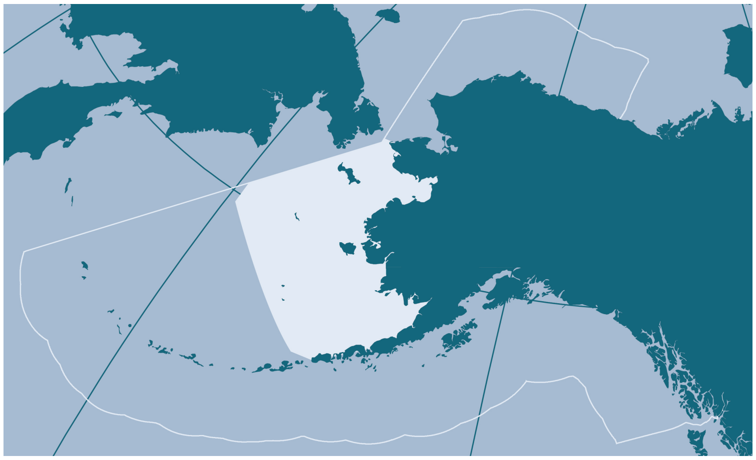
Ecosystem Status Report 2019
Eastern Bering Sea



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Eastern Bering Sea 2019 Report Card

For more information on individual Report Card indicators, please see 'Description of the Report Card indicators' (p. 23). For more information on the methods for plotting the Report Card indicators, please see 'Methods Description for the Report Card Indicators' (p. 222).

- The **North Pacific Index (NPI) was mostly positive during 2018 into early 2019**, resulting in relatively high sea level pressures in the region of the Aleutian low. The NPI turned negative in the spring of 2019; negative NPI commonly accompanies El Niño conditions. Plotted here is the Nov–Mar average showing near-neutral conditions for 2019.
- The mean sea ice extent across the Bering Sea (1 August–31 July; western and eastern) has exhibited no long term trend, though **four of the past five seasons have a mean ice extent lower than any season prior to 2014–2015.** Variability in sea ice extent has increased over the time series, with above-average ice in 2012–2013 followed by a steady decline to below-average ice in recent years. The 2018–2019 daily mean sea ice extent was less than half of the 1981–2010 average and is the second lowest of record (only 2017–2018 was lower). Seasonal sea ice extent has implications, for example, to the cold pool, spring bloom strength and timing, and bottom-up productivity.
- The eastern Bering Sea experienced a **second winter of low sea ice conditions**, which resulted in a reduced cold pool over the northern shelf.
- The acoustic survey that provides estimates of euphausiid density occurs biennially in even years. **Look for an update in 2020**.
- The biomass of motile epifauna sampled during the summer bottom trawl survey remains **above the long-term mean, but is down 10% from 2018**. The decrease is due to brittle stars (-3%) and urchins, sand dollars, and cucumbers (-28%), however, both groups remain well above their long-term means. ***Opilio* crab decreased 43% and Tanner crab decreased 38% from 2018**. Trends in motile epifauna biomass indicate benthic productivity, although individual species and/or taxa may reflect varying time scales of productivity.
- The biomass of benthic foragers **remained low in 2019** (4th lowest in the time series) and is largely due to both Yellowfin sole and Northern rock sole being below their long-term means. Northern rock sole have declined steadily since 2010 and are down 10% from 2018. Trends in benthic forager biomass are variable over the time series and indicate availability of infauna (i.e., prey of these species).
- The biomass of pelagic foragers is up 13% from 2018 but **remains below the long-term mean**. Pollock increased 74% and Jellyfish 164%. Pacific herring decreased 24% but remain above their long-term mean. Pacific sandlance have declined each year since 2015 and are down 43% from 2018. Trends in pelagic forager biomass indicate availability of forage fish (i.e., prey to upper trophic levels) as well as predator abundance within the ecosystem.

- The biomass of fish apex predators is up 2% from 2018 and remains approximately equal to the long-term mean. Pacific cod have decreased each year since 2015 and are well below their long-term mean (down 2% from 2018). **Losses in Pacific cod since 2017 have been partially offset by increases in Arrowtooth flounder which are up 13% from 2018**. Trends in apex predator biomass reflect relative predation pressure on zooplankton and juvenile fishes within the ecosystem.
- The multivariate seabird breeding index increased above the long term mean, indicating that overall, **seabirds bred earlier and had better reproductive success in 2019** in relation to the past few years. However, murre numbers remain low, and least auklets on St. Paul Island experienced their fourth year of poor reproduction, indicating incomplete recovery from the previous three years of poor conditions. Reproductive success and/or early breeding are assumed to be mediated through food supply, therefore above-average values indicate better than average recruitment of year classes that seabirds feed on (e.g., age-0 pollock), or better than average supply of forage fish that commercially-fished species feed on (e.g., capelin eaten by both seabirds and Pacific cod).
- Northern fur seal pup production at St. Paul Island in 2018 was 6.1% less than the 2016 estimate. Pup production has been **declining at St. Paul Island at an annual rate of 4.0%** since 1998. Northern fur seal population decline at St. Paul Island may be attributed to low pup growth rates due, in part, to extended foraging trips required for nursing females to provision pups (see p. 30).
- 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. Fishing gear can affect habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity.

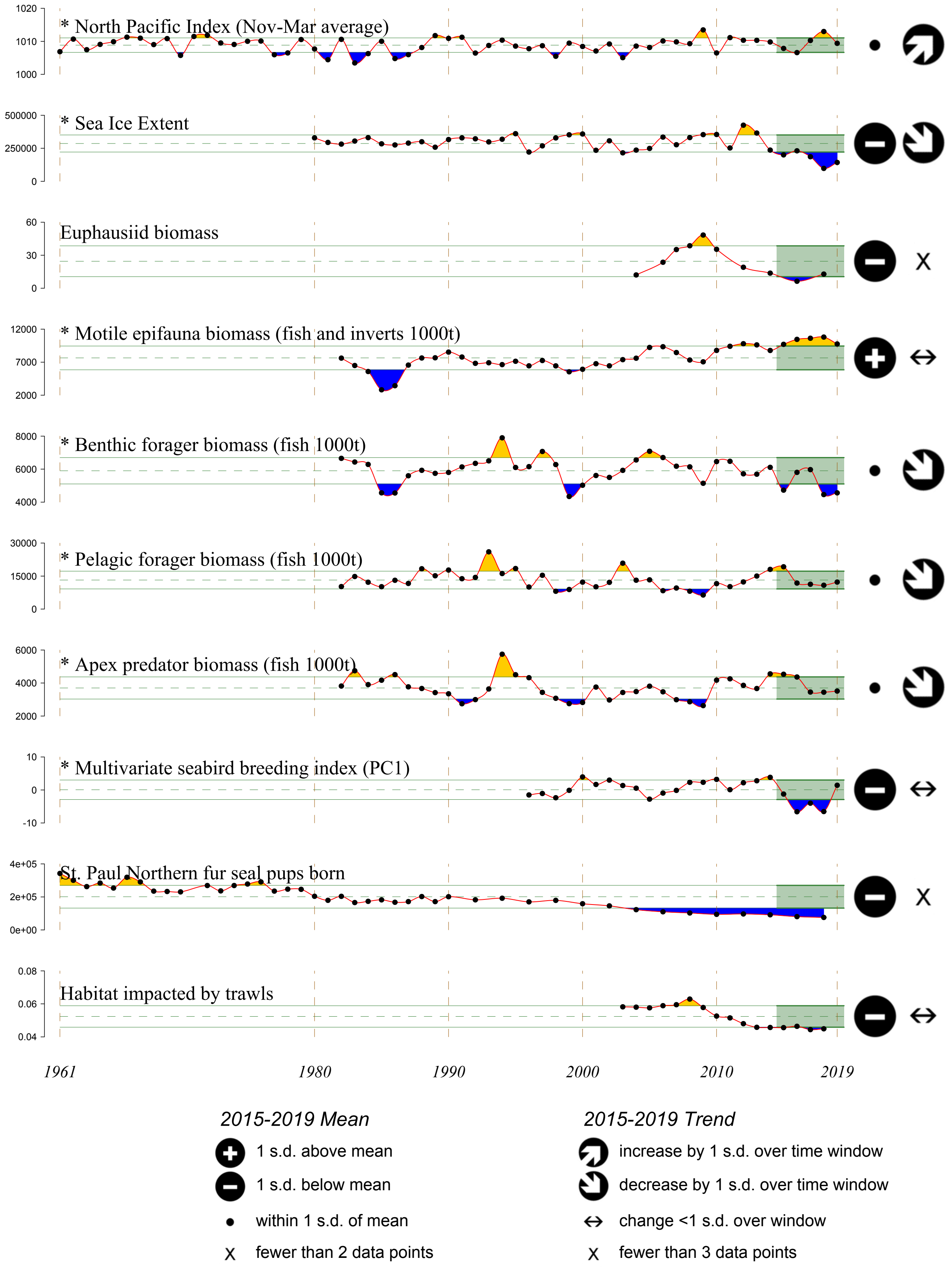

Figure 1: Eastern Bering Sea ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2019.

Executive Summary of Recent Trends in the Eastern Bering Sea

This section provides highlights and links to full contributions contained in this Report. The links are organized within four sections: Noteworthy, Physical and Environmental Trends, Ecosystem Trends, and Fishing and Human Dimensions Trends.

Noteworthy

- In May 2019, elevated numbers of gray whale strandings prompted NOAA to declare an Unusual Mortality Event (UME). From January 1 through October 14, 2019, a total of 213 gray whale strandings were reported with 49 in Alaskan waters (p. 26).
- In spring and summer of 2018 and 2019, 282 ice seal carcasses (primarily young) were reported from the Bering and Chukchi seas prompting NOAA to declare an Unusual Mortality Event (p. 28).
- Northern fur seal population decline at St. Paul Island may be attributed to low pup growth rates due, in part, to extended foraging trips required for nursing females to provision pups (p. 30).

Physical and Environmental Trends

- The Bering Sea experienced a second winter of very reduced sea ice due to (1) residual heat in the Chukchi in fall of 2018 and (2) anomalous winds from the south in February 2019 causing ice retreat (p. 35, 36).
- The development of a weak/moderate El Niño event occurred in 2018 and persisted into 2019, but its future state is highly uncertain. The significantly positive PDO indicates warmer than normal SST along the west coast of North America and cooler than normal in the central and western North Pacific in spring 2019 (p. 40).
- Seasonal projections of SST from the National Multi-Model Ensemble (NMME) indicate continuation of warm conditions across virtually all of the North Pacific for October–December 2019. However, a reduction in magnitude of the positive anomalies is forecast for the southern Bering Sea shelf (p. 41).
- The 2018–2019 daily mean sea ice extent was the second lowest of record (only 2017–2018 was lower) (p. 44).
- The mean daily sea ice extent for the months October 15–December 15 show variability but a strong negative trend over the past 40 years. The mean early season sea ice extent for 2018–2019 was the lowest of record (p. 44).

- The cold pool extent for summer 2019 was reduced and retracted over the northwest portion of the survey area, reflecting low sea ice extent over the shelf during the winter 2018/2019 (p. 46).
- During the early 2000s warm stanza, much of the warmth was driven by conditions in March–May (southern shelf only) and in June–August (southern and northern shelves). The recent warm years have been warmer than average throughout the year (p. 52).
- Summer surface and bottom temperatures over the shelf increased from 2018 and were significantly warmer than the long-term mean. Unprecedentedly warm bottom temperatures occurred over the inner domain (p. 55).
- The 2019 OSCURS springtime drift pattern indicates unfavorable recruitment success for winter-spawning flatfish due to consistent westerly drift during spring (1 April–30 June) (p. 63).

Ecosystem Trends

- The timing of the peak spring bloom in 2019, estimated from satellite data, was earlier (6 May) than the long term average (15 May; 2003–2019) and earlier than 2018 (p. 67).
- Over the southern shelf, Rapid Zooplankton Assessments (RZA) in spring and fall indicated relatively high abundances of small copepods, low abundances of large copepods, and very low abundances of euphausiids. Similarly in the north, the fall RZA indicated small copepods were very abundant while both large copepod and euphausiid catches were low to zero (p. 80).
- The relative CPUE for jellyfishes in 2019 increased by 118% from 2018, the highest concentration observed since 2012 (p. 85).
- The 2019 Bristol Bay salmon inshore run of 56.6 million sockeye is the 4th largest on record since 1963 (p. 99).
- Abundance estimates for juvenile Chinook salmon were below average in 2019; low juvenile abundance increases the probability that bycatch caps will be reduced in the pollock fishery (p. 103).
- Juvenile pink salmon abundance has varied over time, but is generally higher in warmer years (2003–2005; 2015–2019), and has increased with recent warming conditions (p. 106).
- The energy content of age-0 pollock diets was intermediate to low in 2018 (p. 87).
- Groundfish condition, based on length-weight residuals, was positive for all species measured in the southeastern bottom trawl grid in 2019; in the northern extension, Pacific cod and age-1 pollock residuals were positive while adult pollock residuals were negative (p. 108).
- The CEATTLE model estimates of age-1 predation mortality for pollock, Pacific cod, and Arrowtooth flounder continue to decline from the 2016 peak mortality. Pollock is at the long-term mean, while age-1 Pacific cod and Arrowtooth flounder mortality rates remain below the long-term mean (p. 113).
- Commercial crab biomass remained low in 2019 for Pribilof Islands blue king crab, St. Matthew Island blue king crab (although it increased from 2018), Tanner crabs, snow crab (males), and Bristol Bay red king crab. While female snow crab biomass remains above its long term mean, the biomass decreased from 2018 (p. 130).
- In the southeastern Bering Sea (Pribilof Islands) seabirds had relatively good reproductive success compared to recent years, yet a spatially and temporally comprehensive mortality event occurred for short-tailed shearwaters (p. 132).
- In the northern Bering Sea, the breadth of species impacted and temporal duration of seabird mortality events were noteworthy (p. 132). It is important to note that residents of the Bering Strait region remain concerned about seabird mortality events with respect to food security, public health, and conservation issues.

- The mean lifespan of the southeastern Bering Sea demersal fish community in 2019 is 30.2 years, and is the second highest in the time series. This is up from 27.6 years in 2018 and above the long-term mean of 28.2 years (p. 142).
- The mean length of the southeastern Bering Sea demersal fish community in 2019 is 37.2 cm, which is only slightly less than last year's peak value of 37.6cm (p. 143).
- The stability of groundfish biomass within the southeastern Bering Sea demersal fish community increased dramatically in 2019 to the highest of the time series (p. 145).

Fishing and Human Dimensions Trends

- The proportion of Chinook salmon bycatch in the Bering Sea has increasingly originated in British Columbia and the U.S. West Coast from 2011 through 2017 with significant declines in Chinook originating from Coastal Western Alaska. The stock proportions of chum salmon bycatch are variable with Northeast Asia and the Eastern GOA/Pacific Northwest stocks accounting for the majority of bycatch across years (p. 148).
- To date in 2019, groundfish discard biomass across the eastern Bering Sea for trawl sectors appears consistent with 2014–2018. Discard biomass in the fixed gear sector is lower in the southern Bering Sea and higher in the northern Bering Sea relative to 2014–2018 (p. 151).
- The number of seabirds caught incidentally in eastern Bering Sea in 2018 decreased 24% from 2017. Northern fulmars, shearwaters, and gulls were most commonly caught. The number of northern fulmars and shearwaters decreased compared to 2017 while gulls increased. An unusually high number of Laysan albatross were caught in 2018, but no short-tailed or black-footed albatross were caught (p. 156).
- As of June 30, 2019, no BSAI groundfish stock or stock complex is subjected to overfishing, is considered to be overfished, or to be approaching an overfished condition. Saint Matthews Island blue king crab status changed to overfished while snow crab biomass increased to above the B/B_{MSY} threshold (p. 167).
- Landings in the eastern Bering Sea remained stable through 2018. Landings are predominantly from the pelagic forager group dominated by pollock. Trends in the apex predator group are driven by TAC levels in Pacific cod which saw a marginal drop in 2018 (p. 172).
- In 2018 prices for pollock increased. First-wholesale value dipped in the apex predator group as Pacific cod landings decreased and the average price of sablefish declined (p. 174).
- The unemployment rate in eastern Bering Sea communities decreased slightly to 2.9% in 2018. Unemployment rates in this region have been consistently lower than State and national rates and are the second lowest rate within Alaska regions. The unemployment rate in northern Bering Sea communities decreased to 11.8% in 2018, but have been consistently higher than State and national rates (p. 179).
- Between 2010–2018, the population in the southeastern Bering Sea increased 2.7%, which was higher than State trends (0.4%), yet 46% of communities within the region experienced population decline. The population in the northern Bering Sea increased 6.4% with 19.7% of communities experiencing population decline (p. 184).
- In the southeastern Bering Sea, school enrollment for schools under 25 students continues to trend downward consistent with overall decreasing school enrollment in most boroughs. The graduation rate has increased since 2015 from 75.6% to 78.5% in 2018. In the northern Bering Sea, school enrollment is relatively stable with no additional school closures in the last year. Graduation rates are highly variable across districts, but most are well below state graduation averages (p. 194).

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† indicates new contribution
* indicates contribution updated with 2019 data

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Ecosystem Assessment

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Introduction

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 2018 Ecosystem State

Some ecosystem indicators are updated to the current year (2019), 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(s). Below is a complete summary of 2018 that includes information from both previous and current indicators. The next section (Current Conditions: 2019) provides a summary of the 2019 ecosystem state based on indicators updated this year.

With rapidly changing environmental conditions and subsequent changes in sea ice extent in the Bering Sea, NOAA's Alaska Fisheries Science Center has conducted ecosystem and stock assessment surveys in the southeastern and northern Bering Sea to better understand how such changes will impact fish stocks in the region. In this Report, we describe ecosystem responses within the southeastern and northern regions separately, while recognizing that recent reduced sea ice has highlighted the connectivity between them.

The winter of 2017/2018 saw a composite of unusual weather events that resulted in the first unprecedented near-complete lack of sea ice in the northern Bering Sea. 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.

Southeastern Bering Sea
In the southeastern Bering Sea, conditions were typical of a low-ice year with above-average water temperatures and complete lack of a cold pool. Reduced strength of water column stratification meant waters were easily disrupted by storms. Notably, both temperature and salinity below the mixed layer depth were above-average in 2018, which has not been observed previously. A small phytoplankton bloom began May 25 and increased surface dissolved inorganic nitrogen concentrations indicated increased summertime wind mixing events. Higher nutrient stores at the surface generally mean higher production and more energy available for transfer to higher trophic levels. In early spring, small and large copepods were in low abundance, but by late spring small copepod abundances increased to one of the highest levels recorded. Adult euphausiid densities remained low, continuing a trend since 2012. Overall, 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 high, similar to other warm years, but the poor prey base was predicted to result in reduced growth and survival of juvenile fish. The bottom trawl survey indicated Pacific cod and pollock abundances were below their long-term means. Pacific cod abundance was lower, but biomass was higher (fewer, larger fish). 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.

Unusual observations of adult pollock behavior were reported from community members as well as subsistence and commercial fishers in Bristol Bay from May–July 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.).

Samples were sent to NOAA Fisheries and 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.).

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. The decline of northern fur seals is also apparent to Elders, adults, and youth. Subsistence harvests represent the importance of securing seal meat to provide food security for winter (L. Divine, Aleut Community of St. Paul Island).

At the Pribilof Islands, seabird nesting was delayed, and/or unsuccessful and reproduction was poor. 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 2$^{\text{nd}}$ latest hatch date. The Ecosystem Conservation Office (ECO) of the Aleut Community of St. Paul Island reported that St. Paul Island community members noted how 'quiet' the cliffs were in May 2018. Although birds arrived around the usual time of year, they did not engage in typical nest building activities. Residents were unable to collect subsistence murre eggs because there were none on the cliffs during the egging season (June). Least auklets have been declining since 2015; no auklets have been subsistence harvested in the last two years due to declining breeding colonies. 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. 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 (L. Divine, Aleut Community of St. Paul Island).

Northern Bering Sea

2018 marks the lowest ice year on record for the eastern Bering Sea. Bottom temperatures in the northern Bering Sea (NBS) 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 NBS. In 2018, salinity in May was vertically uniform. The lack of salinity structure resulted in weaker vertical stratification, permitting greater vertical mixing.

The near-complete lack of sea ice created an absence of ice algae to 'seed' productivity; the bloom began quite late and stratification was weak. A low proportion of large phytoplankton cells was observed, consistent with indications of low productivity. 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. The low nesting success of thick-billed murres, which eat large zooplankton, provides further evidence that large, lipid-rich zooplankton were in low supply. However, the total energy content of juvenile forage fish species showed positive responses to increased temperature conditions from 2017 to 2018.

Pacific cod and pollock persisted 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 was found in the NBS. With half of the biomass in the northern survey area, stock assessment models for 2019 included NBS data for the first time. In contrast, pollock estimated biomass in the NBS 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.). Gay Sheffield (Alaska Sea Grant Marine Advisory Agent in Nome, Alaska) recounted observations from community members who noted large Pacific cod (1m) caught in crab pots, record returns of pink and silver salmon, and that halibut fishing off Savoonga was 'really great'.

Ice seal distributions were dramatically impacted by the lack of sea ice over the NBS shelf. In 2018, the nearest ice edge over the shelf was about 375km to the northeast of where it was historically found. Ice seals (particularly ribbon seals) were unusually scarce with no evidence that they moved northeast or into Norton Sound following the ice edge. Spotted seal pups weighed less than in recent years, continuing a declining trend in body condition and blubber thickness since 2014. More walrus and bearded seals were seen than typical, likely because the survey was farther north in areas where these species are more prevalent. Large numbers of dead marine mammals were found along the shorelines from north of Bering Strait, throughout Norton Sound, 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 (G. Sheffield, pers. comm.)

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. 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. Thick-billed murres and shearwaters take euphausiids, amphipods, and forage fish while common murres take mostly forage fish. 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. 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.

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 (G. Sheffield, pers. comm.).

Harmful Algal Blooms (HABs)
A 2018 coordinated research effort centered around the Bering Strait Region made progress towards improving baseline understanding of HABs species abundance, distribution, and toxin presence. Research results found no positive toxicity or significant HAB cell counts south of the strait in the NBS (June-September), however high concentrations of HABs cells (*Alexandrium* spp.) were found in the Chukchi Sea in June and August.

Current Conditions: 2019

The eastern Bering Sea experienced the second year with little winter sea ice (winter 2018/2019) and reduced cold pool extent (summer 2019), prompting the expression of a 'double whammy' for ecosystem impacts. The observed effects in 2019 are discussed below in terms of (i) reflecting 2018 conditions, (ii) reflecting 2019 conditions, and (iii) reflecting cumulative impacts of continued warm conditions from 2018 to 2019.

Reflective of 2018 conditions:
Ecosystem responses that may reflect 2018 conditions include the gray whale Unusual Mortality Event (UME) and the short-tailed shearwater die-off event. Lagged (delayed) impacts of poor feeding conditions experienced during 2018 are hypothesized to at least partially explain the mortality events. Both species feed in the Bering Sea during summer; gray whales are benthic feeders (e.g., amphipods) while shearwaters are planktivorous (e.g., euphausiids). Both species embark on long migrations to the southern hemisphere for breeding during the austral summer. Therefore, the 2019 mortality events may reflect 2018 feeding conditions in the Bering Sea, conditions experienced during the breeding season in the southern hemisphere, or lack of available prey to complete the migration to the Bering Sea in 2019.

Reflective of 2019 conditions:
It is important to remember that the 2018/2019 winter sea ice accumulation differed from winter 2017/2018. While residual heat delayed freeze up until mid-December (similar to 2017/2018), accumulation approached the long-term mean sea ice extent through January 2019 (whereas 2018 sea ice never approached normal levels) before southerly winds persisted during February and reduced sea ice (similar timing between years). The impact and subsequent ecosystem effects of early sea ice are not fully understood, although it is hypothesized the small, retracted cold pool (i.e., thermal barrier) may have contributed to the increased biomass of pollock over the southern shelf in 2019.

The timing of the peak spring bloom in 2019, estimated from satellite data, was earlier than the long term average (by approximately 9 days) and earlier than 2018. The spring bloom fuels secondary production of the zooplankton prey community that forms the base of energy transfer for upper trophic levels (e.g., fish, seabirds, mammals). In 2019, the zooplankton community was dominated by small copepods, which is typical of warm-year conditions over the shelf, while large copepod and euphausiid abundance was low. Warm temperatures increase copepod secondary production rates; combined with an earlier bloom, this may have resulted in sustained production and energy transfer into summer 2019. However, larger, lipid-rich copepods and euphausiids remained low across the shelf and could affect energy storage and survival of juvenile fish within the region. Jellyfish, which are pelagic consumers of zooplankton and small fishes, showed a sharp increase in abundance in 2019 relative to 2018 and their long-term mean.

At the Pribilof Islands, reproductive success of several seabird species improved in 2019, indicating that birds were able to find sufficient food resources to support reproductive efforts during 2019. Successful breeding events occurred for fish-eating species (i.e., murres at St. George and red-faced cormorants at St. Paul) and plankton-eating species (both species of kittiwakes at both islands). Feeding conditions and prey availability in the environment were sufficient to support reproduction, but oceanographic surveys showed the zooplankton community dominated by small copepods. Several possible explanations include: (i) seabirds may have been successful at finding lipid-rich copepods and euphausiids, even though abundances were low; (ii) competition for available prey was reduced as a result of shearwater mortalities and/or poor recruitment events for fish species; and/or (iii) colonies at the Pribilof Islands may have benefited from northward shifts in fish populations. Evidence supporting these hypotheses include the below-average coccolithophore bloom index for 2019 and the high abundance of age-0 pollock collected in the northern Bering Sea surface trawl survey.

Unprecedented warmth in the inner domain during summer 2019 likely resulted in increased metabolic demands and may have impacted fish distributions. For example, the increased warmth may have pushed Pacific cod away from warm inshore waters and made them more available to the bottom trawl survey, contributing to the large increase in abundance of young fish in 2019. In Bristol Bay, sockeye salmon returns remained high. The large inshore run in 2019 suggests these stocks experienced positive conditions at entry into the eastern Bering Sea in the summers of 2016 and 2017, and winters of 2016/2017 and 2017/2018.

Reflective of cumulative impacts:
Adult groundfish condition increased in 2019 relative to 2018 and was positive for several key species sampled during the standard bottom trawl survey. Large increases were shown for adult pollock, Yellowfin sole, and Arrowtooth flounder, suggesting a possible shift to a benthic-dominated system. Arrowtooth flounder biomass continued an increasing trend since 2017. Groundfish condition reflects ecosystem productivity, especially when viewed across stocks, and population dynamics within a stock.

The 2018 pollock year class showed strong overwinter survival to age-1. However, several mechanistic relationships based on bottom-up pathways predicted below-average recruitment success for the 2018 year class (see Forecasts and Predictions below). The occurrence of strong recruitment in light of low sea ice, above-average water temperatures, and poor prey quality/quantity challenges our current understanding of recruitment processes for pollock. One hypothesis stems from the anomalous February winds from the southwest. Winds brought warm, moist air from the south over the shelf, but may have also increased on-shelf flow and upwelling conditions. Upwelling of productivity during winter may have subsidized energy transfer and contributed to increased survival of age-0 pollock. In combination with greater overwinter survival, the 2018 year class may have experienced reduced predation pressure from cannibalism because recruitment of recent year classes has been low. Pollock age-1 natural mortality peaked in 2016, but has declined in recent years and the 2019 estimate was at the long-term mean, also demonstrating reduced predation pressure for the 2018 year class. That said, the bottom trawl survey results showed a 75% increase in pollock biomass over the southern shelf from 2018 to 2019, which suggests that adult fish moved into the region (recruitment of small fish could not account for such a large increase in biomass). Therefore, the 2019 year class may experience increased predation pressure from cannibalism (from the 2018 and older age classes).

The declaration of an Unusual Mortality Event for ice seals reflects cumulative impacts of conditions in 2018 and 2019. The increased mortality of seals and the apparent decline in pup condition demonstrate immediate and delayed impacts of the loss of sea ice habitat for pupping and nursing in both years. They could also demonstrate broader ecosystem effects, such as competition for prey from northward shifts of fish populations. At the Pribilof Islands, community members reported unusually high numbers of male fur seals overwintering at St. Paul (i.e., they never left from the 2018 season), reflective of the continuous warmth throughout the year.

Forecasts and Predictions

9-month Ecosystem Forecast for the Eastern Bering Sea:
Since 2013, AFSC and PMEL have produced 9-month ahead forecasts of the eastern Bering Sea cold pool extent that have contributed to the ecosystem assessment. During re-forecasting experiments, and in light of the anomalous conditions of 2018 and 2019, it was determined that the previously-used method of a single ROMS model run is limited in its ability to forecast; in particular, there is a strong "predictability barrier" in January–March that limits the model's ability to forecast conditions past this window. A multi-model ensemble forecast method is currently in development to address this uncertainty for future ecosystem assessments.

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. 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 under changing thermal conditions.

Below we track available predictions for the 2018 year class of pollock:

- The Temperature Change index (p. 118) predicts **above average recruitment** to age-4 from the 2018 year class. The 2018 cohort experienced a cool summer during the age-0 life stage followed by a relatively warm spring during the age-1 period.
- Surface silicate concentrations (an indicator of nutrient availability in surface waters; p. 120) were well above average in 2018, yet age-0 pollock weights were below average, suggesting **below average recruitment** to age-1.
- Diet energy density was low to intermediate for 2018, suggesting **below average recruitment** to age-1. It is worth noting, however, that euphausiids comprised over 50% of age-0 pollock diet (p. 87).
- The energy density of age-0 pollock during late summer 2018 was low and would predict **below average recruitment** to age-1.

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).

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 (i.e., Bering Sea shelf).

Implications: to the Bering Sea are that 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.

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2. Bering Sea ice extent: The Bering Sea ice year is defined as 1 August–31 July. Bering Sea ice extent data is from the National Snow and Ice Center's Sea Ice Index, version 3 (Fetterer et al., 2017), and uses the Sea Ice Index definition of the Bering Sea, effectively south of the line from Cape Prince of Wales to East Cape, Russia. The daily mean annual ice extent integrates the full ice season into a single value. *Implications:* Seasonal sea ice coverage impacts, for example, the extent of the cold pool, bloom strength and timing, and bottom-up productivity.

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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 from acoustic data collected during the biennial eastern Bering Sea summer acoustic-trawl survey. *Implications:* Euphausiids are food for many species of both ecological and commercial importance in the eastern Bering Sea, including walleye pollock.

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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 1977–2019. Eastern Bering Sea biomass trends are summed stock assessment model estimates or scaled survey data (from the eastern Bering Sea summer bottom trawl survey), 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 taken directly 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 summer bottom trawl survey data (for more information, see p.128 and 130). 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 *P. 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. *Implications:* Trends in the biomass of motile epifauna indicate benthic productivity, although individual species and/or taxa may reflect shorter or longer time scales of integrated productivity.

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. *Implications:* Trends in the biomass of benthic foragers indicate availability of infauna (i.e., prey of these species).

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 Sandlance, 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. *Implications:* Trends in the biomass of pelagic foragers largely track Walleye pollock which is an important component of the Bering Sea ecosystem, both as forage and as a predator.

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 summer bottom trawl survey. *Implications:* Trends in the biomass of apex predators indicate relative predation pressure on zooplankton and juvenile fishes within the ecosystem.

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. *Implications:* Above-average index values reflect high reproductive success and/or early breeding (assumed to be mediated through food supply) and indicate better than average recruitment of year classes that seabirds feed on (e.g., age-0 pollock), or better than average supply of forage fish that commercially-fished species feed on (e.g.,capelin eaten by both seabirds and Pacific cod).

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9. St. Paul Northern fur seal pup production: Pup production on St. Paul Island 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 Island 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. *Implications:* Pup production reflects foraging conditions over the eastern Bering Sea shelf with above-average values indicating good foraging conditions.

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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. 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; disturbance is assumed cumulative over the year, therefore the December value is plotted here. Further detail on this index is reported on p. 162. *Implications:* An estimate of the area of seafloor disturbed by trawl gear provides an indication of habitat disturbance.

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Noteworthy (formerly Hot Topics)

Here we present items that are new or noteworthy and of potential interest to fisheries managers.

Unusual Mortality Event: Gray Whales

Since January of 2019, elevated numbers of eastern North Pacific gray whale (*Eschrichtius robustus*) mortalities have occurred along the west coast of North America, stretching from Mexico to Alaska. In May of 2019, the increased strandings were declared an Unusual Mortality Event (UME) (Table 2, Figure 2).

Table 2: Total number of gray whale strandings by location from 1 January–30 October, 2019.

Location	Number by Country	Number by US State
Canada	10	
US Total	122	
(Alaska)		(48)
(Washington)		(34)
(Oregon)		(6)
(California)		(34)
Mexico	81	
Total	213	

Gray whale life history includes an annual round-trip migration of up to 20,000 km. The mortalities started off the western coast of southern Baja California Peninsula where gray whales over-winter to mate and calve. Mortalities followed the late winter/spring migration up to Alaskan waters where foraging occurs before the fasting return journey south. The first Alaskan gray whale stranding occurred on 9 May in Turnagain Arm of Cook Inlet. Mortalities have continued throughout the summer with hotspots around Kodiak Island, Bristol Bay, and coastal waters of the Bering Strait and Chukchi Sea (Figure 3).

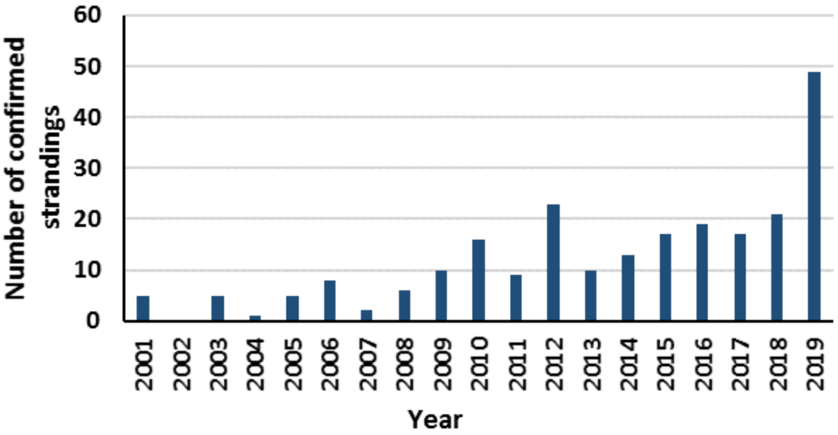


Figure 2: Number of gray whale strandings in Alaska by year, 2001–2019 (2019 numbers through 30 October).

As part of the UME investigation process, NOAA has assembled an independent team of scientists to coordinate with the Working Group on Marine Mammal Unusual Mortality Events to review the data collected, sample stranded whales, and determine the next steps for the investigation. Full or partial necropsy examinations were conducted on a subset of the whales. Preliminary findings in several of the whales have shown evidence of emaciation; however, these findings are not consistent across all of the whales examined. Furthermore, while benthic prey (primarily ampelecid amphipods) in the Bering, Chukchi, and Beaufort Seas are considered the mainstay of gray whale foraging, there is also significant variability in foraging behavior depending on the location, season, year, and subset of whales (Moore et al., 2007; Calambokidis, 2013).

The eastern North Pacific gray whale is considered something of an "ecosystem sentinel" for the North Pacific and western arctic ecosystems. Correlations between changes in the distribution and behavior of gray whales and environmental change in these regions indicates the species may be effective sentinels (Moore, 2008).

A gray whale UME also occurred along the West Coast from Mexico to Alaska in 1999/2000. Although no definite conclusion was reached, the most likely precipitating factor was considered malnutrition, possibly associated with a decrease in the quantity and quality of prey items or the numbers of gray whales overwhelming the prey base as the population reached carrying capacity.

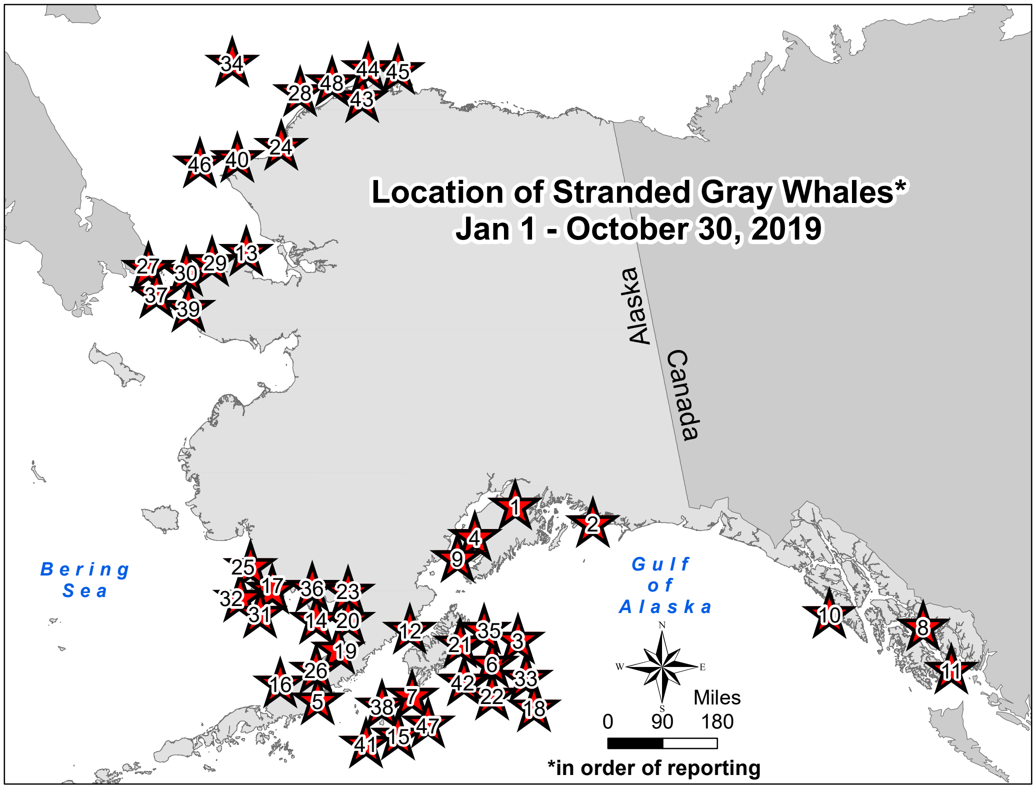


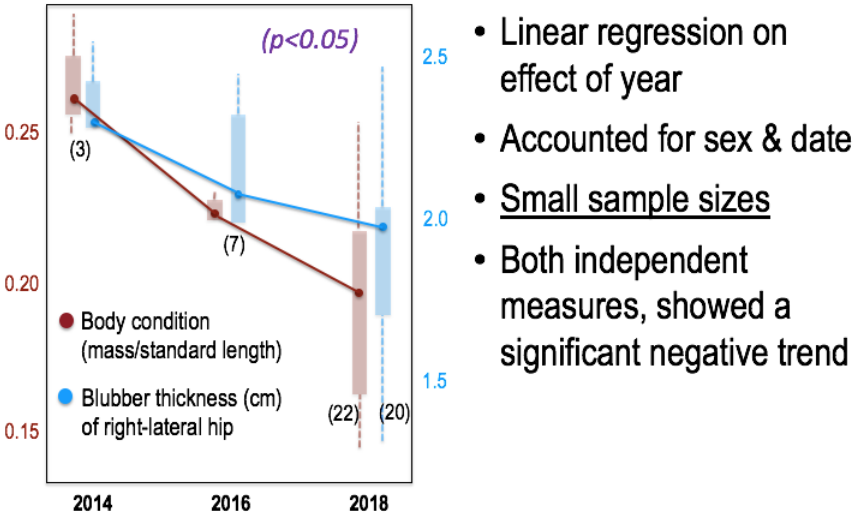
Figure 3: Locations of gray whale strandings in Alaska (NOAA/NMFS Alaska Region Marine Mammal Stranding Network unpublished data).

Contributed by Kate Savage, DVM
NOAA Fisheries
Protected Resources Division

Unusual Mortality Event: Ice Seals

In April, the ice-covered areas of the Bering Sea are crucial reproductive grounds for populations of bearded, ringed, spotted, and ribbon seals that collectively number more than 1 million individuals. But in 2018 and 2019, the April sea ice in the Bering Sea was a small fraction of its typical extent. A NOAA cruise in 2018 found no ribbon or spotted seals in their preferred breeding areas. The nearest sea ice was hundreds of miles to the north, and areas of ice visited by the vessel did not seem to have seal densities high enough to indicate that the breeders had simply relocated to the north. The possibility of major reproductive failures in at least those two species in U.S. waters cannot be ruled out.

Two measures of body condition in spotted seal pups suggested that condition had declined over the period 2014–2018, though the sample sizes are small (Figure 4).



- Linear regression on effect of year
- Accounted for sex & date
- Small sample sizes
- Both independent measures, showed a significant negative trend

Figure 4: Condition of spotted seal pups (April–early May).

In spring and summer of 2018 and 2019, 282 bearded, ringed, spotted, and unidentified seal carcasses (primarily young) were reported from beaches of the Bering and Chukchi seas (Figure 5). Many of the seals appeared to have been emaciated at the time of death.

The numbers of stranded seals were roughly 5–7 times the annual average from 2000–2017, prompting NOAA to declare an unusual mortality event (UME) (Figure 6). Samples were collected from some of the carcasses and analyses are underway to investigate plausible causes of the mortality.

The increased mortality of seals indicated by the strandings in 2018–2019 and the apparent decline in condition of spotted seal pups are, at face value, consistent with the dramatic losses of sea ice habitat for pupping and nursing in both years. However, they could also involve follow-on ecosystem effects such as competition for prey from northward shifts in distribution of large fish predators.

Contributed by Peter Boveng
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Marine Mammal Laboratory

Figure 5: Map of locations of reported ice seal carcasses in 2018 and 2019.

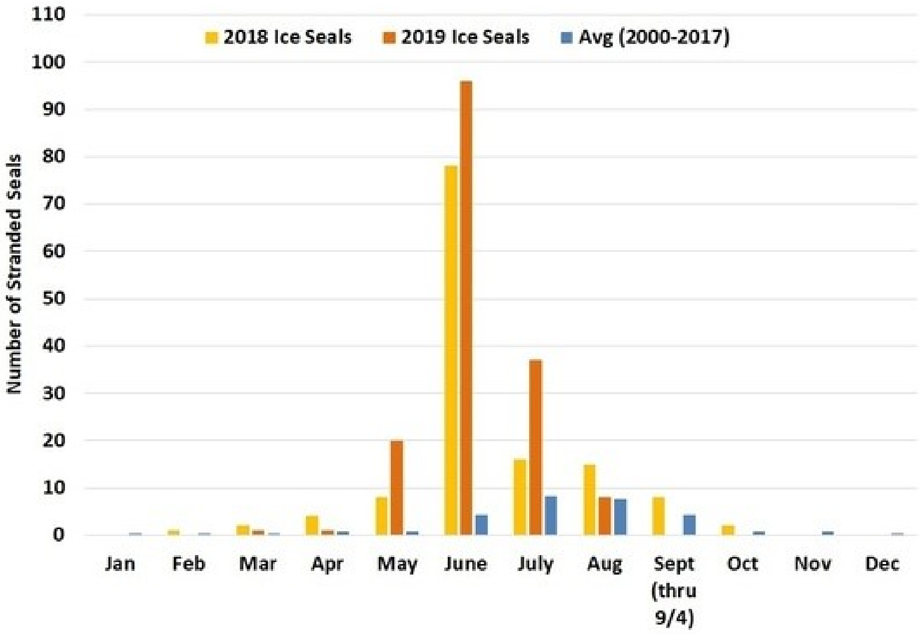

Figure 6: Ice seal strandings by month.

Contrasting Trends in Northern Fur Seal Foraging Effort Between St. Paul and Bogoslof Islands: 2019 Preliminary Results

The Eastern Stock of northern fur seals (*Callorhinus ursinus*), which is comprised of three breeding islands (St. Paul [SP], St. George [SG], and Bogoslof [BG] islands), is listed as depleted under the Marine Mammal Protection Act. Since 1998, pup production on the Pribilof Islands (SP and SG) has declined by 51% or at an annual rate of 3.4% (Towell et al., 2019). In contrast, pup production on BG has increased at an annual rate of 10% since 1997 (Towell et al., 2019). While the ultimate cause(s) of the Pribilof Islands fur seal decline have yet to be identified, low pup growth rates on SP appear to be a key distinction compared to the healthy population and high pup growth rates on BG. The large differences in growth rates between SP and BG are primarily attributed to disparity between the islands in the provisioning cycle of females.

On BG, nursing females make short duration foraging trips and spend a higher proportion of their time on shore provisioning their pup, which results in greater growth rates. Females from SP make extended foraging trips and compensate by spending longer periods on shore but are unable to make up for pup mass loss during these longer trips (Springer et al. (2010), Figure 7).

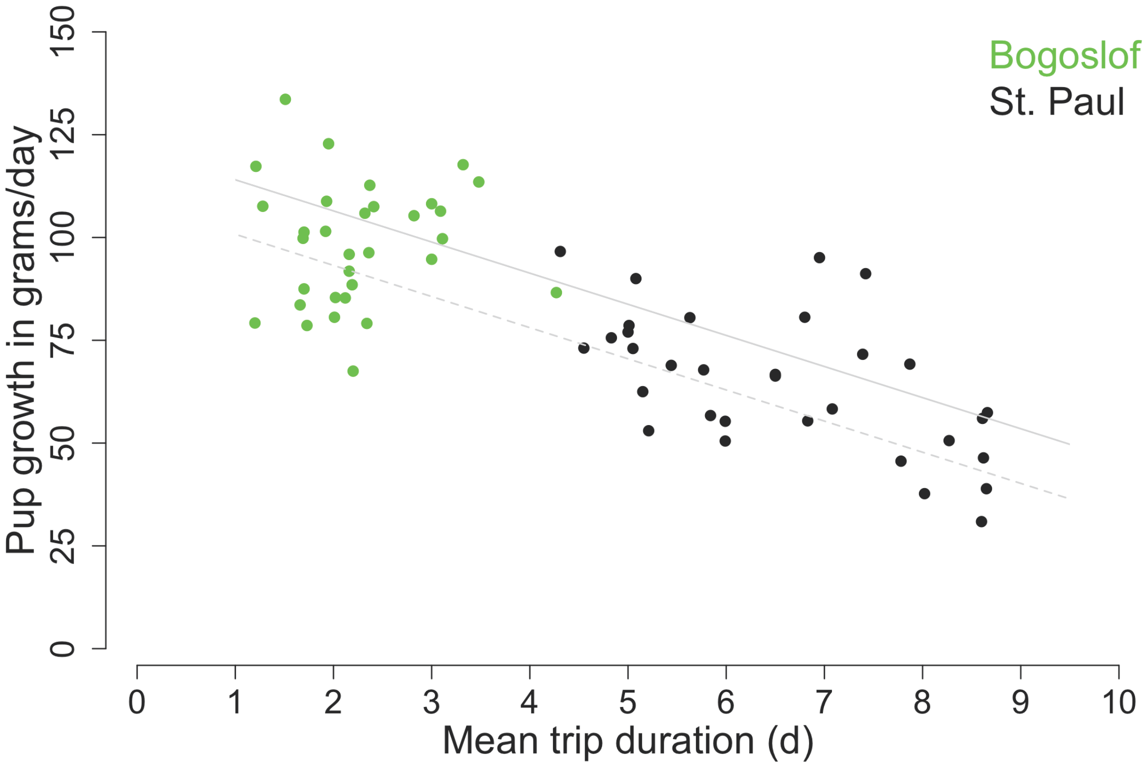

Figure 7: Mean foraging trip durations of lactating northern fur seals tracked from Bogoslof (green) and St. Paul (black) islands during the summer lactation period (2005 and 2006) in relation to daily growth rate for male (solid line) and female (dashed line) pups (data from Springer et al. (2010)).

Researchers at the Alaska Fisheries Science Center Marine Mammal Laboratory (MML) are currently conducting research examining foraging effort for northern fur seals from SP and BG. In August 2019, adult females from each island were equipped with satellite-linked dive recorders to measure foraging trip durations, foraging locations, and dive depth distributions. Preliminary data show that the contrasting trend in foraging effort between SP and BG continues. Average foraging trip duration of fur seals from SP is 7.8±10.4 (SE) days (individual range: 6.5–10.1 days, N=9), whereas trips are significantly shorter (average: 3.9±10.4 days) for fur seals on BG (individual range: 2.9–5.5 days, N=6). The trip durations measured on BG have increased compared to previous years (2011: 3.1±10.2 days), consistent with the hypothesis that fur seals from this population are experiencing localized resource depletion as this population continues to expand (Kuhn et al., 2014). Final data on foraging trip durations will be available after the tracking instruments are recovered (SP, late September) or when instruments stop transmitting (BG).

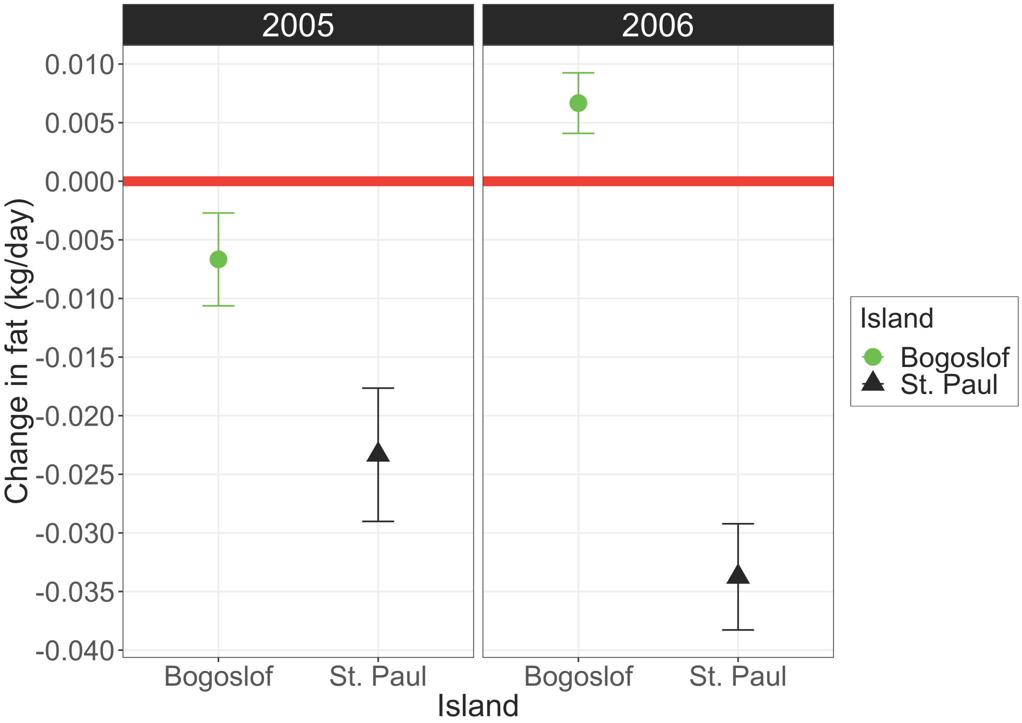

Figure 8: Change in fat mass (±SE) over the lactation period for northern fur seals from Bogoslof (green) and St. Paul (black) islands in 2005 and 2006. Red line denotes no change (data from Springer et al. (2010)).

In conjunction with these ongoing field efforts, a collaborative effort between researchers at the Joint Institute for the Study of the Atmosphere and Ocean (University of Washington), Lenfest Ocean Program, and MML was initiated in 2018 to examine the energetic expenditure of lactating females and the consequences of variation in maternal foraging behavior. This effort involved a retrospective analysis of an existing dataset from 1995 and 1996 on the field metabolic rates of lactating females from the Pribilof Islands, as well as the development of a bioenergetic model to estimate the current energy intake and prey consumption of the fur seal population from the Pribilof Islands. The results of this work have revealed several key findings that provide insights into the apparent links between trip durations and pup growth rates. First, lactating females from the Pribilof Islands appear to have reached a metabolic ceiling, meaning that they are working hard to find food and have very limited flexibility to adjust to changes in prey resources without extending trip durations. Second, the output from the bioenergetic model indicates that lactating females currently consume roughly 26–27% of their body mass per foraging day at sea, a number that is surprisingly similar to a study conducted in the 1970s (Perez and Bigg, 1986). Walleye pollock comprised an average of 42–80% of the total prey biomass consumed in years encompassing 1995–2010, with considerable interannual variation in size-specific consumption. Specifically, consumption of adult pollock generally increased in years when young pollock (age-0 and age-1) were less abundant.

The continued disparities in trip duration between SP and BG in 2019, similar to observations from the mid-2000s (Figure 7), suggest that inter-island differences in pup growth rates are also likely to be present. These findings are relevant given that lower pup growth rates result in a lower mass at weaning, which is likely to lead to a lower probability of survival. The results from the bioenergetics studies suggest that high maternal overhead, as a result of high metabolic rates and long trip durations, is likely reducing the amount of energy available for lactation. This provides an explanation not only for the reduced pup growth rates observed for the Pribilof Islands but also for the inability of females at these islands to gain fat mass across the lactation period (Springer et al. (2010), Figure 8).

Collectively, the results of the foraging effort and bioenergetics studies suggest that lactating females on SP are having difficulty finding food in close proximity to the rookery, which could adversely affect pup growth rates and contribute to the ongoing population decline on St. Paul Island.

Contributed by Carey Kuhn, Jeremy Sterling (NOAA/AFSC/MML),
and Elizabeth McHuron (JISAO, University of Washington)

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). The 2017 ESR identified the LEO Network as a potential platform for tracking these observations 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 and do not provide sufficient breadth to cover the myriad of anomalous environmental observations relevant to the Council. While the LEO Network also suffers from this issue, it still appears to be the citizen science database with the most coverage across species and regions of the state.

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[1]. 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 9).

Figure 10 shows LEO Network observations from 2 August, 2018 to 14 August, 2019 in the northern Bering Sea (NBS) LME with the frequency by category (dates were specified to occlude observations that were part of the ESR in 2018). These categories are based on analysis of the 76 total observations in 2018 and 2019 (for the dates specified above) in the NBS and are not limited to the marine environment. The observations in Figure 10 were made in 29 total communities. Of particular note for northern Bering Sea communities over the last year was the impact of extreme weather events, inclusive of thunderstorms, smoke, and high seasonal temperatures. The latter was noted as delaying ice formation along rivers and coasts, inhibiting normal travel and subsistence hunting and fishing patterns, and leading to deaths in multiple cases when snow machines and four wheelers fell through thin ice.

Similarly to Figure 10, Figure 11 shows LEO Network observations from 2 August, 2018 to 14 August, 2019 in the eastern Bering Sea (EBS) LME with the frequency counts by category. There were 14 total observations in 12 communities over this time period in the EBS.

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[1] `https://www.leonetwork.org/en/docs/about/about`

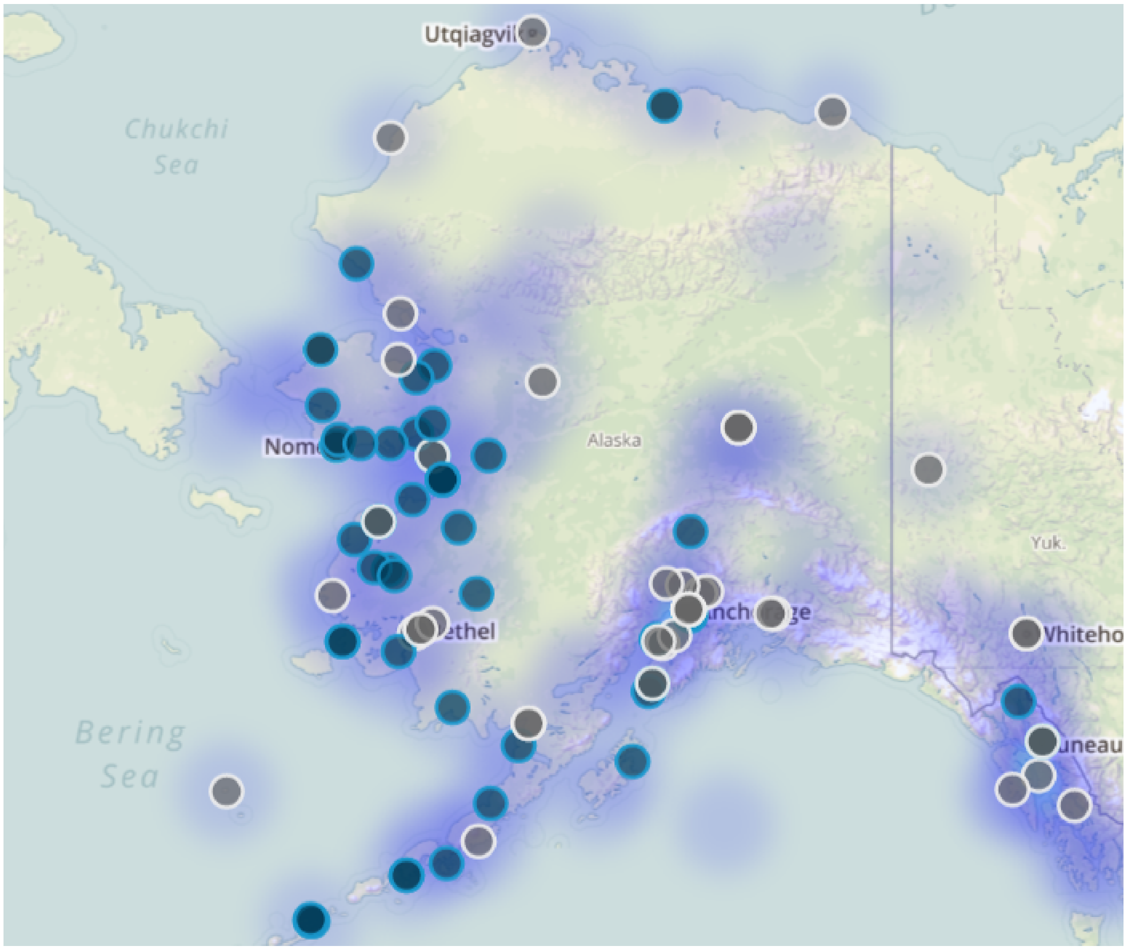

Figure 9: LEO Network observations in Alaska for 2018 and 2019 (August to August). Colors distinguish the source of the observation: gray are from public media (e.g., radio, newspaper) and blue are citizen observations.

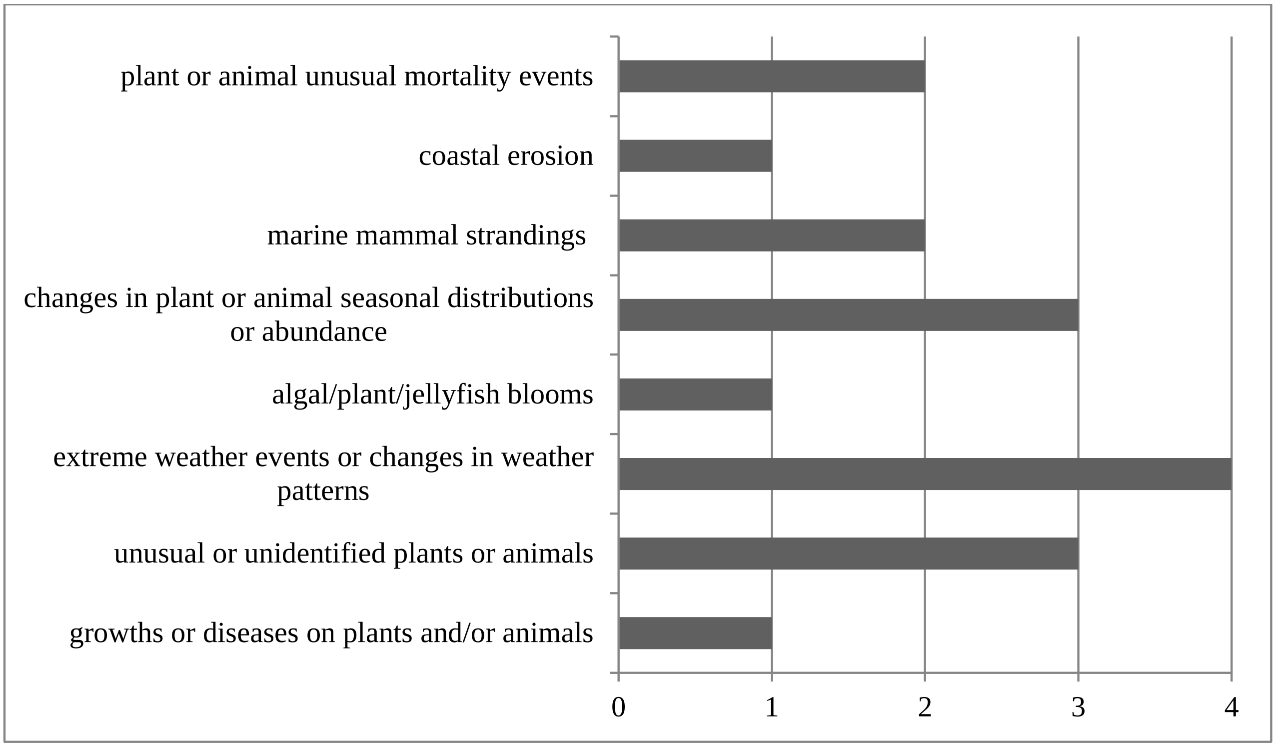

Figure 10: Number of LEO Network observations (counts) in 2018 and 2019 (August through August) by category in northern Bering Sea communities.

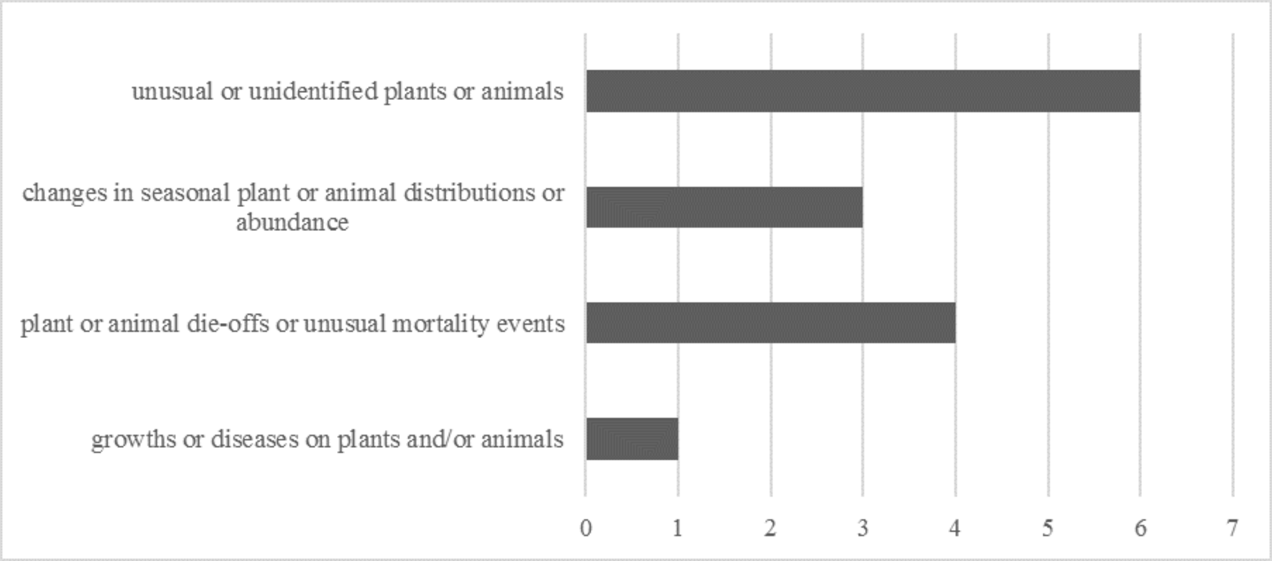

Figure 11: Number of LEO Network observations (counts) in 2018 and 2019 (August through August) by category in eastern Bering Sea communities.

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

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Last updated: August 2019

Summary: *The period of autumn 2018 through summer 2019 included a range of atmospheric circulation patterns and generally warmer than normal temperatures for the North Pacific. The winter of 2018–2019 featured a weak Aleutian low (positive sea level pressure anomalies), which is unusual given the weak-moderate El Niño that was occurring at the same time. The sea surface temperature (SST) anomalies during 2018–2019 tended to be in the positive sense, with prominent warm anomalies in the Bering Sea, Gulf of Alaska, and by summer 2019, off the coast of the Pacific Northwest. The Pacific Decadal Oscillation (PDO) underwent a transition from near zero during autumn 2018 to +1 in the summer of 2019. The climate models used for seasonal weather predictions are indicating a 50–55% chance of neutral conditions in the equatorial Pacific, and a 30% chance of a weak-moderate El Niño, for the winter of 2019–2020. The consensus of the model projections is for a reduction in the magnitude of the SST anomalies in the middle to high latitudes of North Pacific by early 2020.*

Regional Highlights:

Alaska Peninsula and Aleutian Islands. The weather of this region featured a tendency for a westward shift in the Pacific storm track into the western Bering Sea during the winter of 2018–2019. The regional wind anomalies were from the south in an overall sense. Based on synthetic data from NOAA's Global Ocean Data Assimilation System (GODAS), the Alaska Stream appears to have been of typical strength on the south side of the eastern Aleutian Islands. It was generally stronger than that during the previous year of 2017–2018, but not as strong as indicated in 2015–2016. Based on the winds in the vicinity of Unimak Pass, it is assumed that the mass transport of Pacific water into the Bering Sea was of near-normal magnitude in 2018–2019.

Bering Sea. The Bering Sea had another year of very light sea ice. This can be partly attributed to a delayed start of winter due to the Chukchi being so warm in the fall of 2018. The winter of 2018–2019 was warm in the overall sense. A notable exception was a period of cold and northerly winds in late December. It was particularly warm, with anomalous winds from the south in February 2019, during which there was a retreat, rather than the usual southward advance, of ice on the eastern Bering Sea shelf that occurs at that time of year. An important consequence was a cold pool in summer 2019 that was the second smallest on record (2018 represents the historical minimum) with only a tiny area of the region surveyed having bottom temperatures less than 0°C. The weather during summer 2019 was less stormy than usual on the southeast Bering Sea shelf; at the time of this writing it is unknown if suppressed wind mixing helped produce the coccolithophore bloom that has been observed (see p. 77). In the region of the M2 mooring the vertically integrated heat content during the summer of 2019 was the second greatest on record, topped only by 2016.

Arctic. The winter of 2018–2019 was relatively warm in the Arctic, especially in the Barents Sea and north of the Canadian Archipelago. Especially for the latter region, these conditions strengthened during spring 2019. The Arctic's maximum ice extent in mid-March 2019 was the 7th lowest on record but the melt was unusually rapid, with the ice coverage on 1 April 2019 being the least for that date in the last 40 years. The summer of 2019 has been marked by anomalously high SLP over the central Arctic. This atmospheric circulation pattern tends to be accompanied by reduced cloud cover and greater insulation than normal for the central Arctic, and probably accounts for the development of very low ice coverage and ice volume. At the time of this writing, it appears that the minimum ice extent for the Arctic as a whole in 2019 will be well below climatological norms, but slightly more than the extreme minimum ice cover year of 2012. The band of open water along the shore of the Beaufort Sea was very wide during summer of 2019, compared with recent years.

Sea Surface Temperature and Sea Level Pressure Anomalies

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Last updated: September 2019

Description of indices: The state of the North Pacific climate from autumn 2018 through summer 2019 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)[2].

Status and trends: The eastern portion of the North Pacific ocean experienced during 2014–2016 one of the most extreme marine heat waves in the observational record (Scannell et al., 2016). While that event can be considered to have ended, most of the northern portions of the Pacific Ocean have tended to remain warm relative to their 1981–2010 climatological norms. 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 2018 (Figure 12a) was warmer than normal across almost the entire Pacific Ocean north of 35°N. Greater positive ($> 1^\circ$C) anomalies occurred in the Chukchi Sea and in the northern Bering Sea, resulting in a delayed onset of sea ice the following winter. Prominent positive SST anomalies were also observed in the central Gulf of Alaska (GOA). The SST anomalies were positive in the eastern equatorial Pacific in association with a weak Niño. The SLP pattern during autumn 2018 (Figure 13a) featured large positive anomalies over western Canada, with the ridging extending westward into the GOA. Lower than normal SLP was present over the central North Pacific with an anomaly center near 40°N and the dateline. This SLP distribution implies suppressed storminess for the GOA and helps explain the development of the relatively warm SSTs in that region.

The distribution of SST anomalies during winter (Dec–Feb) of 2018–2019 (Figure 12b) resembled those of the previous fall season, with generally some moderation of the magnitude of the positive anomalies in the north, particularly in the Bering Sea and GOA. The equatorial Pacific was characterized by very little change, with SST anomalies barely exceeding $+1^\circ$C near the dateline and 120 to 100°W signifying a weak/moderate El Niño. A highly unusual atmospheric circulation pattern for the North Pacific accompanied this manifestation of El Niño as illustrated by the anomalous SLP pattern for winter 2018–2019 shown in Figure 13b. El Niño generally results in a relatively strong Aleutian low that is displaced to the southeast of its mean position. Virtually the opposite happened, signified by the much higher than normal SLP for a broad region extending from 30°N west of the dateline to southern mainland Alaska. This anomalous ridging in combination with negative SLP anomalies over the Kamchatka Peninsula and western Bering Sea resulted in a pressure pattern that supported extremely strong wind anomalies ($\sim$ 3 to 4 m s^{-1}) from the south across the central and eastern Bering Sea for the second winter in a row. The magnitude of these seasonal anomalies are particularly remarkable considering that an interval of strong winds from the north occurred in the Bering Sea occurred during the latter half of December 2018.

