`. Data provided by Alaska Fisheries Information Network.

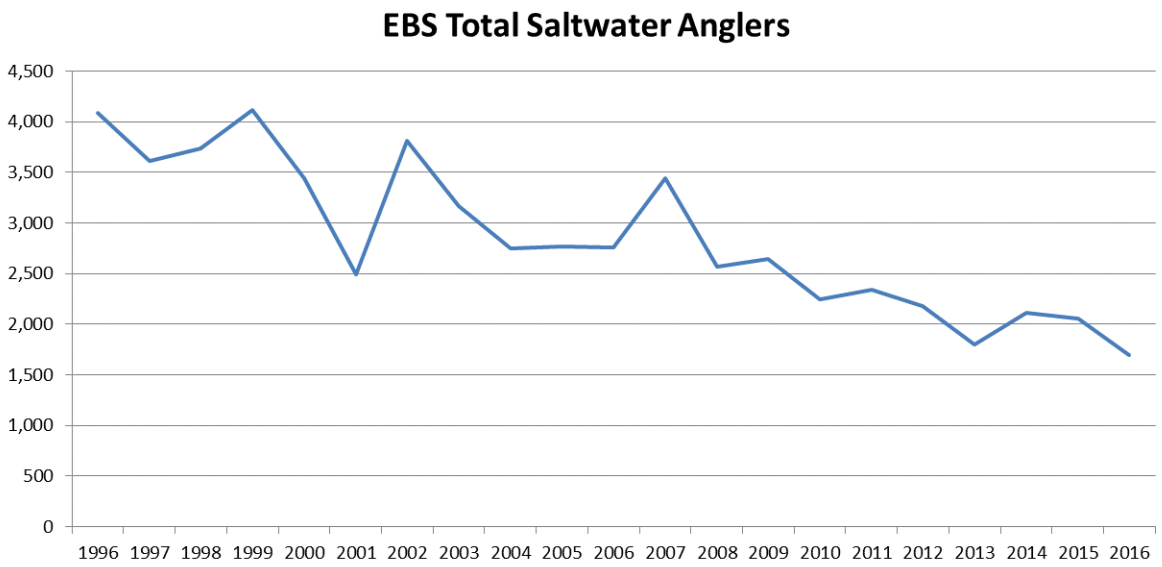

Figure 109: The number of saltwater anglers in the eastern Bering Sea.

Factors influencing observed trends: The amount of saltwater recreational fishing occurring in the EBS is a small fraction of the amount in the Gulf of Alaska, in large part due to the remoteness of the EBS fishing locations and absence of large population centers. The difficulty in accessing fishing locations in the EBS for non-resident anglers means few non-residents fish in the region. The lower resident population sizes of EBS communities result in relatively low numbers of resident anglers as well.

Beyond geographic constraints, saltwater recreational fishing participation in Alaska generally is influenced by a number of factors, including fishing regulations for target species, social and economic factors affecting the angler and the angler's household, and expected fishing conditions (e.g., stock size, timing and size of runs, weather, etc.). Pacific halibut (*Hippoglossus stenolepis*) and Pacific salmon (*Oncorhynchus* spp.) are the most common target species, with other species less frequently being the principal target but being caught on trips targeting halibut or salmon. Fishing regulations for these fish influence decisions about whether or not to fish, where to fish, what species to fish for, and by what means to fish (e.g., unguided or guided fishing).

Fishing regulations in the Pacific halibut sport fishery were first established in 1973, but have changed significantly over the years in the EBS (Meyer, 2010). Beginning in 2014, Southcentral Alaska charter boat anglers, which includes those in Bristol Bay and the Alaska Peninsula, began facing charter-specific bag and size limit and other restrictions (see `https://alaskafisheries.noaa.gov/fisheries/2c-3a-halibut-regs`). Under the Halibut Catch Sharing Plan (CSP), which went into effect during 2014, the management tools used to regulate harvest of Pacific halibut in the recreational sport sector are evaluated annually (79 Federal Register 13906).

ADF&G manages Pacific salmon in Alaska primarily through a policy that involves maintaining spawning habitats and ensuring escapement levels through area closures (Heard, 2009). Allocation between the commercial and recreation sectors is set by the Alaska Board of Fish and can have a profound influence on observed trends.

Macroeconomic factors such as economy-wide recessions likely affect participation patterns in saltwater fishing in Alaska, though national-level factors are less likely to impact recreational fishing levels in EBS due to the low number of non-resident anglers. Instead, the declining trend in the numbers of anglers since the mid-1990s may be related to demographic trends in communities in the EBS, such as the net out-migration of EBS residents in the last decade[4]. The increase in the number of anglers and the number of fishing days in recent years (2013–2015) may be a consequence of households in EBS turning to saltwater recreational fishing as a secondary food source as the state economy has been in a recession (ADLWD, 2017). While conditions in the (primarily state and local) economy are likely to explain some of the observed trends, the statistics generally reflect micro-level decisions made by individual anglers (e.g., Lew and Larson (2011, 2012, 2015, 2017)).

Implications: Monitoring the number of saltwater anglers and fishing days provides a general measure of fishing effort and participation in the saltwater sport fishery and can reflect changes in ecosystem conditions, target stock status, management, economic factors, demographic trends, and other economic, social, and cultural factors. Generally, Alaska is well-known for its sport fishing opportunities and draws anglers both from within and from outside Alaska. In the EBS, however, saltwater recreational fishing effort is currently low. As a result, it likely represents a trivial source of extraction for sport-caught species like Pacific halibut, Pacific salmon, and rockfish. Nevertheless, studies have indicated saltwater fishing in Alaska is valuable to anglers (e.g., Lew and Larson (2011, 2012, 2015, 2017)) and contributes to the economy by creating jobs and generating sales to fishing and non-fishing businesses and income to households (Lovell et al. (2013); Lew and Seung, 2018). Recent estimates of the annual fishing days and total saltwater anglers in the EBS suggest the number of saltwater anglers and the number of fishing days are decreasing slightly. Without significant changes in the demographics of the region or the ecological, economic, management, or socio-cultural factors that are likely to influence EBS-level participation in saltwater recreational fishing, it is likely that saltwater recreational fishing will remain at, or around, recently observed levels.

Saltwater Recreational Fishing in the Eastern Bering Sea: Sport Fishing Harvest by Functional Group

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Last updated: September 2018

Description of indicator: Federal fisheries management objectives include managing healthy ecosystems in part to provide recreational fishing opportunities. In saltwater, recreational anglers often target Pacific salmon (*Oncorhynchus* spp.) and Pacific halibut (*Hippoglossus stenolepis*). Rockfish, lingcod, Pacific cod, sharks, smelt, and sablefish are also caught and kept by recreational anglers in marine waters. We use saltwater harvest to represent trends in recreational fishing on species in Alaska. The magnitude of recreational fishing harvest is captured by harvest levels for three functional groups: (a) salmonids (Chinook, coho, pink, sockeye, and chum salmon), (b) apex

[4]See population estimates by borough/census area at `http://live.laborstats.alaska.gov/pop/index.cfm`.

predators (Pacific halibut, Pacific cod, sharks, sablefish, and lingcod), and (c) pelagic foragers (rockfish and smelt).

The Alaska Department of Fish and Game (ADF&G) conducts an annual survey of anglers to collect information on participation, catch, and harvest (e.g., Jennings et al. (2015); Romberg (2016))[5]. Annual estimates of the total harvest of Pacific salmon, Pacific halibut, rockfish, and smelt are available from 1977 to 2016. Estimates of the total harvest of lingcod are available from 1990 to 2016, while Pacific cod and shark estimates are available for 1996 to 2016. Sablefish harvest estimates are available for 2010 to 2016. For the purposes of this indicator, ADF&G Sport Fishing Areas R-Z comprise the EBS (see `http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=main.home`).

Status and trends: In the EBS, positive harvest levels of saltwater recreational fish were first recorded in 1981. Total annual harvest of saltwater recreational species has only exceeded 15,000 total fish in two years–1989 and 1990. Salmonid and apex predator harvests have exceeded the harvest of other functional groups since the early 1990s except for in one year, 2015. Annual salmonid harvest has ranged from a low of 1,089 fish to a high of 17,124, while apex predator harvest has been between 264 and 7,578. Harvest of both functional groups vary year to year, with recent harvest levels being between 3,000 and 5,400 fish for salmonids and between 1,900 and 2,600 fish for apex predators. The apex predator functional group harvest is dominated by Pacific halibut and Pacific cod harvest with very few, if any, shark or sablefish being harvested in a given year and lingcod contributing fewer than 1,000 fish each year. Note that lingcod does not appear in the apex predator harvest estimates until 1990, Pacific cod and sharks do not appear until 1996, and sablefish do not appear until 2010. This means that the pre-1990 apex predator harvest estimates are composed solely of Pacific halibut harvest. Pelagic species harvest ranged from a low of 62 in 1983 to as high as 19,988 in 1989, the latter of which is four times higher than the next highest annual harvest level. Recent annual harvest levels have been between about 1,000 and 2,000 fish for the pelagic forager functional group. Except for in two years (1987 and 1989), the pelagic forager functional group harvest was always below the salmonids harvest level (Figure 110).

Factors influencing observed trends: The amount of recreational fishing harvest occurring in the EBS is a small fraction of the amount in the Gulf of Alaska, in large part due to the remoteness of the EBS fishing locations and absence of large population centers. The difficulty in accessing fishing locations in the EBS for non-resident anglers means few non-residents fish in the region. The lower resident population sizes of EBS communities result in relatively low numbers of resident anglers, as well. This translates to low overall harvest levels.

Beyond geographic constraints, saltwater recreational fishing participation in Alaska generally is influenced by a number of factors, including fishing regulations for target species, social and economic factors affecting the angler and the angler's household, and expected fishing conditions (e.g., stock size, timing and size of runs, weather, etc.). Pacific halibut and Pacific salmon are the most common target species, with other species less frequently being the principal target but being caught on trips targeting these species. Fishing regulations for these fish influence decisions about whether or not to fish, where to fish, what species to fish for, and by what means to fish (e.g., unguided or guided fishing).

Fishing regulations in the Pacific halibut sport fishery were first established in 1973, but have

[5] ADFG Division of Sport Fish Alaska Sport Fishing Survey database. Public data available at `https://www.adfg.alaska.gov/sf/sportfishingsurvey/`. Data provided by Alaska Fisheries Information Network.

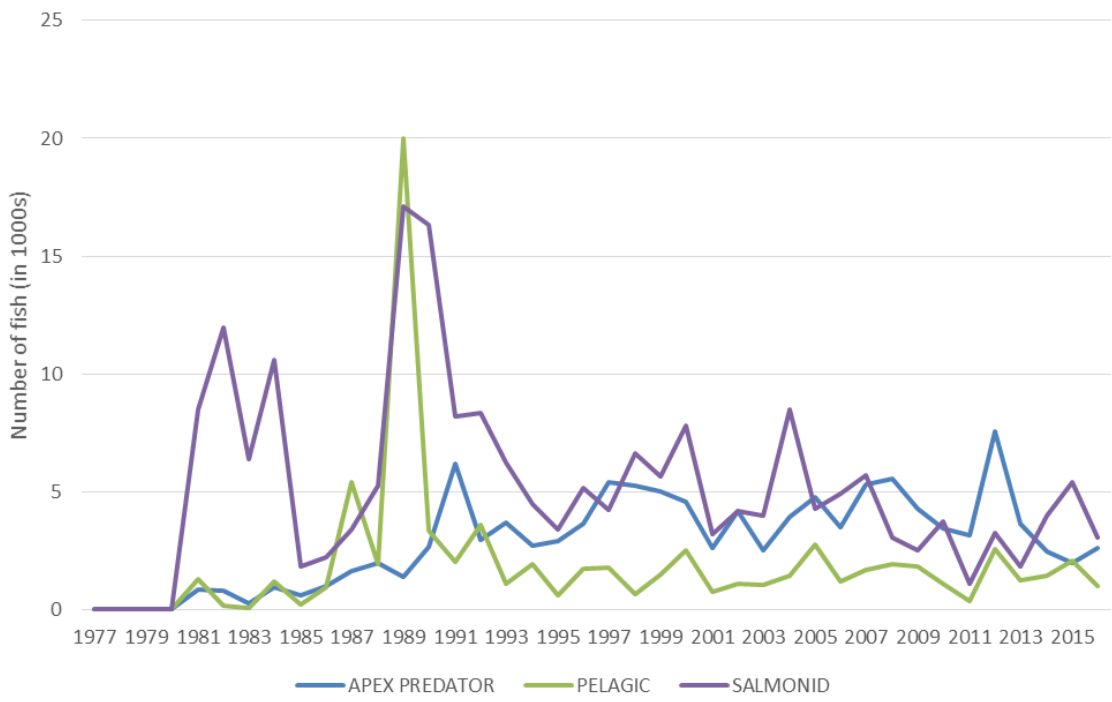

Figure 110: Eastern Bering Sea saltwater recreational harvest by functional group.

changed significantly over the years in the EBS (Meyer, 2010). Beginning in 2014, Southcentral Alaska charter boat anglers, which include those in Bristol Bay and the Alaska Peninsula, began facing charter-specific bag and size limit and other restrictions (see `https://alaskafisheries.noaa.gov/fisheries/2c-3a-halibut-regs`). Under the Halibut Catch Sharing Plan (CSP), which went into effect during 2014, the management tools used to regulate harvest of Pacific halibut in the recreational sport sector are evaluated annually (79 Federal Register 13906).

ADF&G manages Pacific salmon in Alaska primarily through a policy that involves maintaining spawning habitats and ensuring escapement levels through area closures (Heard, 2009). Allocation between the commercial and recreation sectors is set by the Alaska Board of Fish and can have a profound influence on observed trends. ADF&G also manages harvest of rockfish, lingcod, and shark using bag limits in some areas (for current regulations, see `http://www.adfg.alaska.gov/index.cfm?adfg=fishregulations.sport`).

