Ecosystem Status Report 2018

Gulf of Alaska

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Western Gulf of Alaska 2018 Report Card

- The Gulf of Alaska in 2018 remained **characterized by warm conditions** which have moderated since the extreme heatwave of 2014–2016. The **PDO declined toward neutral**.
- The **freshwater runoff into the GOA appears to have been enhanced during winter 2017/2018 and suppressed during the spring of 2018**.
- **Mesozooplankton biomass measured by the continuous plankton recorder** has often shown a largely biennial trend, however biomass has **remained greater than average in 2014–2017**. Multiple indicators support a pattern of plentiful, but smaller, zooplankton during the heatwave.
- **Copepod community size increased in 2017**, indicating that there were more large species available. This suggests an **improvement in foraging conditions for planktivorous predators**.
- Bottom trawl **survey biomass of motile epifauna** was **below its long-term mean for the first time since 2001**. The increase from 1987 to 2001 was driven by hermit crabs and brittle stars, which continue to dominate the biomass. Octopus catches, which were record high in 2015, declined to a low not seen since 1990.
- Trends in capelin as sampled by seabirds and groundfish have indicated that **capelin were abundant from 2008 to 2013, but declined during the warm years of 2015–2016** and continue to be minimal in seabird chick diets. Their apparent **abundance coincided with the period of cold water temperatures** in the Gulf of Alaska.
- **Fish apex predator biomass during 2017 bottom trawl surveys was at its lowest level in the 30 year time series**, and the recent 5-year mean is below the long-term average. **The trend is driven primarily by Pacific cod and arrowtooth flounder** which were both at the lowest abundance in the survey time series. Pacific halibut and arrowtooth flounder have shown a general decline since their peak survey biomasses in 2003. **Pacific cod has continued to decline from a peak survey biomass in 2009**.
- **Black-legged kittiwakes had above average reproductive success in 2018** at the Semedi Islands, in contrast to the complete failure in 2015 for kittiwakes as well as other seabird species. Their reproductive success is typically variable, presumably reflecting foraging conditions prior to the breeding season, during, or both. In general, fish-eating seabirds in the western GOA have had strong reproductive success in 2018
- Modelled estimates of **western Gulf of Alaska Steller sea lion non-pup counts were approaching the long-term mean in 2017**, suggesting conditions had been favorable for sea lions in this area. However, preliminary estimates show a decline in the number of pups from 2015 to 2017 and declines in the number of non-pups in the Cook Inlet, Kodiak, and Semidi area.
- Human populations in fishing communities in the western Gulf of Alaska **have increased since 1990** largely in urban areas.

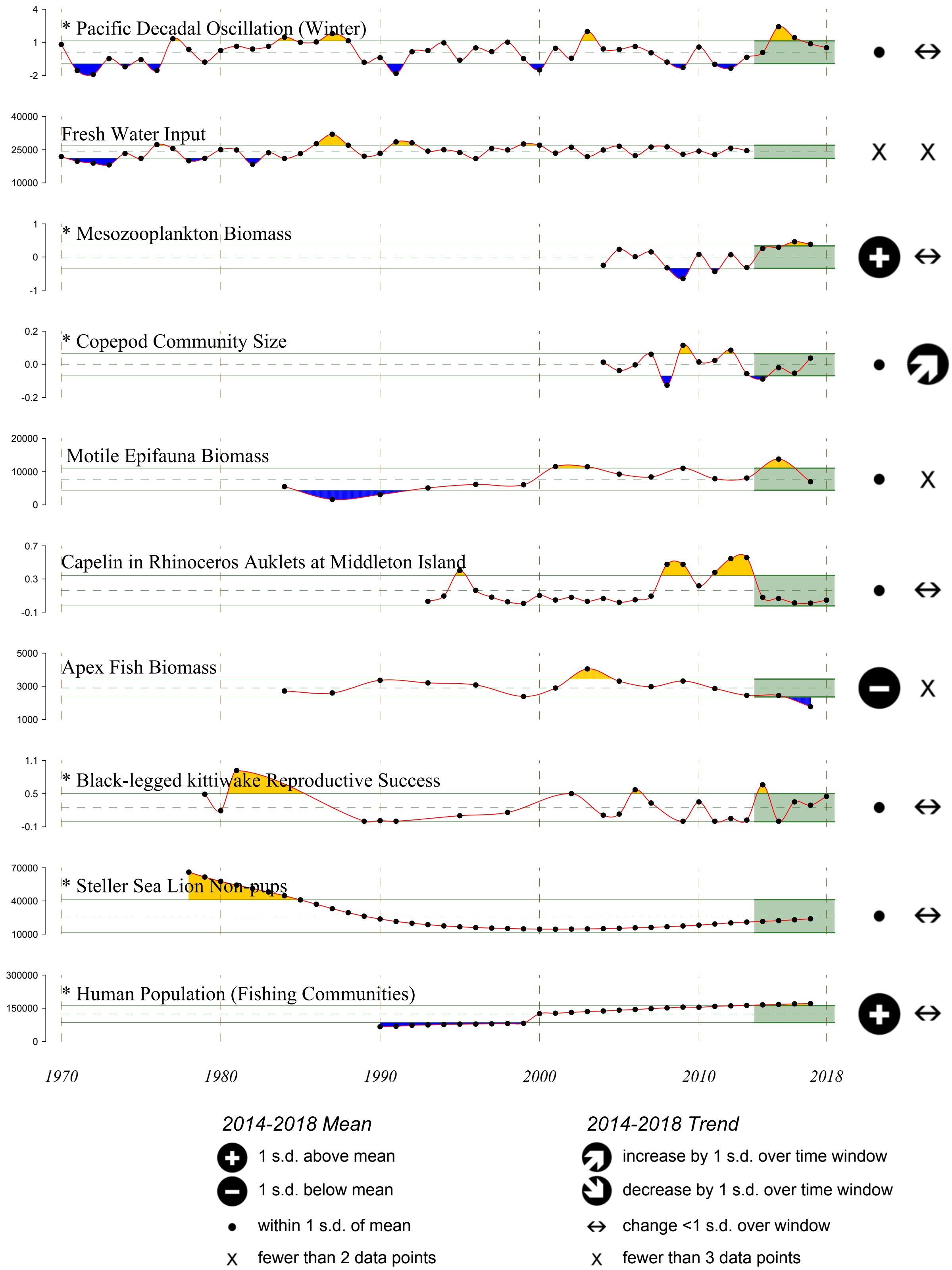

Figure 1: Western Gulf of Alaska report card indicators; see text for descriptions. * indicates time series updated in 2018.

Eastern Gulf of Alaska 2018 Report Card

- A **weak-moderate El Niño and warm sea surface temperatures are expected through next winter**.
- The North Pacific Gyre Oscillation declined, implying that **flows in the Alaska portion of the Subarctic Gyre weakened**, which was consistent with weakly directional surface currents.
- Total **zooplankton density in Icy Strait in 2018 was above average** and the 5th highest density over the 22-year time series. This suggests **improved foraging conditions for planktivorous fish, seabirds, and mammals** relative to the below-average densities during 2013–2016.
- However, this increase was due to **increased small copepod abundances in 2018** whereas large copepod abundance declined, leading to an overall decrease in mean size.
- Bottom trawl **survey biomass of motile epifauna is typically dominated by brittle stars and a group composed of sea urchins, sand dollars and sea cucumbers**. Record catches of hermit crabs influenced the peak biomass estimate in 2013. Catches of many of the more dominant members of this foraging guild were low in 2015. Brittle stars and miscellaneous crabs were the most abundant in 2017.
- A **decrease in estimated total mature herring biomass in southeastern Alaska has been observed since the peak in 2011**. Modeling indicates that the declines in biomass may be related to lower survival.
- Bottom-trawl survey **fish apex predator biomass is currently below its 30-year mean**, following a peak in 2015. **The trend is driven primarily by arrowtooth flounder** which were caught in great numbers in 2015. Pacific halibut and sablefish, the next most abundant species in this foraging guild have shown variable but generally stable trends in recent surveys. Pacific cod were at their lowest abundance in the time series in 2017, but had been at their highest relative abundance in 2015.
- **Growth rates of piscivorous rhinoceros auklet chicks were anomalously low during the heatwave, and there were no chicks to measure in 2018**, suggesting that the adult birds were not able to find sufficient prey to support successful chick growth. This is in contrast to 2012 and 2013, when chick growth rates were above the long term average.
- Modelled estimates of eastern Gulf of Alaska **Steller sea lion non-pups counts are above the long term mean through 2017**. However, preliminary estimates suggest that non-pup counts declined 12% in 2017 relative to 2015. This unusual recent decline in a long-increasing stock may indicate adverse responses to the marine heatwave of recent years.
- Human populations in fishing communities in the eastern Gulf of Alaska **have increased in large (>1,500 people) communities but have decreased in small communities since 1990**.

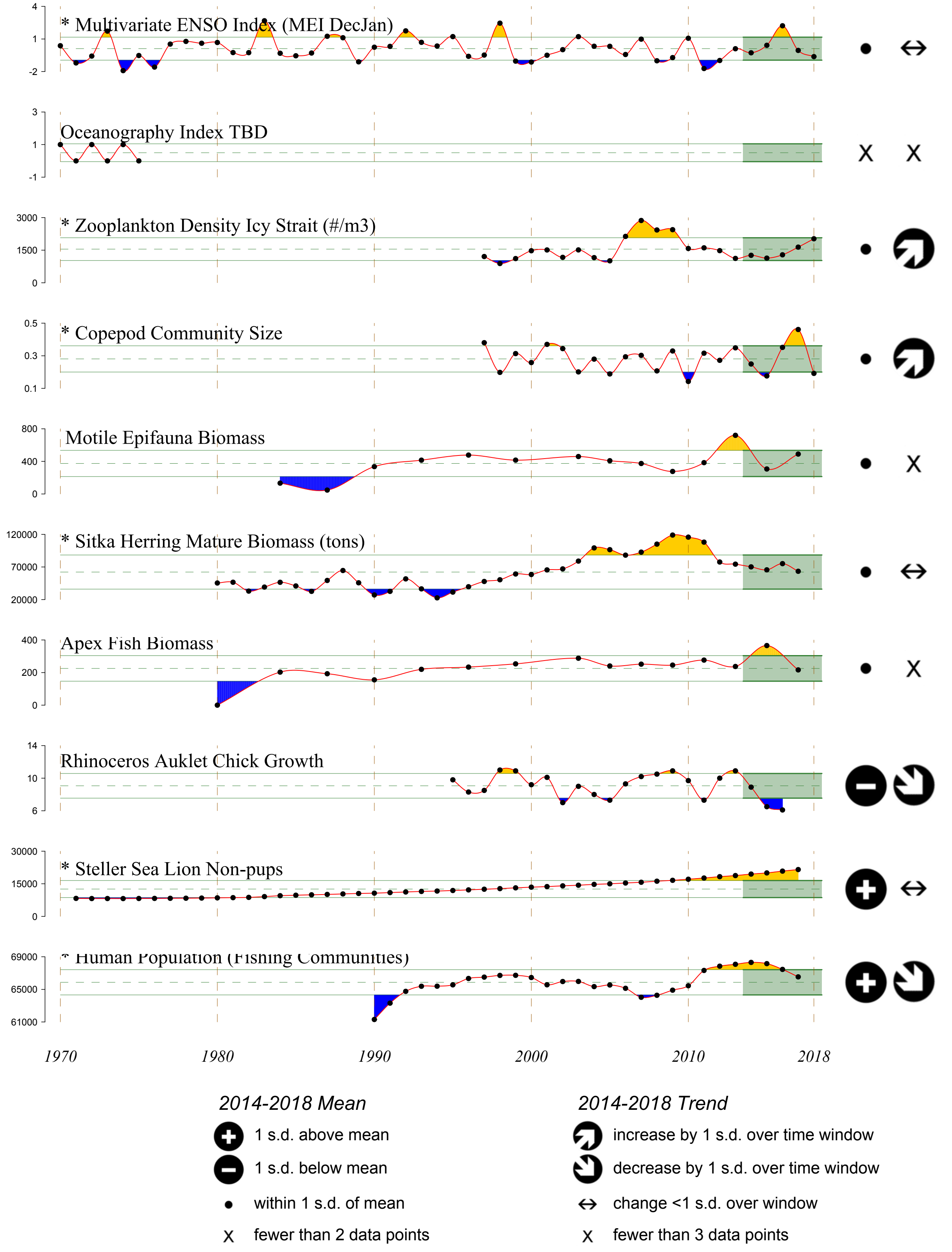

Figure 2: Eastern Gulf of Alaska report card indicators; see text for descriptions. * indicates time series updated in 2018.

Ecosystem Assessment

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The primary intent of this assessment is to summarize and synthesize climate, biological, and fishing effects on the shelf and slope regions of the Gulf of Alaska (GOA) from an ecosystem perspective and to provide where possible an assessment of the possible future effects of climate and fishing on ecosystem structure and function. This serves the larger goal of the Ecosystem Status Reports (ESRs) to provide ecosystem context for tactical fisheries management decisions. This assessment ties together the myriad indicator data into a narrative of the current and likely future ecosystem state, including information based on new or unexpected observations that may have implications for groundfish management. Report cards are presented at the front of this ESR to provide a succinct summary of the state of the ecosystem based on a short list of indicators.

This assessment reflects the recognition that the western and eastern GOA ecosystems have substantial differences. The GOA is characterized by topographical complexity, including: islands; deep sea mounts; continental shelf interrupted by large gullies; and varied and massive coastline features such as the Cook Inlet, Prince William Sound, Copper River, and Cross Sound, which bring both freshwater and nutrients into the GOA. The topographical complexity leads to ecological complexity, such that species richness and diversity differ from the western to eastern GOA. Thus, local effects of ecosystem drivers may swamp basin-wide signals. With this in mind, we present report cards and assessments of current ecosystem state for the western and eastern GOA ecoregions separately to highlight inherent differences.

The report card indicators were selected to best reflect the complexity of the GOA. Although there are many more people living in both large and small communities throughout the GOA relative to the Aleutian Islands or eastern Bering Sea, the complexity of the system requires a high-degree of local understanding to disentangle broad-scale patterns from local processes. We consider the GOA to be ecosystem data-moderate relative to the Aleutian Islands (data-poor) and eastern Bering Sea (data-rich). However, the division of the GOA into separate ecoregions highlights data gaps. For example, comparable forage fish indicators are not available for both regions. Also, while fresh water input is considered informative for the west, a comparable oceanographic indicator remains to be selected for the east. The report card indicators are described at the beginning of the Indicators section of this ESR. We will continue to revise and update these indicators in future editions of this report.

Complete Recap of the 2017 Ecosystem State

Some ecosystem indicators are updated to the current year (2018), while others can only be updated to the previous year (or earlier) due to the nature of the data collected, sample processing, or modelling efforts. Therefore, some of the "new" updates in each Ecosystem Considerations Report reflect information from the previous year. This year we include a complete summary of the ecosystem status of the GOA during 2017 that includes information from both previous and current indicators. The next section (Current conditions: 2018) provides separate summaries of the 2018 ecosystem state for the western and eastern GOA based on indicators updated this year. We plan to continue developing the ecosystem assessments with this ecoregional focus in future editions.

The North Pacific atmosphere-ocean climate system was in a more moderate state during 2017 than during the previous two years. In particular, the warm sea surface temperature anomalies associated with the extreme marine heatwave of 2014–2016 moderated. A weak La Niña developed during winter 2016–2017 along with a weaker than normal Aleutian Low. The Pacific Decadal Oscillation remained in a positive state but with lower amplitude. The weather of the coastal GOA was generally warmer than normal. The freshwater runoff into the GOA was somewhat less than normal in summer 2017, with implications for the baroclinic component of the Alaska Coastal Current. The sub-arctic front was farther south than the year before, consistent with the winter surface currents shown in the Papa Trajectory Index, which has its southernmost extent since the 1930s. This patterns suggests that there was reduced transport into the Alaska Current during 2017. Eddy kinetic energy was low through most of the year, suggesting that phytoplankton and nutrients were more tightly confined to the shelf. Sea temperatures were average through the top 100m along the Seward Line in May and eastern Gulf of Alaska shelf during summer. Water temperature profiles taken during the summer bottom-trawl survey throughout the GOA showed slight overall cooling compared to the previous survey in 2015 during the heatwave, but were still among the warmer years in the survey's record. However, the warmest water did not penetrate as deeply into the upper 100 m as in 2015. Temperature in PWS remained elevated, which is typical as PWS temperatures generally lag the Gulf of Alaska by about a year. Eastern GOA waters were 2–3°C cooler in 2017 than in the previous 3 years, although still in the range of warm. The intensity of stratification, and the shallowness of "deep" cold water offshore was notable. Average mixed layer water temperature was cooler in 2017 than in 2016, confirming that the "Warm Blob" was dissipating. Taken together, these suggest that the GOA water column was largely returning to average conditions in 2017.

Zooplankton continued to show the general pattern seen during the heatwave of abundant, but smaller, less lipid-rich taxa, with some signs of shifts to larger copepods and euphausiids. The continuous plankton recorder showed a fourth year of above average mesozooplankton abundance, but the first year since 2012 that the mean size of copepods was above average, indicating a shift in 2017 toward larger-sized species that are more lipid-rich. The biomass of copepods during May along the Seward line was above average for the third year, but euphausiid abundance remained low. The rapid zooplankton assessment during spring and summer in the western GOA noted some hot spots of large copepods during spring, but the numbers declined over the summer. Compared with historical estimates in Shelikof Straits, large copepod abundances were similar to the long-term mean and higher than they were in 2015, the year of the last survey. Small copepods were widespread in spring and increased in abundance in summer, with both values about equal to the long term mean. The smaller life-stages of euphausiids that are sampled in the rapid zooplankton assessment appeared to be more abundant compared to historical estimates and to the low estimates in 2015. This pattern was in contrast to the preliminary euphausiid abundance estimate from the acoustic survey, which samples larger juveniles and adults, and which found less euphausiid biomass in 2017 than in 2015. Zooplankton lipid content was below average for all taxa sampled in Icy Strait.

Gelatinous zooplankton were observed in high biomass on the eastern GOA shelf and oceanic waters. Oceanic waters contained a high biomass of tunicates (doliolids and salps), while the nearshore zooplankton biomasses consisted of a high number of small (<0.25 mm) juvenile shelled pteropods, *Limacina helicina*, at a single station. High densities of zooplankton (cnidarians and pterodpods) were observed near the freshwater plume emanating from Alsek River south of Yakutat. A mix of oceanic and shelf species assemblages on the shelf in 2017 indicated weak horizontal density gradients and confirmed the weak Alaska Coastal Current described by the PAPA Trajectory Index. For the third continuous warm year, the biomass of large-bodied jellyfish *Chrysaora melanaster* was down, and this species failed to dominant catches as they have in the past. Instead, jellyfish was dominated by *Ctenophora* and *Aequorea* in biomass and Ctenophores and Hydrozoans in terms of abundance. Shifts from large bodies to small bodied jellyfish may be due to shifts in water mass properties that shift distributions or a result of environmental forcing on growth and survival on the polyp stage on the benthos. The first record of pelagic tunicates *Pyrosoma atlanticum* in NOAA's acoustic, surface, and bottom trawl surveys conducted since 1982 as well as commercial fisheries were a unique tropical creature seen in the Gulf of Alaska.

Ichthyoplankton abundances for most species in the western GOA in 2017 returned to long-term averages with the notable exception of Pacific cod which remained below average. Larval arrowtooth flounder abundances were above average as was their energy density as measured in samples from the eastern GOA. Larval walleye pollock rough counts were above average and distributed widely with few zero catches. The distribution pattern contrasted notably from the extremely abundant larval pollock in 2013, which was more concentrated to the west of the Shumagin Islands and did not materialize into a large year-class. Late summer catches of pollock remained high—the second-highest in the record—and were concentrated through Shelikof Strait and east of Kodiak. Their distribution may have favored their survival over the summer as they were caught as age-1s in the winter Shelikof survey. Also, the energy density was above average for age-0 pollock in the eastern GOA in 2017, another favorable indicator for the 2017 pollock year class.

In general, forage fish abundances (age-0 pollock, age-0 Pacific cod, sablefish, juvenile salmon) and their energy density (with exception of age-0 pollock and arrowtooth) were low in surface trawl surveys of the inside waters and shelf waters of the eastern GOA during late summer. Surveys during late summer that targeted age-0 sablefish found few offshore in 2017, unlike the many found in 2016, but an exploratory extension of the survey found age-0 sablefish farther north near Kayak Island.

Overall, marine survival was low and body size was small for salmon in 2017, but there were mixed signals in terms of their energy density as juveniles. Marine survival was poor for coho salmon (piscivores) and average for pink salmon (planktivores) that left Auke Creek and entered saltwater in 2016 and returned as adults in 2017. Auke Creek weir operators recorded low numbers of pink and coho salmon smolt outmigrants in 2016. These migrating smolts experienced warm creek temperatures and low water depths due to a lack of snowfall and snowmelt. These 2016 coho salmon out migrants had the lowest marine survival and pink salmon average marine survival for the 1980–2017 time series. Conditions for smolt outmigration improved in 2017 with cooler freshwater temperature (2°C) and deeper creek depths. Juvenile salmon sampled in inside waters en route to the GOA had small average body size but high energy density in 2017. However, offshore juvenile pink and Chinook salmon had low energy density. Marine survival was low for 2017 and 2018 outmigrants from Auke Creek in northern southeast Alaska.

During the 2017 bottom trawl survey, all groundfish species but Pacific cod had below average body condition, suggesting that overall, the Pacific cod that survived the heatwave were able to forage sufficiently in 2017 to effectively improve their body condition. An analysis of their condition by size class that is in the 2018 Pacific cod assessment shows that the overall pattern of good body condition was seen in the larger cod, but that the smaller cod remained thin, further supporting the hypothesis that adult cod can quickly take advantage of improved foraging conditions as predicted by their short-lived/high growth potential life history strategy. Fish condition for arrowtooth flounder and northern rockfish were the lowest on record, indicating that foraging conditions for most species remained poor following the heatwave. Pacific cod diets, particularly in the larger sizes, contained large proportions of pollock and *C. bairdi* crab, which had been noticeably absent in 2015. The depth distribution of rockfish caught during the bottom trawl survey remained unchanged relative to previous years. Their mean distribution relative to temperature was lower, reflecting the temperature difference in the water column.

Seabirds and marine mammals continued to do poorly overall in 2017 with some exceptions. Several fish-eating seabirds had unusually low reproductive success in 2017. In general, murres appear to have been negatively affected during the heatwave of the past few years, with widespread reproductive failures, die-offs, and low attendance at breeding colonies. Other species did not show broad-scale failures during this period; planktivorous seabirds were generally successful, perhaps reflecting the abundant, although small, copepods. Despite overall low reproductive success of murres in 2017, some improvement in murre attendance and fledging success indicated some improvement in foraging conditions. In Glacier Bay, biologists only documented two mother-calf humpback whale pairs, which was the second year in a row of anomalously low birth rates. In addition, one of the whale mothers in 2017 appeared to be abnormally thin, and the other lost her calf by mid-July. Counts of humpback whales throughout northern southeast Alaska were low. Counts of steller sea lions indicated that there was a significant decline in pup counts in the eastern and central GOA relative to 2015 (Sweeny and Fritz pers. comm). These were the first region-wide declines in western Steller sea lion pup counts that the NOAA Marine Mammal Lab has observed east of Samalga Pass since the overall stock decline ceased in the early 2000s. Pup counts had consistently increased at all rookeries in these 2 regions through 2013, and through 2015 at 8 of the 10. Whatever caused the substantial drop in pup counts observed in 2017 appears to have had the greatest impact in the Prince William Sound area, where herring abundance has remained low for over 20 years, and less impact to the west and east.

Current Environmental State—Western Gulf of Alaska

The North Pacific atmosphere-ocean system in 2017–2018 was similar to that from the year before, as seen in the continuation of largely average conditions in the western Gulf of Alaska following the end of the 2014–2016 marine heatwave. The Pacific Decadal Oscillation index shifted to a neutral state, reflecting a broad scale pattern of warmer than average temperature across the North Pacific. Across the western GOA, sea surface temperatures were largely average with some warming during the spring. At a local scale, sea temperatures within the top 100m along the Seward Line showed average to slightly cooler than average temperatures during May. Surface currents during winter were not strongly directional, indicating weak flow into the Alaska current. Eddy kinetic energy continued to be low, indicating less cross-shelf exchange of nutrients. By late summer, temperatures crossed a threshold to be considered a heatwave. The intensity so far is not as great as that in 2014–2016 and the duration is unknown, yet sustained warm temperatures can be expected to be unfavorable for lower trophic organisms such as zooplankton and age-0 fish heading into winter. Climate models are forecasting a weak-moderate El Niño as well as anomalously warm sea surface temperatures throughout the winter in the GOA, which would mean a return to warm conditions for the GOA ecosystem.

The limited indicators of zooplankton abundance available for 2018 show mixed signals. The biomass of copepods and euphausiids during May along the Seward line was above average. This was the fourth year of abundant copepods, but the first for euphausiids since 2014, indicating an increase in higher quality zooplankton prey for predators. The only other indicator of zooplankton availability to predators in the western GOA in 2018 is reproductive success of planktivorous seabirds. Parakeet auklets had poor reproductive success in the Semidi Islands south of the Alaska Peninsula. This is notable because they maintained average-to-high reproductive success through the heatwave years and last had poor reproductive success in 2011. In the Barren Islands at the mouth of the Cook Inlet, fork-tailed storm petrels had average reproductive success, suggesting zooplankton availability was moderate in that region.

In contrast, piscivorous seabirds had above average reproductive success at the Semidi Islands, indicating that there were sufficient forage fish prey (including possibly age-0 gadids) to raise chicks. Kittiwakes and rhinoceros auklet chick diets at Middleton Island showed notable increases in sand lance, an important forage fish, but few capelin, which disappeared from chick diets during the heatwave. However, based on reproductive success, prey appeared to be limiting for the surface-foraging kittiwakes but sufficient for average production for diving rhinoceros auklets. Kittiwakes also had below average reproductive success at the Barren Islands. Taken together, these observations suggest that forage fish were abundant and available around the Semidi Islands, but less so, at least to surface foragers, to the northeast.