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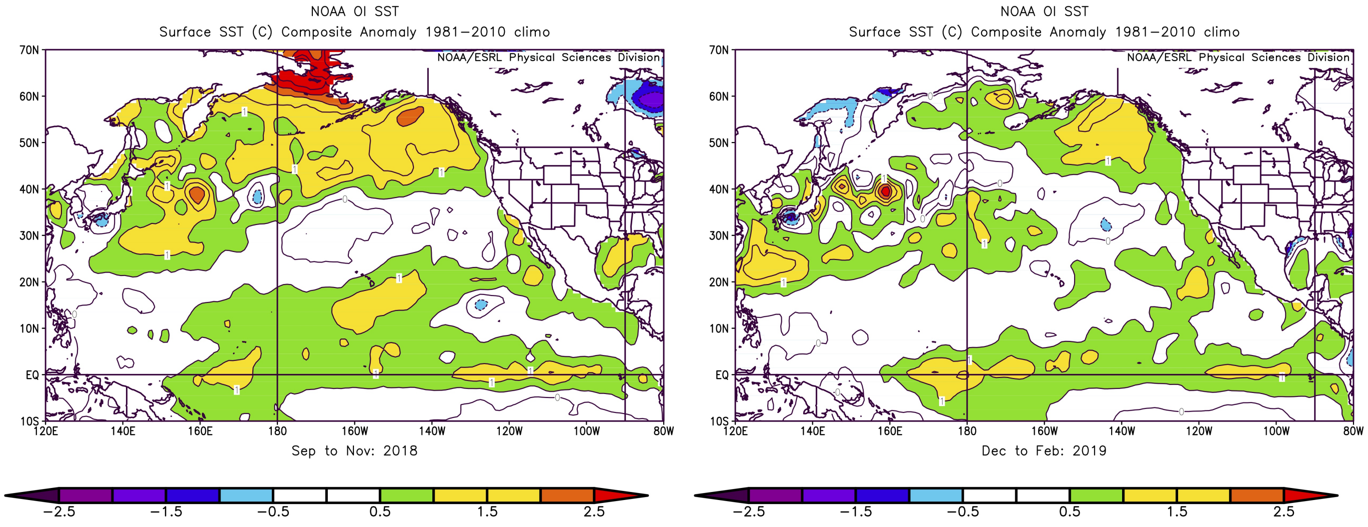
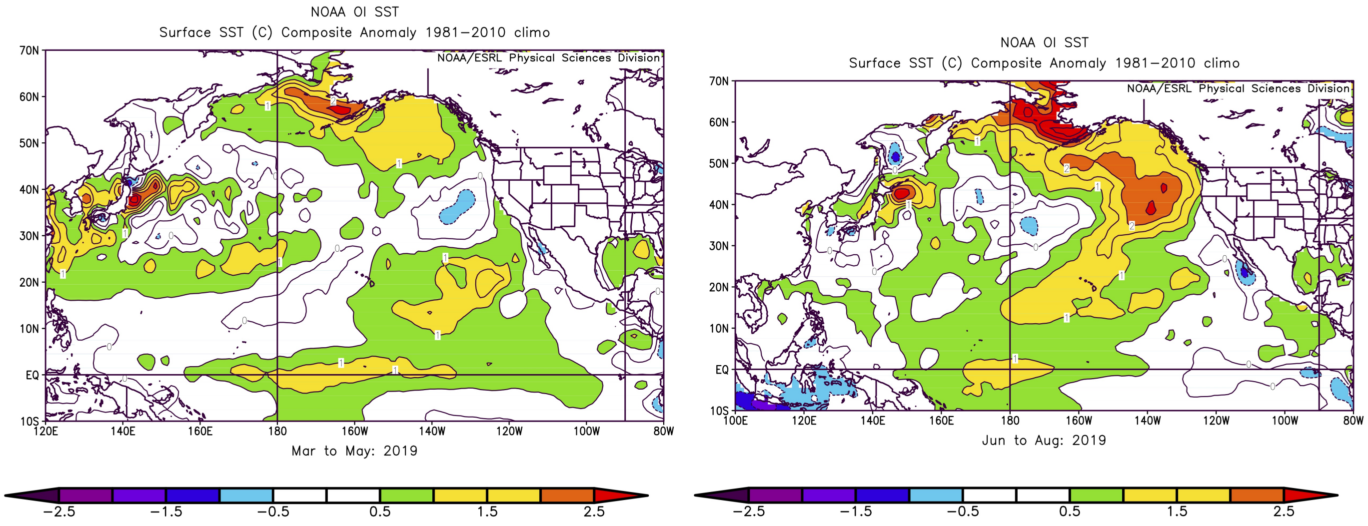
[2] `http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl`

The overall SST anomaly pattern during the spring (Mar–May) of 2019 (Figure 12c) was similar to that of the previous winter season. The most prominent exception was significant warming relative in the eastern Bering Sea in association with yet another year of much reduced sea ice. The SST anomalies in the tropical Pacific were of minor amplitude aside from the dateline to 140°E as El Niño slowly wound down. The SLP anomaly pattern (Figure 13c) for spring 2018 featured a large area of negative anomalies in the North Pacific north of 40°N and west of 150°W and a smaller region of positive anomalies in the eastern GOA. The atmospheric circulation in the northeast Pacific promoted a continuation of a warm low-level flow from the south into the eastern Bering Sea and western and central GOA.

The SST anomaly pattern in the North Pacific during summer (Jun–Aug) 2019 is shown in Figure 12d. This period featured an increase in the warming of the northern and eastern Bering Sea and the development of sizable positive temperature anomalies (exceeding 2°C) offshore of the Pacific Northwest. Cooler than normal SSTs emerged from about 30 to 40°N near the dateline. The SST anomaly pattern for the North Pacific as a whole began resembling the canonical distribution associated with the positive phase of the Pacific Decadal Oscillation (PDO). The SST anomalies in the tropical Pacific continued to slowly moderate; NOAA's Climate Prediction Center (CPC) declared the end of El Niño in early August 2019. The distribution of anomalous SLP (Figure 13d) during summer 2019 included a north-south dipole of higher than normal pressure from eastern Siberia across the Bering Sea into the western GOA and lower pressure in the central North Pacific centered near 35°N north of the Hawaiian Islands. This set-up resulted in suppressed storminess for the Bering Sea and GOA, contributing to the development of the very warm SSTs in those regions shown in Figure 12d.

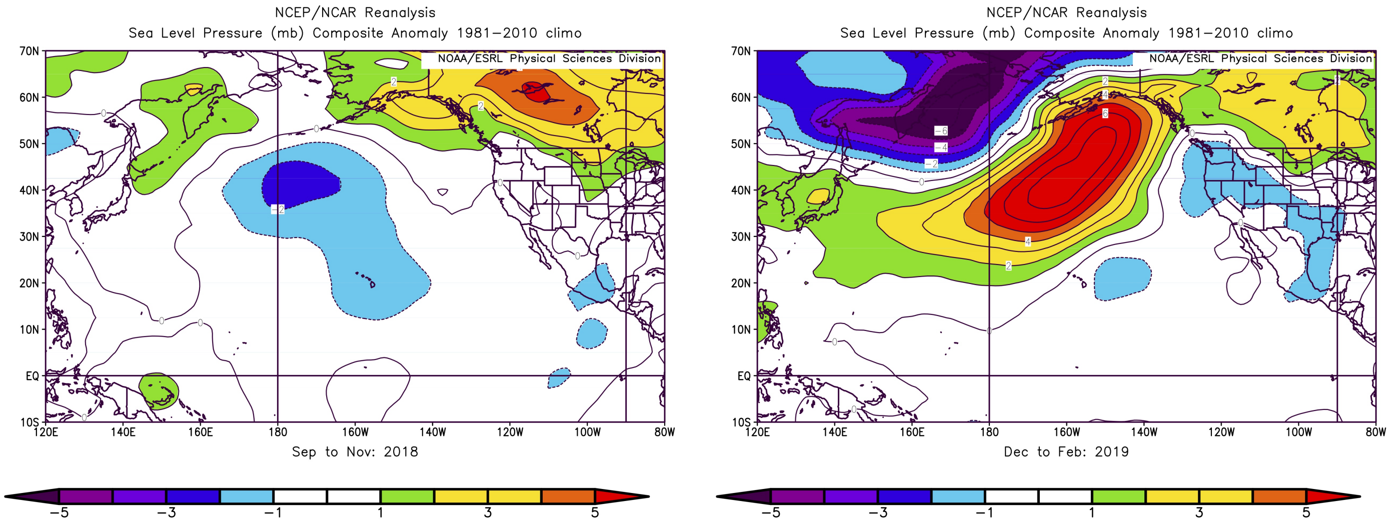


(a) Autumn (b) Winter

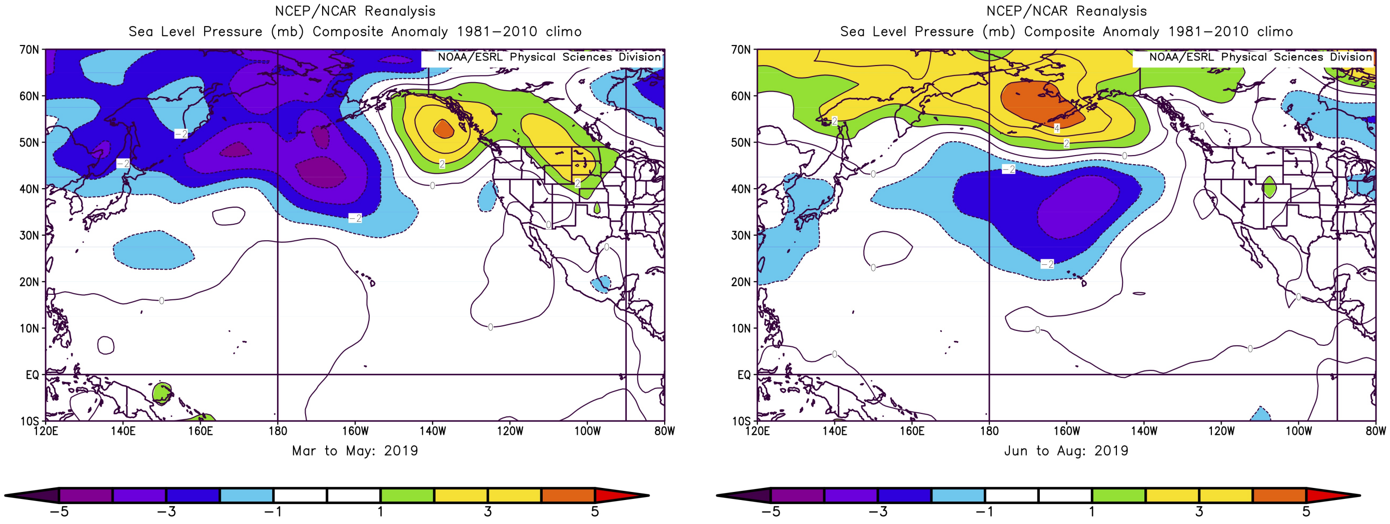


(c) Spring (d) Summer

Figure 12: SST anomolies for autumn (September–November 2018), winter (December 2018–February 2019), spring (March–May 2019), and summer (June–August 2019).



(a) Autumn (b) Winter



(c) Spring (d) Summer

Figure 13: SLP anomolies for autumn (September–November 2018), winter (December 2018–February 2019), spring (March–May 2019), and summer (June–August 2019).

Climate Indices

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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, 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 2009 into spring/summer 2019 are plotted in Figure 14.

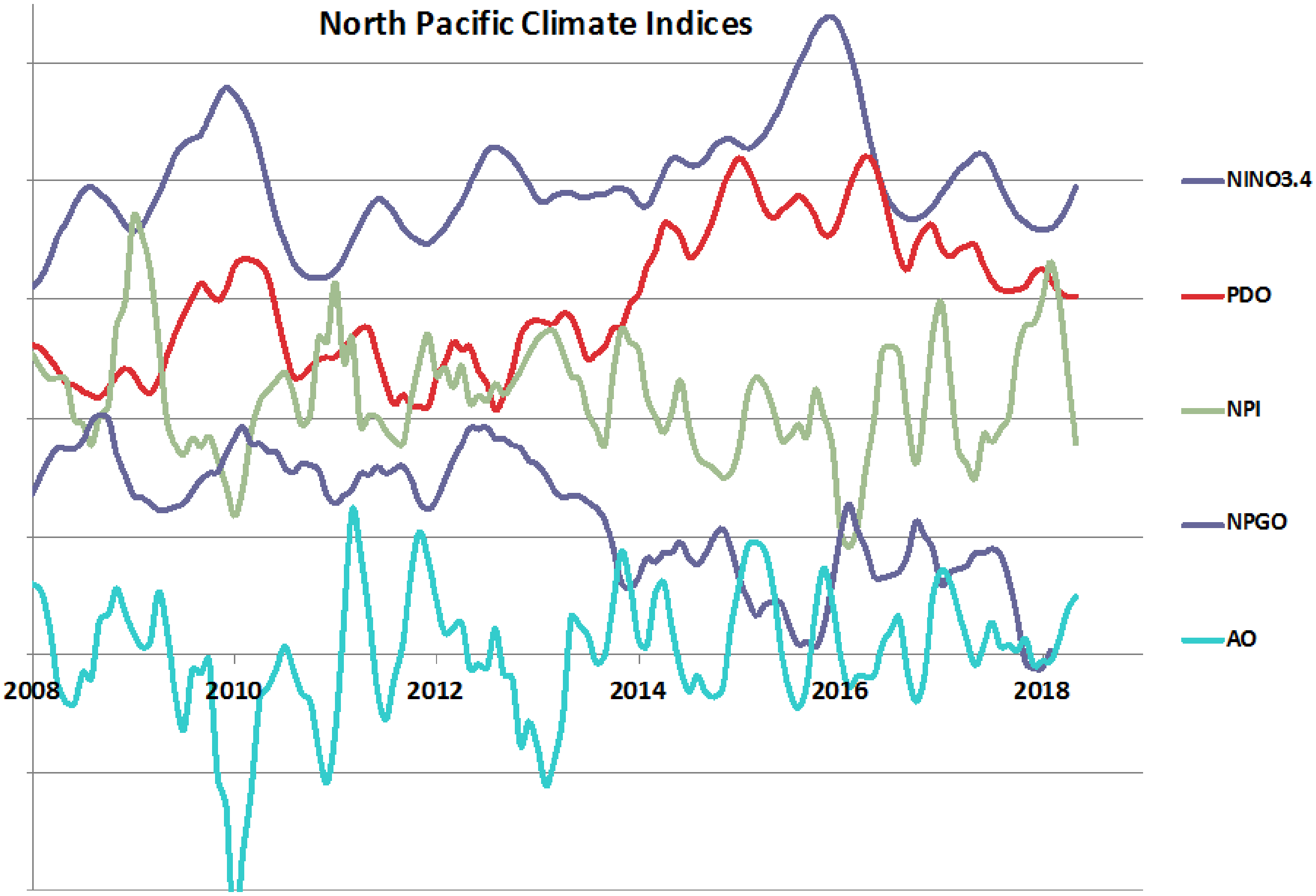

Figure 14: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices for 2009–2019. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running 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[3].

Status and trends: The NINO3.4 index underwent a transition from negative to positive during 2018 in association with the development of a weak/moderate El Niño event that persisted into 2019. It bears emphasizing that its magnitude was considerably weaker than the previous events of 2009–2010 and 2015–2016. The PDO became significantly positive (indicating warmer than normal SST along the west coast of North America and cooler than normal in the central and western North Pacific) in spring 2019 and was about +1 in the summer of 2019; it bears noting that this does not necessarily herald the start of an extended period of positive PDO conditions such as what occurred from 2014 into 2017. The NPI was mostly greater than zero, signifying relatively high SLP in the region of the Aleutian low, during 2018 into early 2019. A negative sense for the NPI commonly accompanies El Niño, as mentioned above. The NPI did turn negative in the spring of 2019 but due to its high-frequency, intrinsic variability, its future state is highly uncertain.

The NPGO was strongly negative for all of 2018 into 2019, and has undergone an overall decline from positive values during the period of 2008 to 2012. The negative sense of the NPGO implies a relatively weak west-wind drift for the eastern North Pacific and a reduction in the strengths of the both the poleward flow in the eastern GOA with the sub-arctic gyre and the equator-ward flow in the California Current System (CCS). 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 North Pacific and North Atlantic at a latitude of roughly 45°N. It was in a positive state during most of the last half of 2018 into early 2019 with a transition to a negative state in spring 2019 that has continued into summer. A consequence has been relatively high pressure in the Arctic during the 2019 ice melt season to date.

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

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Last updated: September 2019

Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figures 15. 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[4].

Status and trends: The projections from a year ago are first reviewed briefly. In general, the SST forecasts from late summer 2018 for the upcoming fall and winter indicated basin-scale anomaly patterns for the North Pacific that resembled those observed. The magnitudes of the observed anomalies in some cases differed from their forecast counterparts. Specifically, while the sign of the anomalies were correct, the northern Bering Sea and GOA during fall 2018 were substantially warmer than forecast. The opposite sort of error occurred for the tropical Pacific in winter 2018–2019, when El Niño ended up weaker than indicated by the ensemble model projections. The winter into spring of 2019 also included under-prediction of the SST anomalies on the Bering Sea shelf. Nevertheless, the overall skill of the model projections, as demonstrated for recent years and not just this past example, is encouraging.

These NMME forecasts of three-month average SST anomalies indicate a continuation of warm conditions across virtually all of the North Pacific north of about 40°N through the end of the year (Oct–Dec 2019), with a reduction in magnitude of the positive anomalies on the southern Bering Sea shelf, and offshore of the Pacific Northwest (Figure 15a). The magnitude of the positive anomalies is projected to be greatest (exceeding 2°C) north of the Kuroshio Extension in the far western North Pacific. Weak SST anomalies are projected in the equatorial Pacific. As of early September 2019, 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 a 50–55% chance of neutral conditions and a 30% chance of El Niño. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December

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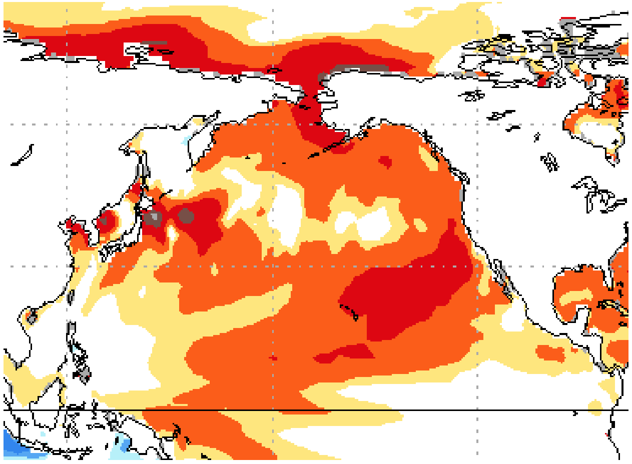
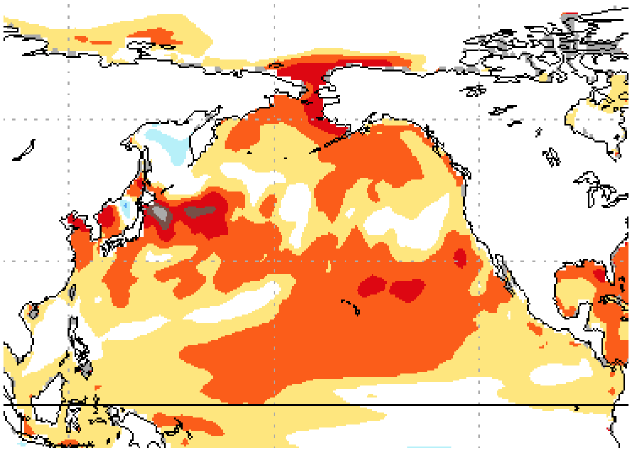
[4] More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`

2019–February 2020 (Figure 15b) and February–April 2020 (Figure 15c) with mostly a diminution in the magnitudes of the anomalies, especially in the eastern Bering Sea, GOA, and off the coast of the Pacific Northwest.

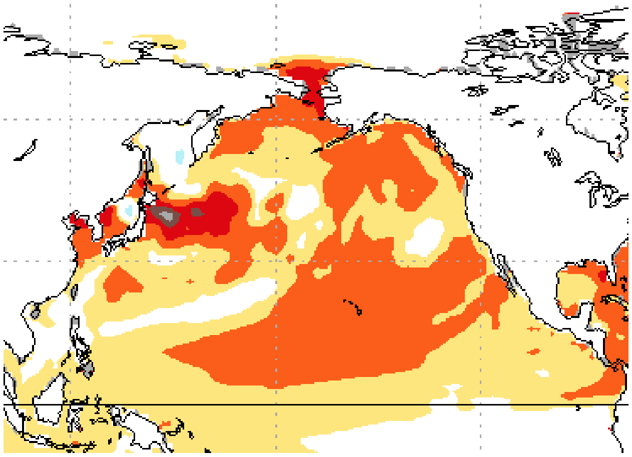
Implications: There is currently a lack of consensus among the climate models about the mean regional circulation anomalies associated with the variability of the Aleutian low during the upcoming autumn and winter. This result is consistent with the absence of predictability associated with neutral conditions in the equatorial Pacific. The models do show a weak tendency for a positive phase of the AO, which often, but by no means always, results in a cooler winter for the Bering Sea. The PDO is positive during the summer of 2019, but it may not remain in that state too much longer. The models as a group are indicating both warming of the negative anomalies in the North Pacific west of the dateline, along with some cooling along the west coast of North America, during the winter of 2019–2020. These changes, assuming they actually occur, would bring about a SST anomaly pattern that does not strongly project on the PDO by early 2020.



(a) Months Oct–Nov–Dec



(b) Months Dec–Jan–Feb



(c) Months Feb–Mar–Apr

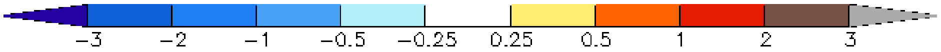


Figure 15: Predicted SST anomalies from the NMME model for Oct–Nov–Dec (1-month lead), Dec–Jan–Feb (3-month lead), and Feb–Mar–Apr (5-month lead) for the 2019–2020 season.

Sea Ice Metrics for the Bering Sea

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Indicator: Annual Bering Sea Ice Extent
The Bering Sea has historically been ice-free in the middle and late summer, with ice developing in protected bays and the brackish waters near river outlooks during the second half of October. To account for this seasonal cycle, the Bering Sea ice year here is defined as 1 August to 31 July. Bering Sea ice extent data are from the National Snow and Ice Center's Sea Ice Index, version 3 (Fetterer et al., 2017), and uses the Sea Ice Index definition of the Bering Sea (effectively south of line from Cape Prince of Wales to East Cape, Russia). The daily mean ice annual ice extent integrates the full ice season into a single value. The mean extent has exhibited no long term trend, though four of the past five seasons have a mean extent lower than any season prior to 2014–2015. The 2018–2019 daily mean extent of 142,770 km^2 is less than half of the 1981–2010 average and is the second lowest of record (only 2017–2018 lower).

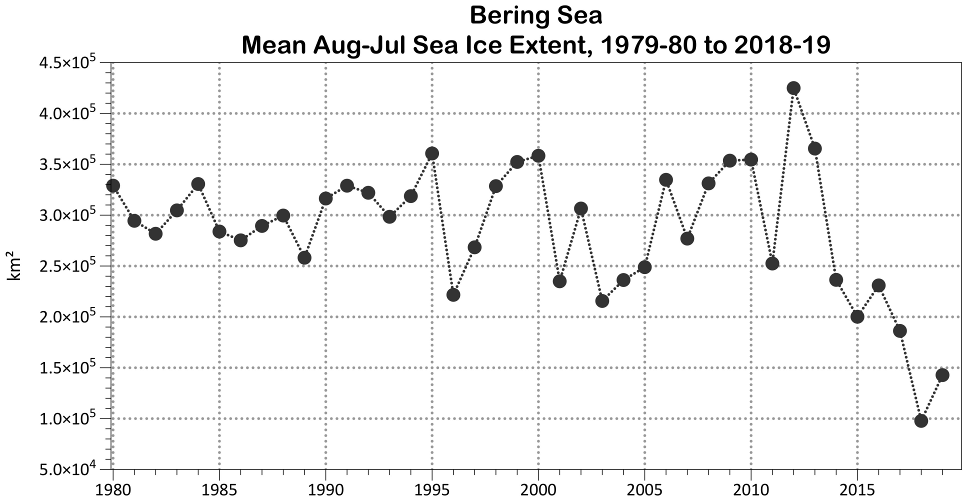

Figure 16: Mean sea ice extent in the Bering Sea from 1 August to 31 July, 1979/1980–2018/2019.

Indicator: Seasonal Bering Sea Ice Extent Thresholds
Another integrated indicator of overall Bering sea ice conditions are total days when the ice extent exceeds some threshold value. Although the thresholds are arbitrary, they allow a consistent assessment of season duration. Below are time series of two thresholds: (1) The extent area of 50,000 km^2 is used as an overall indicator of season length. This 50,000 km^2 threshold (an area a bit larger than Norton Sound) is chosen because this is large enough to be well above the inherent uncertainty in the passive microwave historical record but is less than 10% of the mean annual maximum. (2) The 500,000 km^2 threshold is chosen as the threshold for reflecting the duration of ice coverage over the open Bering Sea, well away from the Alaska and Chukotka coasts. The 50,000 km^2 threshold has been declining during the 41–year passive microwave record, even prior to the most recent years. In contrast, the 500,000 km^2 "open ocean" threshold showed no trend at all, or even any significant periods of longer vs. shorter duration stanzas until very recently. During the 2018–2019 season, days exceeding both the 50,000 km^2 and 500,000 km^2 thresholds were the second lowest of record (only 2017–2018 lower).

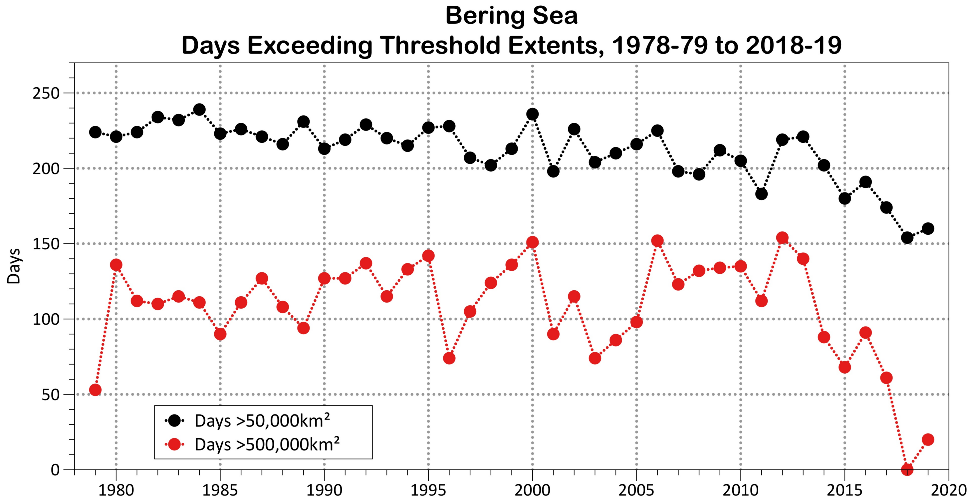

Figure 17: Number of days when sea ice extent in the Bering Sea exceeded threshold extents, 1978/1979–2018/2019.

Indicator: Early Season Ice Extent

While mean annual ice extent has shown no significant trend until very recently, this is not the case for early season ice. The presence or absence of early sea ice in the Bering Sea is important because, at least during the passive microwave era, nearly all ice in the Bering Sea is first year, so that Bering Sea ice thickness is related to both the air temperature and the age of the ice. The mean daily extent for the two months from October 15 through December 15 show considerable interannual variability but with a strong negative linear trend during in the past 40 years; this trend was robust even prior to the two recent low ice seasons. The mean early season ice extent for 2018–2019 of 29425 km^2 was the lowest of record.

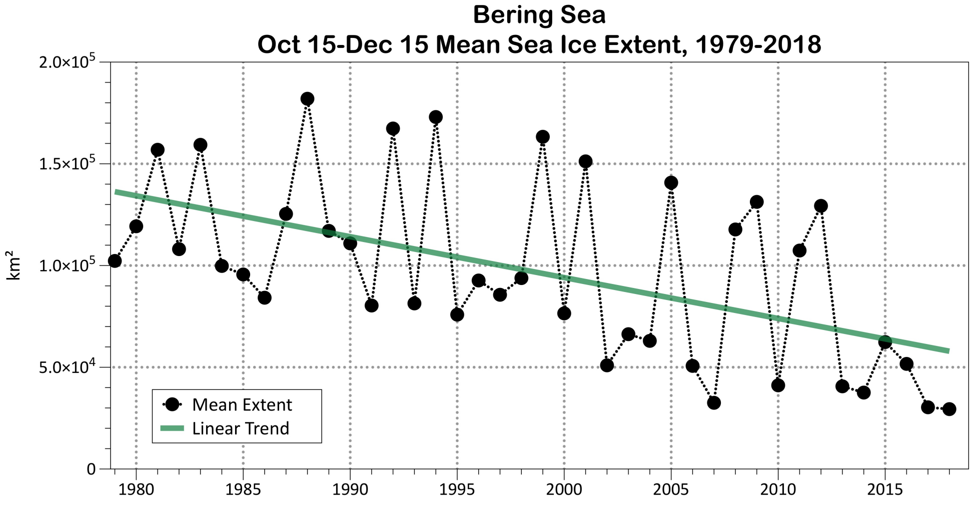

Figure 18: Early (15 October–15 December) mean sea ice extent in the Bering Sea, 1979–2018.

Eastern Bering Sea Climate - FOCI

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Summary. The eastern Bering Sea has experienced warm conditions due to anomalously low sea ice extent during the winters of 2017/2018 and 2018/2019. For example, in January–April 2018, the northern Bering Sea experienced >+5°C air temperature anomalies. In 2019, 6°C warm anomalies occurred in winter and spring due, in part, to strong southerly winds during February and March. Combined, three climatic forces contributed to the warm conditions over the eastern Bering Sea during 2018 and 2019: (i) residual heat maintained above-average water temperatures that caused delayed freeze-up, (ii) a large and persistent high pressure system during spring (February–March) over the Aleutian Islands and southern Bering Sea, which shifted the position of the Aleutian Low Pressure System northwest over Siberia, and (iii) highly unusual southerly winds during spring that brought warm air over the Bering Sea and prevented sea ice from forming. The southern Bering Sea shelf experienced conditions typical of low sea ice and above-average temperature years, while the northern Bering Sea experienced a 'double whammy' of a second year with little sea ice and reduced cold pool extent.

Air temperatures Positive near surface air temperature anomalies occurred over the southeastern Bering Sea shelf (+3°C) during winter and spring (January–May) 2019, while strongly positive temperature anomalies persisted over the northern Bering Sea (+6°C) (Figure 19 top). Sea level pressure patterns resulted in wind vectors perpendicular to the Alaska Peninsula during February–March 2019, indicating strong southerly warm winds over the shelf (Figure 19 bottom).

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 positive since April 2014 for nearly every single month.

Sea ice. The greatest ice extent occurred in the winter and early spring of 2011–2012. The ice extent from mid-December 2018 through late January 2019 approached the long-term mean, but then strong, warm winds from the south in February 2019 forced a rapid retreat of sea ice (Figure 21). Warm conduction in fall 2018 delayed ice formation and lead to fairly thin sea ice, therefore the southerly winds in February caused it to break up.

Ocean temperatures. The cold pool (Figure 22), 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 2019 was reduced and retracted over the northwest portion of the survey area, reflecting low sea ice extent over the shelf during the winter 2018/2019.

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 23), 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). Depth-averaged temperatures at M2 remained >3°C for the entire summer 2019. Summer warming increased depth-averaged temperatures to >8°C, which was slightly warmer than the previous maximum temperature in 2016. There was virtually no ice on the southern Bering Sea shelf in winter 2019. The recent warm stanza began in 2014, with only 2017 having ice at M2 and therefore colder temperatures.

Bottom temperatures at M8 in summer of 2018 were the highest ever recorded (Figure 24). In late October with the vertical mixing of warm surface temperatures downward, bottom temperatures reached an unheard of 4.5C. Sea ice in late November and December cooled the water column, reaching freezing (approximately -1.7C) in February. Maximum ice extent occurred on 25 January, 2019. After that the ice retreated rapidly and advection warmed the water column to above -1C in March. Lowest

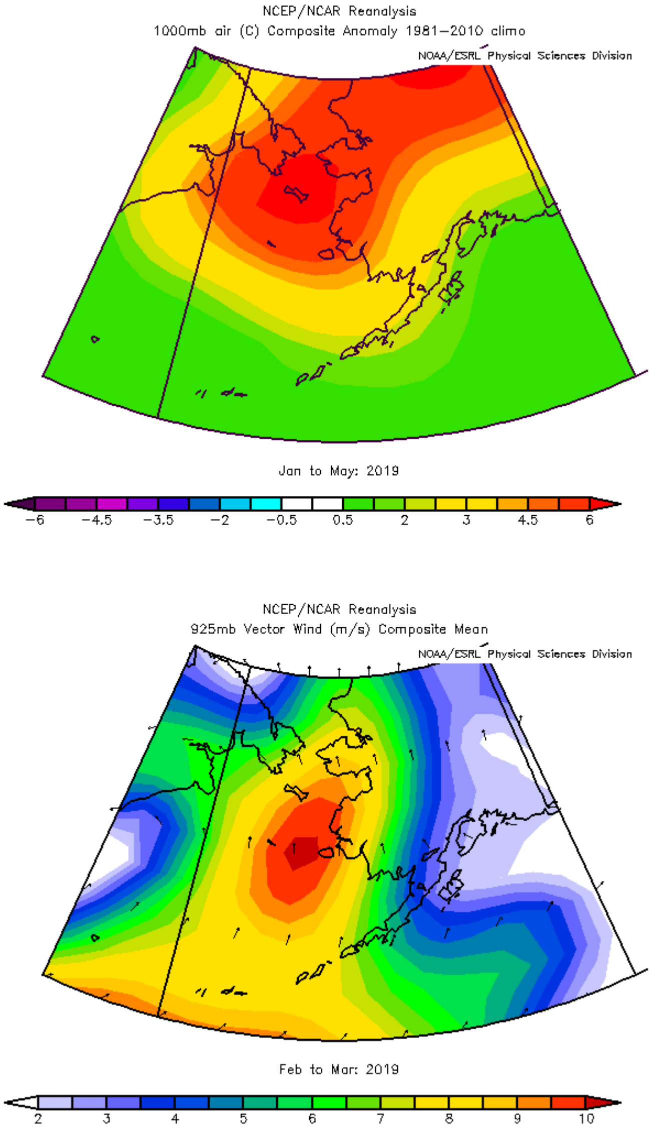


Figure 19: Near surface positive air temperature anomalies over the eastern Bering Sea for January–May 2019 (top) and wind vectors for February–March 2019 (bottom).

winter ice extent occurred on 1 March after which ice increased until 21 March, never again reaching the Jan 25 ice extent. While in 2019, bottom temperatures at M8 never reached those of 2018, they were well above the long-term average (2005-2017).

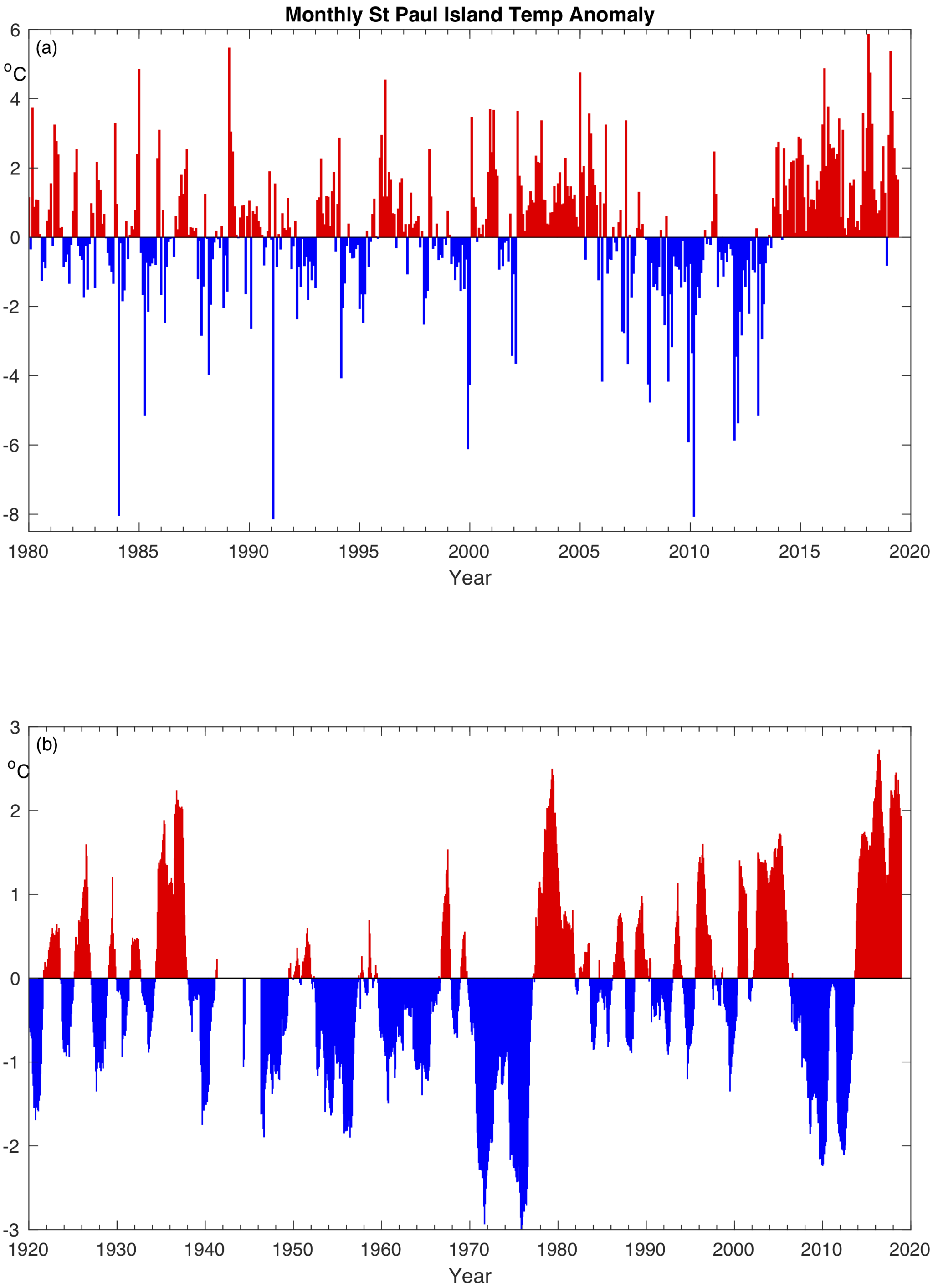


Figure 20: Mean monthly surface air temperatures anomalies at St. Paul (Pribilof Islands). (a) Unsmoothed 1980–2019 and (b) smoothed by 13-month running averages, January 1920 through August 2019. The base period for calculating anomalies is 1981–2010.

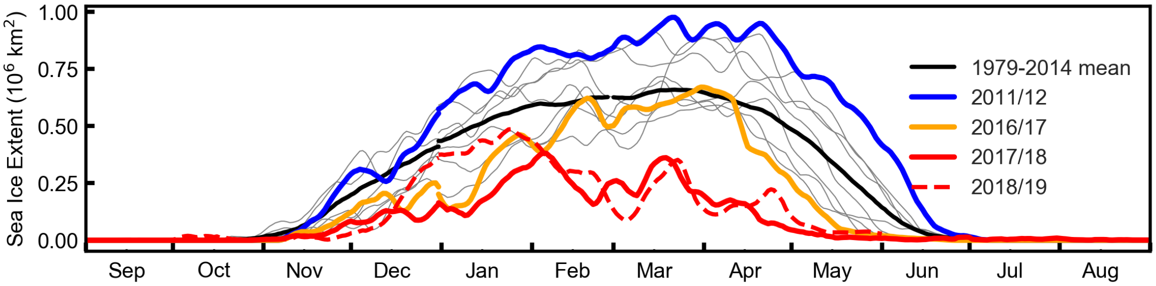
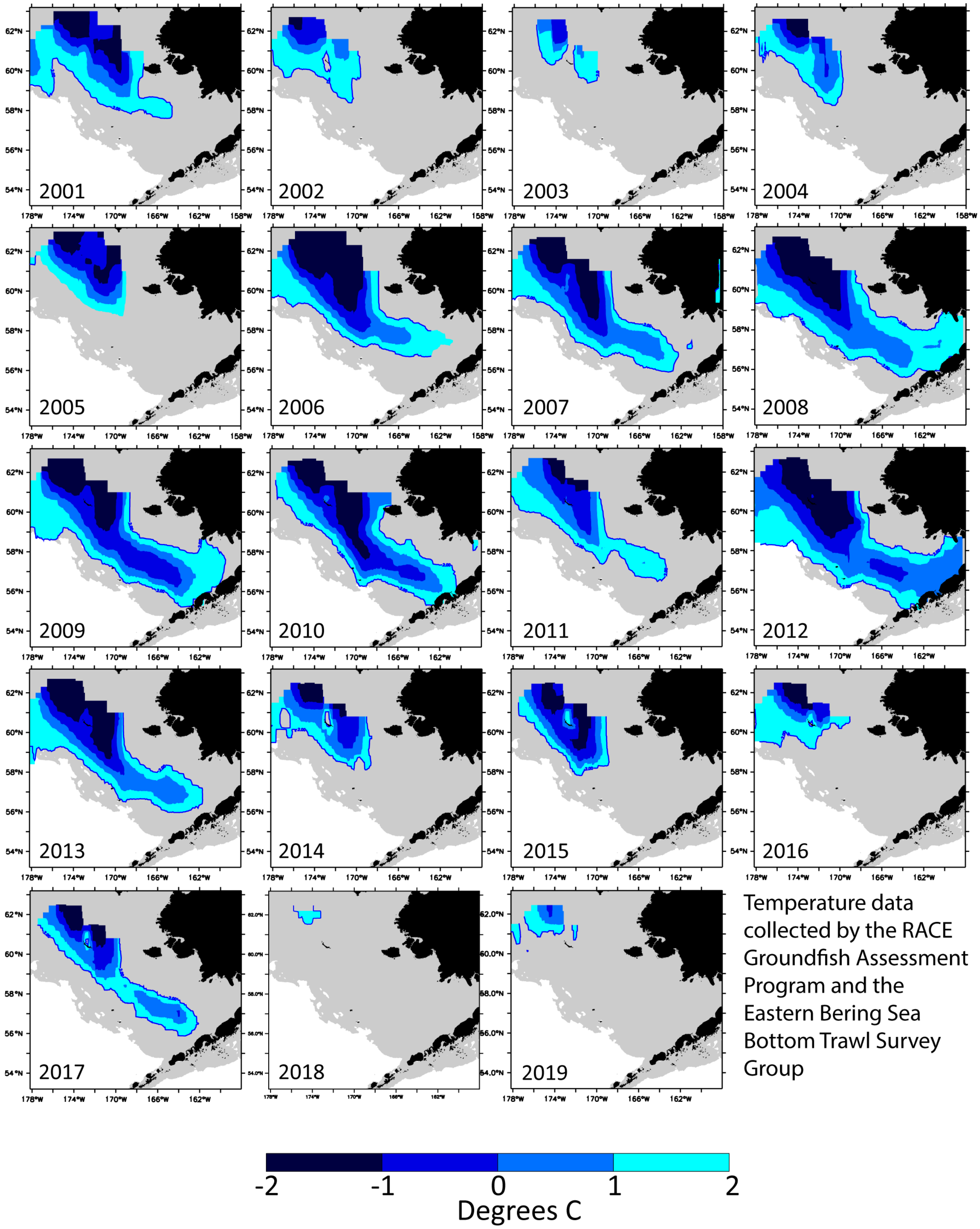


Figure 21: Sea ice extent on the eastern Bering Sea shelf as far west as 168°E.



Temperature data collected by the RACE Groundfish Assessment Program and the Eastern Bering Sea Bottom Trawl Survey Group

Figure 22: Cold pool extent in the eastern Bering Sea from 2001–2019. 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 while in 2019 a reduced cold pool occurred over the northwest portion of the shelf.

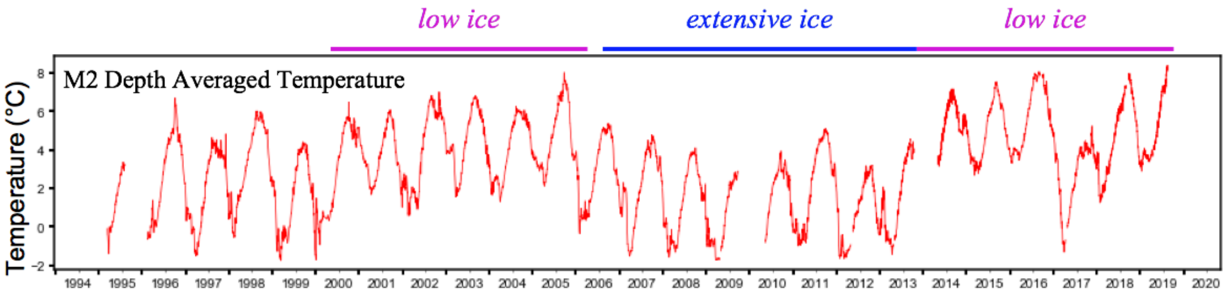


Figure 23: Depth-averaged temperature at M2 mooring in ∼74m of water.

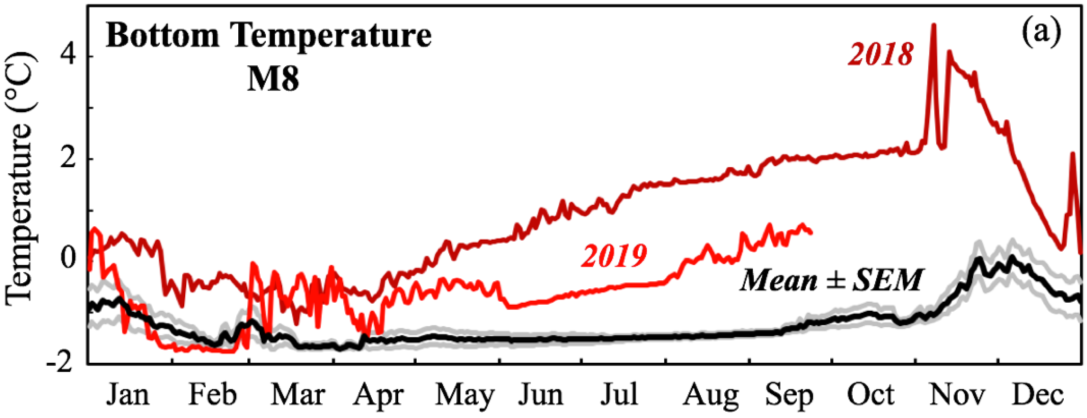


Figure 24: Bottom temperatures measured at M8 mooring. The black line is the mean ±1 standard error of the mean from 2005–2017.

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

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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 only during seasonal surveys.

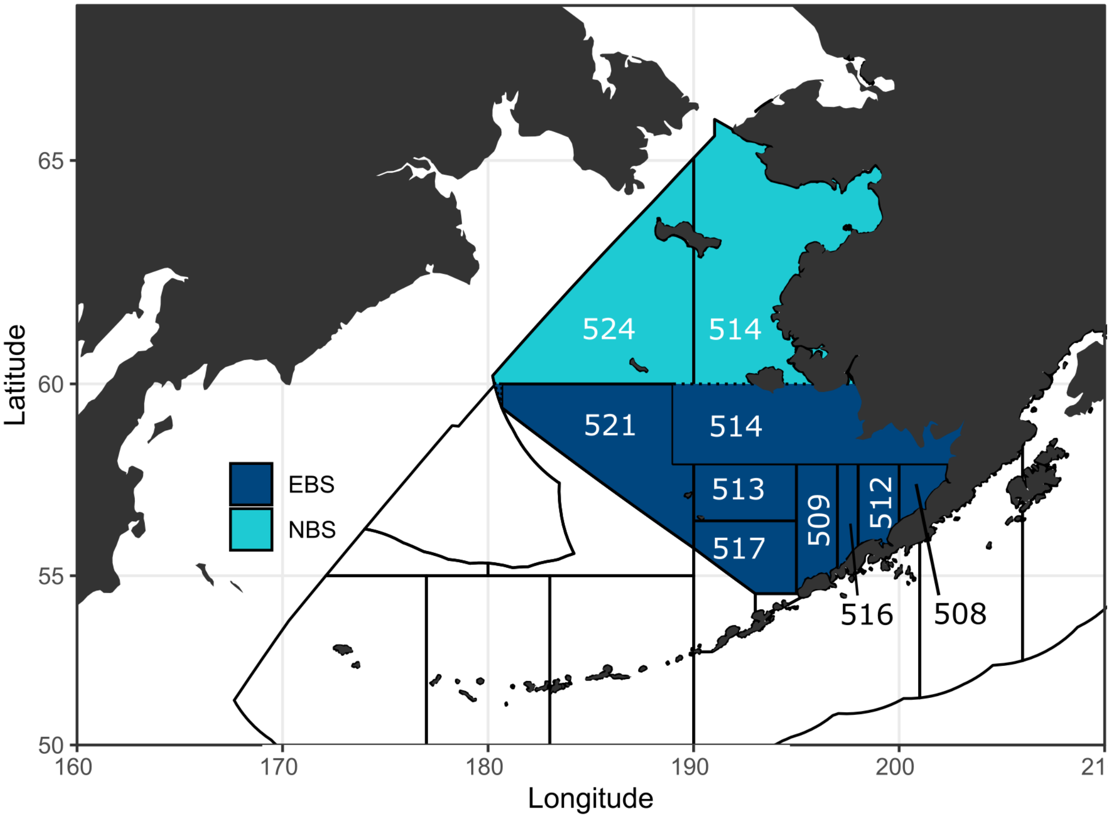

Figure 25: Map of the NMFS area boundaries for the eastern (EBS) and northern (NBS) Bering Seas, as defined for this ecosystem indicator. The dotted line illustrates the latitude split of NMFS area 514 between the EBS and the NBS.

A 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[5]. Daily SST data were accessed via the NOAA Coast Watch West Coast Node ERDDAP server[6] and SST values were averaged daily by Alaska

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[5] `https://mur.jpl.nasa.gov/InformationText.php`

[6] `https://coastwatch.pfeg.noaa.gov/erddap/`

Department of Fish and Game (ADF&G) groundfish statistical areas. More detailed methods are available online (Watson, 2019).

For this indicator, the Bering Sea was divided into two regions. The eastern Bering Sea (EBS) was identified as ADF&G statistical areas that fell within NMFS areas 508, 509, 512, 513, 514, 516, 517, 521, or 524 and for which the northern most latitude was <60°N. The northern Bering Sea (NBS) was identified as ADF&G statistical areas between 60°N and 65.5°N and falling within NMFS areas 514 or 524. Figure 25 illustrates the boundaries of these NMFS areas.

As an ecosystem indicator for the Bering Sea (Figure 26), daily mean temperatures were averaged by month and anomalies were calculated by season for the eastern and northern Bering Seas. The seasons (Dec–Feb, Mar–May, Jun–Aug, Sept–Nov) were chosen for consistency with other climatological ecosystem indicators in this Report. The December data included in Dec–Feb are those from the previous year (e.g., Dec–Feb 2003 includes December 2002). Horizontal dashed lines in Figure 26 are provided as a reference.

Status and trends: The satellite derived time series of summer sea surface temperatures demonstrates a general spatial coherence between Bering Sea regions across seasons and years. Interestingly, while the early 2000s are generally considered to be a warm period in the Bering Sea, this breakout of seasons demonstrates that much of the warming may have been driven primarily by conditions in Mar–May (EBS only) and Jun–Aug (both EBS and NBS). In contrast, the more recent years have been warmer than average throughout the year instead of only during spring and summer.

Factors influencing observed trends: Reduced sea ice and a diminished cold pool are likely to contribute to the warmer temperatures throughout the year during the recent warm period, as opposed to only during a portion of the year during the previous warm period.

Implications: Recent warming in the EBS and NBS is unlike previous warm periods. The magnitude and seasonality of warming suggests that loss of sea ice may lead to an entirely different ecosystem, which could have drastic impacts on prey quality, predator-prey overlap, and locations of commercial fish populations. Given that the physical environment is changing so drastically, it is not unreasonable to highlight the value that could be gleaned from annual surveys in the EBS and NBS until a new baseline of ecosystem dynamics can be established.

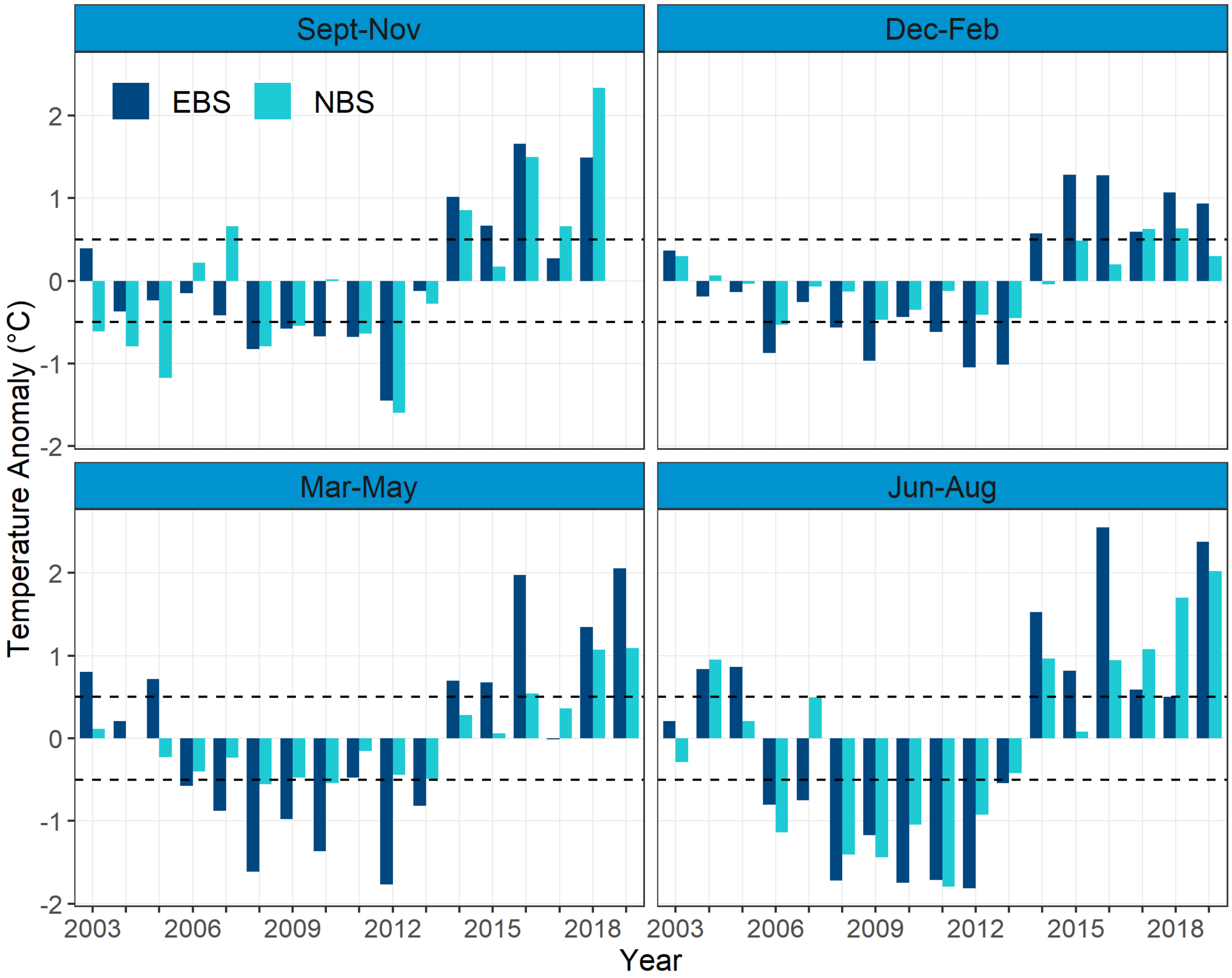

Figure 26: Seasonal sea surface temperature anomalies for the eastern (EBS) and northern (NBS) Bering Sea. Time series begins with December 2002 and ends with August 2019.

Summer Bottom and Surface Temperatures - Eastern Bering Sea Shelf

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Last updated: October 2019

Description of indicator: Survey operations for the annual AFSC eastern Bering Sea shelf bottom trawl survey in 2019 started on 3 June and ended on 26 July.

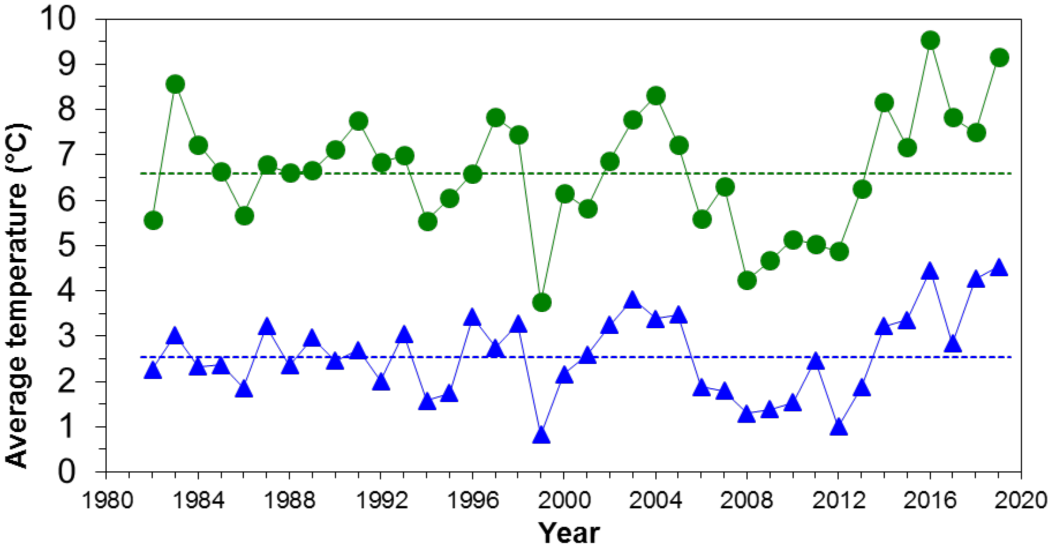

Figure 27: Average summer surface (green circles) and bottom (blue triangles) temperatures (°C) of the eastern Bering Sea shelf collected during the standard bottom trawl surveys from 1982–2019. Water temperatures samples from each station were weighted by the proportion of their assigned stratum area. Dotted lines represent the time-series mean for 1982–2019.

Status and trends: Surface and bottom temperature means for the 2019 eastern Bering Sea shelf increased from the 2018 estimates, and were significantly warmer than the long-term time-series mean (Figure 27). The 2019 mean surface temperature was 9.2°C, which was 1.7°C greater than 2018 and 2.6°C above the time-series mean (6.6°C). The 2019 mean bottom temperature was 4.5°C, which was 0.2°C higher than 2018, and 2.0°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 28). Moreover, it was the 2^{nd} lowest areal coverage of the cold pool in the 38-year EBS shelf time-series. (Figure 29).

Factors influencing observed trends: Warm and cold years are the result of inter annual variability in climatic conditions that effect the extent, timing, and retreat of sea ice on the eastern Bering Sea shelf. During warm years, sea ice generally does not extend as far down the shelf and retreats sooner.

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; Hunt et al., 2011).

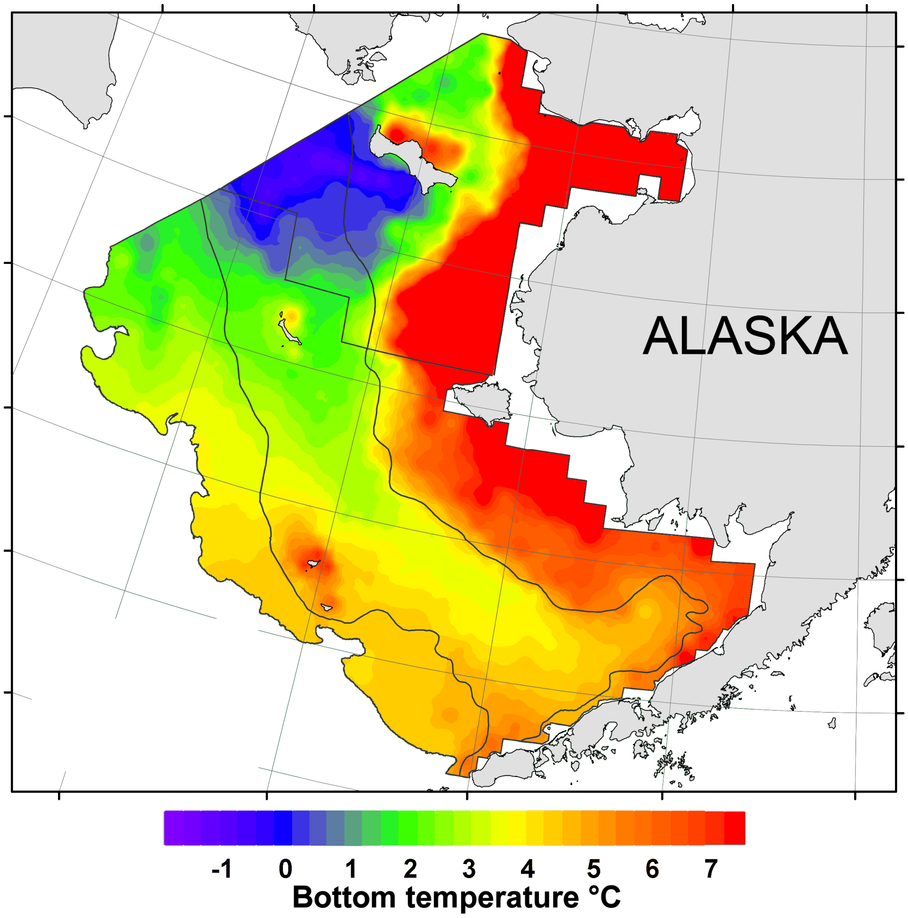

Figure 28: Contour map of the near-bottom temperatures from the 2019 eastern Bering Sea shelf bottom trawl survey.

Variations in Temperature and Salinity During Late Summer/ Early Fall 2002–2018 in the Eastern Bering Sea–BASIS

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Last updated: August 2019

Description of indicator: Oceanographic and fisheries data were collected over the eastern Bering Sea (EBS) shelf during fall 2002–2018 for a multiyear fisheries oceanography research program, Bering-Arctic-SubArctic Integrated Survey (BASIS). Stations were located between 54.5°N and 65°N, at ~60 km resolution. Bristol Bay stations were sampled from mid-August to early September (with the exception of 2018 in late September). Stations in the central and north EBS were generally sampled from mid-September to early October. Physical oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles. Mean temperature and salinity above and below the mixed layer depth (MLD) were estimated for each station following methods in Danielson et al. (2011). Normalized anomalies of temperature and salinity (mean yearly value minus average for time period, normalized by standard deviation) were separately computed for each Bering Sea Project

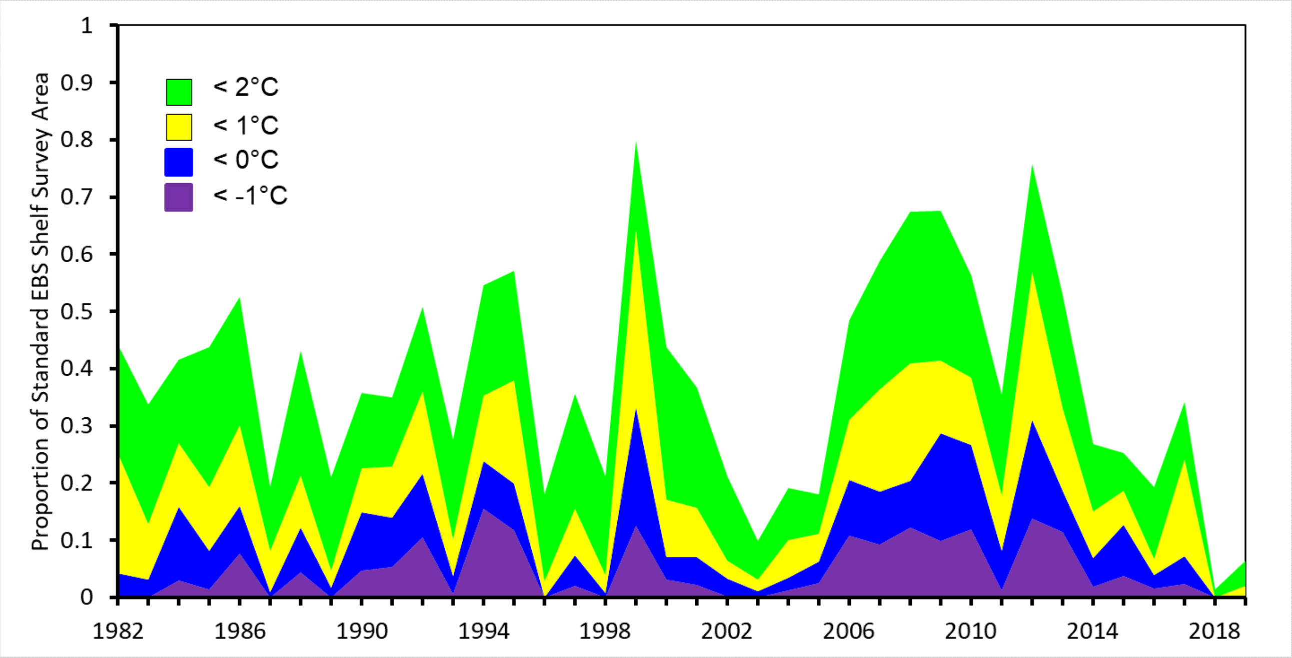


Figure 29: Proportion of the standard eastern Bering Sea shelf survey area where bottom temperatures were <2°C, <1°C, <0°C, and <-1°C for the 38-year time series.

region (Ortiz et al., 2012) (Figures 30–34). Normalized anomalies of MLD were similarly estimated for middle and outer domain regions (Figure 35). Only station locations sampled 5+ years were included in the analyses (Figure 30).

Status and trends: Temperatures above and below the MLD (Tabove, Tbelow) for the area <63°N (regions 1–11) were generally warmer than average (anomalies > 0.5) in 2002–2004 (or 2005), cooler in 2007–2012 and warmer in 2014 (or 2015)–2018 (Figures 31 and 32). In recent years high values were first seen in 2014 for Tabove and in 2015 for Tbelow in the south middle shelf region 3, with high temperatures seen throughout the water column for all regions in 2016 and for northern regions in 2018. South middle shelf regions also had high Tbelow in 2018. Above 63°N, the warm period began in 2003 and lasted to 2007, but showed similarities to regions below 63°N for 2009–2018.

Salinities above and below the MLD (Sabove, Sbelow) for the south middle shelf (regions 3, 6) were generally higher in warm years (2002–2005, 2014–2018; no data for 2017) than in cold years (2006–2012), (Figures 33 and 34). For the north middle shelf (regions 9, 10), Sabove was lower from 2006–2016 than in 2002–2005 and 2017–2018; Sbelow was move variable across temperature regimes. Above 63°N, salinity varied among regions and within temperature regimes. For example, very low salinity (anomaly <-2) was observed in 2016, while high salinity was observed in 2017 and 2018. Very high salinity anomalies (both salty >2 and fresh <-2) were observed only in warm years (2002, 2005, 2014, 2015, 2016, 2018).

The MLD varied ∼10 m in the south middle domain (regions 3, 6), 6–7 m in the north middle domain (regions 9, 10), and 13 m in the south outer domain (region 4) with the exception of 2015 and 2018; variations did not appear to co-vary with warm/cold year periods (Figure 35). The deep MLD in 2015 and 2018 were due to the timing of sampling in relation to mixing from fall storms (early storms in 2015 and late sampling in 2018).

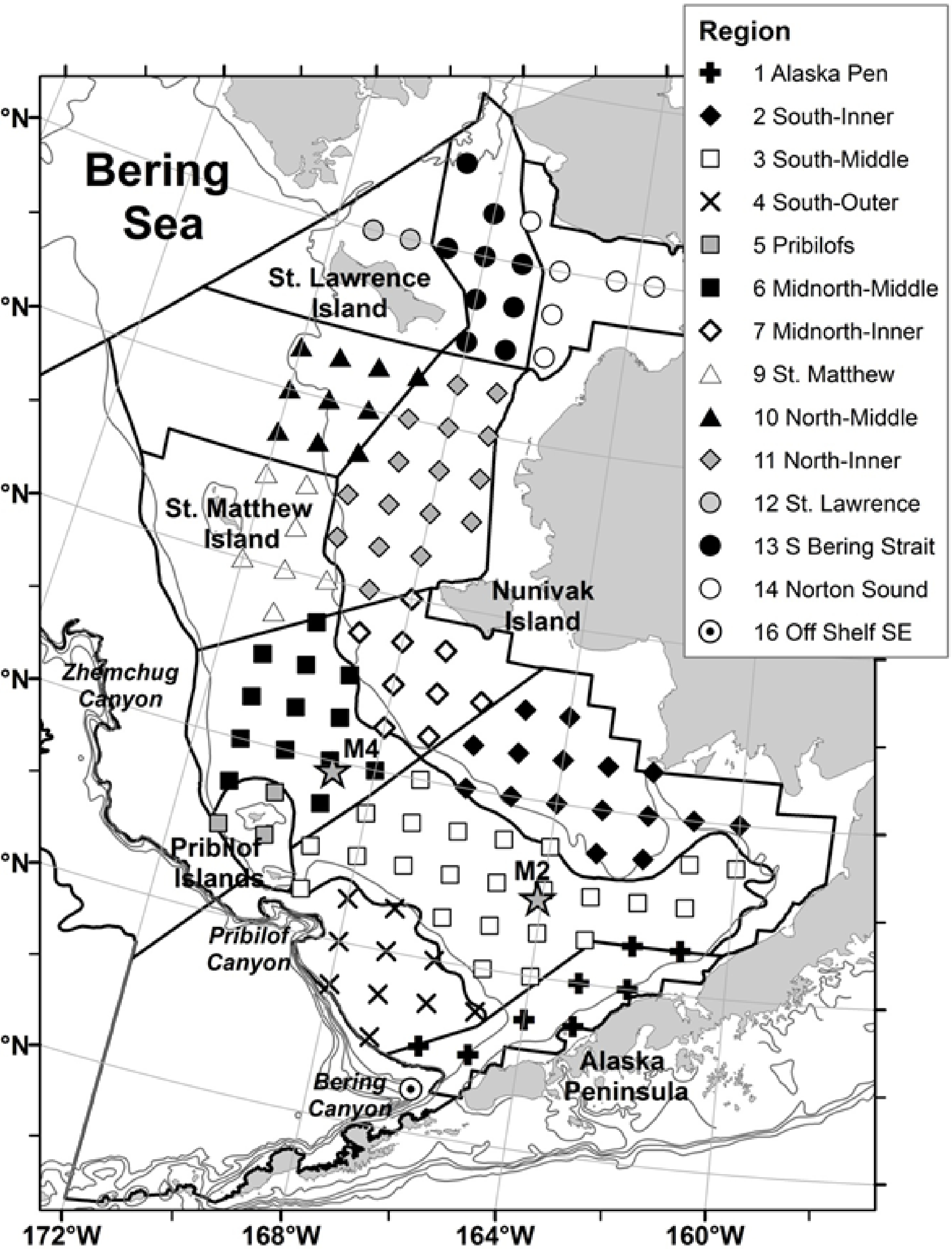
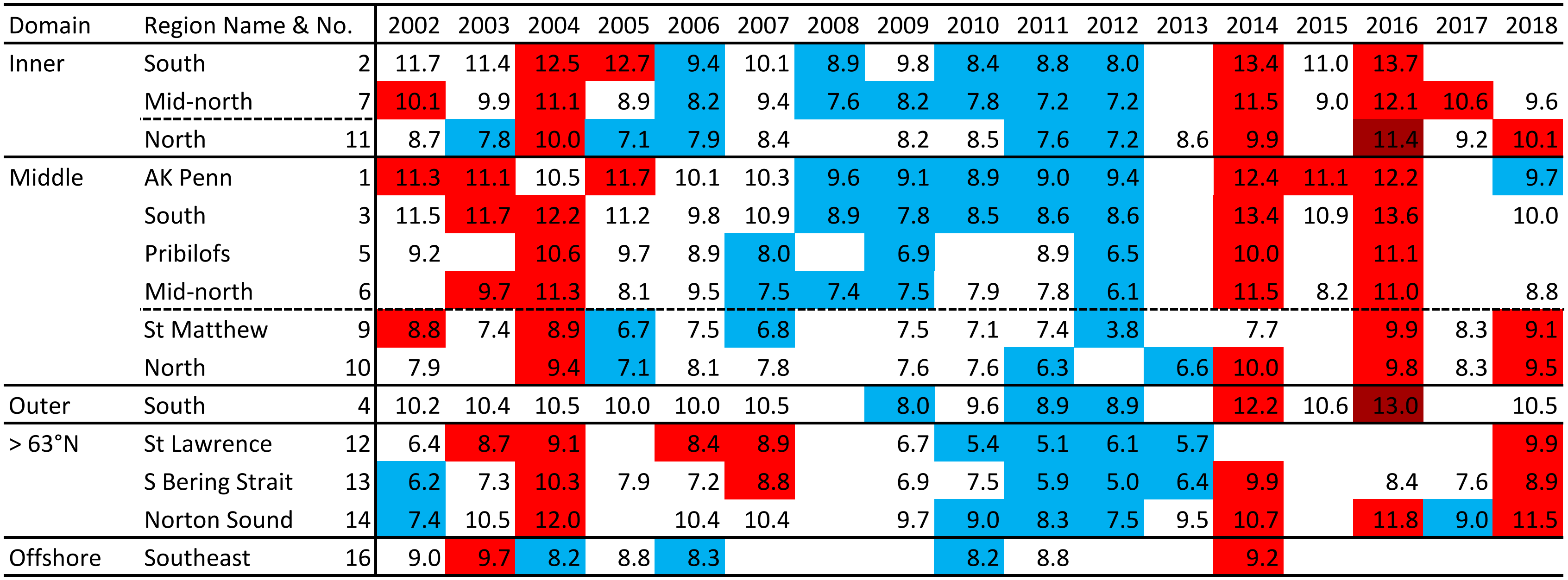
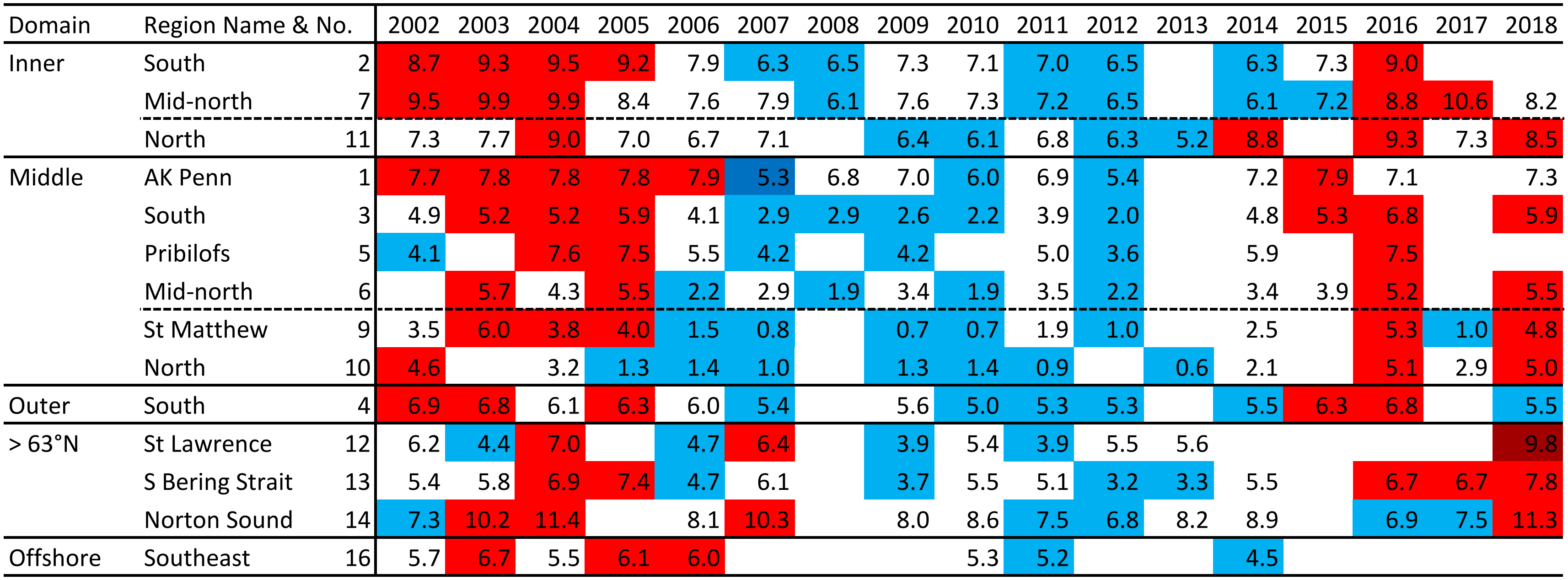


Figure 30: Map of stations within each Bering Sea Project region (Ortiz et al., 2012) sampled a minimum of 5 years between 2002 and 2018. We sampled three inner shelf regions (regions 2, 7, 11), six middle shelf regions (regions 1, 3, 5, 6, 9, 10), one outer shelf region (region 4) and three regions north and east of St. Lawrence Island (regions 12, 13, and 14).