Macroeconomic factors, such as economy-wide recessions, likely affect participation patterns in saltwater fishing in Alaska, and hence harvest levels, though national level factors are less likely to impact recreational fishing levels in EBS due to the low number of non-resident anglers. However, the migration in or out of EBS communities may play an important role[6], as would households in EBS turning to saltwater recreational fishing as a secondary food source in tougher economic times, such as when the state economy is in a recession (ADLWD, 2017). While conditions in the (primarily state and local) economy are likely to explain some of the observed trends, the statistics generally reflect micro-level decisions made by individual anglers (e.g., Lew and Larson (2011, 2012, 2015, 2017)).

[6]See population estimates by borough/census area at `http://live.laborstats.alaska.gov/pop/index.cfm`.

Note that one micro-level decision that many Pacific salmon anglers face is whether to fish in saltwater or freshwater. While the focus here is on saltwater harvest, it is important to recognize that the vast majority of the total Pacific salmon harvest in EBS from 1996–2016 has been from freshwater fishing, not saltwater. The proportion of the total salmon harvest attributable to saltwater fishing has ranged from 1–5% across these years.

Implications: Monitoring the amount of saltwater sportfish harvests provides a general measure of fishing effort in the saltwater sport fishery and can reflect changes in ecosystem conditions, target stock status, management, demographic trends, and other economic, social, and cultural factors. Generally, Alaska is well-known for its sport fishing opportunities and draws anglers both from within and from outside Alaska. In the EBS, however, saltwater recreational fishing effort is currently low. As a result, it likely represents a trivial source of extraction for all functional groups. Nevertheless, studies have indicated saltwater fishing in Alaska is valuable to anglers (e.g., Lew and Larson (2011, 2012, 2015, 2017)) and contributes to the economy by creating jobs and generating sales to fishing and non-fishing businesses and income to households (Lovell et al. (2013); Lew and Seung, 2018). Without significant changes in the demographics of the region or the ecological, economic, management, or socio-cultural factors that are likely to influence EBS-level participation in saltwater recreational fishing, it is likely that harvest levels by saltwater recreational fishing will remain low.

Employment

Trends in Unemployment in the Eastern Bering Sea and Northern Bering Sea

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Last updated: September 2018

Description of indicator: Unemployment is a significant factor in the Eastern Bering Sea (EBS) and Northern Bering Sea (NBS) ecoregions, and for groundfish fishery management, as many communities in western Alaska rely upon fisheries to support their economies and to meet subsistence and cultural needs. As with other areas neighboring the Arctic, unemployment is an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems (SES) research has demonstrated the importance of incorporating social variables in ecosystem management and monitoring, and unemployment reflects economic settings of a SES (Turner et al., 2003; Ostrom, 2007). For example, variation in resource access, availability, or employment opportunities may influence human migration patterns, which in turn may decrease human activity in one area of an ecosystem while increasing activity in another.

This section summarizes trends in unemployment over time in the EBS and NBS. EBS communities are located within the Lake and Peninsula (facing the Bering Sea), Bristol Bay, Dillingham, and Bethel Borough communities located below 60° latitude. Communities of the NBS are of the Bethel Borough located above 60° latitude and those of the Kusilvak and Nome Boroughs. Communities were included if they are geographically located within 50 miles of the coast, based upon their historical involvement in Bering Sea fisheries, and if they were included in one of the North Pacific Fishery Management Council's Bering Sea fishery programs, such as the Community Quota Entity program. Unemployment data was aggregated and weighted to account for varying community populations across Alaska Boroughs. Estimates are presented annually from 1990–2017 (ADLWD, 2018). Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2017 (ADLWD, 2018).

Status and trends:
Eastern Bering Sea
The unemployment rate in the EBS was 3.1% in 2017. This is a slight decrease from 2014 when the unemployment rate was the highest (3.6%) since 1990. Unemployment rates in the EBS between 1990 and 2017 were lower than State and national rates (Figures 111 and 112). The unemployment peaks of 1996, 2003, and 2010 reflect State trends yet the EBS had the second lowest unemployment rate (central Aleutian Islands had the lowest) of all regions. However, the unemployment rate of the EBS region increased 94.3% between 1990 and 2017.

Northern Bering Sea
The unemployment rate in the NBS was 12.4% in 2017. This is a slight decrease from 2014 when the unemployment rate was the highest (13.7%) since 1990. Unemployment rates in the NBS between 1990 and 2017 were higher than State and national rates (Figures 111 and 112). The unemployment rate in the NBS was lowest in 1990 (6.9%) and highest in 2014 (13.7%). The unemployment peaks during the 1990s and early 2000s reflect State trends yet the unemployment rate of the NBS

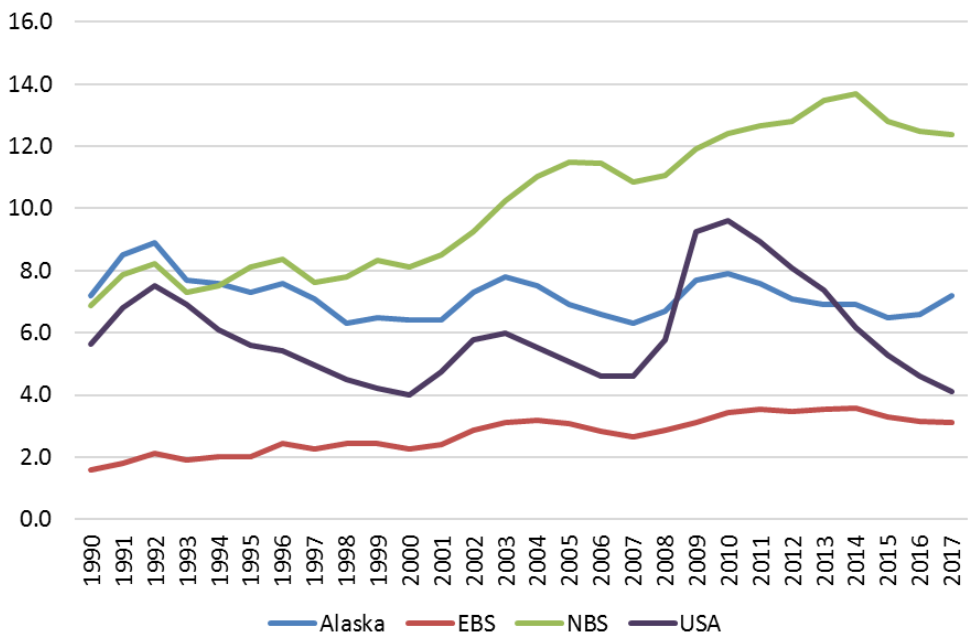

Figure 111: Unemployment rates for Alaska, Eastern Bering Sea (EBS), Northern Bering Sea (NBS), and USA between 1990 and 2017.

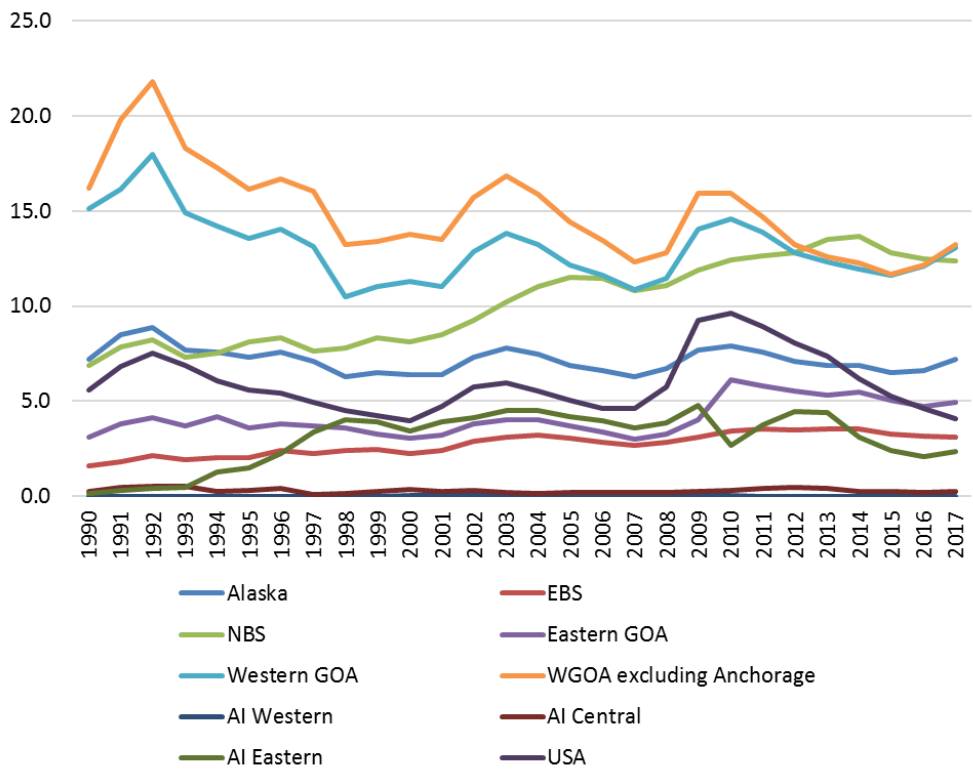

Figure 112: Unemployment rates for all regions, Alaska, and USA between 1990 and 2017.

continued to increase despite State and national decline after 2010. The unemployment rate in NBS communities increased 80.1% between 1990 and 2017.

Factors influencing observed trends: Alaska State has experienced several boom and bust economic cycles. Peaks in employment occurred during the construction of the Alaska pipeline in the 1970s and oil boom of the 1980s, whereas unemployment peaks occurred following completion of the pipeline, during the oil bust of the late 1980s, and during the great recession of 2007–2009 (ADLWD, 2016)[7]. However, during the great recession, Alaska's employment decreased only 0.4% whereas the national drop was 4.3% partly because of the jobs provided by the oil industry (ADLWD, 2016).

The EBS area had the second lowest unemployment rates between 1990 and 2017. Many communities in the region rely upon seasonal fisheries and construction opportunities for employment, and individuals seek these types of employment in Dillingham (Himes-Cornell et al., 2013). The NBS area had the highest unemployment rates between 2004 and 2015. Communities in the region rely mainly upon seasonal employment and subsistence activity and year-round employment opportunities are sparse (Himes-Cornell et al., 2013). The EBS and NBS regions are forecasted to experience job loss, similar to State trends since 2015, due to reduced oil revenues (ADLWD, 2018).

Implications: Fisheries contribute to community vitality of the EBS and NBS therefore reduced fishing opportunities and employment may lead to out-migration and population decline, particularly in small communities with few job alternatives (Donkersloot and Carothers, 2016). Changes in groundfish policy and management may have implications for small communities and those of the Bering Sea Community Quota Entities. Also, with a large proportion of western Alaska population being Alaska Natives, resource managers may benefit from working with communities holding traditional ecological knowledge (TEK) to incorporate TEK into ecosystem management (Huntington et al., 2004).

[7]For more detailed information see `http://live.laborstats.alaska.gov/pop/estimates/data/ex2.pdf`

Socio-Cultural Dimensions

Defining Fishing Communities

Within the context of marine resource management, what constitutes a fishing community is complex and has been long debated. Fishing communities can be defined geographically, occupationally, or based on shared practice or interests. The Magnuson-Stevens Fisheries Conservation Act (MSA) defines fishing communities as those "substantially dependent on or substantially engaged in the harvest or processing of fishery resources to meet social and economic needs, and includes fishing vessel owners, operators, and crew and United States fish processors that are based in such community" (Magnuson-Stevens Fishery Conservation and Management Act. Public Law, 94, 265). Within the MSA, National Standard 8 requires conservation and management measures to "take into account the importance of fishery resources to fishing communities in order to: (1) provide for the sustained participation of such communities; and (2) to the extent practicable, minimize adverse economic impacts on such communities" (MSA, National Standard 8, last updated 4/26/2018). Identifying and considering appropriate communities is central to effective marine resource management. The National Marine Fisheries Service interprets the MSA definition to emphasize the relevance of geographic place, stating "A fishing community is a social or economic group whose members reside in a specific location..." (50 CFR 600.345–National Standard 8–Communities). Pacific States Marine Fisheries Commission adheres to this definition as well, although it is recognized that taking social networks and shared interests into account "would result in a greater understanding of socioeconomic indicators" (Langdon-Pollock, 2004). While relatively easy to determine, defining fishing community solely on geographical location risks excluding social networks valuable to the flow of people, information, goods, and services. Some managers have turned to "multiple constructions of communities" (Olson, 2005) to better understand fishing communities.

By restricting the definition of fishing community to a geographic place–particularly in the marine environment, Martin and Hall-Arber (2008) argue that geographically restricted notions of community ignore the complexity of social landscapes. The authors expand "community" to include those areas, resources, and social networks on which people depend (Martin and Hall-Arber, 2008). In an effort to acknowledge women's role in fisheries, Calhoun, Conway, and Russel (2016) discuss fishing community in terms of participation in the broader industry (Calhoun et al., 2016). Acknowledging power dynamics and the issue of scale when describing "fishing community', Clay and Olson (2008) complicate the MSA definition, bringing forward the importance of "political, social, and economic relationships".

In the context of the Ecosystem Status Reports, fishing communities were identified by three criteria: 1) geographical location, 2) current fishing engagement (commercial and recreational); and 3) historical linkages to subsistence fishing. Engagement was defined as the value of each indicator as a percentage of the total present in the state. The quantitative indicators used to represent commercial fisheries participation included commercial fisheries landings (e.g., landings, number of processors, number of vessels delivering to a community), those communities registered as homeports of participating vessels, and those that are home to documented participants in the fisheries (e.g., crew license holders, state and federal permit holders, and vessel owners). Recreational fisheries participation included sportfish licenses sold in the community, sportfish licenses held by residents, and the number of charter businesses and guides registered in the community. Given the heavy dependence on subsistence fishing for survival in Alaska, as well as the reliance on river networks for marine resource extraction, a buffer area was created along coastal Alaska to identify

those communities living near coastal resources. Up river communities with historic ties to subsistence fishing were included. Anchorage and Fairbanks were excluded in some analyses in order to avoid skewing results.