Indications of groundfish biomass trends in 2018, an "off-year" for the GOA-wide bottom trawl surveys, are based on ADF&G surveys off Kodiak Island over Barnabus Gully and in two inshore bays. Catch rates were below the long-term mean for arrowtooth flounder, Pacific halibut, Pacific cod, skates, and flathead sole. Catch rates were above the long-term mean for pollock offshore, but below at the inshore bays. While there has been a generally decreasing trend in total catch rates for 10–15 years, there was a slight increase in 2018. In this offshore region, the increase from the previous year was primarily due to increases in the pollock and arrowtooth catch relative to last year.

Upper trophic marine birds and mammals appear to continue to show signs of negative impacts from the marine heatwave. Numbers of murres showing up to breed in the Semedis were low—although those that were there did well reproductively—possibly reflecting a population impact of the immense die-off seen during the heatwave. Similarly, encounter rates of humpback whales in PWS fall surveys were very low in 2018, similar to what was observed in 2017. The highest encounter rates were noted just before and at the beginning of the heatwave. The murre die-off (2015–2016), large whale Unusual Mortality Event (2015–2016), and decline in sea lion counts during and immediately after the heatwave signaled the extreme impact of the heatwave and lagged responses to adverse conditions that would be expected in long-lived, k-selected species such as these.

Current Environmental State—Eastern Gulf of Alaska

The eastern Gulf of Alaska atmosphere and ocean temperatures in coastal regions continued to return to average conditions in 2018 following the marine heatwave of 2014–2016. Winter and spring sea temperatures were normal followed by slightly above average temperatures during summer in the eastern GOA. Satellite derived monthly temperatures on the eastern Gulf of Alaska shelf indicate a cooling off in southeast Alaska waters during the winter (Dec–April) and summer (March–Sept) of 2018. During May within the archipelago of northern southeast Alaska, the top 10-m integrated temperatures were average for the 22-year time series. However, freshwater temperatures during the summer were warmest on record in Auke Creek since 1980. In general, the return to normal temperatures throughout the summer was followed by a reappearance of warm waters in the eastern Gulf of Alaska during fall of 2018. Predictions for 2019 indicate a return of warm waters in the eastern Gulf of Alaska.

Zooplankton sampled in archipelago waters of northern southeast Alaska showed an increase in total densities consisting primarily of small copepods and a higher lipid content of most zooplankton taxa. Although zooplankton densities were above average in Icy Strait, the community consisted primarily of small calanoid copepods. Densities of larger zooplankton, which are prey items for small fish, were below average for large calanoid copepods, euphausiids, hyperiid amphipods, and gastropods. The lipid contents increased to above average in 2018 for small calanoid copepods, *Calanus marshallae* and *Pseudocalanus* spp., young euphausiids (furcillia and juveniles), *Limacina helicina* (gastropod), and *Themisto pacifica* (hyperiid amphipod), but decreased for the large calanoid copepods.

Humpback whale presence in southeast Alaska waters continued to remain low. In Glacier Bay, the number of calves and juvenile return rates of humpback whales have declined substantially starting in 2015. In Glacier Bay, crude birth rates, number of calves per adult whale sighted, remained anomalously low from 2016–2018. During the SPLISH surveys of northern southeast Alaska, crude birth rates of humpback whales continue to drop. Only two calves were seen in southeast Alaska waters during the summer of 2018, one of these is believed to have died, and no calves were seen during the SPLISH survey window (June–August). Some whales have poor body condition but to a lesser extent than was observed in 2016 and 2017. These changes in calving and juvenile return rates may be related to recent changes in whale prey availability and/or quality, which may in turn be negatively affecting maternal body condition and therefore reproductive success and/or overall juvenile survival.

Salmon captured during the summer surface trawl surveys in Icy Strait were in low numbers and had small body sizes, with the exception of an increase in juvenile Chinook salmon (2^{nd} highest) and sockeye salmon abundance (but still low) since 1997 for the 22-year time series. Juvenile salmon lengths and weights were below average in 2018 indicating poor feeding conditions or a delayed migration.

Salmon monitoring at Auke Creek weir in northern southeast Alaska since 1980 showed low adult returns and poor freshwater and marine survival of salmon. Age-0 coho salmon that outmigrated as smolts in 2018 had record low marine survival when they returned later in 2018. Age-1 coho salmon that migrated from freshwater to saltwater in 2017 and returned as adult in 2018 to Auke Creek had the second lowest marine survival for the weir since 1980. The 2018 outmigrating smolts experienced warm creek temperatures and low water depths. Lack of snowfall and snowmelt contributed to warmer creek temperatures in 2017 and 2018. Pink salmon had low marine survival and a record low numbers of adult pink salmon returns in 2018 since 1980. These trends indicate poor conditions for salmon survival in the Gulf of Alaska during 2017 and 2018.

Executive Summary of Recent Trends in the Gulf of Alaska

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

Physical and Environmental Trends

North Pacific

- The North Pacific atmospheric-ocean climate system during fall 2017 to summer 2018 was similar to that during 2016–2017 (p. 41).
- The prominent sea surface temperature anomalies during 2017–18 tended to be positive, with persistent warmth in the subtropical eastern North Pacific Ocean (p. 41).
- A weak La Niña developed during winter 2017–2018 along with a weaker than normal Aleutian Low, similar to the previous year (p. 46).
- The Pacific Decadal Oscillation (PDO) was slightly positive during the past year, with a decline to near zero in the summer of 2018 reflecting the wide-scale warm pattern across the North Pacific Ocean (p. 46).
- The North Pacific Index (NPI) was strongly positive from fall 2017 into 2018 due to the relatively high sea level pressure in the region of the Aleutian Low, which was displaced to the northwest, over Siberia, and causing persistent warm winds from the southwest over the Bering Sea last winter (p. 42).
- The North Pacific Gyre Oscillation (NPGO) declined from a small to a large negative value from 2017 to early 2018, implying that flows in the Alaska portion of the Subarctic Gyre weakened and low nitrate levels along Line P extending from Vancouver Island to Station PAPA (p. 46).
- The climate models used for seasonal weather predictions are forecasting about a 70% chance of a weak-moderate El Niño for the winter of 2018–2019, and warmer than normal SSTs in both the western and eastern mid-latitude North Pacific in early 2019 (p. 46).

Gulf of Alaska

- The weather of the coastal GOA was generally normal during the past year (p. 41).
- Near-real-time data suggest that eddy activity was low in the central and western Gulf of Alaska along the shelf break during spring/summer 2018 indicating less cross-shelf exchange (p. 50).

- The PAPA trajectory Index for 2017/18 was close to zero, indicating average surface current inflow to the Gulf of Alaska during last winter (p. 52).
- A new satellite-derived SST indicator presents seasonal anomalies over time in the western and eastern Gulf of Alaska. The overall pattern of summer anomalies demonstrated a brief warm stanza during the summers of 2004 and 2005, with a broader cold stanza from 2006–2012. In 2013, waters began warming and 2014–2016 were notably warmer than the previous stanza. By summer 2017, the intensity of warming had returned to near average (p. 54).
- Early May sea temperature to 100m depths in the northern Gulf of Alaska across the shelf along the Seward Line returned to the long-term 22 year mean during 2017 and 2018 (p. 55)
- Near surface (2m) temperatures in central Prince William Sound returned to near the long term average in 2018 relative to 1974–2017 (p. 57)
- Nearshore sea temperature in Icy Strait in 2018 was near the long-term average, increasing by approximately 0.4°C from the anomalously cool temperatures in 2017 (p. 71).
- Freshwater temperatures in Auke Creek in southeast Alaska were above average during summer 2018, and had been below average during 2017 (p. 58).

Ecosystem Trends

- In the Alaskan Shelf region sampled by the continuous plankton recorder, diatom abundance anomalies were very high in 2017 relative to those in the previous 6 years (p. 65).
- Copepod community size anomalies were larger for the Alaskan Shelf and oceanic habitats in 2017, after a period of smaller size copepods during the marine heat wave (2013–2016), and mesozooplankton biomass anomalies were positive for the 4th consecutive year (p. 65).
- In 2018, mean biomass (mg/m^3) of calanoids and euphausiids along the Seward Line during May were higher than the long-term mean (1998–2017) This was the 4th consecutive year for above average calanoid biomass (p. 66).
- In 2017, lower than average abundances of zooplankton were observed in Prince William Sound, while more warm water copepods were seen earlier in the year followed by a mixture of warm and cold water species (p. 67).
- Zooplankton density in Icy Strait in 2018 was above average and the 5th highest density observed over the 22-year time series. Zooplankton density was below average from 2013–2016 (p. 71).
- In 2018, the density of small calanoids was above average, the 5th highest density in the 22-year time series. All other taxa were at (gastropods) or below (large calanoid copepods, euphausiids, and hyperiid amphipods) average (p. 71).
- The lipid content of all zooplankton taxa examined increased from 2017 to 2018, indicating an increase in the nutritional quality of the prey field utilized by larval and juvenile fish in Icy Strait, northern southeast Alaska (p. 74).
- Nearshore intertidal ecosystem components of the western Gulf of Alaska in 2017 had reductions in fucus algae (habitat for mussels), mussel density (prey of sea stars), and sea star abundance (predators) from western Prince William Sound to the Alaska Peninsula, except for a large increase in mussels in Kenai Fjords (p. 61).
- In 2017, abundances for most larval fish surveyed in the western Gulf of Alaska returned towards average levels following the 2014–2016 marine heatwave, but remained low for the ronquils, Pacific cod, starry founder, and northern lampfish (p. 76).

- Herring, sand lance, and sablefish were prevalent in black-legged kittiwake diets in 2018 at Middleton Island. Sand lance constituted about 50% of the forage fish fed to auklet chicks, continuing an increasing trend in proportion of diets since 2013 (p. 77).
- A new indicator presents a 6-year time-series of energy density of 5 pelagic life stages of salmon and groundfish species. In 2017, energy density was below average for young-of-year sablefish, juvenile Chinook salmon, and juvenile pink salmon, and above average for young-of-year pollock and arrowtooth flounder in the eastern Gulf of Alaska (p. 81)
- Herring biomass in Prince William Sound remains low after the steep decline in the early 1990s. In 2018, the observed mile-days of milt from spawning herring declined to the lowest level over the 1974–2018 period (p. 84).
- Although the two largest and most consistent herring stocks in southeast Alaska—Sitka Sound and Craig—have declined substantially from their peaks of 2009 and 2011, respectively, they continue to be at levels well above the thresholds necessary to allow commercial fisheries (p. 85).
- In nearshore waters of Icy Strait in northern southeast Alaska during 2018, juvenile and adult salmon catch rates were among the lowest since the survey began in 1997 (p. 89).
- In the same Icy Strait survey, juvenile salmon length and weight were below average in 2018 relative to the 21-year time series. Energy density values declined in 2017 relative to 2016, but have been at or above the long-term mean since 2014 90).
- Low marine survival and a record low number of adult pink salmon returns to Auke Creek weir in 2018 indicate poor conditions for survival in the Gulf of Alaska during the summer and winter of 2017 (p. 92).
- The second lowest and lowest marine survival rates since 1980 were recorded for age-1 ocean and age-0 ocean coho salmon, respectively, returning to the Auke Creek weir in 2018. These indicate poor conditions for survival in the Gulf of Alaska from the summer of 2017 through the summer of 2018 (p. 95).
- Arrowtooth flounder, flathead sole, and other flatfish continue to dominate the catches in the ADF&G trawl survey off Kodiak, but not to the same degree as seen in previous surveys. A sharp decrease in overall biomass is apparent from 2007 to 2017 from the years of record high catches occurring from 2002 to 2005. There was a slight increase in total biomass in 2018 (p. 97).
- In 2018, survey catch rates for arrowtooth flounder, flathead sole, Pacific cod, Pacific halibut, and skates were below average. Above average anomaly values for Tanner crab in 2018 were due to a large increase in numbers of juvenile crab captured in both inshore and offshore areas that have not been observed for several years (p. 97).
- Fish-eating seabirds in the Gulf of Alaska had generally normal reproductive success at monitored colonies in 2018. Murres had better colony attendance and fledging rates that during 2015–2016, but the overall numbers of breeding birds was still low. Timing of breeding was normal for most species at Chowiet (Semidi Islands), late for murres at East Amatuli (Barren Islands), and late for murres and gulls at St. Lazaria (Southeast Alaska)(p. 102).
- Humpback whale calving and juvenile return rates in Glacier Bay and Icy Strait declined substantially beginning in 2015. Crude birth rates remained anomalously low from 2016–2018. These changes in calving and juvenile return rates may be related to recent changes in whale prey availability and/or quality, which may in turn be negatively affecting maternal body condition and therefore reproductive success and/or overall juvenile survival (p. 105).
- The 8th fall survey of whales in Prince William Sound found the second lowest number of humpback whales (n=17), lack of whale/herring hotspots, low acoustic signals for pollock and krill, and low numbers of humpback whales, marine birds, herring, and forage fish relative to earlier surveys (p. 107).

- Stellar sea lion pup counts declined in the eastern and central Gulf of Alaska population from 2015-2017. Non-pup counts remained stable in the western population but declined in southeast Alaska (p. 108).
- A new indicator demonstrates that the stability (inverse biomass coefficient of variation) of groundfish biomass has been relatively constant from 2007–2017. Stability decreased slightly in the Western and remained relatively constant in the Eastern Gulf of Alaska from 2015 to 2017 (p. 111 and 115).
- A new indicator tracks fluctuations in the size of groundfish sampled over time by the Gulf of Alaska bottom trawl survey. The mean length of the groundfish community in the Western and Eastern Gulf of Alaska has generally been stable over the years 1984–2017. Fluctuations are largely the result of variation in the biomass indices of forage species, such as herring, that are not well sampled by the bottom-trawl (p. 112 and 116).
- A new indicator tracks the mean life span of the groundfish sampled by the Gulf of Alaska bottom trawl survey over time. This indicator serves as a proxy for the mean turnover rate of species and communities" and is intended to reflect ecosystem stability and resistance to perturbations. The metric has been largely stable over the time period with some interannual variation due to high biomass estimates of short-lived species such as herring (p. 113 and 117).
- The prevalence of *Ichthyophonus* infections in sport-caught Pacific halibut landed at Homer increased from 19–59% from 2011–2017. Despite the high infection prevalence, there was no indication that the parasite caused serious damage to the host; thus it appears that *Ichthyophonus* can occur at high infection prevalence with concomitant low infection intensities in Pacific halibut (p. 119).

Fishing and Human Dimensions Trends

- Since 1993 discard rates of groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in both pollock and non-pollock trawl fisheries in the Gulf of Alaska. Rates in the fixed gear (hook-and-line and pot) sector have varied over time. Due to a significant reduction in the 2018 GOA Pacific cod TAC, total discard biomass in the fixed gear sector declined (p. 121).
- In 2017, non-target catch of scyphozoan jellyfish, structural epifauna, and assorted invertebrates declined from those in 2015–2016 in trawl fisheries in the Gulf of Alaska (p. 124).
- Stock composition of Chinook salmon bycatch in Gulf of Alaska trawl fisheries was relatively stable from 2010–2016, with British Columbia stocks dominating the bycatch, and West Coast U.S. stocks either similar to British Columbia stocks, or less, in most years (p. 125).
- The numbers of seabirds estimated to be caught incidentally in Gulf of Alaska fisheries in 2017 increased from that in 2016 by 138%, and was 41% above the 2007–2016 average of 1,066 birds, primarily due to increases in black-footed albatross, northern fulmar, and gulls (p. 128).
- With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling (p. 132).
- The percent of area disturbed due to commercial fishing interactions (pelagic and non-pelagic trawl, longline, and pot) has decreased slightly or remained steady in the Gulf of Alaska (p. 134).
- No Gulf of Alaska groundfish stock or stock complex were subjected to overfishing, known to be overfished, or known to be approaching an overfished condition (p. 138)
- Annual surplus production for groundfish has been variable over time, with peak associated with large recruitment events. When computed without pollock included, annual surplus production shows a significant, long-term decline with the lowest (negative) value in 2017 (p. 143).
- Total exploitation rates for the groundfish complex have ranged from 2.5–7.2% over the past few decades. Peak rates occurred during 1984–1985 and 2015–2017 (p. 143).

- Landings (pounds) are used to characterize commercial seafood production. Landings decreased from 2016 to 2017 primarily due to a reduction in salmonid landings, then apex predators, and motile epifauna. Increases in landing occurred in pelagic and benthic foragers (p. 146).
- The Western GOA represented 47% of the total subsistence salmon harvest statewide in 2016, including Anchorage; whereas the Eastern GOA represented 5%. Western GOA subsistence use decreased slightly for halibut, and 30% for salmon with decreased in pink salmon, coho salmon, chum salmon, and sockeye salmon, and increased slightly for Chinook salmon in 2016 relative to 2015 (p. 147).
- There has been a statewide decline in halibut subsistence harvest through 2016, but this trend may be due to subsistence survey methodology (p. 147).
- Economic values of 5 functional groups (apex predators, benthic foragers, motile epifauna, pelagic foragers, and salmonids) show an increase in real ex-vessel value, primarily due to salmon and pelagic foragers ; an increase in real first-wholesale value in all groups except benthic foragers and motile epifauna; and an increase for the second year in a row in ratio of first-wholesale to total catch unit value for groups combined from 2016 to 2017 (p. 152).
- Saltwater recreational fishing participation included approximately 850,000 million days fished and 370,000 saltwater anglers in 2016, representing a decrease from 2015 that was possibly due to economics, fish levels, and harvest allocations (p. 156).
- A new indicator tracks recreational saltwater fishing harvest in Gulf of Alaska by ecological functional group. Pacific halibut (apex predator) and salmonids are the most common targets. Sport harvest decreased for salmon and apex predators (mostly halibut) and increased for pelagic fish (rockfish and smelt) from 2015 to 2016 (p. 158).
- Unemployment rates in fishing communities were lower than statewide and national rates in the eastern GOA but increased over 50% from 1990 to 2017, while rates were higher than statewide and national rates in the western GOA but decreased 13% from 1990 to 2017 (p. 162).
- Since the 1990s, human populations in Gulf of Alaska fishing communities have increased in both small and large communities in the western GOA and large communities in the eastern GOA, but decreased in small eastern GOA between 1990 and 2017. The majority of population increases occurred in urban areas and were due to migration (p. 166).
- Western GOA school enrollment decreased in 1 (Homer) of 8 schools with enrollment over 500 and in 5of 7 schools in the Kodiak Island Borough. School enrollment has remained fairly stable recently, showing a slight decrease for larger schools with 500–4,500 students. Smaller schools have had more variable enrollment year-to-year and an overall downward trend. As of 2017, 27 schools have enrollment under 30 students, and 12 schools have enrollments under 15 students, and 7 schools were closed. Dropout rates vary but typically stay below 6% (p. 170).
- Eastern GOA school enrollment decreased in 1 (Juneau) of 8 schools with enrollment over 500 and in 3 of 11 schools in smaller schools (100-500 enrolled). As of 2017, there have been 9 school closures, 3 of which were consolidations of Junior/Senior High schools into one K–12 school. Dropout rates typically stay below 10% (p. 170).

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General Introduction and Background

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

- Report Card(s)
- Ecosystem Assessment
- Executive Summary
- Ecosystem Indicators

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

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

The purpose of the third section, the Executive Summary, is to provide a concise summary of new or updated information contained in each report. Page links to sections with more detail are provided.

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

[1]The Arctic report is under development

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

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

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

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

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

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

We initiated a regional approach to the ESR in 2010 and presented a new ecosystem assessment for the eastern Bering Sea. In 2011, we followed the same approach and presented a new assessment for the Aleutian Islands based on a similar format to that of the eastern Bering Sea. In 2012, we provided a preliminary ecosystem assessment on the Arctic. Our intent was to provide an overview of general Arctic ecosystem information that may form the basis for more comprehensive future Arctic ecosystem assessments. In 2015, we presented a new Gulf of Alaska report card and assessment, which was further divided into Western and Eastern Gulf of Alaska report cards beginning in 2016. This was also the year that the previous Alaska-wide ESR was split into four separate report, one for the Gulf of Alaska, Aleutian Islands, eastern Bering Sea, and the Arctic[2].

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

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

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

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

[2]The Arctic report is under development

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

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

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

Ecosystem Indicators

Report Card Indicator Descriptions

We present separate Western and Eastern Gulf of Alaska Report Cards to highlight inherent differences in ecosystem structure and function between the eastern and western ecoregions. Top-ranked indicators were selected for each category: physical, plankton, benthic, forage fish, non-forage fish, seabirds, marine mammals, and humans. We include two physical and plankton indicators and one from each of the other categories where available. The indicators are defined below.

Western Gulf of Alaska

Winter Pacific Decadal Oscillation The leading mode of monthly sea surface temperature anomalies in the North Pacific Ocean, poleward of 20°N. The monthly mean global average SST anomalies are removed to separate this pattern of variability from any "global warming" signal that may be present in the data. The winter index is the average monthly values from December–February. Data from `http://research.jisao.washington.edu/pdo/PDO.latest`.

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Fresh water input The GAK 1 oceanographic station is located at the mouth of Resurrection Bay near Seward. Temperature and salinity versus depth profiles have been taken at this station since December, 1970. The GAK 1 discharge time series is a low-resolution "model" (estimate) of discharge that accounts for little more than monthly mean air temperatures over the GOA drainage basin, estimated precipitation, and some seasonal lags. The data are the annually-averaged monthly discharge value for each calendar year.

Although the GAK 1 time series has been used as a measure of freshwater discharge in the past, salinity is affected by a number of factors, including wind mixing, evolution of stratification, and shelf advection. Thus, there is need for a better indicator, which may become available from outputs of a new, high resolution discharge hindcast model by David Hill at Oregon State University. This improved discharge model uses a snowpack model, elevations, reanalysis precipitation, and streamflow routing to estimate freshwater discharge and is tuned against USGS discharge measurements. The model is at about 1 km resolution and provides hourly estimates all along the GOA coast. We hope to use this model to improve this indicator in future editions of this report (Seth Danielson, pers. comm.).

Mesozooplankton biomass Mesozooplankton biomass is estimated from taxon-specific abundance data collect from Continuous Plankton Recorders (CPRs). These have been deployed in the North Pacific routinely since 2000. The transect for the region known as the Alaska Shelf is sampled monthly (∼Apr-Sept) and presented here. Anomaly time series of each index are calculated as follows: a monthly mean value (geometric mean) was first calculated. Each sampled month was then compared to the mean of that month and an anomaly calculated (Log_{10}). The mean anomaly of all sampled months in each year was calculated to give an annual anomaly.

Contact: Sonia.Batten@mba.ac.uk

Copepod community size Mean copepod community size (Richardson et al., 2006) as sampled by Continuous Plankton Recorders is presented as an indicator of community composition. The methods used to calculate this indicator is listed above for mesozooplankton biomass.

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Motile epifauna biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The next survey will be in 2019. The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community of the western GOA. In the 2016 report, this indicator included the entire survey area.

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Capelin Previously we used the common trend identified by Dynamic Factor Analysis of capelin in prey composition time series from various piscivorous seabird and groundfish species, considered to be "samplers" of the forage fish community. Data were not available in time for this indicator to be updated this year. Instead, for this year, we use the time series that loaded most strongly on the DFA trend: the percent biomass of capelin from rhinocerous auklets (*Cerorhinca monocerata*) chick diets at Middleton Island (ISRC).

Contact: stephani.zador@noaa.gov; shatch.isrc@gmail.com

Apex predator biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The next survey will be in 2019. The apex predator foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. Fish in this guild include: Pacific cod, arrowtooth flounder, halibut, sablefish, large sculpins, and skates. Marine mammals, seabirds, and some other fishes such as sharks are included as constant ecopath-estimated biomasses. .

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Black-legged kittiwake reproductive success Black-legged kittiwakes are common surface-foraging, piscivorous seabirds that nest in the GOA. Reproductive success is defined as the proportion of nest sites with fledged chicks from the total nest sites that had eggs laid. Reproductive success of this species is considered to be more sensitive to foraging conditions than that of common murres, another common seabird that has less variable reproductive success due to behaviors that can buffer the effects of poor food supply. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service.

Contact: heather_renner@fws.gov

Steller sea lion non-pup estimates The R package agTrend model was used to produce abundance estimates of Steller sea lions within the bounds of the GOA. This region includes the GOA portion of the western Distinct Population Segment (known as the west, central and east GOA).

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Human population This indicator summarizes trends in human population over time in 86 fishing communities in the western GOA, excluding Anchorage. Communities were included if: 1) they were within 50 miles of the coast, 2) they exhibited historical involvement in Gulf of Alaska fisheries, and 3) they were included in one of the North Pacific Fishery Management Councils GOA fishery programs, such as the Community Quota Entity program.

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Eastern Gulf of Alaska

Multivariate ENSO Index (MEI) The MEI represents trends in the El Niño/La Niña Southern Oscillation. It is calculated from the first principal component of six variables observed over the tropical Pacific. These are: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. Data are from `http://www.esrl.noaa.gov/psd/enso/mei/table.html`.

Oceanographic index to be determined A suitable oceanographic index has yet to be selected. We hope to present one next year.

Mesozooplankton biomass Zooplankton biomass is represented by zooplankton density (number per m^3) as captured by 333-μm bongo net samples during summer months in Icy Strait.

Copepod Community size The ratio of large calanoid copepods to total large and small calanoid copepods as sampled in Icy Strait is used to represent copepod community size.

Motile epifauna biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The next survey will be in 2019. The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community of the GOA. These values are summarized for the eastern region, where survey efforts vary among years.