Domain	Region Name & No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Inner	South	2	11.7	11.4	12.5	12.7	9.4	10.1	8.9	9.8	8.4	8.8	8.0		13.4	11.0	13.7		
	Mid-north	7	10.1	9.9	11.1	8.9	8.2	9.4	7.6	8.2	7.8	7.2	7.2		11.5	9.0	12.1	10.6	9.6
	North	11	8.7	7.8	10.0	7.1	7.9	8.4		8.2	8.5	7.6	7.2	8.6	9.9		11.4	9.2	10.1
Middle	AK Penn	1	11.3	11.1	10.5	11.7	10.1	10.3	9.6	9.1	8.9	9.0	9.4		12.4	11.1	12.2		9.7
	South	3	11.5	11.7	12.2	11.2	9.8	10.9	8.9	7.8	8.5	8.6	8.6		13.4	10.9	13.6		10.0
	Pribilofs	5	9.2		10.6	9.7	8.9	8.0		6.9		8.9	6.5		10.0		11.1		
	Mid-north	6		9.7	11.3	8.1	9.5	7.5	7.4	7.5	7.9	7.8	6.1		11.5	8.2	11.0		8.8
	St Matthew	9	8.8	7.4	8.9	6.7	7.5	6.8		7.5	7.1	7.4	3.8		7.7		9.9	8.3	9.1
	North	10	7.9		9.4	7.1	8.1	7.8		7.6	7.6	6.3		6.6	10.0		9.8	8.3	9.5
Outer	South	4	10.2	10.4	10.5	10.0	10.0	10.5		8.0	9.6	8.9	8.9		12.2	10.6	13.0		10.5
> 63°N	St Lawrence	12	6.4	8.7	9.1		8.4	8.9		6.7	5.4	5.1	6.1	5.7					9.9
	S Bering Strait	13	6.2	7.3	10.3	7.9	7.2	8.8		6.9	7.5	5.9	5.0	6.4	9.9		8.4	7.6	8.9
	Norton Sound	14	7.4	10.5	12.0		10.4	10.4		9.7	9.0	8.3	7.5	9.5	10.7		11.8	9.0	11.5
Offshore	Southeast	16	9.0	9.7	8.2	8.8	8.3				8.2	8.8			9.2				

Figure 31: Mean Tabove (°C) color coded with anomaly normalized by standard deviation for each region, 2002–2018. Red indicates above average (>0.5), no shading indicates average (-0.5 to 0.5), and blue indicates below average (<-0.5) normalized anomaly. Dark red and dark blue indicate anomalies of >=2 or <=-2, respectively. Dashed lines separate regions ~54.5–60°N from those 60–63°N within inner and middle domains.

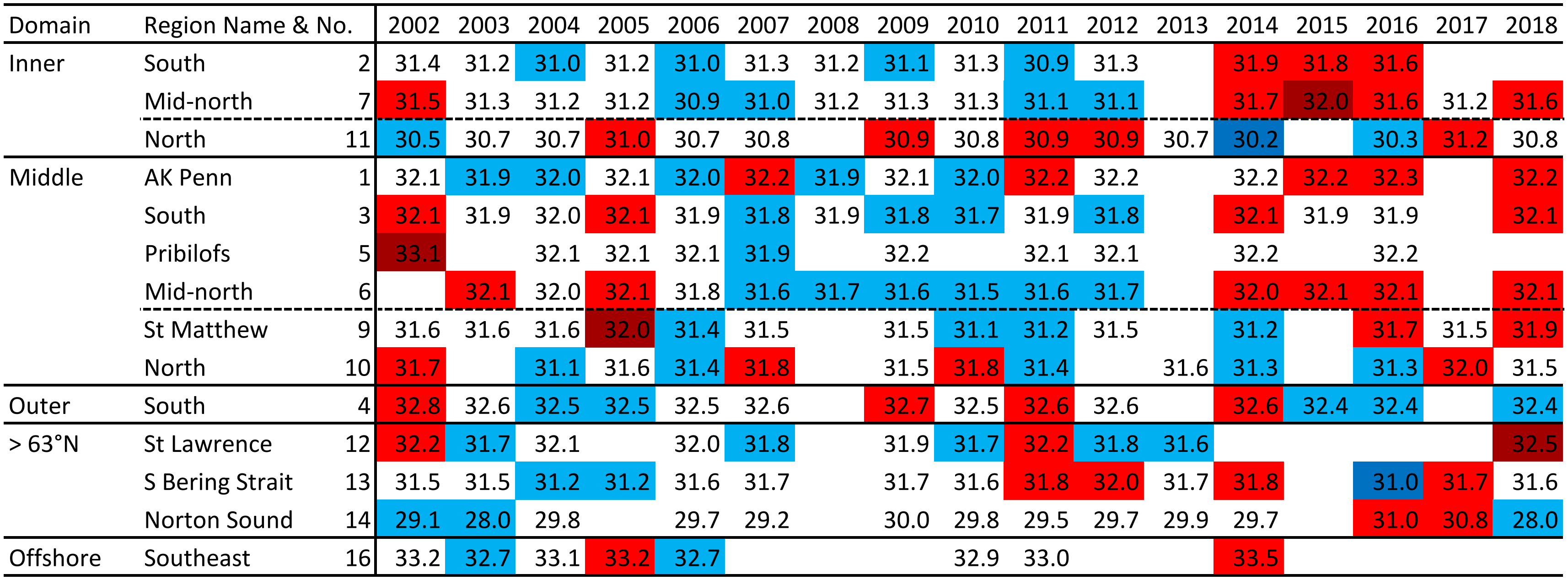


Domain	Region Name & No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Inner	South	2	8.7	9.3	9.5	9.2	7.9	6.3	6.5	7.3	7.1	7.0	6.5		6.3	7.3	9.0		
	Mid-north	7	9.5	9.9	9.9	8.4	7.6	7.9	6.1	7.6	7.3	7.2	6.5		6.1	7.2	8.8	10.6	8.2
	North	11	7.3	7.7	9.0	7.0	6.7	7.1		6.4	6.1	6.8	6.3	5.2	8.8		9.3	7.3	8.5
Middle	AK Penn	1	7.7	7.8	7.8	7.8	7.9	5.3	6.8	7.0	6.0	6.9	5.4		7.2	7.9	7.1		7.3
	South	3	4.9	5.2	5.2	5.9	4.1	2.9	2.9	2.6	2.2	3.9	2.0		4.8	5.3	6.8		5.9
	Pribilofs	5	4.1		7.6	7.5	5.5	4.2		4.2		5.0	3.6		5.9		7.5		
	Mid-north	6		5.7	4.3	5.5	2.2	2.9	1.9	3.4	1.9	3.5	2.2		3.4	3.9	5.2		5.5
	St Matthew	9	3.5	6.0	3.8	4.0	1.5	0.8		0.7	0.7	1.9	1.0		2.5		5.3	1.0	4.8
	North	10	4.6		3.2	1.3	1.4	1.0		1.3	1.4	0.9		0.6	2.1		5.1	2.9	5.0
Outer	South	4	6.9	6.8	6.1	6.3	6.0	5.4		5.6	5.0	5.3	5.3		5.5	6.3	6.8		5.5
> 63°N	St Lawrence	12	6.2	4.4	7.0		4.7	6.4		3.9	5.4	3.9	5.5	5.6					9.8
	S Bering Strait	13	5.4	5.8	6.9	7.4	4.7	6.1		3.7	5.5	5.1	3.2	3.3	5.5		6.7	6.7	7.8
	Norton Sound	14	7.3	10.2	11.4		8.1	10.3		8.0	8.6	7.5	6.8	8.2	8.9		6.9	7.5	11.3
Offshore	Southeast	16	5.7	6.7	5.5	6.1	6.0				5.3	5.2			4.5				

Figure 32: Mean Tbelow (°C) color coded by normalized anomaly as described in Figure 31.

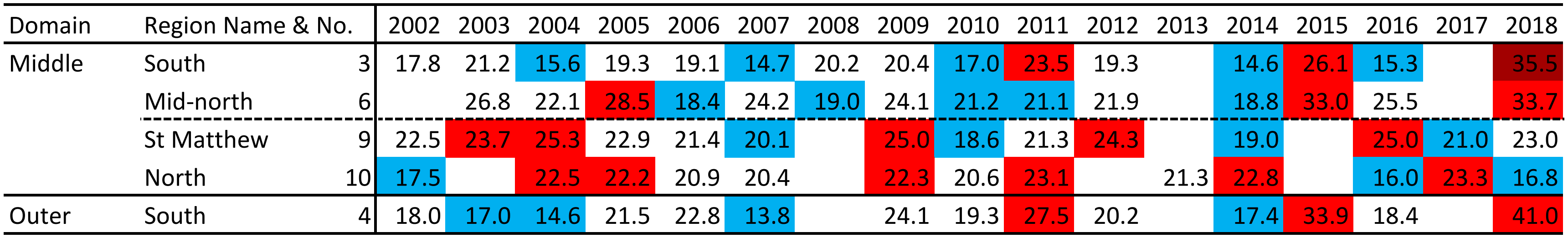
Domain	Region Name & No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Inner	South	2	31.0	30.9	30.9	30.6	30.6	31.1	30.8	30.6	31.1	30.6	31.1		31.5	31.3	31.2		
	Mid-north	7	31.4	31.3	31.2	31.1	30.9	31.0	31.1	31.2	31.2	31.1	31.0		31.4	31.8	31.4	31.2	31.5
	North	11	30.1	30.5	30.3	31.0	30.6	30.6		30.8	30.6	30.8	30.7	30.3	30.1		30.0	30.7	30.7
Middle	AK Penn	1	31.9	31.6	31.7	31.8	31.7	31.8	31.8	31.8	31.7	32.0	31.8		31.8	31.9	31.8		32.0
	South	3	31.9	31.6	31.7	31.7	31.4	31.4	31.5	31.4	31.3	31.5	31.4		31.8	31.7	31.7		31.9
	Pribilofs	5	32.8		31.9	32.0	32.0	31.7		31.8		31.7	31.7		31.9		32.0		
	Mid-north	6		31.9	31.9	32.0	31.5	31.5	31.4	31.4	31.2	31.3	31.4		31.6	31.8	31.8		31.9
	St Matthew	9	31.3	31.5	31.6	31.8	31.0	31.1		31.2	30.7	31.0	31.2		30.8		31.2	31.3	31.7
	North	10	31.5		31.1	31.3	30.9	31.2		30.9	31.1	31.1		30.8	30.7		31.0	31.4	31.2
Outer	South	4	32.2	31.9	31.9	32.0	31.9	31.9		32.0	31.8	32.1	32.1		31.9	31.9	31.8		32.0
> 63°N	St Lawrence	12	32.2	31.4	32.1		31.9	31.6		31.5	31.6	32.0	31.7	31.6					32.2
	S Bering Strait	13	31.1	30.5	30.8	31.2	31.3	31.4		30.6	31.2	31.5	31.5	31.2	31.1		29.8	31.0	31.4
	Norton Sound	14	27.9	26.4	28.7		25.6	28.7		27.6	28.1	28.2	28.4	28.2	26.2		23.7	28.6	27.3
Offshore	Southeast	16	32.6	32.4	32.6	32.8	32.4				32.6	32.5			32.6				

Figure 33: Sabove (PSU) color coded by normalized anomaly as described in Figure 31.



Domain	Region Name & No.	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Inner	South 2	31.4	31.2	31.0	31.2	31.0	31.3	31.2	31.1	31.3	30.9	31.3		31.9	31.8	31.6		
	Mid-north 7	31.5	31.3	31.2	31.2	30.9	31.0	31.2	31.3	31.3	31.1	31.1		31.7	32.0	31.6	31.2	31.6
	North 11	30.5	30.7	30.7	31.0	30.7	30.8		30.9	30.8	30.9	30.9	30.7	30.2		30.3	31.2	30.8
Middle	AK Penn 1	32.1	31.9	32.0	32.1	32.0	32.2	31.9	32.1	32.0	32.2	32.2		32.2	32.2	32.3		32.2
	South 3	32.1	31.9	32.0	32.1	31.9	31.8	31.9	31.8	31.7	31.9	31.8		32.1	31.9	31.9		32.1
	Pribilofs 5	33.1		32.1	32.1	32.1	31.9		32.2		32.1	32.1		32.2		32.2		
	Mid-north 6		32.1	32.0	32.1	31.8	31.6	31.7	31.6	31.5	31.6	31.7		32.0	32.1	32.1		32.1
	St Matthew 9	31.6	31.6	31.6	32.0	31.4	31.5		31.5	31.1	31.2	31.5		31.2		31.7	31.5	31.9
	North 10	31.7		31.1	31.6	31.4	31.8		31.5	31.8	31.4		31.6	31.3		31.3	32.0	31.5
Outer	South 4	32.8	32.6	32.5	32.5	32.5	32.6		32.7	32.5	32.6	32.6		32.6	32.4	32.4		32.4
> 63°N	St Lawrence 12	32.2	31.7	32.1		32.0	31.8		31.9	31.7	32.2	31.8	31.6					32.5
	S Bering Strait 13	31.5	31.5	31.2	31.2	31.6	31.7		31.7	31.6	31.8	32.0	31.7	31.8		31.0	31.7	31.6
	Norton Sound 14	29.1	28.0	29.8		29.7	29.2		30.0	29.8	29.5	29.7	29.9	29.7		31.0	30.8	28.0
Offshore	Southeast 16	33.2	32.7	33.1	33.2	32.7				32.9	33.0			33.5				

Figure 34: Sbelow (PSU) color coded by normalized anomaly as described in Figure 31.



Domain	Region Name & No.	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Middle	South 3	17.8	21.2	15.6	19.3	19.1	14.7	20.2	20.4	17.0	23.5	19.3		14.6	26.1	15.3		35.5
	Mid-north 6		26.8	22.1	28.5	18.4	24.2	19.0	24.1	21.2	21.1	21.9		18.8	33.0	25.5		33.7
	St Matthew 9	22.5	23.7	25.3	22.9	21.4	20.1		25.0	18.6	21.3	24.3		19.0		25.0	21.0	23.0
	North 10	17.5		22.5	22.2	20.9	20.4		22.3	20.6	23.1		21.3	22.8		16.0	23.3	16.8
Outer	South 4	18.0	17.0	14.6	21.5	22.8	13.8		24.1	19.3	27.5	20.2		17.4	33.9	18.4		41.0

Figure 35: Mixed layer depth (MLD; m) color coded by normalized anomaly as described in Figure 31.

Factors influencing observed trends: Sea ice during winter and spring extended further to the south as the climate cooled. The cold pool is related to sea ice and thus extends further south in years with higher sea ice coverage in the southern Bering Sea. The cold pool (located below the MLD) was always present in the north Bering Sea in the past (Stabeno et al., 2012), however this changed in recent years (2018, 2019) with very little ice in the northern Bering and early ice melt, resulting in high Tbelow for most regions. The lower bottom salinities near the coast (e.g., inner domain regions and Norton Sound) indicate major freshwater input from the Yukon and Kuskoquim rivers (Figures 30, 33, and 34). Variations in salinity in the middle and outer shelf may be partially related to wind direction, with southeasterly winds producing enhanced on-shelf flows of oceanic water in warm years (Danielson et al., 2012). Therefore, the lower salinity in cold years on the south middle shelf may be due to ice melt and possibly reduced onshore flow of higher salinity waters. Tabove and Sabove are influenced by temporal mixing events relating to episodic wind mixing/storm events, while Tbelow and Sbelow may better reflect longer term climatic shifts.

Implications: The variations of temperature and salinity between Bering Sea Project regions indicate that water mass properties vary considerably both spatially (horizontally across regions and vertically above and below the MLD) and interannually, and will impact ecosystem dynamics and distributions of zooplankton, fish, and other higher trophic levels. For example, larger more lipid rich zooplankton generally show increases in abundance in both the water column and in forage fish diets in cold compared to warm years (Coyle et al., 2011; Eisner et al., 2014, 2016). In addition, the high temperature and salinity north of St. Lawrence Island in 2018 may be associated with changes in currents and sea ice extent that led to recent movement of pollock and Pacific cod into this region. The co-occurrence of above average Tbelow and Sbelow was not observed in prior years at this location.

Eastern Bering Sea Winter Spawning Flatfish Recruitment and Wind Forcing

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Last updated: October 2019

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 change to off-shore in the 1990–1997 time series coincided 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 2019 and shown for 2011 through 2019 in Figure 36.

Status and trends: The 2019 springtime drift pattern appears unfavorable with consistent westerly drift during the 90-day period of the index. In contrast, 2018 was favorable where winds were predominately northward during the 90-day index. The 2017 drift pattern was mixed causing some difficulty in the 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 runs that are consistent with those which produced above-average recruitment in the original analysis (2015, 2018). The 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 offshore drift years, suggesting that this species may have different timing for spawning, larval occurrence, and settlement

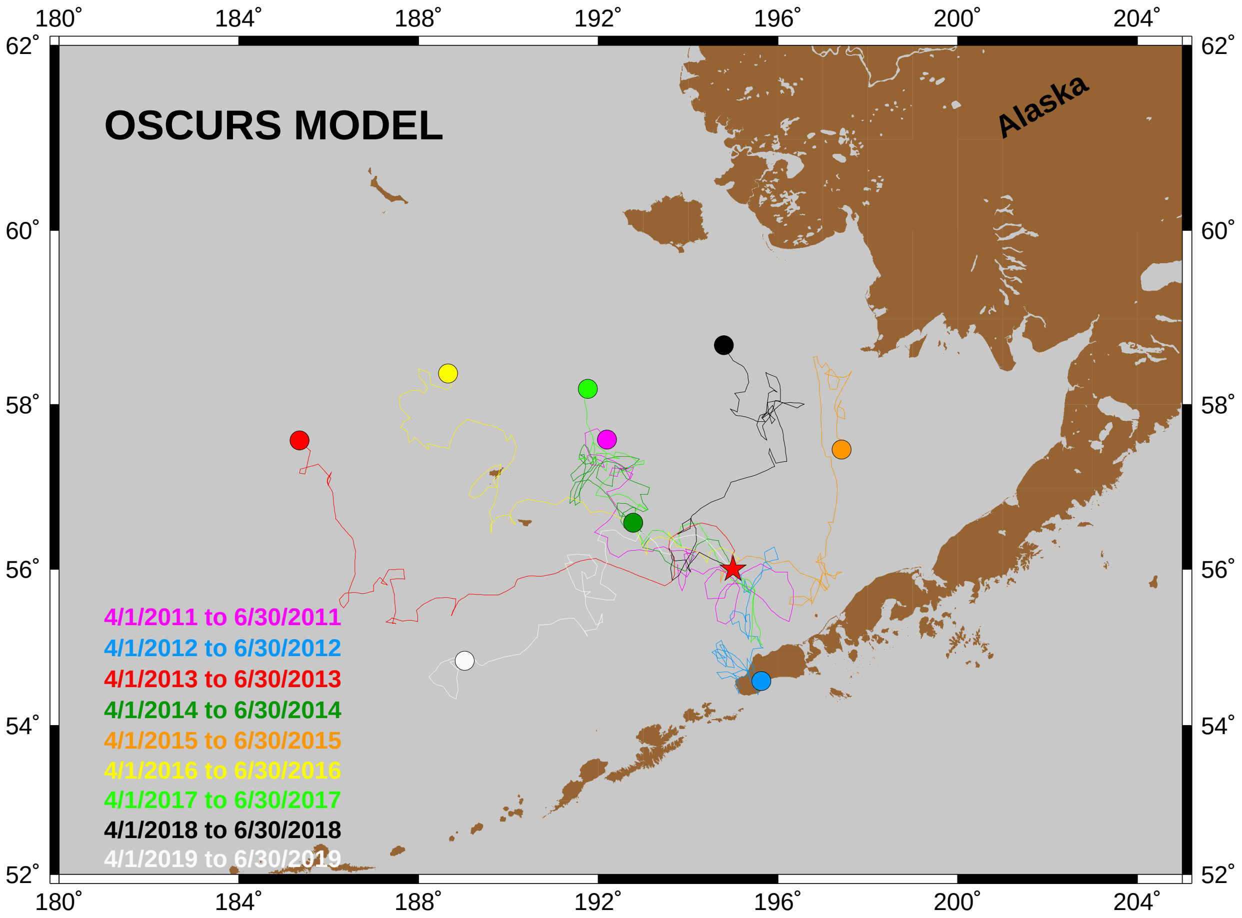

Figure 36: OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56°N, 164°W from 1 April–30 June for 2011–2019.

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 2019 springtime drift pattern appears to be consistent with years when below-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. Tidal transport may also play a role in larval dispersal (Wilderbuer et al., 2016).

Habitat

Structural Epifauna - Eastern Bering Sea Shelf

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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 (kg per hectare) was calculated and plotted for each species group by year for 1982–2019. 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 2016–2018, which were lower than the catch rates during 2010–2015, and sea whip estimates decreased from 2018 to a catch rate similar to that seen in 2017. These trends should be viewed with caution, however, because the consistency and quality of 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 37).

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.

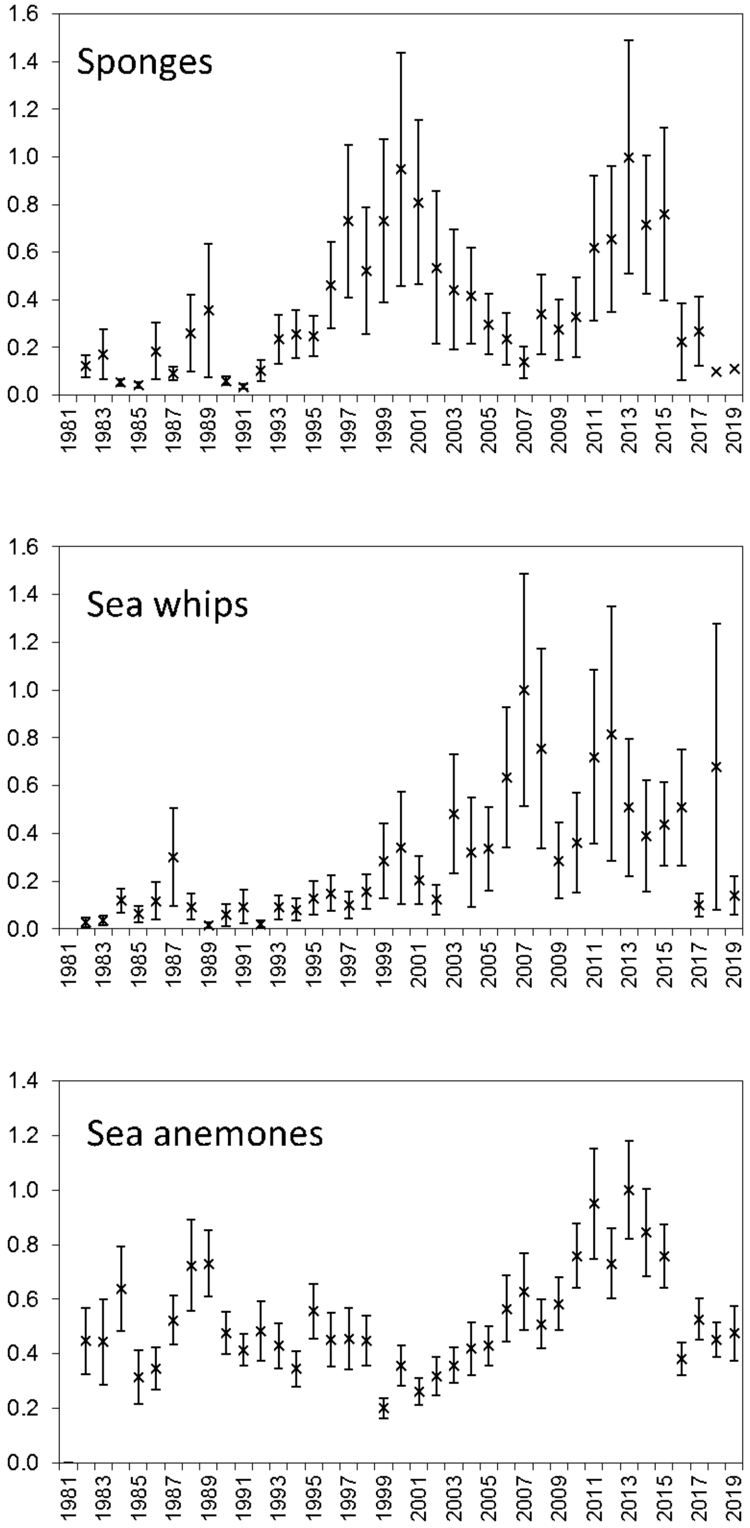

Figure 37: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE (kg per hectare) for benthic epifauna during the May to August time period from 1982–2019.

Primary Production

Phenology and Magnitude of Primary Production in the Eastern Bering Sea

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Description of indicator: In subarctic systems, such as the Bering Sea, the timing and magnitude of phytoplankton production can have high and long lasting effects on biological production (Lewandowska et al., 2015) which impact higher trophic level species including commercial fish stocks (Platt et al., 2003). The fate of the spring bloom, its timing, and the composition of the primary producers also impact benthic grazers in the Bering Sea (Hunt et al., 2002; Brown and Arrigo, 2013). Recent climatic changes in Bering Sea have resulted in lower sea ice and warming ocean temperatures (Stabeno and Bell, 2019), with consequent changes to the pelagic food web (DuffyAnderson et al., 2019). Understanding how such climatic changes impact primary production is essential, yet recent studies have suggested that warming could both increase or decrease primary production in this region (Brown and Arrigo (2013), and references therein), motivating future analyses.

Estimates of primary production rates vary depending on the methods (Cassar et al., 2015). Gross primary production (GPP) is the total amount of energy (often expressed in carbon units) produced by primary producers (e.g., phytoplankton, ice algae) during a given time. Net primary production (NPP) is the GPP minus autotrophic (e.g., phytoplankton) respiration (Cassar et al., 2015). Both metrics are informative yet it is important to realize the differences between them.

Here, we develop a production indicator that captures inter-annual phenology and magnitude of primary production in the eastern Bering Sea using satellite and mooring measurements. We used satellite data from 2003–2019 available from MODIS at a 4x4 km resolution and aggregated as 8-day composites[7]. There are several advantages of satellite data, including high spatial coverage, but these products are limited to measurements within the surface ocean and also have missing data due to ice and cloud cover, particularly in high latitude systems such as the Bering Sea (Cole et al., 2012). Because the satellite data are 8-day composites there is an inherent uncertainty of 8 days in the estimates of, for example, peak timing. Furthermore, these estimates only use a temperature-dependent production term to model phytoplankton growth and do not account for limitation of phytoplankton growth due to factors such as nutrient limitation, something that often occurs in the Bering Sea, particularly during mid to late summer (Eisner et al., 2016).

Daily in-situ measurements from moorings can provide more detailed information, albeit at a smaller spatial scale, on water column integrated primary production and provide full profiles to incorporate subsurface maxima. Here, we use the mooring data to validate the indicator estimates calculated from the satellite data. In the southeastern Bering Sea, sustained observations at the M2 mooring (56.9°N, -164.1°W) provide good representation of the middle Bering Sea shelf biophysical conditions (Stabeno et al., 2001). Starting in 2016, a surface buoy was deployed adjacent to M2 in spring and summer. A Profiling Crawler (Prawler) was attached to the mooring line to continuously collect vertical profiles of physical and biological data, including chlorophyll (chl-a) and dissolved oxygen, from the surface to approximately 50 meter depth.

Based on satellite measurements of sea surface chl-a, temperature, and light levels, we estimated NPP using the global VGPM model (Behrenfeld and Falkowski, 1997) in a 1° latitude x 1° longitude box

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[7] `https://coastwatch.pfeg.noaa.gov/erddap/index.html`

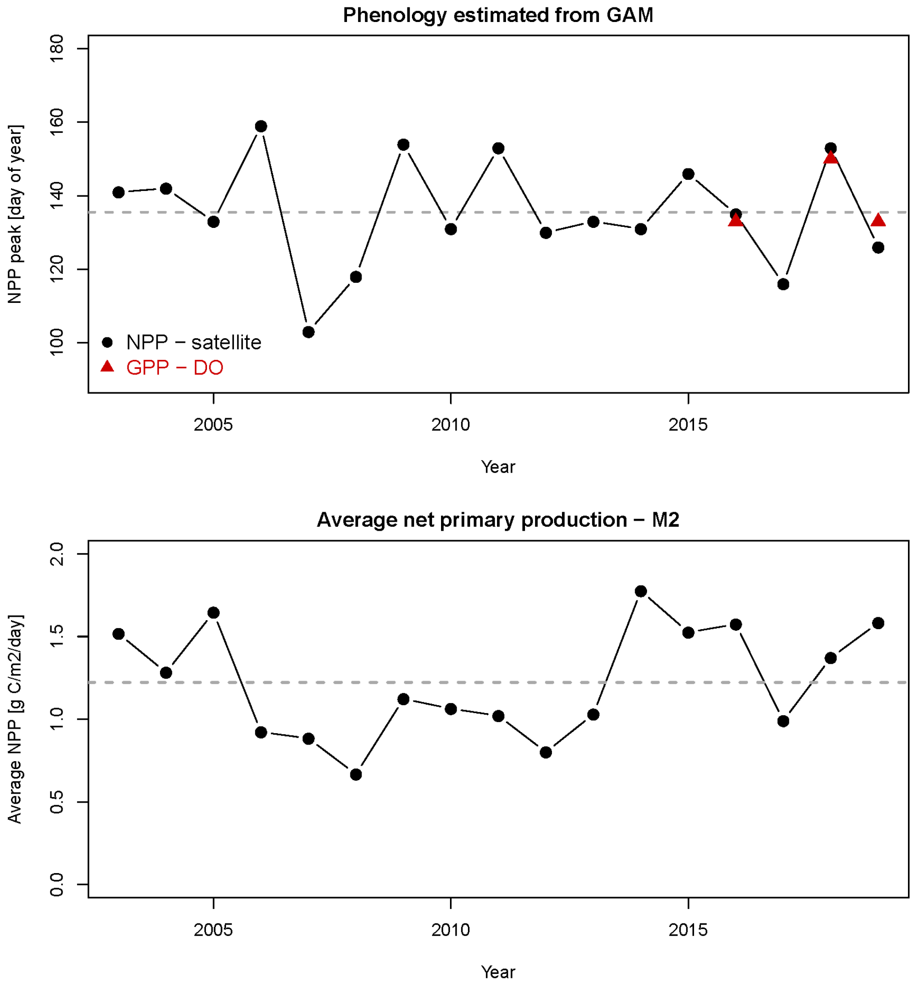

Figure 38: Long term dynamics at mooring M2 showing (i) the timing of net primary production (black) and gross primary production (red triangles) based on GAM phenology models and (ii) average daily net primary production for the period 15 April–18 September based on satellite estimates (black dots). The gray dotted line denotes the long term average of peak timing or total net primary production from the satellite estimates. Note that the phenology of gross primary production for 2019 is the earliest sampled data that was also the highest value. For 2017 no phenology estimate was possible as the phytoplankton bloom had already started by the time the Prawler was deployed.

surrounding M2 for 2003–2019. This area was chosen as the best comparison to the Prawler data because it includes enough pixels to retrieve consistent temporal coverage. We calculated total NPP for data covering the seasonal period 15 April–18 September, which allowed inclusion of data from 2019. Comparative analyses of data from 2003–2018 between our calculations and covering what can be considered a full growing season (15 March–30 October) were highly correlated (r^2=0.98, $p<0.01$, N=16, data not shown).

From the M2 Prawler, we estimated daily rates of GPP using dissolved oxygen for 2016–2019 (Cox et al., 2015). The GPP estimates provide daily estimates but were smoothed to a 15-day window following recommendations in Cox et al. (2015). Also note that the GPP estimate for 2019 was restricted to the period 1 May–30 June, compared to the other three years. We then calculated i) total satellite derived NPP during the ice-free growing season (15 April–18 September) and ii) the timing of the peak spring bloom based on NPP (satellite) and GPP (dissolved oxygen) data. The timing of the bloom was estimated by fitting simple GAM models (Wood and Wood, 2016; Boyce et al., 2017) to the NPP and GPP data. Lastly, we provide a more detailed evaluation for 2018 and 2019 of how well satellite and Prawler data captured the seasonal dynamics by comparing satellite-derived chl-a and NPP and Prawler GPP and chl-a estimates estimates.

Status and trends: The timing of the peak bloom in 2019 estimated from satellite data was earlier (6 May) than the long term average (15 May) based on the entire time series from 2003–2019, and earlier than 2018. The 2018 bloom peak at M2, estimated as 2 June, was late as also noted elsewhere in the eastern Bering Sea (bloom initiation around 25 May, DuffyAnderson et al. (2019)). Estimated long term average production was slightly above average in 2019 and higher than 2018 which was also close to the long-term average. 2019 production was close to values observed during warmer years in 2014–2016 (Figure 38, see Overland et al. in Siddon and Zador (2018)). Prawler data were available for the years 2016–2019; in all but 2017 the Prawler was deployed by the initiation of the spring bloom.

Overall, estimates of peak oxygen-derived GPP closely followed the phenology estimates from the satellite-derived NPP (Figure 38, red triangles). No peak estimate was possible for the year 2017, as the Prawler was deployed after the bloom initiation. In addition, the year 2017 deserves more attention as this was a highly abnormal year with a long subsurface chl-a max during spring, a feature verified from fluorometers moored at discrete depths on the primary M2 mooring. A closer look at the seasonal cycles of 2018 and 2019 (Figure 39) show that the Prawler, satellite chl-a, NPP, and oxygen GPP data generally capture the annual phenological cycle well. Overall, the similarity between these data supports the value in integrating these metrics to further improve estimates of primary production for the eastern Bering Sea.

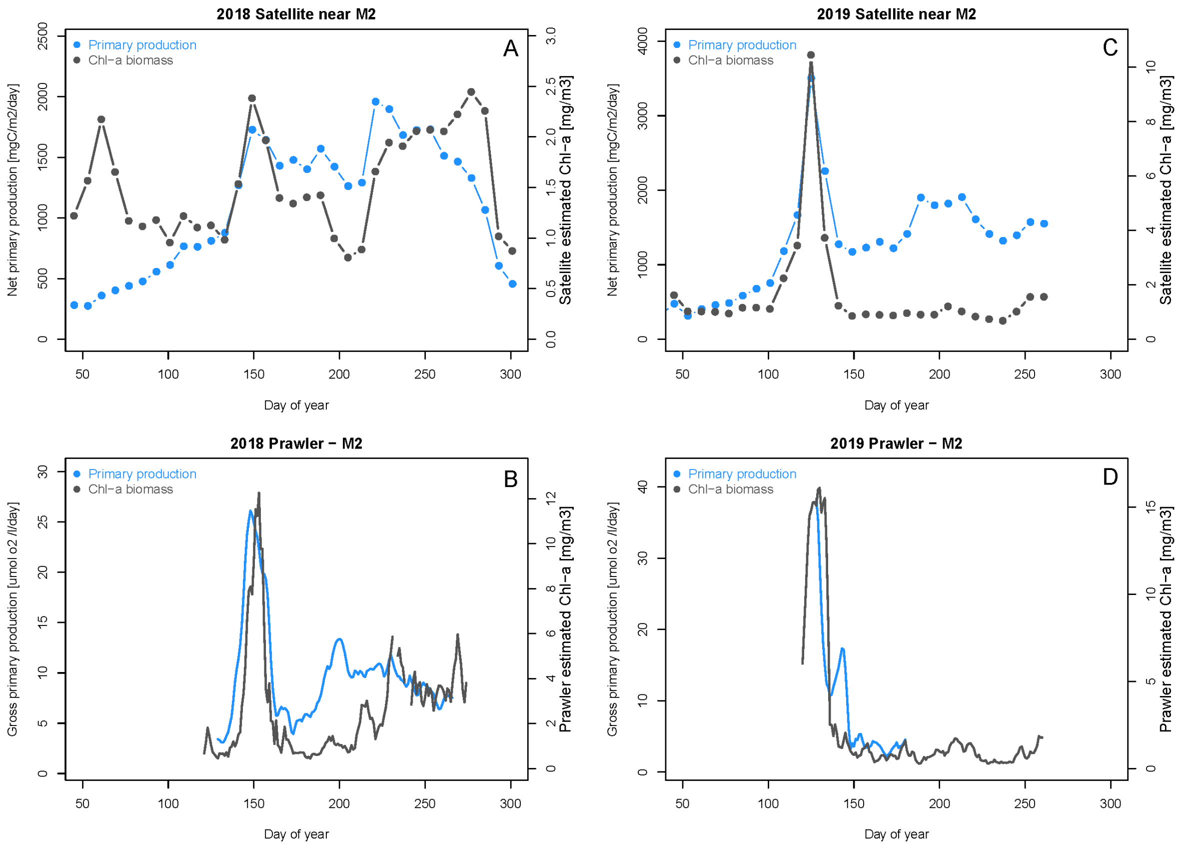

Figure 39: Seasonal cycle for 2018 (A,B) and 2019 (C,D), showing satellite estimated NPP (blue) and chlorophyll-a (black) in (A) and (C) and M2 Prawler surface (0-10m) averaged GPP from dissolved oxygen (blue) and chlorophyll-a (black) from in situ fluorometer measurements (not calibrated with discrete samples) in (B) and (D). For 2019 GPP estimates from the dissolved oxygen data were not calculated for the entire cycle due to uncertainty in the data after 30 June.

Factors influencing observed trends: Increasing temperatures enhance phytoplankton growth rates (Kremer et al., 2017) and our findings of higher average NPP during the growing season in the recent warm years, including 2019, concur with other NPP satellite estimates of warm years (Brown and Arrigo, 2013). Previous studies have highlighted that there is a good coupling between temperature and sea ice dynamics and the fate of primary production, however the lack of sea ice in the Bering Sea in recent years (DuffyAnderson et al., 2019; Stabeno and Bell, 2019) could suggest that the timing of the bloom is now less constrained by sea ice than previously. Our analyses are preliminary and restricted to NPP estimates from a global satellite model and preliminary GPP estimates based on oxygen Prawler data. Currently our comparisons primarily show relative trends across years. The different metrics are not currently directly comparable in absolute terms.

Implications: Primary producers provide fundamental energy and nutrients for grazers and higher trophic level species. Understanding how climatic perturbations, and particularly the recent warm periods (Stabeno and Bell, 2019) influence primary production is a critical component in understanding ecosystem dynamics in the Bering Sea. Lack of sea ice also changes the phytoplankton composition in favor of more pelagic species instead of ice algae, changes that likely have strong impacts on benthic-pelagic energy fluxes (Hunt et al., 2002). These metrics help better capture how climatic changes influence production dynamics, which have implications for the amount of energy available for higher trophic level species in the eastern Bering Sea.

Dissolved Total Inorganic Nitrogen Concentrations Above and Below the Pycnocline in the Eastern Bering Sea

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Last updated: August 2019

Description of indicator: We viewed total dissolved inorganic nitrogen (DIN) concentrations (μm) above and below the pycnocline during late summer/early fall, 2003–2018 in the eastern Bering Sea. Data are divided by oceanographic domain (inner [0–50 m] and middle [51–100 m]; outer [101–200 m] is omitted due to inconsistent sampling) and further split between the northern and southern shelf at 60°N. DIN (nitrate, nitrite, and ammonia) above the pycnocline at the surface mixed layer represent what is currently available for primary production at the end of summer (storm activity/wind mixing of deep nutrients to the surface tend to be lower during the summer, and surface nutrient stores are often depleted). Nutrients below the pycnocline represent what is potentially available should wind mixing become strong enough to break down the pycnocline and mix deep water to the surface. Sometime during autumn when wind storms increase in frequency and intensity, there is usually a second significant bloom of phytoplankton (though smaller than the spring bloom) after the summer pycnocline breaks down. During this time deep nutrient stores are brought to the surface. This process is important for sending a new round of energy through the food web just prior to the onset of winter.

Status and trends: DIN above and below the pycnocline varies from year to year over the eastern Bering Sea shelf in all domains. As expected, the inner domain, which is more thoroughly mixed from surface to deep, is more highly correlated between the surface and deep waters (with significant correlation in both the north and south ($P = 0.047$ and $P = 0.031$, respectively), while in the middle domain there is considerably less correlation (Figure 40). Also as expected, deeper stores of nutrients are more often found at higher concentrations than their surface counterparts. Dissolved inorganic nitrogen both above and below the pycnocline were notably high during 2018.

Factors influencing observed trends: During summer, the strength and frequency of summer storm events and water column stratification influence the amount of nutrients brought to surface waters from depth. Late summer concentrations of DIN at the surface may serve as an indicator of nutrient availability, with higher concentrations seen during windy years and lower stratification, and low concentrations seen when storm activity is minimal and stratification is high (Gann et al., 2016; Eisner et al., 2016). Accordingly, years with higher water column chlorophyll a (estimate of

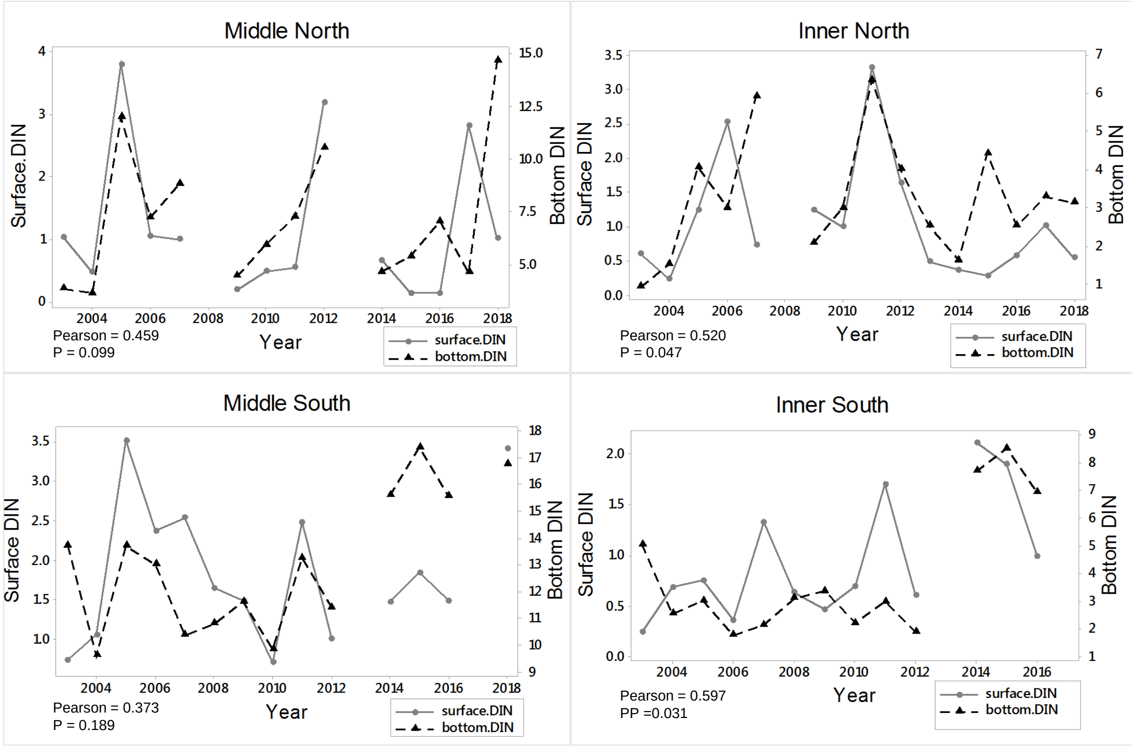

Figure 40: Mean total dissolved inorganic nitrogen concentrations (μm) above and below the pycnocline with Pearson's correlation coefficient (surface DIN vs bottom DIN) and P-values shown (2003–2018). Note: missing data indicate areas and years where no survey was conducted.

phytoplankton biomass) are associated with higher wind mixing (see p. 72). Diminished nutrient stores leading to lower production in the upper water column may directly affect food stores for higher trophic levels and lead to slowed growth of age-0 pollock during summer months. However, there was a divergence between the values for surface silicic acid and pollock weight during 2018 that may indicate signs of a changing dynamic between nutrients and age-0 pollock in the south Bering Sea (see p. 120).

Implications: An increase in surface DIN concentrations may imply an increase in summertime wind mixing events during 2018. Generally higher nutrient stores at the surface mean higher production and more energy available for transfer to higher trophic levels. However, due to the divergence observed between nutrient stores and age-0 pollock in the south middle domain mentioned above, it is unclear how the 2018 year class will fare in their recruitment to age-1.

Phytoplankton Biomass and Size Structure During Late Summer to Early Fall in the Eastern Bering Sea

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Last updated: October 2019

Description of indicator: BASIS fisheries oceanography surveys were conducted in the eastern Bering Sea mid-August to late September for seven warm (2003–2005, 2014–2016, and 2018), one average (2006), and six cold (2007–2012) years. Variations in chlorophyll a (chla) were used to evaluate spatial and interannual differences in total phytoplankton biomass and size structure (an indication of phytoplankton species). The ratio of large (>10 μm) phytoplankton biomass to total biomass (>10 μm chla / total chla) were estimated from discrete water samples filtered through GFF and 10 μm filters and analyzed with standard fluorometric methods (Parsons et al., 1984). Integrated chla values were estimated from CTD fluorescence profiles, calibrated with discrete chla (GFF) samples. Chla data were averaged over the top 50 m of the water column or to the bottom for shallower stations. Water column stability was estimated over the top 70 m (Simpson et al., 1978). Similarly, a stratification index was estimated at PMEL Mooring 2 (M2) (Ladd and Stabeno, 2012; Eisner et al., 2016). Friction velocity cubed (u^{*3}), a proxy for wind mixing, was obtained from NCEP reanalysis at M2 (courtesy of Nick Bond). Normalized anomalies of temperature, u^{*3}, stratification index, integrated chla and large size fraction chla are shown for the southeastern Bering Sea middle shelf for 2003–2018 (Figure 41).

Status and trends: Highest phytoplankton biomass was observed in the south outer shelf (100–200 m) with highest values inshore of Bering Canyon, near the Pribilof Islands, along the Aleutian Islands, north of St. Lawrence Island and on the south inner shelf (<50 m) (Figure 42). Larger phytoplankton were observed on the inner shelf and near the Pribilof Islands, and smaller phytoplankton on the south middle and outer shelf. Integrated chla varied 3-fold among all years, with the highest values seen in 2005 in the south and 2003 in the north (Figure 43). For the earlier years (2003–2012) higher fractions of large phytoplankton were associated with higher integrated chla. The mean size of phytoplankton assemblages were larger in early warm (2003–2005) than in cold (2006–2012) years in the south. In contrast, in 2014–2016 and 2018 (warm years) integrated chla was average, whereas large size fraction ratios were below average in 2014–2016, but above average in 2018 (Figure 41). The lowest percent large (highest % small) phytoplankton for our time series was seen in 2014 (Figure 43). This 2014 anomaly was due to an extensive coccolithophore bloom over the north and south middle shelf (see p. 77). Coccolithophores are small phytoplankton cells (2–5 μm) with calcium carbonate plates that give the water a milky aqua appearance. Coccolithophores were also observed in 2015 and 2016, but not in 2018. In 2018, the large size fraction ratio was low in the north, in contrast to the south (Figure 43).

	T above	T below	u^{*3}	Stability index	Int Chla	Large chla ratio
2003	0.7	0.7	-0.6	0.3	1.1	0.9
2004	1.2	0.5	0.6	1.6	0.6	1.4
2005	0.4	1	2.7	0.6	2.5	2.2
2006	-0.1	-0.4	-0.2	-0.6	-0.6	-0.3
2007	-0.2	-0.7	-0.3	1.5	-1.1	-0.9
2008	-0.8	-0.8	-1.4	-1.1	-1.3	-0.7
2009	-1.3	-0.7	0.4	-0.8	0.1	0.1
2010	-1	-1.2	-0.2	-0.1	-0.8	-0.5
2011	-0.9	-0.2	-0.1	0	0.7	-0.1
2012	-1.3	-1.2	0	-1.3	0.4	-0.1
2013	NA	NA	NA		NA	NA
2014	1.6	0.1	-1.2		-0.5	-1.5
2015	0.3	0.6	0.4		-0.2	-0.7
2016	1.6	1.3	-0.8		-0.5	-0.6
2017	NA	NA	NA		NA	NA
2018	-0.2	1	0.6		-0.4	0.8

Figure 41: Normalized anomalies (mean yearly value minus time series average, normalized by standard deviation) for 2003 to 2018 (or to 2012 for stratification index) for the south middle shelf (Bering Project regions 3 and 6, Ortiz et al. (2012)). Anomalies were calculated for temperature (T) above and below the pycnocline, integrated chla and ratio of large (>10 μm) to total chla over the top 50 m for August–September from BASIS, and stratification index and friction velocity cubed (u^{*3}) for August at M2. Year is colored as red for warm, black for average, and blue for cold. Shading indicates if anomaly is positive (dark gray, >0.5), small (no shading, -0.5 to 0.5), or negative (light gray, <-0.5).

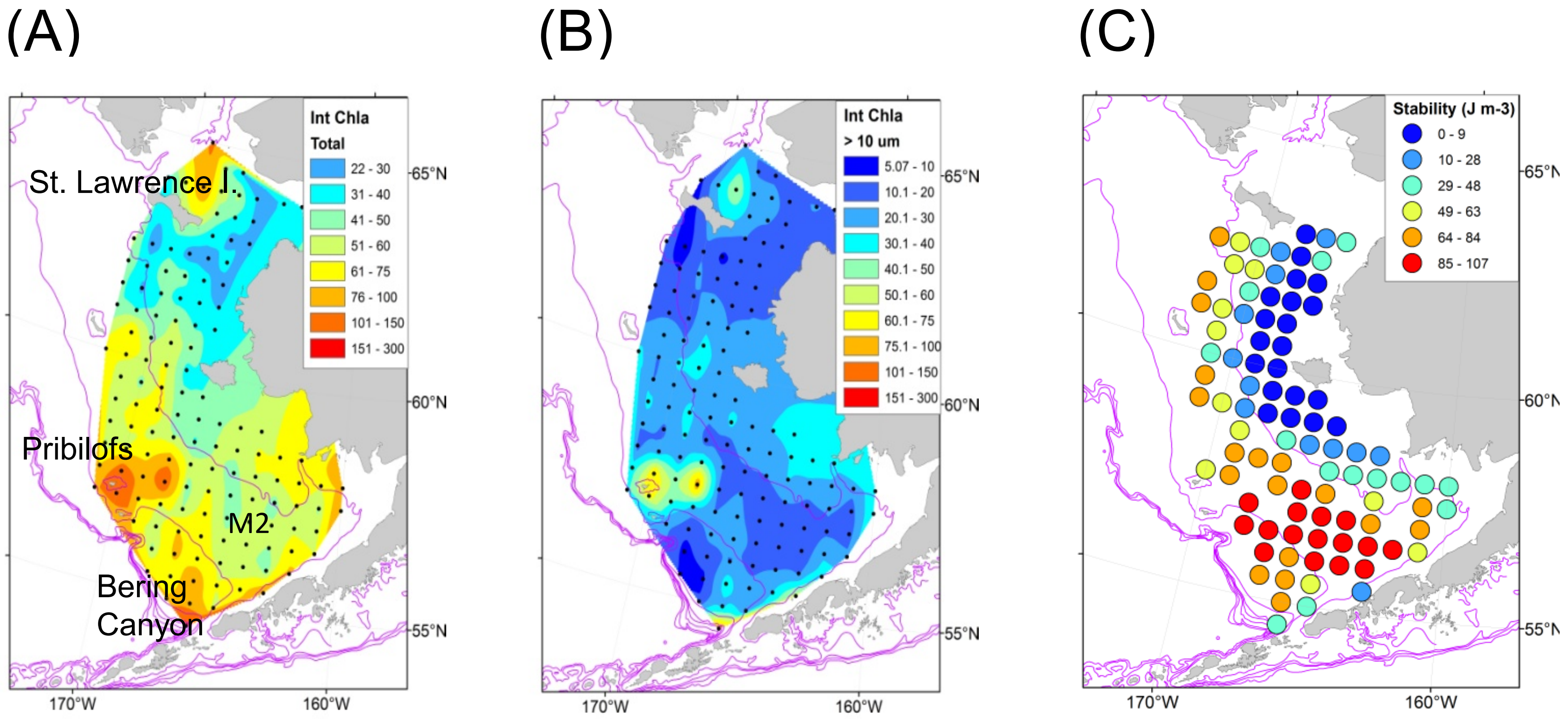

Figure 42: Contours of integrated total chla (mg m^{-2}) (A) and integrated >10 μm chla (B) averaged over 2003–2012, and stability (C) averaged over 2003–2009. Bathymetry contours are shown for 50 m, 100 m, and 200 m (shelf break).

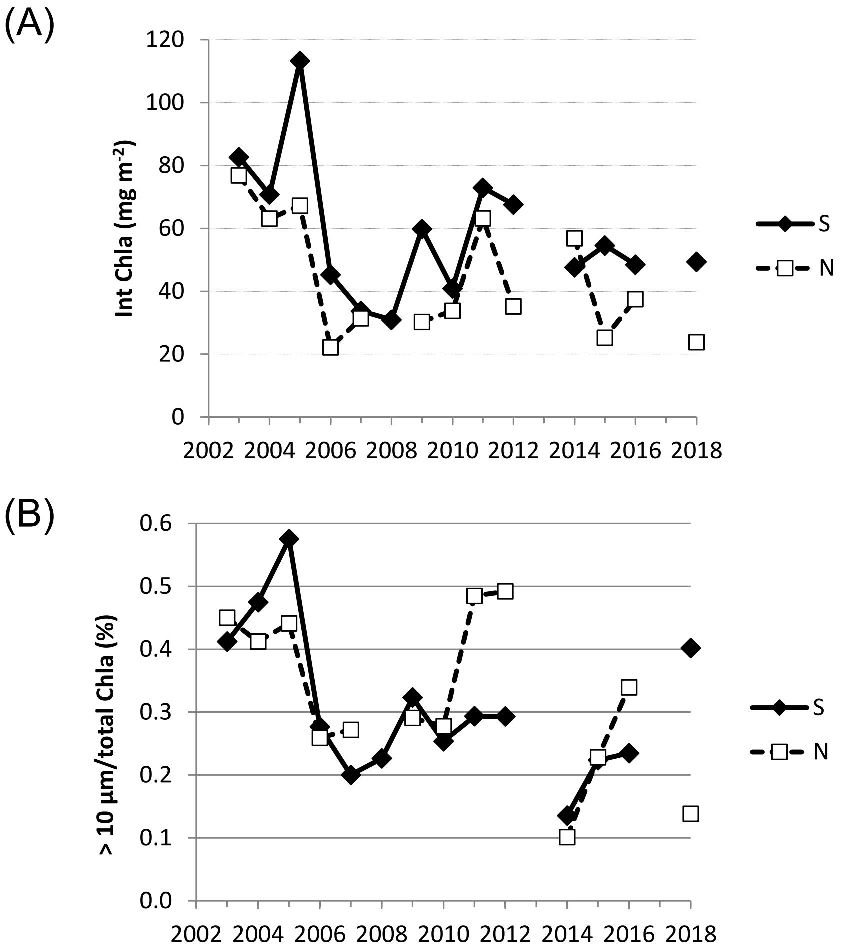

Figure 43: Integrated total chla (A) and ratio of large assemblages to total (>10 μm /total chla) (B) for the middle shelf in the south (S, 54.5–59.5°N, Bering Sea Project regions 3 and 6) and north (N, 60–63°N, Bering Sea Project regions 9 and 10) for 2003–2018. No data for 2013 or 2017. Note that north middle shelf data were sparse (n=6, 5, and 6 stations for (A) and 6, 5, and 4 stations for (B) for 2015, 2016, and 2018 respectively).

Factors influencing observed trends: Water column stability (or stratification), wind, and temperature can influence interannual and spatial variations in phytoplankton biomass. For the south middle shelf, a positive association was observed between August u^{*3} (wind mixing 2–3 weeks prior to chla sampling) and integrated chla in the top 50 m (Figure 44). Deep, nutrient-rich waters may be mixed to the surface to fuel production of assemblages of large phytoplankton (e.g., diatoms) during periods of high winds and low water column stability. Phytoplankton growth may be enhanced at higher temperatures, depending on species. For example, the highest chla and largest size fractions were seen in 2005, a period with high August wind mixing, average stability, and high water column temperature (Figure 41). In 2018, the above average wind mixing was associated with above average integrated chla. Note that the south Bering Sea survey in 2018 was 3 weeks later than average and may have captured fall (i.e., start of fall bloom) rather than late summer conditions. The lowest chla and smallest size fractions were observed in 2008, a period with low wind mixing, high stability, and low water column temperature. The low wind mixing in 2014 could also have favored formation of the coccolithophore bloom; these blooms are thought to be associated with low nutrient conditions. Spatially, low chla and small phytoplankton assemblages were seen in the area of highest stability, in the southeastern middle shelf near M2 (Figure 42).

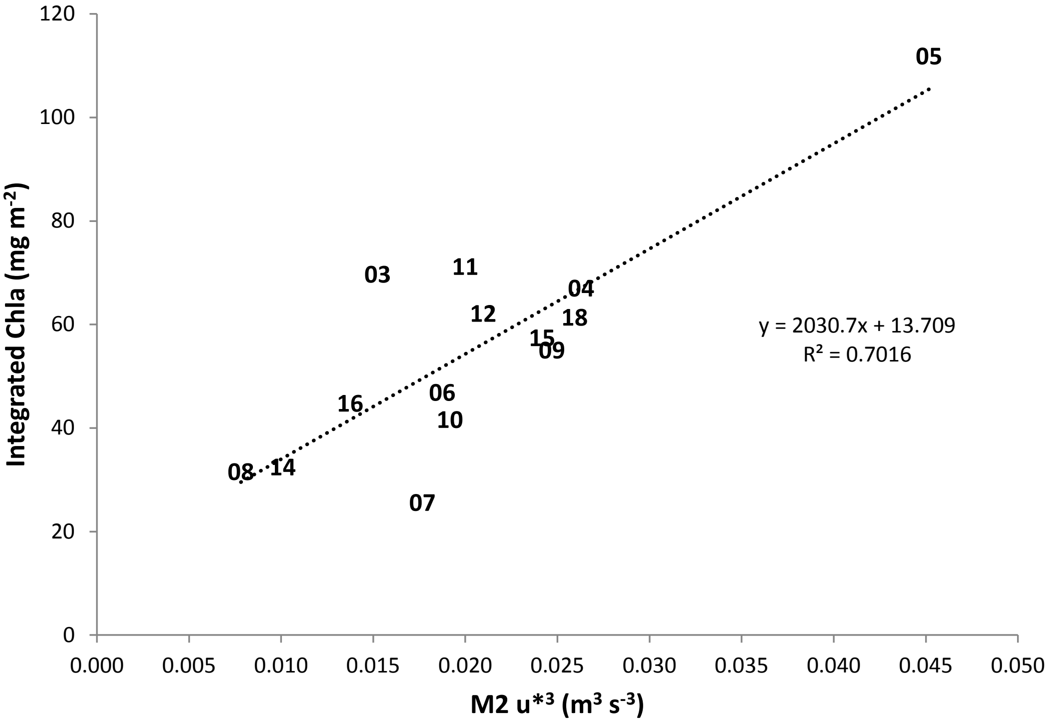

Figure 44: Linear regression between mean August u^{*3}, an indicator of wind mixing, at M2 and integrated chla for the south middle shelf in Bering Sea Project region 3 (region near M2) for 2003–2018. No data for 2013 or 2017. For 2018, chla data were collected ∼3 weeks late (28 September) compared to other years (mean 2003–2016=5 September, SD=8.5 days). To account for this delay we estimated the mean u^{*3} for the period 23 August–22 September for 2018, instead of 1–31 August as used for earlier years.

Implications: Phytoplankton dynamics determine the amount and quality of food available to zooplankton and higher trophic levels, and are thus important to ecosystem function. For example, smaller phytoplankton assemblages may lead to longer food webs and a less efficient transfer of energy to seabirds, fish, and marine mammals. The cloudy water associated with coccolithophore blooms may also limit feeding by visual predators (e.g., surface feeding fish and seabirds). The low percent of large phytoplankton cells in the north in 2018 is consistent with other measures of low productivity in this region (e.g., few large copepods, lower abundances of forage fish, extensive sea bird die-offs, (DuffyAnderson et al., 2019). Phytoplankton size and biomass data can help us discern relevant ecosystem processes during the critical late summer period prior to the over-wintering of key forage fish (e.g., juvenile pollock, cod, salmon) (Eisner et al., 2016).

Coccolithophores in the Bering Sea

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Description of indicator: Blooms of coccolithophores, a unicellular calcium carbonate-producing phytoplanktonic organism, are easily observed by satellite ocean color instruments due to their high reflectivity (Figure 45). Coccolithophores produce calcium carbonate plates (coccoliths) that contribute to particulate inorganic carbon (PIC) in the ocean (Matson et al., 2019). Blooms are most commonly observed and cloud cover is typically lower during September than other months allowing for better quantification (Iida et al., 2012). An interannual index of the average area (km^2) covered by coccolithophores during the month of September is calculated with monthly average mapped PIC (Balch et al., 2005; Gordon et al., 2001) data from the MODIS-Aqua satellite (available since 2002) provided by NASA Goddard Space Flight Center, Ocean Ecology Laboratory (MODIS-Aqua, 2018). PIC >0.0011 mol/m^3 was used to estimate the location of the influence of coccolithophore blooms. This threshold was derived by Matson et al. (2019). Highly reflective waters in shallow water near the coast can be due to re-suspended diatom frustules rather than coccoliths (Broerse et al., 2003). Thus, the index is calculated from the region south of 60°N and deeper than 30m depth to avoid contamination by shallow regions around St. Matthew and St. Lawrence islands and along the Alaskan coast, as well as sediment associated with the Yukon River. Because blooms are often largely confined to either the middle shelf or the inner shelf (Ladd et al., 2018), two indices are calculated, one for the middle shelf (50–100m depth) and one for the inner shelf (30–50m depth).

Note that the methodology for calculating the index has changed since the previous contribution (2017). Because the index represents only a monthly estimate of spatial area influenced by coccolithophore blooms (and not more rigorous biomass or other biogeochemical estimates), it was determined that PIC provided the necessary information and is easily available data. Correlation with the previous index is $R^2=0.98$.

Before 1997, coccolithophore blooms in the eastern Bering Sea were rare. A large bloom (primarily *Emiliania huxleyi*) occurred in 1997 (Napp and Hunt, 2001; Stockwell et al., 2001) and for several years thereafter. During the 1997 bloom, the bloom was associated with a die-off of short-tailed shearwaters (*Puffinus tenuirostris*), a seabird commonly seen in these waters (Baduini et al., 2001). It was thought that the bloom may have made it difficult for the shearwaters to see their zooplankton prey from the air and even underwater (Lovvorn et al., 2001). Since then, coccolithophore blooms in the eastern Bering Sea have become more common. Satellite ocean color data suggest that blooms are only found where water depths are between 20 and 100 m. Blooms typically peak in September and interannual variability is related to both very weak and strong stratification (Iida et al., 2012; Ladd et al., 2018).

Status and trends: Annual images (Figure 45) show the spatial and temporal variability of coccolithophore blooms in September. Annual indices are obtained from these satellite data by averaging spatially over the inner and middle shelf (Figure 46). Coccolithophore blooms were particularly large during the early part of the record, 1997–2000 (not shown). At the start of the MODIS-Aqua record, the index was low and remained low ($<$50,000 km^2) through 2006. In 2007, the index rose to almost double that observed in 2006 ($\sim$102,000 km^2). A higher index ($>$50,000 km^2) was observed in 2007, 2009, 2011, 2014, and 2016 for the middle shelf and in 2011 and 2014 ($>$20,000 km^2) for the inner shelf. September 2017 exhibited the lowest index of the record with 2,369 km^2 over both middle and inner shelves. The bloom index remained below average in 2018 and 2019.

Factors influencing observed trends: It has been suggested that the strength of density stratification is the key parameter controlling variability of coccolithophore blooms in the eastern Bering Sea (Iida et al., 2012; Ladd et al., 2018). Stratification influences nutrient supply to the surface layer. Stratification in this region is determined by the relative properties (both temperature and salinity) of two water masses formed in different seasons, the warm surface layer formed in summer and the cold

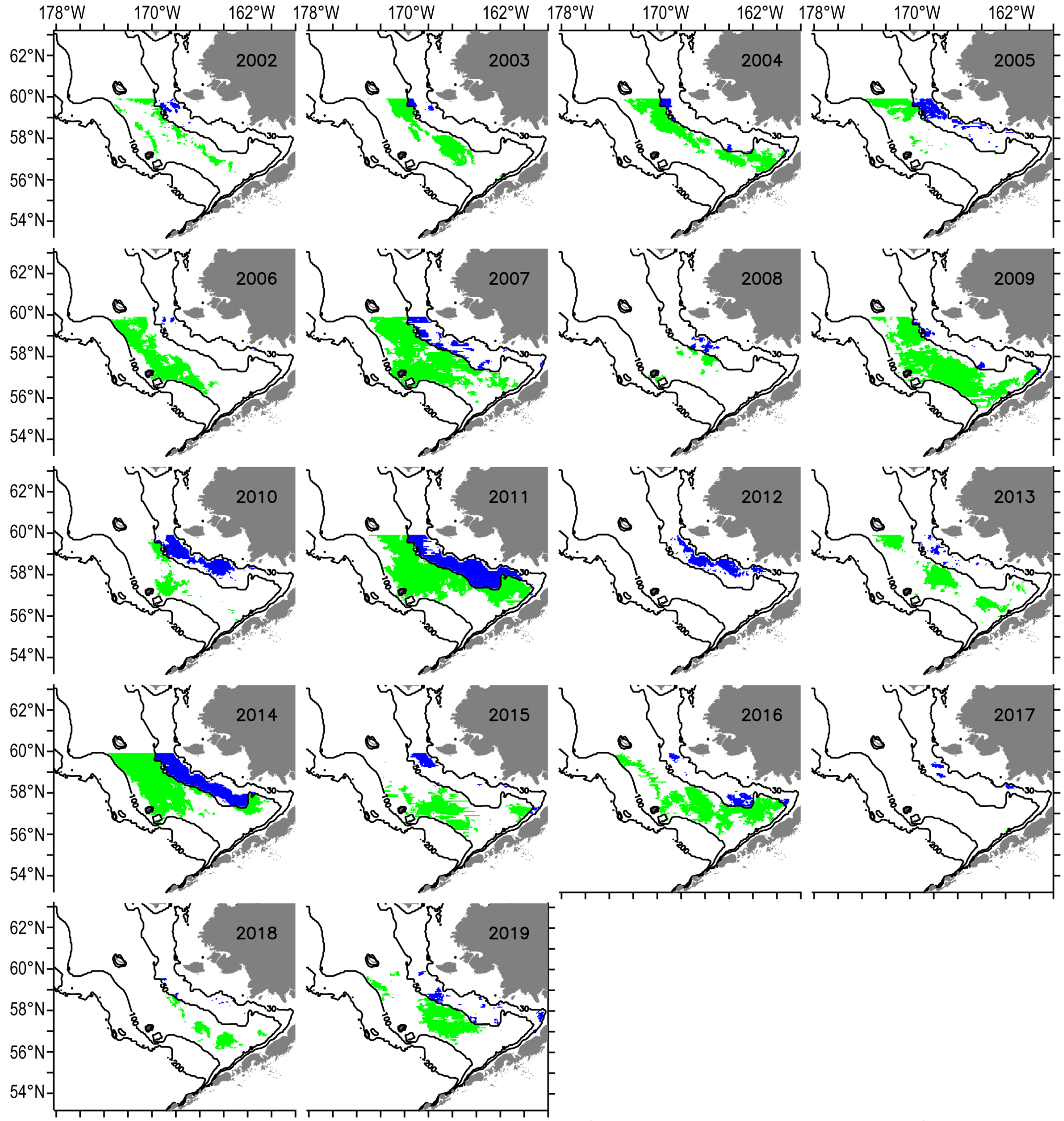

Figure 45: Maps illustrating the location and extent of coccolithophore blooms in September. Color satellite ocean color pixels exceeding the threshold indicating coccolithophore bloom conditions; blue is inner shelf and green is middle shelf. These data are used to calculate the areal index in Figure 46.

bottom water influenced by ice distributions the previous winter. Thus, the strength of stratification is not solely determined by summer temperatures and warm years can have weak stratification and vice versa (Ladd and Stabeno, 2012).