The data used were gathered from the Alaska Department of Fish and Game Division of Subsistence database. A broad definition of subsistence "fishing community" was used for this analysis due to the importance of subsistence foods for daily life, particularly in rural Alaska. An estimated 36.9 million pounds of wild foods are harvested annually by rural subsistence users. Residents of more populated urban areas harvest about 13.4 million pounds of wild food under subsistence, personal use, and sport regulations. Given the reliance on subsistence foods, all communities within 50 miles of coastal waters were included in the analysis in order to capture subsistence use of marine resources. In addition, upriver communities identified as highly engaged in subsistence fisheries were included in the analysis. This included communities that historically fit the criteria (given the time period for which data is available (1991 onward). Level of engagement was evaluated by several criteria: 1) the number of Subsistence Halibut Registration Certificates (SHARC) issued to residents; 2) total pounds harvested of all fish and marine invertebrates; 3) the number of salmon harvested; and 4) pounds of marine mammals harvested. In order to document changes in subsistence use, communities once identified as engaged in subsistence fisheries were kept in the analysis regardless of changing engagement.

Contributed by Sarah P. Wise

Trends in Human Population in the Southeastern and Northern Bering Sea

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Description of indicator: Human population is a significant factor in the Southeastern Bering Sea (SEBS) and Northern Bering Sea (NBS) ecoregions, and indicator for groundfish fishery management, as many communities in the region rely upon fisheries to support their local economies and to meet subsistence and cultural needs. As with other regions neighboring the Arctic, population is an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems (SES) research has demonstrated the importance of incorporating social variables in ecosystem management and monitoring, and this indicator reflects socio-cultural and economic aspects within SES (Turner et al., 2003; Ostrom, 2007). For example, variation in resource access or availability or employment opportunities may influence human migration patterns, which in turn may decrease human activity in one area of an ecosystem while increasing activity in another.

This section summarizes trends in human population over time in the EBS and NBS. EBS communities are located within the Lake and Peninsula (facing the Bering Sea), Bristol Bay, Dillingham, and Bethel Borough communities located below 60° latitude. Communities of the NBS are of the

Table 9: Southeastern Bering Sea (SEBS) population 1880–2017. Percent change rates are decadal until 2010.

Year	Alaska	% change	EBS	% change
1880	33,426		1,504	
1890	32,052	-4.11	1,022	-32.05
1900	63,592	98.4	1,203	17.71
1910	64,356	1.2	688	-42.81
1920	55,036	-14.48	1,279	85.9
1930	59,278	7.71	1,369	7.04
1940	72,524	22.35	2,292	67.42
1950	128,643	77.38	3,212	40.14
1960	226,167	75.81	4,633	44.24
1970	302,583	33.79	5,445	17.53
1980	401,851	32.81	7,428	36.42
1990	550,043	36.88	9,339	25.73
2000	626,932	13.98	10,383	11.18
2010	710,231	13.29	10,025	-3.45
2017	737,080	3.78	10,243	2.17

Bethel Borough located above 60° latitude and those of the Kusilvak and Nome Boroughs. Communities were included if they are geographically located within 50 miles of the coast, based upon their historical involvement in Bering Sea fisheries, and if they were included in one of the North Pacific Fishery Management Council's Bering Sea fishery programs, such as the Community Quota Entity program. Communities were divided into two categories as part of this analysis; small (population $<$ 1,500) and large (population $>$=1,500). Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2017 (ADLWD, 2018).

Status and trends:

Southeastern Bering Sea

The SEBS is comprised of 34 coastal communities with a total population of 10,243 as of 2017. The total population of small communities (population less than 1,500) was 7,908. The community of Dillingham is the only community of this ecoregion with a population over 1,500 (2017 population = 2,335). The overall population increased steadily since 1880 with the greatest population increase of 44.2% occurring between 1950 and 1960 (Table 9 and Figure 113). This is consistent with Alaska State trends as population change peaked during these periods (over 75% by 1960 and 36.9% by 1990). Population increase leveled off after 1990 with lower rates in the following decades in the EBS and Alaska State.

Between 1990 and 2017, the population of EBS increased 9.7% which was much lower than State trends during this time period (34.0%). The population of small communities increased 8.0%, and Dillingham 15.77% during this time period. The population of the EBS has remained relatively stable (based on aggregated data), yet 41% of communities in the EBS experienced population decline between 1990 and 2017. For example, Portage Creek had a documented population of 5 in 1990, it increased to 45 in 2003, and was reduced to 1 in 2017 (an 80% decrease between 1990 and 2017). Nelson Lagoon, King Salmon, Saint George, Saint Paul, and South Naknek also experienced population declines ranging from 45.6% to 63.9% during this time period. Conversely, Port Alsworth had the greatest population increase over this time period (332.7%).

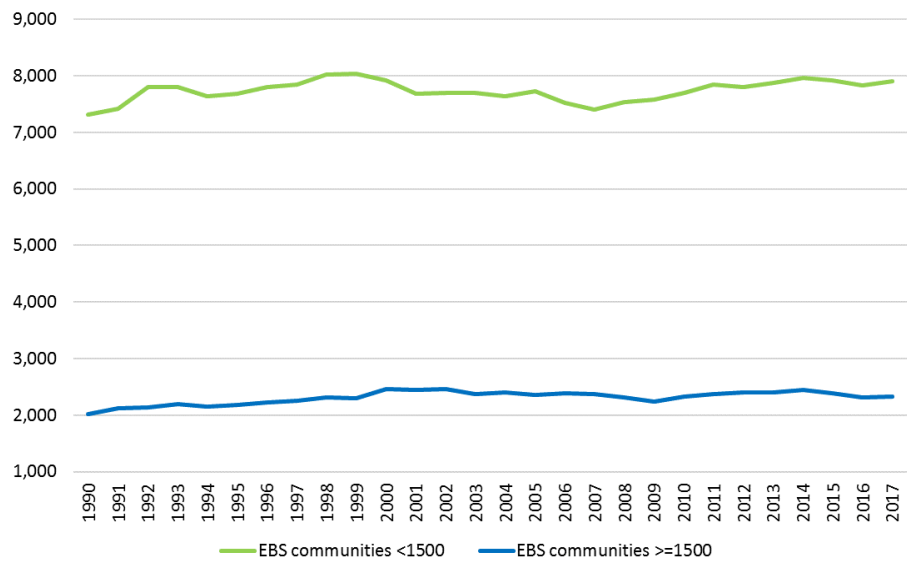

Figure 113: Southeastern Bering Sea population 1990–2017.

Many EBS communities are small and/or remote and Indigenous Americans comprise up to 82% of the population of small communities in remote areas, and more Native Americans reside in Alaska than any U.S. state (Goldsmith et al., 2004). As of 2014, 15% of Alaska's population was Alaska Native or American Indian (ADLWD, 2016) and as of 2015, 75.7% of the population in the EBS identified as Native American alone or combination with another race (DCCED, 2016). In addition, there has been increased migration of Alaska Natives from rural to urban areas (Goldsmith et al., 2004; Williams, 2004), yet the majority of population growth that has occurred in Alaska is of the Caucasian demographic (ADLWD, 2016).

Northern Bering Sea

The Northern Bering Sea is comprised of 60 coastal communities with a total population of 33,620 as of 2017. The population of small communities (population less than 1,500) was 23,778 and large communities 9,842. The small communities exclude Bethel (population in 2017 = 6,151) and Nome (population in 2017 = 3,691) which are the only two communities with populations exceeding 1,500 people. The total NBS population increased steadily since 1880 with the greatest population increase occurring between 1890 and 1900 (901.1%) and later between 1950 and 1960 (47.6%) (Table 10 and Figure 114). The latter increase is consistent with Alaska State trends as population increased by over 75% between 1950 and 1960. Population increase leveled off after 1990 with lower rates in the following decades in the NBS and Alaska State.

Between 1990 and 2017, the population of the NBS increased 28.53% which was lower than State trends during this time period (34.0%). Small community population increased 32.22% and large communities 20.41% during this time period. The population of communities in the NBS has slowly increased. Only 18% of all NBS communities experienced population decline between 1990 and 2017. Many NBS communities are small and/or remote. Of the smaller communities, Brevig Mission had the highest population increase of 115% during this time period. Port Clarence, Shageluk, Diomede, and Holy Cross had the greatest decreases in their populations during this time period (100.0%, 46.8%, 42.7%, and 39.7%, respectively). Port Clarence had a population of zero as of 2001, and since the 1990s the population hovered between 22 and 29 residents.

Table 10: Northern Bering Sea (NBS) population 1880–2017. Percent change rates are decadal until 2010.

Year	Alaska	% change	NBS	% change
1880	33,426		3,376	
1890	32,052	-4.11	2,528	-25.12
1900	63,592	98.4	20,453	709.06
1910	64,356	1.2	5,201	-74.57
1920	55,036	-14.48	4,538	-12.75
1930	59,278	7.71	5,527	21.79
1940	72,524	22.35	7,596	37.43
1950	128,643	77.38	9,435	24.21
1960	226,167	75.81	13,940	47.75
1970	302,583	33.79	16,424	17.82
1980	401,851	32.81	20,828	26.81
1990	550,043	36.88	26,157	25.59
2000	626,932	13.98	30,202	15.46
2010	710,231	13.29	31,548	4.46
2017	737,080	3.78	33,620	6.57

As of 2015, 90.2% of the population in the NBS identified as Native American alone or combination with another race (DCCED, 2016). As stated above, many Alaskans are migrating from small rural communities to urban centers such as Anchorage. These migration patterns affect population size of small communities in the NBS.

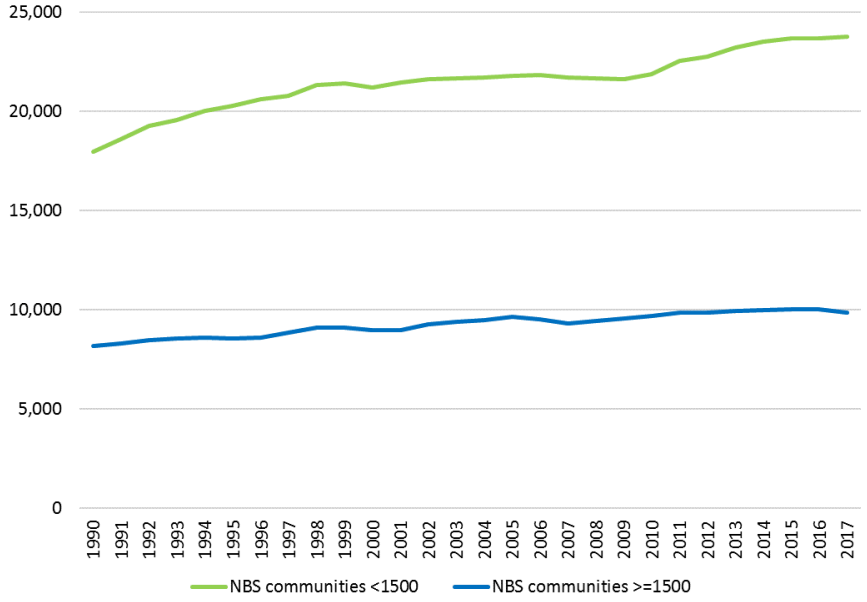

Figure 114: Northern Bering Sea population 1990–2017.

Factors influencing observed trends: Overall population increase in the EBS between 1990 and 2017 (9.7%) was much lower than State trends (34.0%). Population increase in the NBS between 1990 and 2017 (28.53%) was significantly higher than the EBS but was consistent with State

trends. The lower population increase in the EBS is because population growth is highest in urban areas, such as Anchorage, where 40% of Alaska's population currently resides (ADLWD, 2016). The high population increase in the NBS can be attributed to mining and extraction prospects in the region. Alaska has high rates of population turnover because of migration (ADLWD, 2016). The main factors that affect population growth are natural increase (births minus deaths) and migration, with the latter being the most unpredictable aspect of population change (Williams, 2004; ADLWD, 2016). In 2010, 61% of Alaska's population was born out of State (Rasmussen et al., 2015).

In terms of natural growth, from 2010 to 2014 the average annual birth rate in Alaska was 1.6 per 100 people which was higher than the national rate of 1.3 (ADLWD, 2016). From 2010–2014 the Aleutian chain and Southeast Alaska had the lowest natural increase (0.0–1.0%) whereas the NBS area had the highest (1.5–3.0%). The Kusilvak census area had the highest birth rate of 3 births per 100 people (ADLWD, 2016). The estimated natural growth rates of the EBS had a range of 0.5–3.0% (ADLWD, 2016). The NBS area has steadily increased in population with higher than national level birth rates and net migration of less than zero (ADLWD, 2016). The net annual migration of the EBS was very low (<0) since the region has among the lowest migration rates in the State (Williams, 2004; ADLWD, 2016). The highest net migration occurs in the Gulf of Alaska region and the Matanuska-Susitna Borough has the highest growth rate in the State (ADLWD, 2016).

Population trends in Alaska are largely the result of changes in resource extraction and military activity (Williams, 2004). Historically, the gold rush of the late 19th century doubled the State's population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD, 2016). The NBS high population increase of 1900 occurred in Nome because of the gold rush. However, the population of some communities declined in the 1990s because of Coast Guard cut-backs and military base closures (Williams, 2006). The fishing industry also influences community population. Kodiak and the Aleutian Islands have the most transient populations because of the seafood processing industry (Williams, 2004). Some EBS communities experienced fishery permit loss and population decline, such as South Naknek. Factors that influence population shifts and migration include employment, retirement, educational choices, cost of living, climate, and quality of life (Donkersloot and Carothers, 2016).