Sitka mature herring biomass The stock assessment estimates of the Sitka herring stock is used to represent forage fish trends in the eastern GOA region. Previously, total mature herring biomass was estimated from nine primary sites for which regular assessments are conducted and probably account for the majority of the spawning biomass in southeastern Alaska in any given year. The Sitka stock has the longest time series of assessed biomass.

Apex predator biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The next survey will be in 2019. The apex predator foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. Fish in this guild include: Pacific cod, arrowtooth flounder, halibut, sablefish, large sculpins, and skates. Marine mammals, seabirds, and some other fishes such as sharks are included as constant ecopath-estimated biomasses. These values are summarized for the eastern region, where survey efforts vary among years.

Rhinoceros auklet chick growth rate Mean growth rates of rhinoceros auklet chicks at St. Lazaria Island. Reproductive success is difficult to determine for these burrow-nesting seabirds because they are sensitive to disturbance. Data are only included for chicks that were measured at least three times during the linear phase of growth; chicks that did not exhibit linear growth were excluded. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service. The colony was not monitored in 2017.

Steller sea lion non-pup estimates The R package agTrend model was used to produce abundance estimates of Steller sea lions within the bounds of the GOA. This region includes the eastern Distinct Population Segment known as southeast Alaska.

Human population This indicator summarizes trends in human population over time in 45 fishing communities in the eastern GOA. Communities were included: if they were within 50 miles of the coast, based on their historical involvement in Gulf of Alaska fisheries, and if they were included in one of the North Pacific Fishery Management Councils GOA fishery programs, such as the Community Quota Entity program.

Noteworthy (formerly Hot Topics)

This section replaces the previously-named Hot Topics. We include information here that is deemed of relevance to ecosystem considerations of fisheries managers, but does not fit our typical indicator format. Information included here is often new, a one-time event, qualitative, or some other type of non-standard ecosystem indicator.

Fall 2018 marine heatwave

The Gulf of Alaska is currently (as of 21 October 2018) experiencing a marine heatwave. Impacts of this heatwave to the ecosystem are currently unknown, but will likely depend on its extent and duration.

Methods The daily sea surface temperatures for 1981 through October 2018 were retrieved from the NOAA High-resolution Blended Analysis Data database (NOAA 2017) and filtered to only include data from the central Gulf of Alaska between 145°W and 160°W longitude for waters less than 300m in depth. The overall daily mean sea surface temperature was then calculated for the entire region. These daily mean sea surface temperatures data were processed through the R package heatwaveR (Schlegel and Smit 2018) to obtain the marine heatwave cumulative intensity (MHWCI)(Hobday et al., 2016) value where we defined a heat wave as 5 days or more with daily mean sea surface temperatures greater than the 90th percentile of the 1 January 1983 through 31 December 2012 time series. The MHWCI were then summed for each year to create an annual index of MHWCI and summed for each year for the months of January through March, November, and December to create an annual winter index of MHWCI.

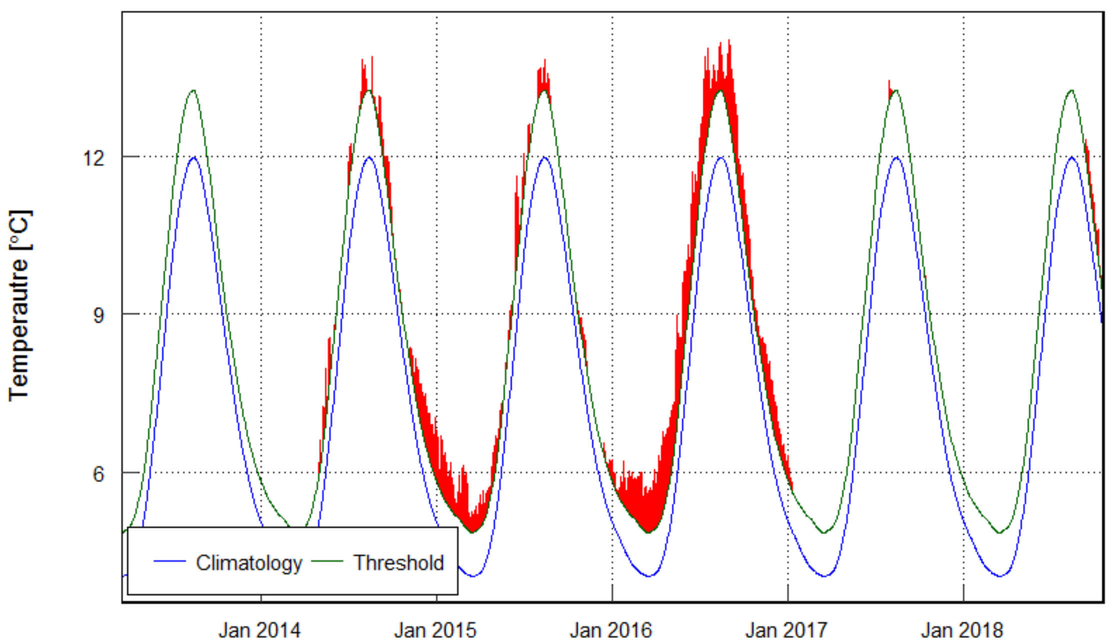

Figure 4: Index of the sum of the annual marine heatwave cumulative intensity (°C days) for 1981–2018 (larger red points) and index of the sum of the annual winter marine heatwave cumulative intensity for 1981–2018 (smaller blue points) from the daily mean sea surface temperatures NOAA high resolution blended analysis data for the Central Gulf of Alaska. The 2018 index value is the sum through 21 October 2018.

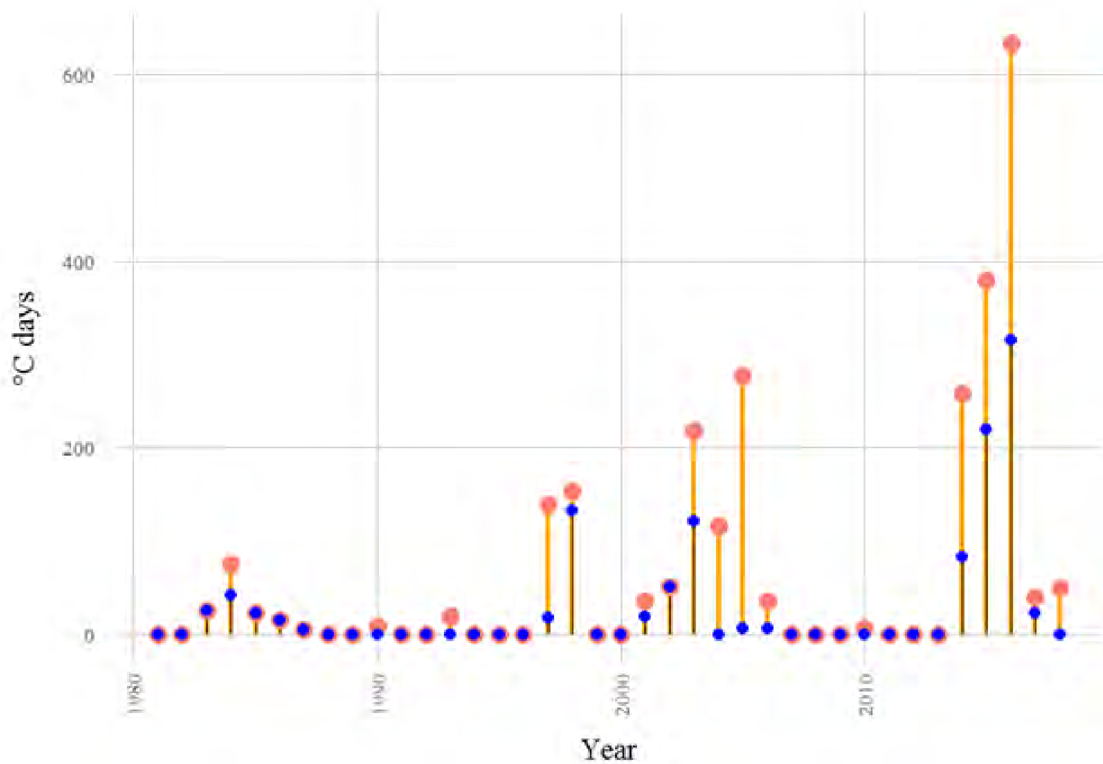

Figure 5: Gulf of Alaska temperatures with heatwaves noted as defined by Hobday et al. (2016).

Contributed by Steve Barbeaux

Local Environmental (LEO) Network

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

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

Figure 6 shows LEO Network observations from January 1, 2017 to August 1, 2018 in Gulf of Alaska (GOA) LME with the frequency by category. These categories are based on analysis of the 44 total observations in 2017 and 2018 (through August 1st) in the GOA and are not limited to the marine environment (Figure 7). The categories are also based on observations for the Eastern Bering Sea ecosystem, which are described in that ESR; therefore, not all categories have observations in the GOA. The observations in Figure 7 were made in 19 total communities.

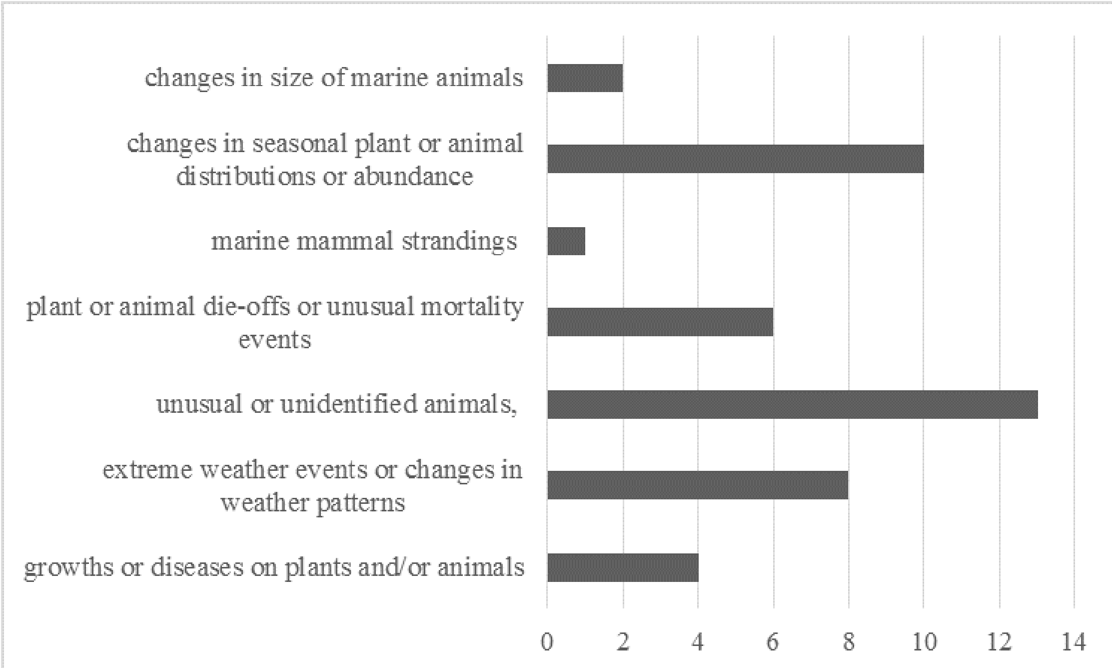

Figure 6: Distribution of 2017 and 2018 (through August 1st) LEO Network Observations in GOA communities

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

Contributed by Marysia Szymkowiak

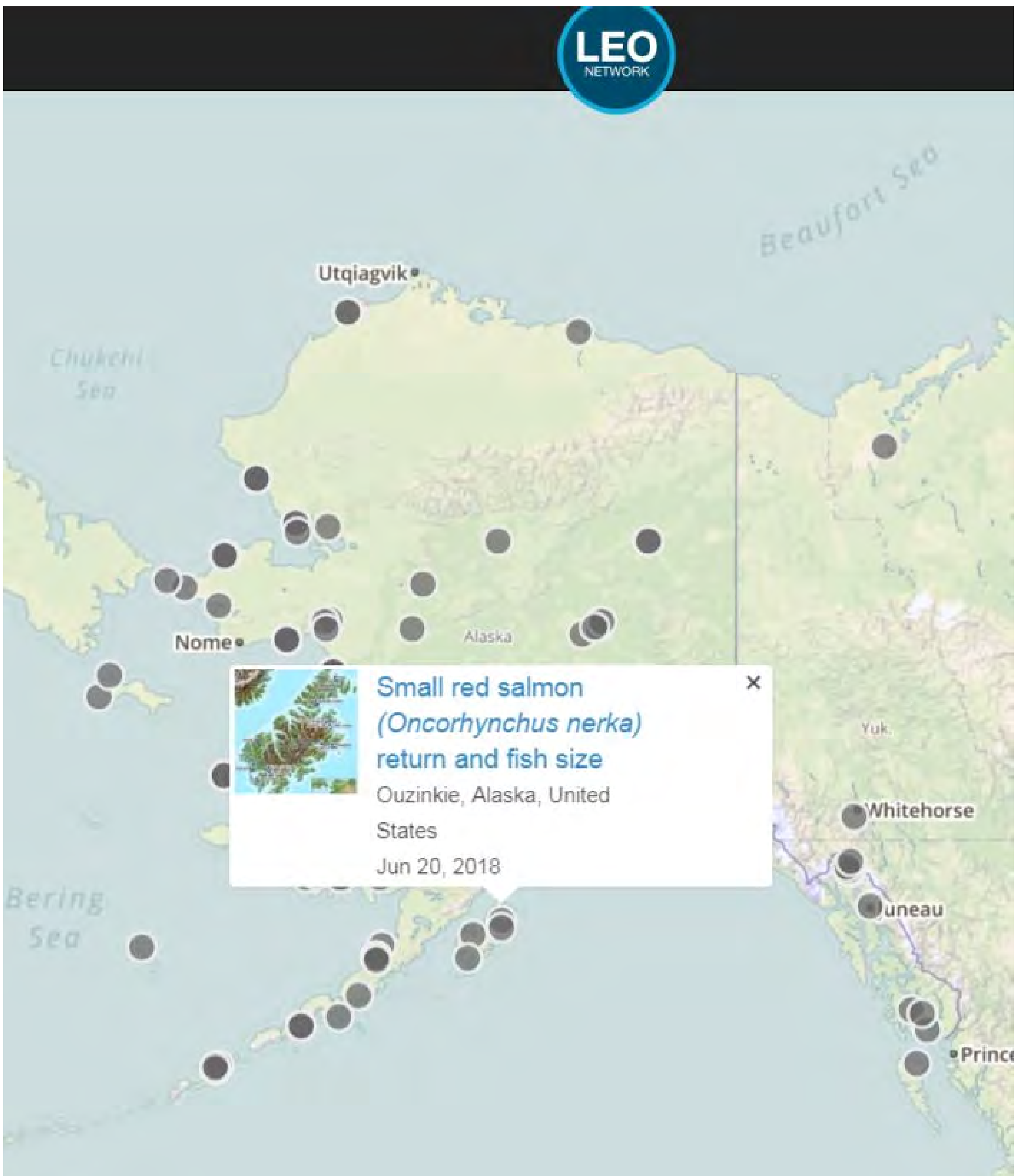

Figure 7: LEO Network Observations in Alaska for 2017 and 2018 (through August 1st) with example of observation description, source: `https://www.leonetwork.org`

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 2018

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

Regional Highlights:

Arctic. The winter of 2017/18 was relatively warm in the Arctic, and included an extreme heatwave (for the season) in the central Arctic during February. The Arctic's maximum ice extent in mid-March 2018 was the 2^{nd} lowest on record. On the other hand, the decline in sea ice coverage during the late spring and early summer of 2018 was on the slow side, primarily in association with relatively low SLP in the central Arctic and cool and cloudy weather. The west winds accompanying this circulation pattern helped maintain a wide band of ice near the coast east of Pt. Barrow. Relatively rapid losses in sea ice concentrations and coverage occurred here in late July 2018. The edge of the pack ice in the Chukchi Sea was well north of its usual position during the summer of 2018. At the time of this writing, it appears that the minimum ice extent for the Arctic as a whole will be well below of climatological norms, but more akin to the years of 2013 and 2014 rather than the extreme minimum ice cover year of 2012.

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

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

Gulf of Alaska. The weather of the coastal GOA featured warmer than normal air temperatures from late fall 2017 into winter and then again in the following summer of 2018. There was generally less precipitation than usual in the coastal watersheds of the eastern GOA from winter into summer 2018. The freshwater runoff in this region appears to have been enhanced during the winter of 2017/18 and suppressed during the spring of 2018. The GOA coastal winds anomalies were in a clockwise sense during the winter of 2017/18; they were still in the downwelling-favorable sense, but to a lesser extent than normal. These winds were reflected in the surface currents estimated with NOAA's Ocean Surface Current Simulator (OSCURS), which tended to indicate relatively weak south to north flow in the eastern GOA. More on this subject is provided in the Ocean Surface Currents PAPA Trajectory Index (p. 52).

West Coast of Lower 48. This region experienced generally warmer than normal ocean temperatures from late 2017 into 2018 followed by cooling in the north relative to seasonal norms, and continued warmth south of Pt. Conception. The winter of 2017/18 was wetter and slightly cooler than normal in the Pacific Northwest, and relatively warm and dry in California. The abundant snowpack in the Pacific Northwest melted rapidly in May in association with unusually warm weather. The coastal wind anomalies were upwelling-favorable for the states of Oregon and Washington during the late spring and early summer raising concerns about hypoxia developing to a greater extent than usual. Many streams in the Pacific Northwest had above normal temperatures due to the combination of low flows and hot air temperatures. Mostly upwelling-favorable wind anomalies occurred along the northern and central portions of California. Strong downwelling-favorable winds developed in early summer in the Southern California Bight, resulting in a thin layer of very warm water in the immediate vicinity of the coast. The SST at the Scripps Pier in La Jolla, CA observed the warmest SST (25.9°C) in its entire historical record extending back to 1916. There were sightings of large assemblages of pyrosomes in the coastal waters of the Pacific Northwest for the second year in a row.

Sea Surface Temperature and Sea Level Pressure Anomalies

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Last updated: September 2018

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

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

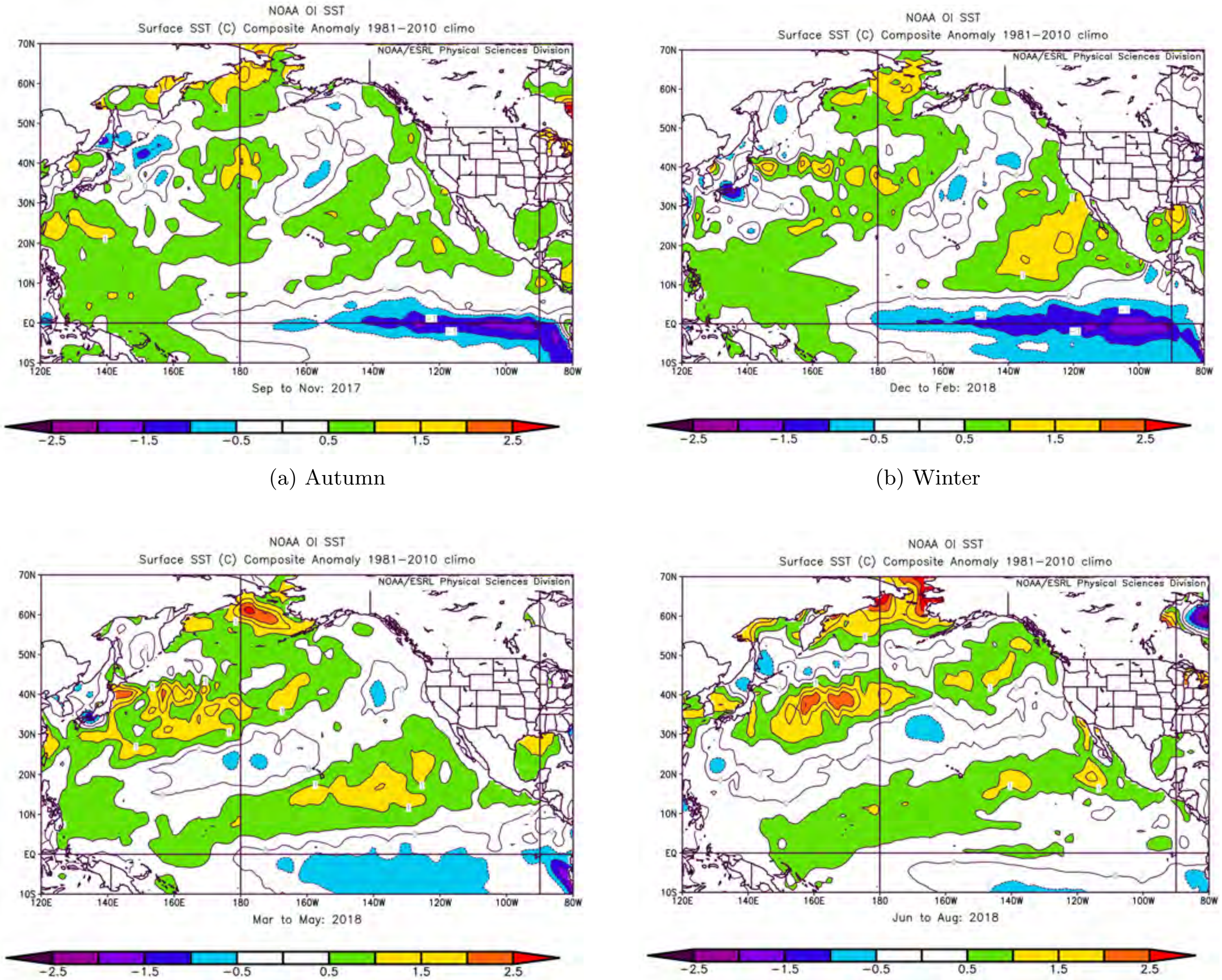
The SST during the autumn (Sep–Nov) of 2017 (Figure 8a) was warmer than normal across almost the entire North Pacific Ocean. Greater positive (> 1°C) anomalies occurred in the Chukchi Sea and northwest Bering Sea in the northern and eastern Bering Sea, resulting in a delayed onset of sea ice the following winter. The SST anomalies were negative in the eastern equatorial Pacific in association with the development of La

Niña. The SLP pattern during autumn 2017 featured prominent positive anomalies over the north central portion of the North Pacific Ocean, with the greatest departures from normal over the open ocean south of the western tip of the Alaska Peninsula (Figure 9a). This SLP distribution implies an enhanced storm track along the east coast of Asia, and suppressed storminess from the Aleutians into the Gulf of Alaska (GOA).

The North Pacific atmosphere-ocean system during winter (Dec–Feb) of 2017-18 reflected to large extent a continuation of the previous fall season. The distribution of SST anomalies (Figure 8b) was quite similar, with some additional warming in the subtropical northeastern Pacific extending southwestward from southern California. The equatorial Pacific was characterized by weak/moderate La Niña conditions with the strongest negative SST anomalies well east of the dateline. The SLP during this period (Figure 9b) featured an expansion of the pattern of the season before in terms of both magnitude and area, with substantial positive anomalies from about 160°E to western North America north of about 30°N. This relatively high SLP in combination with negative SLP anomalies over the East Siberian Sea resulted in a pressure pattern that supported extremely strong wind anomalies ($\sim$3 to 4 m s^{-1}) from the southwest across the Bering Sea.

The distribution of anomalous SST in the North Pacific during spring (Mar–May) of 2018 (Figure 8c) was similar to that during the previous winter season. Exceptions were warming relative to seasonal normal in the eastern Bering Sea and in an east-west band from 25° to 40°N from Japan to the dateline. The SST anomalies in the tropical Pacific were of minor amplitude with the ending of La Niña. The SLP anomaly pattern (Figure 9c) for spring 2018 featured bands of lower than normal pressure from eastern Siberia to northwestern Alaska and higher pressure from south of the Aleutian Islands to the GOA, resulting in another season of warm, southwesterly flow anomalies across the Bering Sea. The atmospheric circulation in the northeast Pacific promoted relatively upwelling-favorable winds in the coastal GOA.

The SST anomaly pattern in the North Pacific during summer (Jun–Aug) 2018 is shown in Figure 8d. Positive anomalies continued in a broad band extending from Japan to the southeastern GOA and from the northern Bering Sea into the Chukchi Sea. In the latter area, particularly strong positive temperature anomalies (exceeding 2°C) developed in the vicinity of Bering Strait. Near normal SSTs were present along most of the west coast of North America from Vancouver Island to southern California. Warmth continued in the subtropical eastern North Pacific from Baja California to the equatorial Pacific east of the dateline, where temperatures were roughly 0.5°C above normal. The distribution of anomalous SLP (Figure 9d) during summer 2018 included mostly just weak anomalies, which is typical for the season. A band of higher than normal pressure extended from the western North Pacific north of about 30°N into the GOA. Lower pressure extended from northwestern Canada across interior Alaska into the Bering Sea.