Implications: Coccolithophore blooms can have important biogeochemical implications. The Bering Sea can be either a source or a sink of atmospheric CO_2, with the magnitude of coccolithophore blooms and the associated calcification playing a role (Iida et al., 2012). In addition, variability in the dominant phytoplankton (diatoms vs. coccolithophores) is likely to influence trophic connections with the smaller coccolithophores resulting in longer trophic chains. Coccolithophores may be a less desirable food source for microzooplankton in this region (Olson and Strom, 2002). As noted previously, the striking milky aquamarine color of the water during a coccolithophore bloom can also reduce foraging success for visual predators.

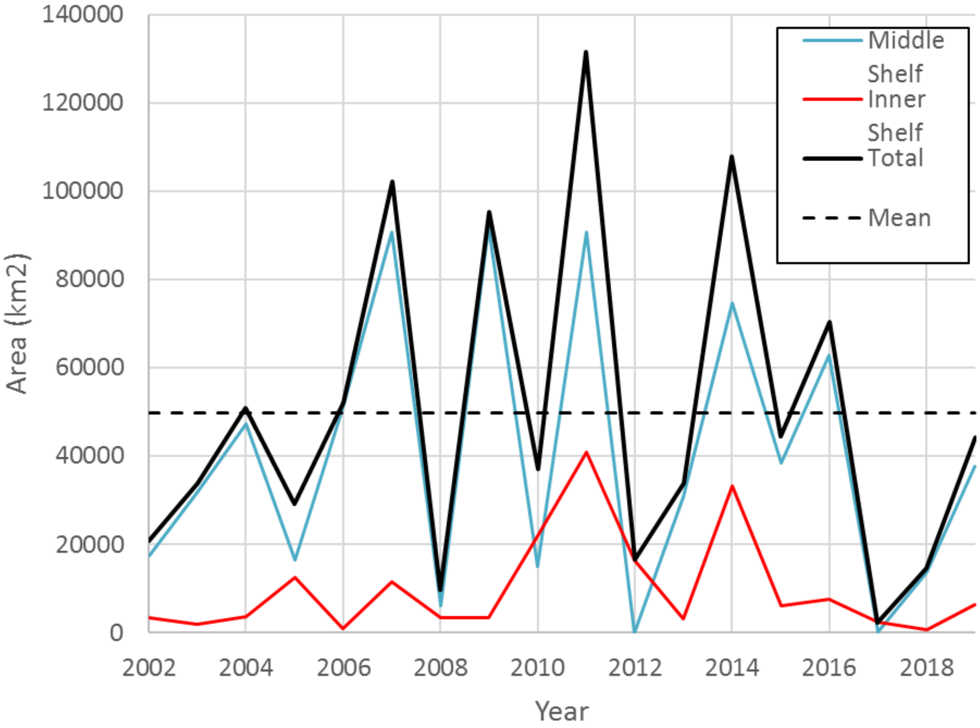

Figure 46: Coccolithophore index for the southeastern Bering Sea shelf (south of 60°N). Blue: average over the inner shelf (30–50m depth), Red: average over the middle shelf (50–100m depth), Black: total.

Zooplankton

Leading Zooplankton Indicator for the Southeastern Bering Sea: 2019 Rapid Zooplankton Assessment

Contributed by David Kimmel[1], Jesse Lamb[1], James Murphy[2], Melanie Paquin[1], Lauren Rogers[1], Fletcher Sewall[2], and Charles Waters[2]
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Last updated: October 2019

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 300m, 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 ($\leq$ 2mm; example species: *Acartia* spp., *Pseudocalanus* spp., and *Oithona* spp.), large copepods ($>$ 2mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids ($<$ 15mm; 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. RZA abundance estimates should not be expected to closely match historical estimates of abundance as methods differ between laboratory processing and ship-board RZA. Rather, RZA abundances should be considered estimates of relative abundance trends overall. A detailed comparison of RZA data versus historical, laboratory processed data will be forthcoming in the next year. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1+ years post survey).

Southeastern Bering Sea

For the southeastern Bering Sea, the 70m isobath transect and Unimak Box were sampled 19 April–2 May and again from 18 September–2 October 2019. In order to provide comparison to yearly RZA data, long-term time-series for the middle shelf was developed from archived data. Long-term time-series for the inner and outer shelves are not shown as these regions were not sampled in 2019. Furthermore, there were too few data points to generate a time-series for the fall survey. The mean spring abundance of each RZA category was plotted for the southern middle 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.

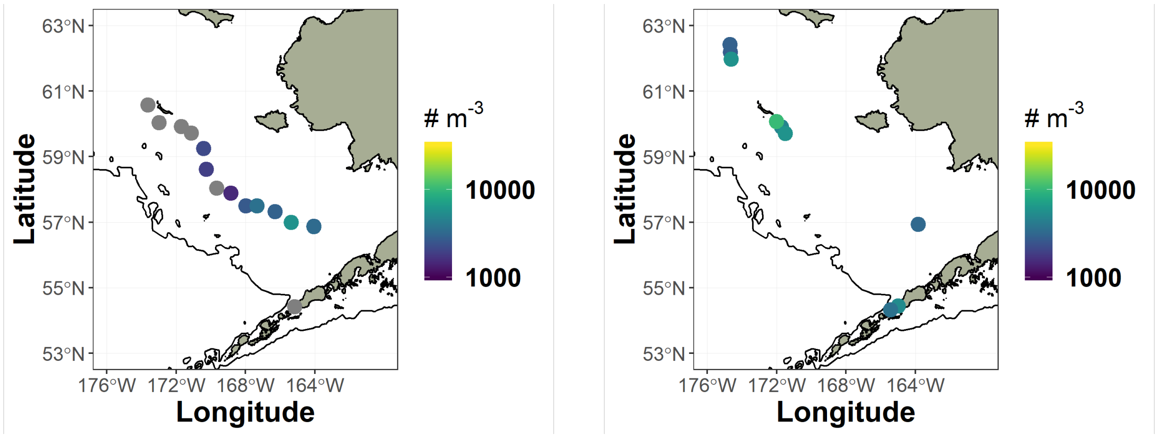
Northern Bering Sea

The northern Bering Sea survey was sampled 27 August–18 September 2019 over the inner domain. This represented the second time the RZA was completed in this region and therefore comparisons to previous years are not possible; however, time-series for this region are in development.

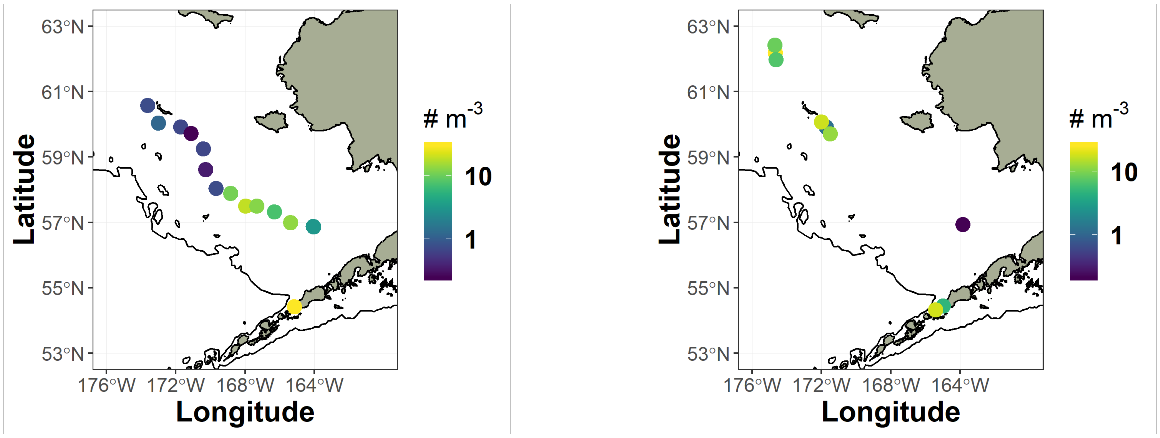
Status and trends:

Southeastern Bering Sea

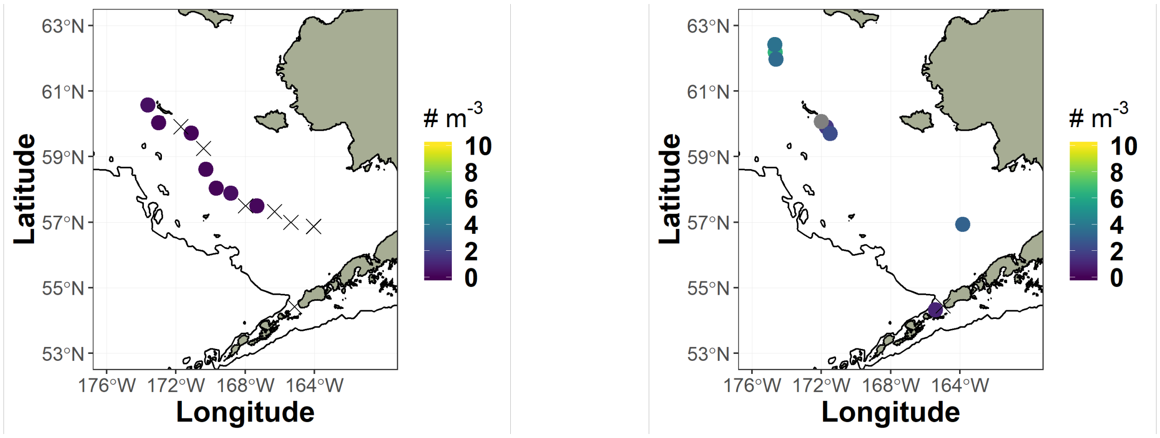
In 2019, small copepod abundances were similar along the 70m isobath during spring and fall, with slightly higher abundances during fall (Figure 47a and b). Numbers of small copepods during spring were high compared to historical abundances (Figure 48 top panel). Large copepods had very low abundances along the 70m isobath and there was a distinct north/south gradient in the abundance during spring that reversed during fall (Figure 47c and d). Numbers of large copepods were lower than in 2018, but above the low abundances of 2017 during spring (Figure 48 middle panel). Euphausiid abundances were very low along the 70m isobaths during spring (Figure 47e) as well as very low



(a) Small copepods (≤2mm) Spring 70m survey (b) Small copepods (≤2mm) Fall 70m survey



(c) Large copepods (>2mm) Spring 70m survey (d) Large copepods (>2mm) Fall 70m survey



(e) Euphausiids (<15mm) Spring 70m survey (f) Euphausiids (<15mm) Fall 70m survey

Figure 47: Maps of the abundance of small copepods, large copepods, and euphausiid larvae/juveniles as estimated by the Rapid Zooplankton Assessment from the 70m survey during spring (left) and fall (right) 2019. X indicates a sample with abundance of zero individuals m^{-3}.

compared to historical values (Figure 48 bottom panel). Numbers of euphausiids increased, particularly in the northern section of the survey, during fall (Figure 47f).

Northern Bering Sea
In the northern Bering Sea, small copepods were very abundant across the sampling area, with abundances approaching 10,000 ind. m^{-3} (Figure 49a). In contrast, large copepod abundances were low overall, with many stations having no large copepods present (Figure 49b). In 2018, greater abundances (approximately 100 ind m^{-3}) of large copepods were observed, particularly in the northern portion of the survey area. Euphausiid numbers were also very low across the northern Bering Sea, with no smaller euphausiids recorded north of 62°N (Figure 49c). This is the opposite of what was observed in 2018, where euphausiid numbers were higher north of 62°N.

Factors influencing observed trends:
Southeastern Bering Sea
Small copepods are less susceptible to temperature-driven changes in development times than larger copepods. It is interesting to note that small copepod abundances remained at historic highs relative to the long-term time-series, suggesting that recent years with little to no sea ice seem to favor higher abundances of small copepods. It is likely that small copepod abundances will remain high if warm conditions persists. The north-south gradient along the 70m isobath observed for large copepods may reflect the differential population growth of large copepods in response to temperature. Temperatures north of 59°N were, on average, 2°C lower than those south of this latitude (data not shown). The resultant temperature difference likely allowed larger copepods to develop to a later stage and increase in abundance in the south relative to the north. A decrease in overall production may also be possible, but difficult to determine without tracking the annual cohort over the course of the year. The north-south gradient reversed in the fall, with higher abundances of large copepods further north. Again, this suggests that copepods in the south may have entered into diapause, whereas some larger copepods remained in the water column. The very low euphausiid numbers can be partially explained by the development of euphausiids resulting in larger sized individuals that can effectively avoid the 60-cm bongo net as low numbers are present in the historical record. However, as with the large copepods, a reduction in local production may also be occurring.

Northern Bering Sea
The warm temperatures of 2018 and 2019 appeared to have elevated small zooplankton abundances overall relative to large zooplankton. This makes sense with respect to life history characteristics of small copepods, e.g. multiple generations per year, faster turnover times, and metabolic rates that scale less dramatically with temperature. In comparing 2018 to 2019, the overall abundance of both large and small copepods was lower in 2019, suggesting that an overall decline in production is also a possibility. The northern Bering Sea had very low abundances of large copepods. Large copepods abundances would be expected to be higher, based on the accumulation of *Calanus* spp. C5 stages later in the year (Stabeno and Bell, 2019). However, above average temperatures in the region have likely caused earlier entry into diapause or significant advection of local populations of *Calanus* spp. into the Chukchi Sea. Euphausiid abundances showed a similar pattern to large copepods and this can be explained as development of euphausiids to the adult stage, a stage that is able to avoid the bongo nets. Alternatively, productivity may also be reduced as numbers for the other two zooplankton groups were also low.

Implications: Smaller copepods form the prey base for larval to early juvenile Walleye pollock (*Gadus chalcogrammus*) during spring. 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). The fall 70-m survey data suggest that large copepod numbers remained low and larger copepods were absent over the southern portion of the shelf. This is further supported by the low, large copepod numbers in the northern Bering Sea survey. This may result in less lipid-rich large copepods available to age-0 fish prior to overwintering. It has been suggested that euphausiids may compensate for a lack of copepods during fall (Duffy-Anderson et al., 2017) and 2019 data indicated a lack of euphausiid presence in the northern Bering Sea. The lack of smaller euphausiids has not

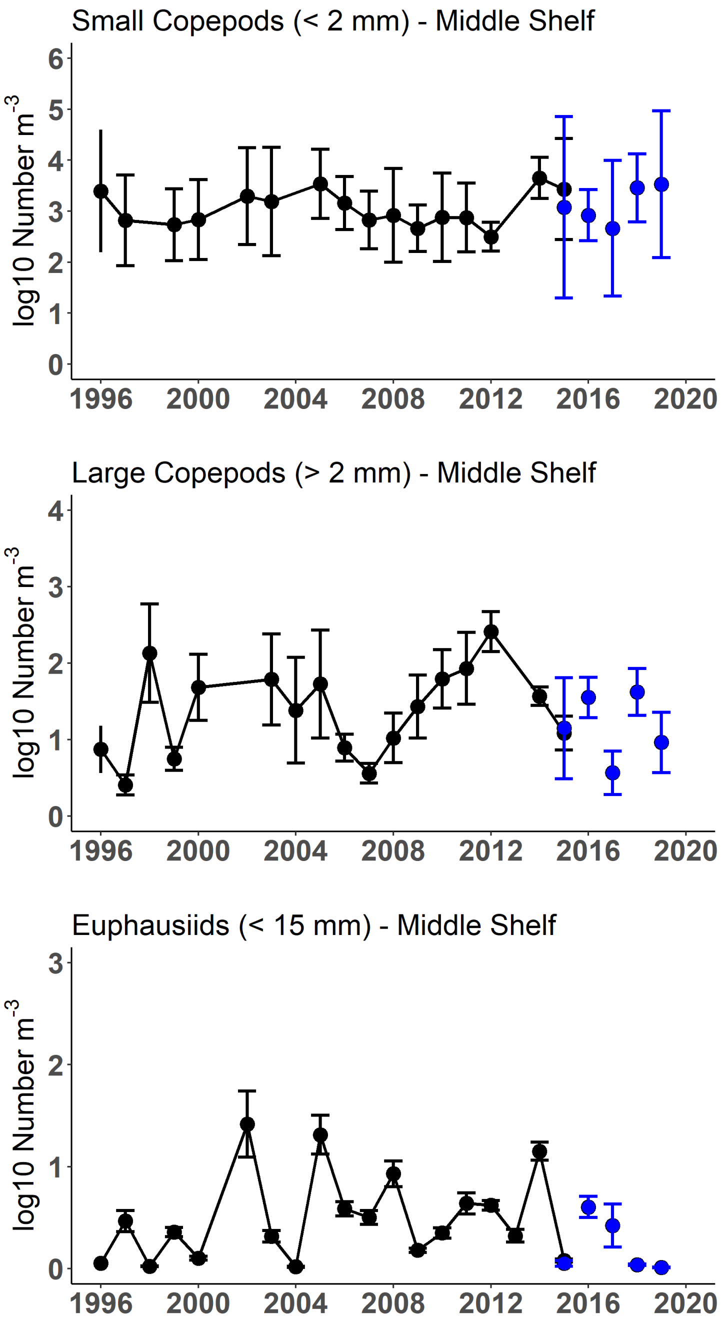
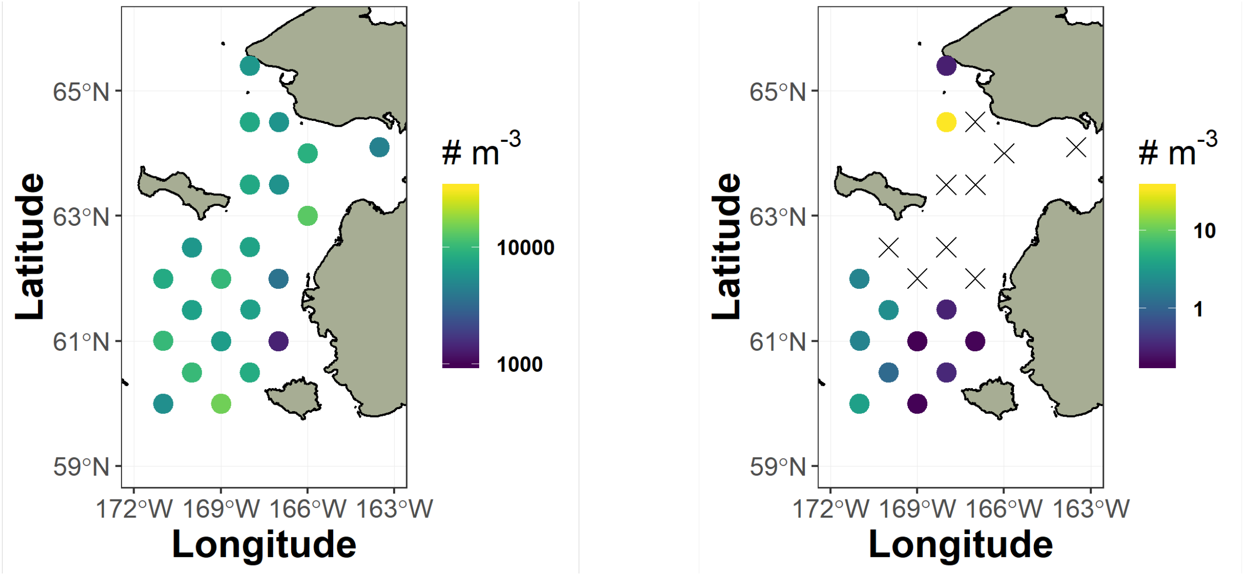


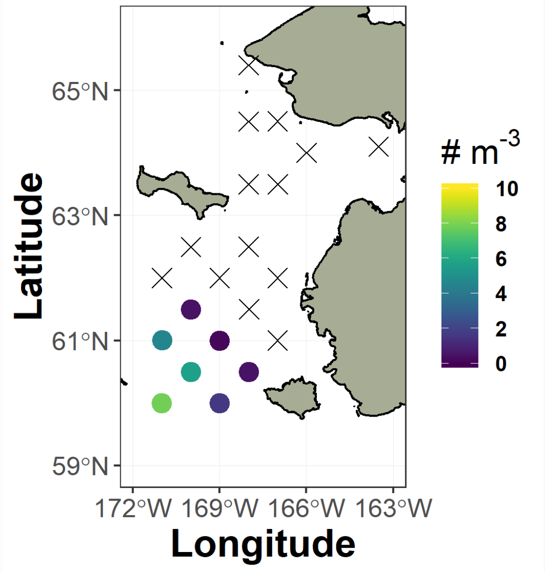
Figure 48: Annual mean abundance of small copepods, large copepods, and euphausiids in the southeastern middle-shelf region of the Bering Sea (Ortiz et al., 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.

been strongly related to the abundance of adult euphausiids, so we are unable to determine if the lack of smaller euphausiids extended to the adult stages. The lack of larger, lipid-rich copepods and euphausiids could affect the body condition and survival of overwintering groundfish within the region.



(a) Small copepods (≤2mm)

(b) Large copepods (>2mm)



(c) Euphausiids (<15mm)

Figure 49: Maps of the abundance of small copepods, large copepods, and euphausiid larvae/juveniles as estimated by the Rapid Zooplankton Assessment in the northern Bering Sea. X indicates a sample with abundance of zero individuals m^{-3}.

Jellyfish

Jellyfishes - Eastern Bering Sea Shelf

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Last updated: October 2019

Description of indicator: The time series for jellyfishes (primarily *Chrysaora melanaster*) relative CPUE by weight (kg per hectare) was updated for 2019 (Figure 50). 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.

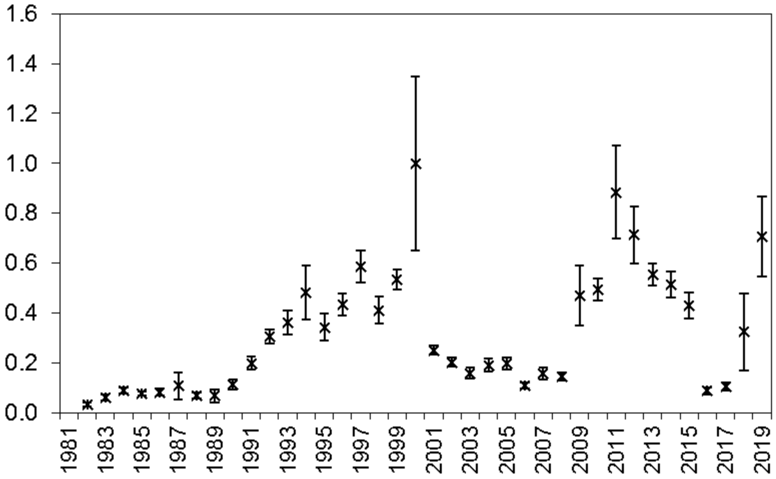

Figure 50: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE (kg per hectare) for jellyfish during the May to August time period from 1982–2019.

Status and trends: The relative CPUE for jellyfishes in 2019 increased by 118% from 2018, the highest concentration observed since 2012. 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's from 2001 to 2008 and then a second period with relatively higher CPUE values from 2009 to 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.

Ichthyoplankton

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

Forage Fish

Prey Quality Provides a Leading Indicator of Energetic Content for Age-0 Walleye Pollock

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Description of indicator: This leading indicator uses data obtained from on-board diet analyses of age-0 Walleye pollock (*Gadus chalcogrammus*) to calculate a diet energy density. These data were collected from the middle domain (between the 50–100m isobaths) during the fall southeastern Bering Sea survey (BASIS). The indicator provides a rapid assessment of prey quality as a predictor of age-0 pollock energetic content. Energetic content of age-0 pollock has been linked to overwinter survival and recruitment success to age-1 (Hunt et al. (2011); Heintz et al. (2013), see p. 124). Previous research indicates that zooplankton composition (i.e., ratio of small and large copepod taxa) changes with thermal regime (Coyle et al., 2011). These changes in prey availability are linked with changes in energy content and recruitment success of age-0 pollock (Siddon et al., 2013*a*). Specifically, availability of large copepods have been linked with survival and recruitment success of pollock (see p. 122).

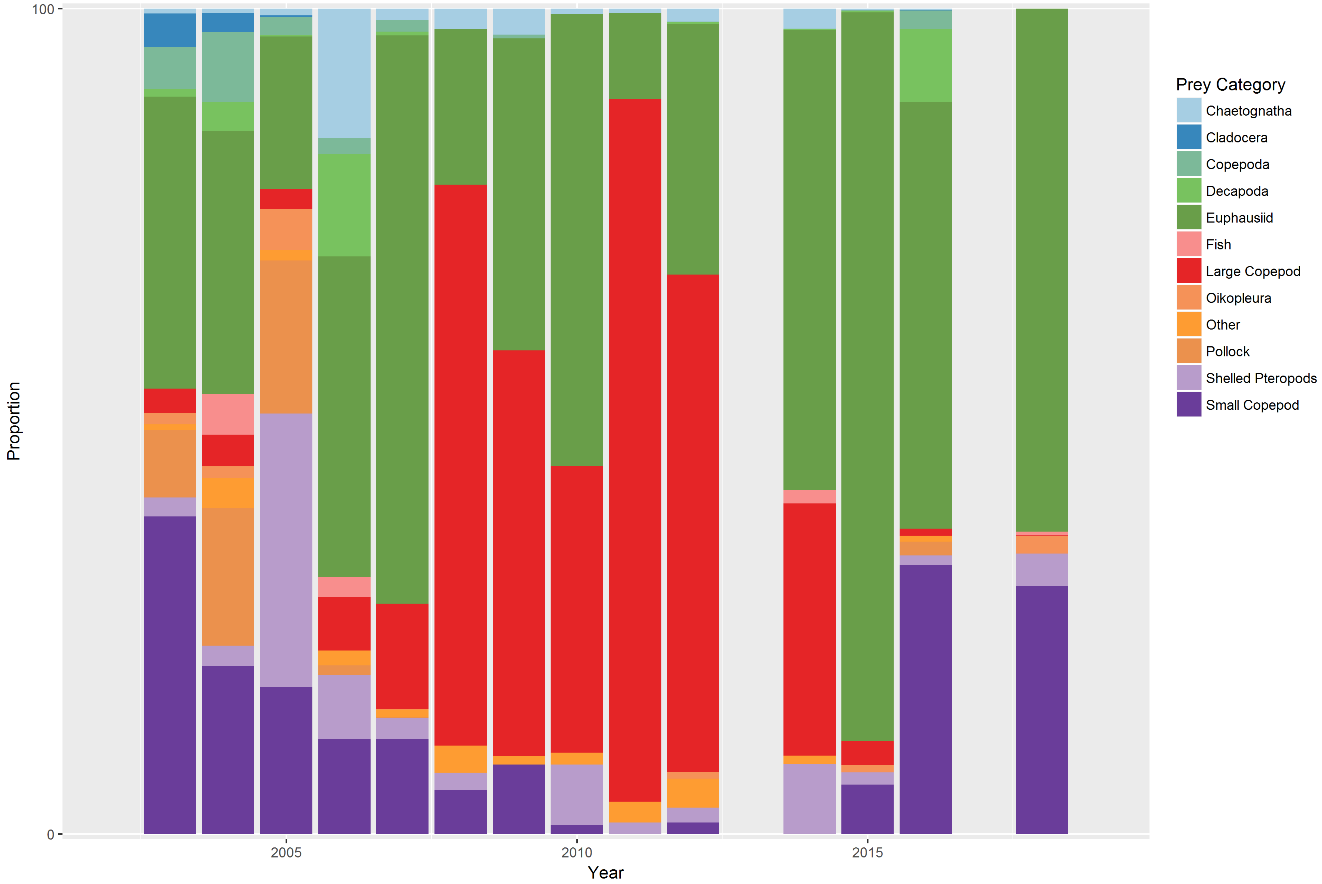

Figure 51: Percent composition of age-0 pollock diets collected from the middle domain in the southeastern Bering Sea during fall. No surveys were conducted in 2013 and 2017.

The composition of prey contents was summarized by taxonomic group (Figure 51). A catch weighted average of the diet energetic content of age-0 pollock was calculated using energetic density values from the literature. The weighted averages of dietary energetic content are strongly related to the energetic content of age-0 pollock collected from the same surveys (Figure 52).

Status and trends: The energetic content of age-0 pollock diets varies across thermal regime (Figure 53). Higher proportions of small copepods are found during warm years while higher proportions of large copepods are found during series of cold years. Diet energy density was lower during the warm years of 2003–2005, intermediate during 2006, but returned to high diet energy density during the cold years of 2007–2012. Diet energy density was intermediate to low during the warm years of 2014–2016 and 2018. No surveys were conducted in 2013 and 2017.

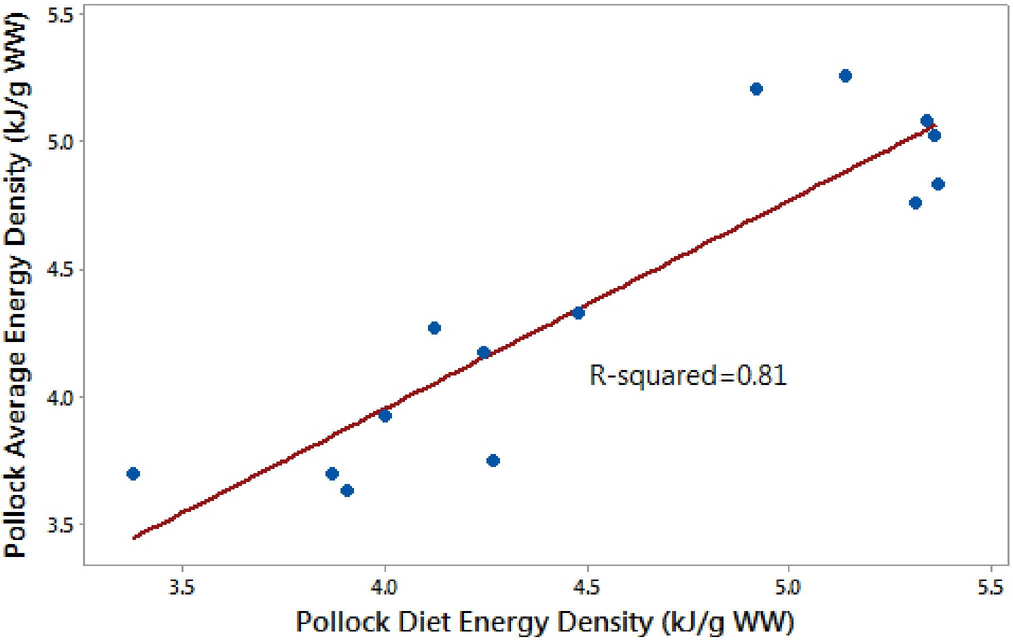

Figure 52: Linear relationship between age-0 pollock average energy density versus diet energy density (kJ/g wet weight) from the middle domain of the southeastern Bering Sea during fall.

Factors influencing observed trends: Oceanographic forcing has resulted in dynamic zooplankton composition between warm and cold stanzas over the southeastern Bering Sea shelf (Coyle et al., 2011). Prey quality varies across taxa, with warm-year taxa generally having lower energy density than cold-year taxa (Heintz et al., 2013; Siddon et al., 2013*a*). Such changes in the prey composition and quality are transferred up the food chain and result in age-0 pollock having lower (higher) energy content in warm (cold) years.

Implications: Ongoing research suggests the energetic content of age-0 pollock is a good predictor of overwinter survival and subsequent recruitment success (Heintz et al. (2013), see p. 124). Under the current warm conditions (beginning in 2014 and continuing through at least the summer of 2019), prey quality and diet energy content are expected to be low and therefore age-0 pollock energy density is also predicted to be low. Low age-0 pollock energy density tends to result in below-average recruitment success.

Age-0 pollock energy density must be determined in the laboratory, therefore that information is not available for consideration during the quota-setting process in the fall. Age-0 diet energy density can be calculated from on board diet analyses soon after the survey and therefore may provide a useful leading indicator of age-0 pollock energy density.

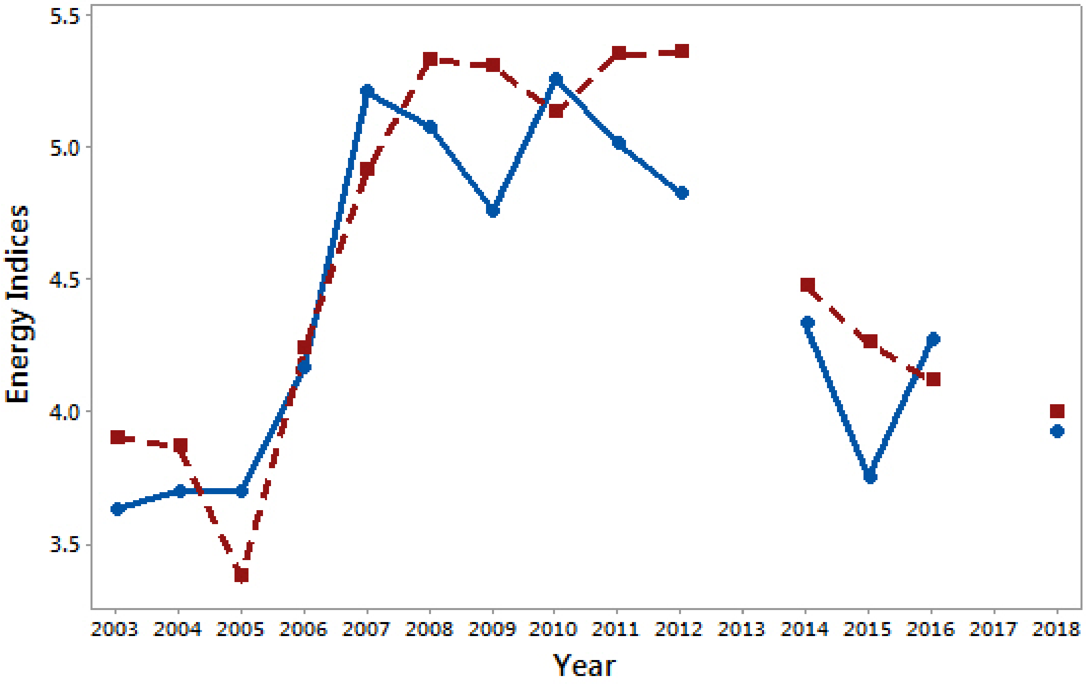

Figure 53: Comparison of age-0 pollock diet energy density (red squares) calculated from on-board diets to whole fish energy density (blue circles) determined in the laboratory based on samples collected in the fall.

Trends in the Abundance of Forage Fish in the Northern Bering Sea, 2002–2019

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Last updated: October 2019

Description of indicator: Fish were sampled using a trawl net towed in the upper 20m of the northern (60 to 65.5°N, -168 to -172°W) Bering Sea during the Alaska Fisheries Science Center's survey, 2002–2019 (no survey was conducted in 2008). Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes. Area swept was estimated from horizontal net opening and distance towed. Fish catch was estimated in kilograms. Five fish groups were commonly caught with the surface trawl: age-0 Walleye pollock, Pacific herring, juvenile Chinook salmon, juvenile chum salmon, and juvenile coho salmon.

Biomass (metric tonnes) in the area and during the time of the survey was estimated using the single species model VAST package version 2.8.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016a,b) using Microsoft Open R software version 3.5.3 (Team, 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015); Thorson and Kristensen (2016) to estimate indices of abundance for stock assessments. We estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 30 knots.

Status and trends: Temporal trends in the total estimated biomass of these fish groups indicated a decline in the productivity of fish in pelagic waters of the eastern Bering Sea in 2019 (Figure 54). Relative to 2018, the abundance of herring and juvenile chum salmon increased, while there were notable decreases in the biomass of age-0 pollock, juvenile Chinook salmon, and juvenile coho salmon.

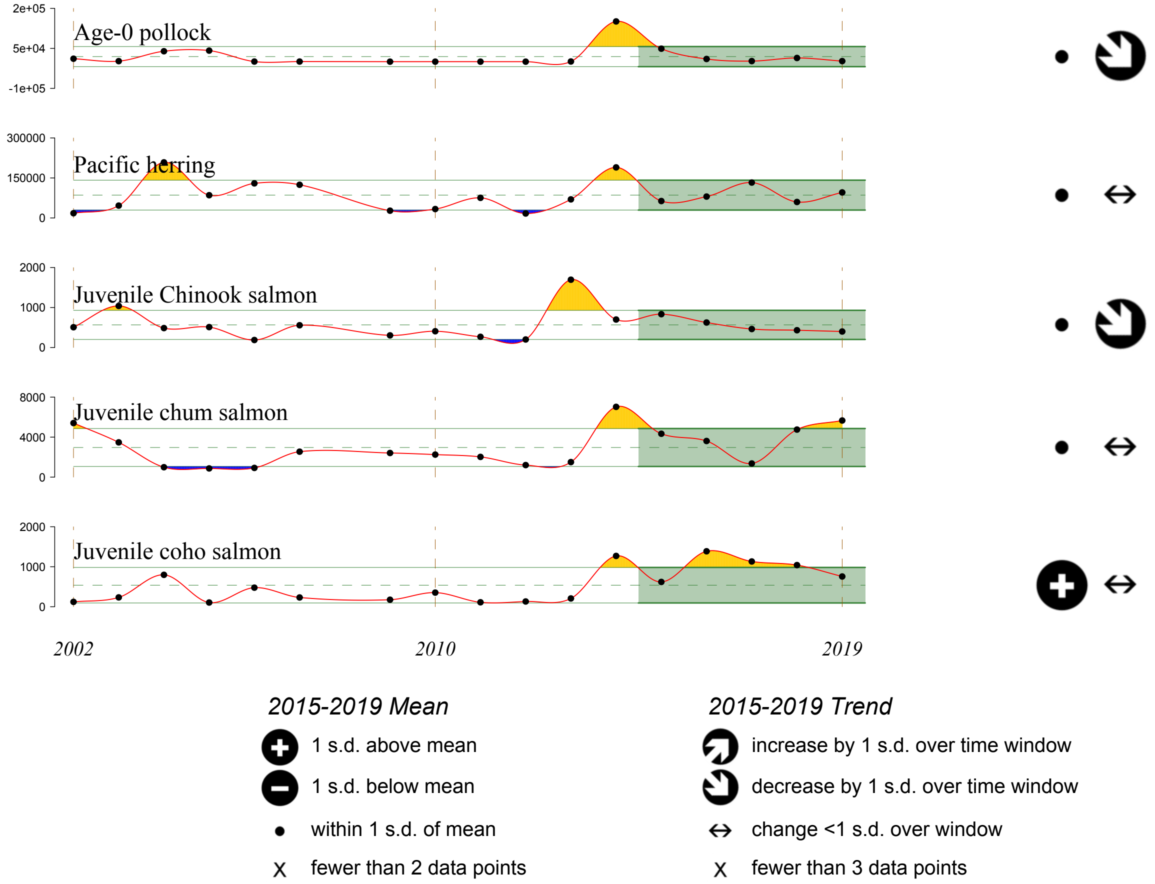

Figure 54: Relative biomass (metric tonnes) of forage fish in pelagic waters of the northern Bering Sea during late summer, 2002–2019.

Factors influencing observed trends: Biomass of these fish in pelagic waters during 2019, the sixth consecutive warm year, indicate poor environmental conditions for the growth and survival in the northern Bering Sea during summer. Another possible explanation for decreased abundance is the movement of fish north into Arctic waters.

Implications: Lower abundances of forage fish in surface waters during 2019 indicate a change in productivity in pelagic waters. The age-0 pollock abundances increased north of the survey area, possibly in search of food during years of low lipid-rich prey such as large zooplankton (Coyle et al., 2011). Herring typically increase in abundance during warm years.

Total Energy Trends Among Juvenile Fishes in the Northern Bering Sea

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Last updated: September 2019

Description of indicator: In high-latitude systems, the total energy content of juvenile fish as they approach their critical first winter can provide a useful index in describing mechanisms driving survival and recruitment. Surviving the winter period of reduced food availability is generally promoted by achieving large size and adequate energy stores by autumn, which reflect summer growing and feeding conditions. Trends in total energy (kJ), the product of fish weight (g) and energy density (kJ/g), may therefore provide insight into the mechanisms by which changing ocean conditions influence the health and resiliency of fish populations.

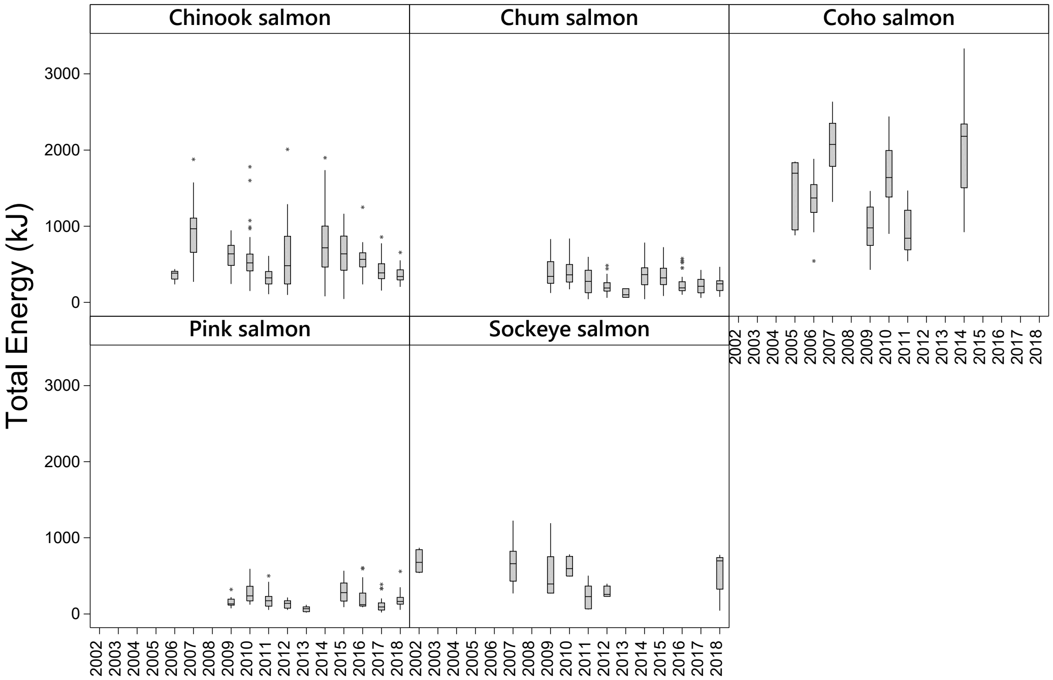

Figure 55: Average annual total energy (kJ) of juvenile Pacific salmon collected in autumn (Aug–Oct) surface trawls in the northern Bering Sea.

Individual weight and energy density measurements have been used to estimate total energy for multiple species of juvenile salmon (Figure 55), gadids, and forage fishes (Figure 56) collected from surface trawl surveys in the northern Bering Sea since the early- to mid-2000s. This report presents average annual total energy data available through 2018, with gaps in the record that vary by species. Surveys occurred in autumn, with the majority of catches occurring in September. Annual average June–September sea surface temperature (SST) from ERDDAP satellite data[8] for the survey area was used to assess the response of fish total energy to ocean conditions during the summer–autumn months immediately before and at time of capture.

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[8] NASA jplMURSST41 dataset, downloaded 9/13/2019; `https://coastwatch.pfeg.noaa.gov/erddap/jplMURSST41mday`

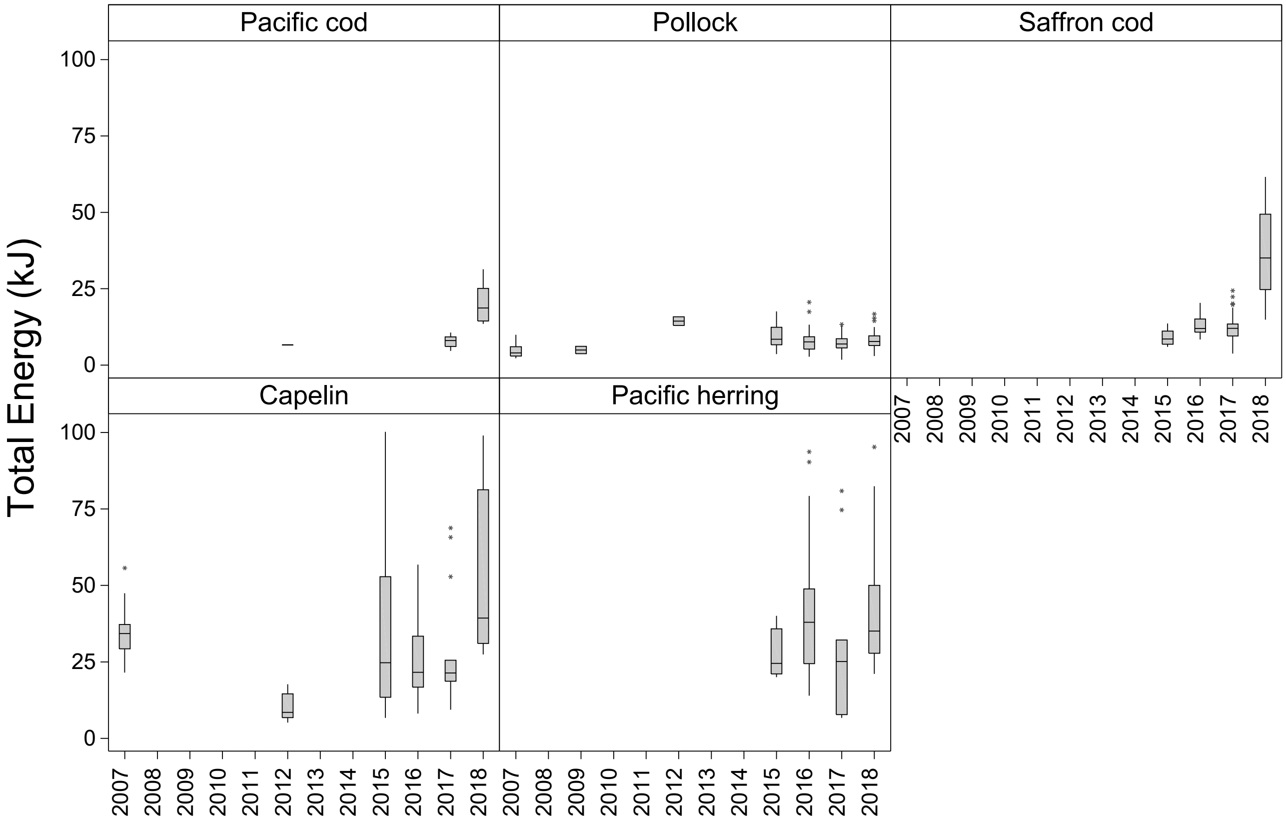

Figure 56: Average annual total energy (kJ) of juvenile gadids (Pacific cod, pollock, and saffron cod) and forage fishes (capelin and Pacific herring) collected in autumn (Aug–Oct) surface trawls in the northern Bering Sea.

Status and trends: Exploratory rank-based correlations of energy density among species and SST showed most species responded positively to increased temperature. Few relationships were statistically significant, however, due to high variability and limited years of data (Table 3). Moreover, the data were limited for many species in colder years. In the most recent two years, most species showed an increase in total energy in 2018 relative to 2017, which corresponds with warmer temperatures in 2018. Strong, positive relationships were observed between the annual average total energy of Chinook and coho salmon, two generally piscivorous species, and between pink and chum salmon, which are more planktivorous. Chinook salmon were typically negatively correlated with all non-salmon species, while pollock tended to be negatively correlated with all other species, though the relationships were generally not statistically significant.

Factors causing observed trends: Growth rate and energy storage of juvenile fish is known to increase with temperature as long as sufficient food is available and temperature does not exceed a species-dependent optimum. The present findings indicate that the total energy of juvenile fish species varied, but generally responded positively to increasing summer–autumn temperatures in the northern Bering Sea. The available energy data are limited mostly to recent warm years, and trends may not continue if future food production is insufficient to meet demand or temperatures exceed optimal levels for fish. Continued monitoring and comparisons of trends in the total energy of multiple species of juvenile fishes in the northern Bering Sea will provide useful information for understanding the processes determining the viability and health of Pacific sub-Arctic fish populations as ocean conditions change.

Table 3: Spearman's rank correlation test results for select pairs of variables from a correlation matrix of 11 variables. Only significant or marginal results (α=0.05) for tests with 4 or more years of data are shown.

Variable	Variable	Spearman ρ	N	p
SST	Coho salmon	0.93	7	0.003
SST	Pacific herring	1.00	4	<0.001
SST	Saffron cod	1.00	4	<0.001
SST	Sockeye salmon	0.71	4	0.071
Chinook salmon	Coho salmon	0.83	6	0.042
Chum salmon	Pink salmon	0.77	9	0.016
Coho salmon	Sockeye salmon	1.00	4	<0.001
Pacific herring	Saffron cod	1.00	4	<0.001

Implications: The observed responses of total energy to temperature indicate that lower trophic level production was generally not limiting the growth and condition of juvenile fishes for some species the northern Bering Sea through 2018. Highly correlated trends in total energy between species may reflect common trophic strategies in some cases, as seen in the strong relationships among piscivorous salmon species and among planktivorous salmon species. More broadly, the positive responses to increasing temperature seen across a range of species indicate recent warm SSTs through 2018 support favorable conditions for the growth and condition of many juvenile fishes in the northern Bering Sea.

Herring

Togiak Herring Population Trends

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Last updated: October 2019

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. A statistical catch-at-age model is then used to forecast Pacific 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 model include 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 model increased from a low of 63,000 short tons in 1980 to over 400,000 short tons from 1985 to 1987 (Figure 57), due to large age-4 recruitments in 1981 and 1982 (Figure 58). 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.

Recent biomass forecasts for Togiak have been based on aerial survey estimates prior to 2016 and annual age composition, weight-at-age, and harvest data. The last aerial survey with a non-zero confidence rating in the model was 2015 (228,809 short tons), due to budget cuts in 2016 and poor weather in 2017 and 2018. The magnitude of recent forecasts has depended largely on age composition information. The forecast for 2019 was greater than any forecast in the last couple of decades, due largely to a large recruitment in 2017 and a very large recruitment in 2018 (the largest estimated recruitment since 1982, Figure 58).

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 20,631 tons over the last 10 years (2009–2018).

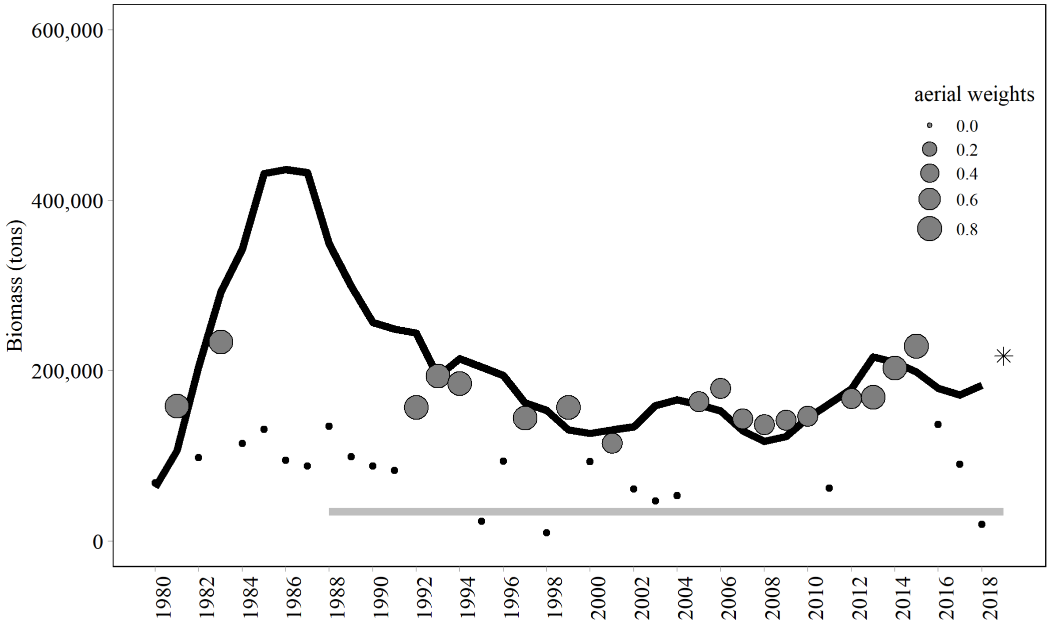

Figure 57: Aerial survey-estimated biomass plus pre-peak catch that were included in the model (grey points), model-estimated mature biomass (black solid line), and model-estimated mature biomass forecast (black star). The size of the grey points reflects the confidence weighting of each aerial survey 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). Grey line denotes a biomass threshold below which no harvest is allowed.

Factors causing observed trends: Pacific herring recruitment is both highly variable and cyclic with large recruitment events (age-4) occurring roughly every 8–10 years in this population. Biomass trends are influenced greatly by recruitment, with the highest biomasses in 1985–1987 resulting from the largest age-4 recruitments in 1981 and 1982. The high recruitment in 2018 may lead to an increase in the population in upcoming years. Williams and Quinn (2000) demonstrate that Pacific 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. Wespestad and Gunderson (1991) suggest that recruitment variation in the EBS relates to the degree of larval retention in near-coastal nursery areas where temperatures and feeding conditions are optimal for rapid growth. Specifically, they indicate that above average year-classes occur in years with warm sea surface temperatures when the direction of transport is north to northeast (onshore) and wind-driven transport velocity is low, whereas weak year classes occur in years when sea-surface temperature is cold, wind transport is west to northwest (offshore), and wind-driven transport velocity is high. We believe that closer examination of environmental conditions such as sea surface temperature, air temperature, surface winds, 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, the directed Dutch Harbor bait fishery, and prohibited species catch in the EBS groundfish fisheries. The cyclic nature of recruitment into this population has implications for predators and prey of Pacific herring as well as the fishery. The Alaska Department of Fish and Game considers this population healthy and sustainable at current harvest levels.

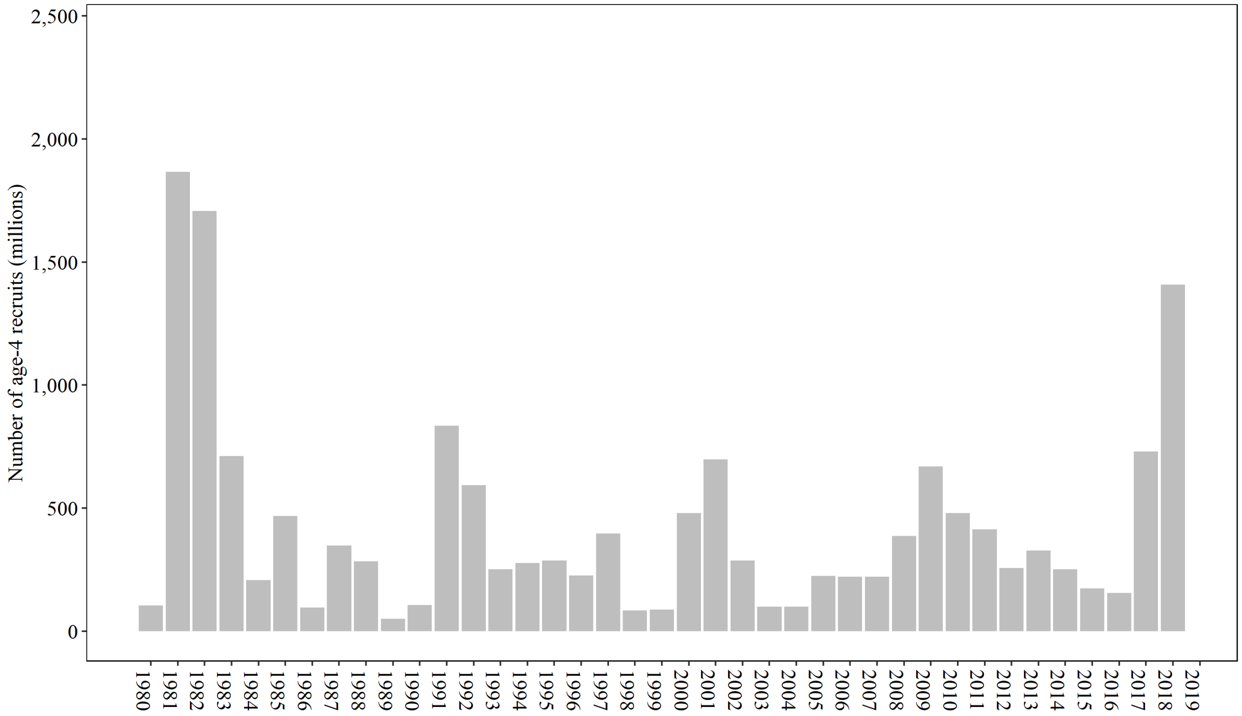

Figure 58: Model estimates of age-4 recruit strength (numbers of age-4 mature and immature fish).

Salmon

Historical and Current Alaska Salmon Trends – Bering Sea

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Last updated: August 2019

Description of indicator: This contribution provides historic and current catch information for salmon of the Bering Sea. This contribution summarizes available information that is included in current Alaska Department of Fish and Game (ADF&G) agency reports (e.g., Brenner et al. (2019)).

Pacific salmon in Alaska are managed in four regions based on freshwater drainage basins[9]: Southeast/Yakutat, Central (encompassing Prince William Sound, Cook Inlet, and Bristol Bay), Arctic-Yukon-Kuskokwim, and Westward (Kodiak, Chignik, and Alaska peninsula). ADF&G prepares harvest projections for all areas rather than conducting run size forecasts for each salmon run. There are five Pacific salmon species with directed commercial fisheries in Alaska; they are sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*).

Status and trends:

Statewide

Catches from directed fisheries on the five salmon species have fluctuated over recent decades (Figure 59) but in total have been generally strong. According to ADF&G, total salmon commercial harvests from 2018 totaled 115.7 million fish, which was about 31.6 million less than the preseason forecast of 147.3 million. The 2018 total salmon harvest was less than the 2017 total harvest of 225.7 million which was bolstered by the catch of 141.6 million pink salmon. In 2019 ADF&G is projecting an increase in the total commercial salmon catch to 213.2 million fish, due to expected increases in the number of pink and chum salmon.

Bering Sea

Chinook salmon abundance in the Arctic-Yukon-Kuskokwim region has been low since the mid-2000s and generally remains low. There has been some indication of a Chinook rebound in the Yukon area since 2016 (Murphy et al., 2017; Estensen et al., 2018), however, for the eleventh consecutive year, no commercial periods targeting summer season Chinook salmon were allowed due to generally low run size. In the Kuskokwim Area, Chinook salmon met their 2018 escapement goal but run size was lower than the long term average (Smith, 2019). In Norton Sound, one of two Chinook salmon escapement goals were met. In Bristol Bay, the total 2018 Chinook salmon commercial harvest of 44,720 was approximately equal to the recent 20-year average (Salomone et al., 2019).

The 2018 commercial catch of 161,884 coho salmon in Bristol Bay is well above the recent 20 year average of 91,537 and is the third highest commercial catch since 1998 (Salomone et al., 2019). Coho abundance in the Arctic-Yukon-Kuskokwim region in 2018 was healthy and the harvest of 261,000 in the Norton Sound area was far in excess of the previous record of 191,254. Similarly, the chum salmon harvest of 238,000 in Norton Sound was the second highest on record. And the chum salmon harvest of 695,153 in Kotzebue Sound in 2018 was a new record. The harvest of 1.6 million chum salmon in Bristol Bay was above the recent 20 year average.

The 2018 Bristol Bay sockeye salmon run of 62.3 million fish was the largest ever recorded and the harvest of 41.9 million was the second highest ever (Salomone et al., 2019). Escapement goals for sockeye salmon were met or exceeded in every drainage in Bristol Bay where escapement is defined. Historically, total runs to Bristol Bay have been highly variable, but in recent years (2014–2018), sockeye salmon runs have been well above the recent 20 year mean of 36.8 million. The forecast for the 2019 Bristol Bay sockeye total run is 40.18 million (27.9–52.46 million range), which is less than the recent 10 year average of 44.4 million. See p. 99 for more information.

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[9] `https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmonareas`

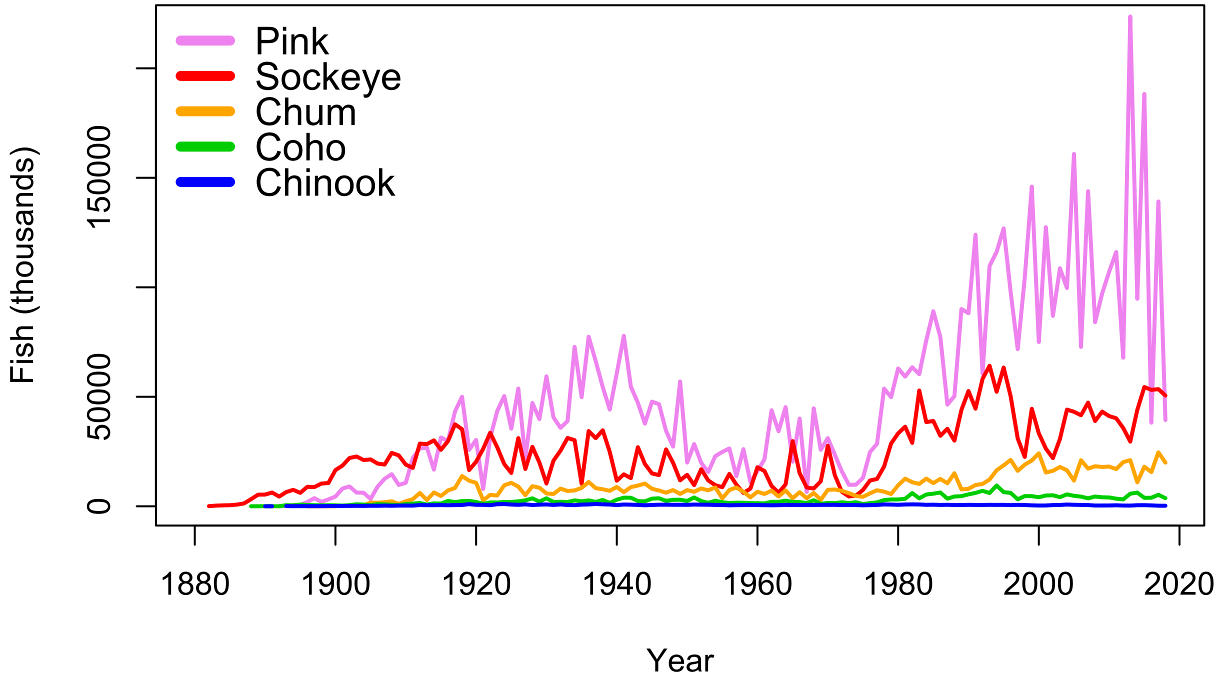

Figure 59: Alaska historical commercial salmon catches; 2018 values are preliminary. Source: ADF&G; `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.)

Factors influencing observed trends: Salmon have complex life histories and are subject to stressors in the freshwater and marine environments, as well as anthropogenic pressures. These forces do not affect all species and stocks equally or in the same direction, and resolving what is driving the population dynamics of a particular stock is challenging (Rogers and Schindler, 2011). Interannual variation in Alaska statewide total salmon abundance is partly due to the even-year, odd-year cycle in pink salmon, particularly production from the Prince William Sound stock of pink salmon which typically have larger runs in odd years. Chinook runs have been declining statewide since 2007. Size-dependent mortality during the first year in the marine environment is thought to be a leading contributor to low Chinook run sizes (Beamish and Mahnken, 2001; Graham et al., 2019).

In the Bering Sea, sockeye salmon are the most abundant salmonid and since the early 2000s they have had consistently strong runs which have supported large harvests. Bristol Bay sockeye salmon display a variety of life history types. For example, their spawning habitat is highly variable and demonstrates the adaptive and diverse nature of sockeye salmon in this area (Hilborn et al., 2003). Therefore, productivity within these various habitats may be affected differently depending upon varying conditions, such as climate (Mantua et al., 1997), so more diverse sets of populations provide greater overall stability (Schindler et al., 2010). The abundance of Bristol Bay sockeye salmon may also vary over centennial time scales, with brief periods of high abundance separated by extended periods of low abundance (Schindler et al., 2006).

Implications: Salmon have important influences on Alaska marine ecosystems through interactions with marine food webs as predators on lower trophic levels and as prey for other species such as Steller sea lions. In years of great abundance, salmon may exploit prey resources more efficiently than their competitors. A negative relationship between seabird reproductive success and years of high pink salmon abundance has been demonstrated (Springer and van Vliet, 2014). Directed salmon fisheries are economically important for the state of Alaska. The trend in total salmon catch in recent decades has been for generally strong harvests, despite annual fluctuations.

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

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Last updated: September 2019

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 2019 Bristol Bay salmon inshore run of 56.6 million sockeye is the 4th largest on record since 1963 and is 32.5% higher than the recent 10-year average of 42.7 million sockeye, and 72.6% higher than the 1963–2019 average of 32.8 million sockeye. The temporal trend in Bristol Bay sockeye salmon indicates a large increase during the recent 5-year period, with inshore run sizes in 2015–2019 above recent and long-term averages. Also of note, inshore runs to the Nushagak District in 2019, 2018, and 2017 are the 3rd, 1st, and 2nd highest runs on record since 1963. Nushagak District inshore run sizes during this period of 17.8, 33.8, and 20.0 million sockeye salmon respectively were 156.2%, 385.3% and 188.0% higher than the 1963–2019 average of 6.95 million.
Note: At this time 2019 Bristol Bay inshore run size numbers are preliminary and subject to change.

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 2019 and the preceding 4-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 2019 Bristol Bay sockeye salmon inshore run suggests these stocks experienced positive conditions at entry into the eastern Bering Sea in the summers of 2016 and 2017, and winters of 2016–2017 and 2017–2018.

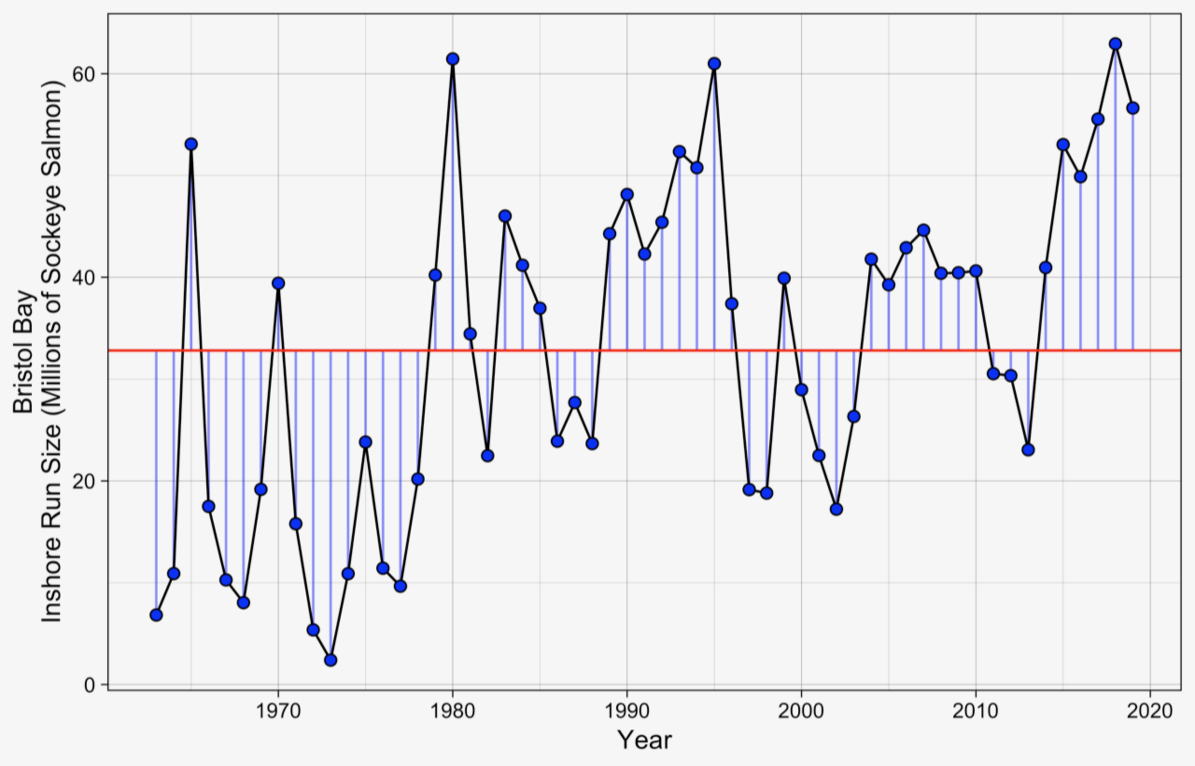

Figure 60: Annual Bristol Bay sockeye salmon inshore run size 1963–2019. Red line is the time series average of 32.8 million sockeye.

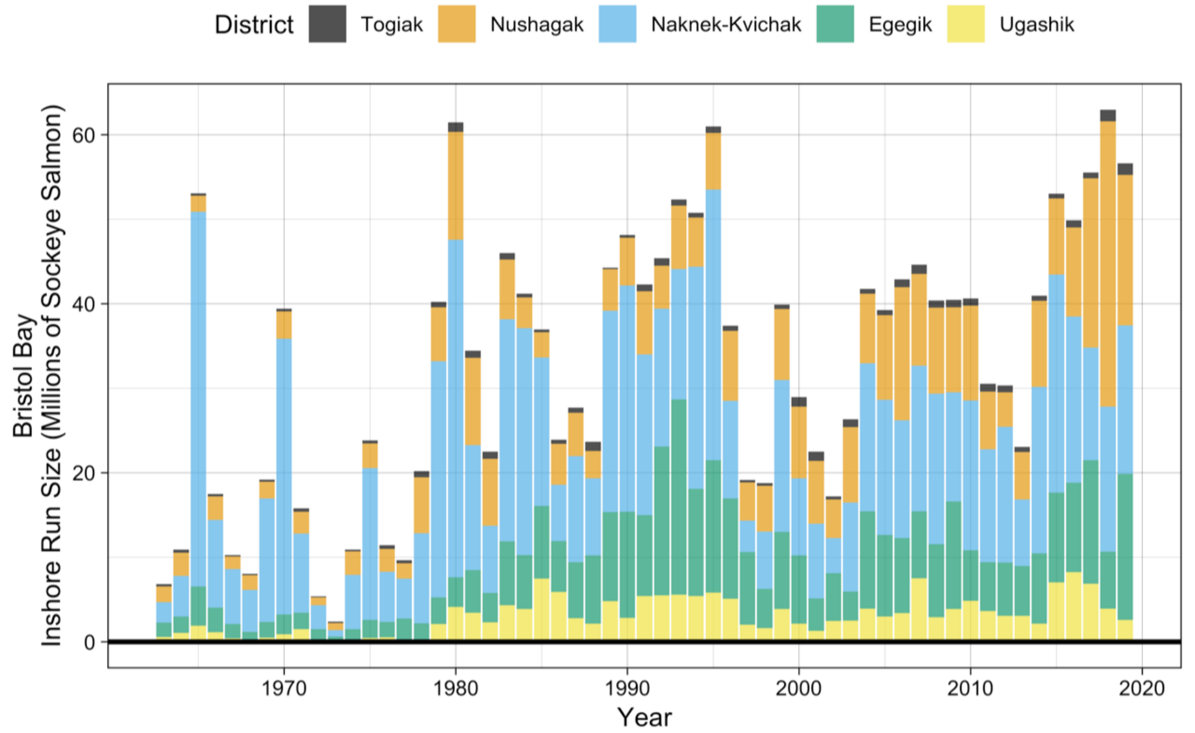

Figure 61: Annual Bristol Bay sockeye salmon inshore run size 1963–2019 by commercial fishing district.