Implications: Population shifts can affect pressures on fisheries resources, however inferences about human impacts on resources should account for economic shifts and global market demand for seafood and other extractive resources of the ecoregion. Population change in Alaska is largely fueled by increased net migration rather than natural increase, and there has been increased migration from rural to urban areas. This is evident with population decline of many small communities. Fisheries contribute to community vitality of the EBS and NBS and reduced fishing opportunities and employment may lead to out-migration and population decline, particularly in small communities with few job alternatives (Donkersloot and Carothers, 2016). Changes in groundfish policy and management, such as increased regulations, may have implications for small communities and those of the Bering Sea Community Quota Entities. Also, with a large proportion of the EBS and NBS population being Native Alaskans, resource managers may benefit from working with communities holding traditional ecological knowledge (TEK) to incorporate TEK into ecosystem management (Huntington et al., 2004).

K–12 School Enrollment, Graduation and Dropout rates in Coastal Communities in the Southeastern and Northern Bering Sea

Contributed by Sarah P. Wise[1] and Kim Sparks[1,2]
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Description of indicator: Ensuring the productivity and sustainability of fishing communities is a core mandate of Federal fisheries management. One indicator to evaluate community vitality is K-12 public school enrollment. Enrollment trends are of particular relevant due to the value of schools to community cohesion and identity. Public school enrollment was analyzed in the Eastern Bering Sea (EBS) by borough and community level in order to examine broader regional trends as well as the social and economic vitality of individual rural communities. Enrollment statistics for K-12 grades by school and region were compiled for the years 1996-2018 from the Alaska Department of Education and Early Development (http://www.eed.state.ak.us/stats/). Current school locations and names were verified using the EPA EJ mapping tool (https://ejscreen.epa.gov/mapper/). It should be noted that the Aleutians East and Lower Kuskokwim school districts overlap with other ecoregions; these school districts were analyzed using only those schools that fall within the southeastern or northern Bering Sea regions. School graduation rates are based off of the four year adjusted cohort graduation rate, which was implemented in Alaska starting with the 2011–2012 school year. Graduation rates are reported for 2015–2017 cohorts based upon school district. Dropout rates are reported by school district from 1990–2017. All data originate from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`).

Status and trends:
Southeastern Bering Sea
In the SEBS region there has been a general downward trend in school enrollment in most boroughs, with the exception of the Lower Kuskokwim School district, which has increased 23% from 530 students in 1996 to 688 students in 2018 (Figure 115). In schools with enrollment under 20 students, the decrease in enrollment is steeper. School enrollment numbers have fluctuated widely since 1996, highlighting the difficulties in maintaining sustainable communities within the rural coastal Alaskan ecosystem. Several community school have closed since 2005 (Figure 116), including Nelson Lagoon, South Naknek, Portage Creek, Egegik, and most recently St. George in 2018. Clark's Point school re-opened in 2018 with 13 students after being closed from 2013–2017.

Graduation rates for SEBS school districts vary substantially. The graduation rates for Lower Kuskokwim district consistently fall in the lower 1/3 of school districts analyzed in the Ecosystem Status Report, while the graduation rates for the Lake and Peninsula and Pribilof school districts are consistently in the upper 1/3 (Figure 117). The graduation rate average in Alaska was 75.6% (2015), 76.1% (2016), and 78.2% (2017). Dropout rates vary for SEBS vary from 0-16%, with greater variability since 1990. The greatest outlier is Dillingham, with a 17.3% dropout rate in 2000.

Northern Bering Sea
Unlike many of the other regions, NBS school district enrollment levels are relatively stable. The

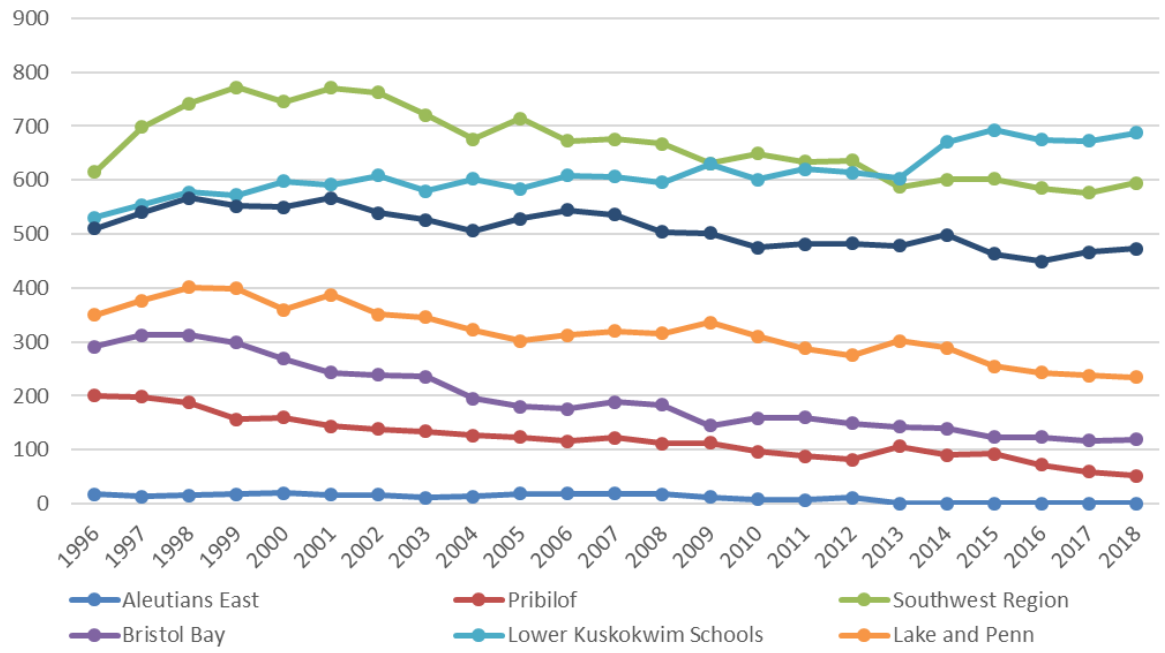

Figure 115: Enrollment for SEBS schools.

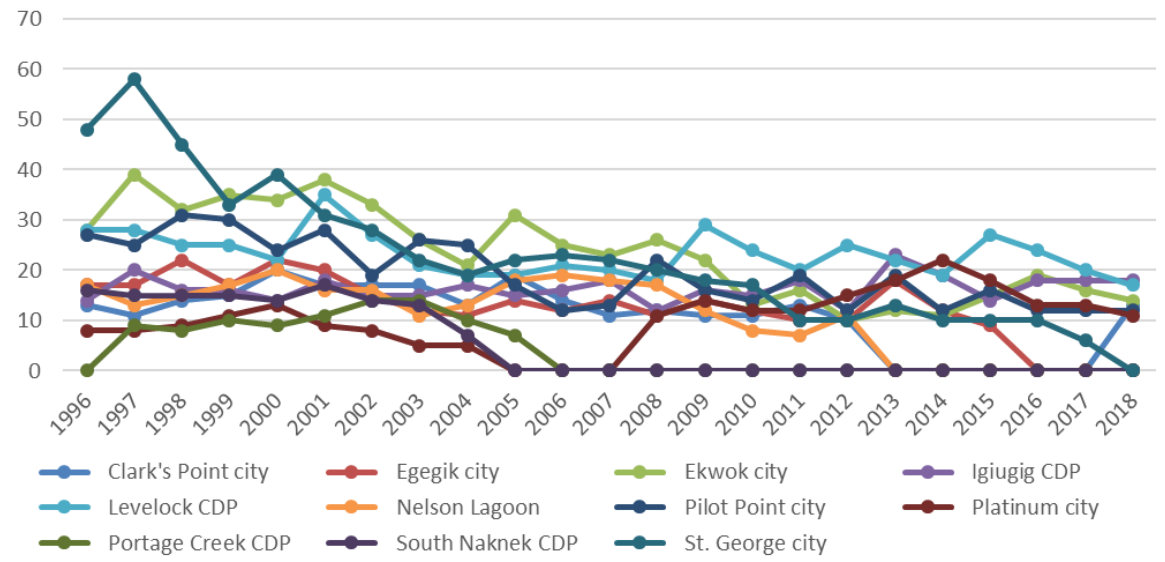

Figure 116: SEBS schools with enrollment under 20 students.

Lower Kuskokwim school district increased enrollment from 2,656 students in 1996 to 3,442 students in 2018; this is a 23% increase (Figure 118). For the Bering Strait school district, overall trends are relatively stable with some slight variation. In comparison to other regions, there have been very few school closures (specifically two: Pitkas Point CDP and Leonard Seppala High School in Nome). There are only five schools with enrollment levels that are 30 or fewer students out of 64 schools.

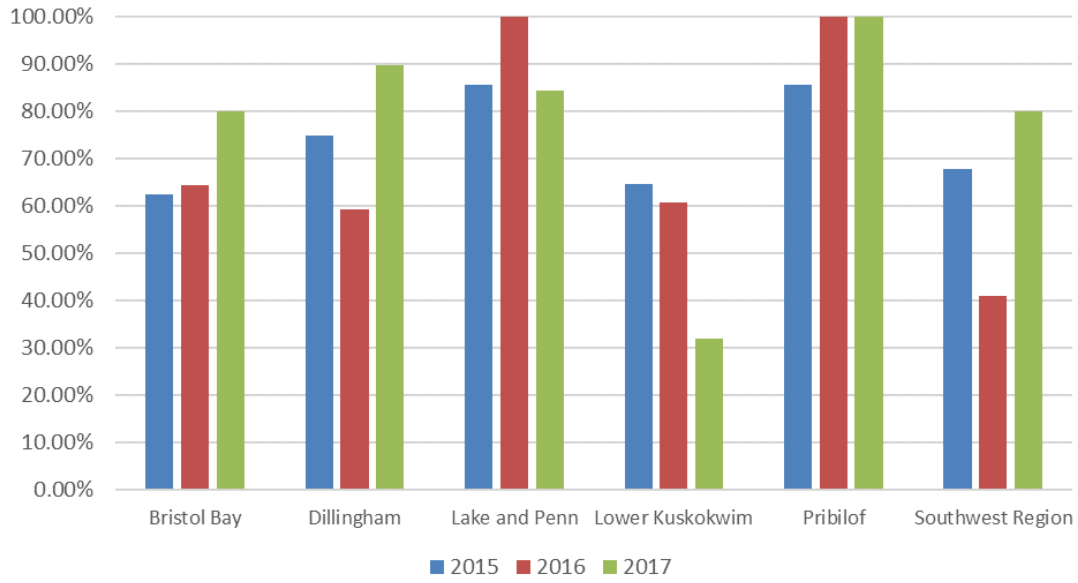

Figure 117: Graduation rates for SEBS school districts, 2015–2017.

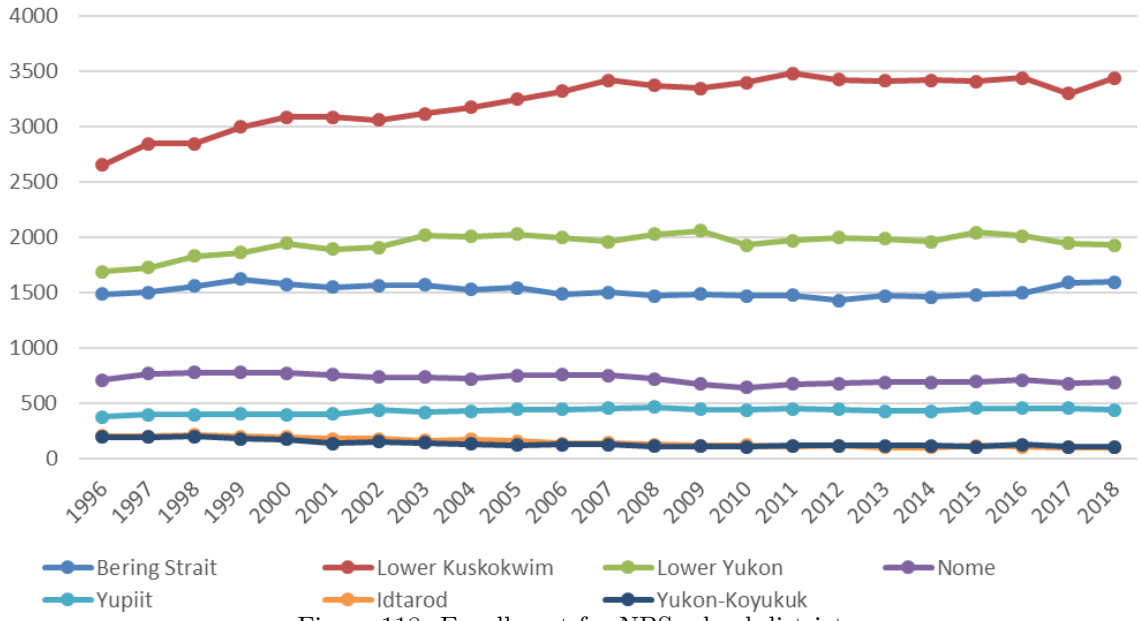

Figure 118: Enrollment for NBS school districts.

There is large variation in the graduation rates of NBS school districts, most of which are well below state graduation averages. The graduation rates for Lower Kuskokwim, Nome, and Yupiit school districts consistently fall in the lower 1/3 of school districts analyzed in the Ecosystem Status Report for all three cohort years (Figure 119). Dropout rates for NBS vary greatly from 0-18.6%, with much greater variability since 1990. The greatest outlier is the Yupiit School district, with consistently higher dropout rates. It is also worth noting that the NBS region has the highest dropout rates compared to other regions, with an overall average of 10% for multiple years.