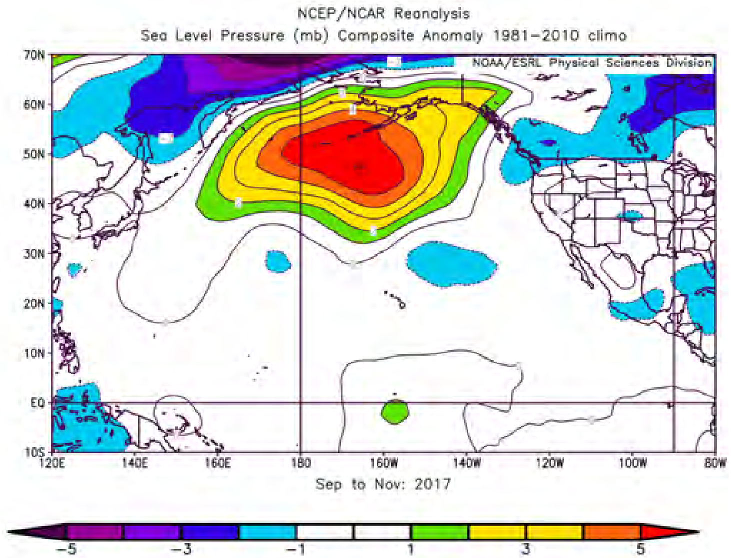
(a) Autumn

(b) Winter

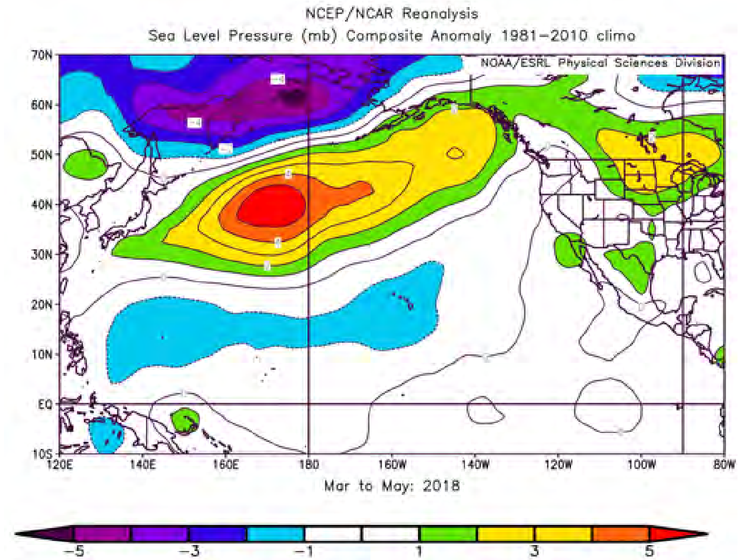
(c) Spring

(d) Summer

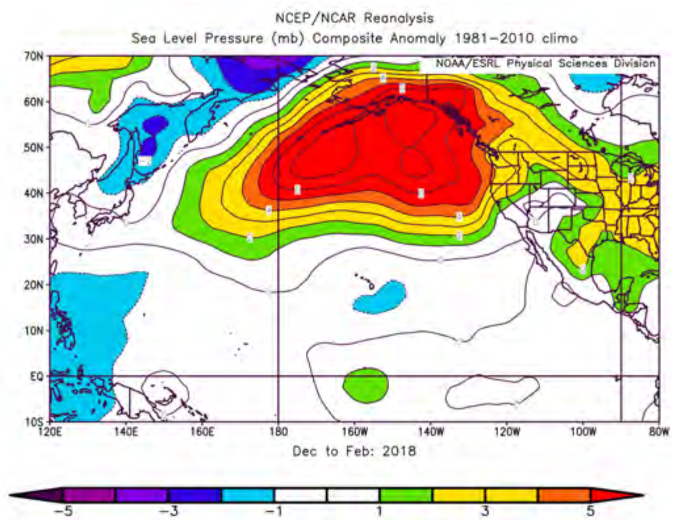
Figure 8: SST anomolies for autumn (September–November 2017), winter (December 2017–February 2018), spring (March–May 2018), and summer (June–August 2018).



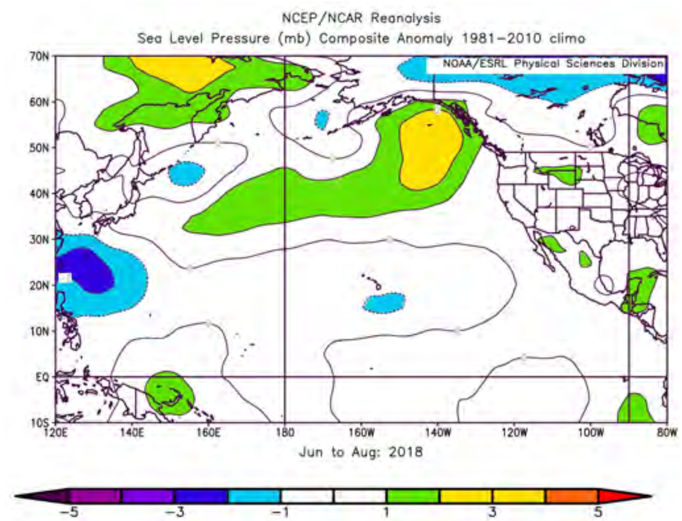
(a) Autumn



(b) Winter



(c) Spring



(d) Summer

Figure 9: SLP anomolies for autumn (September–November 2017), winter (December 2017–February 2018), spring (March–May 2018), and summer (June–August 2018).

Climate Indices

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Last updated: September 2018

Description of indices: Climate indices provide an alternative means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, Pacific Decadal Oscillation (PDO) index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO), and Arctic Oscillation (AO). The time series of these indices from 2008 into spring/summer 2018 are plotted in Figure 10.

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

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

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

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Last updated: September 2018

Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figures 11. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.

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

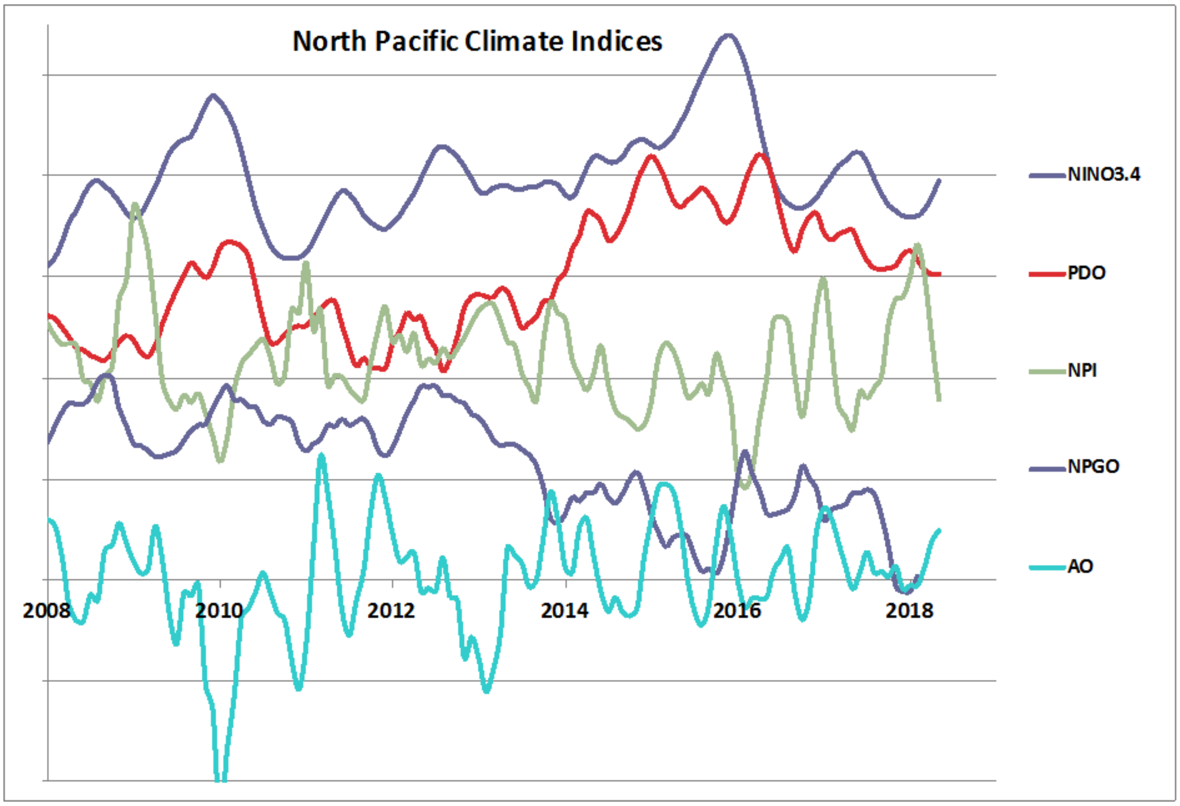


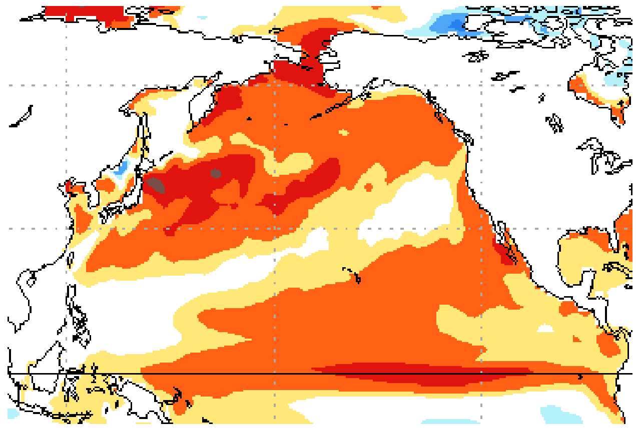
Figure 10: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices for 2008–2018. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Earth Systems Laboratory at `http://www.esrl.noaa.gov/psd/data/climateindices/`.

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

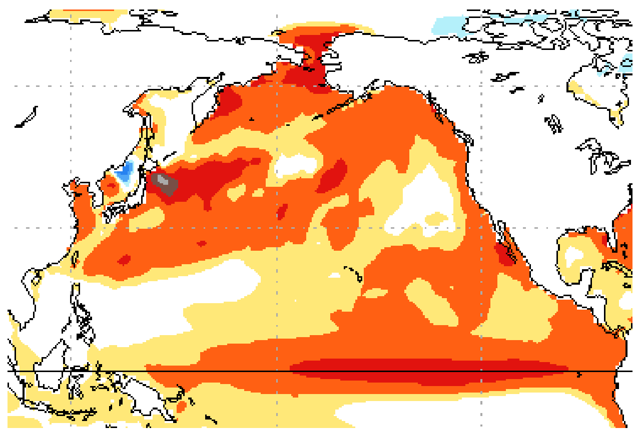
These NMME forecasts of three-month average SST anomalies indicate a continuation of warm conditions across virtually all of the North Pacific through the end of the year (Oct–Dec 2018) with a reduction in the longitudinal extent of cooler than normal temperatures offshore of the Pacific Northwest (Figure 11a). The magnitude of the positive anomalies is projected to be greatest (exceeding 1°C) north of the Kuroshio Extension in the western North Pacific and in the northern portion of the Bering Sea. Positive SST anomalies are projected in the central and eastern equatorial Pacific. The ensemble model average is strong enough to constitute El Niño of weak to moderate magnitude. As of early September 2018, the probabilistic forecast provided by NOAA's Climate Prediction Center (CPC) in collaboration with the International Research Institute for Climate and Society (IRI) for the upcoming fall through winter indicates about a 70% chance of

El Niño, and otherwise equatorial SSTs in the neutral category. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2018–February 2019 (Figure 11b) and February–April 2019 (Figure 11c). There is moderate but by no means a complete consensus among the models that the Aleutian low will be deeper than normal (negative SLP anomalies) during the latter portion of the winter of 2018–2019. This is a common remote response to El Niño, and tends to result in relatively warm late winter and early spring weather for Alaska that is liable to be enhanced by the effects of the warmth of the waters surrounding Alaska. For the period of February–April 2019, the models are projecting little noticeable decline in the magnitude of the equatorial Pacific temperature anomalies even though El Niño often weakens during the boreal spring. The positive SST anomalies along the west coast of North America that are indicated in Figure 11c commonly occur after El Niño winters.

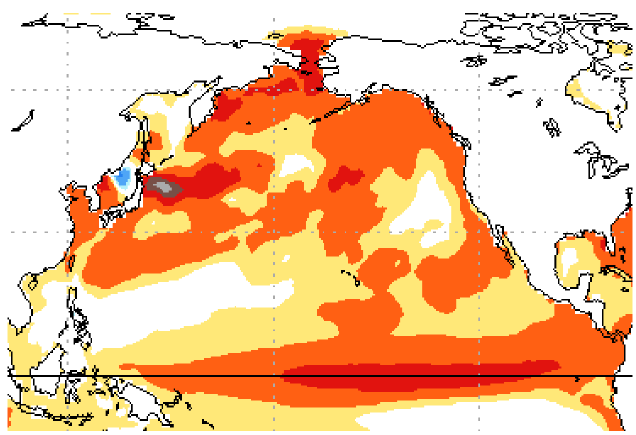
Implications: The PDO has also generally been positive during these kinds of periods in the past, but the predicted warmth in both the western and eastern portions of the mid-latitude North Pacific does not resemble the characteristic pattern of the PDO. An important implication is that the PDO is liable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



(a) Months OND



(b) Months DJF



(c) Months FMA

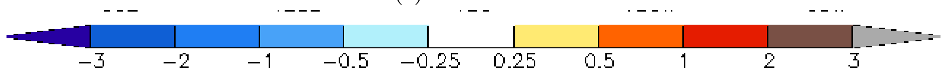


Figure 11: Predicted SST anomalies from the NMME model for OND (1 month lead), DJF (3 month lead), and JFM (4 month lead) for the 2017–2018 season.

Eddies in the Gulf of Alaska

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Last updated: August 2018

Description of indicator: Eddies in the northern Gulf of Alaska have been shown to influence distributions of nutrients (Ladd et al., 2009, 2005, 2007), including dissolved iron (Crusius et al., 2017; Ladd et al., 2009) phytoplankton (Brickley and Thomas, 2004), ichthyoplankton (Atwood et al., 2010), and the foraging patterns of fur seals (Ream et al., 2005). Eddies propagating along the slope in the northern and western Gulf of Alaska are generally formed in the eastern Gulf in autumn or early winter (Okkonen et al., 2001) sometimes associated with gap winds from Cross Sound (Ladd and Cheng, 2016). Using altimetry data from 1993 to 2001, Okkonen et al. (2003) found that strong, persistent eddies occurred more often after 1997 than in the period from 1993 to 1997. Ladd (2007) extended that analysis and found that, in the region near Kodiak Island (Figure 12; region c), eddy energy in the years 2002–2004 was the highest in the altimetry record.

Since 1992, a suite of satellite altimeters has been monitoring sea surface height. Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (merged TOPEX/Poseidon, ERS-1/2, Jason and Envisat; (Ducet et al., 2000), giving a measure of the mesoscale energy in the system. A map of eddy kinetic energy in the Gulf of Alaska averaged over the altimetry record (updated from Ladd (2007)) shows four regions with local maxima (labeled a, b, c and d in Figure 12). The first two regions are associated with the formation of Haida (a) and Sitka (b) eddies. Eddies that move along the shelf-break often feed into the third and fourth high EKE regions (c and d; Figure 12). By averaging EKE over regions c and d (see boxes in Figure 12), we obtain an index of energy associated with eddies in these regions (Figure 13). The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS) (`http://www.marine.copernicus.eu`).

Status and trends: The seasonal cycle of EKE averaged over the two regions (c and d) are out of phase with each other. Region (c) exhibits high EKE in the spring (March–May) and lower EKE in the autumn (September–November) while region (d) exhibits high EKE in the autumn and low EKE in the spring. EKE was particularly high in region (c) in 2002–2004 when three large persistent eddies passed through the region. The highest EKE observed in region (c) occurred in 2016 when a strong persistent eddy remained in the region for multiple months. In region (d), high EKE was observed in 1993, 1995, 2000, 2002, 2004, 2006, 2007, 2010, 2012, 2013, 2015and 2017. Near-real-time data suggest that EKE was low in region (d) and average in region (c) in spring/summer 2018.

Factors influencing observed trends: In the eastern Gulf of Alaska, interannual changes in surface winds (related to the Pacific Decadal Oscillation, El Niño), and the strength of the Aleutian Low modulate the development of eddies (Combes and Di Lorenzo, 2007; Di Lorenzo et al., 2013). Regional scale gap-wind events may also play a role in eddy formation in the eastern Gulf of Alaska (Ladd and Cheng, 2016). In the western Gulf of Alaska, variability is related both to the propagation of eddies from their formation regions in the east and to intrinsic variability.

Implications: EKE may have implications for the ecosystem. Phytoplankton biomass was probably more tightly confined to the shelf during spring 2018 due to the absence of eddies, while in 2007, 2010, 2012, 2013, and 2015 (region (d)) and 2016 (region (c)), phytoplankton biomass likely extended farther off the shelf. In addition, cross-shelf transport of heat, salinity, and nutrients were probably weaker in 2018 than in years with large persistent eddies. Eddies sampled in 2002–2004 were found to contain different ichthyoplankton assemblages than surrounding slope and basin waters indicating that eddies along the slope may influence the distribution and survival of fish (Atwood et al., 2010). In addition, carbon isotope values suggest that cross-shelf exchange due to eddies may be important to the marine survival rate of pink salmon (Kline, 2010).

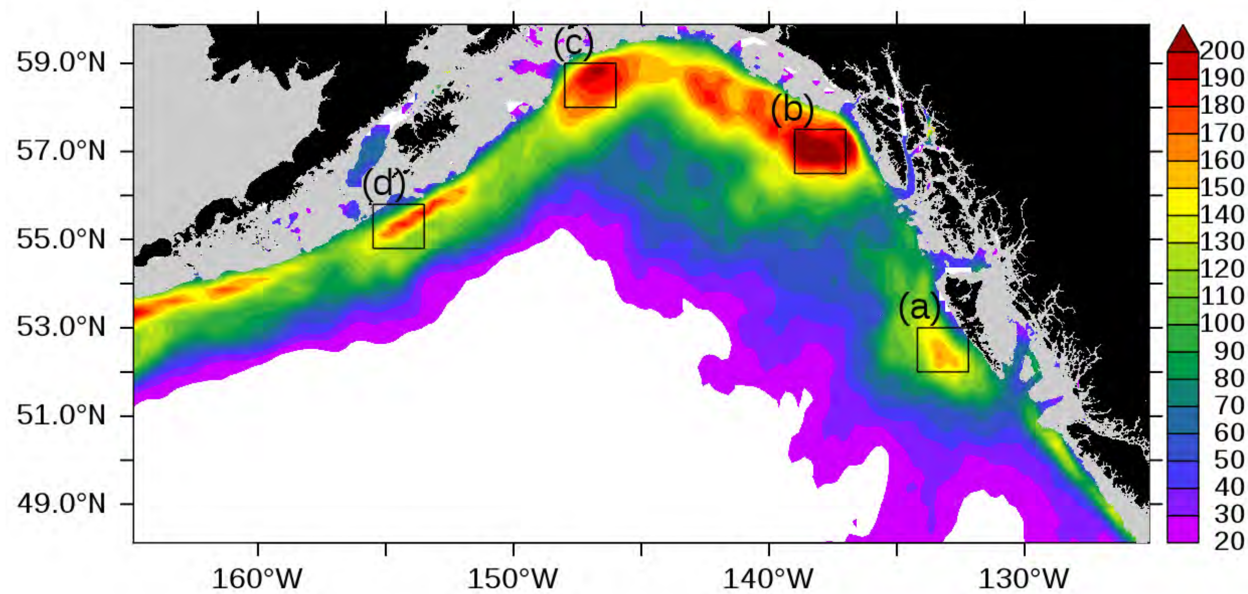

Figure 12: Eddy Kinetic Energy averaged over January 1993–December 2017 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 13.

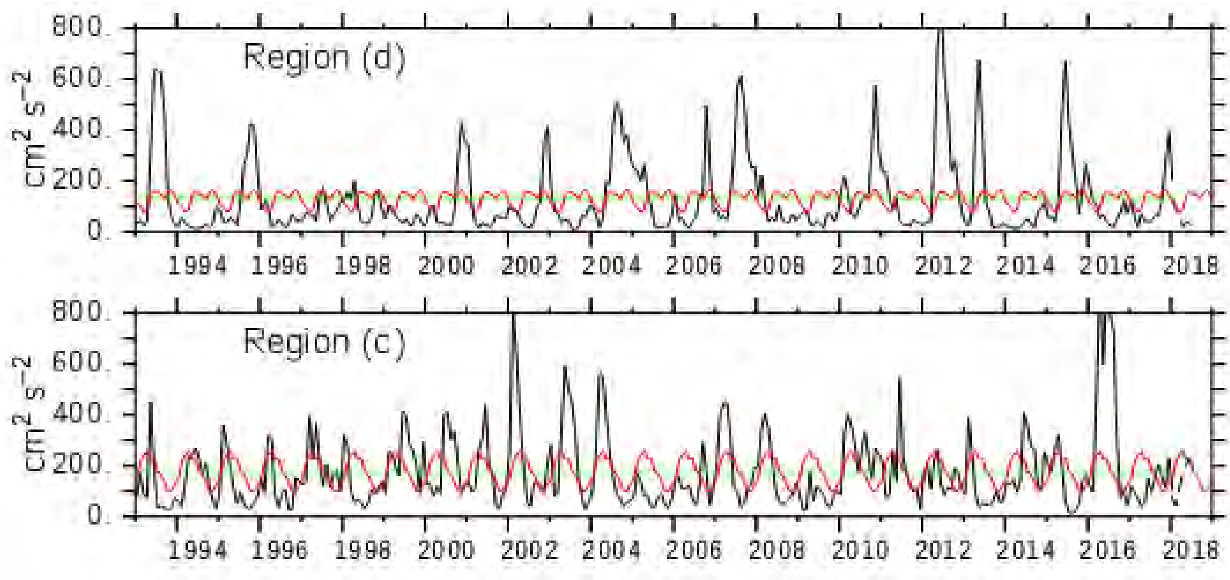

Figure 13: Eddy kinetic energy (cm^2 s^{-2}) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 12. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product), Red: seasonal cycle. Green (straight line): mean over entire time series.

Ocean Surface Currents—PAPA Trajectory Index

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Last updated: August 2018

Description of indicator: The PAPA Trajectory Index (PTI) provides an annual index of near-surface water movement variability, based on the trajectory of a simulated surface drifter released at Ocean Station PAPA (50°N, 145°W; Figure 14). The simulation for each year is conducted using the "Ocean Surface CURrent Simulator" (OSCURS; `http://oceanview.pfeg.noaa.gov/oscurs`). Using daily gridded atmospheric pressure fields, OSCURS calculates the speed and direction of water movement at the ocean's surface at the location of a simulated surface drifter. It uses this information to update the position of the simulated drifter on a daily basis over a specified time period. For the index presented here, OSCURS was run for 90 days to simulate a surface drifter released at Ocean Station PAPA on December 1 for each year from 1901 to 2017 (trajectory endpoints years 1902–2018).

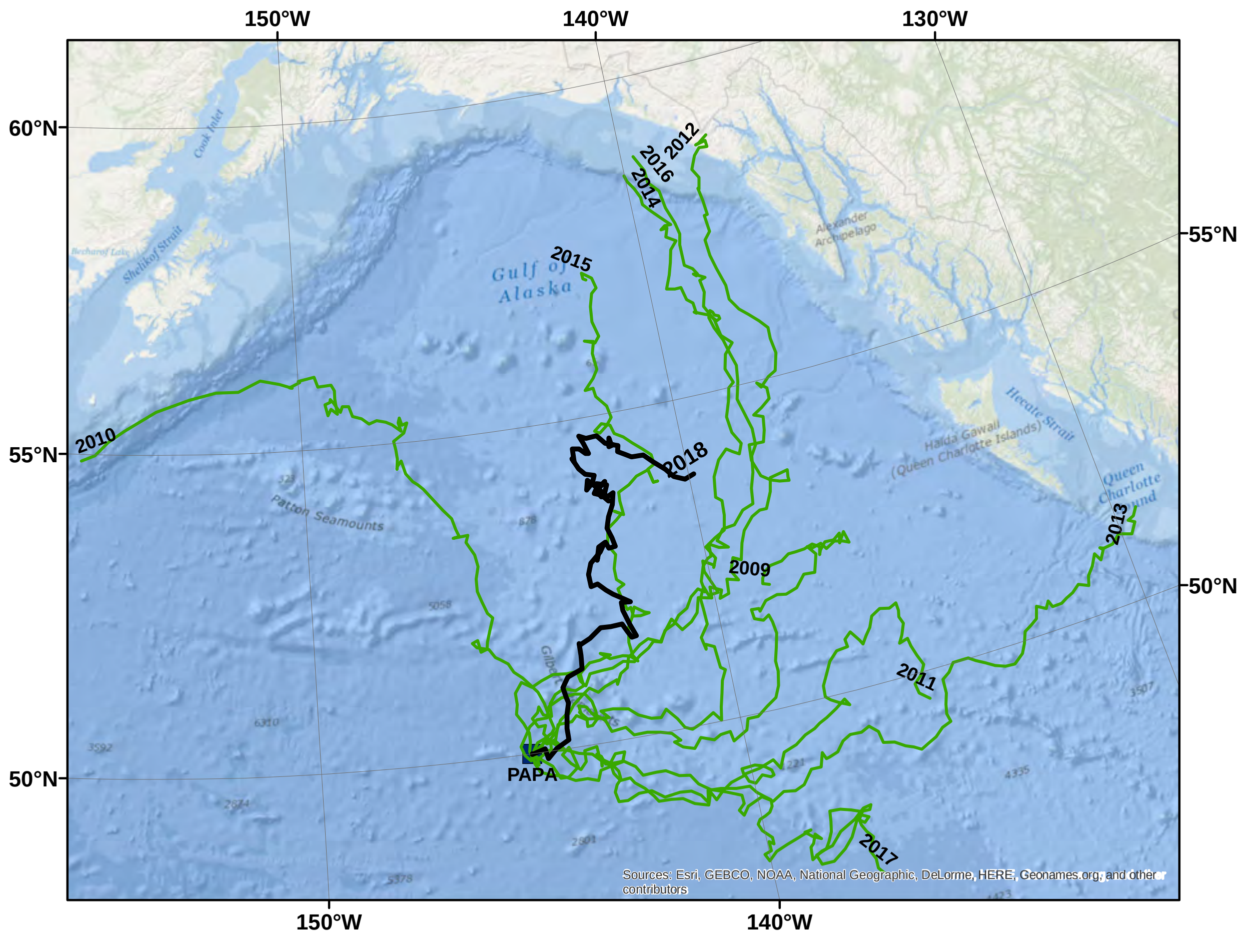

Figure 14: Simulated surface drifter trajectories for winters 2008–2018 (endpoint year). End points of 90-day trajectories for simulated surface drifters released on Dec. 1 of the previous year at Ocean Weather Station PAPA are labeled with the year of the endpoint (50°N, 145°W).