Fall Energetic Condition of Juvenile Chinook and Chum Salmon in the Southeastern Bering Sea 2005–2018

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Last updated: October 2019

Description of indicator: This indicator shows anomalies of energy densities of juvenile Chinook and chum salmon in the southeastern Bering Sea (SEBS). Samples were obtained during the Alaska Fisheries Science Center's Bering Arctic Subarctic Integrated Survey (BASIS) during the fall of 2005–2018.

The index reflects the annual mean energy density (kJ/g wet mass) of Chinook and chum salmon in their first oceanic year of life from the SEBS. Annual means are catch-weighted by multiplying the station average by total number of fish caught at that station, summing across stations, and then dividing by the total number of fish at the stations. A similar catch-weighting procedure was used to estimate standard deviations. Station averages are based on energy densities measured for at least two fish. The number of sampled stations varied among years (Table 4). Fish from an average 70% of the stations where Chinook were present were analyzed each year and fish from an average 90% of the stations where chum salmon were present were analyzed. Warm and cold temperature classification, characterized by ice retreat timing, are shown relative to energy density anomalies standardized to the mean (observed/mean – 1).

Status and trends: In general, the temporal trend of the energy density anomalies shows above average values in 'cool' years and below average values in 'warm' years (Figure 62). For both species the lowest observed energy densities occurred in 2016. Chinook salmon seem to have below average energy densities during warm stanzas and above average energy densities in cool stanzas in the SEBS. Chum salmon, however, do not follow this trend and are more variable within stanzas.

Factors influencing observed trends: There is remarkable coherence to the overall pattern of energy density relative to temperature stanzas for Chinook salmon when compared with EDs for age-0 pollock and Pacific cod in the SEBS, but the same is not true for chum salmon. Note that few stations of Chinook salmon were processed in 2018 (Table 4), limiting our ability to interpret the 2018 observation. Diet likely plays a role in these differences. Chum salmon are more generalist and consume greater amounts of lower quality gelatinous prey (Farley and Moss, 2009; Quinn, 2018) than Chinook salmon.

Typically, a warmer season leads to lower quality prey available to higher trophic levels in the SEBS (Coyle et al., 2011; Heintz et al., 2013; Farley et al., 2016). Decreased availability of high-lipid prey as well as metabolic responses to warming oceanic temperatures are likely factors contributing to a decreased energetic condition among Chinook salmon in warm years. Chinook salmon are often piscivorous, but without specific diet information it is unclear if reduced energy density results from eating lower quality crustacean zooplankton or forage fish with lower energy density. Regardless, there appears to be a relationship between Chinook salmon and energy flow through crustacean zooplankton. Factors underlying the chum salmon pattern are less clear, because there are few data describing the quality of chum prey and how those prey respond to varying environmental conditions. Moreover, observations of chum salmon prey may be biased because gelatinous zooplankton may be underrepresented in stomach contents. Recent studies have shown greater energy flow through gelatinous zooplankton trophic linkages under warming conditions in the California Current (Brodeur et al., 2011). Perhaps conditions favoring energy flow through gelatinous zooplankton are independent of temperature in the SEBS. However, the lack of coherence between Chinook and chum salmon energy densities indicates that chum salmon nutritional state is driven by something other than temperature in the SEBS, in contrast to Chinook salmon.

Table 4: Catch-weighted mean energy density (ED) and standard deviation (SD) of juvenile Chinook and chum salmon in the southeastern Bering Sea, fall 2005–2018. The number of stations at which fish were caught is shown as "Stations Present"; the number of observations used to calculate the average and SD is shown as "Stations Processed". Note the number of samples analyzed per station varied between 1 and 4.

	Chinook salmon				Chum salmon			
	Avg. ED	SD	Stations present	Stations processed	Avg. ED	SD	Stations present	Stations processed
2005	4.79	0.21	30	21	-	-	-	-
2006	-	-	-	-	-	-	-	-
2007	5.1	0.02	19	8	-	-	-	-
2008	5.2	0.16	4	4	-	-	-	-
2009	-	-	-	-	5.86	0.35	24	24
2010	5.25	0.19	7	5	4.61	0.16	18	16
2011	-	-	-	-	-	-	-	-
2012	-	-	-	-	5.94	0.31	6	5
2013	-	-	-	-	-	-	-	-
2014	4.99	0.21	7	7	5.02	0.37	7	7
2015	-	-	-	-	-	-	-	-
2016	4.67	0.2	12	9	4.16	0.3	28	24
2017	-	-	-	-	-	-	-	-
2018	5.27	0.03	4	4	4.95	0.56	15	13
Total Average	5.04				5.09			

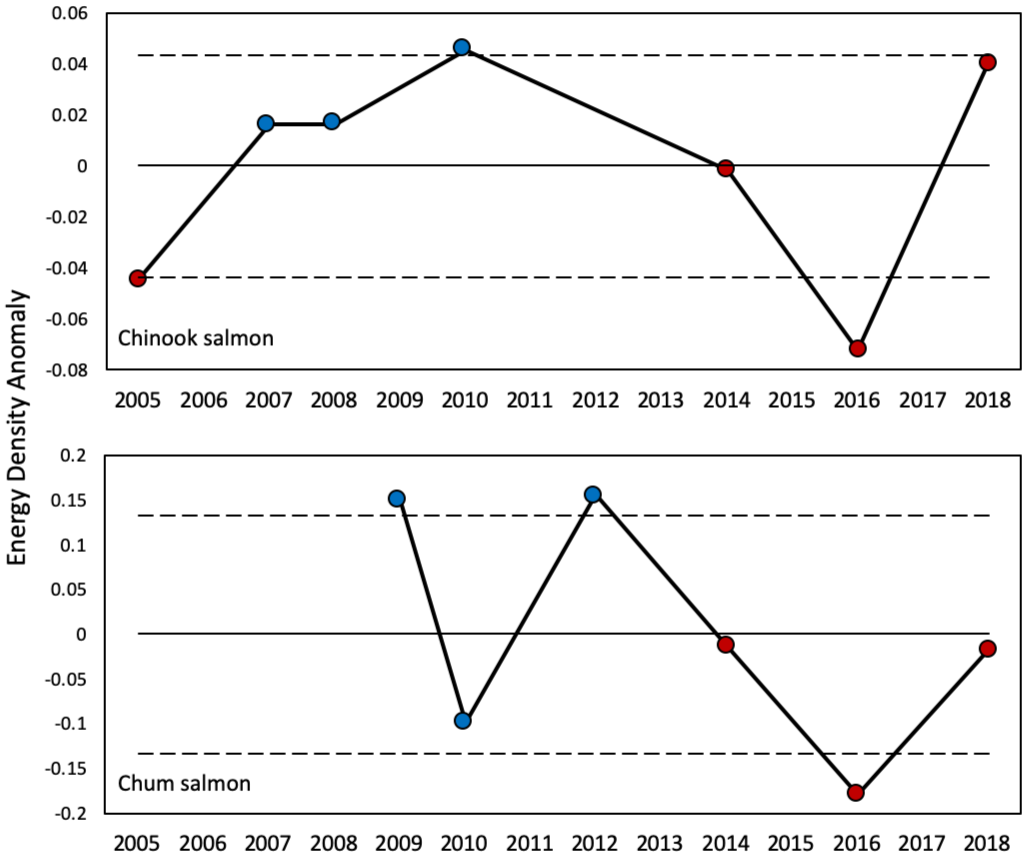

Figure 62: Energy density anomalies of juvenile Chinook and chum salmon in the southeastern Bering Sea, fall 2005–2018. Red indicates 'warm' years; blue indicates 'cold' years; dashed line denotes one standard deviation.

Implications: Warming temperatures in the Bering Sea may reduce the energy content of juvenile Chinook salmon prey and therefore impact the overall condition of these fish. Reduced energy content of age-0 pollock and Pacific cod in warm years have been documented elsewhere in this report (see p. 124). Lower body condition may indicate lower survival rates of juvenile salmon in the Bering Sea and a subsequent decline in returning adults to the population. However, we are unable to compare returns to condition since the origin of these fish is unknown. In contrast, conditions favoring improved condition for chum salmon remain unknown, however they appear to be decoupled from the system that produces higher lipid crustacean zooplankton, age-0 pollock, Pacific cod, and Chinook salmon.

Juvenile Chinook Salmon Abundance in the Northern Bering Sea

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Last updated: October 2019

Description of indicator: Stock-specific abundance of juvenile (first year at sea) Chinook salmon (*Oncorhynchus tshawytscha*) in the northern Bering Sea is estimated for the Yukon River stock group and the Canadian-origin (Upper Yukon) stock group within the Yukon River. Abundance estimates are based on late summer surface trawl catch-per-unit-effort (CPUE) data adjusted for mixed layer depth and estimates of genetic stock origin. The abundance of the Yukon River stock group has ranged from 1.3 million to 5.1 million juveniles with an overall average of 2.8 million, and the abundance of the Canadian-origin stock group within the Yukon River has ranged from 0.8 million to 2.8 million juveniles with an overall average of 1.5 million, 2003–2019 (Figure 63).

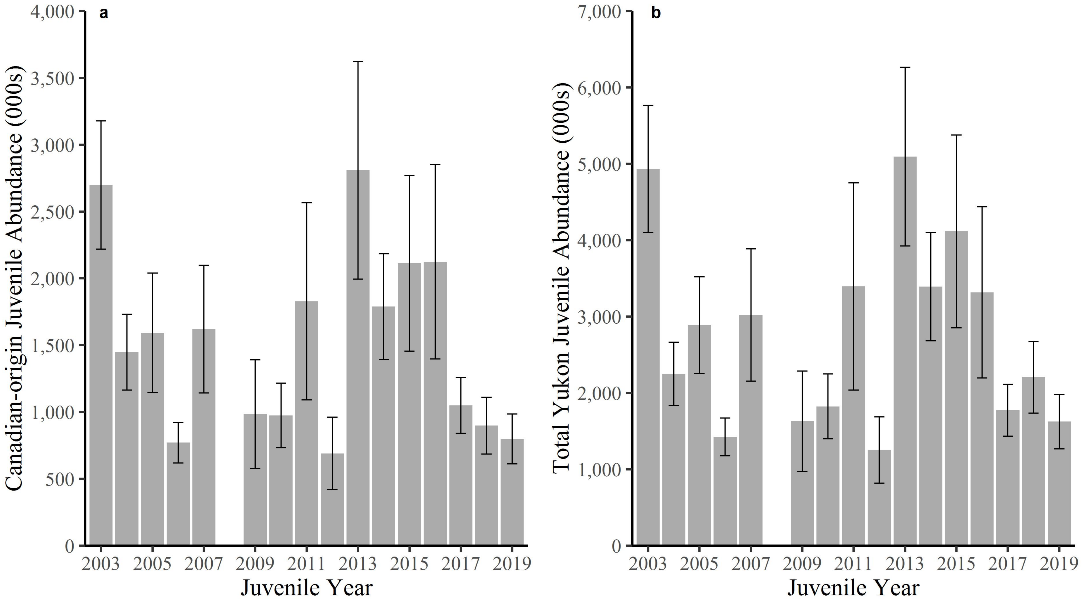

Figure 63: Juvenile Chinook salmon abundance estimates for the Canadian-origin stock group in the Yukon River (a) and the abundance of all Yukon River stock groups (b), 2003–2019. Error bars are one standard deviation above and below juvenile abundance estimates. The 2019 estimates are preliminary.

Status and trends: Abundance estimates for both stock groups of Chinook salmon were below average in 2019 and have been below average since 2017. Juvenile abundance has steadily declined from its latest peak in 2013.

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 64), is the primary factor influencing juvenile abundance in the northern Bering Sea. The number of juveniles-per-spawner in 2019 is the lowest observed since 2003.

Implications: Juvenile Chinook salmon abundance of the Yukon River and Canadian-origin stock groups are significantly correlated with adult returns (Figure 65). This relationship indicates that much of the year-to-year variability in juvenile survival occurs during their early life stages (freshwater and initial marine). The Canadian-origin stock group of Chinook salmon is the largest stock group in the Yukon River and has a complex management framework, directed by both domestic and international (US/Canada) management policies and decisions. Juvenile abundance is used to assist pre-season fisheries management planning and decisions within the Yukon River. The Canadian-origin stock group is also a key stock group used to define abundance-based bycatch caps in the eastern Bering Sea pollock fishery. Low juvenile abundance of this stock group increases the probability that future bycatch caps will be reduced in the pollock fishery.

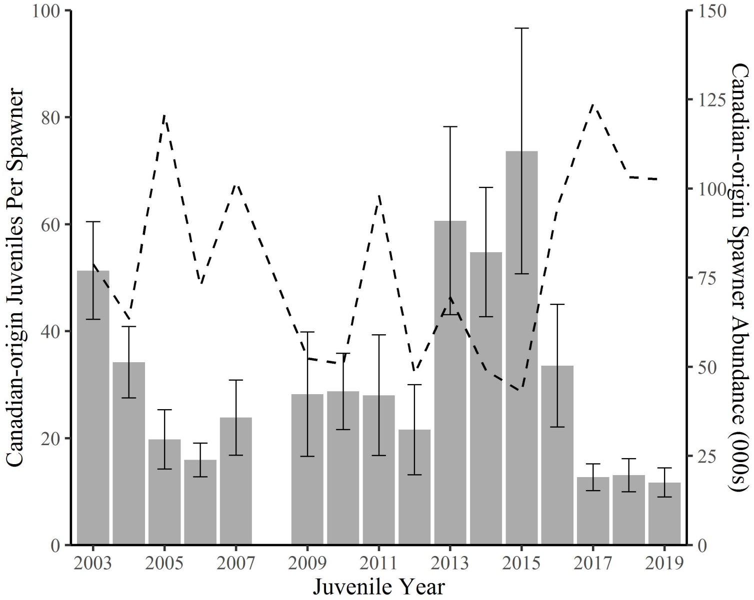

Figure 64: Estimated number of juveniles-per-spawner (bars) and spawner abundance (dashed line) for the Canadian-origin stock group of Chinook salmon in the Yukon River, 2003–2019. Error bars are one standard deviation above and below of juvenile per spawner estimates. The 2019 estimates are preliminary.

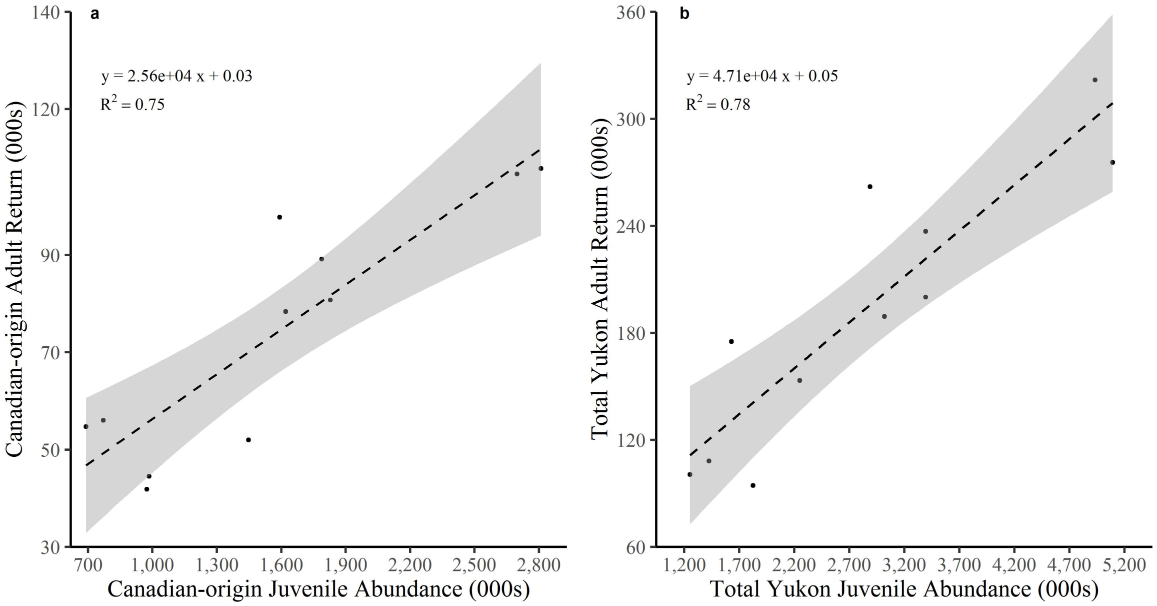

Figure 65: Relationships between juvenile abundance and adult abundance for the Canadian-origin stock group of Chinook salmon in the Yukon River (a) and all stock groups within the Yukon River (b) for juvenile years 2003–2014. Adult abundance is the number of returning adults and only includes years where all juveniles have returned to the Yukon River.

Juvenile Pink Salmon Abundance in the Northern Bering Sea

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Last updated: October 2019

Description of indicator: A relative abundance index of juvenile (first year at sea) pink salmon (*Oncorhynchus gorbuscha*) abundance was constructed from late-summer (typically September) surface trawl and oceanographic surveys in the northern Bering Sea (NBS). The index is based on trawl catch-per-unit-effort data (log) and mixed layer depth, and has ranged from 1.0 to 5.4 with an overall average of 2.9 from 2003 to 2019 (Figure 66). The index is significantly correlated with pink salmon returns to Yukon and Norton Sound rivers and provides an informative tool to forecast adult returns to these regions (Figure 67). The preliminary index for 2019 is 5.3, which forecasts an adult return of 6.5 million pink salmon to the region in 2020.

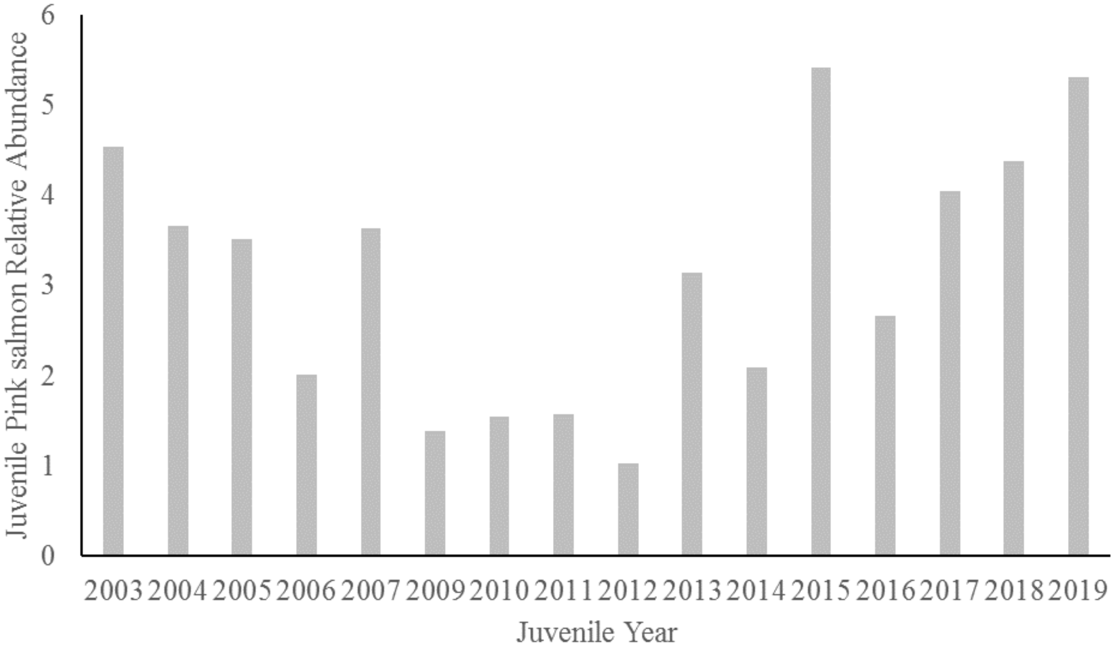

Figure 66: Juvenile pink salmon relative abundance index for the northern Bering Sea, 2003–2019.

Status and trends: Juvenile pink salmon index has varied over time, but is generally higher in warmer years (2003–2005; 2015–2019), and has increased along with the recent warming conditions in the eastern Bering Sea.

Factors influencing observed trends: The NBS is experiencing significant warming and extremes in seasonal ice extent and thickness that may benefit pelagic production during summer months which could improve growth and survival of local pink salmon stocks in freshwater and early marine life history stages.

Implications: Pink salmon appear to be taking advantage of warming freshwater and marine environments of the NBS and may portend further changes in the NBS region as a result of ongoing warming. Higher pink salmon production in the NBS region may be linked to the northward movement of salmon into the Arctic as pink salmon seek other areas to colonize.

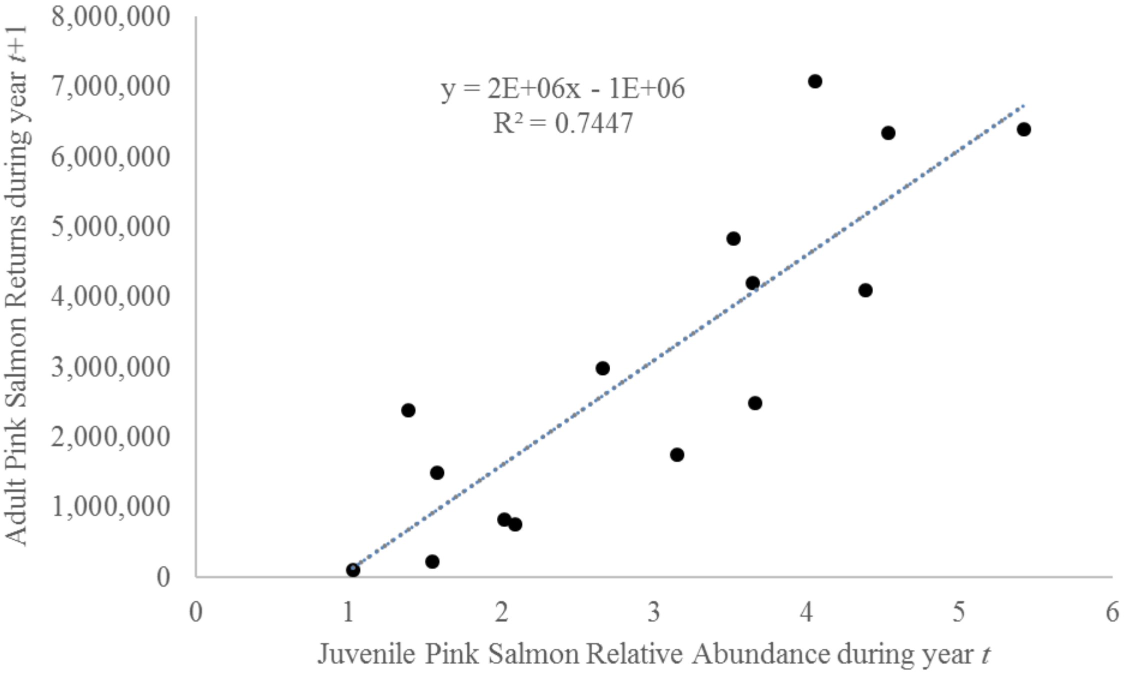

Figure 67: The relationship between juvenile pink salmon relative abundance index (2003–2018) and pink salmon returns (2004–2019) to Yukon and Norton Sound rivers the following year.

Groundfish

Eastern and Northern Bering Sea Groundfish Condition

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Description of indicator: Length-weight residuals represent how heavy a fish is per unit body length and are an indicator of somatic growth (Brodeur et al., 2004). Therefore, length-weight residuals, as a proxy for fish condition via somatic growth, can be considered an indicator of ecosystem productivity. Positive length-weight residuals indicate better condition (i.e., heavier per unit length) than negative residuals indicating poorer condition (i.e., lighter per unit length). Fish condition calculated in this way likely reflects fish growth trajectories which likely have implications for their survival (Paul et al., 1997; Boldt and Haldorson, 2004).

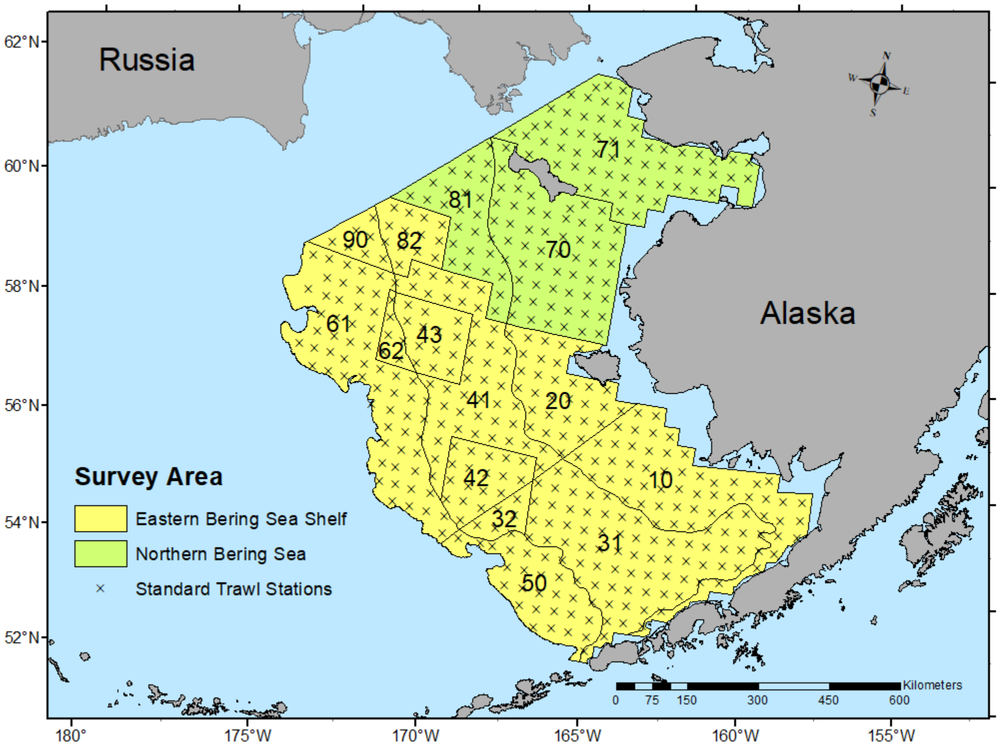

Figure 68: NOAA Alaska Fisheries Science Center summer bottom trawl survey strata (10–90) and station locations (x) on the eastern Bering Sea (EBS) shelf and Northern Bering Sea (NBS).

Paired lengths and weights of individual fishes were examined from the Alaska Fisheries Science Center's Resource and Conservation Engineering (AFSC/RACE) Groundfish Assessment Program (GAP) bottom trawl surveys of the eastern Bering Sea (EBS) shelf and Northern Bering Sea (NBS). Fish condition analyses focused on Walleye pollock (*Gadus chalcogrammus*), Pacific cod (*G. macrocephalus*), Arrowtooth flounder (*Atheresthes stomias*), Yellowfin sole (*Limanda aspera*), Flathead sole (*Hippoglossoides elassodon*), Northern rock sole (*Lepidopsetta polyxystra*), and Alaska Plaice (*Pleuronectes quadrituberculatus*) collected in bottom trawls at standard stations (Figure 68); no corner stations or non-standard strata were included. For these analyses and results summaries, survey strata 31 and 32 were combined as stratum 30; strata 41, 42, and 43 were combined as stratum 40; and strata 61 and 62 were combined as stratum 60. Non-standard survey strata 82 and 90 were excluded from these analyses. Length-weight relationships for each species were estimated with a linear regression of log-transformed values over all years and areas where data were available (EBS: 1982–2019, NBS: 2010 2017–2019); length-weight relationships for age-1 pollock (fork length=100–250 mm) and older (fork length>250 mm) were calculated independently. Outliers were removed using a Bonferroni outlier test (with a cutoff test statistic of 0.7 for removal). Predicted weights-at-length were calculated and subtracted from corresponding observed weights to compute individual residuals per fish. Length-weight residuals were then averaged by summer bottom trawl survey year over each survey area (i.e., EBS or NBS) and plotted relative to the long-term average. Average length-weight residuals were also compared by stratum and year on the EBS shelf to examine spatial variation in fish condition over this area.

Status and trends: Fish condition, indicated by length-weight residuals, has varied over time for all species examined (Figures 69 and 70). On the EBS shelf, with the exception of age-1 pollock, length-weight residuals in 2019 were positive or have continued an upward trend that began in 2017 or 2018 (Figure 69). Condition of age-1 pollock appears to have remained relatively constant on the EBS shelf. It is interesting to note that the length-weight residuals for all EBS shelf species (where data were available) were negative in 1999, a cold year in the Bering Sea. In the NBS, the trends in fish condition are similar to those on the EBS shelf with length-weight residuals becoming more positive for adult pollock and Pacific cod, although length-weight residuals overall for adult pollock were negative (Figure 70).

Spatial patterns of length-weight residuals over the EBS shelf were apparent for most species (Figure 71); the legend identifying each stratum is plotted in the Arrowtooth flounder plate over a section of the plot without data. Generally, fish were in better condition on the outer shelf (strata 50 and 60) and length-weight residuals were positive for nearly all species in the last 3–5 survey years; gadids tended toward having negative residuals on the inner shelf (strata 10 and 20). Flatfishes demonstrated more mixed results within species and across strata with positive residuals in all strata for Northern rock sole, Yellowfin sole, and Arrowtooth flounder as well as lower condition for Alaska plaice on the inner shelf and for Flathead sole on the outer shelf.

Factors influencing observed trends: There are several factors that may influence the observed temporal and spatial patterns in fish condition over the EBS shelf and NBS. Water temperature could explain some of the spatial and temporal variability in length-weight residuals. Water temperatures during the 1999 survey were particularly cold in the Bering Sea and this corresponded to 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), temperature-dependent groundfish spatial distributions may have affected the spatial overlap of fish and their prey impacting fish growth and condition in that year. Cold temperatures may have also affected fish energy requirements in that year. Conversely, recent and continuing warm temperatures across the Bering Sea shelf since the "Warm Blob" (Bond et al., 2015; Stabeno and Bell, 2019) may be influencing the present positive trend in fish condition for the species examined.

Other factors that could affect length-weight residuals include survey timing, stomach fullness, and fish movement patterns, all of which may be confounded by warming water temperatures as the NOAA AFSC summer bottom trawl survey progresses from the southeast to the northwest across the study area. The starting date of length-weight data collections has varied annually from late May to early June (except 1998, where the first data available were collected in late July). Since the survey begins on the inner shelf and progresses to the outer shelf, higher fish condition on the outer shelf could relate to the timing of collection as well as to the location where fish are caught. Another consideration that cannot be addressed with the present data set is that the fish weights used in these analyses are typically inclusive of stomach weights so that gut fullness could influence the length-weight residuals. Since feeding conditions likely change over space and time, how much the fish ate at its last meal and the proportion of its total body weight attributable to the gut weight could be an important factor influencing the length-weight residuals. We can also expect some fish to exhibit seasonal or ontogenetic

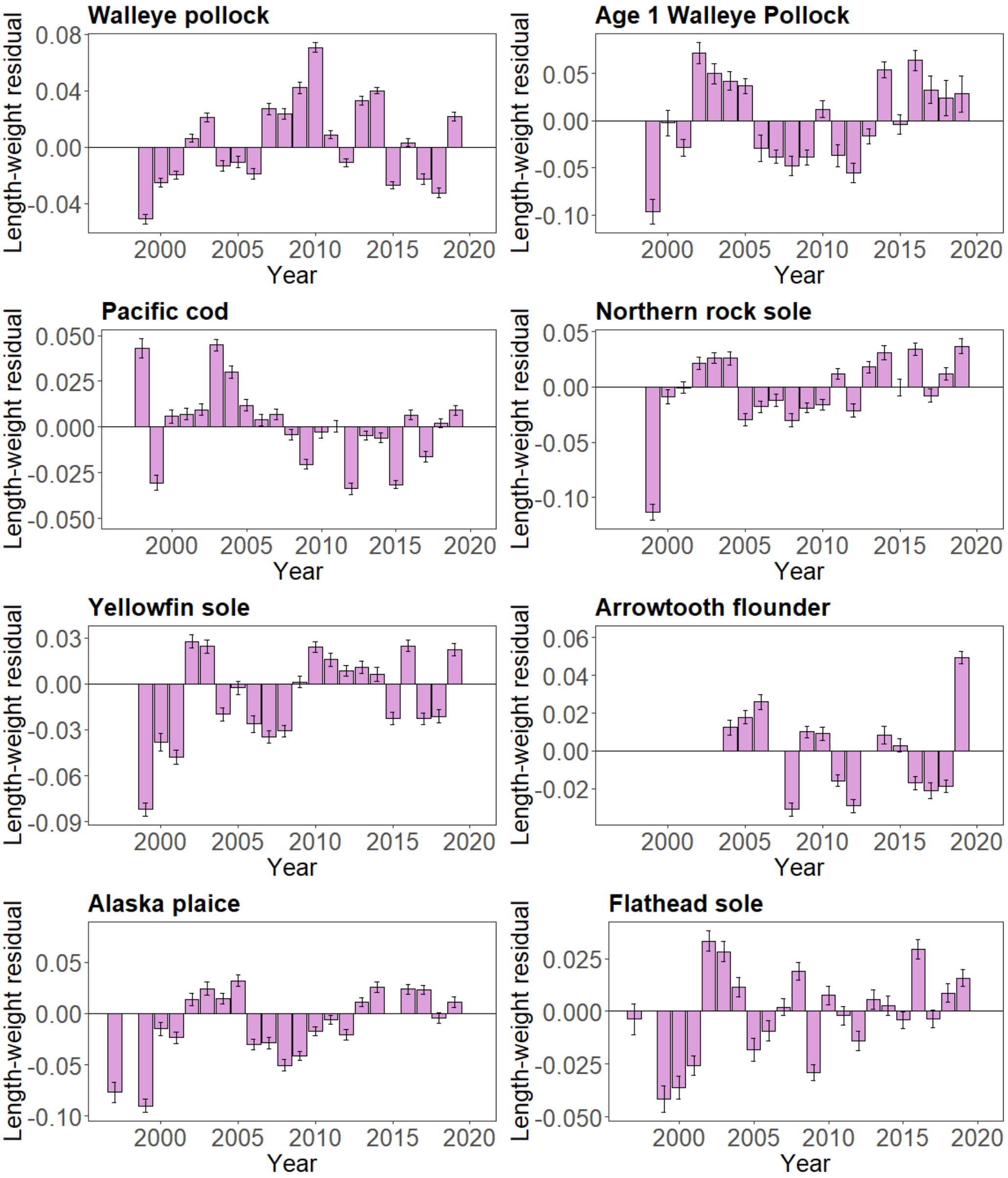

Figure 69: Length-weight residuals for seven groundfish species and age-1 pollock collected on the NOAA AFSC standard summer bottom trawl survey of the eastern Bering Sea shelf, 1997–2019.

movement patterns during 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; 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; and Arrowtooth flounder are distributed throughout the continental shelf until age 4, when, at older ages, they disperse to occupy both the shelf and the slope (Witherell, 2000). How these and other factors influence fish condition derived from length-weight residuals is not known at this time and it is unlikely that we can separate in-season spatiotemporal trends with these data. It is also important to note that the data and analyses reported here depict spatial and temporal variation of length-weight residuals for a small subset of the fish species collected in the NOAA AFSC summer bottom trawl surveys of the EBS and NBS and that they do not inform the mechanisms or processes behind the observed patterns.

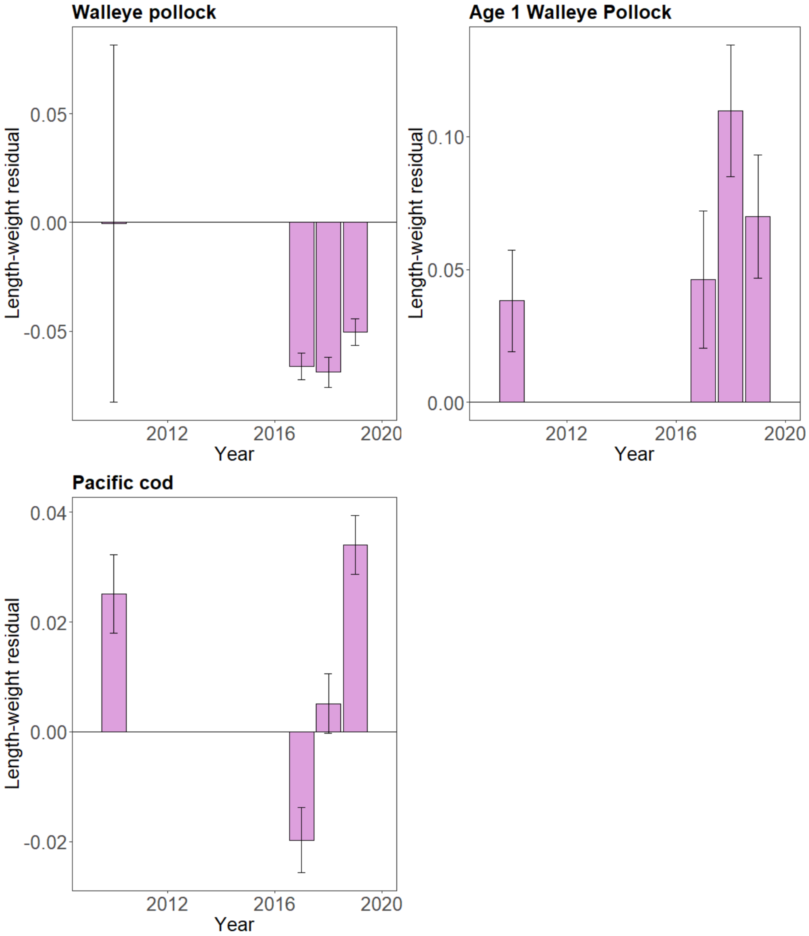

Figure 70: Length-weight residuals for two groundfish species and age-1 pollock collected on the NOAA AFSC summer bottom trawl survey of the northern Bering Sea, 2010 and 2017–2019.

Implications: Fish condition can be considered an indicator of ecosystem productivity with implications for fish survival. In Prince William Sound, the condition of herring prior to the winter may determine their subsequent survival (Paul and Paul, 1999). Thus, the condition of EBS and NBS groundfishes may provide us with insight into ecosystem productivity as well as fish survival and population health. However, survivorship is likely affected by many factors not examined here. We also must consider that, in these analyses, fish condition was computed for all sizes of fishes combined. Examining condition of early juvenile stage fishes not yet recruited to the fishery, or the condition of adult fishes separately, could provide greater insight into the value of length-weight residuals as an indicator of individual health or survivorship. Research on this topic in Alaska is currently under way and will examine correlative relationships between length-weight residuals and survivorship for early and late juvenile stages as well as for adults (Rooper et al. in prep.).

The positive trend in fish condition observed over the last two to three NOAA AFSC EBS and NBS bottom trawl surveys (i.e., increasingly positive length-weight residuals) could be related to concurrent trends in other ecosystem covariates and needs to be examined further. Trends such as warmer water temperatures following the "Warm Blob" event of 2014–2015 (Bond et al., 2015) and reduced sea ice and cold pool areal extent in the eastern Bering Sea (Stabeno and Bell, 2019) may affect fish condition here in ways that are yet to be determined. As we continue to add years of fish condition indices to the record and expand on our knowledge of the relationships between condition, growth, production, survival, and the ecosystem, these data may increase our insight into the health of fish populations in the EBS and NBS.

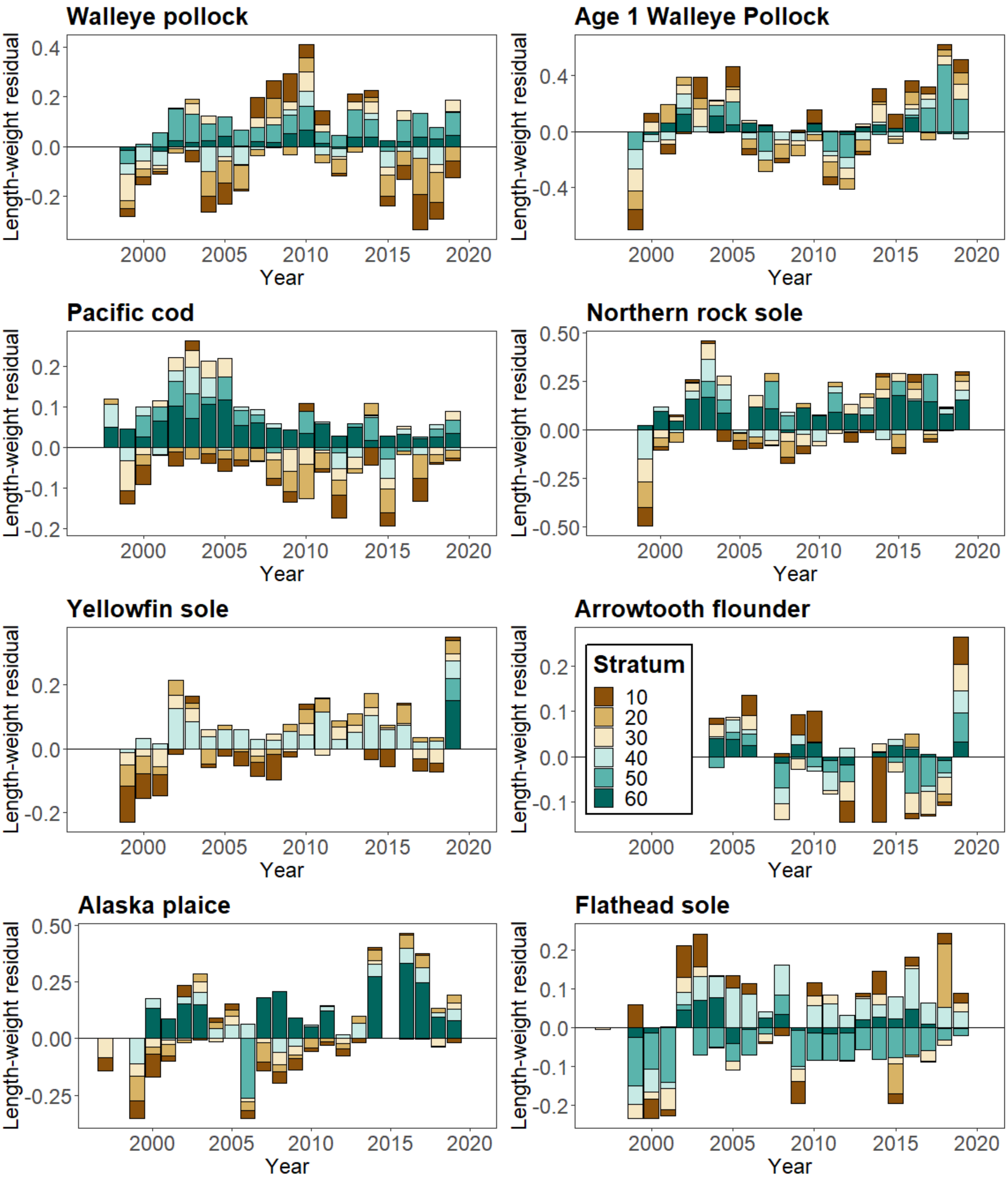

Figure 71: Length-weight residuals by survey stratum (10–60) for seven eastern Bering Sea shelf groundfish species sampled in the NOAA AFSC standard summer bottom trawl survey. Legend describing survey strata is located in the Arrowtooth flounder panel.

Multispecies Model Estimates of Time-varying Natural Mortality

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Last updated: October 2019

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 (hereafter "P. cod"), and Arrowtooth flounder peaked in 2016. At 1.49 yr^{-1}, age-1 mortality estimated by the model was greatest for pollock and lower for P. cod and Arrowtooth, with total age-1 natural mortality at around 0.69 and 0.65 yr^{-1}. 2019 natural mortality across species is 23% to 33% lower than in 2016 and is no longer above average for pollock (relative to the long-term mean) (Figure 72), while P. cod and Arrowtooth mortality continue to decline and are well below the long-term mean.

The total biomass of each species consumed by the predators in the model reflects patterns in age-1 natural mortality. In 2019, the total biomass of pollock consumed by all three predators in the model (typically 1-3 yr old fish) remained slightly above the long-term mean and was similar to 2017 and 2017. Meanwhile, P. cod and Arrowtooth biomass consumed was below and near the long-term means, respectively (i.e., within 1 SD of the long-term mean; Figure 73).

Factors influencing observed trends: Temporal patterns in natural mortality reflect annually varying changes in predation mortality that primarily impact age-1 fish (and to a lesser degree impact ages 2 and 3 fish in the model). Pollock are primarily consumed by older conspecifics, and pollock cannibalism accounts for 58% (on average) of total age-1 predation mortality, with the exception of the years 2006–2008 when predation by Arrowtooth exceeded cannibalism as the largest source of predation mortality of age-1 pollock; Figure 74). The relative proportion of pollock consumed by P. cod predators declined in 2019 and is estimated to be roughly equivalent to the proportion consumed by Arrowtooth flounder.

Combined annual predation demand (annual ration) of pollock, P. cod, and Arrowtooth flounder in 2019 was 7.3 million tons, down slightly from the 7.86 million t annual average during the warm years of 2014–2016. Pollock represent approximately 79% of the model estimates of combined prey consumed with a long term average of 5.31 million tons of pollock consumed annually by all three predators in the model. Individual annual rations remain significantly above average for all three predator species, driven by anomalously warm water temperatures in the Bering Sea during recent years (Figure 75).

Implications: We find evidence of continued decline in predation mortality on age-1 pollock, P. cod, and Arrowtooth flounder. While warm temperatures continue to lead to high metabolic (and energetic) demand of predators, declines in total predator biomass are contributing to an overall decline in total consumption and therefore reduced predation rates and mortality. This pattern may also explain recent increases in recruitment of EBS pollock over 2017–2019 and P. cod in 2019.

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 8.35 million t per year), and in recent years (collectively 7.72 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 P. cod that dominated the age composition of the two species in 2006. Similarly, the recent peaks in mortality in 2016 reflect anomalously warm water temperatures combined with the maturation of the large 2010-2012 year classes of pollock.

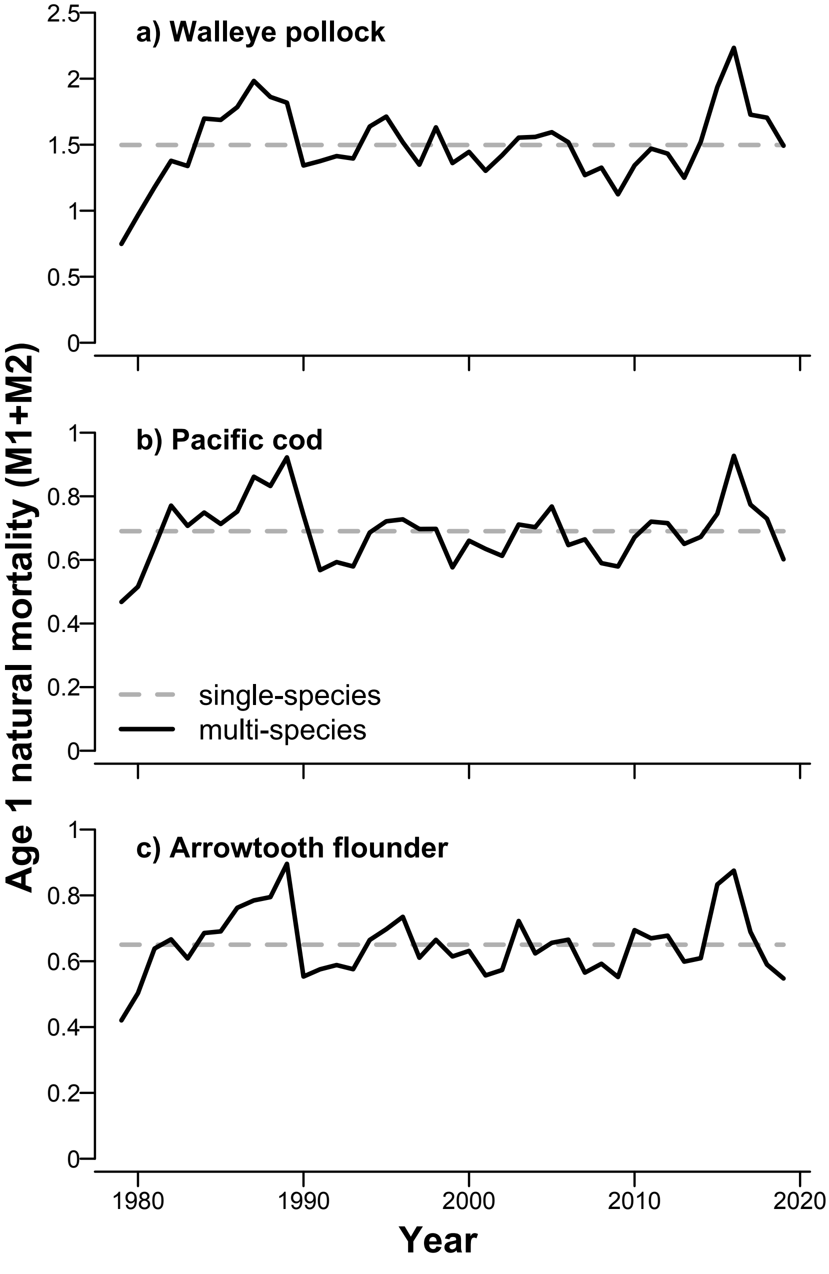

Figure 72: Annual variation in total mortality ($M1_{i1} + M2_{i1,y}$) for age-1 pollock (a), Pacific cod (b), and Arrowtooth flounder (c) from the single-species models (dashed gray line) and the multi-species models with temperature (black line). Updated from Holsman et al. (2016); more model detail can be found in Appendix 1 of the BSAI pollock stock assessment for 2019.

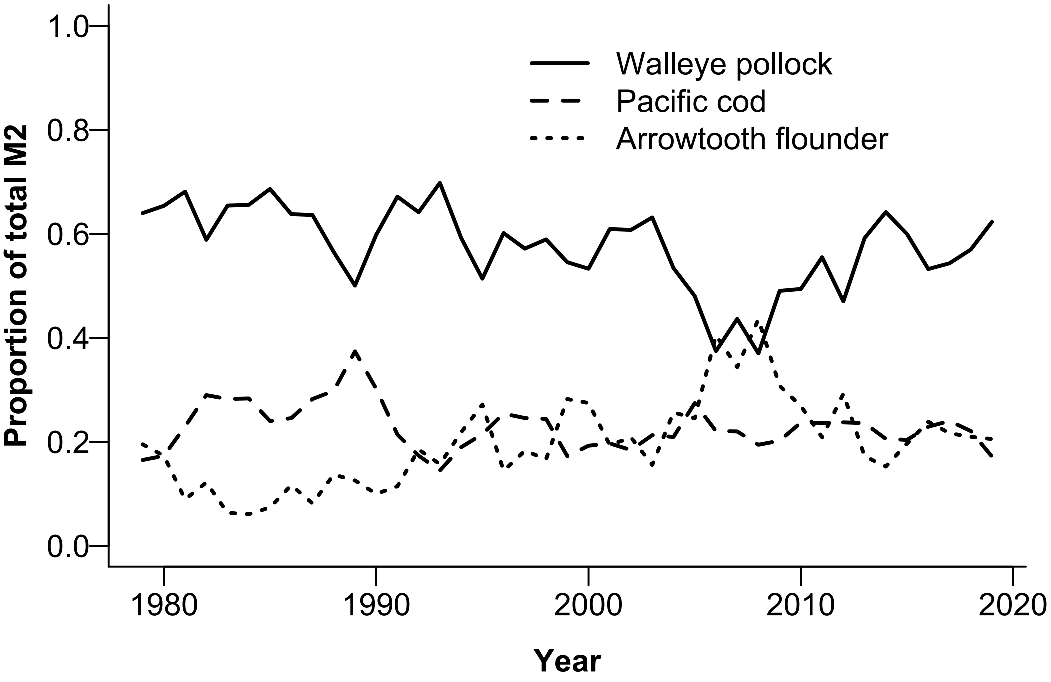

Figure 73: Proportion of total predation mortality for age-1 pollock from pollock (solid), Pacific cod (dashed), and Arrowtooth flounder (dotted) predators across years. Updated from Holsman et al. (2016); more model detail can be found in Appendix 1 of the BSAI pollock stock assessment for 2019.

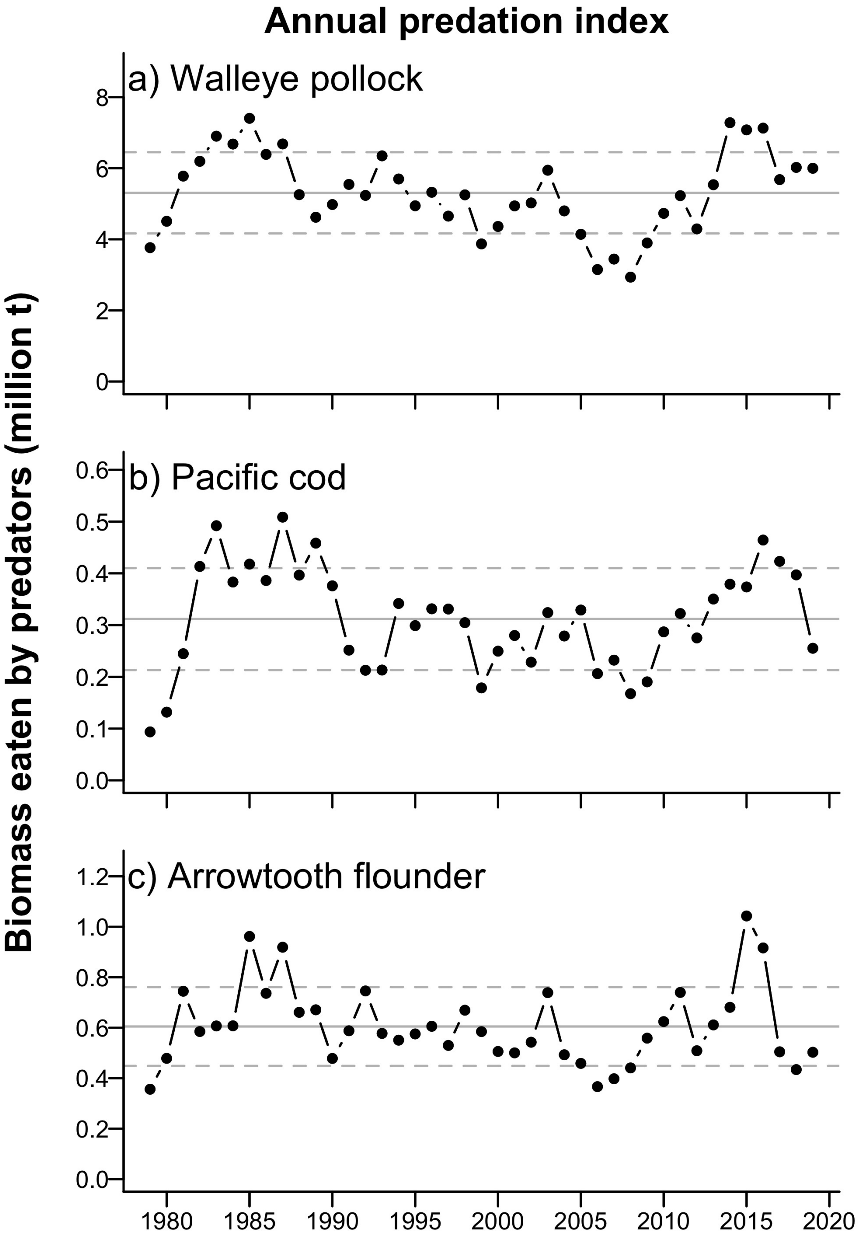

Figure 74: Multispecies estimates of prey species biomass consumed by all predators in the model a) total biomass of pollock consumed by predators annually b) total biomass of Pacific cod consumed by predators annually, c) total biomass of Arrowtooth flounder consumed by predators annually. Gray lines indicate 1979–2019 mean estimates for each species.

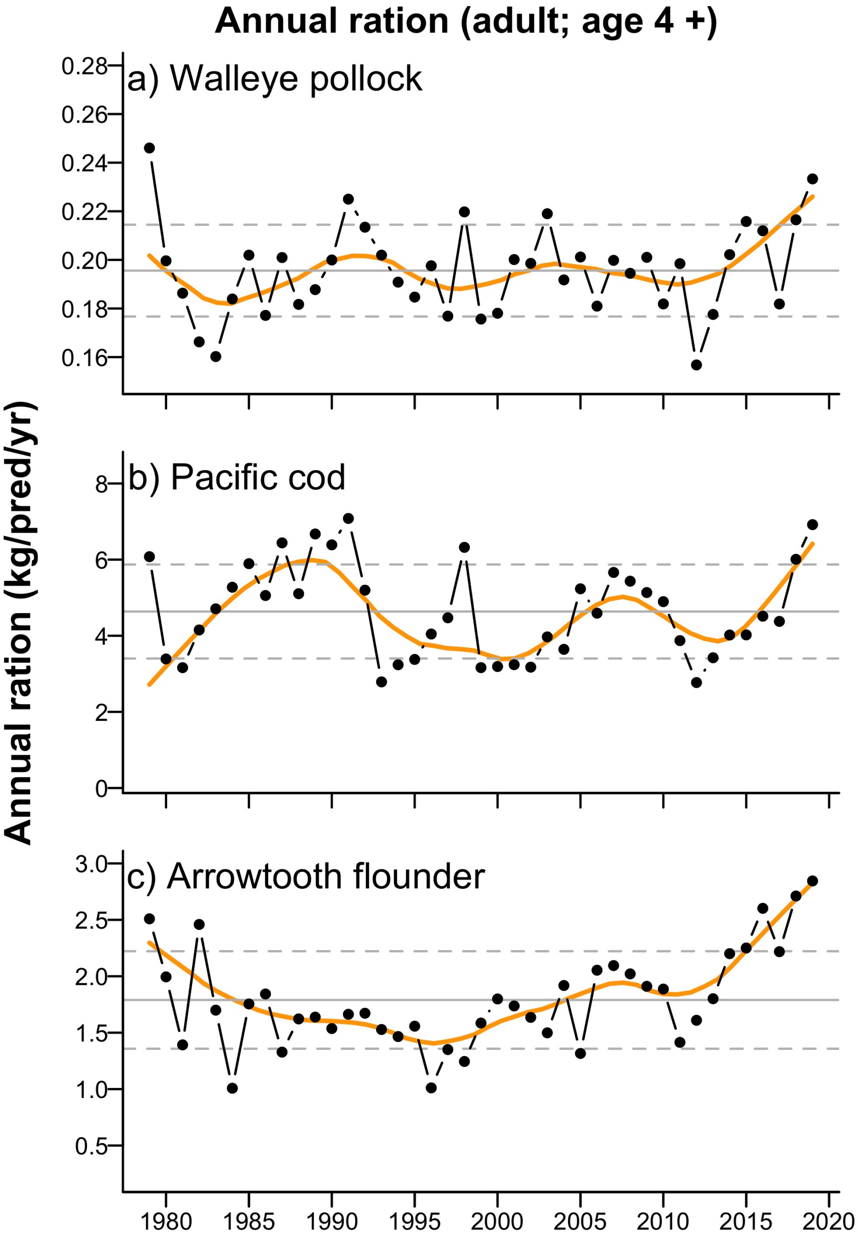

Figure 75: Multispecies estimates of annual ration (kg consumed per indiviudal per year) for adult (age 4+) predators: a) pollock, b) P. cod, and c) Arrowtooth flounder. Gray lines indicate 1979–2019 mean estimates and 1 SD for each species; orange line is a 10-y (symmetric) loess polynomial smoother indicating trends in ration over time.

Groundfish Recruitment Predictions

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

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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 76) 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.

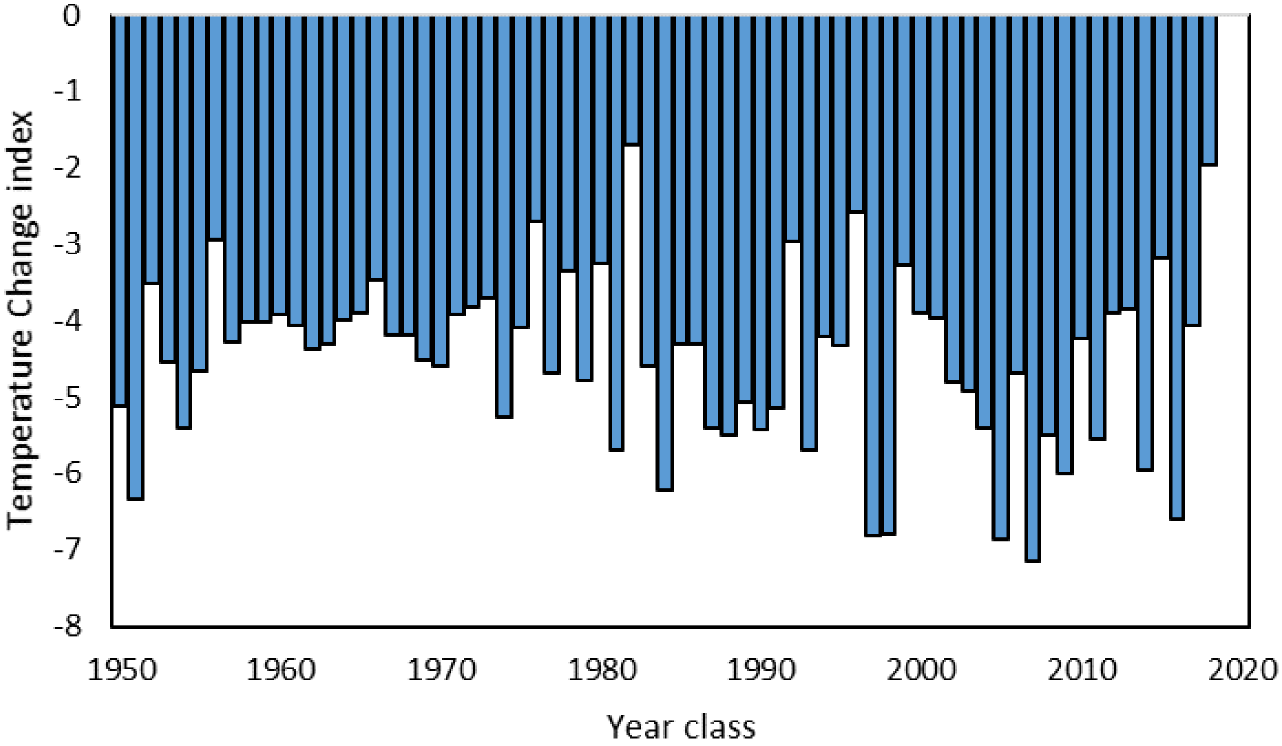

Figure 76: The Temperature Change index values from 1950 to 2019. Values represent the differences in sea temperatures on the southeastern Bering Sea shelf experienced by the 1949–2018 year classes of pollock. Less favorable conditions (more negative values) represent a warm summer during the age-0 life 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 2019 TC index value is -1.96, higher than the 2018 TC index value of -4.1, indicating improved conditions for pollock survival from age-0 and age-1 from 2018 to 2019, respectively. The increase in expected survival is due to the smaller difference in sea temperature from late summer (average) to the following spring (warmer). The late summer sea surface temperature (10.2°C) in 2018 was near the longer term average (9.8°C) and spring sea temperatures (8.2°C) in 2018 were warmer than the long-term average of 5.3°C in spring since 1949.

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 2018 year class of pollock experienced average summer temperatures during the age-0 stage and a warm spring in 2019 during the age-1 stage indicating slightly above average conditions for over wintering survival from age-0 to age-1.

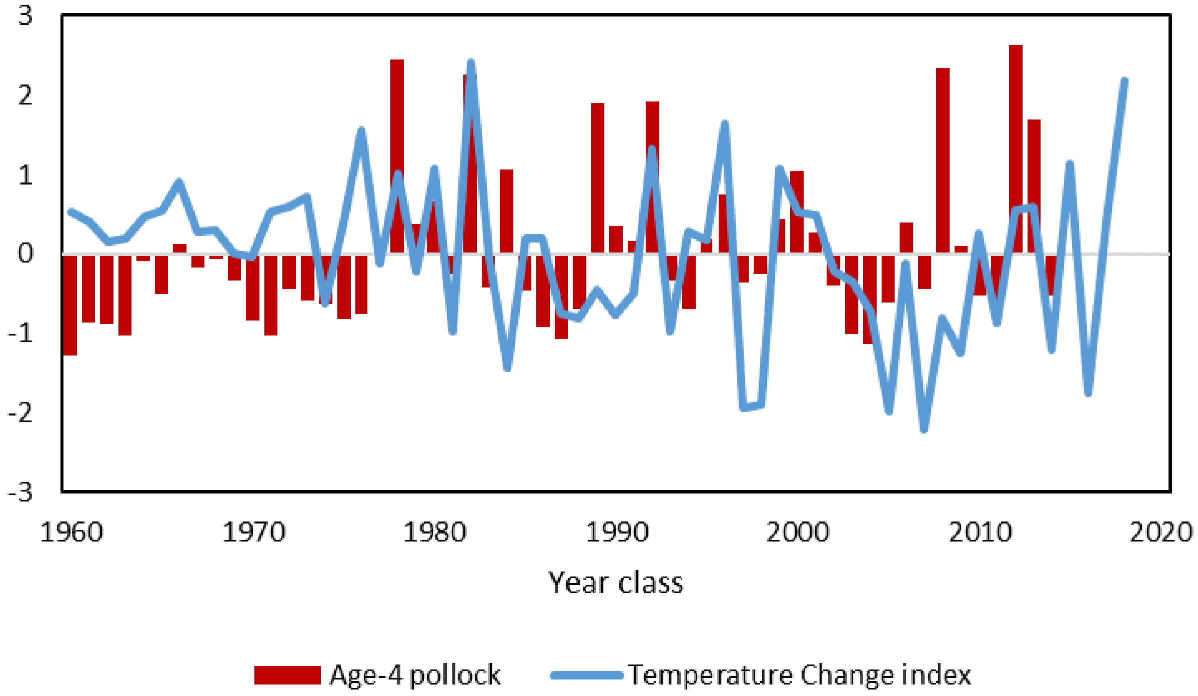

Figure 77: Normalized time series values of the temperature change index indicating conditions experienced by the 1960–2018 year classes of pollock during the summer age-0 and spring age-1 life stages. Normalized values of the estimated abundance of age-4 walleye pollock in the southeastern Bering Sea from 1964–2018 for the 1960–2014 year classes. Age-4 walleye pollock estimates are from Table 28 in Ianelli et al. (2018). The TC index indicates above average conditions for the 2017 and 2018 year classes of pollock.

Implications: The 2019 TC index value of -1.96 was above the long-term average of -4.56, therefore we expect above average recruitment of pollock to age-4 in 2022 from the 2018 year class (Figure 77).

Implications for Age-0 Walleye Pollock (*Gadus chalcogrammus*) Condition Based on Late Summer Surface Silicic Acid Concentrations.

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Last updated: August 2019

Description of indicator: Nitrogen (nitrate, nitrite or ammonium) is usually the principal limiting nutrient in the eastern Bering Sea (EBS) for phytoplankton growth. It is however, often near detection limits during late summer/ early fall for stratified surface waters. Therefore, inter-annual variations in surface nitrogen are difficult to measure during this time. In contrast, surface silicate (silicic acid) is found in higher concentrations than nitrogen and inter-annual variations are reliably detectable making silicate a possible indicator of nutrient availability in surface waters.

The condition of age-0 Walleye pollock (*Gadus chalcogrammus*) during late summer/early fall can be an indicator for recruitment to age-1, where pollock weight is sometimes used as a general proxy for condition. Surface silicic acid is observed during late summer/early fall, in conjunction with age-0 pollock weights, to look for possible connections between nutrients, phytoplankton growth, and young-of-the-year (age-0) pollock condition as they approach their first winter at sea.

Status and trends: Pollock weight and silicic acid values were both above average, and trending slightly upwards from 2014–2016 when viewed within the years 2006–2018. The year 2018 trended downward for both parameters: 2018 silicic acid decreased slightly, though still remained above average, while pollock weight decreased considerably more, and fell below the mean for the same span of time. Bering Sea pollock recruitment to age-1 was up during 2014 and 2015 (representing the 2013 and 2014 year classes), but has continued to trend down since then through 2018 (Ianelli et al., 2016). The year with the lowest surface silicic acid concentrations by the end of summer (2007) also had the lowest average body weights of age-0 pollock with low recruitment to age-1. In addition, 2012 also had lowered silicic acid concentrations, age-0 pollock weights, and low recruitment to age-1 compared with other years (2006–2018). A scatterplot showing age-0 pollock weight with silicic acid values reveals a possible positive relationship, although not significant (Figure 78).

Factors influencing observed trends: During summer, the strength and frequency of summer storm events and water column stratification will influence the amount of nutrients (including silicic acid) that are brought to surface waters from depth. Late summer concentrations of surface silicic acid may serve as an indicator of nutrient availability, with higher concentrations seen during windy years and lower stratification, and low concentrations seen when storm activity is minimal and stratification is high (Gann et al., 2016; Eisner et al., 2016). Diminished nutrient stores leading to lower production in the upper water column may directly affect food stores for higher trophic levels and lead to slowed growth of age-0 pollock during summer months.

Implications: The general positive correlation silicic acid has with age-0 pollock weight (Figure 79) could mark its potential as a variable for use in age-1 pollock recruitment models. The downward trend in pollock weight during 2018 may signal poorer recruitment to age-1 (for the 2018 year class) than in other recent years, however silicate values, while they did drop, were still well above the time series average, and may indicate a new unknown variable causing the lower pollock weight.

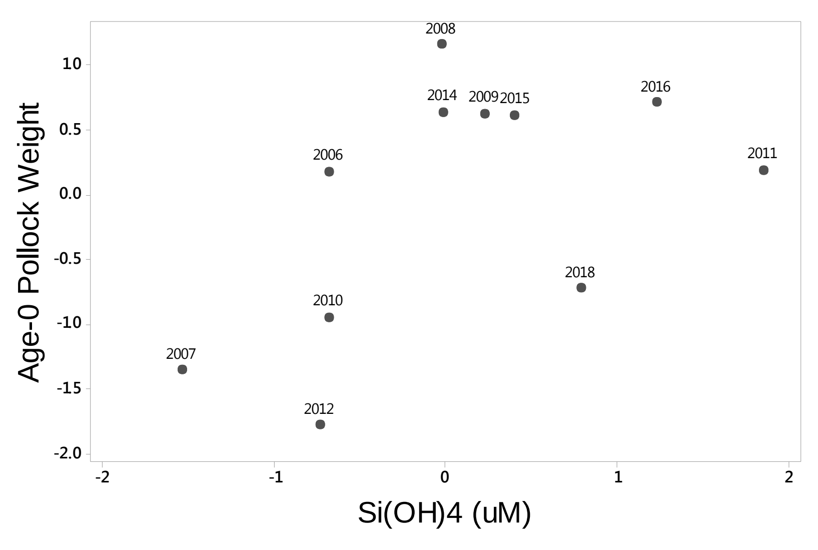

Figure 78: Normalized yearly averages for age-0 pollock weight and silicic acid ($Si(OH)_4$). See explanation of normalization under Figure 79).