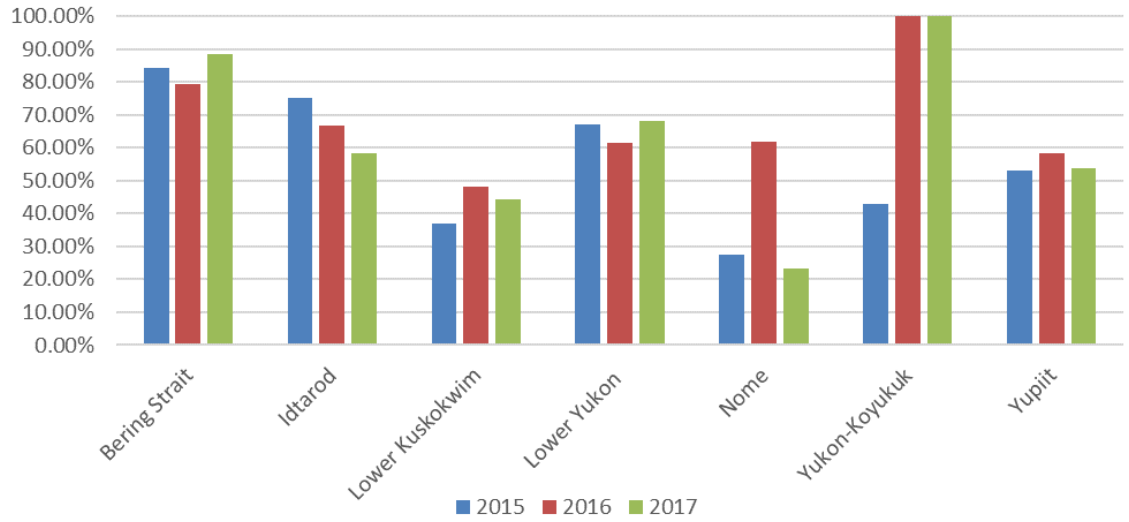

Figure 119: Graduation rates for NBS school districts, 2015–2017.

Factors influencing observed trends:

Southeastern Bering Sea

The SEBS ecosystem varies substantially in population, community structure, and vitality. The SEBS is a large and diverse area with many small rural communities. High dependence on natural resources may drive population shifts according to season and availability. As people migrate to other areas, populations increase in adjacent communities. It is possible that enrollment may shift to the larger communities as more convenient schools open. However other factors must be considered including existing infrastructure such as functional ports, airports, or medical facilities to provide support for a viable community structure. Those schools with enrollment under 30 students experience the greatest uncertainty in terms of educational stability.

As of 2017, 11 schools had enrollment under 30 students, and four schools reported under 15 students. With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and possible community disruption. The reasons for decreasing enrollment likely involve complex social and economic drivers including migratory patterns, resource availability, and employment. Additional research into the specific reasons for diminishing school enrollment in rural areas, as well as the impacts on these communities would inform and benefit management decisions.

Northern Bering Sea

In the NBS ecosystem, limited access to infrastructure may stabilize school populations to some degree. Rural schools are vulnerable to closure and possible community disruption. Schools in remote villages often serve as meeting places, libraries, places of lodging, and provide access to the Internet. The closure of a school in these places would have a profound effect. Additional research into the relationship between school enrollment and remote communities would inform management decisions.

Implications: Community residents are closely tied to the ecosystem through sense of place and daily experience and activity. Schools are cultural centers and serve as important indicators of social and economic viability, and community well-being (Lyson (2002); Thomas, 2002; Thomas, 2005). Within rural communities, in particular, schools are valuable symbols for community identity,

autonomy, and shared social values (Peshkin (1978, 1982); Thomas, 2005). Research indicates that school closures negatively affect communities and student achievement (Buzzard, 2016; Thorsen, 2017). Closed school buildings can be a drain on community and school district resources (Barber, 2018). Patterns of diminishing enrollment and school consolidation suggest a decrease in property values and taxes, fragmented community, and lost business, as well as declines in reported quality of life scores (Sell and Leistritz (1997); Thomas, 2002). Some research finds the rate of participation in community organizations decreases in communities experiencing school closures (Oncescu and Giles, 2014; Sell and Leistritz, 1997). These finding suggest that reduced enrollment and school closures may flag disruptions in social cohesion, possibly leading to less vibrant and sustainable communities.

Responses to Comments from the Scientific and Statistical Committee (SSC)

December 2017 SSC Comments

This year, as in the past, the Ecosystem Considerations Reports are insightful, well written and well edited. Both chapters were helpful in providing a context within which to assess the stocks of commercially harvested fish in Federal waters off Alaska. The editors and authors have been very responsive to the comments and suggestions provided by the SSC in 2016. Last year the SSC raised the question as to whether sufficient resources were being devoted to the compilation and editing of the Ecosystem Considerations chapters. The SSC recognizes that this year NOAA provided additional staff resources to sustain the improvement of these documents, and that these additional resources allowed for more in-depth analyses of recent environmental changes, such as the examination of the sudden decline in Pacific cod in the Gulf of Alaska.

Thank you. As a result of continued staffing support from AFSC, this year we provide updates to the Eastern Bering Sea (Siddon & Zador), Gulf of Alaska (Zador & Yasumiishi, with Rob Suryan providing coordination with Gulf Watch Alaska), and Aleutian Islands (Zador & Ortiz) Ecosystem Status Reports.

The SSC was pleased to see the addition of the rapid zooplankton assessments included for both EBS and GOA Ecosystem reports. As requested by the SSC, these data are shown with historical context for small and large copepods, and euphausiids. Additionally, this indicator now estimates abundance rather than proportional catches, which aids in interpretation.

The RZA continues to be applied to more surveys, for example the northern Bering Sea, and we have also added contextual information for zooplankton condition in the form of lipid percentages. We have also standardized the presentation style of maps and time-series for ease of interpretation moving forward. Finally, we will be able to present a comparison of RZA to fully processed net samples in the coming year to assess the efficacy of the RZA.

There are expanded analyses of abundance and distribution shifts of groundfish and jellyfish from AFSC bottom trawl surveys. New indicators for groundfish from these surveys (mean length, lifespan and total biomass) have remained relatively stable over the time series. The SSC appreciates the inclusion of these new indicators, but suggests that even small changes could have far reaching implications as these are relatively gross-scale indicators. The SSC requests further development

of these indicators as anomalies to better discern long-term trends. The SSC looks forward to the eventual inclusion of comparisons of events in the different LMEs, and how events in one LME may affect another LME.

The indicators for Mean Lifespan and Mean Length of the Fish Community as well as the Stability of Groundfish Biomass indicator have been revised in 2018 to include both a mean and trendline over the respective timeseries to better discern long-term patterns and detect significant differences in the slope of the trendline. Comparisons across LMEs remains a gap in the Reports, but something the author and Report editors will continue to work towards for future Reports. One of the issues with comparisons across LMEs is that a difference in indicator value does not necessarily indicate that one system is healthier than the other. Differences in indicators between LMEs may reflect fundamental differences in the ecosystem structures and species compositions.

The editors present a new "Groundfish Recruitment Predictions" section, which includes a new indicator for Pacific cod and five new indicators for walleye pollock. The SSC supports the development of these predictions based on ecosystem indicators that are firmly grounded in mechanistic relationships. Effort should be directed toward the eventual incorporation of these recruitment indicators in the assessment models. The SSC recommends that these species-specific predictions are transitioned to the ESPs (Ecosystem Socio-economic Profile) to ensure that they are considered by the stock assessment authors.

The contribution authors and Report editors are maintaining open communication with stock assessment authors and those involved in producing the ESPs. These species-specific indicators will be transitioned to the appropriate ESPs as they become available.

The SSC commends the ongoing efforts to expand the treatment of the Human Dimensions portion of the Ecosystem Considerations chapters. In particular, a number of new indicators have been incorporated. The SSC notes that development of indicators on the "health" of fishing communities lags behind that of indicators for the health of the fish stocks and that the latter were developed and refined over a long time period. The SSC encourages the continued development of this section and, in particular, the development of indicators on which the Council might be able to act in the advent of evidence of a problem. Specific to the human population indicators, regional characterizations mask rural trends relative to urban centers. The SSC recommends the inclusion of maps demonstrating finer scale shifts in population trends as well as school enrollment trends, both of which are strong indicators of community stability or vulnerability.

The Economic and Social Sciences Research program, in collaboration with the Report editors, has made further improvements to the Human Dimensions indicators for 2018, although some of these updates are reflected in the Groundfish Economic SAFE report that will be reviewed by the SSC in February 2019. For this version of the report, we have (i) re-evaluated the definition of fishing communities and redrew the boundary for inclusion in the analysis to reflect a better representation of how coastal communities are impacted on an ecosystem scale for all Human Dimensions indicators, (ii) broadened school enrollment indicator to include "school readiness" (as illustrated by graduation and drop-out rates) to examine not just number of students enrolled, but to what degree of success were communities educating their youth, and (iii) conducted the analysis on an ecosystem scale, but attention was paid to community level impacts to highlight connectivity across regions. Additional detailed information on selected groundfish communities will be highlighted in the Groundfish Economic SAFE report in February. We have considered the use of maps to display the human dimensions indicators data and are exploring ways to incorporate

this type of information in future versions of the Groundfish Economic SAFE report.

The influences on the economic and social life in Alaska's coastal communities are many and the SSC cautions against facile causal interpretations. At the same time, it would be a mistake to dismiss the indicators presented in the chapter as being disconnected from and unrelated to the Council's sphere of influence. The policy choices made by the Council and the US Congress directly influence the possibilities presented to the communities of the North Pacific. The SSC suggests that the Human Dimensions ecosystem indicators be a topic for discussion by the newly formed Social Science Planning Team.

The Report editors welcome collaborating with the Social Science Planning Team to best represent and report coastal communities and impacts of policy choices on Alaskans.

The LEO Network is a potentially valuable resource for ecosystem considerations that invites community members to record unusual observations which are then vetted by scientific consultants before being published on the network. The SSC recommends the exploration of projects within this tool that ask specific questions to solicit relevant observations from communities. It is not clear how this network is publicized or the level of community awareness and involvement. Specific to the northern Bering Sea, the SSC endorses the Plan Team recommendation for continued evaluation of approaches to incorporate local ecological knowledge into the Ecosystems Considerations chapters. In addition, the SSC encourages exploration of other more active approaches to gathering and engaging citizen science/LTK from communities.

Community awareness of, and involvement in, efforts to engage citizen science/LTK have increased, both through the LEO Network and through direct communication with NOAA employees and Report editors. For example, the observations of pollock in Bristol Bay (p. 3) were communicated directly from a subsistence fisher to NOAA's Alaska Regional Office who forwarded the contact to Elizabeth Siddon, editor of the EBS Ecosystem Status Report. That communication resulted in additional direct reports from fishers in the area, samples collected for processing at AFSC and NWFSC, and a LEO Network report. We attempted to initiate a project on NBS community observations but were unsuccessful this past year. However, we provide updates to the LEO reports again this year and will continue to pursue this tool as well as other avenues for communication. The Ecosystem Status Report editors believe citizen engagement will continue to increase as awareness increases.

Last year the SSC raised the issue of how well report authors have managed to address the implications of their indicator findings for the current year. One of the important reasons for the existence of the Ecosystem Considerations chapters is to provide the Council with information that may be relevant for adjusting the coming year's harvest specifications or biological reference points. Thus, the indices and their implications that are most valuable will be those that provide information that inform Council decisions. The Implications Sections that merely state that an indicator might be important for management are not particularly helpful. The SSC recognizes that the editors are planning to revise the instructions to authors to clarify this issue, and looks forward to improvements in this area.

The Report editors continue to review Implications section for utility and relevance to adjusting harvest specifications or biological reference points. We provide examples of useful Implications and assist authors in better realizing direct implications of their indicators. It is an on-going effort.

The editors raised the question as to the possibility of a change in the organization of the Ecosystem

Considerations chapters. Currently, the report is organized by trophic level, reflecting the flow of energy and material to fish stocks and the fishing community within each LME. The editors are considering reformatting by ecosystem-scale management objectives created by Congress (see Table 1 in each of the chapters). The SSC questions the utility of the proposed change from a document focused on understanding of relevant portions of the marine ecosystem in which fishing is occurring to one that focuses more on fisheries management objectives. This organization could be appropriate for the fishing and human dimensions indicators, but not the physical and ecological indicators in the Ecosystem Indicators section. The SSC has been on record for many years in requesting that the Ecosystem Considerations chapters and their components follow an organization scheme based on trophic level.

The organization of the Ecosystem Status Reports remains by trophic level for physical and ecological indicators and by management objectives for the human dimensions section, as was done for the 2017 Reports (i.e., no change).

New this year, we are working with the AFSC communications staff to produce a "public-friendly" version of the ESRs. We hope to have the first edition of the EBS ESR brochure available to the public in January. We will be using the term Hot Topics to reflect the most important ecosystem assessment features for the current year. Thus, we will use 'Noteworthy' as the new title for the former Hot Topics in the ESR assessments. This new title is more appropriate as this section is used for noteworthy information that cannot be presented in the format of our standard indicator contributions, but are not necessarily the most important topics of the year.

Eastern Bering Sea

In the EBS Chapter, the "Hot Topics" section included an excellent discussion of large biomasses of Pacific cod and walleye pollock in the northern Bering Sea. The presence of these fish in large numbers that far north raises important questions about their persistence there and their relationship to the stocks in the eastern Bering Sea. Although in 2017 there may have been a wider pathway north in the inner shelf than usual, an important question is now whether the fish observed in the north are a separate stock and, if they are not a separate stock, will the population return south prior to winter. Likewise, high numbers of age-0 pollock were observed in the northern Bering Sea. It is not known what proportion of these fish will return to the southeastern Bering Sea.

A composite of unusual weather events during the winter of 2017/2018 resulted in an unprecedented lack of sea ice in the northern Bering Sea. Residual heat in the system delayed sea ice formation in the Chukchi Sea, and a persistent high-pressure system brought warm air from the southwest over the Bering Sea shelf through winter and spring, largely preventing the formation of sea ice in the NBS. Although uncertainty remains, it is possible that some portion of the Pacific cod and pollock remained in the northern Bering Sea last winter, thereby likely causing a shift in the food-web balance in that ecoregion.

In this year's Noteworthy section (formerly Hot Topics), we present genetic work contributed by Spies et al. indicating that the Pacific cod in the northern Bering Sea were most similar to spawning populations from Pervenets, Pribilof, and Unimak Pass (p. 40).