Status and trends: In general, the trajectories fan out northeastwardly toward the North American continent (Figure 14). The 2009/2010 trajectory was an exception and resulted in the westernmost trajectory endpoint for the entire set of model runs (1902–2017 endpoints). Under the influence of contemporaneous El Niño conditions, the Aleutian Low in the winter of 2009–2010 was anomalously deep and displaced to the southeast of its usual position in winter (Bond and Guy, 2010), resulting in anomalously high easterly (blowing west) wind anomalies north of Ocean Station PAPA. The 2011/2012 trajectory followed the general northeastwardly path of most drifters, but was notable because its ending latitude was the northernmost of all trajectories since 1994 (Figure 15). The trajectory for 2012/13 was notable as ending up the furthest east among trajectories in recent years, driven by very strong westerly anomalies in the northeast Pacific. The trajectories for 2013/14, 2014/15, and 2015/16 trajectories were very similar to that for 2011/12, although these did not reach quite as as far north as in 2011/12. These trajectories coincided with the development (2013/14) and continuation (2014/15, 2015/16) of the "Blob" of warm surface waters along the eastern Pacific coast and the return of the Pacific Decadal Oscillation (PDO) to a warm, positive phase associated with winds from the south near the coast. The increased southerly winds contributed to well above-average sea surface temperatures in the Gulf of Alaska in 2015/16. Although the PDO remained in a positive phase during the winter of 2016/17, strong positive sea-level pressure anomalies over the northeast Pacific centered to the west of the Gulf of Alaska during the winter (`http://www.cpc.ncep.noaa.gov/products/GODAS/ocean_briefing_gif/global_ocean_monitoring_2017_03.pdf`) drove strong northerly winds that pushed the drifter trajectory to its most southerly latitude since the late 1930s (Figure 15). The 2017/18 trajectory was rather unremarkable. The PDO during the winter was weak and positive sea-level pressure anomalies during early winter were centered to the east of the Gulf of Alaska, giving rise to more southerly winds that pushed the trajectory to the north during this time period. The sea-level pressure anomalies shifted to the west later in the winter, resulting in southerly winds in the vicinity of the drifter and a subsequent reversal in latitudinal trend such that the PTI for 2017/18 was close to zero (Figure 15).

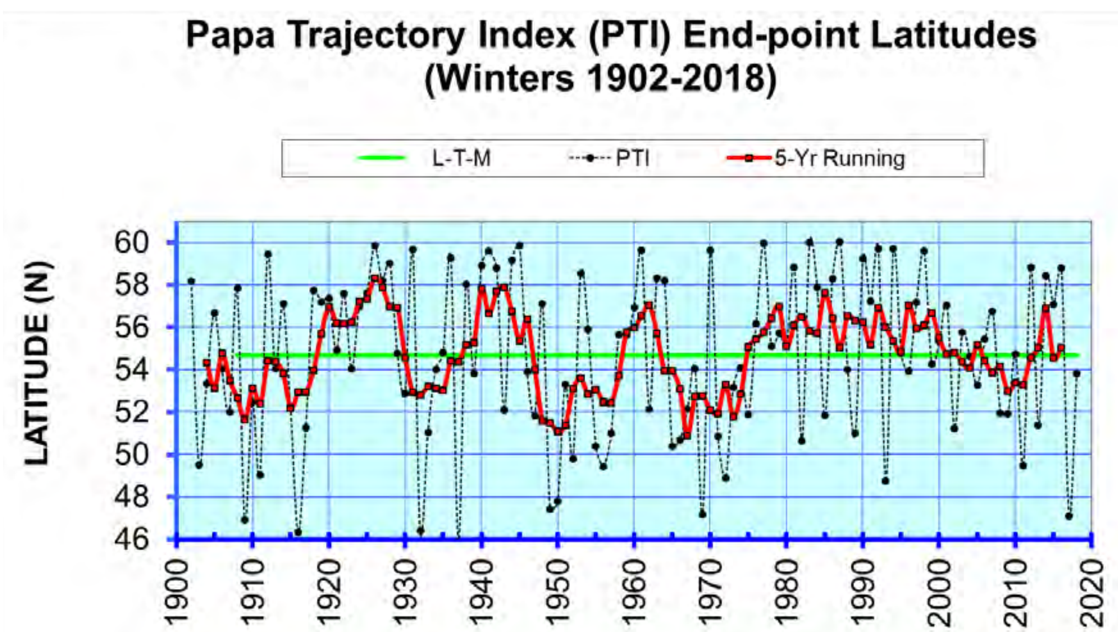

Figure 15: Annual, long-term mean (green line), and 5-year running mean (red line and squares) of the PAPA Trajectory Index time series (dotted black line and points) for 1902–2017 winters.

The PTI time series (Figure 15, black dotted line and points) indicates high interannual variation in the north/south component of drifter trajectories, with an average between-year change of >4° and a maximum change of greater than 13° (between 1931–1932). The change in the PTI between 2010/11 and 2011/12 was the largest since 1994, while the changes between 2011/12 and 2012/13, and between 2012/13 and 2013/14, represented reversals with slightly less, but diminishing, magnitude. Such swings, however, were not uncommon over the entire time series. The changes from 2013/14 to 2015/16 constituted a relatively rare event when the index changed very little over three successive years.

Over the past century, the filtered (5-year running average) PTI has undergone four complete oscillations with distinct crossings of the mean, although the durations of the oscillations are not identical: 26 years (1904–1930), 17 years (1930–1947), 17 years (1947–1964), and 41 years (1964–2005). The filtered index indicates that a shift occurred in the mid 2000s to predominantly southerly anomalous flow following a 20+ year period of predominantly northerly anomalous flow. This was indicative of a return to conditions (at least in terms of surface drift) similar to those prior to the 1977 environmental regime shift. This part of the cycle apparently ended rather quickly, however, as it now appears the filtered PTI has crossed the mean in the opposite direction. The recent period of predominantly southern flow has been the shortest and weakest in the time series.

Factors influencing observed trends: Individual trajectories reflect interannual variability in regional (northeast Pacific) wind patterns which drive short term changes in ocean surface currents, as well as longer term changes in atmospheric forcing that influence oceanic current patterns on decadal time scales. Filtered PTI values greater than the long-term mean are indicative of increased transport and/or a northerly shift in the Alaska Current, which transports warm water northward along the west coast of Canada and southeast Alaska from the south and consequently plays a major role in the Gulf of Alaskas heat budget.

Implications: The year-to-year variability in near-surface water movements in the North Pacific Ocean has been shown to have important effects on the survival of walleye pollock (*Gadus chalcogrammus*) by affecting its spatial overlap with predators (Wespestad et al., 2000), as well as to influence recruitment success of winter spawning flatfish in the eastern Bering Sea (EBS; Wilderbuer et al. (2002)). Filtered PTI values greater than the long-term mean are indicative of increased transport and/or a northerly shift in the Alaska Current, which transports warm water northward along the west coast of Canada and southeast Alaska from the south and consequently plays a major role in the Gulf of Alaskas heat budget. Interdecadal changes in the PTI reflect changes in ocean climate that appear to have widespread impacts on biological variability at multiple trophic levels (King, 2005). There is strong evidence that the productivity and possibly the carrying capacity of the Alaska Gyre and of the continental shelf were enhanced during the "warm" regime that began in 1977. Zooplankton production was positively affected after the 1977 regime shift (Brodeur and Ware, 1992), as were recruitment and survival of salmon and demersal fish species. Recruitment of rockfish (Pacific ocean perch) and flatfish (arrowtooth flounder, halibut, and flathead sole) also increased. However, shrimp and forage fish such as capelin were negatively affected by the 1977 shift (Anderson, 2003). The reduced availability of forage fish may have contributed to the decline in marine mammal and seabird populations observed after the 1977 shift (Piatt and Anderson, 1996).

Satellite-derived Sea Surface Temperature Anomalies in the Gulf of Alaska

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Last updated: August 2018

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

A common limitation of SST records derived from satellites has been missing data as a result of cloud cover. Using the NASA multi-scale ultra-high resolution (MUR) SST dataset however, a combination of collection modalities creates a gap-free blend of data (`https://mur.jpl.nasa.gov/InformationText.php`). Data are available at the daily level for the North Pacific from mid-2002 to present and can be downloaded from the NOAA Coast Watch West Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/`) where they are searchable as "Multi-scale ultra-high resolution (MUR) SST Analysis fv04.1, Global, 0.01°, 2002–present, daily". More than 24 billion individual daily temperature records were downloaded (October 1, 2002–September 30, 2018) and the data were averaged daily by Alaska Department of Fish and Game (ADF&G) groundfish statistical areas (also called stat6 areas; `www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByFishery.statmaps`), yielding about 10 million temperature records (a daily record for each of the 1,736 statistical areas). More detailed methods are available online (`github.com/jordanwatson/ERDDAP`). The full dataset (or aggregated versions) can be obtained by contacting the author of this contribution.

As an ecosystem indicator for the Gulf of Alaska (GOA), daily temperatures were averaged by month for the GOA ecosystem regions (from ADF&G statistical areas in the western GOA [WGOA], 144 W - 163 W; eastern GOA [EGOA], 133 °W 144°W; and southeast Alaska (SEAK), inside waters east of 137°W [`https://alaskafisheries.noaa.gov/maps`]) and anomalies were calculated (Figure 1). Monthly anomalies were aggregated by winter (October–March) and summer (April–September). In Figure 1reffig.watsonsstgoa, winter 2002 refers to October–December 2002 and January–March 2003. Horizontal dashed lines in Figure 1 are provided as a reference at an anomaly of ±0.5.

Status and trends: The WGOA and EGOA demonstrated consistently similar trends within seasons and years, though in several cases, the magnitude (and direction) of anomaly was different for SEAK inside waters versus the GOA (Figure 16). The overall patterns of summer anomalies demonstrated a brief warm stanza during the summers of 2004 and 2005, with a broader cold stanza from 2006–2012. In 2013, waters began warming and 2014–2016 were notably warmer than the previous stanza. By summer 2017, the intensity of warming had returned to near average. Winter anomalies however were characterized by cold water from 2006–2012 and much warmer waters in 2014–2016.

Factors influencing observed trends: The time period illustrated here includes the well-documented "warm blob" period (Bond et al., 2015; Hu et al., 2017), which is identified by the anomalously warm winters, 2014–2016. The WGOA region includes Prince William Sound (NMFS area 649) which consists of some colder, glacially influenced fjord environments.

Implications: As researchers and managers explore drivers of recent seabird die-offs, declines of Pacific cod, low Chinook salmon returns, or other dynamics related to changes in the Gulf of Alaska ecosystem, it is increasingly important to have indicators available at varying spatial and temporal scales. These temperature time series provide quick and simple illustrations of a major environmental index that can be explored in conjunction with fishery-relevant data throughout the year and across space, depending on the questions being asked by researchers or policy makers. For researchers that study fishery effects directly, the daily SST data described here are being linked to fish ticket data in AKFIN so that landings information will be explicitly associated with the temperature of the ADF&G statistical areas in which the fish were reported to have been caught.

Seward Line May Temperatures

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Last updated: AMay 2018

Description of indicator: Hydrographic transects have been completed south of Seward Alaska typically during the first 10 days of May for over two decades, 1998–2018. Temperature data is averaged over the top 100m of the water column to provide an index of the heat on the northern Gulf of Alaska shelf that is not affected by short-term weather that can interfere with satellite-based temperature observations. This project is funded in part by the Gulf Watch Alaska long-term monitoring program funded by the *Exxon Valdez* Oil

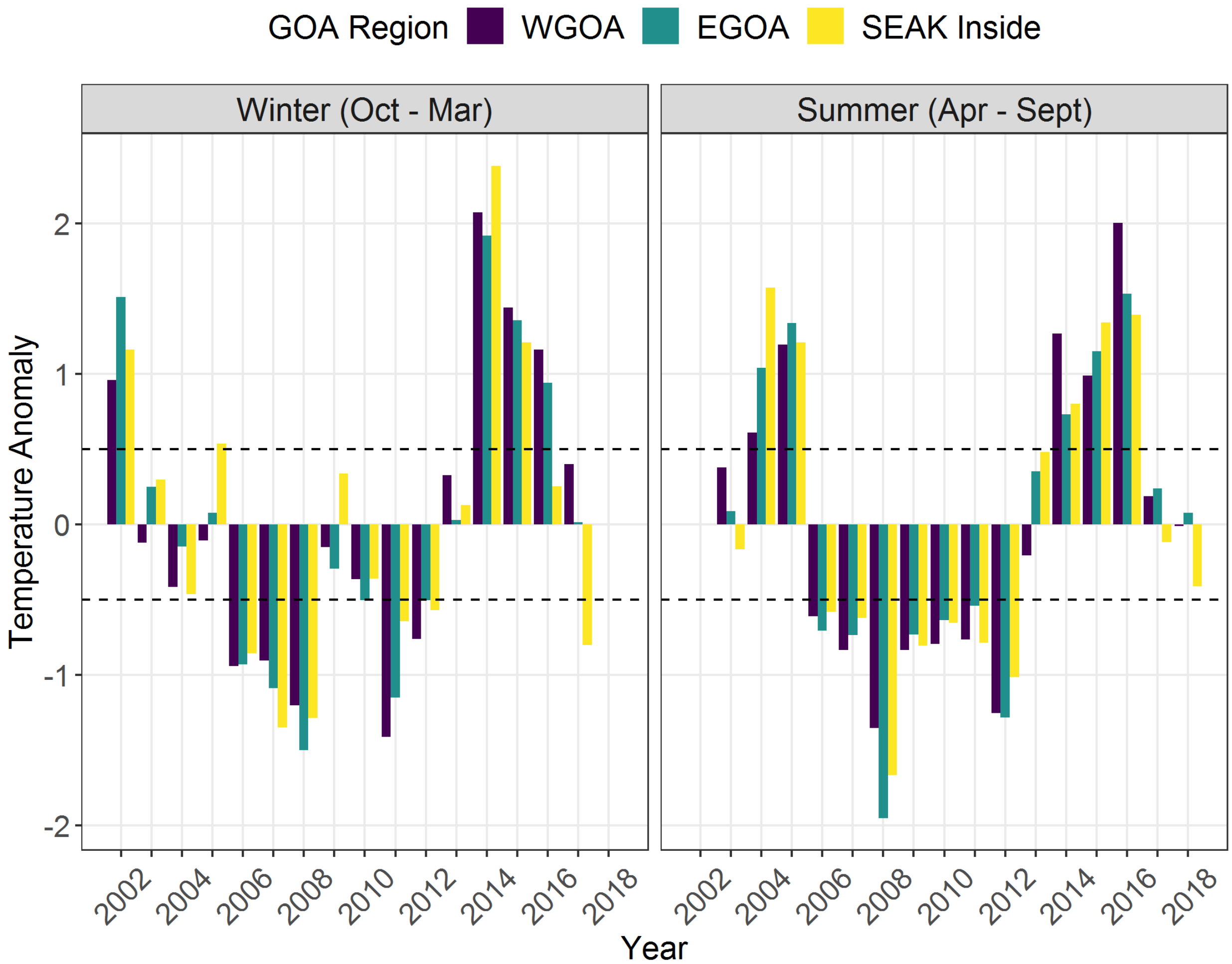

Figure 16: Seasonal sea surface temperature anomalies for Gulf of Alaska regions. The boundary between WGOA and EGOA is 144°W; SEAK refers to the inside waters of southeast Alaska. Data were unavailable for summer 2002 and winter 2018, so these portions of their respective figures are omitted.

Spill Trustee Council.

Status and trends: Temperatures have returned to long-term (21 year) means during 2017 and 2018 (Figure 17). The northernmost station, GAK1, that has been occupied for nearly 50 years, shows long-term warming and surface freshening of the Gulf of Alaska Coastal Current. The Seward Line temperatures highlight events such as El Ños that have occurred across the shelf during 1998, 2003, and 2016, as well as the marine heatwave of 2014–2016.

Factors influencing observed trends: There are currently no anomalous atmospheric conditions influencing the Gulf of Alaska.

Implications: Ocean temperatures in the Gulf of Alaska can be expected to be relatively "normal" during 2018. Growth rates of all cold-blooded are influenced by temperature. While higher growth rates can be achieved in warmer water, greater quantities of food are required to do so than in colder waters. The dynamics and magnitude of the spring bloom are highly influenced by water temperatures, with colder years typically having greater productivity.

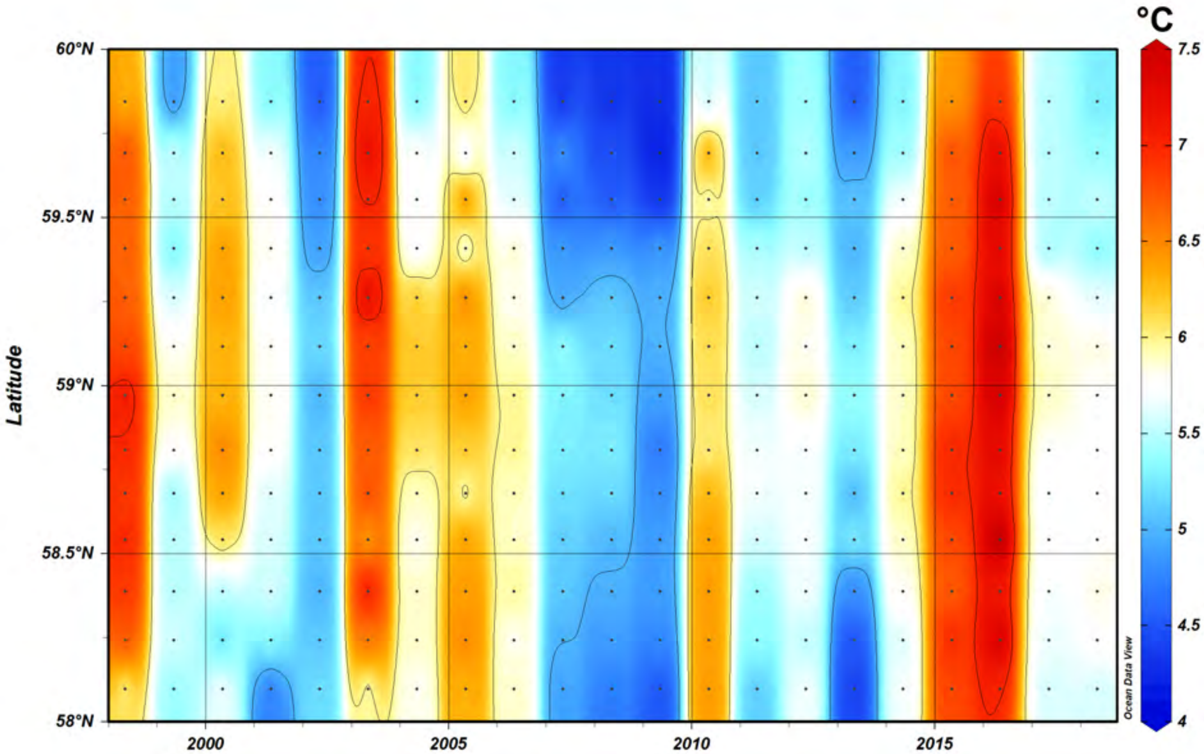

Figure 17: May sea temperatures averaged over the top 100m along the Seward Line in the northern Gulf of Alaska, 1998–2018.

Temperature trends in the surface waters of Prince William Sound

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Last updated: September 2018

Description of indicator: A 45-year time series of sea surface temperature (SST) was compiled in Prince William Sound (PWS), western Gulf of Alaska region, 1974–2018. Sea surface temperature anomalies were calculated as the residual of the 2nd order cosine fit to daily temperature data, to remove seasonality. Data were collected from the World Ocean Database (NOAA), and an unpublished database of casts done by the University of Alaska Fairbanks (UAF). The data represent an exhaustive collation of historical data from prior projects, and the data were collected with a variety of instruments from numerous platforms. Recent data (>2010) is from ongoing Gulf Watch Alaska (`gulfwatchalaska.org`) projects conducted by the PWS Science Center, UAF, and NOAA.

Status and trends: SST has been increasing in central PWS for the last four decades, at approximately 0.20 to 0.25°C per decade (Figure 18), although there is substantial year-to-year variability. In 2013, anomalies shifted towards strongly positive, and stayed that way into 2017, which reflects a basin scale marine heatwave that was noted throughout the Gulf of Alaska. Temperature in PWS remained elevated for about 1 year longer than was observed offshore, which is typical—PWS generally lags the Gulf of Alaska by about 12 months (Campbell, 2018). Temperatures appear to have returned to near the long term average in 2018.

Factors influencing observed trends: Temperatures in PWS generally track those of the Gulf of Alaska

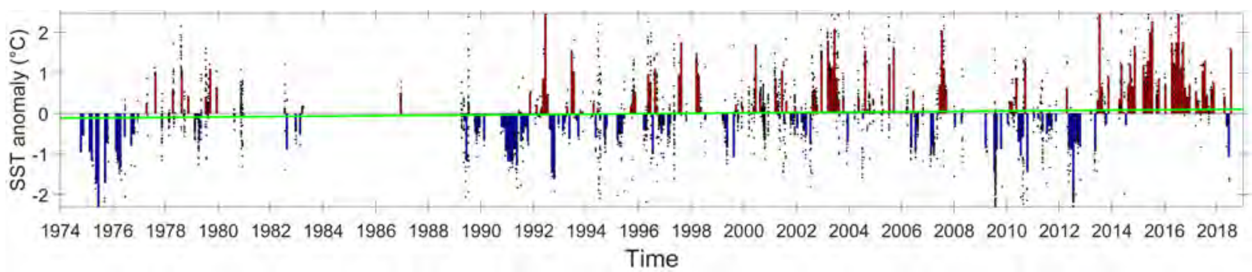

Figure 18: Near surface (2 m) temperature anomalies in central Prince William Sound, 1974–2018. Black dots indicate observations, and bars are monthly averages; the green line is the long term trend. Anomalies were calculated as the residuals of a second order cosine curve fit to all years data (to remove seasonality)

in general, with a lag of about 12 months which is driven by circulation within the region (Campbell, 2018). The onset of the marine heatwave in PWS was concurrent with the increase in temperatures basin-wide, because the driver of the onset of the heatwave was atmospheric (a prolonged period of calm winter weather where heat was not mixed out of the surface layer in winter as it usually is) and also basin-wide. The long term trend towards warming also matches a long term warming trend observed in the Gulf of Alaska (Royer and Grosch, 2006; Janout et al., 2010). The role of temperature in structuring the components of marine plankton ecosystems is less well understood. Warm-preferring species are generally more common within PWS than on the adjacent shelf and PWS may be a "refuge" of sorts for those species. The increase in their relative abundance during the marine heatwave years may have been in part because those species do tend to be found in PWS and were already there, and thus able to grow and reproduce better during the marine heatwave years. Similarly, cool water species may have been at a competitive disadvantage during the marine heatwave years.

Implications: The changes in temperature in PWS in the last few decades mirror those observed basin-wide in the Gulf of Alaska and have been driven by a warming trend that is in turn driven by warming trends observed globally (Levitus et al., 2001) and because much of the increased heat flux has been taken up by the ocean. That warming trend is restructuring marine ecosystems in ways that are difficult to predict, much less to observe as they happen. Temperature is an important forcing function for the vital rates of most lower trophic level players (e.g. growth rates by cold-blooded organisms). Different species have different temperature preferences, and temperature also influences what species are present. Temperature thus influences the food environment of fish predators, as well as their growth rates.

Watershed Dynamics in the Auke Creek System, Southeast Alaska

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Last updated: September 2018

Description of indicator: The Auke Creek Research Station has been in permanent operation since 1980 and provides a unique opportunity to study migratory salmonids due to the operation of a weir capable of the near-perfect capture of all migrating juvenile and adult salmon. In addition to the capture of migrating individuals, daily recordings of environmental variables are also collected. These variables include: creek temperature, and creek height. Creek temperature is collected using an in-creek probe that records temperature on an hourly basis and is located 25 meters upstream of the weir structure. Creek height is recorded using a staff gauge that is permanently installed directly downstream of the weir structure and approximately 7 meters above the average low tide line. Thirty-nine years of temperature data are available

(1980–2018), and 13 years of creek height data (2006–2018). These variables provide a valuable addition to the fisheries data collected at the Auke Creek Research Station.

Status and trends: The historical trends of yearly average creek temperature in Auke Creek varies from 8.6°C to 11.9°C with an average temperature of 10.3°C from 1980–2018. The average temperature for 2017 was 10.1°C and 10.8°C for 2018. From 2006–2018, average yearly creek height varied from 21.4ft to 21.9ft, with an average of 21.7 ft. The average gauge height for 2017 was 21.8ft and 21.4ft for 2018. Historical trends and the most recent two years are shown for creek temperature (Figure 19) and gauge height (Figure 20).

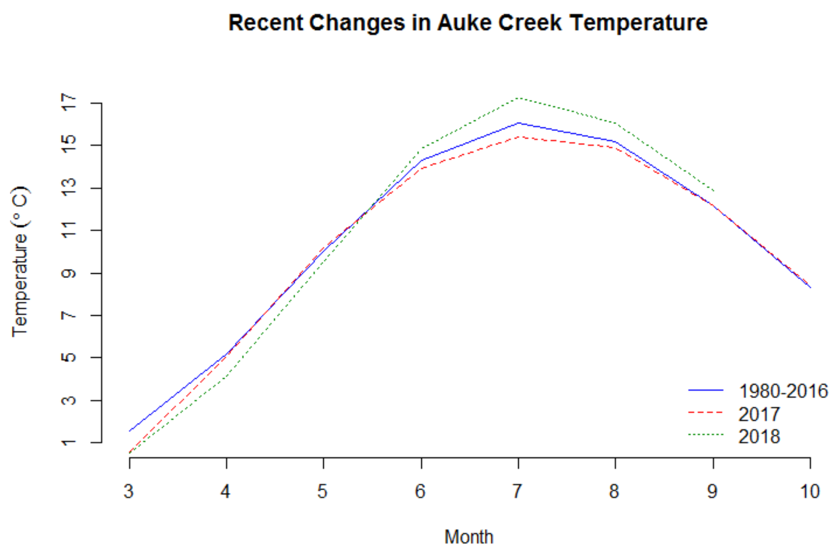

Figure 19: Auke Creek average temperature by months of operation for 1980–2016, 2017, and 2018.