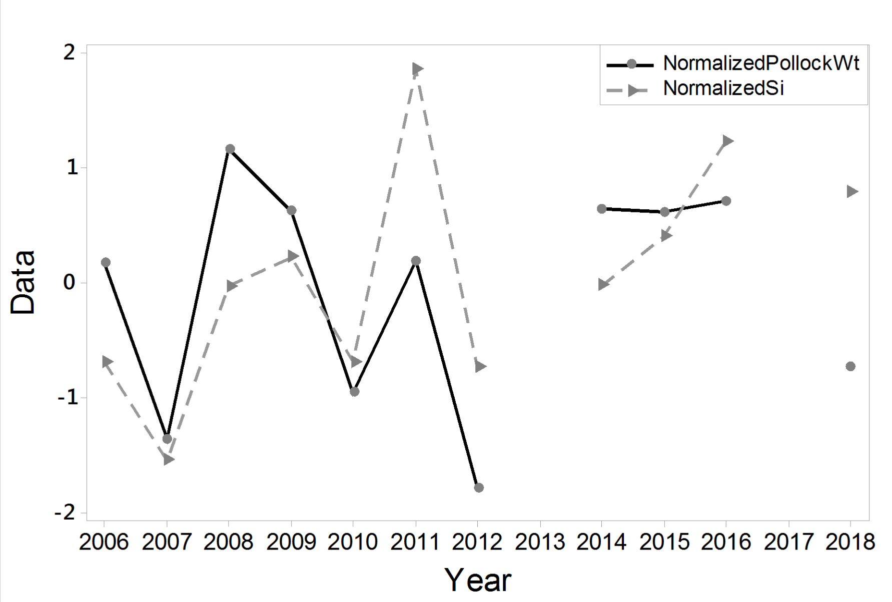

Figure 79: Interannual variability of normalized surface silicic acid ($Si(OH)_4$) from Bering Sea south middle shelf (Region 3) and normalized mean weights of age-0 pollock (south of 60°N). Values were normalized by subtracting the mean from the value for each year and dividing by the standard deviation.

Large Copepod Abundance (Sample-Based and Modeled) as an Indicator of Pollock Recruitment to Age-3 in the Southeastern Bering Sea

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Last updated: September 2019

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), which are taxa typically important in age-0 pollock diets (Coyle et al., 2011). 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 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) years using methods in Eisner et al. (2014). Zooplankton data were not available for 2013. Age-3 pollock abundance was obtained from the stock assessment report for the 2002–2015 year classes (Ianelli et al., 2018). Two estimates of large copepod abundances were calculated, the first using means among stations (sample-based), and the second using the means estimated from the geostatistical model, Vector Autoregressive Spatial Temporal (VAST) package version 8.2.0 (Thorson et al., 2016*a*,*b*; Thorson and Barnett, 2017). We specified 50 knots, a log normal distribution, and the delta link function between probability or encounter and positive catch rate in VAST.

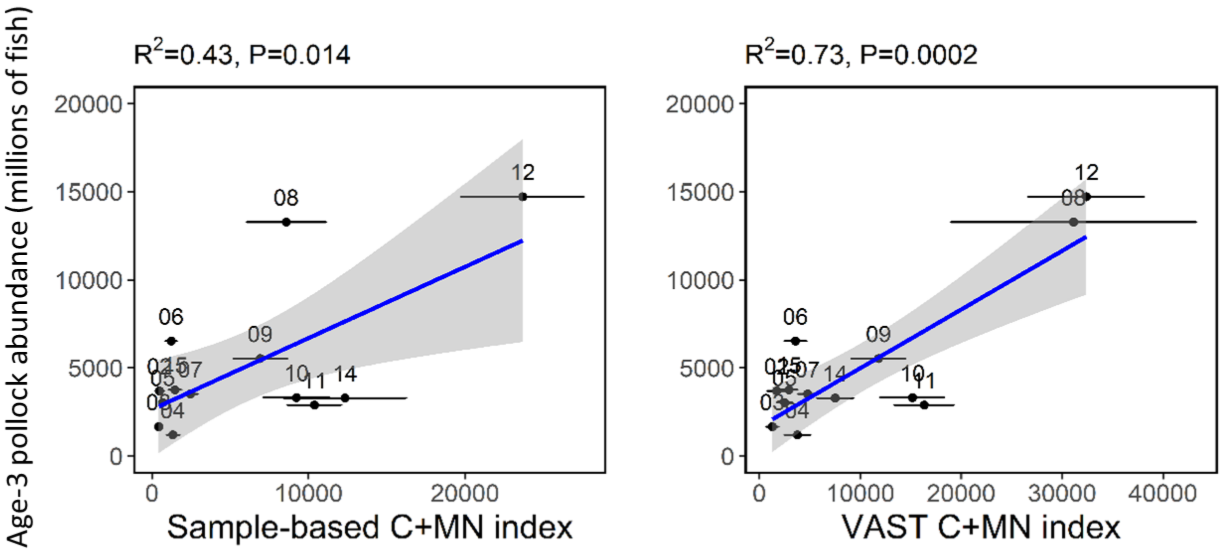

Figure 80: Linear relationships between sample-based (left) or VAST-model (right) estimated mean abundance of large copepods (C+MN, sum of *Calanus marshallae/glacialis*, *Metridia pacifica*, and *Neocalanus* spp.) during the age-0 life stage of pollock, and the estimated abundance of age-3 pollock from (Ianelli et al., 2018) for 2002–2015 year classes. No zooplankton data were available for 2013.

Status and trends: Positive significant linear relationships were found between sample-based and VAST-modeled mean abundances of large copepods collected during the age-0 stage of pollock and stock assessment estimates of age-3 pollock for the 2002–2015 year classes (Figure 80). The stronger relationship using the VAST model compared to observed means among stations ($R^2 = 0.73$ vs. $R^2 = 0.43$) appears to be partially due to the VAST model filling in data for survey area 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 large copepod estimates from the VAST model and compared to the pollock stock assessment estimates from Ianelli et al. (2018) (Figure 81). Our linear regression model using the VAST copepod estimates predicts below average abundance of age-3 pollock for the 2016 year class.

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 2016 were not favorable for age-0 pollock overwinter survival and recruitment to age-3. If the relationship remains significant between age-3 pollock and large copepods (collected when these pollock are age-0), the index can be used to predict the recruitment of pollock three years in advance. 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).

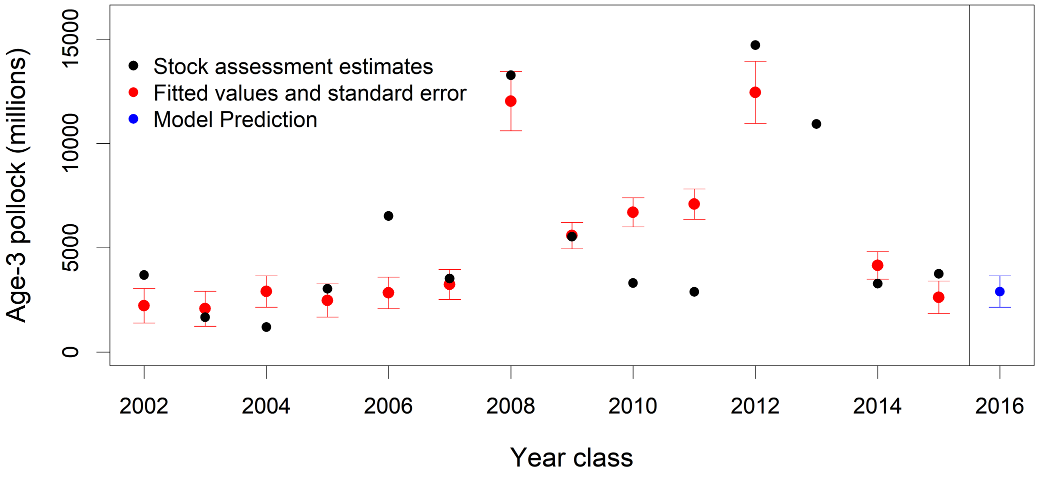

Figure 81: Fitted means and standard errors of the age-3 pollock abundance estimated from the linear regression models using the VAST model estimates of large copepods (red) and means from the pollock stock assessment estimates (black) from Ianelli et al. (2018). Predicted estimates of age-3 pollock for the 2016 year class (recruited into fishery as age-3s in 2019) are shown in blue.

Condition of Age-0 Walleye Pollock and Pacific Cod

Contributed by Elizabeth Siddon[1], Tayler Jarvis[1,2], Ron Heintz[1,2], Ed Farley[1], and Bryan Cormack[1]
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Last updated: October 2019

Description of indicator: This indicator presents average length (mm), energy density (kJ/g), and average energy content (kJ/fish) for age-0 Walleye pollock (*Gadus chalcogrammus*) and Pacific cod (*Gadus macrocephalus*). Fish were collected from surface trawls during the late-summer BASIS survey in the southeastern Bering Sea (SEBS) from 2003–2018 (except in 2015 when oblique [water column] trawls were used). No survey occurred in 2013.

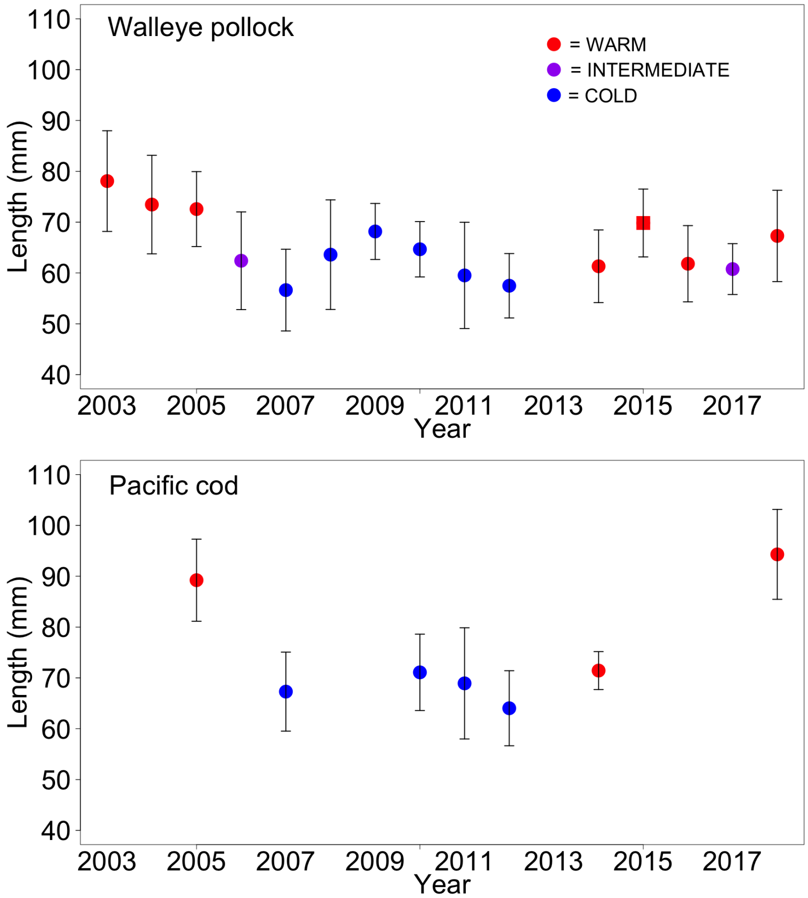

Figure 82: Average length (mm) of age-0 Walleye pollock and Pacific cod collected during the late-summer BASIS survey in the southeastern Bering Sea 2003–2018. No survey in 2013.

The average individual mass is calculated by dividing the total mass by the total number of age-0 fish 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. Average energy content is the product of the average individual mass (g) and average energy density (kJ/g) in a given year.

Here, we show temporal trends in fish size (length, mm) and energy density (kJ/g) for age-0 pollock and Pacific cod across recent warm and cold stanzas. In addition, we relate the average energy content to the number of age-1 recruits per spawning stock biomass for both stocks, as well as the relationship between pollock and Pacific cod recruitment to age-1 and average energy density.

Status and trends: The SEBS experienced above-average ('warm') thermal conditions from 2003–2005 characterized by early ice retreat. Thermal conditions in 2006 were 'intermediate', indicating a transition, and ice retreated much later ('cold' conditions) in the years 2007–2013. Warm conditions returned in 2014–2016 while 2017 was moderate (i.e., 'intermediate'). Following the winter 2017/2018 with an unprecedented lack of sea ice in the northern Bering Sea, 2018 was 'warm' over the SEBS.

Standard length (SL; mm) and energy density (kJ/g) of age-0 pollock and Pacific cod have been measured annually since 2003 (unless no fish were caught; no survey in 2013). Age-0 pollock and Pacific cod tend to be larger in length during warm years. For both species, smallest lengths were observed in 2007 and 2017, both cold years. The largest pollock occurred during the warm stanza of 2003–2005 while the largest Pacific cod were observed in 2018 (Figure 82).

Conversely, energy densities for pollock and Pacific cod were lower under warm conditions. Pollock energy density was at a minimum in 2003 (3.63 kJ/g) and increased to a maximum of 5.26 kJ/g in 2010. Pacific cod energy density was lowest in 2018 (3.95 kJ/g) and was at a maximum in 2007 (4.43 kJ/g) with an overall decline from 2005–2018 (Figure 83).

The average energy content of age-0 pollock in warm years between 2003–2017 accounts for 72% of the variation in age-1 recruits per spawning biomass, but only 9% in cold years (Figure 84). For Pacific cod all years were combined due to smaller sample size; the average energy content accounted for 16% of the variation in age-1 recruits per spawning biomass between 2005–2014 (Figure 85).

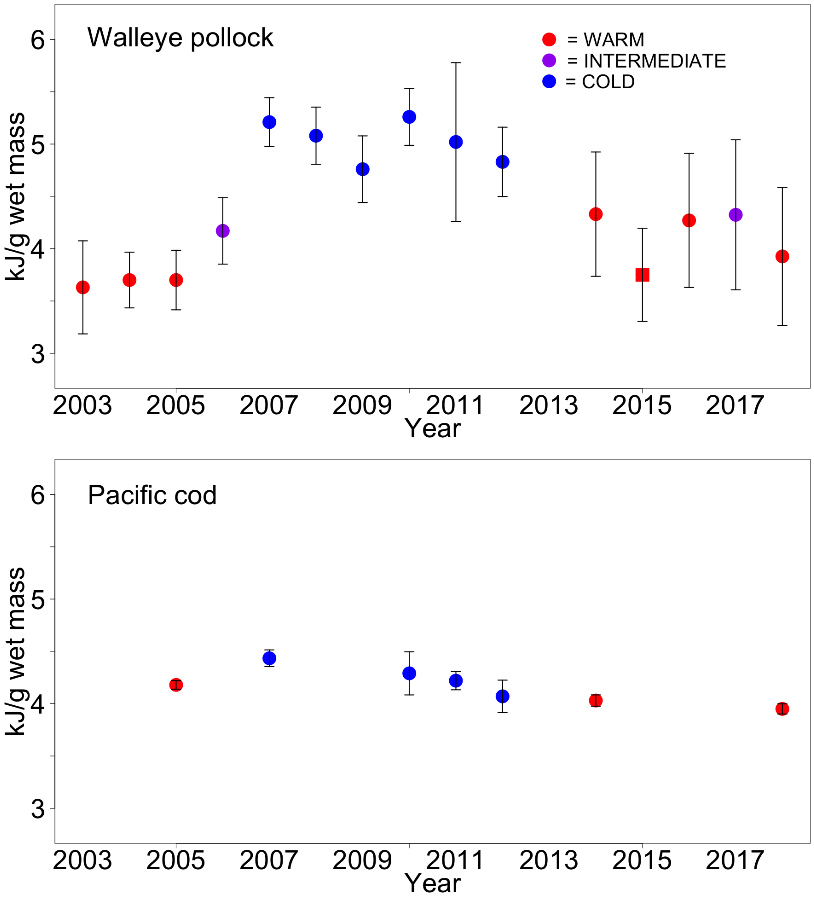

Figure 83: Average energy density (kJ/g wet mass) of age-0 Walleye pollock and Pacific cod collected during the late-summer BASIS survey in the southeastern Bering Sea 2003–2018. No survey in 2013.

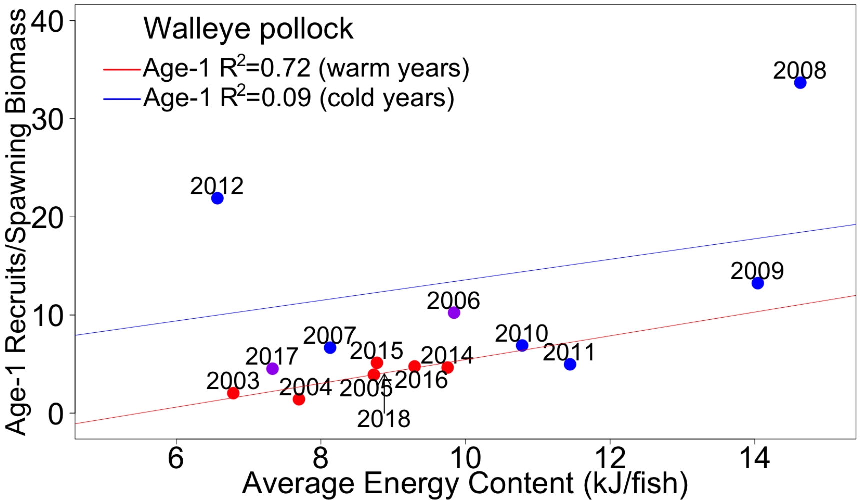

Figure 84: Relationship between average energy content of individual age-0 Walleye pollock and the number of age-1 recruits per spawning biomass from the 2018 stock assessment (Ianelli et al., 2018). Fish were collected with a surface trawl in all years except in 2015 when an oblique trawl was used.

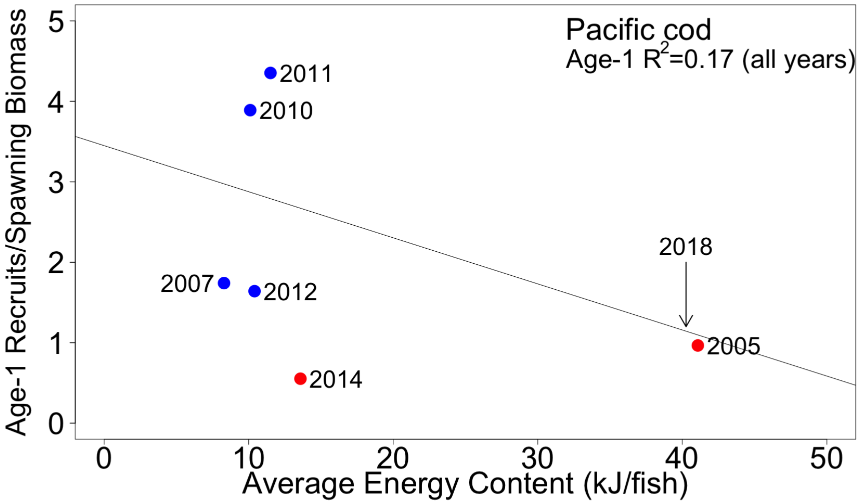

Figure 85: Relationship between average energy content of individual age-0 Pacific cod and the number of age-1 recruits per spawning biomass from the 2018 stock assessment (Thompson, 2018).

While historical recruitment trends between these two gadid species have mirrored each other, suggesting the species respond similarly to environmental conditions, the timeseries appear to decouple after 2010 and may indicate broad-scale transitions in the southeastern Bering Sea ecosystem (e.g., from pelagic- to benthic-dominated production) (Figure 86).

Factors influencing observed trends: The average energy content 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 fish (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*).

For age-0 pollock, prey availability 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

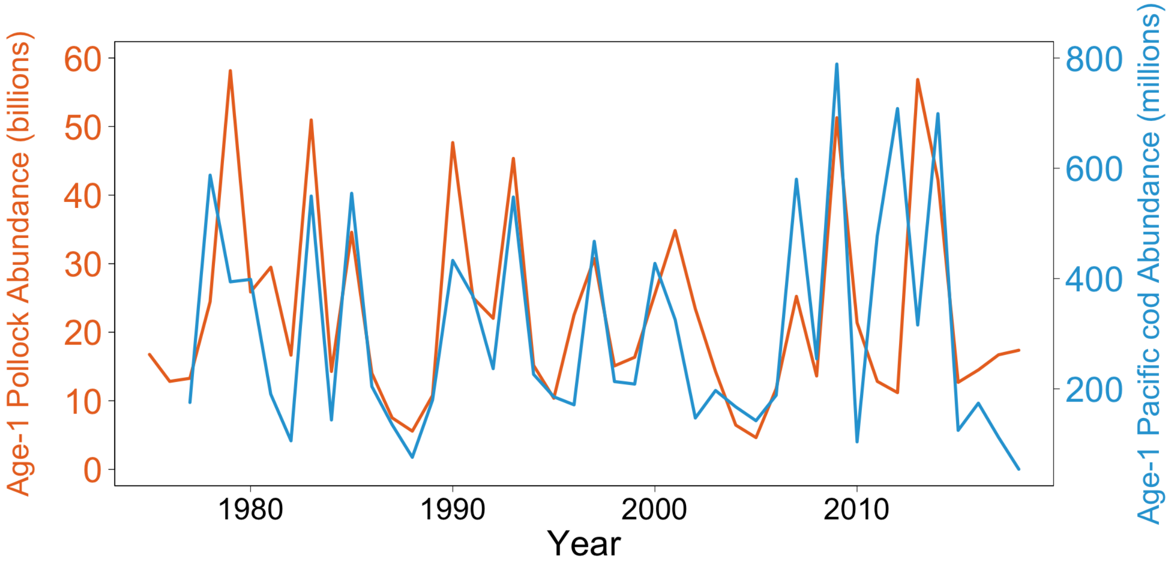

Figure 86: Age-1 abundance timeseries for pollock (orange; in billions) and Pacific cod (blue; in millions) from 1975–2018 (Ianelli et al., 2018; Thompson, 2018).

age-0 pollock a higher energy diet than that consumed in warm years (see. p. 87). Lower water temperatures also optimize their ability to store lipid (Kooka et al., 2007).

For age-0 Pacific cod, early life history dynamics and subsequent drivers of survival and recruitment success may differ from pollock. For example, the timing of settlement from pelagic to benthic habitats impacts food availability and energy density. The duration of the pelagic phase determines survey catchability to surface trawls and therefore the results presented here reflect pre-settlement fish.

Implications: For both pollock and Pacific cod, age-0 fish were larger (i.e., longer) in warm years, but had lower energy densities; in cold years fish were shorter, but had higher energy densities.

For age-0 pollock, the relationship between average energy content and recruitment to age-1 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. 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. 2018 was a warm year in the southeastern Bering Sea in terms of thermal conditions, following the first winter of unprecedented lack of sea ice in the northern Bering Sea and near-complete lack of a cold pool. However, anomalous winds from the southwest during February 2019 may have bolstered productivity over the SEBS, sustained metabolic demands, and subsidized overwinter survival of the 2018 year class of pollock. The 2018 year class may have also experienced less predation as adult pollock and Pacific cod distributions have expanded northward.

For age-0 Pacific cod, our results reflect the condition of pre-settlement fish and therefore may not be indicative of survival or recruitment success to age-1. However, it is important to note that the condition of sampled fish has been declining since 2007.

The mechanisms driving early life history survival versus recruitment success of these gadid species may differ based on pelagic versus benthic habitat (e.g., prey availability) associations. The decoupling of abundance timeseries after 2010 suggests a shift (or greater disparity) between drivers of survival in these two populations.

Benthic Communities and Non-target Fish Species

Miscellaneous Species - Eastern Bering Sea Shelf

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Last updated: October 2019

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 (kg per hectare) was calculated and plotted for each species or species group by year for 1982–2019. 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 2019 relative CPUE for eelpouts remained about the same as in 2018 (0.7% increase), just above the average of the estimates over the last 10 years. The poacher group CPUE increased by 33% since 2018, reversing a decreasing trend observed from 2015 to 2018. However, the 2019 poacher estimate still ranked as the 5th lowest since 1982. The sea stars as a group increased by 12% from 2018 to 2019, and the 2019 CPUE ranked as the 4th highest since 1982 (Figure 87).

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.

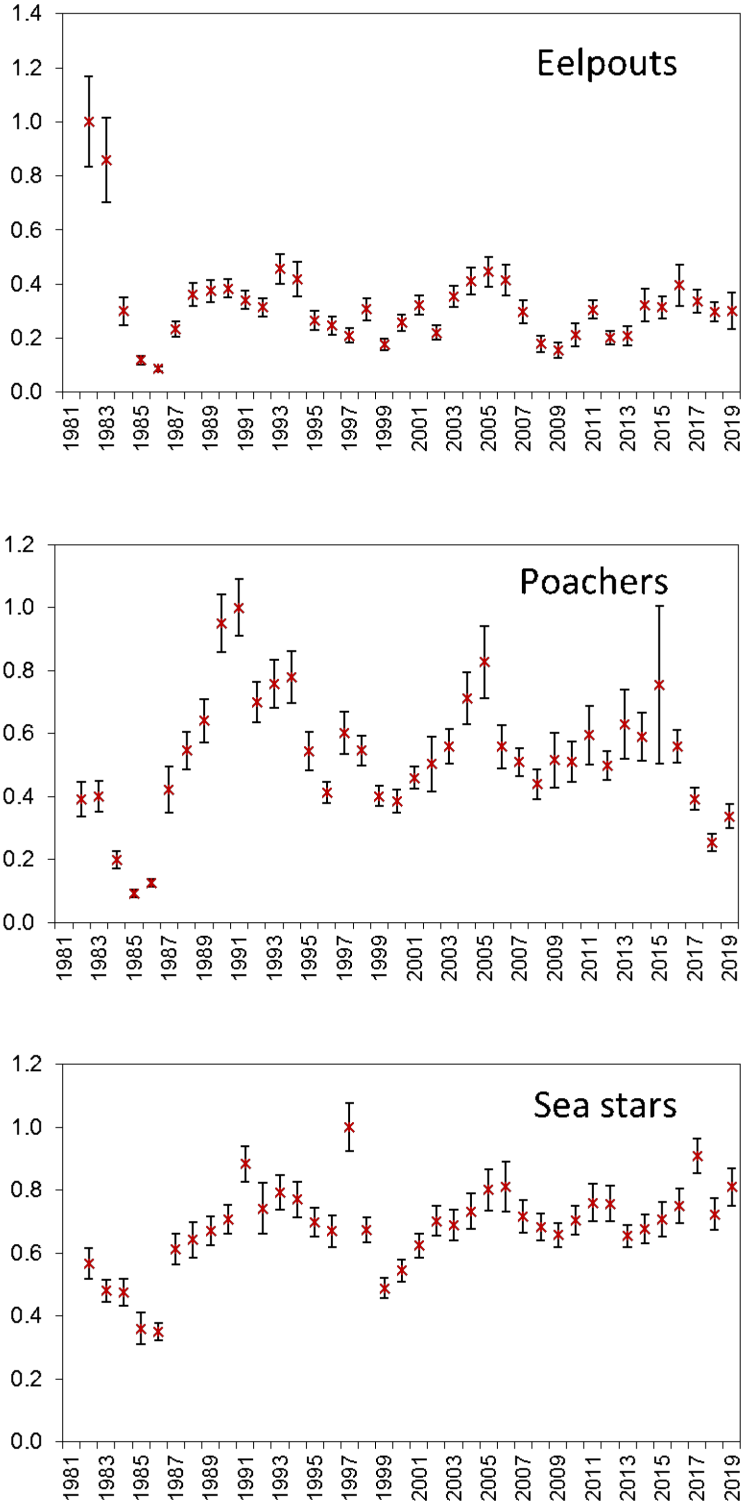

Figure 87: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE (kg per hectare) for miscellaneous fish species during the May to August time period from 1982–2019.

Eastern Bering Sea Commercial Crab Stock Biomass Indices

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Last updated: October 2019

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. 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 2019, 375 standard stations were sampled on the eastern Bering Sea shelf from 3 June to 28 July. The observed trends in crab biomass may be indicative of trends in either benthic production, or benthic response to environmental variability. The commercial crab biomass is also indicative of trends in exploited resources over time.

Status and trends: The historical trends of commercial crab biomass and abundance are highly variable (Figure 88). In 2019, overall decreases were observed in biomass estimates for red king crab and Tanner crab. Bristol Bay mature male red king crab biomass declined by -6% relative to 2018 estimates, continuing a -74% decline since 2014, reaching the lowest point observed in 36 years. Mature female red king crab biomass increased by +6%, although abundance decreased similarly, due to remaining females being larger, with this being the second lowest observation in 23 years and only 2018 being lower. The St. Matthew blue king crab adult male stock increased by +79%, marking an improvement to a continuous decline observed since 2014. Female blue king crab biomass is not adequately sampled during this survey due to a nearshore distribution around St. Matthew Island. Mature male Tanner crab biomass declined by -42 to -59%. The -59% decline in western district mature males marks a dramatic departure from recent stable/increasing trends. Mature females increased in the western district (+9%) and decreased slightly (-4%) in the eastern district. Total snow crab biomass declined by -40% relative to 2018, with this being driven by declines in immature female (-94%), mature female (-34%), and immature males (-38%). Mature males, however, increased by +16% as the large juvenile cohorts that have been observed in the 2017 and 2018 surveys have begun to mature. Pribilof Islands crab stocks remain extremely depressed with highly variable survey biomass estimates due to trawl survey limitations related to crab habitat and the patchy 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 on the benthic substrates. 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 and adult 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.

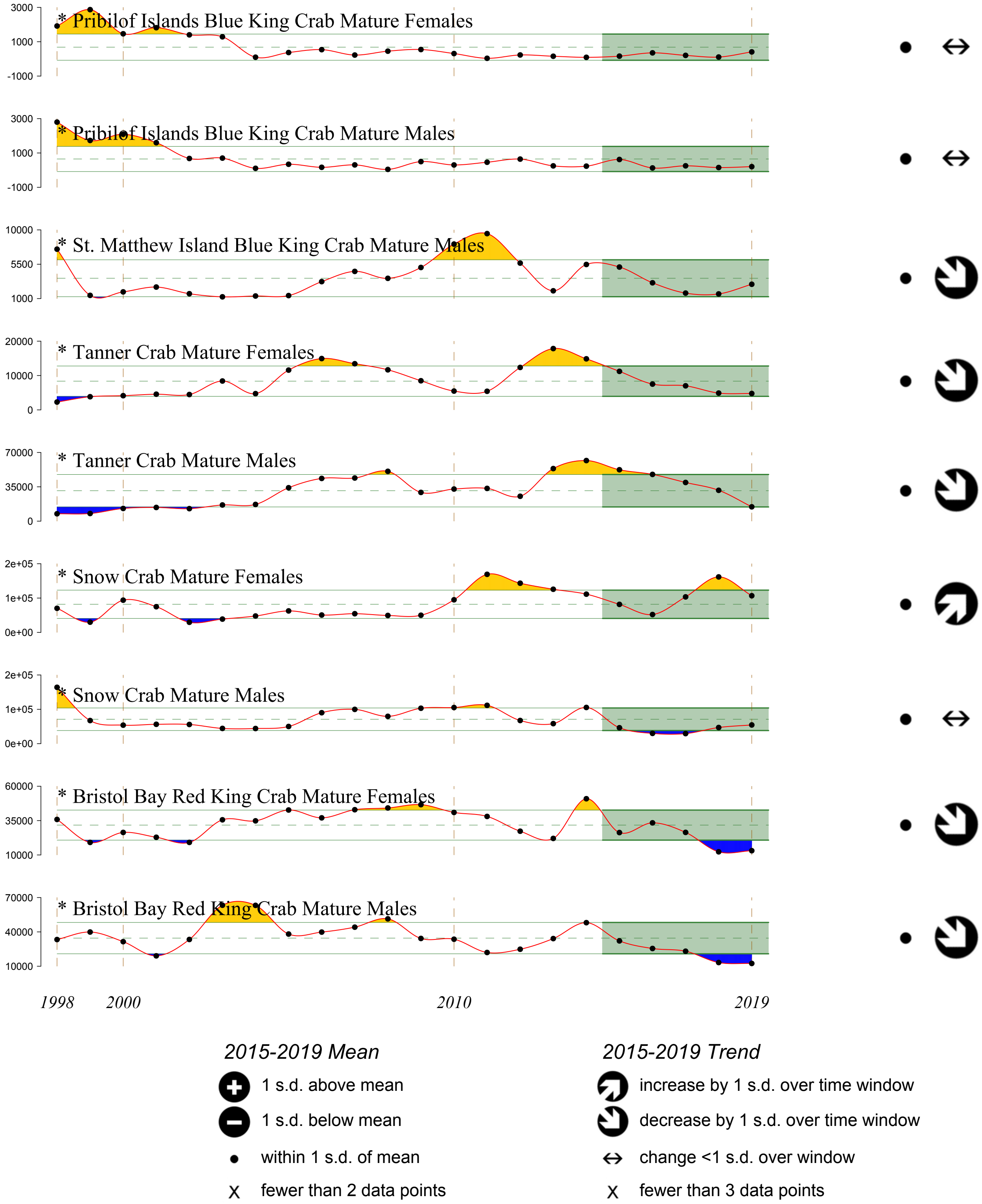


Figure 88: Historical biomass for commercial crab stocks caught on the National Marine Fisheries Service eastern Bering Sea bottom trawl survey, 1998–2019.

Seabirds

Integrated Seabird Information

With contributions from:
Marc Romano (U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge, Homer, AK)
Kathy Kuletz, Robert Kaler, and Elizabeth Labunski (U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage, AK)
Gay Sheffield (University of Alaska Fairbanks, College of Fisheries and Ocean Sciences, Alaska Sea Grant, Nome, AK)
Lauren Divine (Director, Ecosystem Conservation Office at Aleut Community of St. Paul Island)
Hillary Burgess and Tim Jones (Coastal Observation and Seabird Survey Team (COASST))
Catie Bursch (Commercial set-net fisher based at Pilot Point, Ugashik River, Bristol Bay)
Last updated: October 2019

Introduction: In this section, we aim to synthesize seabird information and observations provided from a variety of sources to provide an overview of environmental impacts to seabirds and what that may indicate for ecosystem productivity as it pertains to fisheries management. This integration is in response to collaborative efforts to summarize observations from many sources, including agency/university researchers, citizen science organizations, and coastal community members. Here we merge across information sources to derive regional summaries within the southeastern and northern Bering Sea that can be used by resource managers within the eastern Bering Sea.

Information and observations were contributed from the following:

- The Alaska Maritime National Wildlife Refuge has monitored seabirds at colonies around Alaska in most years since the early- to mid-1970s. Monitored colonies in the eastern Bering Sea include St. Paul and St. George Islands. Here, we focus on cliff-nesting, primarily fish-eating species: common murre (*Uria aalge*), thick-billed murre (*U. lomvia*), black-legged kittiwake (*Rissa tridactyla*), red-legged kittiwake (*R. brevirostris*), and red-faced cormorants (*Phalacrocorax urile*). We also include notes on one crevice-nesting, planktivorous species: least auklet (*Aethia pusilla*). 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. See Figure 89 for time series plots of reproductive success of several species of seabirds at the Pribilof Islands. Monitored colonies in the northern Bering Sea include St. Matthew and Hall islands. Again, we focus on cliff-nesting seabird populations. Counts are compared to data collected during the most recent visit to these islands in 2012. See Figure 90 for a summary of seabird productivity across Alaska Maritime National Wildlife Refuge monitored colonies.
- UAF Alaska Sea Grant, Nome, Alaska made available seabird reports, observations, and carcasses provided by coastal communities throughout the Bering Strait/southern Chukchi Sea region.
- The Aleut Community of St. Paul Ecosystem Conservation Office on behalf of community members from St. Paul Island.
- The Coastal Observation and Seabird Survey Team (COASST) and regional partners provide a standardized measure of relative beached bird abundance.
- Catie Bursch, commercial set-net fisher based in Pilot Point on the Ugashik River, Bristol Bay. Catie has been fishing “the same stretch of beach...same piece of mud” for over three decades and provides observations, samples, and photographs of unusual events in the Pilot Point area.

Implications: Below we summarize regional observations of biological attributes of seabirds that may serve as broader ecosystem indicators important to fisheries managers. Specifically, reproductive success (or failure) can be a reflection of feeding conditions and prey availability in the environment for breeding birds and has implications on subsistence egging practices, harvest of adult birds (e.g., kittiwakes), as well as food security and human health. In general, timing of seabird reproductive stages (phenology) at colonies can reflect ecosystem conditions encountered by birds during the months preceding the breeding season, as long-lived seabirds may delay or defer breeding if foraging conditions limit their ability to build up their energy reserves to support energy demands during the breeding season. For example, earlier attendance at colonies may indicate that respective foraging conditions were favorable, such that birds were able to build enough energy reserves to prepare them for the breeding season. Also, reproductive failure during the breeding season, such as abandonment of nest sites, may indicate that (i) that foraging conditions were poor during the non-breeding season and birds did not return to the colony in good condition, (ii) foraging conditions deteriorated rapidly, or (iii) the presence of disturbance at the colony such as from land-based predators. Reproductive success within a season can differ among planktivorous (primarily zooplankton-feeding), piscivorous (primarily forage fish-feeding), and mixed planktivorous/piscivorous species (see Figure 90), reflecting potential differences among those different prey resources. Population information, such as colony counts, may reflect differences in the proportion of birds attempting to breed or may reflect survival trends, although confounded by non-breeding birds and failed breeders who also attend the colony. Large impacts to populations, such as in the case of seabird die-off events, may also indicate broader ecosystem concerns (e.g., harmful algal blooms, broad-scale lack of prey).

Regional Observations

Southeastern Bering Sea including the Pribilof Islands, Bristol Bay, Round Island, Bogoslof Island, Cape Peirce, and Aiktak Island.

At the Pribilof Islands, both thick-billed and common **murres** had relatively good reproductive success in 2019 in the colonies that were monitored. Reproductive success of murres on St. George was higher than that on St. Paul. However, colony attendance of both species, on both islands, appeared down in 2019, especially for common murres. As a result, total production of murre chicks for both colonies was likely low when compared to years when a greater number of birds attempt to breed. The Aleut Community of St. Paul reported that both thick-billed and common murres were ‘notably absent’ from the cliffs, including Otter Island, in July and August. They had only one report of egging from the community, a total collection of seven eggs, which is ‘really low’ (L. Divine, pers. comm.). The mean hatch date for both species of murre on both islands was not very dissimilar to the long-term mean.

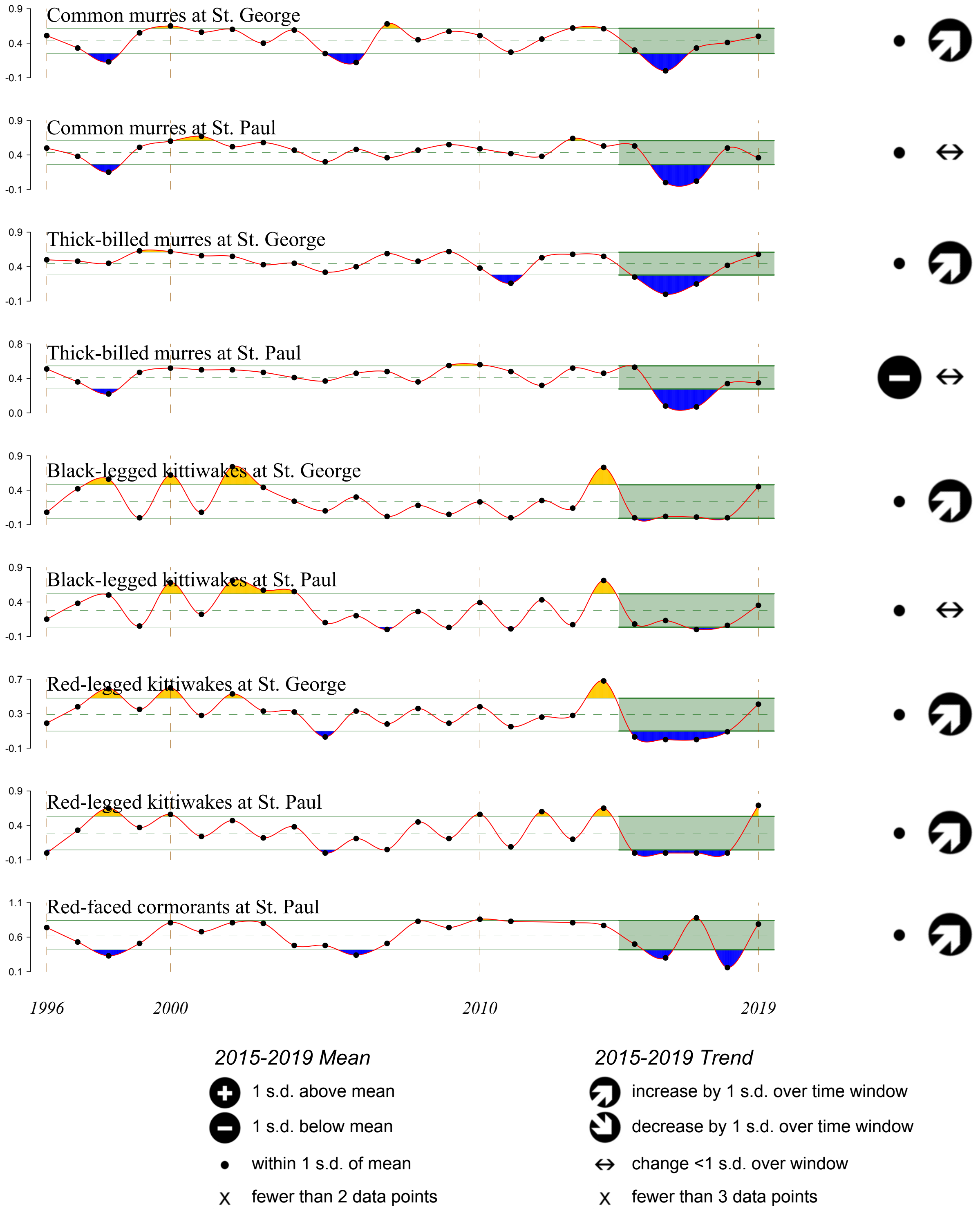
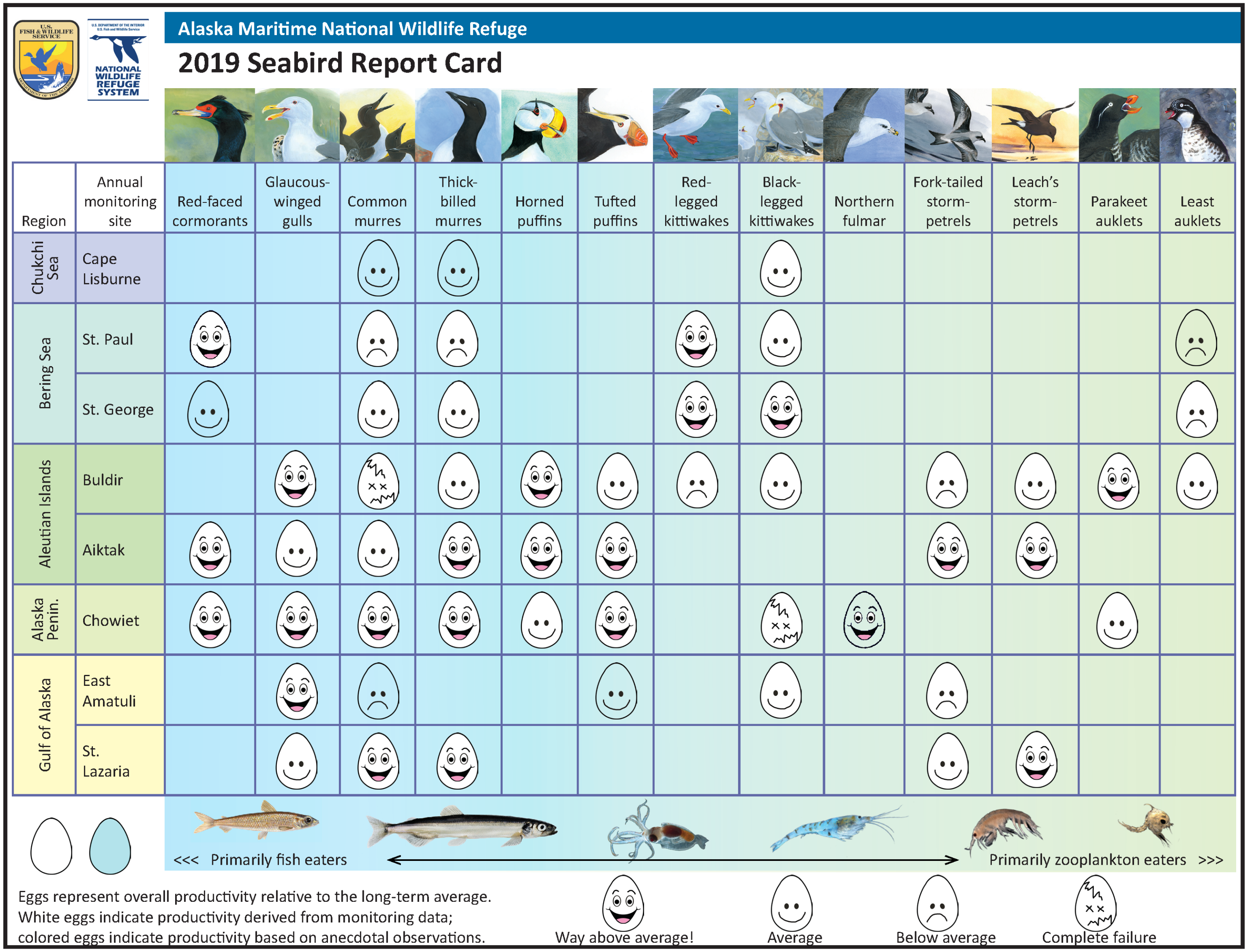


Figure 89: Reproductive success of five seabird species at St. George and St. Paul Islands between 1996–2019.



Alaska Maritime National Wildlife Refuge

2019 Seabird Report Card

Region	Annual monitoring site	Red-faced cormorants	Glaucous-winged gulls	Common murres	Thick-billed murres	Horned puffins	Tufted puffins	Red-legged kittiwakes	Black-legged kittiwakes	Northern fulmar	Fork-tailed storm-petrels	Leach's storm-petrels	Parakeet auklets	Least auklets
Chukchi Sea	Cape Lisburne			🙂	🙂				🙂					
Bering Sea	St. Paul	😁		🙁	🙁			😁	🙂					🙁
	St. George	🙂		🙂	🙂			😁	😁					🙁
Aleutian Islands	Buldir		😁	😵	🙂	😁	🙂	🙁	🙂		🙁	🙂	😁	🙂
	Aiktak	😁	🙂	🙂	😁	😁	😁				😁	😁		
Alaska Penin.	Chowiet	😁	😁	😁	😁	🙂	😁		😵	😁			🙂	
Gulf of Alaska	East Amatuli		😁	🙁			🙂		🙂		🙁			
	St. Lazaria		🙂	😁	😁						🙂	😁		

<<< Primarily fish eaters ⟷ Primarily zooplankton eaters >>>

Eggs represent overall productivity relative to the long-term average.
White eggs indicate productivity derived from monitoring data;
colored eggs indicate productivity based on anecdotal observations.

😁 Way above average!
🙂 Average
🙁 Below average
😵 Complete failure

Figure 90: 2019 Seabird Report Card showing a summary of seabird productivity across Alaska Maritime National Wildlife Refuge monitored colonies.

Least auklets at the Pribilof Islands continued the recent trend of lower reproductive success, earlier mean hatch dates, and very low colony attendance. Their abundance is ‘depressingly low’ to St. Paul community members who ‘remember the constant noise and chatter from former breeding areas’. Community members expect least auklets to ’virtually disappear within the next decade unless their food source (i.e., copepods) becomes much more abundant in the nearshore areas’ of the Pribilof Islands. On St. George Island, least auklets experienced their fourth consecutive year of poor reproductive performance. The 2019 mean hatch date was several days earlier than the long-term mean while the mean hatch date for 2014–2019 (3 July) was two weeks earlier than the mean hatch from 2008–2013 (17 July). Finally, the mean count of least auklets at colony attendance plots on St. George in 2019 was the lowest ever recorded (90 birds) and nearly an order of magnitude lower than the long-term mean (879 birds).

Both **red-legged and black-legged kittiwake** species showed significant increases in reproductive success in 2019 at both islands. This is noteworthy because kittiwakes experienced four years of complete, or near complete, reproductive failure from 2015–2018. Community members also noted that red-legged kittiwakes were ‘more abundant for the first time in a few years!’ and noted more red-legged kittiwake chicks than previous years. Mean hatch dates for both species on both islands were significantly earlier than the long-term mean. In fact, for red-legged kittiwakes at St. George Island, 2019 was the earliest mean hatch date ever recorded for the species and 45 days earlier than the mean hatch date recorded in 2018.

Red-faced cormorants reproductive success at St. Paul Island in 2019 was above the long-term mean, and mean clutch size was equal to the highest ever recorded at this location (3.5 chicks/nest with eggs). However, for the second year in a row, laying success (nest sites with egg/total nest starts) was very low due to early abandonment of nests.

Community members at St. Paul Island also reported that tufted and horned puffins were lower in abundance in 2019, as they have been the last 2 to 3 years.

Beached Bird Monitoring
Monitoring by the Coastal Observation and Seabird Survey Team (COASST) and regional partners provides a standardized measure of relative beached bird abundance for the Pribilof Islands from 2006 to present. Time-series of month-averaged beached bird abundance for the Pribilof Islands show several of the recent mortality events that have affected the Bering Sea (Figure 91).

At the Pribilof Islands, mortality events were noted in late 2016 and in 2019. The 2016 event was predominantly tufted puffins (Oct–Dec) followed by crested auklets (Nov–Jan). In total, 350 carcasses were counted; the event was particularly anomalous given the late fall/winter timing when typically the number of beached birds is low. The 2019 event was almost entirely short-tailed shearwaters (Jun–Aug), with mortality of this species extending from the Aleutian Islands, throughout the southeastern Bering Sea, and into the Bering Strait and Chukchi Sea. It is important to note that shearwaters do not breed in Alaska, but spend summers there for feeding. Therefore, 2019 mortality events may reflect poor or insufficient foraging conditions during summer 2018, austral summer 2019 (when breeding in the Southern Hemisphere), and/or summer 2019. From COASST surveys on the Pribilof Islands, the abundance of beach-cast shearwaters peaked in August at over 100 birds per km, representing 100 times higher than baseline for that month. In Bristol Bay, shearwater mortalities were first noted in mid-July and continued into early August. Shearwater mortalities on St. Paul seemed ‘a bit delayed from other regions, but then ramped up in July’ (L. Divine).

Northern Bering Sea including the Bering Strait region, St. Matthew and Hall islands, St. Lawrence Island, Bluff, Nome, and Sledge Island.

The Alaska Maritime National Wildlife Refuge visited St. Matthew and Hall islands in 2019 to collect data on cliff-nesting seabird populations. Counts were conducted of birds attending long-term population monitoring plots and are compared here to data collected during the most recent visit to these islands in 2012. While some data are still being analyzed, anecdotal observations indicate common **murre** numbers are much lower in 2019 compared to 2012. Thick-billed murre numbers also appeared to be lower, though not nearly as low as common murres. Both species appeared to suffer almost complete reproductive failure during 2019.

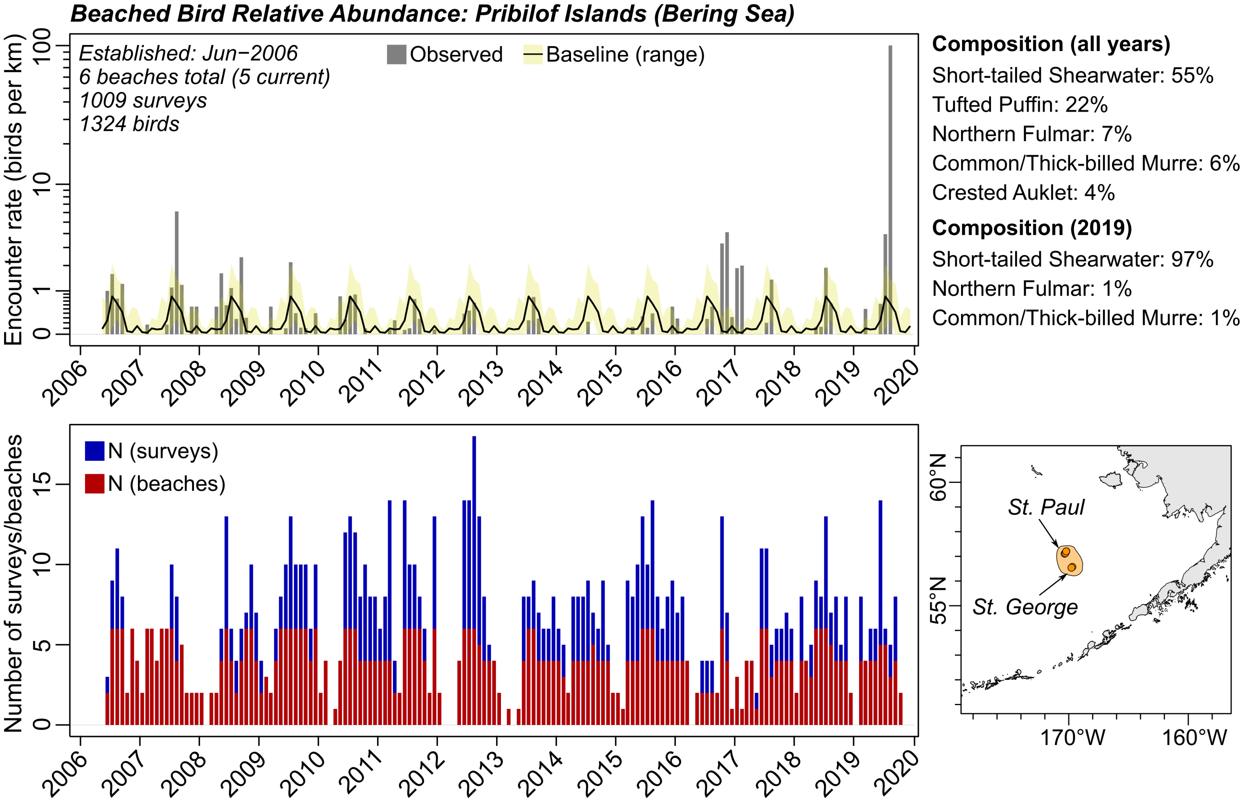


Figure 91: Month-averaged beached bird abundance, standardized per km of survey effort, for the Pribilof Islands. The top panel shows the month-averaged encounter rate (ER: birds per km) as well as a long-term baseline calculated as the mean and range in month-specific encounter rate across years, excluding mortality events (months with ER >5 times baseline). The bottom panel shows survey effort at the monthly scale. Map inset shows monitored beach locations (circles).

In the Bering Strait region, community members from Gambell (St. Lawrence Island) reported the presence of several hundred murres nearshore in open water during December of 2018. By February of 2019, Gambell residents continued to report several seabird species, including cormorants, guillemot, and murres, nearshore to Gambell at a time when there was open ocean and very large waves. A Nome resident reported 'a normal amount of cormorants around, normal number of scoters, but fewer numbers of murres' during June 2019. In fact, eggers 'went to Sledge Island...to check on murre eggs. When we arrived at the cliffs our guess is approximately 80–90% of the murres were gone." A report from Diomede indicated that murres had arrived to their waters in MArch 2019.

Community members throughout the northern Bering Sea provided observations on additional seabird species. Savoonga residents in August 2019 reported that least auklets failed to reproduce; birds laid eggs but abandoned the chicks. They noted 'catastrophic' failures for both least and crested auklets and that guillemots 'crashed'. Diomede reported 'more crested auklets than least auklets' in June 2019. Golovin (east of Nome) residents reported 'seeing live puffins on the inside of Golovin Bay and Lagoon [in July], where they have never seen them before; they thought that it was a weird sighting'.

The Alaska Maritime National Wildlife Refuge biologists noted that black-legged **kittiwake** numbers appeared to be lower in 2019 when compared to 2012, though there is evidence to suggest that this species has been declining at both St. Matthew and Hall islands since the early 1990s. However, red-legged kittiwakes were observed at St. Matthew Island in 2018 and breeding was confirmed in 2019. Approximately 250 red-legged kittiwakes were counted in 2019, which established St. Matthew Island as the fifth largest breeding colony for the species. Both black- and red-legged kittiwakes appeared to experience very high reproductive success during 2019, with many active nests containing chicks observed.

Beached Bird Monitoring

COASST works with regional partners (e.g., USFWS, Alaska Sea Grant, volunteer community members) to provide a standardized measure of relative beached bird abundance for the Bering Strait/southern Chukchi Sea from 2009 to present. Time-series of month-averaged beached bird abundance for the Chukchi Sea show several of the recent mortality events that have affected the Bering Strait/southern Chukchi Sea region (Figure 92).

In the Bering Strait/southern Chukchi Sea, elevated beached bird abundance was documented in 2017, mid 2018, and 2019. The 2017 event was predominantly short-tailed shearwaters, common/thick-billed murres, and northern fulmars. The 2018 event peaked in May–June and was dominated by common/thick-billed murres with a smaller number of black-legged kittiwakes. In 2019, beached bird abundance peaked in June, with a mixed assemblage of alcids (i.e., murres, puffins, auklets), and later in August which was dominated by short-tailed shearwaters. For the Bering Strait and Chukchi Sea, abundances peaked at 11 birds per km, representing 10 times higher than baseline. Notably, 2017–2019 all displayed early pulses (May–Jun) of murre mortality, which was absent from prior years.

Communities throughout the Bering Strait region reported observations of dead or dying seabirds to the regional seabird responders in the hub community of Nome, who provided information and/or specimens to the USFWS. These data were transferred from USFWS to COASST and are reflected in the above description. It is important to note that seabird mortality in the Bering Strait region is not solely a conservation issue, but also food security and public health concerns. Communities reporting dead seabirds included (from south to north within the region): Gambell, Savoonga, Unalakleet, Golovin, Nome, Wales, and Shishmaref, Kotzebue, Cape Lisburne, and Point Thomson. The species reported included shearwaters, but also (in alphabetical order, not according to the abundance of mortalities): auklets, cormorants, gulls, kittiwakes, murres, and puffins (Figure 93). Neighboring communities on the Chukotka Peninsula (Russia) reported dead auklets, cormorants, guillemots, gulls, murres, puffins, and shearwaters, with an epecially large pulse of dead seabirds during late August 2019. Over 65 seabird carcasses were provided by Bering Strait communities to the regional hub (Nome) where they were catalogued before shipping to USFWS for processing. As of October 2019, USGS Alaska Science Center reports no saxitoxin has been detected in tissues from birds collected from Bristol Bay or Bering Strait regions, and starvation continues to be identified by the USGS National Wildlife Health Center as the predominent cause of death.

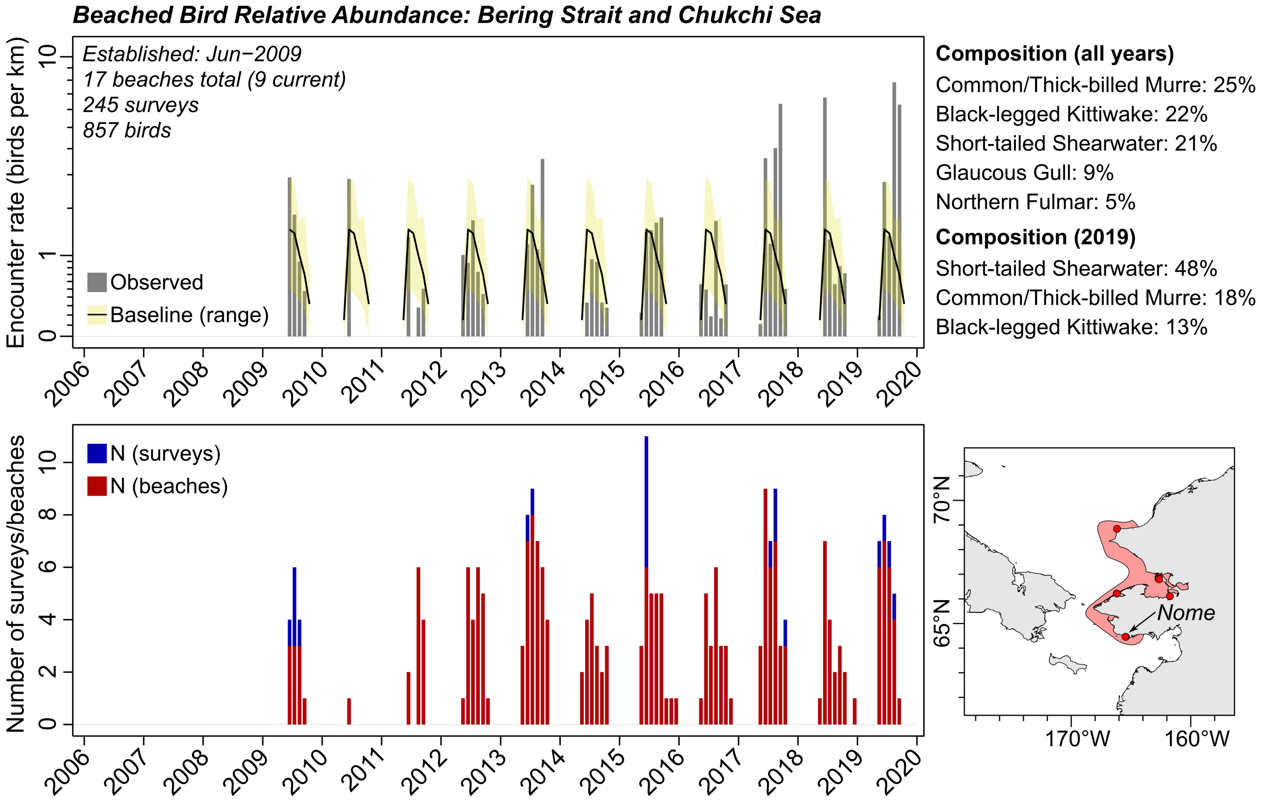


Figure 92: Month-averaged beached bird abundance, standardized per km of survey effort, for the Bering Strait/Chukchi Sea. See Figure 91 for details.

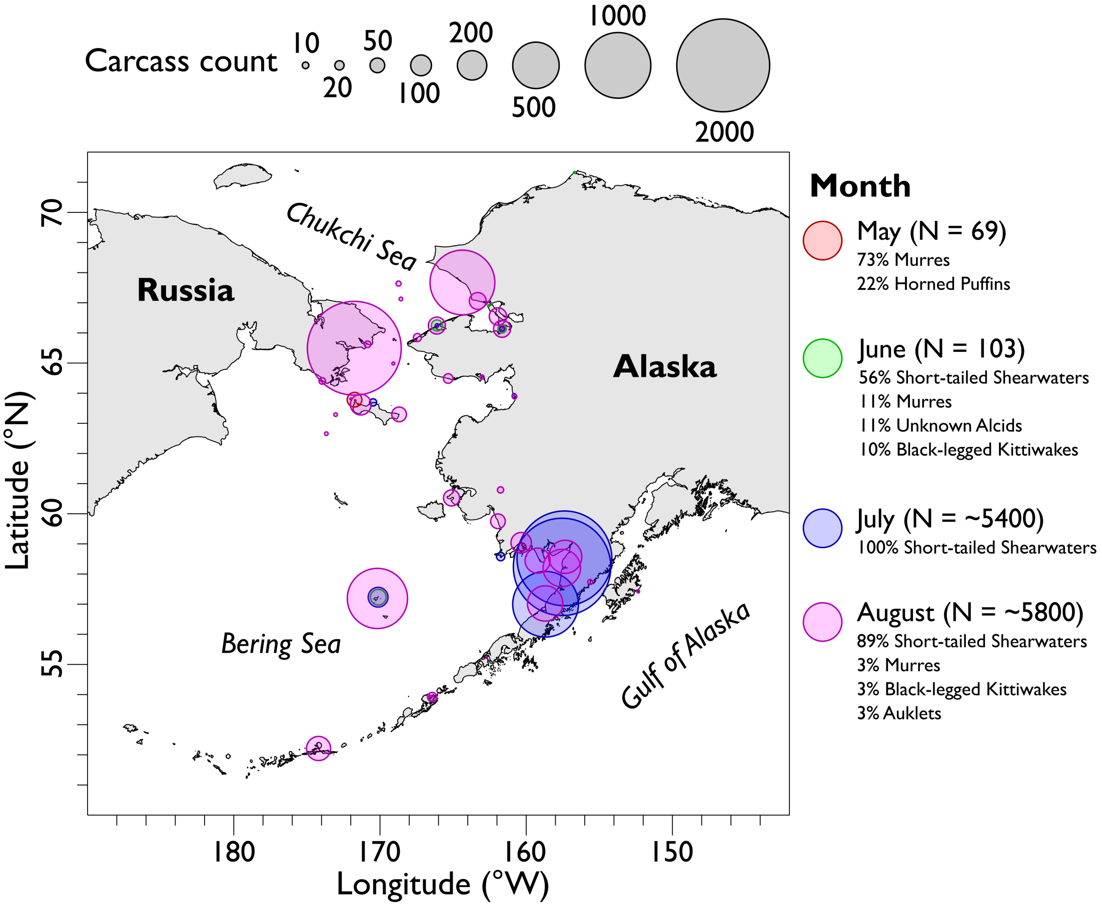


Figure 93: Counts of seabird mortalities across Alaska from May–August 2019.

Marine Mammals

The Marine Mammal Laboratory provided new contributions to the Noteworthy section of the report this year. Please see p. 28 and 30. See the contribution archive for previous indicators at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`.

Ecosystem or Community Indicators

Mean Lifespan of the Fish Community

Contributed by George A. Whitehouse[1] and Geoffrey M. Lang[2]
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Last updated: September 2019

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[10]. The groundfish community mean lifespan is weighted by biomass indices calculated from the bottom-trawl survey catch data.

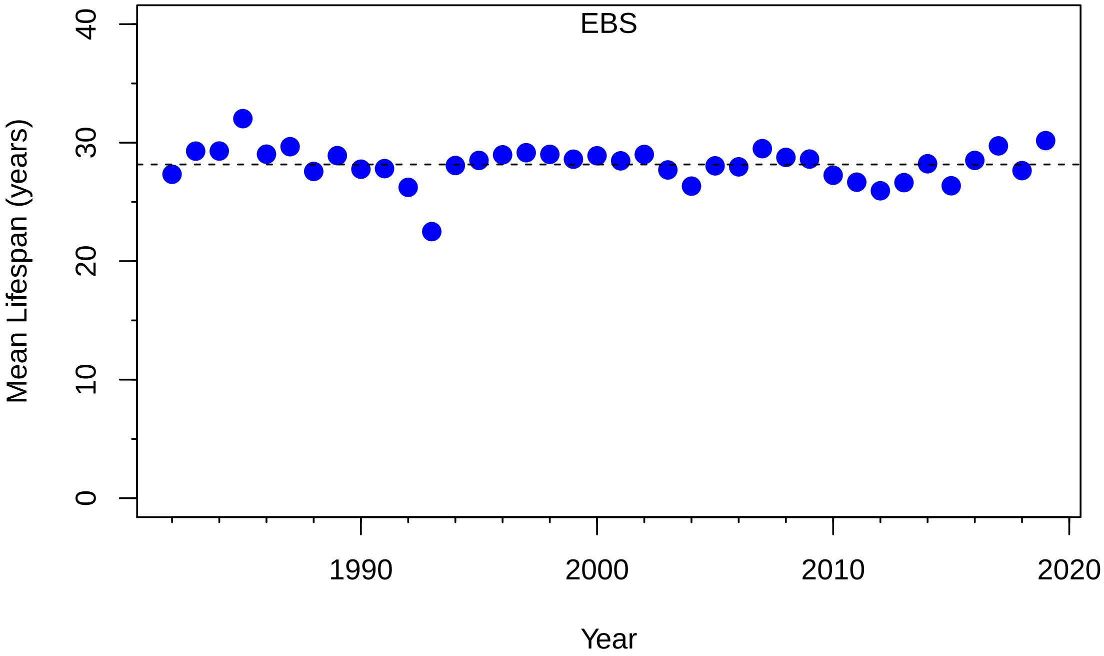

Figure 94: The mean lifespan of the southeastern Bering Sea demersal fish community, weighted by biomass indices calculated from the NMFS/AFSC annual summer bottom trawl survey. The dashed line is the long-term mean.

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-trawling gear are excluded from this indicator (e.g., sharks, grenadiers, myctophids, pelagic smelts).

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[10] `https://access.afsc.noaa.gov/reem/LHWeb/Index.php`

Status and trends: The mean lifespan of the southeastern Bering Sea demersal fish community in 2019 is 30.2 years, and is the second highest over the time series. This is up from 27.6 years in 2018 and above the long-term mean of 28.2 years (Figure 94). Mean groundfish lifespan has generally been stable over the 38-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 week recruitment could also influence the mean community lifespan by altering the relative abundance of age classes and species. For example, the low value observed in 1993 reflects a year of peak biomass index for capelin, a shorter lived species. While the peak mean lifespan in 1985 was, in part, elevated by high biomass indices for long-lived species such as sablefish.

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 2019

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). This indicator is also sensitive to shifting community composition of species with different mean sizes. 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).

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 38 years of the time series. Another eleven species were sampled between 11 and 35 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.

Status and trends: The mean length of the EBS groundfish community in 2019 is 37.2 cm, which is only slightly less than last year's peak value (37.6 cm). Since 1982, the mean length has shown variation from year to year and has been trending upward since 2012 (Figure 95). A trendline over the time series has a positive slope (p=0.005) indicating a slow increase over time.

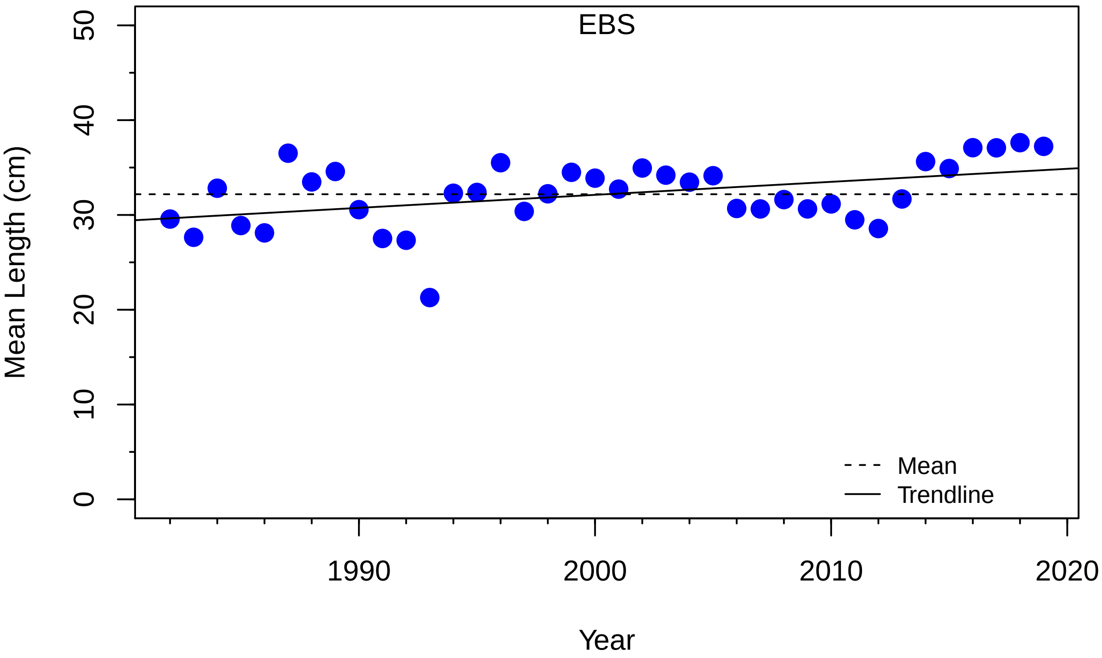

Figure 95: Mean length of the groundfish community sampled during the NMFS/AFSC annual summer bottom-trawl survey of the southeastern Bering Sea (1982–2019). The groundfish community mean length is weighted by the relative biomass of the sampled species. The dashed line represents the mean of the time series (1982–2019) and the solid line is a trendline with slope =0.137.