Our best information is that both walleye pollock and Pacific cod lack the antifreeze proteins needed to prevent tissues from freezing at the sub-zero water column temperatures almost certain to occur over the shelf in the coming winter. Observations around Norton Sound of the presence of cod and pollock and their condition this winter could be most helpful in evaluating the implications of

this new distribution pattern. It would be of interest to survey local communities in the northern Bering Sea to obtain information about their past experiences with groundfish in these waters, and when they have been observed to arrive and depart. Specifically, the authors should investigate whether data from the Norton Sound winter king crab fishery is useful. With regard to Pacific cod in particular, results from the 2017 northern Bering Sea survey, in concert with the observed decline in biomass from the EBS bottom trawl survey, suggest that we might need to be adaptive not only in our management, but also in our surveying of commercial fish stocks. The SSC strongly supports conducting additional surveys in the northern Bering Sea.

Again, unusual weather events during the winter of 2017/2018 resulted in a near-complete lack of sea ice over the northern Bering Sea, such that lacking anti-freeze protein may not have been as limiting as in other years. The Assessment (p. 3) contains observations from communities in the northern Bering Sea that may help inform our understanding of Pacific cod and pollock distribution and behavior in the northern Bering Sea last winter.

During the 2018 field season, standard and additional surveys were completed in the northern Bering Sea to provide information on population dynamic and ecosystem responses. AFSC surveys included: bottom trawl standard and northern extension surveys, midwater acoustics standard and northern extension surveys, and northern Bering Sea surface trawl survey. The Report editors commend and thank AFSC staff and survey participants for their efforts to provide timely information from these 2018 surveys into the 2018 Ecosystem Status Reports.

In the EBS chapter, the suite of contributions showing the relationships among the availability of large, lipid-rich zooplankton, diets of age-0 pollock, the lipid content of these juvenile fish and their survival to age-3 is remarkable. The demonstrated predictive ability suggests that we are making progress toward having the understanding and data available for input to the pollock assessment model that may improve predictions of year-class strength. Additional information shows that year-class strengths of cod and pollock are strongly correlated and suggests that prediction of Pacific cod year-class strength may also become possible.

The authors of the 'Large Copepod Abundance' contribution (p. 121) provided the large copepod density time series 2002–2016 to the EBS pollock stock assessment author. Authors are working with scientist focused on the NPZ model to develop a time series of large copepod densities long enough to incorporate the index into the stock assessment model.

The SSC expressed interest in having information on the status and trends of marine mammals in addition to northern fur seals. Two species that may be of particular interest in the EBS are walrus and harbor seals. Diet studies indicate walrus are still primarily benthic foragers, but also utilize fish resources. Recent reports from communities indicate that harbor seal populations in Bristol Bay are increasing. As harbor seal diets include forage fish and groundfish, monitoring their populations may contribute to ecosystem status and pattern interpretation. Changes in ice seal distribution or abundance may help in assessing changes in commercially important stocks, or the prey on which they depend.

In response to the unprecedented lack of sea ice in the northern Bering Sea during winter 2017/2018, the AFSC convened experts across NOAA line offices, other agencies, academia, and community stakeholders together with relevant stock assessment authors to compile and synthesize real-time data and observations of the northern Bering Sea ecosystem. The expert group reviewed findings from survey results, local community observations, and climate models. There was evidence of

unusual distributions, poor condition, and strandings of marine mammals and that information has been incorporated into the Assessment (p. 3). The EBS Report also includes preliminary results of northern fur seal pup production at the Pribilof Islands (p. 136). We will continue to pursue relevant marine mammal information to inform our assessments.

A few notable trends in the EBS

Groundfish

Groundfish condition declined from 2016–2017 for all species, except for age-1 pollock and Alaska plaice, e.g., length-weight residuals for adult walleye pollock and Pacific cod were both negative. The SSC requests that the authors consult with the stock assessment authors and select a common index of fish condition. Poor condition may compromise overwinter survival. Also, based on the CEATTLE model, estimated mortality for age-1 pollock, Pacific cod and arrowtooth flounder remained elevated in 2017, and predictions based on the relationship between the North Pacific Index and Pacific cod recruitment deviations suggest that poor cod recruitment is likely. The results from these three indicators in concert (poor condition, increased mortality and negative recruitment deviations) may signal an upcoming period of poor Pacific cod recruitment. On a more positive note, cooler temperatures are forecast for 2018, which should lead to increased large zooplankton, and better survival of juvenile pollock and cod.

Report editors, authors, and stock assessment authors have selected a common index of fish condition (see p. 107). In addition, the contributing authors have provided R code to enable comparable indicators to be developed for other surveys/timeseries.

Flatfish

Springtime drift patterns were consistent with below average flatfish recruitment for winter spawners. There have been very few years with drift patterns that indicate strong recruitment for flatfish over the last decade, and, this relationship may be weakening for certain species. The extended period of poor flatfish recruitment should be monitored.

The 2018 OSCURS model for springtime drift appears favorable with consistent drift in a northerly direction towards suitable nursery grounds. However, correspondence between drift patterns and recruitment success have weakened for Arrowtooth flounder and Flathead sole (see p. 73).

Crab and motile epifauna

Commercial crab biomass decreased in 2017 again, whereas brittle stars and sand dollars continue to increase. The SSC raised the possibility that a restructuring of this part of the ecosystem is occurring, or has already occurred, and recognizes the continued depression of commercial crab stocks.

In 2018, continued declines in commercial crab stock biomass were observed (see p. 131) while the biomass of motile epifauna continues to increase (see EBS Report Card), supporting the suggestion of a restructuring of the benthic component of the ecosystem.

Salmon

Canadian-origin Yukon River juvenile Chinook abundance in the northern Bering Sea was below the long-term average, and there is a potential need for reduced bycatch caps three to four years from now. It could be useful to summarize data on the availability of zooplankton and forage fish to salmon as they enter the ocean.

The 2018 catch of juvenile Chinook abundance during the northern Bering Sea survey were among

the lowest observed since 2003. It is therefore likely that the 2018 estimate will be below average, marking the 2nd consecutive year of below-average abundance, with implications for bycatch caps in the near future (see p. 102).

References

ADLWD. 2016. Alaska Economic Trends. Employment Forecast 2016. Alaska Department of Labor and Workforce Development. January 2016, Volume 36, No. 1. Report.

ADLWD. 2017. Alaska Economic Trends. Alaska Department of Labor and Workforce Development. Report.

ADLWD. 2018. Cities and Census Designated Places (CDPs), 2010 to 2016. Report, Alaska Department of Labor and Workforce Development.

AFSC. 2011. Observer Sampling Manual for 2012. Report, Alaska Fisheries Science Center, Fisheries Monitoring and Analysis Division, North Pacific Groundfish Observer Program, 7600 Sand Point Way, NE.; Seattle WA; 98115.

Alverson, D. L. 1994. A global assessment of fisheries bycatch and discards, volume 339. Food & Agriculture Org.

Andrews, A. G., W. W. Strasburger, E. V. Farley, J. M. Murphy, and K. O. Coyle. 2015. Effects of warm and cold climate conditions on capelin (*Mallotus villosus*) and Pacific herring (*Clupea pallasii*) in the eastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography .

Aydin, K., and F. Mueter. 2007. The Bering Sea - a dynamic food web perspective. Deep Sea Research Part II: Topical Studies in Oceanography **54**:2501–2525.

Baier, C. T., and J. M. Napp. 2003. Climate-induced variability in *Calanus marshallae* populations. Journal of Plankton Research **25**:771–782.

Barber, B. P. 2018. Public School Closures: The Fate of Abandoned School Buildings. Notre Dame JL Ethics & Pub. Pol'y **32**:329.

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography **49**:423–437.

Berkeley, S. A., M. A. Hixon, R. J. Larson, and M. S. Love. 2004. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. Fisheries **29**:23–32.

Blanchard, F., and J. Boucher. 2001. Temporal variability of total biomass in harvested communities of demersal fishes. Fisheries Research **49**:283–293.

Boldt, J. L., and L. J. Haldorson. 2004. Size and condition of wild and hatchery pink salmon juveniles in Prince William Sound, Alaska. Transactions of the American Fisheries Society **133**:173–184.

Brodeur, R., C. Mills, J. Overland, G. Walters, and J. Schumacher. 1999. Recent increase in jellyfish biomass in the Bering Sea: Possible links to climate change. Fisheries Oceanography **8**:286–306.

Brodeur, R. D., M. B. Decker, L. Ciannelli, J. E. Purcell, N. A. Bond, P. J. Stabeno, E. Acuna, and G. L. Hunt. 2008. Rise and fall of jellyfish in the eastern Bering Sea in relation to climate regime shifts. Progress in Oceanography **77**:103–111.

Brodeur, R. D., R. L. Emmett, J. P. Fisher, E. Casillas, D. J. Teel, and T. W. Miller. 2004. Juvenile salmonid distribution, growth, condition, origin, and environmental and species associations in the Northern California Current. Fishery Bulletin **102**:25–46.

Brodeur, R. D., H. Sugisaki, and G. L. Hunt. 2002. Increases in jellyfish biomass in the Bering Sea: implications for the ecosystem. Marine Ecology Progress Series **233**:89–103.

Burger, A. E., and J. F. Piatt. 1990. Flexible time budgets in breeding Common Murres: Buffers against variable prey availability. Studies in Avian Biology **14**:71–83.

Buzzard, R. A. 2016. What Every Policy Maker, School Leader, Parent, and Community Member Needs to Know About the Social, Economic, and Human Capital Costs of Closing a Rural School: A Comprehensive Multi-faceted Investigation. Niagara University.

Cahalan, J., J. Mondragon, and J. Gasper. 2010. Catch sampling and estimation in the Federal groundfish fisheries off Alaska. Report, U.S. Dep. Commer., NOA Tech. Memo. NMFS-AFSC-205, 42 p.

Cahalan, J. A., J. R. Gasper, and J. Mondragon. 2014. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska, 2015 Edition. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center.

Calhoun, S., F. Conway, and S. Russell. 2016. Acknowledging the voice of women: implications for fisheries management and policy. Marine Policy **74**:292–299.

Catchpole, T., C. Frid, and T. Gray. 2006. Resolving the discard problemA case study of the English Nephrops fishery. Marine Policy **30**:821–831.

Cieciel, K., E. V. Farley Jr, and L. B. Eisner. 2009. Jellyfish and juvenile salmon associations with oceanographic characteristics during warm and cool years in the eastern Bering Sea. North Pacific Anadromous Fish Commission Bulletin **5**:209–224.

Clucas, I. 1997. A study of the options for utilization of bycatch and discards from marine capture fisheries. FAO fisheries circular **928**:1–59.

Condon, R. H., D. K. Steinberg, P. A. Del Giorgio, T. C. Bouvier, D. A. Bronk, W. M. Graham, and H. W. Ducklow. 2011. Jellyfish blooms result in a major microbial respiratory sink of carbon in marine systems. Proceedings of the National Academy of Sciences **108**:10225–10230.

Conner, J., and R. Lauth. 2016. Results of the 2013 eastern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate resources. Report.

Conners, M. E., K. Y. Aydin, and C. L. Conrath. 2016. Assessment of the octopus stock complex in the Bering Sea and Aleutian Islands .

Cooper, D. W., and D. G. Nichol. 2016. Juvenile northern rock sole (Lepidopsetta polyxystra) spatial distribution and abundance patterns in the eastern Bering Sea: spatially dependent production linked to temperature. ICES Journal of Marine Science **73**:1138–1146.

Coyle, K., and G. Gibson. 2017. Calanus on the Bering Sea shelf: probable cause for population declines during warm years. Journal of Plankton Research **39**:257–270.

Coyle, K. O., L. Eisner, F. J. Mueter, A. Pinchuk, M. Janout, K. Cieciel, E. Farley, and A. Andrews. 2011. Climate change in the southeastern Bering Sea: impacts on pollock stocks and implications for the Oscillating Control Hypothesis. Fisheries Oceanography **20**:139–156.

Coyle, K. O., and A. Pinchuk. 2002. The abundance and distribution of euphausiids and zero-age pollock on the inner shelf of the southeast Bering Sea near the Inner Front in 19971999. Deep Sea Research Part II: Topical Studies in Oceanography **49**:6009–6030.

DCCED. 2016. State of Alaska Department of Commerce, Community and Economic Development. Community and Regional Analysis, Community Database Online. Report.

De Robertis, A., D. R. McKelvey, and P. H. Ressler. 2010. Development and application of an empirical multifrequency method for backscatter classification. Canadian Journal of Fisheries and Aquatic Sciences **67**:1459–1474.

Dietrich, K. S., and S. M. Fitzgerald. 2010. Analysis of 2004-2007 Vessel-specific Seabird Bycatch Data in Alaska Demersal Longline Fisheries. Alaska Fisheries Science Center, Resource Ecology and Fisheries Management Division.

Dietrich, K. S., and E. F. Melvin. 2008. Alaska Trawl Fisheries: Potential Interations with North Pacific Albatrosses. Report, Washington Sea Grant.

Donkersloot, R., and C. Carothers. 2016. The Graying of the Alaskan Fishing Fleet. Environment: Science and Policy for Sustainable Development **58**:30–42.

Duffy-Anderson, J. T., P. J. Stabeno, E. C. Siddon, A. G. Andrews, D. W. Cooper, L. B. Eisner, E. V. Farley, C. E. Harpold, R. A. Heintz, and D. G. Kimmel. 2017. Return of warm conditions in the southeastern Bering Sea: Phytoplankton-Fish. PloS one **12**:e0178955.

Dulvy, N., S. Rogers, S. Jennings, V. Stelzenmuller, D. Dye, and H. Skjoldal. 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. Journal of Applied Ecology **45**:1029–1039.

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

Eisner, L. B., J. C. Gann, C. Ladd, K. D. Cieciel, and C. W. Mordy. 2015. Late summer/early fall phytoplankton biomass (chlorophyll a) in the eastern Bering Sea: Spatial and temporal variations and factors affecting chlorophyll a concentrations. Deep Sea Research Part II: Topical Studies in Oceanography .