Factors influencing observed trends: The trends that we are observing in the Auke Creek watershed provide further evidence for the rapid climatic change that has been documented in this system. Due to recent fluctuations in winter snowfall, we are seeing shifts from a snowmelt-dominated to a rainfall-dominated watershed at Auke Creek (Shanley et al., 2015)(Figure 20). This lack of snowfall, and subsequent lack of snowmelt, contribute to warmer creek temperatures earlier in the year (Figure 19).

Implications: These changes in stream conditions and climate have been shown to have influence on the median migration date of juvenile and adult salmon in Auke Creek (Kovach et al., 2013). Additionally, changes in time of entry to the marine environment can effect marine survival (Weitkamp et al., 2011). Both of these can have impacts on groundfish and salmon productivity as juvenile salmon serve as an important food source in the early marine environment. (Landingham et al., 1998; Sturdevant et al., 2009, 2012). Additionally, shifts in the timing and magnitude of freshwater and associated nutrient input directly affects processes in the nearshore marine environment (e.g., salinity and temperature).

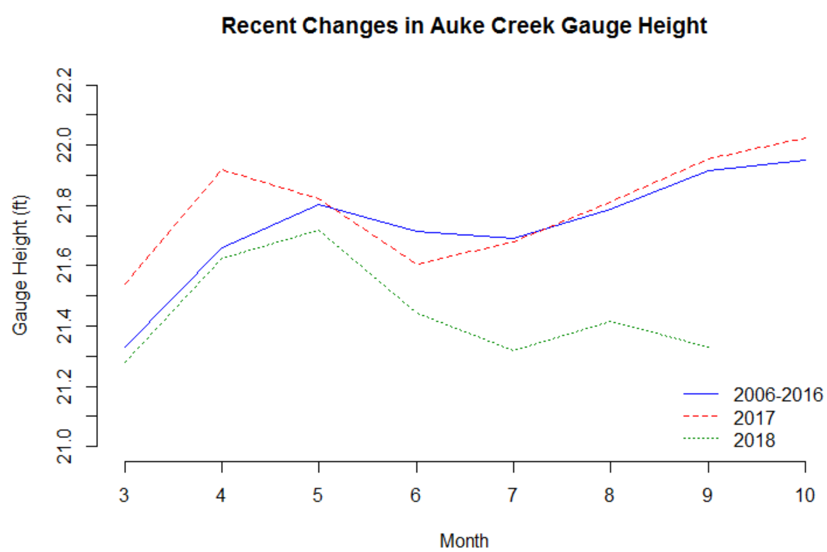

Figure 20: Auke Creek average gauge height by months of operation for 2006–2016, 2017, and 2018.

Habitat

Intertidal Ecosystem Indicators in the Northern Gulf of Alaska

Contributed by Heather Coletti[1], James Bodkin, Thomas Dean, Katrin Iken, Brenda Konar, Daniel Monson, Daniel Esler, Mandy Lindeberg, Robert Suryan
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Last updated: September 2018

Description of indicator: Intertidal monitoring in the Gulf of Alaska (GOA) provides ongoing evaluation of the status and trend of more than 200 species. The spatial extent of sampling includes a total of 21 sites from western Prince William Sound (WPWS) to Kenai Fjords National Park (KEFJ), Kachemak Bay (KBAY) and Katmai National Park (KATM) on the Alaska Peninsula, adjacent to Shelikof Strait. We have selected three biological indicators that represent key intertidal ecosystem components of primary production (algal cover), prey abundance (mussel density), and predator abundance (sea star abundance). Our algal cover indicator in this report is percent cover of rockweed (*Fucus distichus*) sampled in quadrats at the mid intertidal level (1.5 m). Intertidal prey is represented by density estimates of large ($\geq$ 20 mm) Pacific blue mussels (*Mytilus trossulus*) sampled in quadrats along mussel bed sites. Intertidal predator abundance is the total number of sea stars, estimated along a 50 m x 4 m transect at each rocky intertidal site in the GOA. We also include water temperature at the 0.5 m tide level to show that these biological indicators changed in concert with widespread physical forcing in the Gulf of Alaska. This project is funded in part by the Gulf Watch Alaska long-term monitoring program funded by the *Exxon Valdez* Oil Spill Trustee Council.

Status and trends: For nearshore temperature trends, temperature in all four intertidal zones from Prince William Sound to the Alaska Peninsula show a warming trend beginning in 2014 and persisting through 2017 (Figure 21). These results confirm that the 2014–2016 marine heatwave in the Gulf of Alaska affected intertidal zones with some indication of lagged effects, most notably continued persistence through 2017 even though some Gulf of Alaska temperature values were trending back toward long-term means.

For algal cover, despite considerable variability in density among sites and generally positive anomalies through 2014, all sites showed consistently negative trends during the recent marine heatwave and continuing through 2017 (Figure 22).

For large mussel cover, densities of large mussels ($\geq$20 mm) show a strong trend across all sites consistent with the timing of the marine heatwave, in this case switching from generally negative to positive anomalies—an opposite response compared to the other two indicators of *Fucus* and sea stars (Figure 23). Also, in comparison to other indicators, there seems to be higher across-site variability with mussel density, indicating that other variables and local conditions are important drivers of mussel abundance (Bodkin et al., 2018).

For sea star abundance, variability in abundance, diversity and dominance of individual sea star species varied greatly among regions through 2015. In 2016, abundance trends began to decline and have remained strongly negative across all regions through 2018.

Factors influencing observed trends: The negative anomalies of rockweed and sea stars are coincident with warm water temperatures in nearshore areas. The decline in sea star abundance was likely due to sea star wasting disease, which was first detected in 2014 and is generally associated with the warm water temperature anomalies (Eisenlord et al. 2016). The positive anomalies during 2015–2017 for large mussels is possibly in part a response to the reduced predation pressure given the synoptic decline of sea stars. A decline in small mussel density (an indicator of recruitment) was also observed during this time period, possibly because of the decrease in *Fucus* as available settlement habitat.

Implications: Collectively, these indicators demonstrate consistent, large scale perturbations of intertidal ecosystems throughout much of the western Gulf of Alaska, including nearshore regions both inside (WPWS,

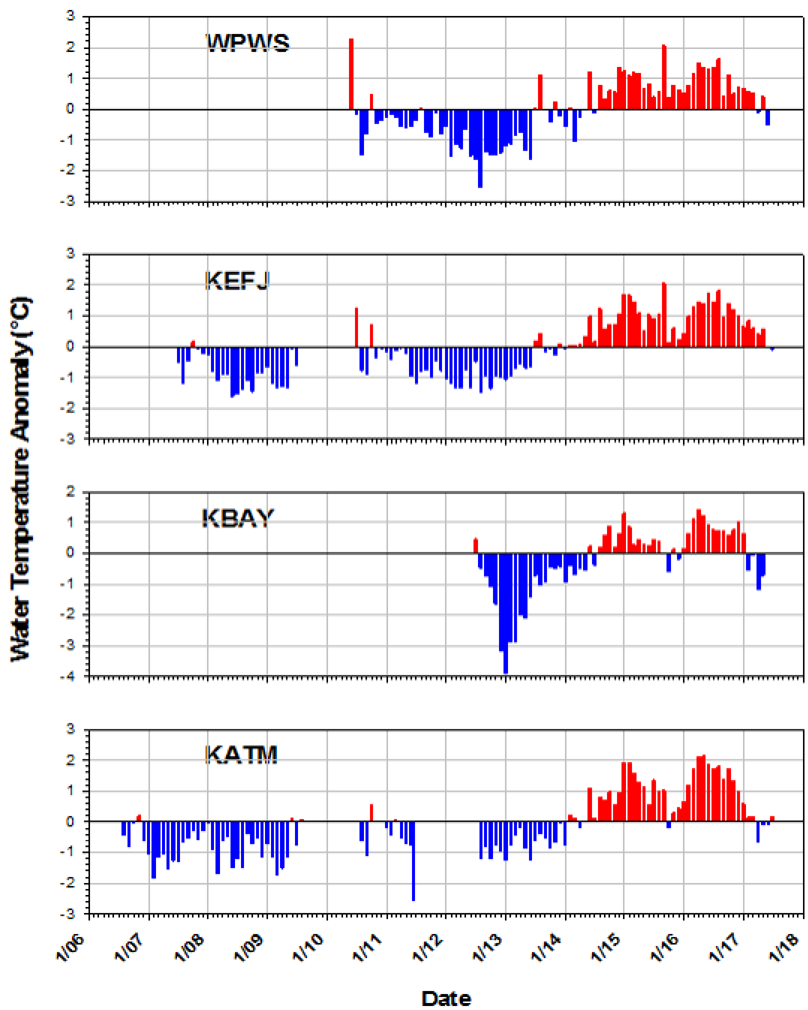

Figure 21: Intertidal temperature anomalies at the 0.5 m tide level four regions of the western Gulf of Alaska (west of 144°W), western Prince William Sound (WPWS; 2011–2018), Kenai Fjords National Park (KEFJ; 2008–2018), Kachemak Bay (KBAY; 2013–2018), and Katmai National Park adjacent to Shelikof Strait (KATM; 2006–2018).

KBAY) and outside (KEFJ and KATM) of inland marine waters. The three indicators signal potentially cascading community level effects with changing water temperatures. The decline in *Fucus* indicates habitat loss for settlement of new mussel recruits and a reduction in nearshore sources of primary productivity, whereas the increase in density of large mussels is likely due in part to the removal of nearshore sea stars.

Other nearshore predators may utilize the abundance of large mussels in the absence of sea stars such as sea otters and sea ducks. In the future, other nearshore predators like sea otters, black oystercatchers and sea ducks may take advantage of the abundance of larger mussels in the absence of sea stars. Intertidal and nearshore ecosystems provide valuable habitat for early life stages of some commercially important species in the Gulf of Alaska. These indicators suggest that nearshore biological responses to the heatwave appear to continue, even into 2018, and could possibly affect future recruitment of species whose early life stages rely on nearshore habitat. We also expect to see responses of nearshore-reliant species (such as sea otters and sea ducks) to shifts in prey availability across the Gulf of Alaska from changing ocean conditions.

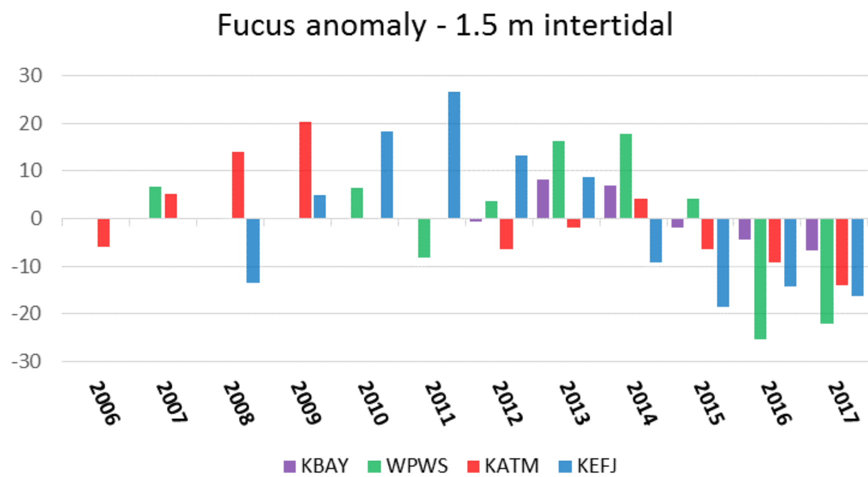

Figure 22: Percent cover anomalies for rockweed (*Fucus distichus subsp. evanescens*) in four regions of the western Gulf of Alaska, WPWS (2007, 2010–2017), KEFJ (2008–2017), KBAY (2012–2017), and KATM (2006–2010, 2012–2017).

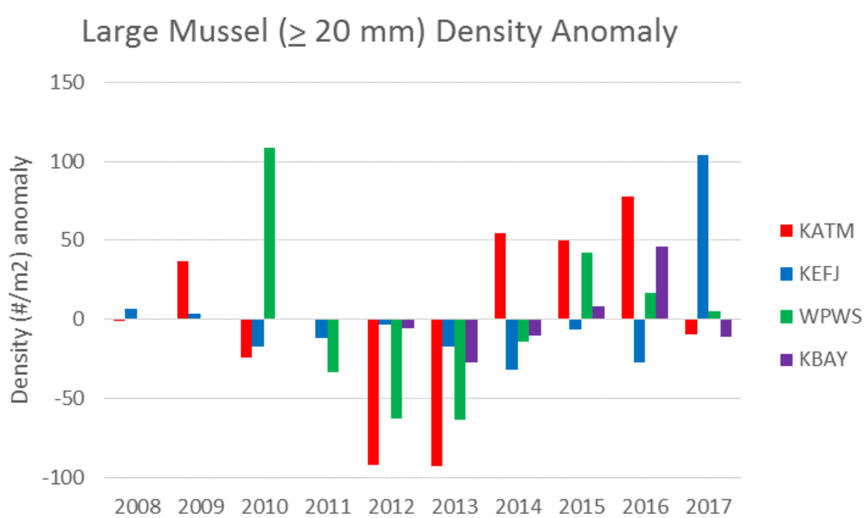

Figure 23: Density anomalies for large mussels (>20 mm) in four study regions spanning the northern Gulf of Alaska. WPWS (2010–2017), KEFJ (2008–2017), KBAY (2012–2017), and KATM (2008–2010, 2012–2017).

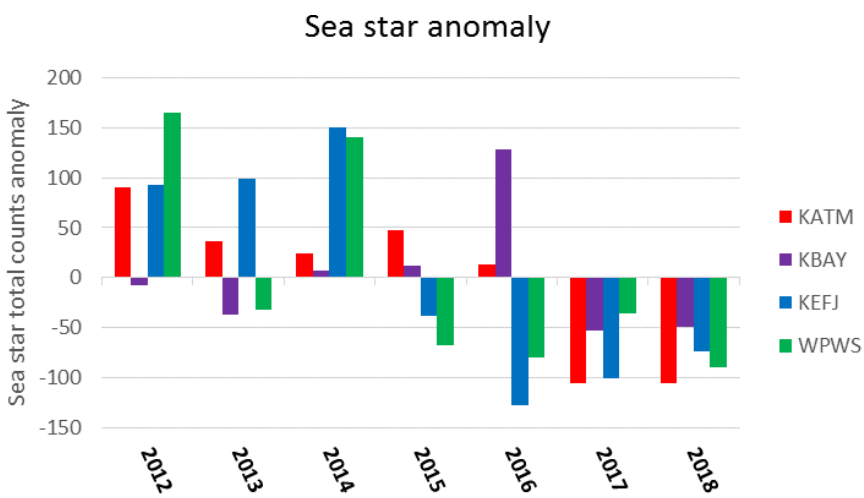

Figure 24: Abundance of sea stars (*Dermasterias imbricata*, *Evasterias troschelii*, *Pisaster ochraceus*, and *Pycnopodia helianthoides*) in four study areas spanning the northern Gulf of Alaska. WPWS (2007, 2010–2018), KEFJ (2008–2018), KBAY (2005, 2009, 2011–2018), and KATM (2006, 2008–2010, 2012–2018).

Primary Production

There are no updates to primary production indicators in this year's report, except for the diatom trends in the Continuous Plankton Recorder contribution by Batten (p. 65. See the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Zooplankton

Continuous Plankton Recorder Data from the Northeast Pacific through 2017

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Last updated: July 2018

Description of indicator: Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. Two transects are sampled seasonally, both originating in the Strait of Juan de Fuca, one sampled monthly (∼Apr–Sept) which terminates in Cook Inlet, the second sampled 3 times per year (in spring, summer and autumn) which follows a great circle route across the Pacific terminating in Asia. Several indicators are now routinely derived from the CPR data and updated annually. In this report we update three indices for three two regions (Figure 25); the abundance per sample of large diatoms (the CPR only retains large, hard-shelled phytoplankton so while a large proportion of the community is not sampled, the data are internally consistent and may reveal trends), mesozooplankton biomass (estimated from taxon-specific weights and abundance data) and mean copepod community size (see Richardson et al., 2006 for details but essentially the length of an adult female of each species is used to represent that species and an average length of all copepods sampled calculated) as an indicator of community composition. Anomaly time series of each index have been calculated as follows: A monthly mean value for each region is first calculated. Each sampled months mean is then compared to the long-term mean of that month and an anomaly calculated (Log_{10}). The mean anomaly of all sampled months in each year is calculated to give an annual anomaly.

The indices are calculated separately for the oceanic Northeast (NE) Pacific and the Alaskan shelf southeast of Cook Inlet (Figure 25). The oceanic NE Pacific region has the best sampling resolution as both transects intersect here. This region has been sampled up to 9 times per year with some months sampled twice. The Alaskan shelf region is sampled 5–6 times per year by the north-south transect. New this year, the top three taxa by abundance and biomass in 2017 are presented to allow comparison across Alaskan CPR sampling regions 1. Biomass is a taxon specific value from literature, not actually measured. Some taxa are a group of many species, some are individual life history stages of a single species. Aggregating by season can mask phenological differences. For example, the copepod *Neocalanus plumchrus* is common in spring but nearly absent in late summer/fall. This project is funded in part by the Gulf Watch Alaska long-term monitoring program funded by the *Exxon Valdez* Oil Spill Trustee Council.

Status and trends: The diatom abundance anomaly for the shelf region was the most positive of the time series in 2017, owing to strong spring and autumn blooms. In the open ocean the diatom abundance was still negative, as it has been for most of the recent years. The copepod community size anomaly was positive in both regions in 2017, ending the run of smaller than average values that had occurred. The zooplankton biomass anomaly continued to be positive on the shelf, and average in the open ocean.

Factors influencing observed trends: Ocean conditions in 2017 had reverted to more typical with the Pacific Decadal Oscillation only slightly positive compared to the preceding years of 2014-2016 which had experienced a marine heatwave (DiLorenzo and Mantua, 2016). A particularly clear response in the lower

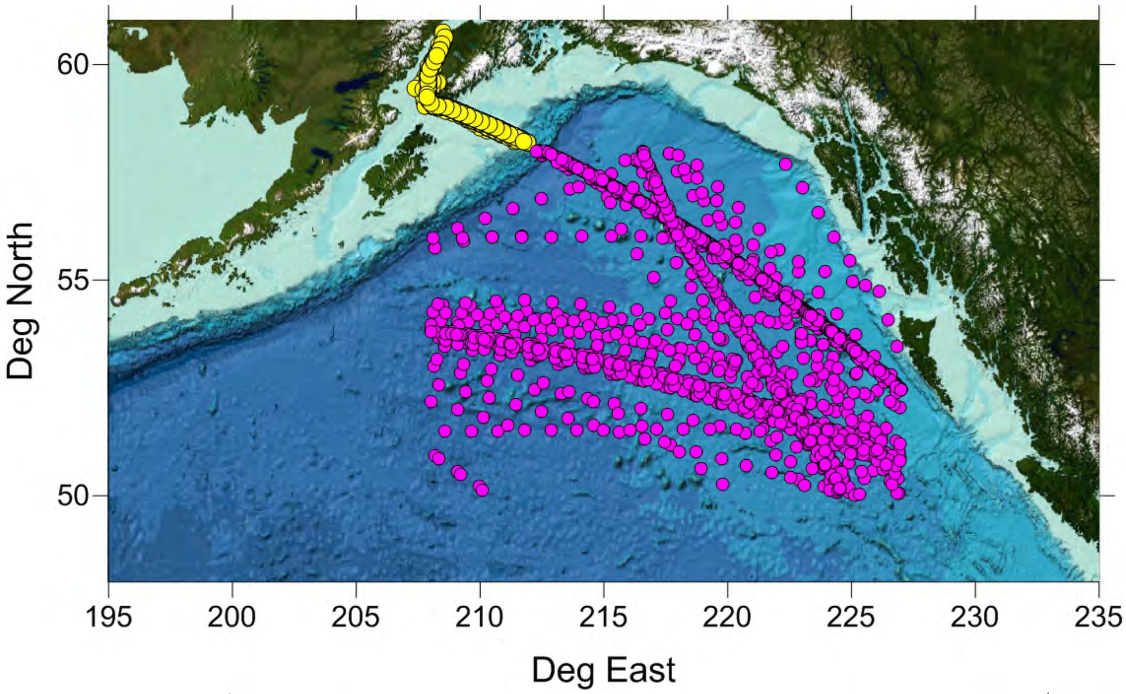

Figure 25: Location of the data used in this report. Dots indicate actual sample positions (note that for the shelf region the multiple transects overlay each other almost entirely).

trophic levels to this reversion was the return to a larger mean copepod community size. In warm conditions smaller species are more abundant and the index was negative throughout the marine heatwave period of 2014-2016, but positive in 2017.

Implications: Each of these plankton variables is important to the way that ocean climate variability is passed through the phytoplankton to zooplankton and up to higher trophic levels. Changes in community composition (e.g. abundance and composition of large diatoms, prey size as indexed by mean copepod community size) may reflect changes in the nutritional quality of the organism to their predators. Changes in abundance or biomass, together with size, influences availability of prey to predators. The large positive anomaly in diatoms on the shelf in 2017 suggests that productivity improved in this region last year (the CPR samples the larger cells which had been much reduced during preceding years) especially coupled with a larger mean copepod size and positive mesozooplankton biomass anomaly. Changes in the open ocean region are more ambiguous since diatoms remained lower than average, mesozooplankton biomass was neutral but the copepods were larger.

May Large Copepod and Euphausiid Biomass along the Seward Line

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Description of indicator: Transects have been completed south of Seward Alaska typically during the first 10 days of May for over two decades to determine species composition, abundance, and biomass of the zooplankton community. Data is averaged over the top 100 m of the water column to provide estimates of wet-weight biomass of zooplankton summarized here for all calanoid copepods and euphausiids (krill) retained by a 0.5mm mesh net. These categories represent key prey for a variety of fish, marine mammals,

Table 1: The top three taxa by abundance and biomass across Alaska CPR regions in 2017.

	Taxa by abundance	Mean # sample	Taxa by Biomass	mg per sample
Southern Bering Sea/Aleutians	*Foraminifera*	214.7	*Neocalanus plumchrus* V	44.2
	Neocalanus plumchrus I_IV	102.7	*Neocalanus flemingeri* V	8.7
	Oithona spp.	91.0	*Eucalanus bungii*	7.4
Alaskan Shelf	*Pseudocalanus spp.*	687.4	*Neocalanus plumchrus* V	23.1
	Limacina helicina	153.7	*Pseudocalanus spp.*	13.4
	Neocalanus plumchrus V	47.4	*Neocalanus cristatus* V_VI	13.0
Oceanic NE Pacific	*Pseudocalanus spp.*	84.9	*Neocalanus cristatus* V_VI	18.3
	Tintinnida Total	83.8	*Neocalanus plumchrus* V	5.0
	Foraminifera	83.3	*Limacina helicina*	2.9

and seabirds. This project is funded in part by the Gulf Watch Alaska long-term monitoring program funded by the *Exxon Valdez* Oil Spill Trustee Council.

Status and trends: In 2018, mean biomass (mg/m^3) of calanoids and euphausiids along the Seward Line during May were higher than the long-term mean, 1998–2017 (Figures 27 and 28).

Factors influencing observed trends: There are currently no anomalous atmospheric conditions influencing the Gulf of Alaska that are pushing zooplankton communities to atypical states. Large copepod biomass tends to track spring temperatures not because there are more of them, but because they grow faster and therefore individuals are larger when waters are warmer. The warm springs of 2015 and 2016, and their subsequent return to more "typical" temperature appears to have a positive impact on overall community biomass, although it has significantly altered the mix of species contributing to it. In contrast, euphausiid biomass appears to be negatively impacted by warm springs, with peaks often driven by high abundances of their larval stages when conditions are favorable (as is currently the case in 2018).

Implications: These zooplankton categories represent key prey for a variety of fish, marine mammals, and seabirds. While high biomass of larger zooplankton does not guarantee success of species dependent upon them (due to a variety of other factors), low biomass does makes predator success challenging. Changes in the mixture (and energetic content) of species contributing to overall biomass may be of consequence to specific predators. With biomass of both large copepods and euphausiids above average during May 2018, there is no reason to expect prey resources to be limiting to vertebrate predators for the remainder of 2018.