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 affecting 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. Additionally, 1993 was a pronounced peak in the biomass index of capelin. This reduced the proportional contribution of other species to total groundfish biomass index, thus reducing the indicator value (i.e., mean length) in 1993. Years where this indicator attained its highest values (1987, 2016–2019) 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 2019 was buoyed by other prominent groundfish such as Alaska skate, Arrowtooth flounder, and Yellowfin sole 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 (1982–2019) with some interannual variation. The collective stability of the combined biomass of relatively larger groundfish species has helped to maintain this indicator at its recent high values. Previous dips in this indicator were in part attributable to spikes in abundance of smaller forage species (e.g., capelin), as opposed to a sustained shift in community composition or reductions in species mean length.

Stability of Groundfish Biomass

Contributed by George A. Whitehouse
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Last updated: September 2019

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 (1982–2019). 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).

Status and trends: The state of this indicator in 2019 is 7.68, which is up from 5.5 in 2017, and is the highest over the time series. The previous high of 7.63 was observed in 1992, which was followed by a steady decrease to a low of 3.9 in 2002. Since then it gradually increased to a value of 5.5 in 2018 before sharply increasing to its new high in 2019. In between the high values at the start of this time series and in 2019, this indicator has remained generally stable and does not exhibit a clear trend (Figure 96). Since 1991, the mean value for this metric is 5.2. 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 effecting 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, 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 in 2019 and at the start of the time series are indicative of stable groundfish biomass with a relatively low CV during the previous ten years. Low values for this

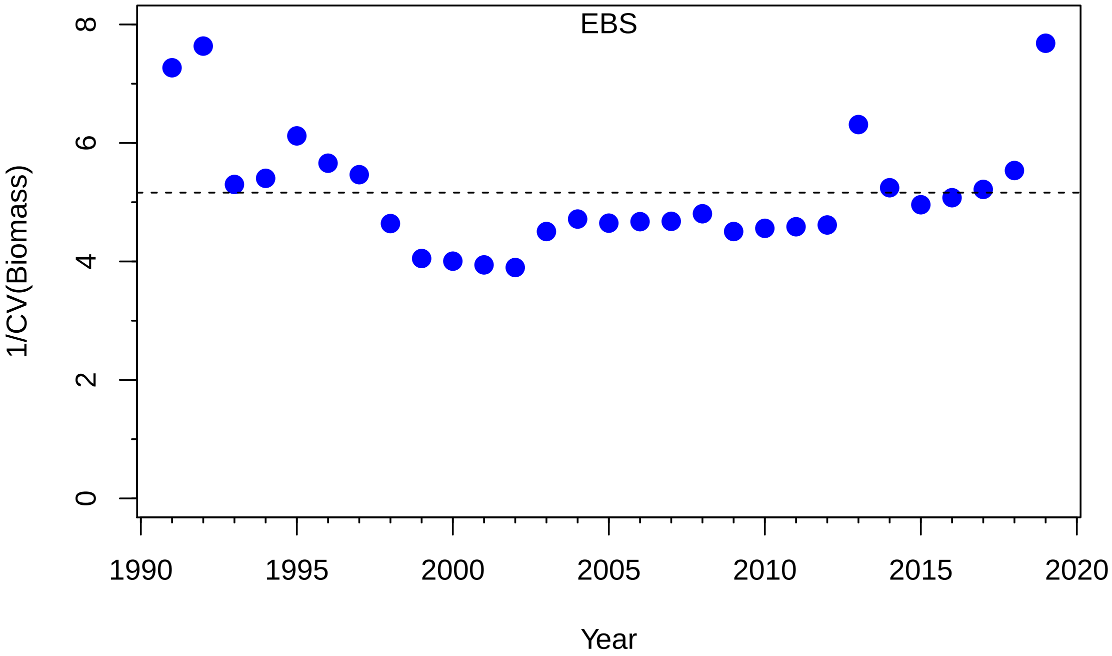

Figure 96: The stability of groundfish in the southeastern Bering Sea represented with the inverse biomass coefficient of variation of total groundfish biomass (1/CV[B]). Ten years of data are required to calculate this metric, so this time series begins in 1991 after the tenth year of the NMFS/AFSC annual summer bottom-trawl survey. The dashed line is the mean value.

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. Similarly, in 2019, the relatively low biomass year of 2009 is now outside the ten year window, reducing the CV. 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 and Chum Salmon Bycatch in Bering Sea Trawl Fisheries

Contributed by Jordan T. Watson, Chuck M. Guthrie III, Christine Kondzela, Maxwell Marsh, Hanhvan T. Nguyen, and Jacqueline Whittle
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Last updated: August 2019

Description of indicator: Chinook (*Oncorhynchus tshawytscha*) and chum (*O. keta*) salmon are highly migratory species that are incidentally caught as bycatch in trawl fisheries in the Bering Sea (Schnaittacher and Narita, 2019). Chinook salmon caught in the Bering Sea originate from as far south as Oregon and as far north as the Yukon River. Chum salmon caught in the Bering Sea originate from as far east as Japan and as far south as Washington (Urawa et al., 2009; Whittle et al., 2019). These economically and culturally valuable species are managed as prohibited species catch in trawl fisheries with a suite of bycatch mitigation measures, including hard caps and industry-managed rolling hotspot closures (Stram and Ianelli, 2014; Little et al., 2015). Chinook and chum salmon originating from western Alaska are particularly valued for their importance to subsistence fisheries and therefore identifying the origins of salmon caught is critical for resolving the impacts of bycatch on particular 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 (Guthrie et al., 2019) and chum salmon (Whittle et al., 2019) bycatch samples for genetic stock identification. Chinook salmon are genetically apportioned to the 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. Meanwhile, chum salmon regional origins are identified as: Southeast Asia, Northeast Asia, Western Alaska, Upper-Middle Yukon River, Southwest Alaska, and Eastern Gulf of Alaska [GOA] / Pacific Northwest. We present the proportional composition of the bycatch for each of these reporting groups for Chinook (Figure 97) and chum salmon (Figure 98).

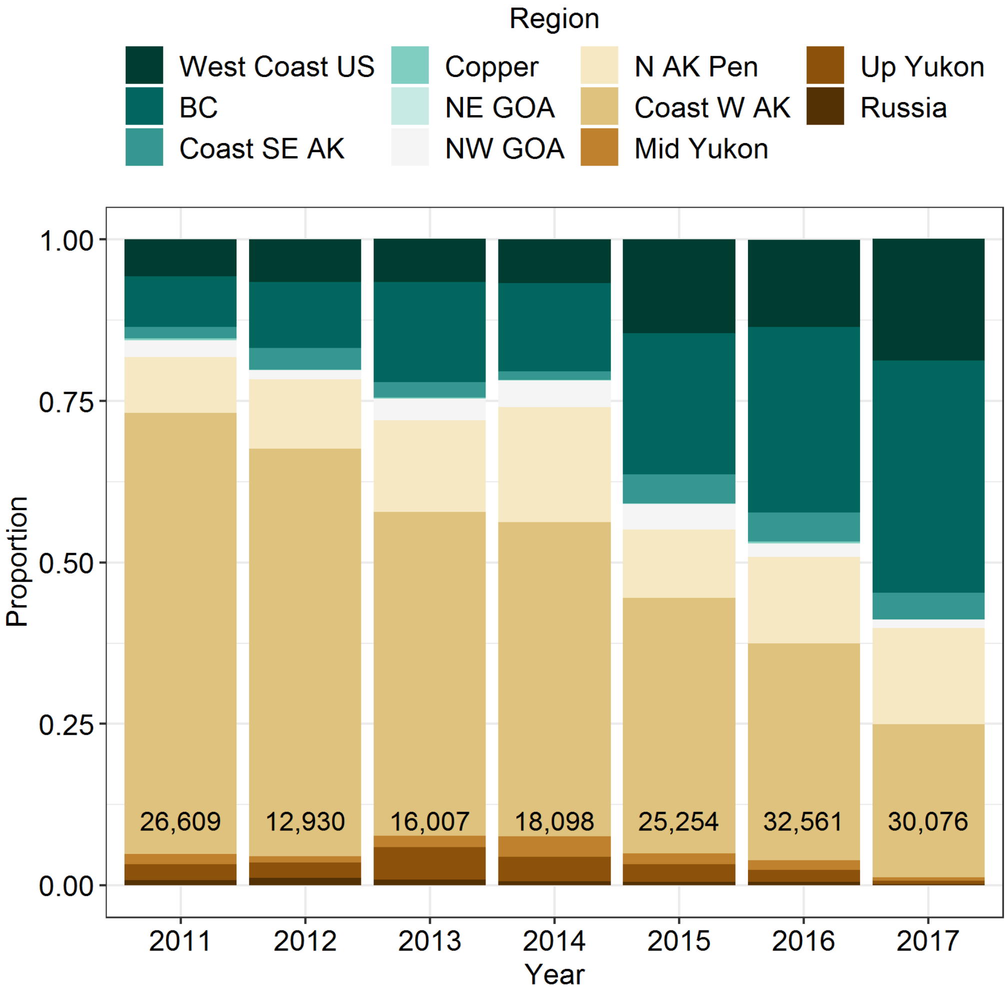

Figure 97: Stock composition (proportion) of Chinook salmon bycatch by year from the Bering Sea pollock trawl fishery with total numbers of Chinook salmon caught provided in lower portion of each bar.

Status and trends: Chinook and chum salmon exhibit notable differences in bycatch within and across years. Chinook salmon is caught primarily early and late in the year, whereas chum salmon is caught almost exclusively in the summer and early fall. The proportion of Chinook salmon bycatch in the Bering Sea has increasingly (linear model $P<0.05$) originated in British Columbia and the U.S. West Coast since 2011 (Figure 97) while significant declines have been observed for Chinook originating from Coastal Western Alaska. No significant trend has been observed for the other Chinook stocks of origin. In contrast to Chinook salmon, the proportions of chum salmon bycatch in the Bering Sea have exhibited a relatively high degree of inter-annual variability (ANOVA $P<0.05$) but with no significant increase or decrease in stock proportion for any of the regions examined (linear model $P>0.05$). Northeast Asia and the Eastern GOA / Pacific Northwest stocks account for the majority of chum salmon bycatch across years.

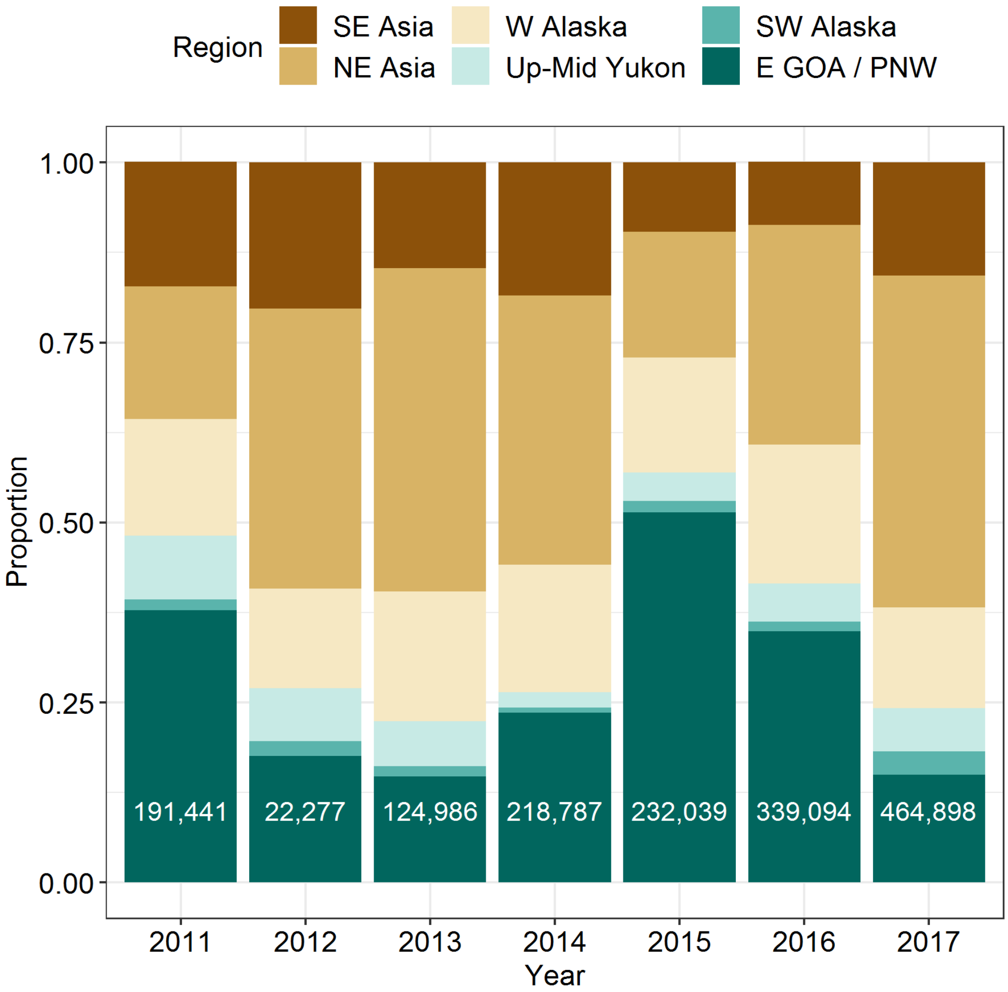

Figure 98: Stock composition (proportion) of chum salmon bycatch by year from the Bering Sea pollock trawl fishery with total numbers of chum salmon caught provided in lower portion of each bar.

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

Chum salmon in the Bering Sea are primarily caught during the pollock B-season, which starts in June. However, in 2017, an earlier-than-usual spike in B-season bycatch may have contributed to some of the variability in that year. Meanwhile, factors like hatchery production in Asia, differences in maturation rates and migration patterns under recent warming events (e.g., the warm blob), and rolling hotspot closures that move fishing fleets may all play a role in the complex stock dynamics.

Implications: Understanding the dynamics of salmon bycatch in trawl fisheries is critical to groundfish management because salmon can drive fisher behavior in trawl fisheries, lead to significant economic impacts to fleets, and have deleterious impacts to commercial and subsistence harvests of targeted salmon fisheries in Alaskan communities. While work is on-going to compile run sizes for different stock groups that will allow us to more effectively monitor changes in stock-level impacts from bycatch, we can still glean valuable information from recent trends.

Recent trends in Chinook bycatch suggest a decreasing impact of trawl fishery bycatch on western Alaska stocks but an increasing proportion of British Columbia fish. Such trends could lead to future concerns during Pacific Salmon Treaty negotiations if they continued and are independent of increased run sizes or hatchery releases. Meanwhile, despite recent decreases in the proportions of eastern Pacific stocks of chum salmon, steadily increasing numbers of chum salmon bycatch could suggest greater overall impacts of chum salmon bycatch on stocks and communities.

Time Trends in Groundfish Discards

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Last updated: September 2019

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 in the North Pacific. Discard rates as shown in Figure 99 below 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. Discards of groundfish in the halibut fishery and discards of forage fish and species managed under prohibited species catch limits, such as halibut, are not included.

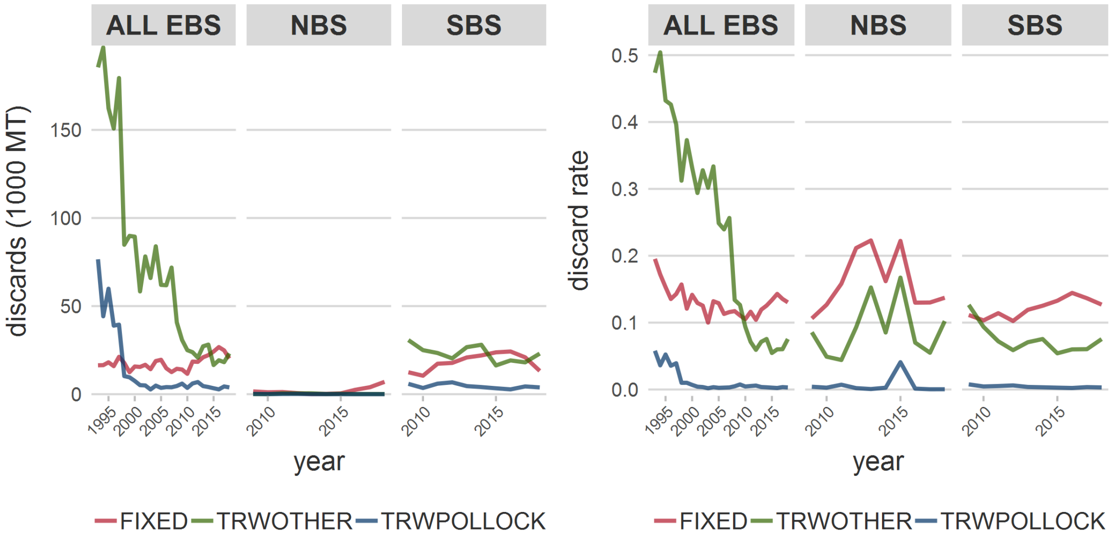

Figure 99: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear (FIXED), pollock trawl (TRWPOLLOCK), and non-pollock trawl sectors (TRWOTHER) for the eastern Bering Sea (ALL EBS) region, 1993–2018; and for northern (NBS) and southern (SBS) subregions, 2009–2018. 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).

Status and trends: Since 1993, discard rates of groundfish in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock and non-pollock trawl fisheries in the eastern Bering Sea (EBS) (Figure 99). 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. Declines in discard biomass in the southern Bering Sea fixed gear sector have offset an upward trend since 2016 in the northern subregion as vessels targeting Pacific cod have moved their fishing activity northward. To date in 2019, discard biomass across the entire EBS through week 34 for both trawl sectors appears consistent with the 2014–2018 period (Figure 100). Discard biomass in the fixed gear sector through week 34 is lower in the southern Bering Sea and higher in the northern Bering Sea for 2019 relative to 2014–2018.

Factors influencing observed trends: Fishery discards may occur for economic or regulatory reasons. Economic discards include discarding of lower value and unmarketable fish, while regulatory discards are those required by regulation (e.g., upon reaching an allowable catch limit for a species). Minimizing 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 et al., 1994; FAO, 1995; Karp et al., 2011). In the North Pacific groundfish fisheries, mechanisms to reduce discards include:

- Limited access privilege programs (LAPPs), which allocate catch quotas and may reduce economic discards by slowing down the pace of fishing
- In-season closure of fisheries once target or bycatch species quotas are attained
- Minimum retention and utilization standards for certain fisheries
- Maximum retainable amounts (MRAs), which allow 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 1990s (NPFMC, 2016, 2017). Pollock roe 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.

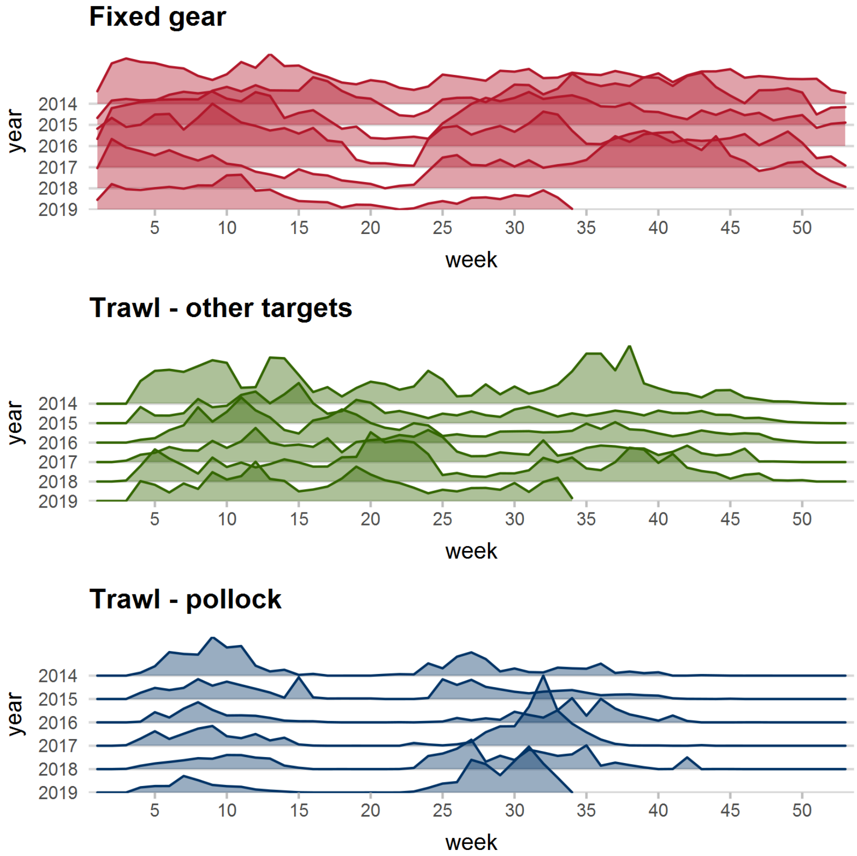

Figure 100: Total biomass of FMP groundfish discarded in the eastern Bering Sea region by sector and week, 2014–2019 (data for 2019 is shown through week 34). Plotted heights are not comparable across sectors.

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 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).

Implications: Fishery bycatch adds to the total human impact on biomass without providing a direct benefit to the Nation and as such is perceived 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 et al., 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 et al., 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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Last updated: August 2019

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[11]. 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 Status 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 Region's 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://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones).

Status and trends: The catch of Scyphozoan jellyfish has fluctuated since 2011 and peaked in 2014 (Figure 101). 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 2018 is 33% more than the catch in 2017 and is the third highest since 2011. Jellyfish are primarily caught in the pollock fishery.

The catch of structural epifauna has been relatively steady from 2011 to 2018 (Figure 101). 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 and 2015–2018. In 2013 and 2014, anemones caught in the Pacific cod fishery were the dominant part of the structural epifauna catch.

Sea stars comprise more than 85% of the assorted invertebrates catch in all years (2011–2018) and are primarily caught in flatfish fisheries (Figure 101). The catch of assorted invertebrates has generally

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[11] See AFSC stock assessment website at `https://www.fisheries.noaa.gov/alaska/population-assessments/2018-north-pacific-groundfish-stock-assessments`

trended upward from 2011–2015, and has decreased slightly each year since. The catch in 2018 is the second lowest since 2011.

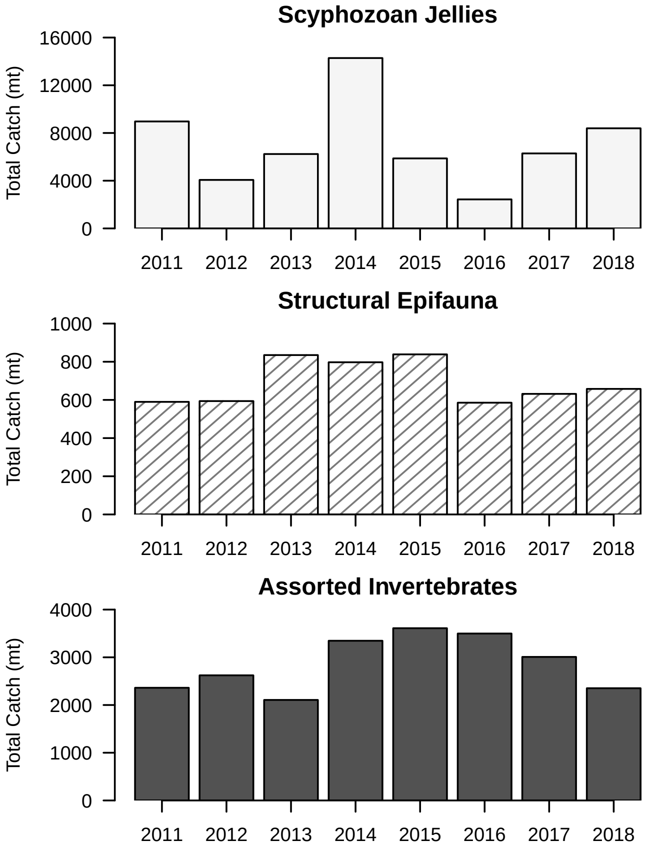

Figure 101: Total catch of non-target species (tons) in EBS groundfish fisheries (2011–2018). **Please note the different y-axis scales** between the species groups.

Factors influencing observed trends: The catch of non-target species may change if fisheries or ecosystems change. 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). 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.

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. 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, 2009–2018

Contributed by Joeseph Krieger[1], Anne Marie Eich[1], Shannon Fitzgerald[2], and Stephani Zador[2]
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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 2009 through 2018. 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 North Pacific 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 2009–2012, 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. Observer deployment plans are reviewed and updated annually in the Annual Deployment Plan[12]. 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. CAS also estimates 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 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.

Estimates of seabird bycatch from the eastern Bering Sea include the reporting areas 508, 509, 512, 513, 514, 516, 517, 521, and 524[13].

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[12] The 2019 plan is available at: `https://www.fisheries.noaa.gov/resource/document/2019-annual-deployment-plan-observers-groundfish-and-halibut-fisheries-alaska`

[13] `https://www.fisheries.noaa.gov/alaska/commercial-fishing/alaska-fisheries-figures-maps-boundaries-regulatory-a`

Table 5: **Estimated** seabird bycatch in eastern Bering Sea groundfish fisheries for all gear types, 2009 through 2018. Note that these numbers represent extrapolations from observed bycatch, not direct observations.

Species Group	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Unidentified Albatross	0	0	0	0	0	12	0	0	0	0
Short-tailed Albatross	0	10	0	0	0	11	0	0	0	0
Laysan Albatross	10	3	28	37	8	13	13	12	28	179
Black-footed Albatross	5	0	1	0	0	7	0	0	0	0
Northern Fulmars	6,393	1,408	5,288	2,778	2,734	677	2,334	5,052	3,516	2,713
Shearwaters	562	500	157	487	196	116	358	3,161	984	582
Gulls	905	257	1,565	810	454	578	927	577	371	503
Kittiwakes	10	0	6	5	3	4	12	5	22	30
Murres	13	0	14	6	3	47	0	52	10	0
Puffins	0	9	0	0	0	0	0	10	0	0
Auklets	0	0	0	7	4	67	18	1	25	0
Other Alcids	105	0	0	0	0	0	0	0	0	5
Cormorant	0	0	0	0	0	0	3	0	0	0
Other Birds	136	0	0	0	0	0	0	0	63	0
Unidentified Birds	493	200	355	300	267	73	144	282	253	77
Grand Total	8,632	2,387	7,414	4,430	3,669	1,605	3,809	9,152	5,272	4,089

Status and trends: The numbers of seabirds estimated to be caught incidentally in the eastern Bering Sea fisheries in 2018 (4,089 birds) decreased from 2017 (5,272 birds) by 24%, and were below the 2009–2017 average of 5,046 birds by 19% (Table 5, Figure 102). Northern fulmars, shearwaters, and gulls were the most common species or species groups caught incidentally in the eastern Bering Sea fisheries in 2018. In 2018, the number of northern fulmars and shearwaters decreased by 22% and 40%, respectively, compared to 2017, and were below the 2009–2017 average of 3,353 and 725 birds by 19% and 20%, respectively. In 2018, the number of gulls increased by 36% compared to 2017, but was below the 2009–2017 average of 716 birds by 30%. An unusually high number of Laysan albatross were caught incidentally in 2018 but no short-tailed albatross or black-footed albatross were caught.

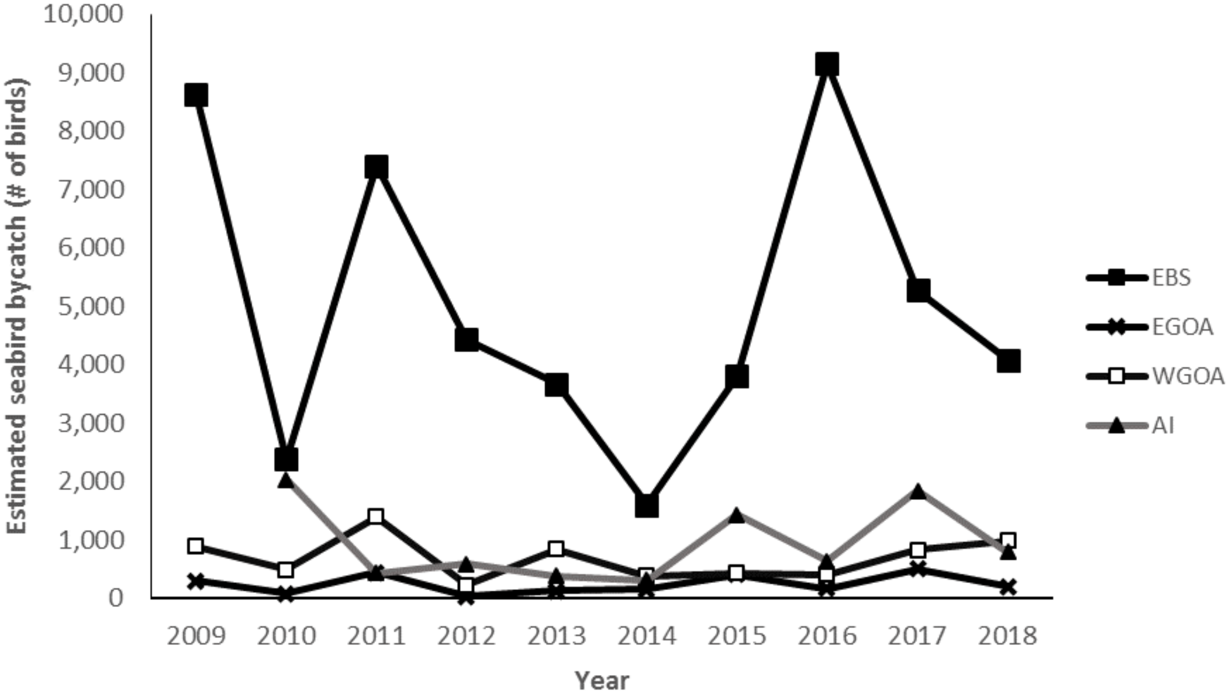


Figure 102: Total estimated seabird bycatch in eastern Bering Sea (EBS), Eastern Gulf of Alaska (EGOA), Western Gulf of Alaska (WGOA), and Aleutian Islands (AI) groundfish fisheries, all gear types combined, 2009–2018.

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 102). 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 with the exception of 2018 (Figure 103).

Examining the three fisheries responsible for the majority of seabird bycatch in federal waters off Alaska - Pacific cod, sablefish, and halibut demersal longline - the average annual seabird bycatch for 2010 through 2018 was 4,522, 717, and 231 birds per year, respectively. In 2018, the Pacific cod, sablefish, and halibut demersal longline estimated seabird bycatch was similar with 4,209, 506, and 256 birds, respectively (Table 13 in Krieger et al. (2019)).

Focusing solely on the bycatch of albatross (unidentified, short-tailed, Laysan, and black-footed) in these fisheries, the Pacific cod, sablefish, and halibut fisheries using demersal longline gear average 39, 365, and 83 albatross per year, respectively, for 2010 through 2018 (average for halibut fisheries calculated for 2013 through 2018; (Krieger et al., 2019)). Seabird bycatch levels and rates are highly variable among years; but some correlation may exist between incidents of seabird takes and fishing effort (Figure 104 A-C).

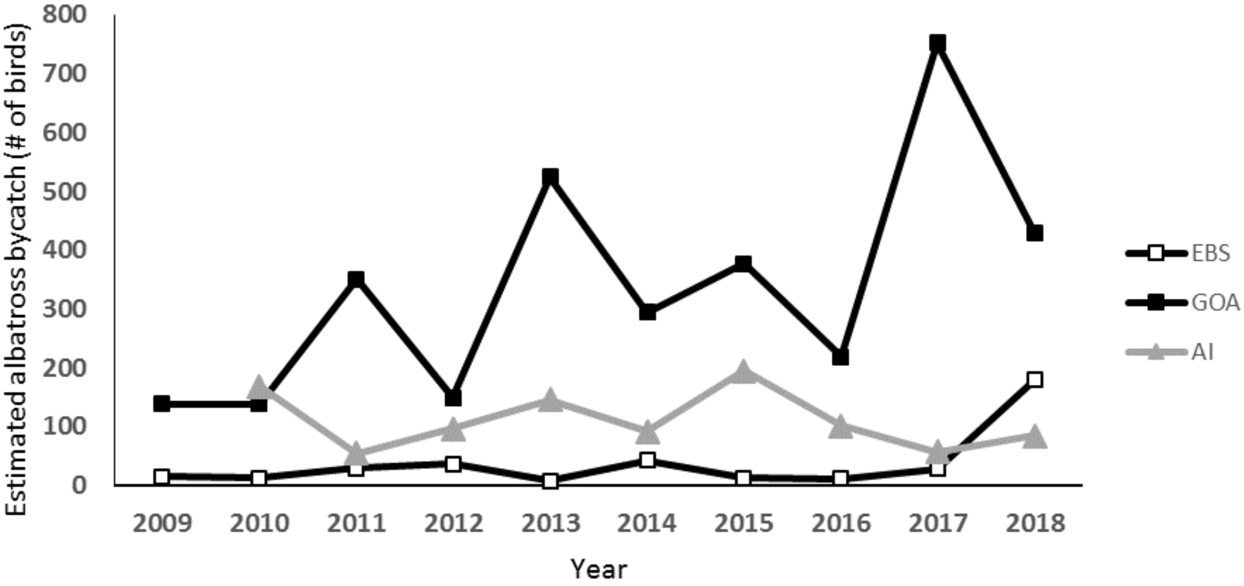
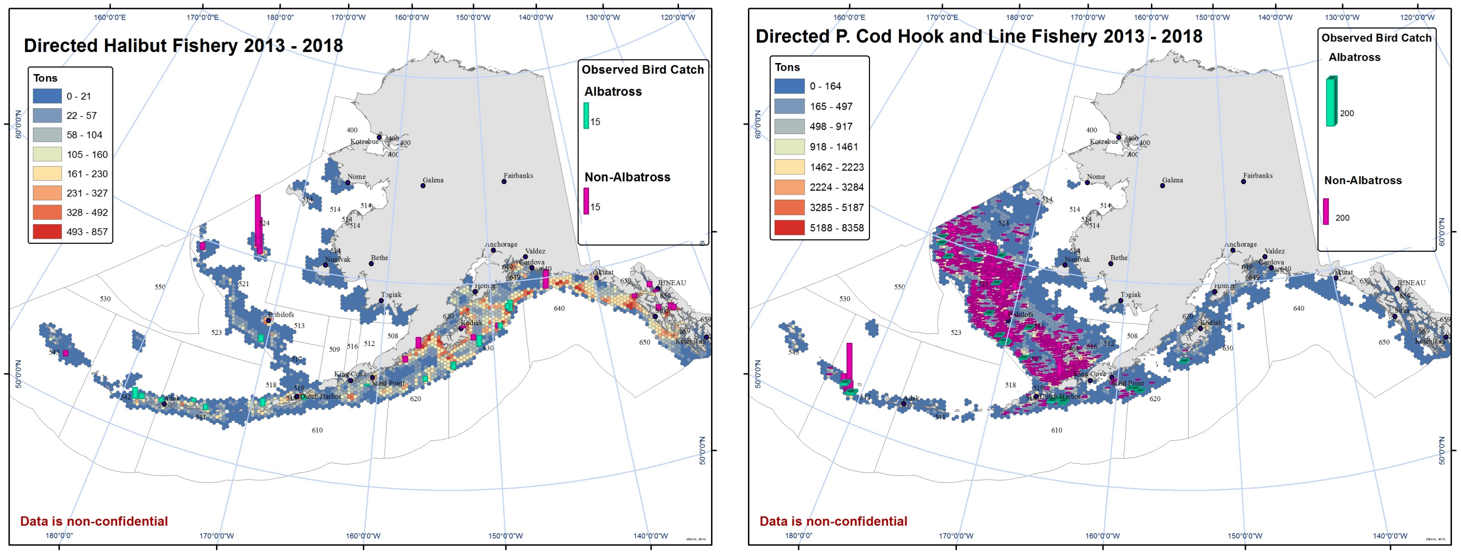
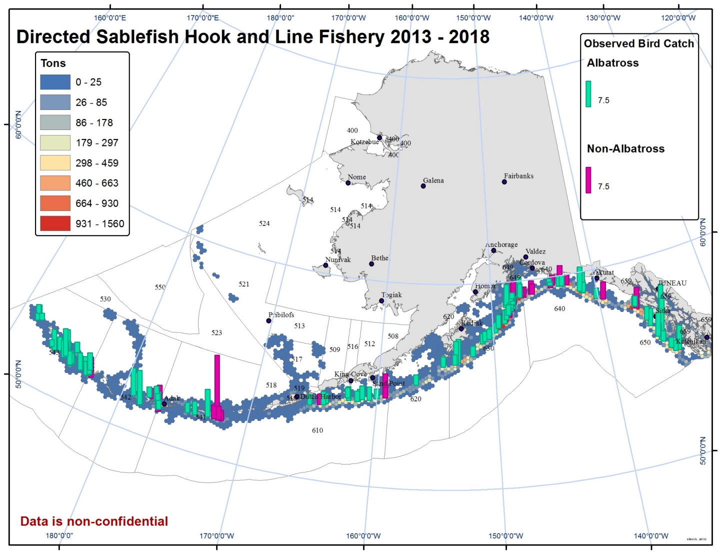


Figure 103: Total estimated albatross bycatch in eastern Bering Sea (EBS), Gulf of Alaska (GOA), and Aleutian Islands (AI) groundfish fisheries, all gear types combined, 2009–2018.



(a) Directed Halibut Fishery, 2013–2018

(b) Directed Pacific cod fishery, 2013–2018



(c) Directed Sablefish fishery, 2013–2018

Figure 104: Spatial distribution of observed seabird bycatch from 2013–2018 from the Halibut, Pacific cod, and Sablefish hook and line fisheries. Colored vertical bars indicate the sum of incidental takes within 1/10 of a degree latitude and longitude. Incidental takes are separated between albatross and non-albatross seabirds. Figures include locations of incidental takes overlaid on heatmaps of fishing effort for each relevant fishery. Note the difference of scale of observed takes of seabirds.

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 entire fleet beginning in February 2004 (69 RF 1930, 13 January, 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, in prep). 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 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 (Krieger et al., 2019).

Implications: Estimated seabird bycatch decreased from 2017 to 2018 in the eastern Bering Sea, but 2018 had an unusually large number of Laysan albatross caught incidentally. Estimated seabirds caught incidentally in the eastern Gulf of Alaska in 2018 relative to the year before was primarily attributed to decreased numbers of black-footed albatross and gulls. In contrast, the increase in the number of estimated seabirds caught incidentally in the western Gulf of Alaska was primarily attributed to increased numbers of gulls and unidentified birds. Estimated seabird bycatch decreased from 2017 to 2018 in the Aleutian Islands, primarily attributed to decreased takes of shearwaters and northern fulmars. These differences indicate localized changes in the Bering Sea, Gulf of Alaska, and Aleutian Islands 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 dissipating in 2017 and continued to be moderating in 2018 (Zador and Yasumiishi, 2018). 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. Numerous seabirds have been reported dead, in poor body condition, or in reproductive failure (Zador and Yasumiishi (2018); Siddon2018; K. Kuletz, pers comm.), though improvements in reproductive success were evident in 2018. Afflicted 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 estimates 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. This probably indicates changes in food availability rather than distinct 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 the Eastern Bering Sea

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Last updated: September 2019

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 over the Bering Sea domain, 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

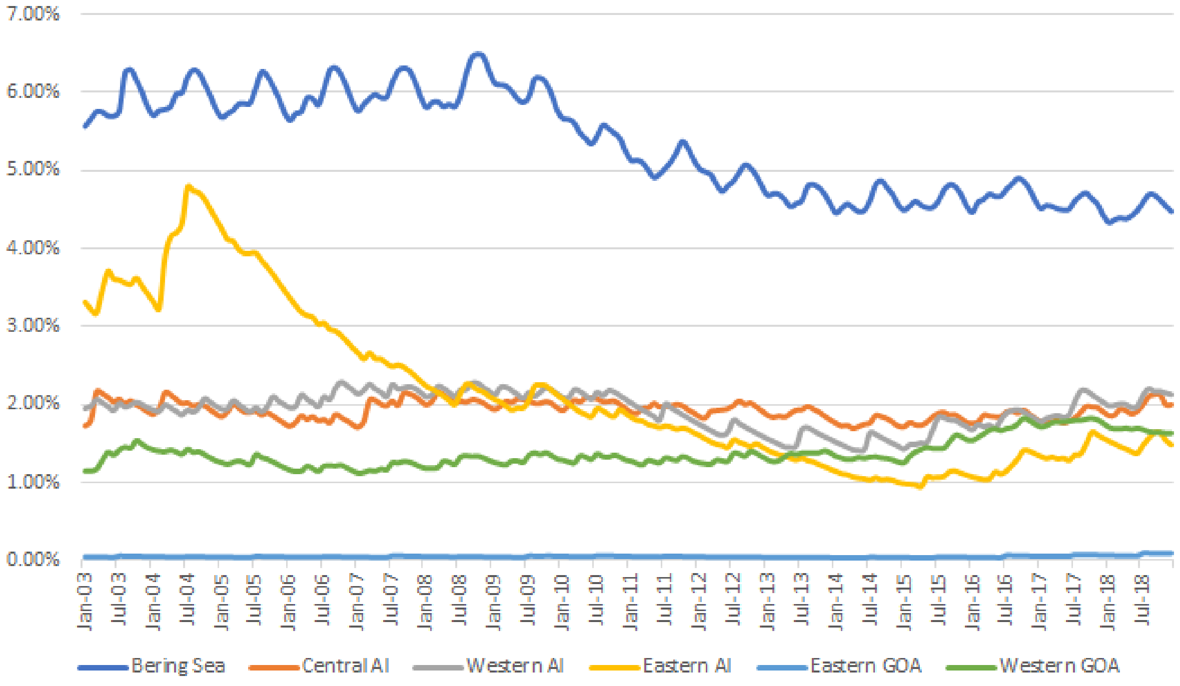

Figure 105: Percent habitat reduction, all gear types combined, from 2003 through 2018.

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 were 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.

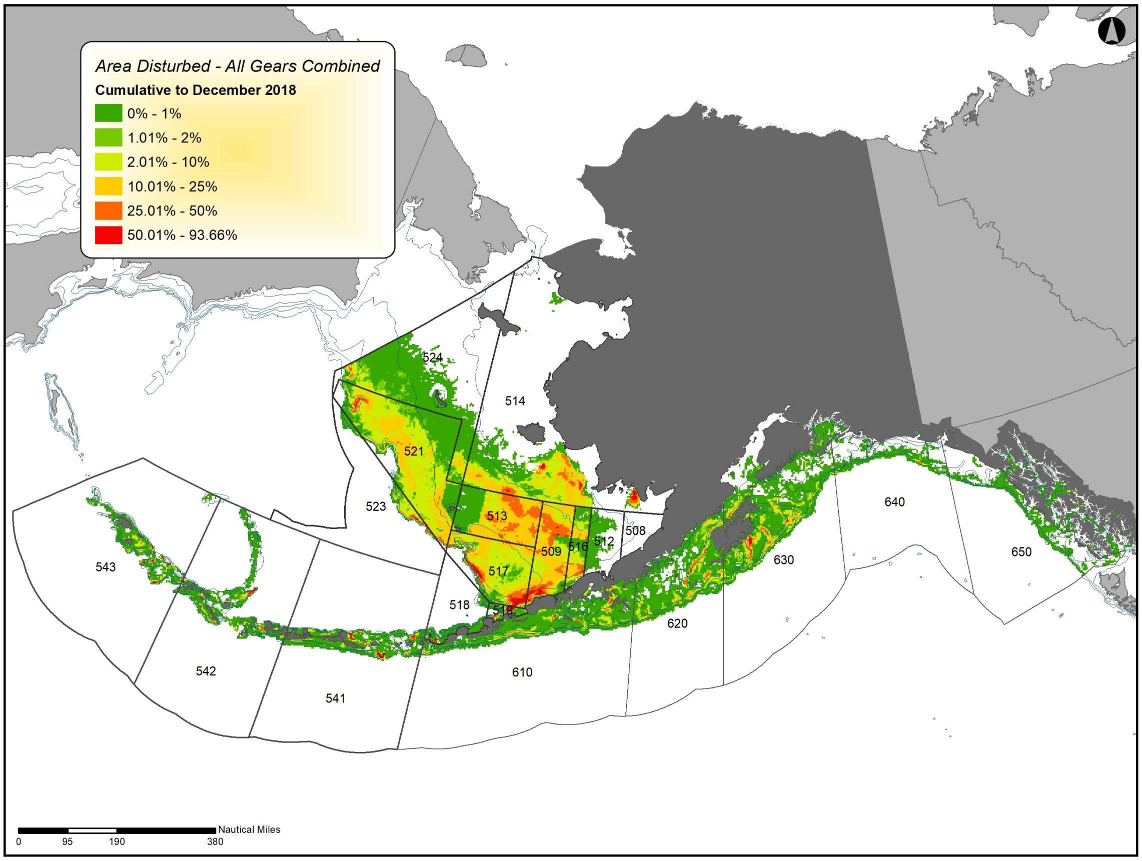

Figure 106: Map of percentage area disturbed per grid cell for all gear types. Effects are cumulative and consider impacts and recovery of features from 2003 to 2018.

Implications: The effects of changes in fishing effort on habitat are largely unknown, although 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[14]. 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

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[14] `ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/TM_NMFS_AFKR/TM_NMFS_FAKR_15.pdf`

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

Contributed by John V. Olson
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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 107, Table 6). 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. 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`

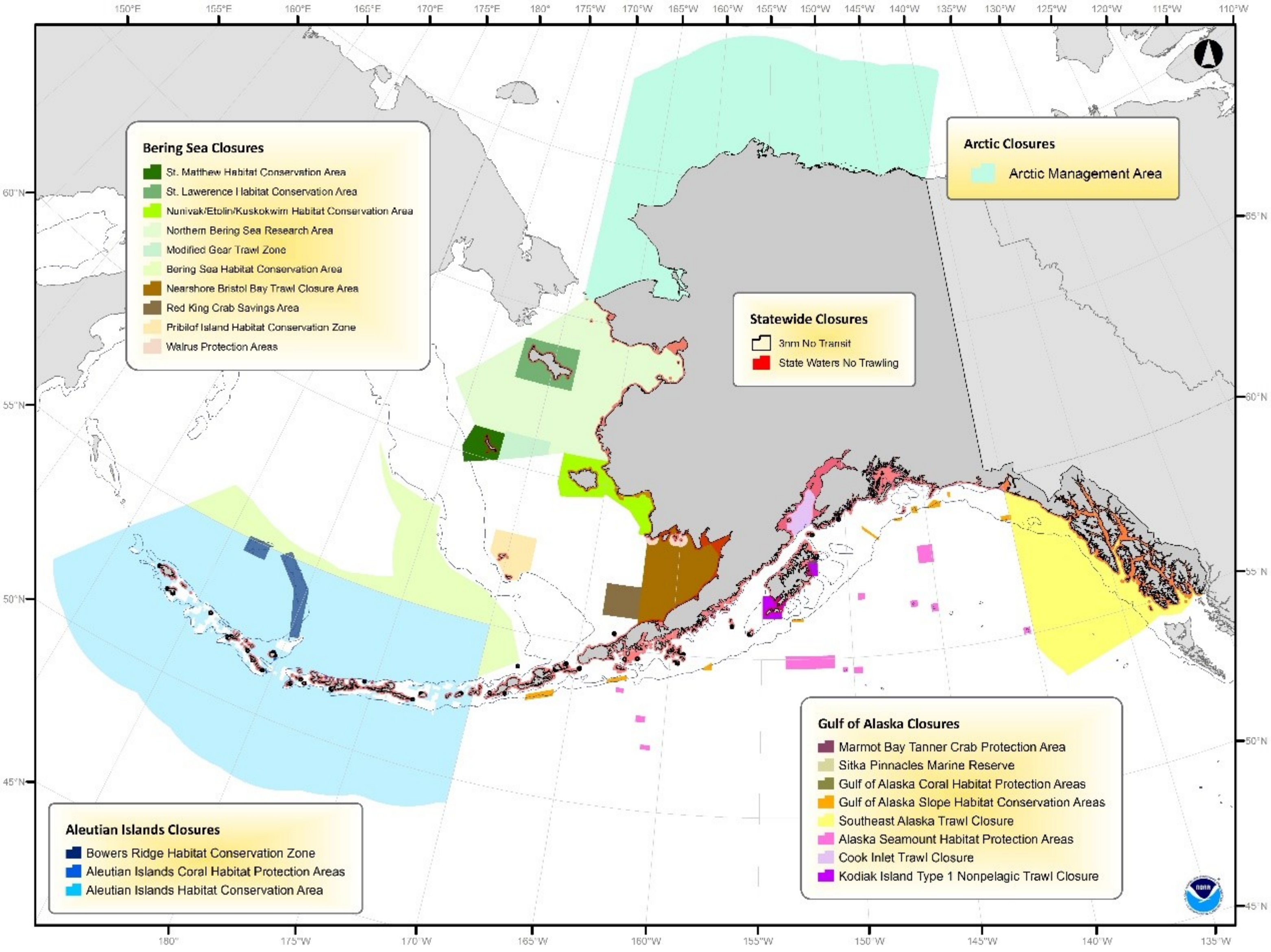

Figure 107: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Table 6: Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2018. 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–Jun)*	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–Jun)	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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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[15]. 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%).

Within the BSAI region there are 22 FSSI stocks (See FSSI Endnotes for stock definitions). With few exceptions, groundfish species (or species 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.

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[16].

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[15] `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`
[16] `https://www.fisheries.noaa.gov/national/population-assessments/status-us-fisheries`

Table 7: Summary of status for the 22 FSSI stocks in the BSAI, updated through June 2019.

BSAI FSSI (22 stocks)	Yes	No	*Unknown*	*Undefined*	N/A
Overfishing	0	22	0	0	0
Overfished	2	20	0	0	0
Approaching Overfished Condition	0	20	0	0	2

Status and trends: As of 30 June, 2019, no BSAI groundfish stock or stock complex is subjected to overfishing, is considered to be overfished, or to be approaching an overfished condition (Table 7). The BSAI groundfish FSSI score is 56 out of a maximum possible 56.

The BSAI king and Tanner crab FSSI is unchanged from last year at 28 out of a possible 32, however, there were some changes to how the points were awarded. St. Matthews Island blue king crab lost a point for their status changing to overfished and snow crab gained a point for biomass increasing to above the B/B_{MSY} threshold.

The overall Bering Sea/Aleutian Islands score is 84 out of a maximum possible score of 88 (Table 8). Since 2006 the BSAI overall FSSI has increased from 74% up to 95.45% (Figure 108).

The current overall Alaska FSSI is down 2 points from last year at 133 out of a possible 144, or 92.4%, based on updates through June 2019 (Figure 109). Until 2019, the overall Alaska FSSI had generally trended upwards from 80% in 2006 to 93.75% in 2018.

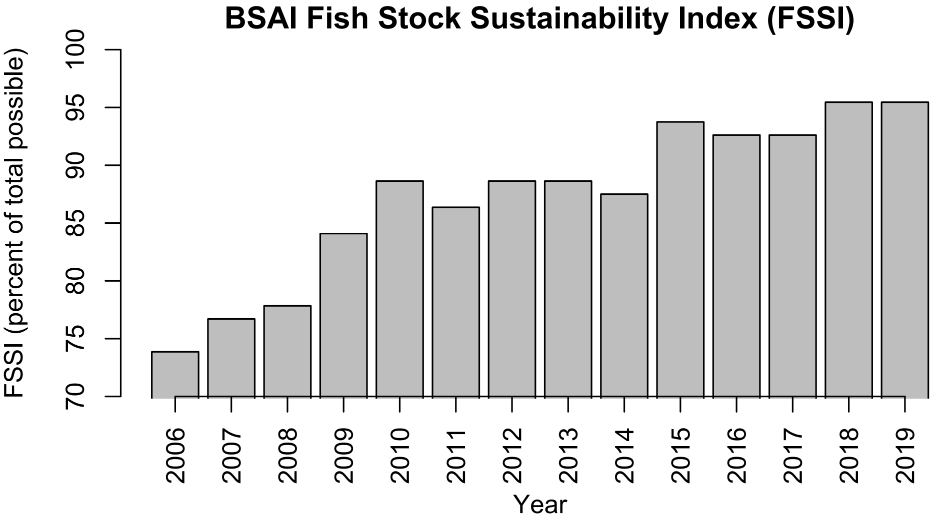

Figure 108: The trend in FSSI from 2006 through 2019 for the BSAI region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

Factors influencing observed trends: The overall trend in Alaska FSSI has been positive over the duration examined here (2006–2019). The decrease in overall score in 2019 is the net result of two points lost for two groundfish stocks in the GOA having biomass drop below 80% of B_{MSY} (Pacific cod and sablefish). The changes in FSSI points awarded for crab stocks in the EBS cancel each other for a net result of no change to the FSSI. The four points deducted from the maximum possible (88) FSSI in the BSAI are taken from the two overfished crab stocks, Pribilof Islands blue king crab and Saint Matthews Island blue king crab. Neither of these crab stocks are subject to overfishing but both lose a point for being overfished. The Pribilof Islands blue king crab stock is in year 4 of a rebuilding plan. The NPFMC was notified that the Saint Matthews Island blue king crab stock is overfished on 22 October, 2018 and have two years from this date to implement a rebuilding plan for this stock. Both of these crab stocks have an additional point deducted for having biomass less than 80% of B_{MSY}.

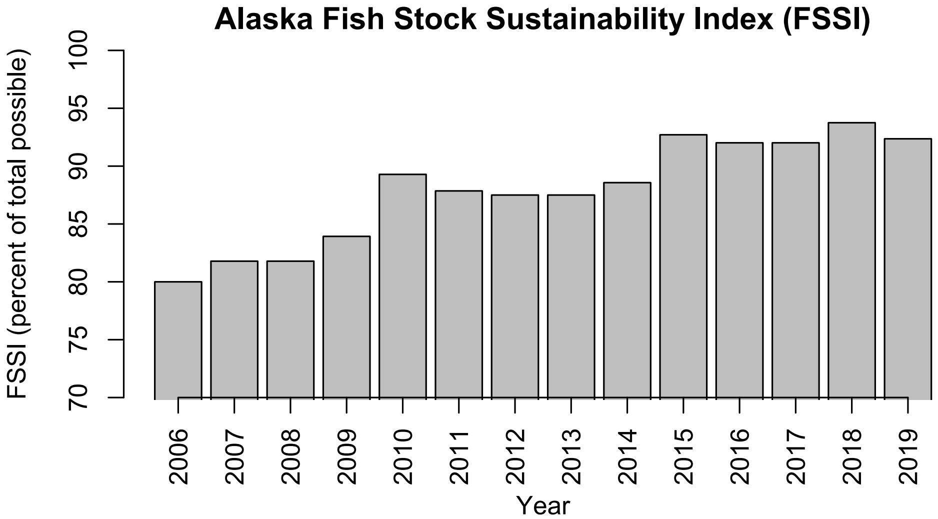

Figure 109: The trend in overall Alaska FSSI, as a percentage of the maximum possible FSSI, from 2006 through 2019. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 onward it is 144. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

Implications: The majority of Alaska groundfish fisheries appear to be sustainably managed. No stocks in the BSAI are subject to overfishing and two crab stocks are considered to be overfished. No other stocks or stock complexes in the BSAI are known to be approaching an overfished condition.

Table 8: BSAI FSSI stocks under NPFMC jurisdiction updated through June 2019 adapted from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`. See FSSI Endnotes for 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	0.06	2
Blue king crab - Saint Matthews Island[b]	No	Yes	N/A	Rebuilding Program	N/A	0.35	2
Golden king crab - Aleutian Islands	No	No	No	N/A	N/A	1.25	4
Red king crab - Bristol Bay	No	No	No	N/A	N/A	0.82	4
Red king crab - Norton Sound	No	No	No	N/A	N/A	1.11	4
Red king crab - Pribilof Islands	No	No	No	N/A	N/A	1.04	4
Snow crab - Bering Sea	No	No	No	N/A	N/A	0.86	4
Southern Tanner crab - Bering Sea	No	No	No	N/A	N/A	1.09	4
BSAI Alaska plaice	No	No	No	N/A	N/A	1.84	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.24	4
BSAI Arrowtooth flounder	No	No	No	N/A	N/A	2.35	4
BSAI Blackspotted and Rougheye rockfish[c]	No	No	No	N/A	N/A	0.94	4
BSAI Flathead sole complex[d]	No	No	No	N/A	N/A	2.08	4
BSAI Rock sole complex[e]	No	No	No	N/A	N/A	2.47	4
BSAI Skate Complex[f]	No	No	No	N/A	N/A	1.7	4
BSAI Greenland halibut	No	No	No	N/A	N/A	1.59	4
BSAI Northern rockfish	No	No	No	N/A	N/A	1.89	4
BS Pacific cod	No	No	No	N/A	N/A	1.32	4
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.81	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	1.26	4
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.56	4
BSAI Yellowfin sole	No	No	No	N/A	N/A	1.81	4

Box A. Endnotes and stock complex definitions for FSSI stocks listed in Table 8, adapted from the Status of U.S. Fisheries website[17].

(a) A new rebuilding plan for this stock was implemented 1 January, 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) The NPFMC was notified that St. Matthews Island blue king crab was overfished on 22 October, 2018, and has two years from this date to implement a rebuilding plan for this stock.

(c) 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.

(d) 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.

(e) 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.

(f) 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.

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[17] `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`

Seafood Production

Economic Indicators in the Eastern Bering Sea Ecosystem – Landings

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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 110). 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 in logs.

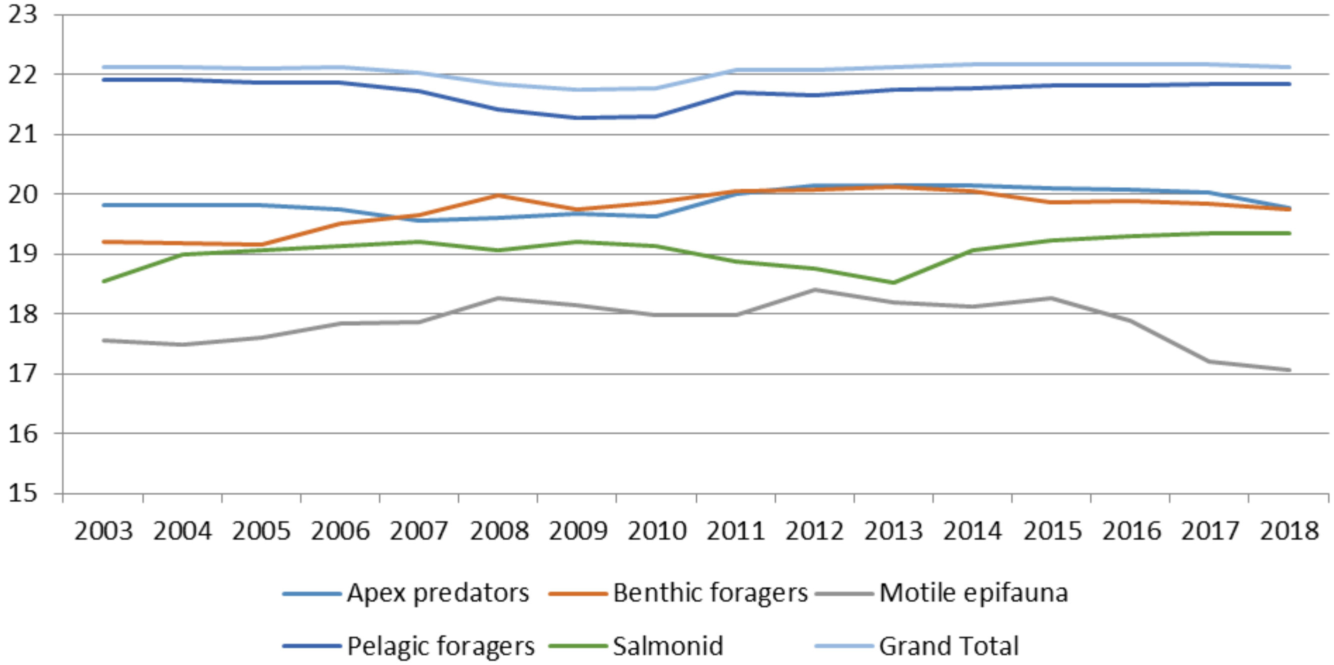

Figure 110: Eastern Bering Sea landings by functional group (log pounds).

Status and trends: Aggregate landings in the eastern Bering Sea (EBS) remained stable through 2018. EBS landings 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 saw a marginal drop in 2018. 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 salmonid functional group also remained stable through 2018. Landings in the crab stocks which comprise the motile epifauna group have trended up gradually since 2003 reflecting largely as a result of increased catch of tanner crab. Landings in the motile epifauna group have been on the decline since 2015 with decreases in both the tanner crab and king crab species groups. In 2017 crab catches declined significantly for all species, particularly tanner crab resulting in the significant decline in the index displayed in Figure 110. This trend continued through 2018.

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. Landings of benthic foragers remained relatively stable through 2018. 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) 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 East 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 110 is that pelagic foragers have been by far the largest share of total landings over the 2003–2018 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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Description of indicator: Three plots are used to characterize economic value in an ecosystem context for the East Bering Sea. Ex-vessel value is the un-processed value of the retained catch (Figure 111). 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 112). 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 113). 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.

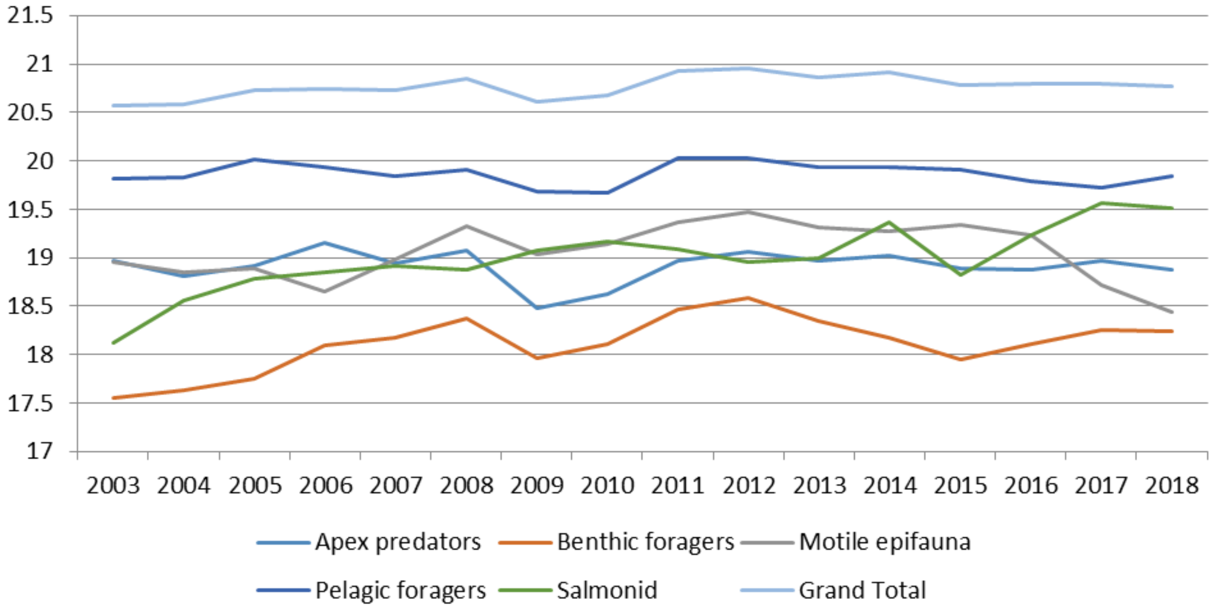

Figure 111: Eastern Bering Sea real ex-vessel value by functional group (log 2018 dollars).

Figures 111 and 112 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.

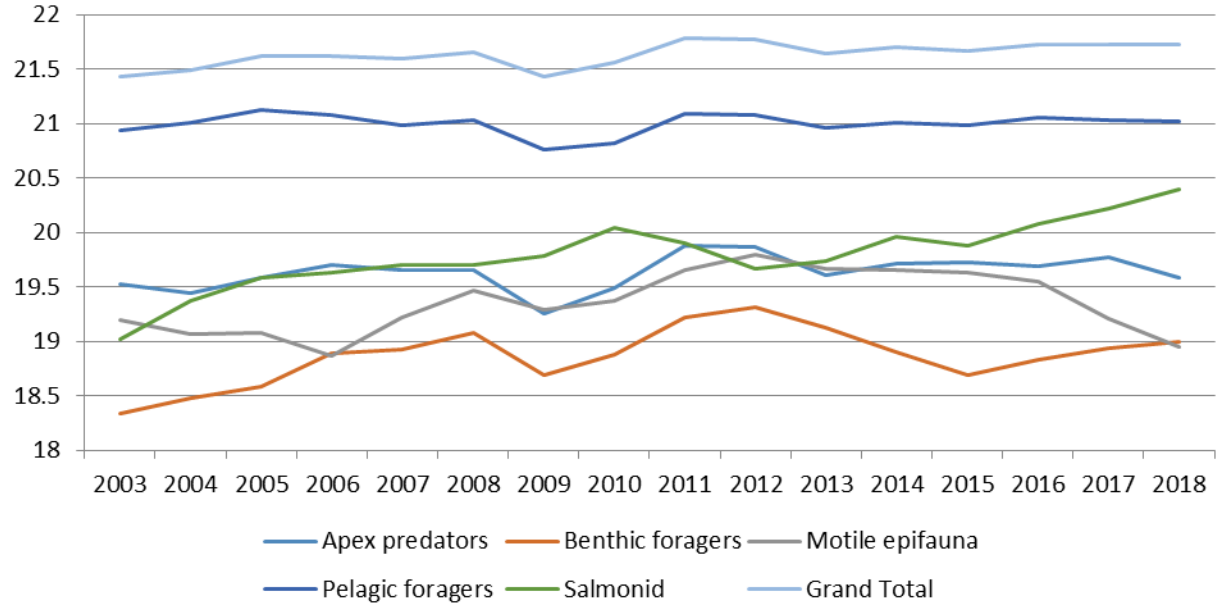

Figure 112: Eastern Bering Sea real first-wholesale value by functional group (log 2018 dollars).

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 decreasing from 2012–2015 as a result of decreased prices and since 2015 price increases have increased value while landings have remained stable. Value in the motile epifauna group has been decreasing 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 111 reflects 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 we low. From 2013–2017 prices for pollock decreased as global pollock supply has been high, but increased landings have had the combined effect of marginal increases in value. In 2018 prices for pollock increased. First-wholesale value dipped in the apex predator group as Pacific cod landings decreased and the average price of sablefish declined. Benthic forager first-wholesale value decreased from 2012 to 2015 with decreases in flatfish prices as demand for these products plateaued with significant supply. Since 2015 supply has been stable and prices have increased. Increased value in the salmonid functional group since 2015 has been the result of increased landings and value. Value in the motile epifauna group has been decreasing in recent years with reductions in landings.

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 this 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. The 2018 unit value increased as many species saw stable or increasing prices, pollock in particular.

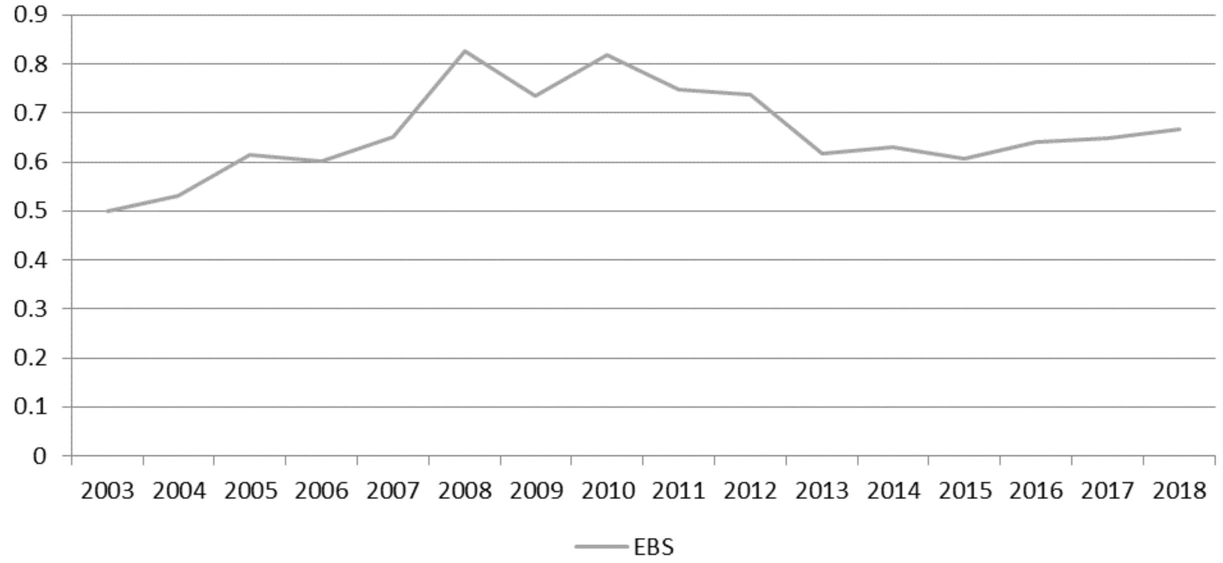

Figure 113: Real first-wholesale to total catch unit value in the Eastern Bering Sea (2018 dollars).

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). In 2018, strong demand and reductions in global supply have put upward pressure on whitefish product prices which has filtered through to ex-vessel market. As a result, revenue increased in 2018 in the pelagic forager group despite stable 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 appears to be attributable to a trend of increasing value in the first-wholesale market.

First-wholesale value is the revenue from the sale of processed fish. Some fish, in particular pollock and Pacific cod, are processed in a 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.

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.

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 are 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

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

Employment

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

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Last updated: August 2019

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.