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

Elison, T., P. Salomone, T. Sands, G. Buck, K. Sechrist, and D. Koster. 2018. 2017 Bristol Bay Area Annual Management Report .

Fall, J., A. Godduhn, L. Hutchinson-Scarbrough, B. Jones, D. Kukkonen, D. Runfola, L. Still, and T. Lemons. 2017. Alaska subsistence and personal use salmon fisheries 2014 annual report. Report, Alaska Department of Fish and Game Division of Subsistence.

Fall, J., and T. Lemons. 2015. Subsistence harvests of Pacific halibut in Alaska, 2014. Report, Alaska Department of Fish and Game Division of Subsistence.

Fall, J. A., N. S. Braem, C. L. Brown, L. B. Hutchinson-Scarbrough, D. S. Koster, and T. M. Krieg. 2013. Continuity and change in subsistence harvests in five Bering Sea communities: Akutan, Emmonak, Savoonga, St. Paul, and Togiak. Deep Sea Research Part II: Topical Studies in Oceanography **94**:274–291.

Farley, E., J. Moss, and R. Beamish. 2007. A Review of the critical size, critical period hypothesis for juvenile Pacific salmon. North Pacific Anadromous Fish Commission Bulletin **4**:311–317.

Farley, E. V., A. Starovoytov, S. Naydenko, R. Heintz, M. Trudel, C. Guthrie, L. Eisner, and J. R. Guyon. 2011. Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. ICES Journal of Marine Science **68**:1138–1146.

Faunce, C. H. 2015. Evolution of Observer Methods to Obtain Genetic Material from Chinook Salmon Bycatch in the Alaska Pollock Fishery. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center.

Funk, F., L. Brannian, and K. Rowell. 1992. Age-Structured Assessment of the Togiak Herring Stock, 1978-1992, and Preliminary Forecast of Abundance for 1993. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J92-11, Juneau. .

Funk, F., and K. A. Rowell. 1995. Population model suggests new threshold for managing Alaskas Togiak Fishery for Pacific herring in Bristol Bay. Alaska Fishery Research Bulletin **2**:125–136.

Gibson, G., and Y. Spitz. 2011. Impacts of biological parameterization, initial conditions, and environmental forcing on parameter sensitivity and uncertainty in a marine ecosystem model for the Bering Sea. Journal of Marine Systems **88**:214–231.

Goldsmith, S., J. Angvik, L. Howe, A. Hill, and L. Leask. 2004. The Status of Alaska Natives Report. I. Anchorage: Institute of Social and Economic Research, University of Alaska.

Graham, N., R. S. Ferro, W. A. Karp, and P. MacMullen. 2007. Fishing practice, gear design, and the ecosystem approachthree case studies demonstrating the effect of management strategy on gear selectivity and discards. ICES Journal of Marine Science **64**:744–750.

Grant, W. S., and F. M. Utter. 1984. Biochemical population genetics of Pacific herring (Clupea pallasi). Canadian Journal of Fisheries and Aquatic Sciences **41**:856–864.

Hare, S. R., N. J. Mantua, and R. C. Francis. 1999. Inverse production regimes: Alaska and west coast Pacific salmon. Fisheries **24**:6–14.

Harris, R., P. Wiebe, L. J., S. H.R., and H. M. 2005. ICES Zooplankton Methodology Manual. Elsevier Academic Press, Amsterdam.

Harvey, H. R., R. L. Pleuthner, E. J. Lessard, M. J. Bernhardt, and C. T. Shaw. 2012. Physical and biochemical properties of the euphausiids Thysanoessa inermis, Thysanoessa raschii, and Thysanoessa longipes in the eastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **65**:173–183.

Haynie, A. C., and L. Pfeiffer. 2013. Climatic and economic drivers of the Bering Sea walleye pollock (*Theragra chalcogramma*) fishery: implications for the future. Canadian Journal of Fisheries and Aquatic Sciences **70**:841–853.

Heard, W. 2009. Alaska Salmon. In 'Our Living Oceans', 6th edition. Report, US Dep. Commerce, NOAA Tech. Memo.

Heintz, R., E. Farley, and E. Siddon. 2010. Fall Condition of YOY Predicts Recruitment of Age-1 Walleye Pollock. In: Zador and Gaichas (Eds.), Ecosystem Considerations for 2011. Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Reports. Report, North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Heintz, R. A., E. C. Siddon, E. V. Farley Jr, and J. M. Napp. 2013. Correlation between recruitment and fall condition of age-0 pollock (*Theragra chalcogramma*) from the eastern Bering Sea under varying climate conditions. Deep Sea Research Part II: Topical Studies in Oceanography .

Hermann, A. J., G. A. Gibson, N. A. Bond, E. N. Curchitser, K. Hedstrom, W. Cheng, M. Wang, P. J. Stabeno, L. Eisner, and K. D. Cieciel. 2013. A multivariate analysis of observed and modeled biophysical variability on the Bering Sea shelf: Multidecadal hindcasts (19702009) and forecasts (20102040). Deep Sea Research Part II: Topical Studies in Oceanography **94**:121–139.

Himes-Cornell, A., K. Hoelting, C. Maguire, L. Munger-Little, J. Lee, J. Fisk, R. Felthoven, C. Geller, and P. Little. 2013. Community profiles for North Pacific fisheries - Alaska. Report, NOAA Tech. Memo.

Holen, D. 2014. Fishing for community and culture: the value of fisheries in rural Alaska. Polar Record **50**:403–413.

Holsman, K. K., and K. Aydin. 2015. Comparative methods for evaluating climate change impacts on the foraging ecology of Alaskan groundfish. Marine Ecology Progress Series **521**:217–235.

Holsman, K. K., J. Ianelli, K. Aydin, A. E. Punt, and E. A. Moffitt. 2016. A comparison of fisheries biological reference points estimated from temperature-specific multi-species and single-species climate-enhanced stock assessment models. Deep Sea Research Part II: Topical Studies in Oceanography **134**:360–378.

Honkalehto, T., and A. McCarthy. 2015. Results of the acoustic-trawl survey of walleye pollock (*Gadus chalcogrammus*) on the U.S. and Russian Bering Sea Shelf in June - August 2014 (DY1407). Report.

Hsieh, C.-h., C. S. Reiss, J. R. Hunter, J. R. Beddington, R. M. May, and G. Sugihara. 2006. Fishing elevates variability in the abundance of exploited species. Nature **443**:859–862.

Hunsicker, M. E., L. Ciannelli, K. M. Bailey, S. Zador, and L. C. Stige. 2013. Climate and Demography Dictate the Strength of Predator-Prey Overlap in a Subarctic Marine Ecosystem. PLoS ONE **8**:e66025.

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

Hunt, G. L., P. H. Ressler, G. A. Gibson, A. De Robertis, K. Aydin, M. F. Sigler, I. Ortiz, E. J. Lessard, B. C. Williams, and A. Pinchuk. 2016. Euphausiids in the eastern Bering Sea: A synthesis of recent studies of euphausiid production, consumption and population control. Deep Sea Research Part II: Topical Studies in Oceanography **134**:204–222.

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

Hunt, G. L., P. J. Stabeno, S. Strom, and J. M. Napp. 2008. Patterns of spatial and temporal variation in the marine ecosystem of the southeastern Bering Sea, with special reference to the Pribilof Domain. Deep-Sea Research Part Ii-Topical Studies in Oceanography **55**:1919–1944.

Huntington, H., T. Callaghan, S. Fox, and I. Krupnik. 2004. Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial ecosystems. Ambio pages 18–23 .

Huntington, H. P., I. Ortiz, G. Noongwook, M. Fidel, D. Childers, M. Morse, J. Beaty, L. Alessa, and A. Kliskey. 2013. Mapping human interaction with the Bering Sea ecosystem: comparing seasonal use areas, lifetime use areas, and calorie-sheds. Deep Sea Research Part II: Topical Studies in Oceanography **94**:292–300.

Ianelli, J., T. Honkalehto, S. Barbeaux, B. Fissel, and S. Kotwicki. 2016. Assessment of Alaska pollock stock in the Eastern Bering Sea. In: Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. Report, North Pacific Fishery Management Council.

Ianelli, J., T. Honkalehto, S. Barbeaux, B. Fissel, and S. Kotwicki. 2017. Assessment of Alaska pollock stock in the Eastern Bering Sea. In: Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. Report, North Pacific Fishery Management Council.

Jennings, G., K. Sundet, and A. Bingham. 2015. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2011. Report, Alaska Department of Fish and Game.

Jurado-Molina, J., P. A. Livingston, and J. N. Ianelli. 2005. Incorporating predation interactions in a statistical catch-at-age model for a predator-prey system in the eastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences **62**:1865–1873.

Kalnay, E., M. Kananitcu, R. Kistler, W. Collins, and D. Deaven. 1996. The NCEP/NCAR 40-year reanalysis project. Bulletin of the American Meteorological Society **77**:437–471.

Karp, W. A., L. L. Desfosse, and S. G. Brooke. 2011. US National bycatch report .

Kelleher, K. 2005. Discards in the world's marine fisheries: an update. Food & Agriculture Org.

Kimmel, D. G., L. B. Eisner, M. T. Wilson, and J. T. DuffyAnderson. 2018. Copepod dynamics across warm and cold periods in the eastern Bering Sea: Implications for walleye pollock (Gadus chalcogrammus) and the Oscillating Control Hypothesis. Fisheries Oceanography **27**:143–158.

Kooka, K., O. Yamamura, A. Nishimura, T. Hamatsu, and T. Yanagimoto. 2007. Optimum temperature for growth of juvenile walleye pollock *Theragra chalcogramma*. Journal of Experimental Marine Biology and Ecology **347**:69–76.

Kotwicki, S., and R. R. Lauth. 2013. Detecting temporal trends and environmentally-driven changes in the spatial distribution of bottom fishes and crabs on the eastern Bering Sea shelf. Deep Sea Research Part II: Topical Studies in Oceanography **94**:231–243.

Krieg, T. M., T. Lemons, and C. Welch. 2015. An Overview of the Subsistence Fisheries of the Bristol Bay Area .

Langdon-Pollock, J. 2004. West coast marine fishing community descriptions. Pacific State Marine Fisheries Commission, Economic Fisheries Information Network, Portland Oregon .

Lauth, R. R. 2011. Results of the 2010 eastern and northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. Report.

Lebida, R. C., and D. C. Whitmore. 1985. Bering Sea Herring Aerial Survey Manual. Alaska Department of Fish and Game, Division of Commercial Fisheries, Bristol Bay Data Report No. 85-2, Anchorage. .

Lee, R. F., W. Hagen, and G. Kattner. 2006. Lipid storage in marine zooplankton. Marine Ecology Progress Series **307**:273–306.

Lew, D. K., and D. M. Larson. 2011. A repeated mixed logit approach to valuing a local sport fishery: the case of Southeast Alaska salmon. Land Economics **87**:712–729.

Lew, D. K., and D. M. Larson. 2012. Economic values for saltwater sport fishing in Alaska: A stated preference analysis. North American journal of fisheries management **32**:745–759.

Lew, D. K., and D. M. Larson. 2015. Stated preferences for size and bag limits of Alaska charter boat anglers. Marine Policy **61**:66–76.

Lew, D. K., and D. M. Larson. 2017. Stated preferences of Alaska resident saltwater anglersfor contemporary regulatory policies. Marine Fisheries Review **79**:12–25.

Little, A. S., C. L. Needle, R. Hilborn, D. S. Holland, and C. T. Marshall. 2015. Realtime spatial management approaches to reduce bycatch and discards: experiences from Europe and the United States. Fish and Fisheries **16**:576–602.

Loring, P. A., and S. C. Gerlach. 2009. Food, culture, and human health in Alaska: an integrative health approach to food security. Environmental Science & Policy **12**:466–478.

Lovell, S., S. Steinback, and J. Hilger. 2013. The Economic Contribution of Marine Angler Expenditures in the United States, 2011. Report.

Lyson, T. A. 2002. What Does a School Mean to a Community? Assessing the Social and Economic Benefits of Schools to Rural Villages in New York .

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, N.J.

Martin, K. S., and M. Hall-Arber. 2008. The missing layer: Geo-technologies, communities, and implications for marine spatial planning. Marine Policy **32**:779–786.

Martinson, E. C., H. H. Stokes, and D. L. Scarnecchia. 2012. Use of juvenile salmon growth and temperature change indices to predict groundfish post age-0 yr class strengths in the Gulf of Alaska and eastern Bering Sea. Fisheries Oceanography **21**:307–319.

McCann, K. S. 2000. The diversity - stability debate. Nature **405**:228–233.

Meyer, S. 2010. Changes Coming for Alaskas Charter Halibut Fishery. Report, Alaska Fish and Wildlife News.

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

Mueter, F. J., and B. A. Megrey. 2006. Maximum productivity estimates for the groundfish complexes of the Gulf of Alaska and Eastern Bering Sea/Aleutian Islands. Fisheries Research **81**:189–201.

Mueter, F. J., and B. L. Norcross. 2002. Spatial and temporal patterns in the demersal fish community on the shelf and upper slope regions of the Gulf of Alaska. Fishery Bulletin **100**:559–581.

Muto, M., V. Helker, R. Angliss, B. Allen, P. Boveng, J. Breiwick, M. Cameron, P. Clapham, S. Dahle, M. Dahlheim, B. Fadely, M. Ferguson, L. Fritz, R. Hobbs, Y. Ivashchenko, A. Kennedy, J. London, S. Mizroch, R. Ream, E. Richmond, K. Shelden, R. Towell, P. Wade, J. Waite, and A. Zerbini. 2016. Alaska marine mammal stock assessments, 2015. Report, U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC-323, 300 p.

NMFS. 2007. Conservation Plan for the eastern Pacific stock of Northern fur seal (*Callorhinus ursinus*). December 2007. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NMFS Protected Resources Division, Alaska Region. 137 pp. `http://www.fakr.noaa.gov/protectedresources/seals/fur/cplan/final1207.pdf` .

Olson, J. 2005. Development in Theory: Re-Placing the Space of Community: A Story of Cultural Politics, Policies, and Fisheries Management. Anthropological Quarterly **78**:247–268.