Zooplankton trends in Prince William Sound

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Last updated: September 2018

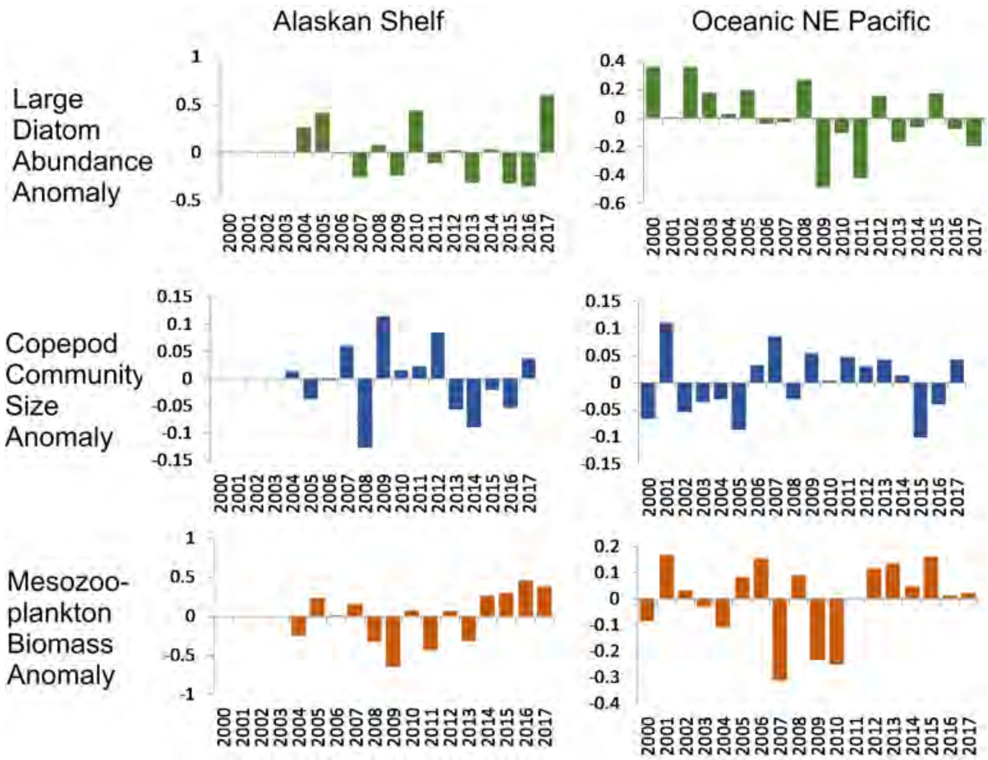

Figure 26: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for both regions shown in Figure 25. Note that sampling of the shelf region did not begin until 2004.

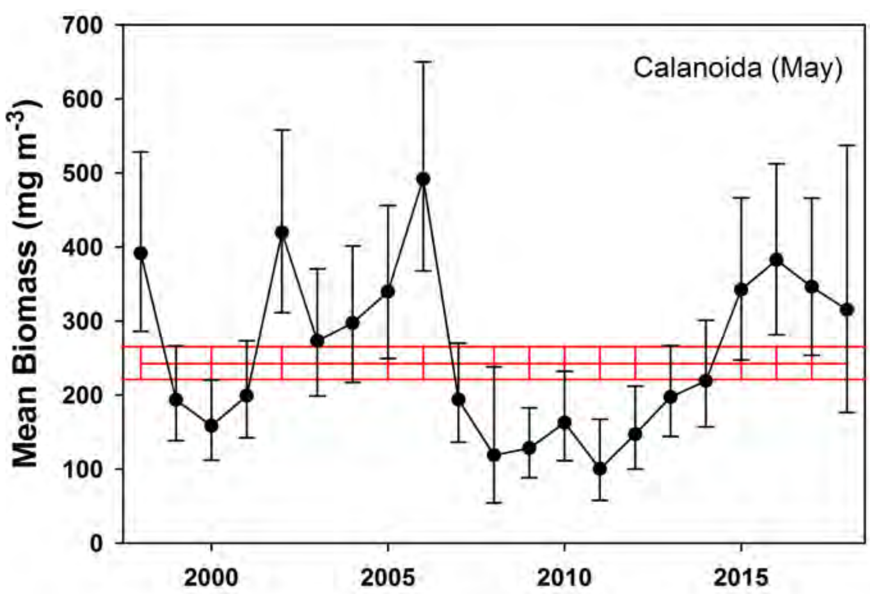

Figure 27: Biomass of Calanoid copepods along the Seward Line sampled using a 0.5-mm mesh at night. Transect means and 95% confidence intervals (black) are calculated on power-transformed data. Long-term means and their confidence intervals are indicated (red).

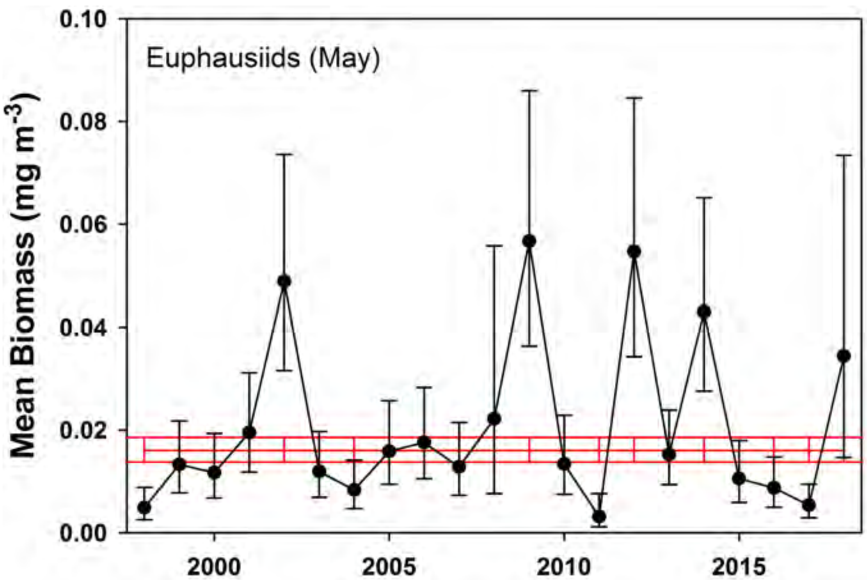

Figure 28: Biomass of Euphausiids along the Seward Line sampled using a 0.5-mm mesh at night. Transect means and 95% confidence intervals (black) are calculated on power-transformed data. Long-term means and their confidence intervals are indicated (red).

Description of indicator: Plankton samples in PWS have been collected and counted since 2010 under the Gulf Watch Alaska program and a predecessor Herring Research and Monitoring program, using standardized methods (McKinstry and Campbell, 2018). Zooplankton was collected using a 202 micron mesh bongo net. Surveys were approximately monthly during the growing season, attempting to sample prior to, during, and after the spring and autumn blooms. Records were much more sparse than temperature observations, because plankton samples are more complicated to collect and their analysis (done by hand, under a microscope) is much slower and expensive. Observations were $\log_{10}+1$ transformed and averaged by month and subtracted from the monthly average to produce an anomaly. This project is funded in part by the Gulf Watch Alaska long-term monitoring program funded by the *Exxon Valdez* Oil Spill Trustee Council.

Status and trends: Zooplankton abundance is extremely variable, and seven years is not a particularly long time series; the observations do however span the 2013–2017 marine heatwave and several years before it. Although there have not been any particularly large trends in the abundance of zooplankton overall (Figure 29, top panel), the species assemblages appear to have shifted, with warm water copepod species becoming much more prevalent during the marine heatwave years (Fig. 2, middle panel), while the abundance of cool water species was lower than average (Figure 29, bottom panel). In 2017, lower than average abundances of zooplankton were observed in Prince William Sound (Figure 29), while more warm water copepods were seen earlier in the year followed by a mixture of warm and cold water species.

Factors influencing observed trends: Temperature is an important forcing function for the vital rates of most lower trophic level players (e.g. growth rates by cold-blooded organisms). Different species have different temperature preferences, and temperature also influences what species are present. Temperature thus influences the food environment of fish predators, as well as their growth rates. Warm-preferring species are generally more common within PWS than on the adjacent shelf and PWS may be a "refuge" of sorts for those species. The increase in their relative abundance during the marine heatwave years may have been in part because those species do tend to be found in PWS and were already there, and thus able to grow and reproduce better during the marine heatwave years. Similarly, cool water species may have been at a competitive disadvantage during the marine heatwave years.

Implications: Abundance of copepod species have been identified as characteristic of warmer or cooler

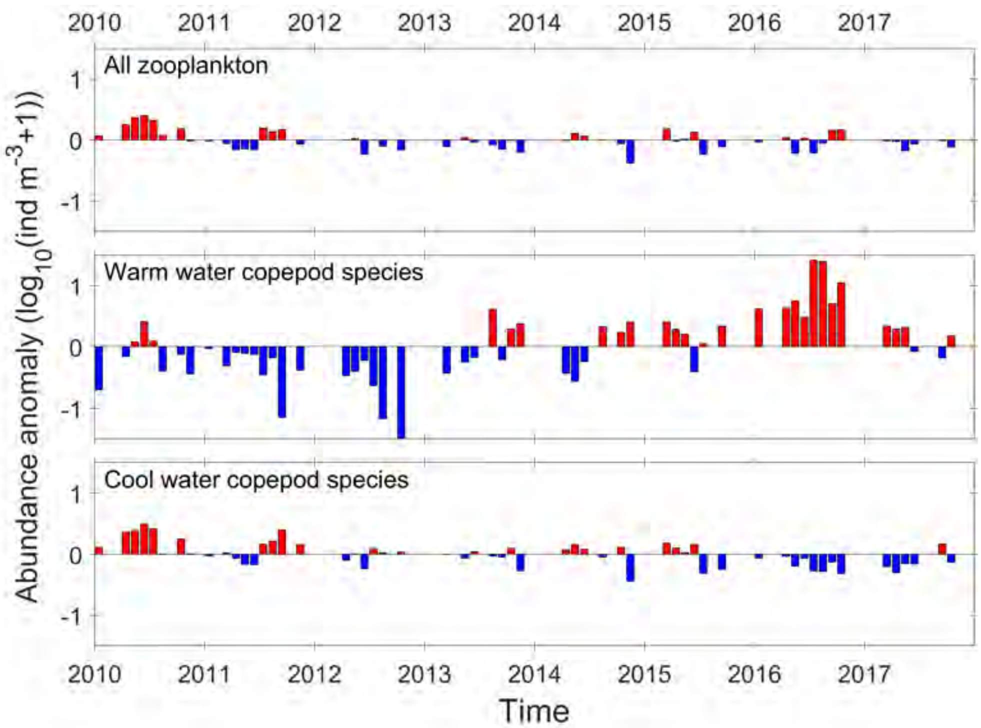

Figure 29: Abundance anomalies of all zooplankton (top panel), warm water copepod species (middle panel) and cool water copepod species (bottom) panel in PWS, 2010–2017. Observations were $\log^{10}+1$ transformed and averaged by month and subtracted from the monthly average to produce an anomaly; no detrending was done. Warm water and cool water species were those identified as indicative by Rykaczewski et al. (2015) and Peterson et al. (2017). Warm water species are *Calanus pacificus*, *Clausocalanus spp.*, *Corycaeus anglicus*, *Ctenocalanus vanus*, *Mesocalanus tenuicornis* and *Paracalanus parvus*. Cool water species are *Calanus marshallae*, *Pseudocalanus spp.*, *Acartia longiremis* and *Oithona similis*.

waters. "Warm" water species are generally common to the southern portion of the Gulf of Alaska and are smaller bodied, and possess smaller lipid reserves. "Cool" water species are more common to northern subarctic waters and are large bodied and often possess very large lipid reserves (>50% of body mass) that are used to fuel a dormant overwintering stage (akin to hibernation). The cool water assemblage is generally a higher quality food for predators, such as forage fish and juvenile groundfish. The continued warming trend in the PWS will likely result in the plankton assemblage of the region shifting towards smaller-bodied forms with lower lipid contents, which will represent a lower quality food source to larval and juvenile fish of many types.

Long-term Zooplankton and Temperature Trends in Icy Strait, Southeast Alaska

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Last updated: September 2018

Description of indicator: The Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories, AFSC, has been investigating how climate change may affect Southeast Alaska (SEAK) nearshore ecosystems in relation to juvenile salmon and associated biophysical factors since 1997 (Fergusson et al., 2013; Orsi et al., 2015). Temperature and zooplankton data have been collected annually in Icy Strait during monthly (May to August) fisheries oceanography surveys.

This report presents 2018 annual values of temperature and zooplankton in relation to the long-term trends in Icy Strait. The Icy Strait Temperature Index (ISTI, °C) is the average temperature of the upper 20-m integrated water column. Zooplankton density (number per m^3) was computed from 333-μm bongo net samples ($\leq$200 m depth) (Orsi et al., 2004; Park et al., 2004). Temperature and zooplankton anomalies were computed as deviations from the long-term annual mean values. The temperature and zooplankton measures were used to describe the nearshore environment utilized by many commercially and ecologically important forage fish in SEAK.

Status and trends: The ISTI shows the annual temperature trend identifying warm and cool years, with 11 years warmer and 11 years cooler than the average (9.2°C). Overall, the ISTIs ranged from 8.2°C to 10.0°C, and anomalies did not exceed ±0.9°C (Figure 30). The ISTI in 2018 was average (9.2°C) and showed an increase by approximately 0.4°C from the anomalously cool temperatures in 2017.

The zooplankton density shows the trend in zooplankton abundance and also reflects the health of this important lower trophic level community. Overall, the long-term mean zooplankton density ranged from 886 to 2,866 organisms per m^3 (Figure 31). The 2018 total density of zooplankton was above average and showed an increase from the 2017 total density. Additionally, the 2018 density is the 5^{th} highest density observed over the 22 year time series. For all years, total zooplankton density and temperature were weakly correlated but not significantly, with positive and negative anomalies occurring in both warm and cold years (r = 0.3, $P = 0.17$). (r = 0.11, $P = 0.64$).

Overall, the zooplankton community was numerically dominated by small ($\leq$2.5 mm length; $\leq$74% composition) and large (>2.5 mm; $\leq$38% composition) calanoid copepod species. Three other taxa, important in fish diets (Sturdevant et al., 2012; Fergusson et al., 2013), contributed to the community in smaller percentages (euphausiids, $\leq$12%; gastropods, $\leq$20%; and hyperiid amphipods, $\leq$3%). For 2018, densities of small calanoids increased from below average to above average, with 2018 being the 5^{th} highest density of small calanoids in the 22 year time series. All other taxa, large calanoid copepods, euphausiids, hyperiid amphipods, and gastropods decreased from 2017 densities and all were below average. Most notably is the dramatic decrease in large calanoid copepods and hyperiid amphipods (from above average to below average). With the exception of small calanoid copepods, all of the zooplankton groups showed a negative response to the increase in the ISTI.

Factors influencing observed trends: Subarctic zooplankton typically follow seasonal cycles of abundance, however as indicated here, responses to climate change may be species-specific. These species-specific differences may be based on life history, seasonal timing cues, physiology, and environmental parameters other than temperature (Mackas et al., 2012), and these responses could depend on the monthly timing, magnitude, and duration of temperature anomalies in warm or cold years. Therefore, the ISTI may not adequately explain shifts in abundance and composition of these prey fields, particularly at broader taxonomic scales. To more accurately reflect critical trophic interactions with respect to climate change, an analysis at the species level would be needed and should include a prey quality measure, such as % lipid.

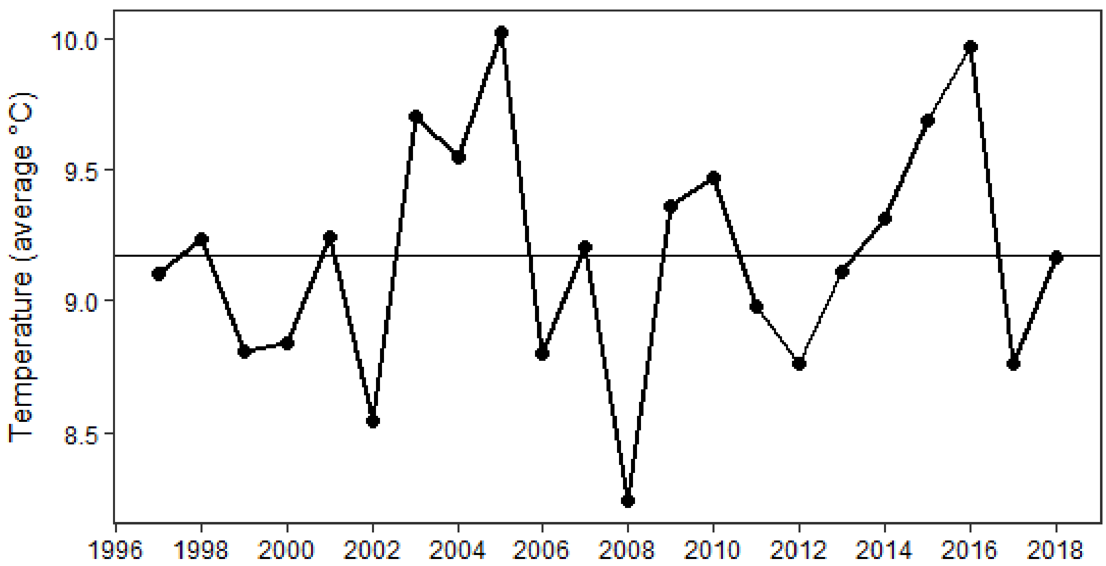

Figure 30: Mean annual Icy Strait Temperature Index (ISTI, °C, 20-m integrated water column, May-August) and 22-year mean ISTI (dashed line), for the northern region of SEAK from the Southeast Coastal Monitoring project time series, 1997–2018

Implications: The increase in small copepods was beneficial to larval fish that depend on these zooplankton as prey. The decrease in densities of the other zooplankton, especially large calanoid copepods and euphausiids indicated a decrease in the available food resource utilized by many commercially important fish that reside in Icy Strait, which may directly or indirectly affect fish growth and recruitment.

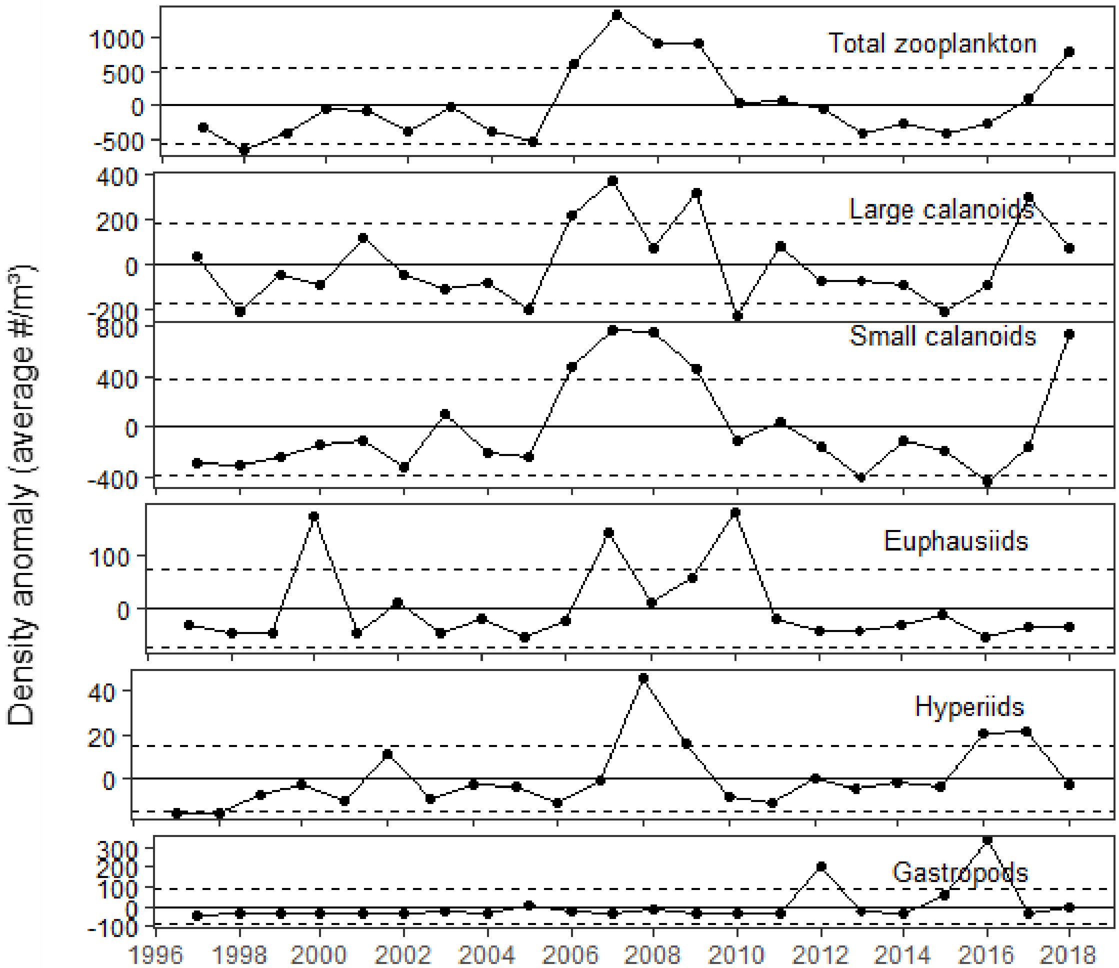

Figure 31: Average annual total zooplankton and taxa specific density anomalies for the northern region of SEAK (Icy Strait) from the Southeast Coastal Monitoring project time series, 1997–2018. One standard deviation above and below the mean is indicated by the dashed lines. Annual densities are composed of zooplankton samples collected monthly from May to August in Icy Strait. No samples were available for August 2006 or May 2007.

Zooplankton Nutritional Quality Trends in Icy Strait, Southeast Alaska

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Last updated: September 2018

Description of indicator: The Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories, AFSC, has been investigating how climate change may affect Southeast Alaska (SEAK) nearshore ecosystems in relation to juvenile salmon and associated biophysical factors since 1997 (Fergusson et al., 2018). Since 2013, zooplankton lipid content data have been collected annually in Icy Strait during monthly (May to August) fisheries oceanography surveys.

This report presents 2018 annual values of zooplankton lipid content for specific taxa in relation to the past 5 year trend in Icy Strait. These zooplankton are an important prey resource to fish that reside in Icy Strait. Lipid content was determined using a modified colorimetric method (Van Handel, 1985). Taxa examined were chosen based on their importance to larval and juvenile fish diets (Fergusson et al., 2013; Sturdevant et al., 2012). These taxa include: large and small calanoid copepods, *Calanus marshallae* and *Pseudocalanus* spp., respectively, young euphausiids (furcillia and juveniles), *Limacina helicina* (gastropod), and *Themisto pacifica* (hyperiid amphipod).

Status and trends: Overall, the lipids of all zooplankton taxa examined in 2018 increased from 2017 lipid values (Figure 32). For all taxa, except the large calanoid copepod, *Calanus marshallae*, all lipid levels increased from below to above the 6 year average lipid level.

Factors influencing observed trends: Subarctic zooplankton communities are influenced by physical and biological factors including basin scale events, water temperature and salinity, advection, freshwater discharge, phytoplankton abundance (zooplankton food), and predator abundance (top-down control). Changes in the zooplankton community influence the trophic food web and may alter fish growth and recruitment. For example, a complete restructuring of the North Sea zooplankton communitys copepod population was observed after the 1990s regime shift (Beaugrand, 2004) that eventually propagated up the food web (Alvarez-Fernandez et al., 2012). In the Bering Sea, high-lipid copepods are more abundant during a cold phase than during a warm phase, when lower lipid copepods dominate the prey field (Coyle et al., 2011). The abundance of high-lipid copepods trophically links to overwinter survival of juvenile pollock that must reach an energy minima if they are to survive through the food-limited winter (Heintz et al., 2013). During cold years in the Bering Sea, juvenile pollock enter winter with a higher energy content, reached by consuming a lipid-rich diet, which results in an increased recruitment of age-1 pollock compared to recruitment during warm years.

Implications: The overall increase in lipid content of all zooplankton taxa examined indicates an increase in the nutritional quality of the prey field utilized by larval and juvenile fish in Icy Strait. The increase may also indicate that the zooplankton community is rebounding from the low lipid levels observed during the El Niño/Blob period of anomalously warm temperatures from 2014–2016. The increase in nutritional quality of zooplankton indicates favorable feeding conditions for larval and juvenile stages of many commercially and ecologically important fish that reside in Icy Strait, which may directly or indirectly affect fish growth and recruitment.

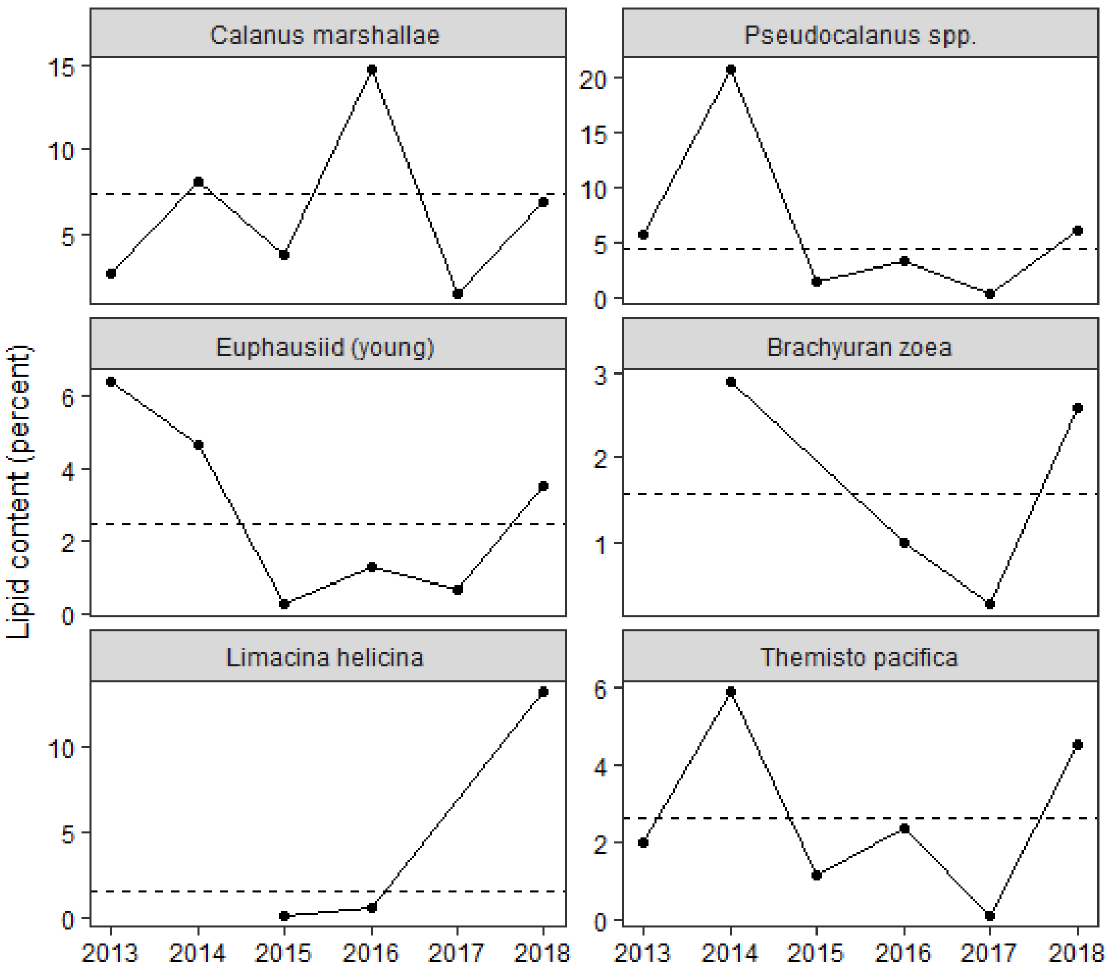

Figure 32: Average annual zooplankton lipid content (percent) from zooplankton collections in Icy Strait, AK by the Southeast Coastal Monitoring project, 2013–2018. Time series average is indicated by the dashed line.