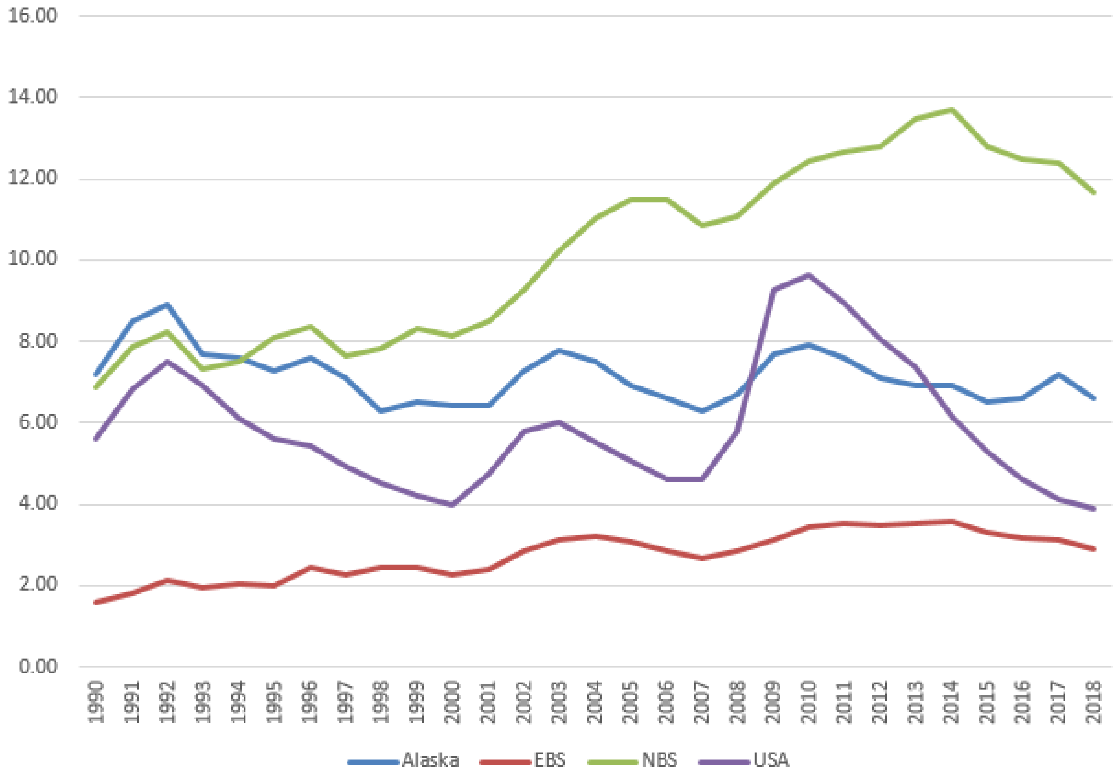

Figure 114: Unemployment rates for Alaska, eastern Bering Sea (EBS), northern Bering Sea (NBS), and USA between 1990 and 2018.

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 were aggregated and weighted to account for varying community populations across Alaska Boroughs. Estimates are presented annually from 1990–2018 (ADLWD, 2019). Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2018 (ADLWD, 2019).

Status and trends:
Eastern Bering Sea
The unemployment rate in the EBS was 2.9% in 2018. 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 2018 were lower than State and national rates (Figures 114 and 115). The unemployment peaks of 1996, 2003, and 2010 reflect State trends yet the EBS has the second lowest unemployment rate (central Aleutian Islands had the lowest) of all regions. However, the unemployment rate of the EBS region increased 80.6% between 1990 and 2018.

Northern Bering Sea
The unemployment rate in the NBS was 11.8% in 2018. 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 2018 were higher than State and national rates (Figures 114 and 115). 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 continued to increase despite State and national decline after 2010. The unemployment rate in NBS communities increased 72.52% between 1990 and 2018.

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)[18]. 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 2018. 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 second highest unemployment rates between 1995 and 2012, and the highest from 2013-2016. 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).

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

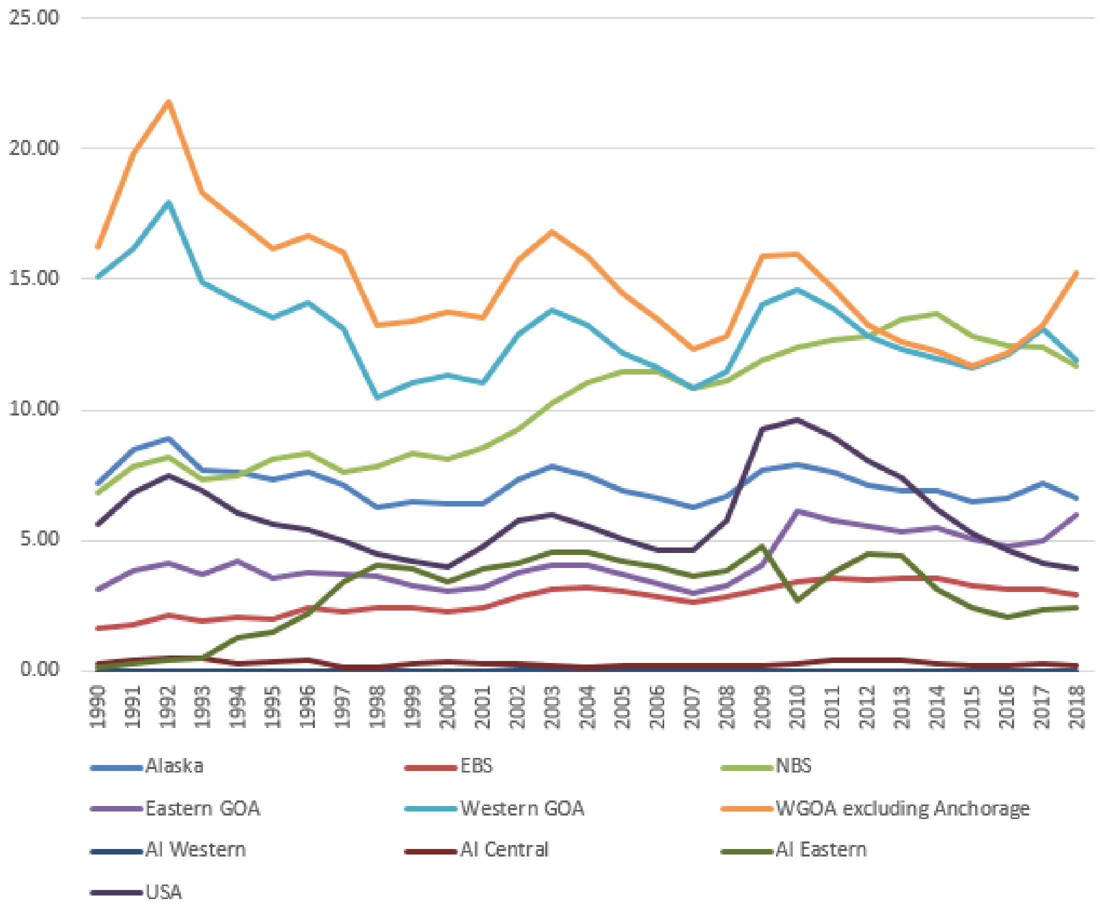

Figure 115: Unemployment rates for all regions, Alaska, and USA between 1990 and 2018.

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).

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 are 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 Bering Sea

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Last updated: August 2019

Description of indicator: Population trends have a significant effect on the communities within the Southeastern Bering Sea (SEBS) and Northern Bering Sea (NBS) ecoregions, and are a useful 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. 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 SEBS and NBS. SEBS 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. 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 1990–2018 (ADLWD, 2018).

Status and trends:

Southeastern Bering Sea

The SEBS is comprised of 34 coastal communities with a total population of 10,309 as of 2018. The total population of small communities (population less than 1,500) was 7,297. The community of Dillingham is the only community of this ecoregion with a population over 1,500 (2018 population = 2,382). The overall population increased steadily since 1880 with the greatest population increase of 44.2% occurring between 1950 and 1960 (Table 9). 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 SEBS and Alaska overall (ADLWD, 2018).

Between 2010 and 2018, the population of SEBS increased 2.69% which was higher than State trends between 2010–2018 (0.4%). The population of small communities increased 2.8%, and Dillingham 2.2% during this time period. The population of the SEBS has remained relatively stable (based on aggregated data), yet 46% of communities in the SEBS experienced population decline between 2010 and 2018 (Figure 116).

Many SEBS communities are small and/or remote and Alaska Natives comprise up to 82% of the population of small communities in remote areas, and the indigenous population in Alaska is greater than any U.S. state (Goldsmith et al., 2004). As of 2016, 15% of Alaska's population was Alaska Native or American Indian (ADLWD, 2017) and as of 2015, 75.7%

Table 9: Southeastern Bering Sea (SEBS) population 1880–2018. Percent change rates are decadal until 2010.

Year	Alaska	% change	SEBS	% 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
2018	736,239	3.66	10,309	2.83

of the population in the SEBS identified as Native American alone or in 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 61 coastal communities with a total population of 34,297 as of 2018. The population of small communities (population less than 1,500) was 24,500 and large communities was 9,797. The small communities exclude Bethel (population in 2018 = 6,135) and Nome (population in 2018 = 3,662) 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 117). The latter increase is consistent with Alaska State trends as population increased by over 75% between 1950 and 1960. Population increases leveled off after 1990 with lower rates in the following decades in the NBS and Alaska State.

Between 2010 and 2018, the population of the NBS increased 6.37% which was higher than state trends during this time period (0.4%). Small community population increased 8.44%, while the population of Bethel increased by 0.90% and Nome by 1.75%. The population of communities in the NBS has slowly increased and 19.7% of all NBS communities experienced population decline between 2010 and 2018. Many NBS communities are small and/or remote. As of 2015, 90.2% of the population in NBS identified as Alaska Native alone or in combination with another race (DCCED, 2016).

Factors influencing observed trends: 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

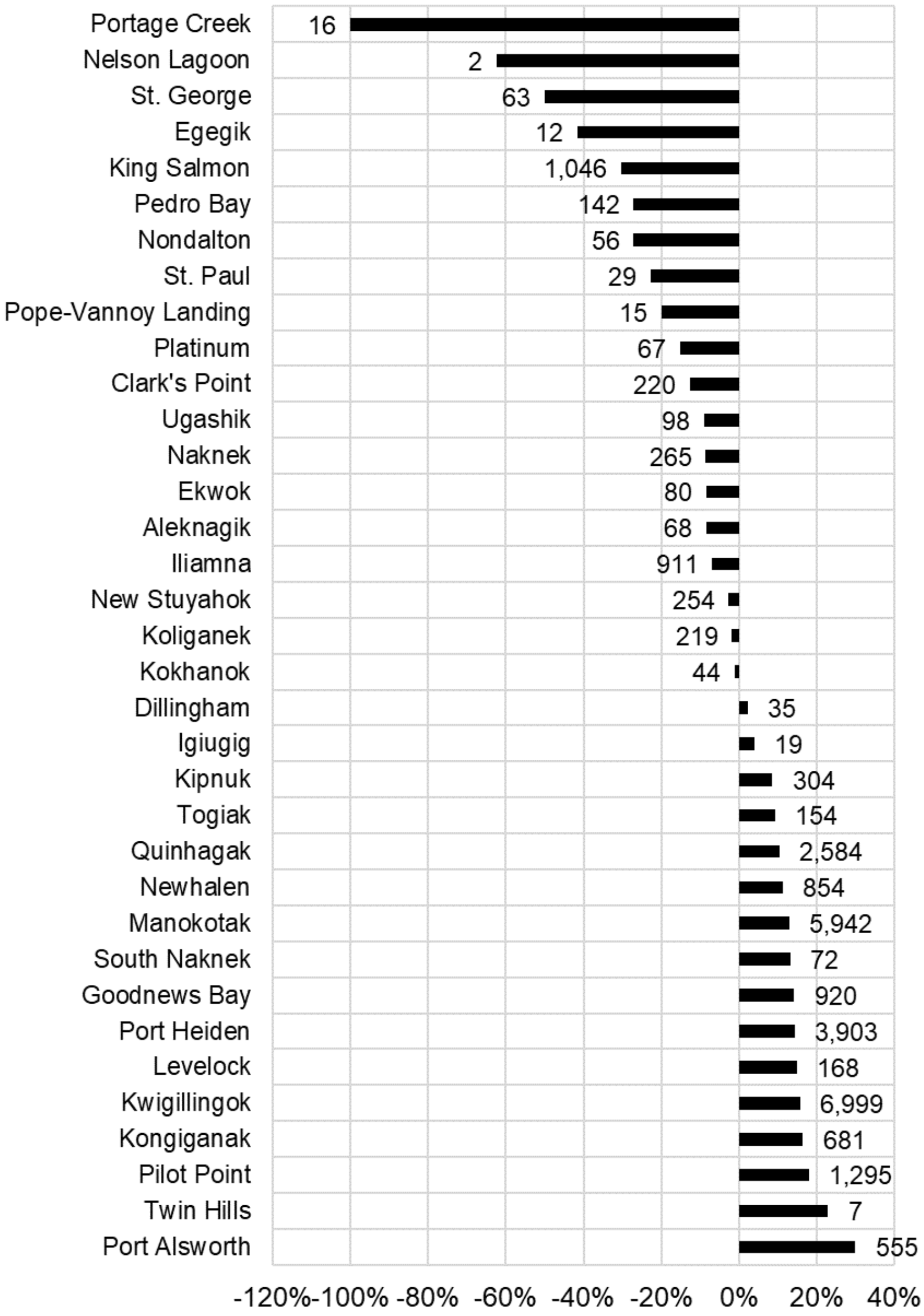

Figure 116: Population and population change of southeastern Bering Sea communities 2010–2018.

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, 2004). 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

Table 10: Northern Bering Sea (NBS) population 1880–2018. 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
2018	736,239	3.66	34,297	8.71

living, climate, and quality of life (Donkersloot and Carothers, 2016).

Overall population growth in the SEBS between 2010 and 2018 (2.7%) and the NBS (6.4%) was higher than State trends (0.4%). Past population increases in the NBS have been attributed to mining and extraction prospects in the region and these activities have contributed to the high rates of population turnover from migration within the state (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). Between 2012–2016, 59% of Alaska's population was born out of State [19]. In terms of natural growth, from 2013 to 2017 the average annual birth rate in Alaska was 1.5 per 100 people which was higher than the national rate of 1.2 (HAVR, 2018; Martin et al., 2018).

From 2010-2017 the Aleutian chain and Southeast Alaska had the lowest natural increase (0.01.0%) in birth rates whereas the NBS area had the highest (1.53.0%). The Kusilvak census area had the highest birth rate of 3 births per 100 people (ADLWD, 2017). The estimated natural growth rates of the SEBS had a range of 0.53.0% (ADLWD, 2017). The NBS area has steadily increased in population with higher than national level birth rates and net migration of less than zero (ADLWD, 2017) with more residents leaving the region than entering. 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, 2017).

Migration of residents can be tracked through individuals who receive the Alaska Permanent Fund Dividend (PFD) to the census area. It is important to note that the majority of Alaskan residents receive the PFD (87% in 2018), but there are eligibility requirements that restrict some individuals from being included. The 87% PFD recipient rate is considered a reliable

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[19] US Census Bureau. 2018. American Community Survey. `https://www.census.gov/programs-surveys/acs/data.html`

source of population estimates as Alaska's response rate for the 2010 U.S. Decennial Census was 64% [20]. Between 2010 and 2018, the majority of individuals moving from both the SEBS and NBS moved out of state and to the western Gulf of Alaska (Figure 118 and Figure 119). Similarly, both regions experienced a negative net migration with the SEBS losing between 1 and 74 individuals a year and the NBS losing between 1 and 149 individuals a year. Migration to the SEBS and NBS primarily come from out of state (Figure 120 and Figure 121) with both in and out migration following current state trends (ADLWD, 2019).

The out of state movement is consistent with long term population trends throughout the state. Alaska's migration patterns have been attributed to the national unemployment rate, with Alaska seeing its lowest net migration rates when the national unemployment rates are at their lowest (ADLWD, 2019). Throughout the Great Recession in the contiguous US, Alaska's population grew steadily while the state economy maintained a relatively stable state compared to the lower 48 (Sandberg, 2018). As the economic conditions began to improve in the lower 48 in 2010, the Alaska economy began to worsen, dampening the population growth and beginning a statewide negative net migration trend (Sandberg, 2018). The Alaskan Recession of 2015 worsened the negative net migration and in 2017, Alaska had a net loss of 8,900 individuals, the greatest number since 1988 (Sandberg, 2018). Previously, natural increases would offset the migration losses but in 2017 and 2018 this was not the case (ADLWD, 2019).

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 SEBS 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 SEBS 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).

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[20] US Census Bureau. 2018. 2010 Census Participation Rates. `https://www.census.gov/data/datasets/2010/dec/2010-participation-rates.html`

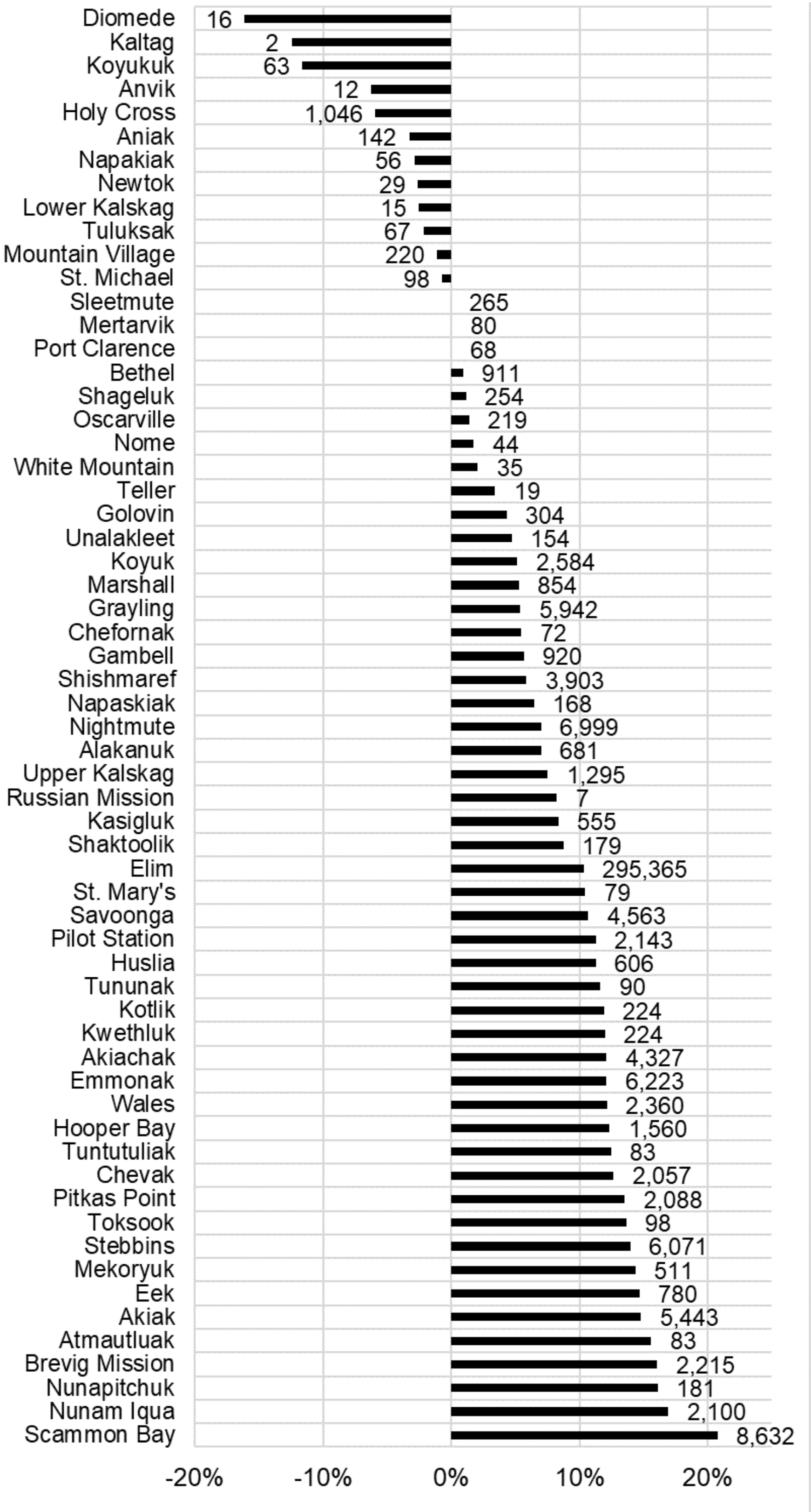

Figure 117: Population and population change of northern Bering Sea communities 2010–2018.

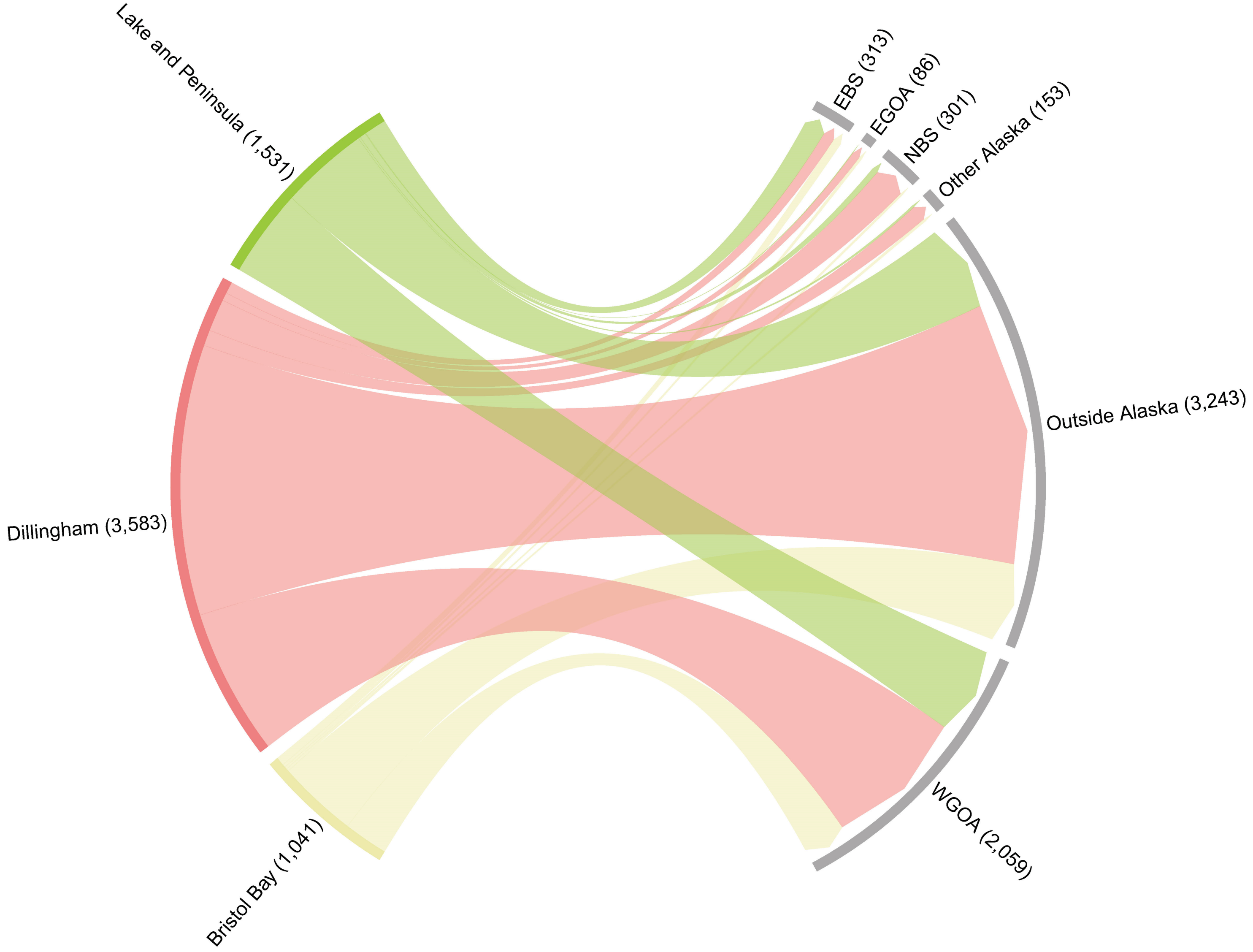

Figure 118: Migration pattern of residents moving from southeastern Bering Sea boroughs 2010–2018.

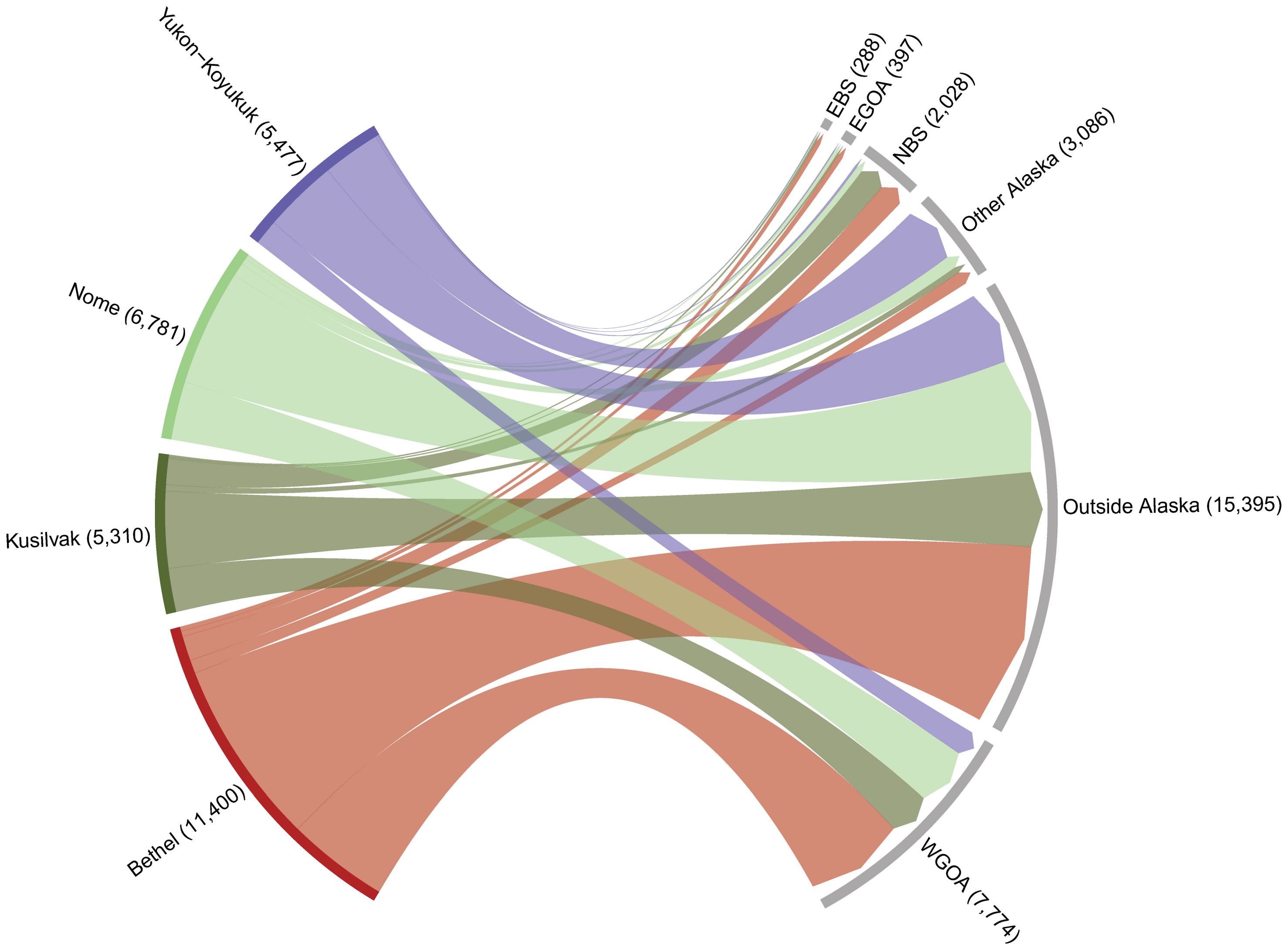

Figure 119: Migration pattern of residents moving from northern Bering Sea boroughs 2010–2018.

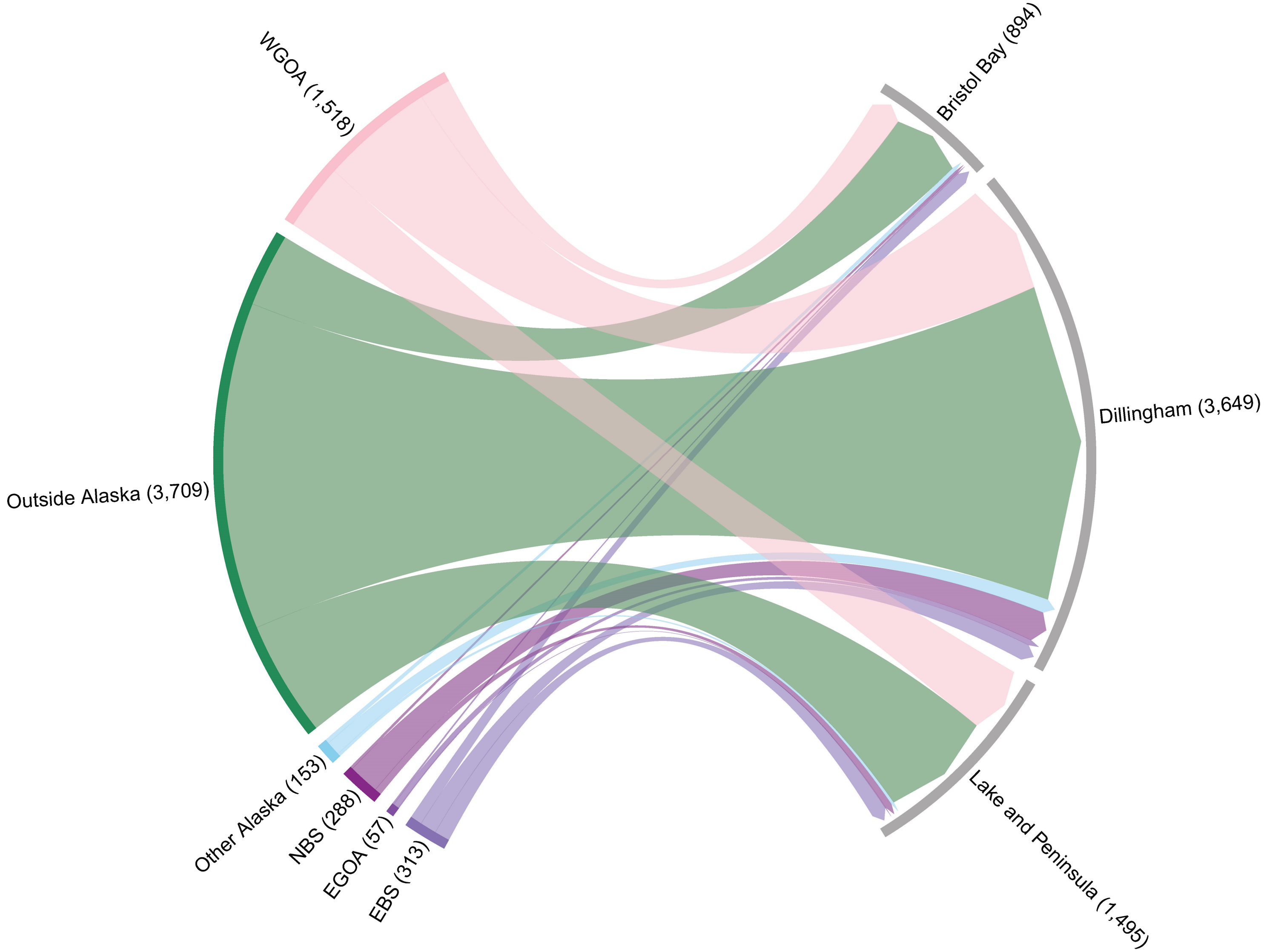

Figure 120: Migration pattern of residents moving to southeastern Bering Sea boroughs 2010–2018.

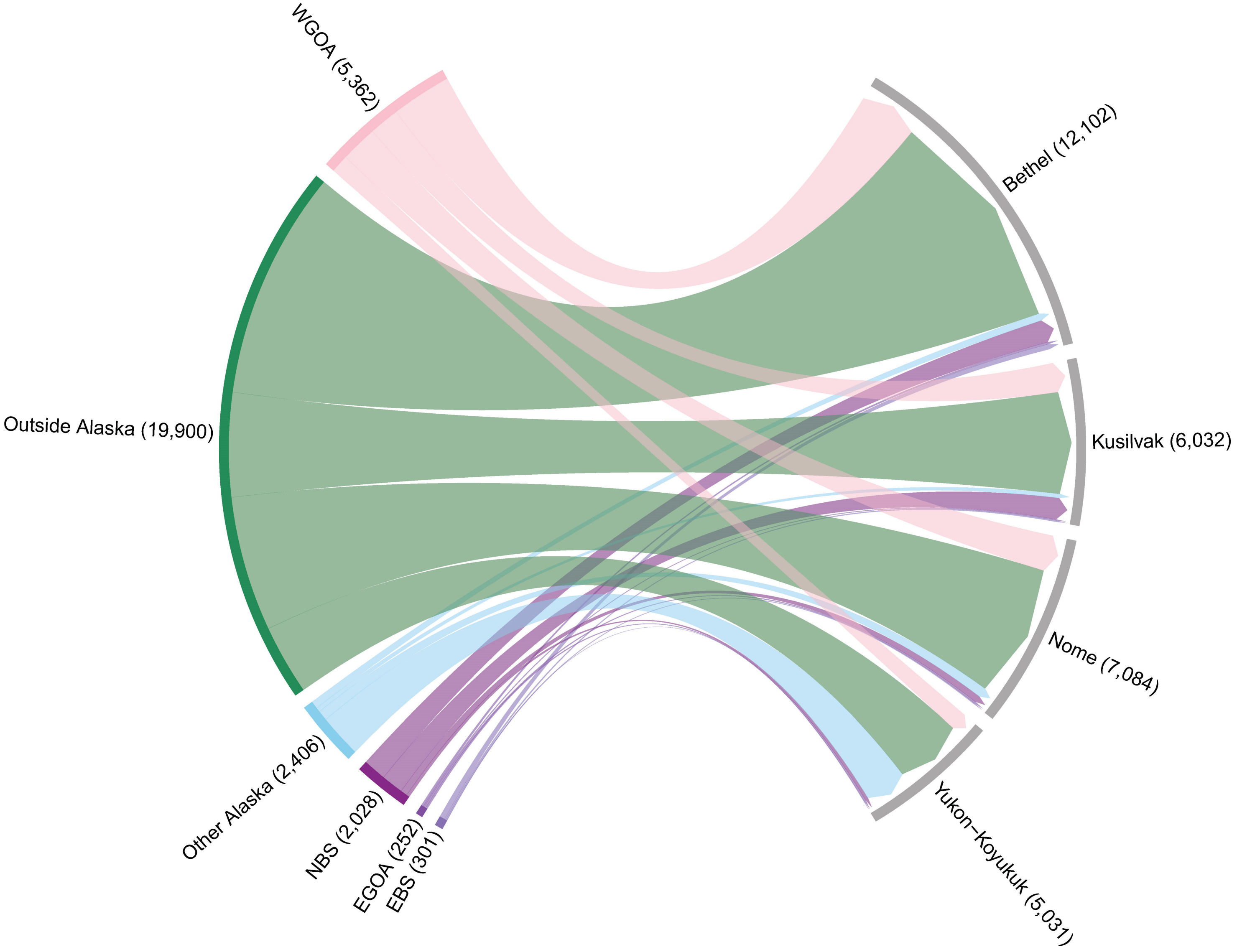

Figure 121: Migration pattern of residents moving to northern Bering Sea boroughs 2010–2018.

K–12 School Enrollment and Graduation 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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Last updated: August 2019

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 southeastern Bering Sea (SEBS) and nothern Bering Sea (NBS) 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 1996–2014 from the National Center for Educational Statistics[21]. More recent enrollment data were available for years 2014–2019 from the Alaska Department of Education and Early Development. Current school locations and names were verified using the EPA EJ mapping tool[22]. 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 2015–2018 cohorts based upon school district. All data originate from the Alaska Department of Education and Early Development[23].

Status and trends:

Southeastern Bering Sea

In the SEBS region, school enrollment numbers have fluctuated widely since 1996, highlighting the difficulties in maintaining sustainable communities within the rural coastal Alaskan ecosystem. Several community schools closed since 2005, most recently St. George School closed in 2017. Schools with lower enrollment show the greatest fluctuation. The overall trend for schools under 25 students continues downward; however some schools are showing an uptick since in the last year. After falling to 17 students in 2018, Levelock CDP (census-designated place) school enrollment increased to 22 (up 29%). Clark's Point school closed due to low enrollment in 2013, but was able to reopen in 2017. Over the past year, Clark's Point increased enrollment from 13 to 15 students (Figure 122).

Figure 123 illustrates enrollment trends by census borough. There has been a general trend toward decreasing school enrollment in most boroughs, although 2019 shows some areas holding steady. Lower Kuskokwin schools dipped in 2019 after increasing slightly to 2014 and then remaining relatively flat since 2014. Within the Aleutians West census area of the SEBS, school enrollment has decreased substantially until 2018 where it appears to pause. Within the Pribilof Islands, St. George City decreased from 48 students in 1996 to 6 students in 2017 and then closed. Students there now rely solely on correspondence courses. St. Paul City's enrollment increased in the last year from 52 to 63 students (up 21%). Although the Lake

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[21] `https://nces.ed.gov/ccd/elsi/tableGenerator.aspx`

[22] `https://ejscreen.epa.gov/mapper/`

[23] `http://www.eed.state.ak.us/stats/`

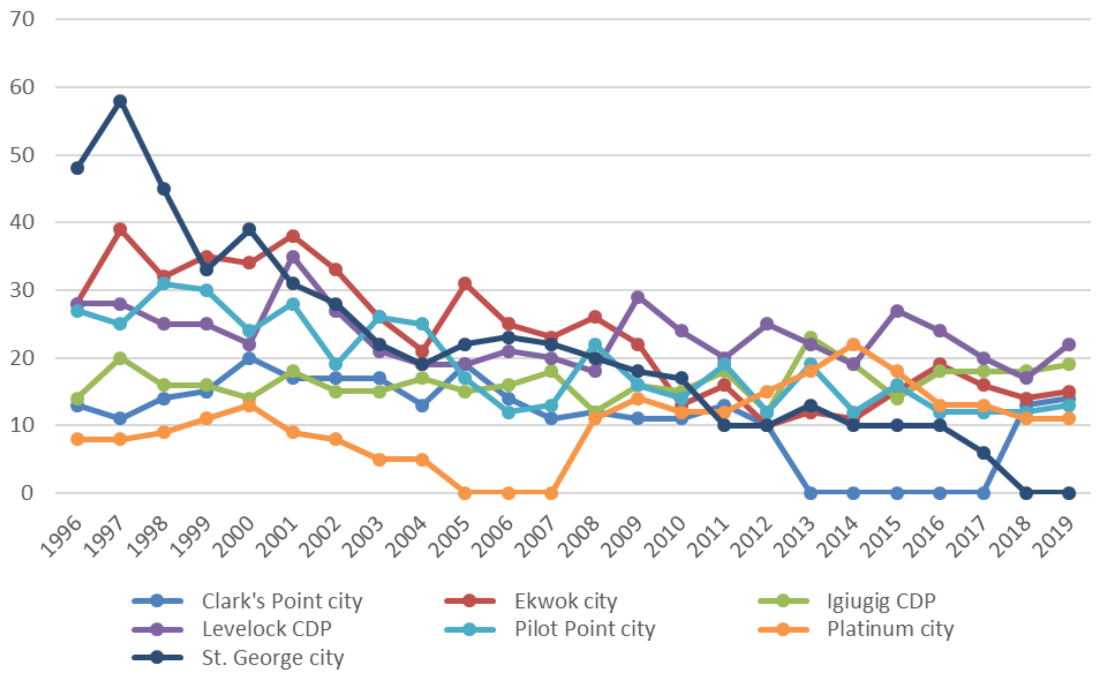

Figure 122: Communities with enrollment under 25 students in the southeastern Bering Sea.

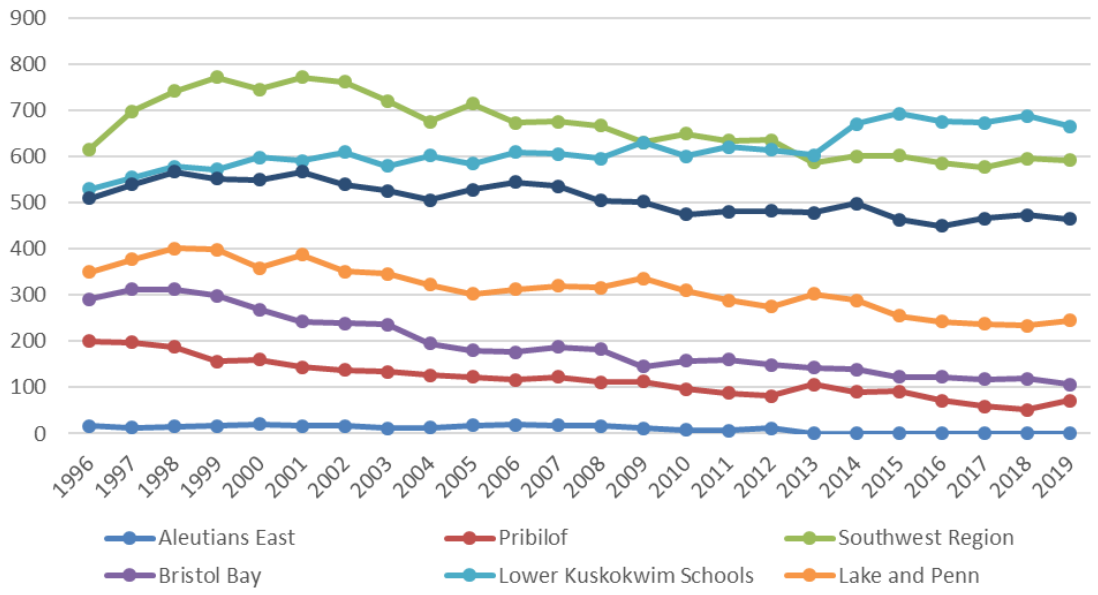

Figure 123: Census borough enrollment in the southeastern Bering Sea.

and Peninsula Borough schools showed some declines including Nondalton City (down 12%), other schools increased their enrollment. Newhalen City grew from 55 to 70 students (up 27%). Having fallen in enrollment by 56 percent since 1996, Pilot Point grew by one student in 2019. Bristol Bay schools were mixed. Naknek Middle/High School showed continued decline: falling an additional 10% from last year, while Naknek Elementary grew from 48 to 53 students (up 5%). The Bethel census area shows an overall decline in enrollment (3%) which the steepest declines in Kongiganak CDP (down 18 students or 10%) and Quinhagak City (down by 8 students or 7%). This eliminates any gain in enrollment seen from the previous year (Figure 123).

Graduation rates for SEBS school districts vary substantially ranging from a low of 61% in the Lower Kuskokwim district to 100% in Bristol Bay district (Figure 124). Only one school remains in the Pribilof school district and no data are available at this time. The graduation rate average in Alaska is increasing slightly: 75.6% (2015), 76.1% (2016), 78.2% (2017), and 78.5% (2018).

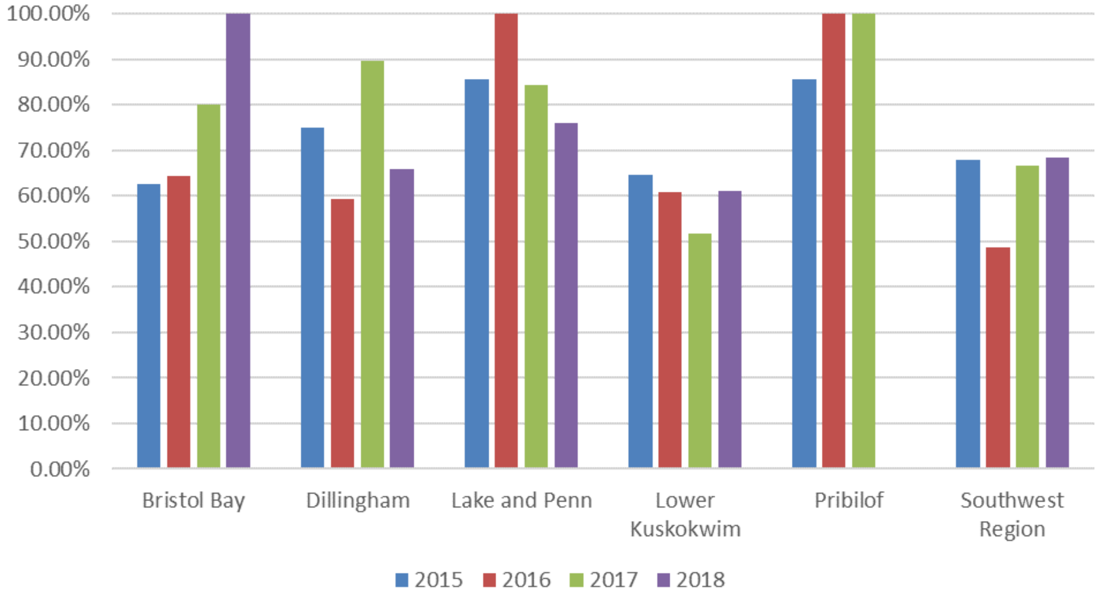

Figure 124: Graduation rates for southeastern Bering Sea school districts, 2015–2018.

Northern Bering Sea

Unlike many of the other regions, NBS school district enrollment levels are relatively stable. The only area that showed a decline was the Lower Kuskokwim school district, which decreased enrollment from 3,442 students in 2018 to 3,406 (down 1%). All others remained constant or increased slightly. The highest percentage increase in enrollment is seen in the Idtarod school district, rising from 106 to 112 students (up 6%) (Figure 125). There have been no additional school closures in the last year. There are eight schools with enrollment levels under 30 students, two with fewer than 15 students.

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, Yukon-Koyukuk, and Yupiit school districts consistently fall in the lower 1/3 of school districts analyzed in the Ecosystem Status Report, for all four cohort years (Figure 126). Nome showed an increase in graduation rate from 62.2% 2017 to 76.7% in 2018. The graduation rate in Iditarod has consistently declined since 2015, falling to 40.7% in 2018.

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. Transportation and access vary significantly among communities. High dependence on natural resources may drive population shifts according to season and availability. As people migrate to other

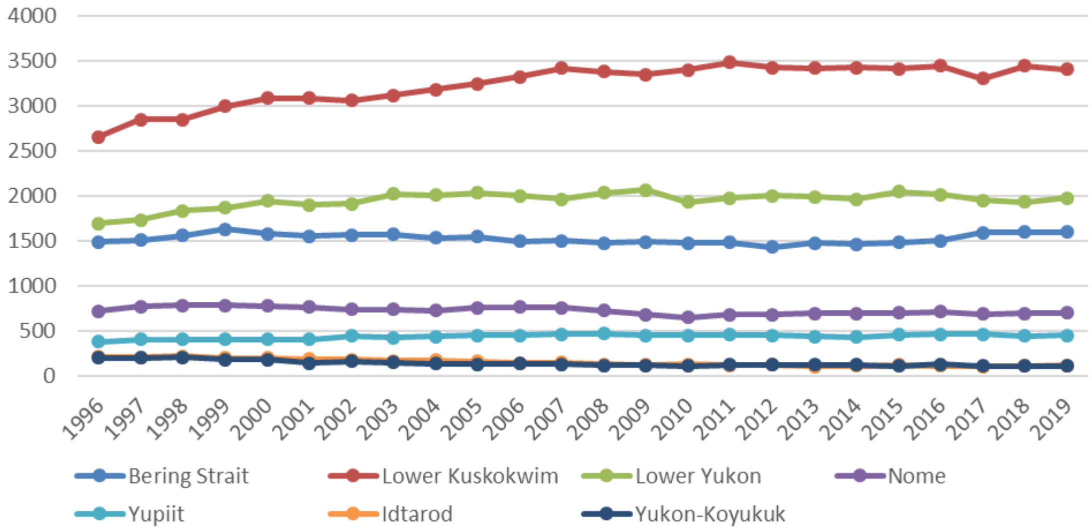

Figure 125: Enrollment for northern Bering Sea school districts.

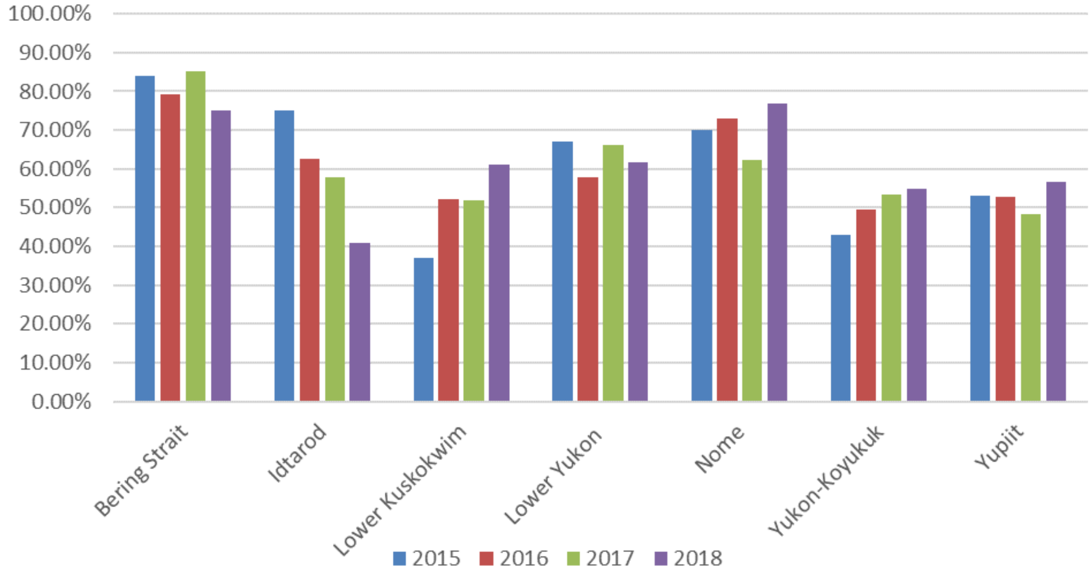

Figure 126: Graduation rates for northern Bering Sea school districts, 2015–2018.

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 20 students experience the greatest uncertainty in terms of educational stability.

As of 2019, there remain 11 schools have enrollment under 30 students, and three schools have under 15 students. With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and possible community disruption. For example, St. George Island is extremely remote. Loss of a community school is serious stressor for such a rural community. Efforts continue to provide educational opportunities for the community such as supporting the correspondence program. 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
The NBS ecosystem is remote and varies substantially in population and community structure and vitality. High dependence on natural resources may drive population shifts according to season and availability; however strong social networks and 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 either of these places would have a profound effect. Additional research into the relationship between of 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, 2005). Within rural communities, in particular, schools are valuable symbols for community identity, autonomy, and shared social values (Peshkin, 1978, 1982; Lyson, 2005). Research indicates that school closures negatively affect communities and student achievement (Buzzard, 2016). 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; Lyson, 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 suggests that reduced enrollments and school closures may flag disruptions in social cohesion, possibility leading to less vibrant and sustainable communities.

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Appendix

History of the ESRs

Since 1995, staff at the Alaska Fisheries Science Center have prepared a separate Ecosystem Status (formerly Considerations) Report within the annual Stock Assessment and Fishery Evaluation (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[24].

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 indicator, summarize the historical trends and current status of the indicator, and identify potential factors causing those trends. Beginning in 2009, contributors were also asked to describe why the indicator is important to groundfish fishery management and implications of indicator 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.

In 2018, a risk table framework was developed for individual stock assessments as a means of documenting concerns external to the stock assessment model, but relevant to setting the Acceptable Biological Catch (ABC) value. These concerns could be categorized as those reflecting the assessment model, the population dynamics of the stock, and environmental and ecosystem concerns—including those based on information from Ecosystem Status Reports. In the past, concerns used to justify an ABC below the maximum calculated by the assessment model were documented in an ad hoc manner in the stock assessment report or in the minutes

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[24] The Arctic report is under development

of the groundfish Plan Teams or Scientific and Statistical Committee reviews. With the risk table, formal consideration of concerns—including ecosystem—are documented and ranked, and the stock assessment author presents a recommendation for the maximum ABC or a value lower. Five risk tables were completed in 2018 as a test case. After review, the Council requested risk tables to be included in all stock assessments in 2019.

In 2019, risk tables were completed for all full assessments. Ecosystem scientists collaborated with stock assessment scientists to use the Ecosystem Status Reports to help inform the ecosystem concerns in the risk tables.

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 127). 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.

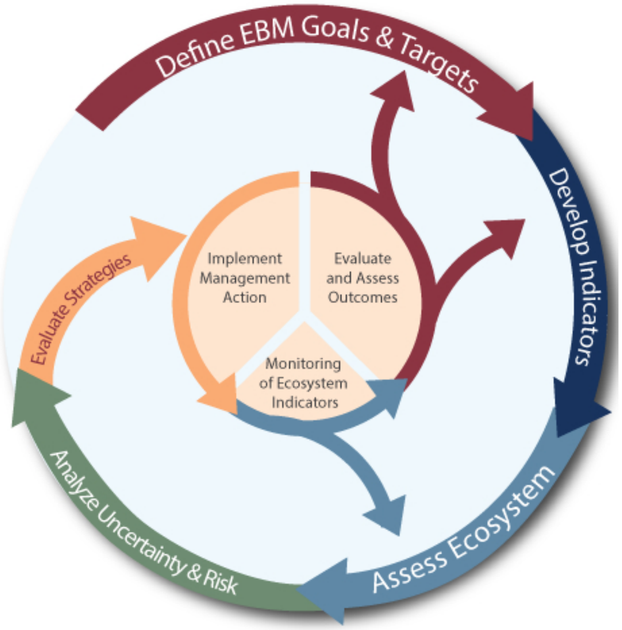

Figure 127: The IEA (integrated ecosystem assessment) process.

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 are also available through the NOAA-wide IEA website at: `https://www.integratedecosystemassessment.noaa.gov/regions/alaska`.

Past reports and all groundfish stock assessments are available at: `https://www.google.com/url?q=https://www.fisheries.noaa.gov/alaska/population-assessments/north-pacific-\groundfish-stock-assessment-and-fishery-evaluation`

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

Responses to SSC comments from December 2018

This year, as in the past, the Ecosystem Status Reports (ESRs) are insightful, well-written, and well-edited. All three chapters were helpful in providing a context within which to assess the stocks of commercially harvested fish in Federal waters of Alaska. The editors and authors have been very responsive to the comments and suggestions provided by the SSC in 2017. In 2016, 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, as was the case last year, NOAA provided sufficient additional resources to sustain the improvement of these documents. These additional resources allowed for more in-depth analyses of recent environmental changes, such as the examination of the reappearance of the heatwave in 2018 in the Gulf of Alaska, and the extraordinary conditions in the northern Bering Sea in 2018.

Thank you. This year we provide updates to the Eastern Bering Sea (Siddon & Zador) and Gulf of Alaska (Zador, Yasumiishi, & Whitehouse, with Rob Suryan providing coordination with Gulf Watch Alaska) Ecosystem Status Reports (ESRs). We anticipate updating the Eastern Bering Sea, Gulf of Alaska, and Aleutian Islands ESRs in 2020 as NOAA continues to support and provide resources to these Reports.

Now that the ESRs are providing a very quick turn around on the occurrence of unusual events that are likely to affect the setting of ABCs, there needs to be a mechanism in place for determining the likely impact of an event on management and a protocol of how to use the data effectively in a precautionary approach. This need is particularly acute for instances when an event occurs in a year when there was no survey of a region.

The risk tables that were introduced in December 2018 and are included in all full stock assessments this year will help to address this comment. By formally documenting ecosystem concerns for a stock that are not addressed within the assessment model, we hope to be able to analyze management response to ecosystem concerns, whether the concerns motivate a reduction in Acceptable Biological Catch or not. We hope that in future years, there will be risk tables for all stock assessments, including partial assessments and those updated in years with no bottom trawls surveys.

The SSC commends the ongoing efforts to expand the treatment of the Human Dimensions portion of the ESRs. 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 these Human Dimensions sections 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, and it is good to see that efforts have been made to identify changes in the smaller communities. Now, there is need to develop implications sections that go beyond stating all the factors that might be responsible for the trends and to suggest, however tentatively, what these trends imply about the futures of the communities described.*

We have worked with the Economics and Social Sciences Research Program staff to develop and refine indicators that are based on more recent data available. Getting within-year data continues to be one of the main challenges for these types of indicators. We culled some indicators that were likely to remain outdated. Refining these indicators and their implications for fisheries managers is on-going. The AFSC is supporting co-production of knowledge with local knowledge and traditional knowledge holders (LK/TK). This year, the Eastern Bering Sea ESR includes an integrated seabird synthesis that is informed by researchers, tribal councils, and community members.

Last year the SSC again raised the issue of how well report authors have managed to address the implications of their indicator findings for the current year. Overall, there appears to be improvement with respect to this issue, though room for further improvement remains. As indicated last year, the purpose of the ESR chapters is to provide the Council with information that may be relevant for adjusting the coming years' 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.

We continue to work with authors to develop/refine their Implications sections.

Last year, the editors raised the question as to the possibility of a change in the organization of the ESR chapters and the SSC is pleased that the editors decided to maintain the present organization based on trophic-level.

This year's Reports are also organized by trophic level within the Ecosystem Status Indicators section; they are organized around objective categories derived from U.S. legislation and current management practices within the Fishing and Human Dimensions Indicators section (as they were in 2018).

The Introduction lists four ecosystem-based management goals of the NPFMC. These are not the same as the six goals listed on page 21 of the Fishery Ecosystem Plan; the two documents should be consistent.

We have edited the Introduction of the ESRs to include the six ecosystem goals of the NPFMC.

There was a discussion on ways to reduce the overall document length and duplication. One example is the Executive Summary not having a bullet for every single contribution but instead only indicators that are outside of normal limits. This, in combination with the table of contents and a list of figures creates essentially three lists of all the indicators and really fattens up the document. Another simple reduction could be accomplished by removing all but the first sentences out of the Table of Figures. If retained, the List of Figures should be written with captions that stand alone. ***The SSC suggests authors explore these and other organization structures that reduce duplication in the documents.***

We have condensed/reduced the Report in the following suggested ways: (1) We have shortened the Executive Summary to reflect only those highlights that stand-out when thinking about ecosystem response to the current-year conditions and (2) the List of Tables and List of Figures now include shortened (but still stand-alone) legends for each table and figure.

The SSC recommends more specific methods descriptions for the report card indicators. *It was not always possible to tell what was being plotted and there are few specifics in the text of report (e.g., how means, standard deviations and trends were calculated). A stand-alone methods section (potentially hot-linked) could be a useful addition to the report.*

We have included a 'Methods Description for the Report Card Indicators' in the Appendix.

The descriptions of report-card indicators do not discuss implications to fishery management although other indicators later in the report do. The SSC encourages the authors to work towards a discussion section of how or whether the 10 indicators are expected to be related to federally-managed stocks. The SSC recognizes that much of this will be stock-specific and ultimately go in ESP's.

We have attempted to include brief statements of implications in the Report Card bullets.

Comments Specific to the Eastern Bering Sea Ecosystem Status Report

The SSC heard a report on the Ecosystem Status Report for the Bering Sea from Elizabeth Siddon and Stephani Zador. There were no public comments.

This year's assessment highlighted ecosystem conditions and responses in the northern Bering Sea (NBS) and southeastern Bering Sea (SEBS) independently, but noted 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.

In this year's Report, the Assessment highlights ecosystem responses that are (i) reflective of 2018 conditions, (ii) reflective of 2019 conditions, and (iii) those that reflect cumulative impacts across 2018 and 2019 while maintaining a 'big picture' perspective of connectedness across the northern and southeastern shelves.

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. 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 NBS were 1°C to 2°C rather than <-1°C, and no cold pool formed. The lack of salinity structure resulted in weaker vertical stratification, and a well-mixed water column. The near-complete lack of sea ice over the NBS shelf created an absence of ice algae to 'seed' productivity. Zooplankton abundance was overall low although it increased with latitude. In addition, lipid content of large copepods and euphausiids was low, with large copepods dominated by lipid-poor Eucalanus bungii. Adult Pollock biomass declined, ice seals were unusually scarce, and pups were in poor condition. Finally, seabird reproductive failures and a broad-scale die-off event were observed.

In each Report, the Assessment contains a complete recap of the previous year's conditions because some indicators can only be updated to the previous year due to the nature of the data collected, sample processing, or modeling efforts. For a full summary of 2018, please see the 'Recap of the 2018 Ecosystem State' in the Assessment.

In the SEBS, 2018 was fairly typical of a low-ice year, exhibiting reduced stratification and a weak, delayed bloom. Zooplankton were low in abundance and quality. Although larval fish production was relatively high, juvenile survival is predicted to be low. Adult pollock biomass was low, while Pacific cod surveys indicated fewer, larger fish. Seabirds at the Pribilof Islands nested late and had low reproductive success, and fur seal pup production continued a long-term decline at St. Paul. Community members, subsistence and commercial fishers from Bristol Bay reported unusual behavior of adult pollock and high numbers of pollock washing ashore dead.

For a full summary of 2018, please see the 'Recap of the 2018 Ecosystem State' in the Assessment.

The SSC was pleased to see that all 10 Report Card Indicators were updated in 2018. In general, the SSC appreciates the huge number of indicators that turn around and get current-year data in fast. This has been a tremendous effort and is paying off to make the Ecosystem Reports relevant in real time.

As ESR editors, we are grateful to the immense efforts by contributors to produce real-time, relevant indicators to inform AFSC and the NPFMC's ecosystem goals in support of ecosystem-based management.

Several indicators were greater than one standard deviation below the long term mean in 2018, although only two were when averaged over the last 5 years. The only biological indicator above the long term mean was motile epifauna biomass. North Pacific Index was also high *for the 2018 datapoint only. The SSC notes that it would be helpful if all indicators included a statement about their relevance to fishery management; it is not clear if positive values in indicators are always related to "ok-ness". In general, more details in the Descriptions of Report Card Indicators would help. Especially important would be information on the schedule for data collection (time of year), and a statement on the expected relevance to fishery management.*

We have attempted to include such information within the 'Description of the Report Card indicators' section, including brief statements of implications to fishery management.

The introduction indicates that the list of 10 Report Card indicators will be updated as part of Fishery Ecosystem Plan currently being developed. That plan has been released and there are several places this is discussed (either in the action module or as a task for core FEP team). Overall the SSC supports this list being updated, although the process is not entirely clear in the Fishery Ecosystem Plan. Ideally the three ESR's would be treated holistically and the Aleutian Island FEP team could re-evaluate the indicators for that ecosystem.

Members of the core FEP team will undertake an examination of indicators for the eastern Bering Sea. This will include consideration of currently available ESR indicators, both in the Report Card and within the Report, with respect to NPFMC ecosystem goals and FEP ecosystem goals.

The SSC recognizes sea temperatures as a primary environmental indicator of interest. Of note, the Bering Sea ESR discussions are largely framed around "warm years" and "cold years", and the 2015–2016 marine "heatwave" was repeatedly referred to in the Gulf of Alaska ESR. ***The SSC encourages the authors to strive for a consistent way of discussing sea temperature in terms of anomalies, heat waves etc.*** *A brief definition of 'heatwave' when the term is first used would be helpful. The SSC appreciated the "Noteworthy" contribution about the current heatwave in the Gulf of Alaska, but notes that model predictions (Fig. 11) indicate larger sea-surface temperature (SST) anomalies in the EBS, suggesting a heatwave in that region as well. The SSC noted that recent SST increases in the Northern and Eastern Bering Seas exceed increases observed during the 1976–1977 regime shift, suggesting the potential for similarly large ecosystem implications. Further, we note that recent annually averaged SSTs in the NBS in 2017 and 2018 are approximately the same as average SSTs in the SEBS over the last 30 years.*

In the EBS ESR, we encouraged authors to provide Physical Environment indicators, such as SST and sea ice extent, as anomalies. Some examples include a new metric for sea ice extent over the Bering Sea shelf (see Report Card), satellite derived SST (p. 52), and variations in temperature and salinity from BASIS (p. 56). Please note that we will continue to pursue an appropriate analysis to determine "heatwave" status for the EBS.

Kudos to the authors and other collaborators on an August workshop and efforts to provide early information on anomalous conditions in the NBS in 2018. This information is extremely valuable and the assessment did a good job of articulating which events were "unprecedented" versus which ones were just unusual. ***The SSC strongly supports continuing to conduct the NBS survey.***

In an effort to formalize the process of considering 'early warning' information, AFSC initiated the Spring PEEC (Preview of Ecosystem and Economic Conditions) meeting with the goal of exchanging information on early physical, biological, and economic conditions to inform upcoming surveys and the NPFMC as part of AFSC's ecosystem-based fisheries management mission. In the future, we anticipate that the Spring PEEC meeting will occur annually.

In the Ecosystem Assessment section and throughout, the SSC encourages the authors to clarify in what months various datasets are collected. *Data presented apparently cover a wide range of seasons from 2017 through September 2018, but readers not familiar with all the surveys often cannot tell what time period is being discussed.*

We have attempted to clarify survey timing and subsequent dataset collection/availability in the Ecosystem Assessment and throughout the Report.

The new section in the Ecosystem Assessment of Local and Traditional knowledge is an excellent and robust addition. The information from this source, especially with regards to the northern Bering Sea, is an important addition to the report. The SSC looks forward to its continuation and expansion as appropriate; However the SSC suggests it not be separated from the rest of the summary. Those pieces of information would easily add to the weight of evidence with the rest of the data. A concern is that it would lose visibility, but ideally it is treated as a regular part of evidence. ***The SSC encourages a continued search for other options for this kind of information and ways to incorporate the long-term information from these sources as a direct indicator.***

We have continued to reach out for LK/TK information from a variety of sources and have integrated that within the Ecosystem Assessment this year. Additionally, we have restructured the Seabird section of the Report to "Integrated Seabird Information" (see p. 132). This integration is in response to collaborative efforts within the seabird community (including researchers, tribal councils, and community members). We have attempted to merge across information sources to derive regional summaries within the southeastern and northern Bering Sea that can be used by resource managers within the eastern Bering Sea.

The SSC appreciated the evaluation of index/indicators and their use at forecasting or predicting (examples were for Pacific cod and pollock and lack of prediction of NPI for cod) and supports further expansion of these types of implications. We need to have these assessments to understand how to apply the indicators we're looking at in terms of fisheries management decisions. The SSC recognizes that the pollock recruitment prediction information will be moved to ESP's. The SSC will provide the authors some suggestions for text clarification in this section.

In this year's report, we have again included a section titled "Groundfish Recruitment Predictions" that contains information that is intended to be transitioned to species-specific ESPs as those are developed. We look forward to the continued development of ESPs as complementary products in AFSC's 'toolbox' to address ecosystem-based fisheries management.

Nine indicators were added or substantially updated in 2018, and the SSC applauds the authors on the continued efforts to curate this report. Of particular note was a new indicator of the annual run size of Bristol Bay sockeye salmon, where 2018 had the largest run on record since 1963. The SSC appreciates the efforts to include many new human dimensions indicators. Many unfortunately only had updates available for 2016 or 2017. The SSC appreciates the editors' responsiveness to the request, but these may not be useful if not able to be current.

This year's report again contains nine indicators that are new or substantially updated in 2019, in addition to completely revamping the Seabirds section of the report.

We have worked with the Economics and Social Sciences Research Program staff to develop and refine indicators that are based on more recent data available. Getting within-year data continues to be one of the main challenges for these types of indicators. We culled some indicators that were likely to remain outdated. Refining these indicators and their implications for fisheries managers is on-going.

The authors reported that there was evidence of unusual distributions, poor condition and strandings of marine mammals in the Bering Sea in 2018. Data from the NMFS Marine Mammal Laboratory (MML) suggests this may be associated with lack of sea ice. As spotted seals' diet includes several commercially important species including pollock and other forage species, the SSC supports continuing to include information on this trend as an indicator of forage species and Pollock availability in the ecosystem. With surveys conducted by MML occurring infrequently, this indicator could be an avenue for direct incorporation of LTK. For example, long-term observations of sealbody condition could be provided by subsistence hunters. The SSC recommends exploring options for incorporating this information, and suggests potentially reaching out to NOAA co-management Alaska Native Organizations like the Ice Seal Committee.

Collaboration with MML has been critical to understanding ecosystem impacts in the EBS in 2018 and 2019. We greatly appreciate MML staff participation in the Spring PEEC meeting with presentations from the Alaska Ecosystems Program, the Polar Ecosystems Program, and the Cetacean Assessment and Ecology Program. Additionally, MML provided several new contributions to the report this year (see p. 28 and 30) and an update to the Northern fur seal pup production estimate for the Report Card. The lack of indicators in the Marine Mammals section of the report does not adequately reflect MML contributions to our understanding of ecosystem impacts and relevance to fisheries management; we will continue to work together with MML to include information in the ESRs.

This year, we received observations on marine mammals from Gay Sheffield, UAF Alaska Sea Grant that are incorporated in the Ecosystem Assessment. Based on SSC and NPFMC review of the new "Integrated Seabird Information" section, this type of integration effort could be used to improve the Marine Mammal section of the report in 2020.

SSC notes that a benthic infauna indicator is lacking and encourages the authors to reach out to Jackie Grebmeier for an option.

We will continue to research sources and reach out to individuals who may have information regarding benthic infauna.

The SSC was pleased to see the inclusion of rat invasion on St. Paul in the "Noteworthy" section as a topic of concern for the Council. This highlights a real risk to communities and wildlife resources that is directly related to fishery activity.

We are engaged in conversations with researchers and community members year-round and are continually trying to stay apprised of topics that pose risks to communities and resources throughout Alaska. We are pleased to provide an update to the rat invasion on St. Paul: the rat was found dead on June 30, 2019.

Last year (2017) the editors indicated that they were working with the AFSC communications staff to produce a "public-friendly" version of the Bering Sea ESR. The authors provided the initial version of this document to the SSC. ***The SSC welcomed this excellent outreach product and congratulated the authors on this new development. The SSC encourages the authors to share this with the communities that provided data.***

Thank you. Based on the positive feedback we received, we will be completing 2019 *In Briefs* for the EBS and GOA with plans to expand the distribution of the briefs to communities that provided information.

Comments Specific to the Aleutian Islands Ecosystem Status Report

We anticipate an update to the Aleutian Islands Report in 2020 and will work to address comments from the SSC at that time.

Methods Description for the Report Card Indicators

For each plot, the mean (green dashed line) and ±1 standard deviation (SD; green solid lines) are shown as calculated for the entire time series. Time periods for which the time series was outside of this ±1 SD range are shown in yellow (for high values) and blue (for low values).

The shaded green window shows the most recent 5 years prior to the date of the current report. The symbols on the right side of the graph are all calculated from data inside this 5-year moving window (maximum of 5 data points). The first symbol represents the "2015–2019 Mean" as follows: '+ or -' if the recent mean is outside of the ±1 SD long-term range, '.' if the recent mean is within this long-term range, or 'x' if there are fewer than 2 data points in the moving window. The symbol choice does not take into account statistical significance of the difference between the recent mean and long-term range. The second symbol represents the "2015–2019 Trend" as follows: if the magnitude of the linear slope of the recent trend is greater than 1 SD/time window (a linear trend of >1 SD in 5 years), then a directional arrow is shown in the direction of the trend (up or down), if the change is <1 SD in 5 years, then a double horizontal arrow is shown, or 'x' if there are fewer than 3 data points in the moving window. Again, the statistical significance of the recent trend is not taken into account in the plotting.

The intention of the figures is to flag ecosystem features and the magnitude of fluctuations within a generalized "fisheries management" time frame (i.e., trends that, if continued linearly, would go from the mean to ±1 SD from the mean within 5 years or less) for further consideration, rather than serving as a full statistical analysis of recent patterns.