Oncescu, J. M., and A. Giles. 2014. Rebuilding a sense of community through reconnection: The impact of a rural school's closure on individuals without school-aged children. Journal of Rural and Community Development **9**.

Ortiz, I., F. Weise, and A. Greig. 2012. Marine regions boundary data for the Bering Sea shelf and slope. UCAR/NCAREarth Observing Laboratory/Computing, Data, and Software Facility. Dataset. doi **10**:D6DF6P6C.

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences **104**:15181–15187.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature **421**:37–42.

Paul, A., and J. Paul. 1998. Comparisons of whole body energy content of captive fasting age zero Alaskan Pacific herring (*Clupea pallasi* Valenciennes) and cohorts over-wintering in nature. Journal of Experimental Marine Biology and Ecology **226**:75–86.

Paul, J. M., A. Paul, and W. E. Barber. 1997. Reproductive biology and distribution of the snow crab from the northeastern Chukchi Sea, pages 287–294 . Bethesda, MD.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres. 1998. Fishing down marine food webs. Science **279**:860–863.

Peshkin, A. 1978. Growing Up American; Schooling and the Survival of Community .

Peshkin, A. 1982. The Imperfect Union. School Consolidation & Community Conflict. ERIC.

Petitgas, P. 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES Journal of Marine Science: Journal du Conseil **50**:285–298.

Picou, J. S., D. A. Gill, C. L. Dyer, and E. W. Curry. 1992. Disruption and stress in an Alaskan fishing community: Initial and continuing impacts of the Exxon Valdez oil spill. Industrial Crisis Quarterly **6**:235–257.

Purcell, J. E., and M. N. Arai. 2001. Interactions of pelagic cnidarians and ctenophores with fish: a review. Hydrobiologia **451**:27–44.

Purcell, J. E., R. A. Hoover, and N. T. Schwarck. 2009. Interannual variation of strobilation by the scyphozoan *Aurelia labiata* in relation to polyp density, temperature, salinity, and light conditions in situ. Marine Ecology Progress Series **375**:139–149.

Queirolo, L. E., L. Fritz, P. Livingston, M. Loefflad, D. Colpo, and Y. DeReynier. 1995. Bycatch, utilization, and discards in the commercial groundfish fisheries of the Gulf of Alaska, eastern Bering Sea, and Aleutian Islands. NOAA Technical Memorandum NMFS-AFSC **58**:148.

Rasmussen, R., G. Hovelsrud, and S. Gearheard. 2015. Community Viability. Copenhagen: Nordisk Ministerrd.

Ressler, P., A. De Robertis, and S. Kotwicki. 2014. The spatial distribution of euphausiids and walleye pollock in the eastern Bering Sea does not imply top-down control by predation. Marine Ecology Progress Series **503**:111–122.

Ressler, P. H., A. De Robertis, J. D. Warren, J. N. Smith, and S. Kotwicki. 2012. Developing an acoustic survey of euphausiids to understand trophic interactions in the Bering Sea ecosystem. Deep Sea Research Part II: Topical Studies in Oceanography **6570**:184–195.

Robinson, K. L., J. J. Ruzicka, M. B. Decker, R. Brodeur, F. Hernandez, J. Quiones, E. Acha, S.-i. Uye, H. Mianzan, and W. Graham. 2014. Jellyfish, forage fish, and the worlds major fisheries. Oceanography **27**:104–115.

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

Romberg, W. 2016. Alaska Statewide Sport Fish Harvest Survey, 2016. Report, Alaska Department of Fish and Game.

Rooper, C. N., M. F. Sigler, P. Goddard, P. Malecha, R. Towler, K. Williams, R. Wilborn, and M. Zimmermann. 2016. Validation and improvement of species distribution models for structure-forming invertebrates in the eastern Bering Sea with an independent survey. Marine Ecology Progress Series **551**:117–130.

Ruggerone, G. T., B. A. Agler, B. M. Connors, E. V. Farley Jr, J. R. Irvine, L. I. Wilson, and E. M. Yasumiishi. 2016. Pink and sockeye salmon interactions at sea and their influence on forecast error of Bristol Bay sockeye salmon. NPAFC Bull pages 349–361 .

Ruggerone, G. T., and J. L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (Oncorhynchus gorbuscha) over other salmonids in the North Pacific Ocean. Reviews in Fish Biology and Fisheries **14**:371–390.

Scannell, H. A., A. J. Pershing, M. A. Alexander, A. C. Thomas, and K. E. Mills. 2016. Frequency of marine heatwaves in the North Atlantic and North Pacific since 1950. Geophysical Research Letters **43**:2069–2076.

Schnaittacher, G. M., R. E. Narita, F. Monitoring, G. Schnaittacher, R. Narita, and N. Doc. 2013. Incidental catches of salmonids by US groundfish fisheries in the Bering Sea/Aleutian Islands and the Gulf of Alaska, 1990-2012. NPAFC Doc **1476**.

Sell, R. S., and F. L. Leistritz. 1997. Socioeconomic impacts of school consolidation on host and vacated communities. Community Development **28**:186–205.

Shin, Y.-J., M.-J. Rochet, S. Jennings, J. G. Field, and H. Gislason. 2005. Using size-based indicators to evaluate the ecosystem effects of fishing. ICES Journal of marine Science **62**:384–396.

Shin, Y.-J., L. J. Shannon, A. Bundy, M. Coll, K. Aydin, N. Bez, J. L. Blanchard, M. d. F. Borges, I. Diallo, and E. Diaz. 2010. Using indicators for evaluating, comparing, and communicating the ecological status of exploited marine ecosystems. 2. Setting the scene. ICES Journal of Marine Science **67**:692–716.

Siddon, E., and S. G. Zador. 2017. Ecosystem Considerations 2017 for the Eastern Bering Sea Marine Ecosystem. Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Siddon, E. C., R. A. Heintz, and F. J. Mueter. 2013*a*. Conceptual model of energy allocation in walleye pollock (*Theragra chalcogramma*) from age-0 to age-1 in the southeastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **94**:140–149.

Siddon, E. C., T. Kristiansen, F. J. Mueter, K. K. Holsman, R. A. Heintz, and E. V. Farley. 2013*b*. Spatial Match-Mismatch between Juvenile Fish and Prey Provides a Mechanism for Recruitment Variability across Contrasting Climate Conditions in the Eastern Bering Sea. PLoS ONE **8**:e84526.

Simonsen, K. A., P. H. Ressler, C. N. Rooper, and S. G. Zador. 2016. Spatio-temporal distribution of euphausiids: an important component to understanding ecosystem processes in the Gulf of Alaska and eastern Bering Sea. ICES Journal of Marine Science: Journal du Conseil page fsv272 .

Smith, J. N., P. H. Ressler, and J. D. Warren. 2013. A distorted wave Born approximation target strength model for Bering Sea euphausiids. ICES Journal of Marine Science: Journal du Conseil **70 (1)**:204–214.

Smith, S. L. 1991. Growth, development and distribution of the euphausiids *Thysanoessa raschi* (M. Sars) and *Thysanoessa inermis* (Kryer) in the southeastern Bering Sea. Polar Research **10**:461–478.

Spencer, P. D. 2008. Density-independent and density-dependent factors affecting temporal changes in spatial distributions of eastern Bering Sea flatfish. Fisheries Oceanography **17**:396–410.

Spencer, P. D., K. Holsman, S. G. Zador, N. Bond, F. J. Mueter, A. Hollowed, and J. N. Ianelli. In press. Modeling spatially-dependent predation of eastern Bering Sea walleye pollock and its implications for stock dynamics under future climate scenarios. ICES Journal of Marine Science .

Spencer, P. D., K. K. Holsman, S. Zador, N. A. Bond, F. J. Mueter, A. B. Hollowed, and J. N. Ianelli. 2016. Modelling spatially dependent predation mortality of eastern Bering Sea walleye pollock, and its implications for stock dynamics under future climate scenarios. ICES Journal of Marine Science: Journal du Conseil page fsw040 .

Stabeno, P. J., J. Farley, E. V., N. B. Kachel, S. Moore, C. W. Mordy, J. M. Napp, J. E. Overland, A. I. Pinchuk, and M. F. Sigler. 2012. A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep-Sea Research Part II-Topical Studies in Oceanography **65-70**:14–30.

Stevenson, D., and G. Hoff. 2009. Species identification confidence in the eastern Bering Sea shelf survey (19822008). AFSC Processed Report 2009-04, 46 pp. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv **7600**.

Stevenson, D., K. Weinberg, and R. Lauth. 2016. Estimating confidence in trawl efficiency and catch quantification for the eastern Bering Sea shelf survey. Report, U.S. Dep. Commer.

Stram, D. L., and J. N. Ianelli. 2014. Evaluating the efficacy of salmon bycatch measures using fishery-dependent data. ICES Journal of Marine Science **72**:1173–1180.

Strasburger, W. W., N. Hillgruber, A. I. Pinchuk, and F. J. Mueter. 2014. Feeding ecology of age-0 walleye pollock (Gadus chalcogrammus) and Pacific cod (Gadus macrocephalus) in the southeastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **109**:172–180.

Team, R. D. C. 2016. R: A language and environment for statistical computing. Vienna, Austria.

Thompson, G. 2017. Assessment of the Pacific Cod Stock in the Eastern Bering Sea and Aleutian Islands Area. Report, North Pacific Fishery Mangement Council.

Thompson, G., and R. Lauth. 2012. Assessment of the Pacific Cod Stock in the Eastern Bering Sea and Aleutian Islands Area. Report, North Pacific Fishery Mangement Council.

Thorsen, H. S. 2017. The effect of school consolidation on student achievement .

Thorson, J. T., and K. Kristensen. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fisheries Research **175**:66–74.

Thorson, J. T., M. L. Pinsky, and E. J. Ward. 2016*a*. Model-based inference for estimating shifts in species distribution, area occupied and centre of gravity. Methods in Ecology and Evolution **7**:990–1002.

Thorson, J. T., A. Rindorf, J. Gao, D. H. Hanselman, and H. Winker. 2016*b*. Density-dependent changes in effective area occupied for sea-bottom-associated marine fishes. Proc. R. Soc. B **283**.

Thorson, J. T., A. O. Shelton, E. J. Ward, and H. J. Skaug. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES Journal of Marine Science **72**:1297–1310.

Tojo, N., G. H. Kruse, and F. C. Funk. 2007. Migration dynamics of Pacific herring (Clupea pallasii) and response to spring environmental variability in the southeastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **54**:2832–2848.

Trenberth, K., and J. W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics **9**:303–319.

Turner, B. L., R. E. Kasperson, P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, and M. L. Martello. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences **100**:8074–8079.

Urawa, S., S. Sato, P. A. Crane, B. Agler, R. Josephson, and T. Azumaya. 2009. Stock-specific ocean distribution and migration of chum salmon in the Bering Sea and North Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull **5**:131–146.

Van Handel, E. 1985. Rapid determination of total lipids in mosquitoes. J Am Mosq Control Assoc **1**:302–304.

Vestfals, C. D., L. Ciannelli, J. T. Duffy-Anderson, and C. Ladd. 2014. Effects of seasonal and interannual variability in along-shelf and cross-shelf transport on groundfish recruitment in the eastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **109**:190–203.

Watson, J. T., and A. C. Haynie. 2018. Paths to resilience: the walleye pollock fleet uses multiple fishing strategies to buffer against environmental change in the Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences **75**:1977–1989.

Whittle, J., C. M. Kondzela, H. T. Nguyen, K. Hauch, D. Cuadra, and J. R. Guyon. 2018. Genetic Stock Composition Analysis of Chum Salmon from the Prohibited Species Catch of the 2016 Bering Sea Walleye Pollock Trawl Fishery and Gulf of Alaska Groundfish Fisheries. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Wilderbuer, T., W. Stockhausen, and N. Bond. 2013. Updated analysis of flatfish recruitment response to climate variability and ocean conditions in the Eastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **94**:157–164.

Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. 2002. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography **55**:235–247.

Williams, E. H., and T. J. Quinn. 2000. Pacific herring, (Clupea pallasi), recruitment in the Bering Sea and north-east Pacific Ocean, I: relationships among different populations. Fisheries Oceanography **9**:285–299.

Williams, J. 2006. Alaska Population Overview: 2003-2004 Estimates. The State of Alaska Department of Labor and Workforce Development, Research and Analysis Section, Demographics Unit. Report.

Williams, J. G. 2004. Alaska Population Overview: 2003-2004 Estimates. Report, The State of Alaska Department of Labor and Workforce Development, Research and Analysis Section, Demographics Unit.

Winemiller, K. O. 2005. Life history strategies, population regulation, and implications for fisheries management. Canadian Journal of Fisheries and Aquatic Sciences **62**:872–885.

Witherell, D. 2000. Groundfish of the Bering Sea and Aleutian Islands Area: Species Profiles 2001. Report, North Pacific Fishery Management Council, 605 West 4th Avenue, Suite 306, Anchorage, AK 99501. `http://www.fakr.noaa.gov/npfmc/summary_reports/species2001.pdf`

Witherell, D., and D. Woodby. 2005. Application of marine protected areas for sustainable production and marine biodiversity off Alaska. Marine Fisheries Review **67**:1–28.

Woillez, M., J. Rivoirard, and P. Petitgas. 2009. Notes on survey-based spatial indicators for monitoring fish populations. Aquatic Living Resources **22**:155–164.

Zador, S., K. Aydin, and J. Cope. 2011. Fine-scale analysis of arrowtooth flounder *Atherestes stomias* catch rates reveals spatial trends in abundance. Marine Ecology Progress Series **438**:229–239.

Zador, S., and E. M. Yasumiishi. 2017. Ecosystem Considerations 2017 for the Gulf of Alaska Marine Ecosystem. Report, North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

Zador, S. G., and S. Fitzgerald. 2008. Seabird Attraction to Trawler Discards. Report, Alaska Fisheries Science Center, NOAA, NMFS.