Jellyfish

There are no new or updated jellyfish indicators this year.

Ichthyoplankton

Larval Fish Abundance in the Gulf of Alaska 1981–2017

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Last updated: August 2018

Description of indicator: The Alaska Fisheries Science Centers (AFSC) Ecosystems and Fisheries Oceanography Coordinated Investigations Program (EcoFOCI) has been sampling ichthyoplankton in the Gulf of Alaska (GOA) from 1972 to the present, with annual sampling from 1981–2011 and biennial sampling during odd-numbered years thereafter. The primary sampling gear used is a 60-cm bongo sampler fitted with 333 or 505-μm mesh nets. Oblique tows are carried out mostly from 100 m depth to the surface or from 10 m off bottom in shallower water (Matarese et al., 2003, Ichthyoplankton Information System `http://access.afsc.noaa.gov/ichthyo/index.php`). Historical sampling has been most intense in the vicinity of Shelikof Strait and Sea Valley during mid-May through early June Figure 33). From this area and time, a subset of data has been developed into time-series of ichthyoplankton abundance (after Doyle et al., 2009)) for the 12 most abundant larval taxa in the GOA, including commercially and ecologically important species (Figure 34). Time series are updated in even years, one year after collection, due to processing time required for quantitative data. On-board counts of a limited number of taxa give rapid assessments of abundance, which are presented in the year of collection (Dougherty and Rogers, 2017).

Status and trends: Abundances for most species have returned towards average levels after the impact of the "Blob" marine heatwave in the Gulf of Alaska. Many species, including Pacific cod and walleye pollock, had record low abundances in 2015, which presaged recruitment failures for these stocks. In 2017, walleye pollock larval abundance was above average, as also indicated by on-board rough counts of larvae presented in Dougherty and Rogers (2017). Pacific cod appear to have recovered somewhat from the low in 2015, but remained below average in 2017. All but three taxa saw an increase in larval abundance from 2015 levels. Larval rockfish departed from the trend of increasing abundance observed since 2007, and declined to the long-term mean. Southern rock sole abundance was anomalously high (second highest on record), and has been increasing, on average, since 2000.

Factors influencing observed trends: The warm blob in the Gulf of Alaska had wide-ranging consequences for the marine ecosystem (Zador et al., 2017). The anomalous warm conditions corresponded to extreme low abundances of larvae for many species. As the Gulf cooled again in 2017, ichthyoplankton data gave an indication that the ecosystem returned to more "normal" conditions. Previous work has explored trends in abundance of these species in relation to atmospheric and oceanographic conditions (Doyle et al., 2009; Doyle and Mier, 2012). Similarities in response to environmental forcing were apparent among species that display similarities in patterns of early life history exposure to the environment (Doyle et al., 2009). For instance, years of high abundance for the late winter to early spring shelf spawners Pacific cod, walleye pollock, and northern rock sole were associated with cooler winters and enhanced alongshore winds during spring. Observations in 2017 continued to support these patterns of common responses for species with similar early life history exposure. Southern rock sole have become more prevalent than their congener northern rock sole, indicating improved conditions for the more southerly species in recent years. Climate-driven phenological shifts may also play a role in measured relative abundance between years.

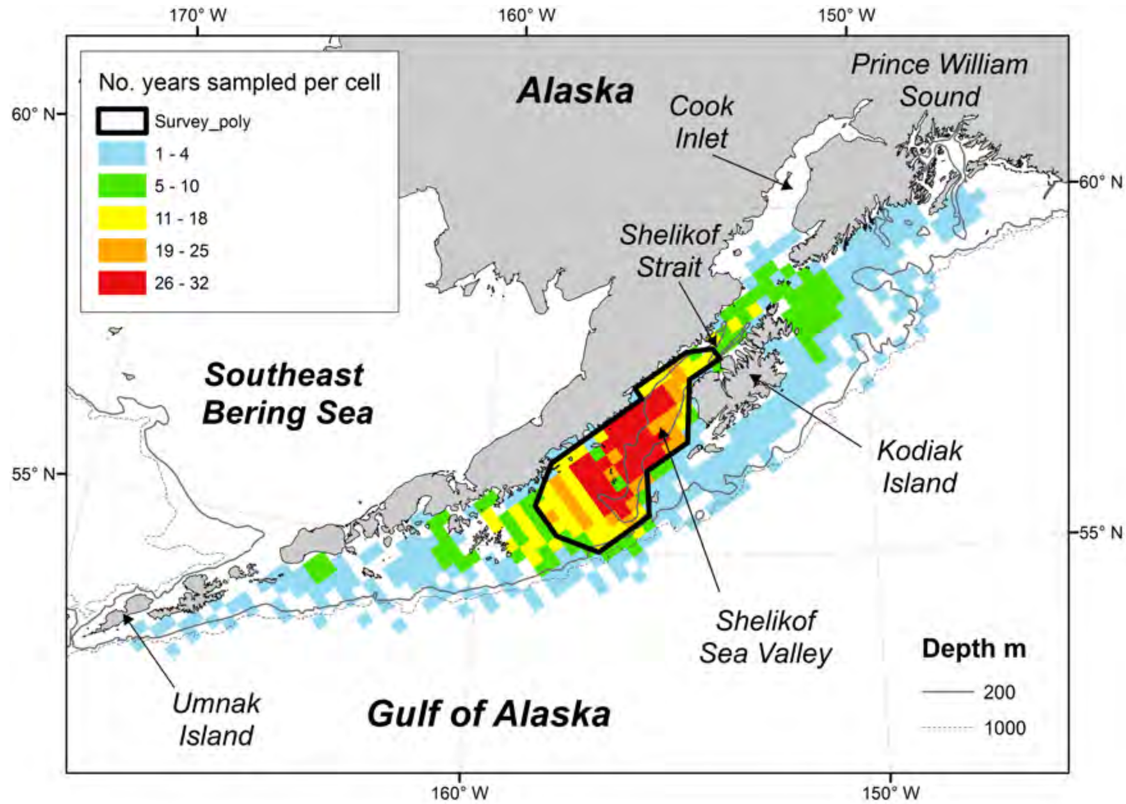

Figure 33: Distribution of historical ichthyoplankton sampling in the Gulf of Alaska by NOAA's Alaska Fisheries Science Center using a 60 cm frame bongo net. Sampling effort is illustrated by the number of years where sampling occurred in each 20 km^2 grid cell during late spring. A time-series has been developed for the years 1981-2017 from collections in the polygonal area outlined in black where sampling has been most consistent during mid-May through early June. Note that this polygon was updated in 2018 to reflect sampling intensity through the most recent years.

Implications: Ichthyoplankton surveys can provide early-warning indicators for ecosystem conditions and recruitment patterns in marine fishes. In 2015, record-low abundances of walleye pollock and Pacific cod larvae were the first indicators of failed year-classes for those species. While mortality during later life stages is clearly important, poor conditions during the first few weeks and months of life can already determine the potential for a large year class, emphasizing the importance of studying processes affecting mortality and abundance of early life history stages. Conditions in 2017 suggest a return to a more average ecosystem state, with increased foraging opportunities for seabirds and potential for stronger year classes of commercially important stocks, especially walleye pollock.

Forage Fish and Squid

Seabird-Derived Forage Fish Indicators from Middleton Island

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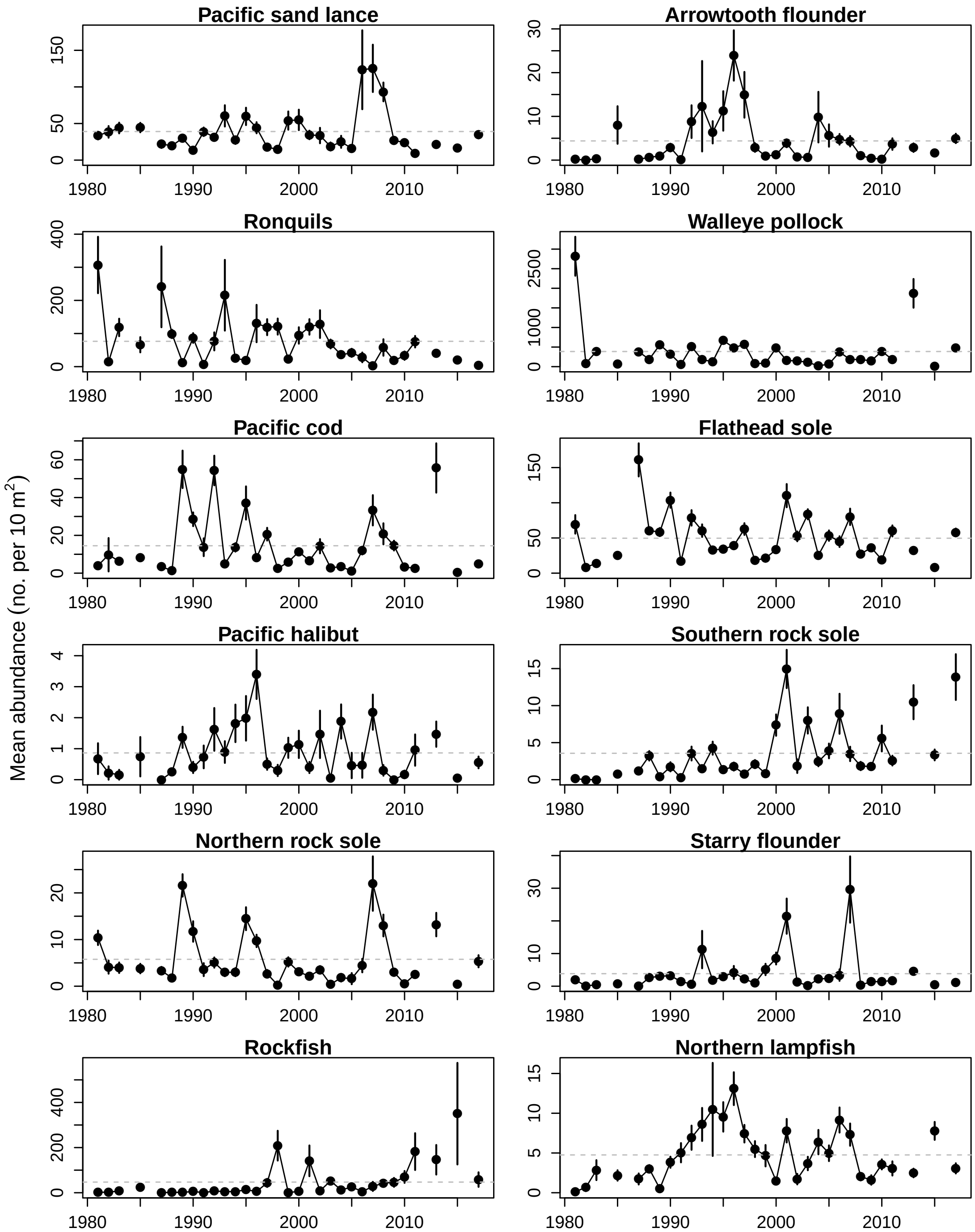

Figure 34: Interannual variation in late spring larval fish abundance in the Gulf of Alaska 1981–2017. The larval abundance index is expressed as the mean abundance (no. 10 m^{-2}), and the long-term mean is indicated by the dashed line. Error bars show +/- 1 SE. No data are available for 1984, 1986, 2012, 2014, or 2016. Time-series may differ slightly from previous versions due to updating the spatial polygon used for selecting historical data.

Last updated: October 2018

Description of indicator: Time series of seabird and forage fish monitoring at Middleton Island in the north-central Gulf of Alaska are among the longest available from any Alaska location. Being situated near the continental shelf edge (lat 59.4375, lon -146.3277), Middletons seabirds sample both neritic habitat and deep ocean waters beyond the shelf break. Consequently, certain species of ecological concern (myctophids) and/or economic concern (0-age group sablefish) figure prominently in seabird diets at Middleton, unlike anywhere else these prey and their seabird predators might be monitored.

In most years since 2000, regurgitated food samples have been collected from adult and/or nestling black-legged kittiwakes (*Rissa tridactyla*) during all months April through August. From an evaluation of alternate methods of analyzing and reporting diet results, the preferred metric for kittiwakes is prey relative occurrence (Hatch, 2013), for which the relevant sample units are numbers of identified prey types in a given sample. Rhinoceros auklet (*Cerorhinca monocerata*) diets are monitored by collecting bill-loads from chick-provisioning adults, usually once or twice a week from early July through early or mid-August. Since 1978, more than 100 kg of auklet prey samples have been collected on Middleton, and auklet diet monitoring provides our single best indicator of forage fish dynamics in the region. This project is funded in part by the Gulf Watch Alaska long-term monitoring program funded by the *Exxon Valdez* Oil Spill Trustee Council.

Status and trends: On average, Middleton kittiwakes take about equal amounts of Pacific sand lance, capelin, and invertebrates, with lesser amounts of herring, sablefish, salmon, and myctophids, depending on stage of the season. The juxtaposition of time series for kittiwakes and rhinoceros auklets since 1978 (Figure 35) shows general agreement between a sustained decline of sand lance and, beginning in 2007, the emergence of capelin as a dominant forage species.

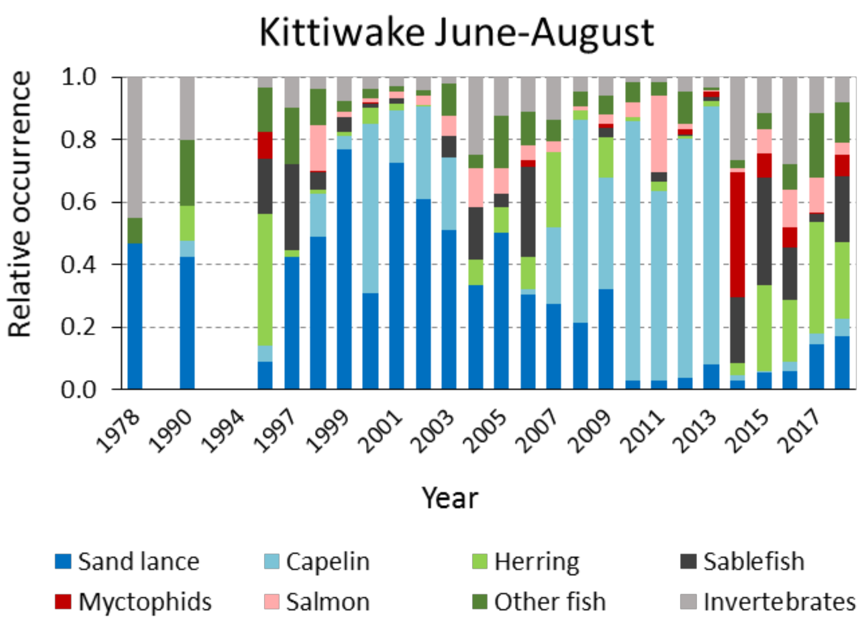

Figure 35: Interannual variation in diet composition of chick-rearing black-legged kittiwakes on Middleton Island, 1978–2018.

Auklet data plotted separately by prey type highlight the interannual dynamics of individual species (Figure 36). By all appearances, sand lance were the overwhelmingly dominant forage species in the northern Gulf in the late 1970s through the early 1980s. Following a period of reduced availability in the mid 1990s, sand lance made a strong comeback by the end of that decade. However, sand lance steadily declined in importance after 2000 and contributed little to seabird diets from 2009 through 2015. The appearance of about 30% sand lance in the auklet diet in 2016 and 2017 is consistent with a known association of sand lance with warm-water conditions (Hatch, 2013). The re-emergence of sand lance continued in 2018, when this species constituted about 50% of the auklet diet by weight (Figure 36). Pacific herring seem also to have benefited from recent warm surface conditions prevalent in the region. However, in years when neither sand lance nor capelin have been prevalent (e.g., 2014–2017), the diets of surface-feeding kittiwakes and diving auklets diverged with respect to prey-switching to alternate species such as myctophids, salmon, and greenlings.

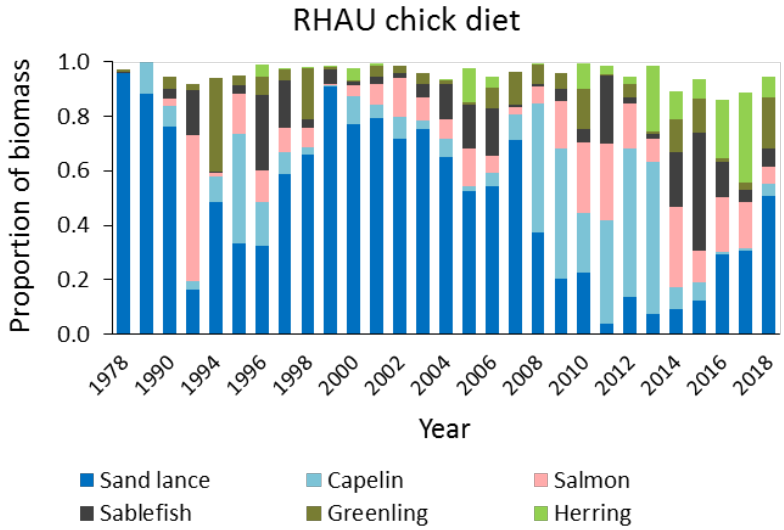

Figure 36: Prey species occurrence in the nestling diet of rhinoceros auklets on Middleton Island from 1978–2018.

Factors influencing observed trends: Seabird diets at Middleton reflect ecosystem shifts in the Gulf of Alaska. This includes specific events recorded and widely discussed in the ecological literature such as the notable shift from "warm" (positive Pacific Decadal Oscillation, PDO) conditions to cold (negative PDO) conditions around 1999–2000 (Greene, 2002; Peterson et al., 2003; Batten and Welch, 2004), a similar but stronger and more persistent shift in 2008 (Hatch, 2013), and a widely reported warm-water anomaly that has dominated the system since late winter 2014 (Bond et al., 2015)). A salient finding during the most recent, anomalous warm-water event has been the virtual disappearance of capelin from the kittiwake diet on Middleton, following 6 prior years when capelin were predominant (Figure 35). An apparent trade-off between Pacific sand lance (warm conditions) and capelin (cold conditions) may be a benchmark of the forage fish community in the region.

Implications: Seabird diets provide further evidence that capelin disappeared in the ecosystem during the recent warm years. Chick diets at Middleton may be informative for sablefish studies. In 2017, the Alaska Fisheries Science Center began using specimens from seabird diet sampling at Middleton for phenology and growth studies of first-year sablefish, which are difficult to sample directly. Seabird diet indicators are potentially applicable to other management concerns in the region, including Pacific herring stocks, which crashed and have not recovered after the Exxon-Valdez Oil Spill in 1989, and year-class strengths of pink and chum salmon, which appear regularly in Middleton seabird diets.

Table 2: Mean energy densities for all species and years in the eastern Gulf of Alaska.

	Pollock	Sablefish	Arrowtooth Flounder	Chinook Salmon	Pink Salmon
2010	-	-		5.07	4.92
2011	-	-	5.85	4.88	4.84
2012	4.38	-	4.55	4.88	5.10
2013	4.49	-	4.50	4.70	5.28
2014	4.23	4.46	4.13	5.18	4.82
2015	4.45	-	4.13	4.99	4.98
2016	4.48	5.26	-	4.95	-
2017	4.61	4.49	5.11	4.58	4.64
Total Average	4.44	4.74	4.48	4.88	4.94

Energy Density Anomalies for Pelagic Life Stages of Five Species in the Eastern Gulf of Alaska during Summer 2010–2017

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Last updated: October 2018

Description of indicator: The indicator shows energy densities of selected juvenile fish species in the eastern Gulf of Alaska (GOA). Species were sampled by a rope trawl in the upper 20 m during the Alaska Fisheries Science Centers eastern GOA Assessment Survey in the summer of 2010–2017. A Nordic 264 trawl was used in 2010 and 2017 while the CanTrawl 400/601 was used in 2011–2016. Stations were positioned approximately 10 nautical miles apart. All species sampled were young-of-the-year (YOY) with the exception of Chinook and pink salmon, which were 1–2 years old and experiencing their first ocean year as juveniles.

Catch weighted energy densities (kJ/g wet weight (ww)) from years 2010–2017 were calculated using CPUE values and averaged across all stations and years for each species. Energy density anomalies were calculated and normalized in order to be accurately compared among the differing species. For some species and years, no energy density data were available and does not reflect the catches of the species.

Status and trends: Temporal trends of energy density anomaly data shows an overall lack of coherence and substantial variation among species (Figure 37). In 2017, energy density was below average for YOY sablefish, juvenile Chinook salmon, and juvenile pink salmon, and above average for YOY pollock and YOY arrowtooth flounder. However, the lowest energy density was observed for all species in 2014, excluding Chinook salmon, which showed the highest energy density in 2014 (Table). For all species, excluding Chinook salmon and sablefish, energy density anomaly values seemed to increase after 2014 (Figure 37).

Factors influencing observed trends: Various feeding strategies are likely to account for the apparent lack of coherence. In 2014, pollock, sablefish, arrowtooth flounder, and pink salmon diets consisted mainly of copepods and euphausiids (ABL, unpublished data). Chinook salmon diets in 2014 consisted mainly of higher trophic level and more energy dense prey items such as fish and squid (ABL, unpublished data). The marine heat wave was building in the eastern GOA in 2014 and increased in intensity in 2016. By 2017, surface waters began cooling but heat could still be detected at depth. Planktivore energy densities dropped in 2014 after experiencing the warming water temperatures, followed by an increase in energy density to

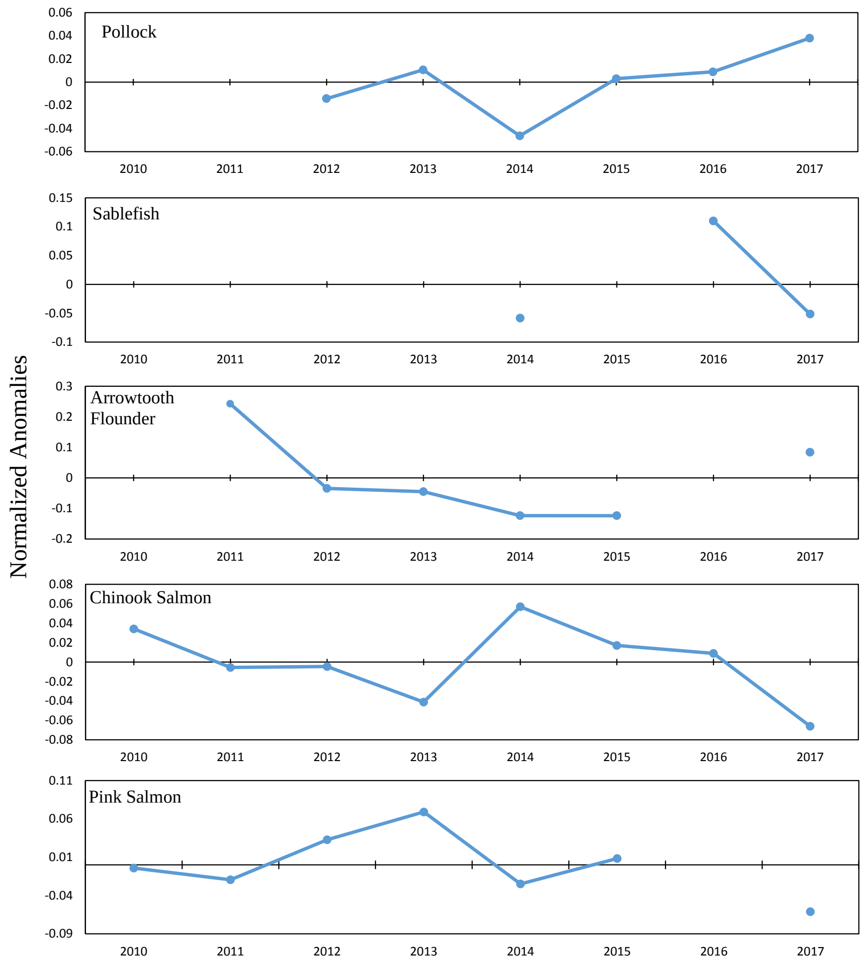

Figure 37: Normalized energy density (kJ/g ww) anomalies of five species in the eastern Gulf of Alaska during the summer months of 2010–2017. Years with no data point indicate no energy density data were available.

date. Higher trophic level consumers may have been buffered for approximately a year before experiencing any effects of warming ocean conditions.

Implications: For pollock, the energy density has been on the rise since the drop in 2014. We anticipate this indicates potential improvements in juvenile survival. However, our limited data from the central GOA suggests condition of pollock in the eastern and central GOA are uncorrelated. Hence, it may be difficult to establish a connection between eastern pollock condition and future survival.

For sablefish, as of 2017, energy density is around the same levels as in 2014. More samples will be analyzed in the coming year.

For arrowtooth flounder, energy density in 2017 had returned to pre-2014 levels. Condition of arrowtooth flounder are suggestive of a return to cooler conditions. Data from the GOAIERP indicate arrowtooth flounder abundance and energy density is inversely related to temperature. The absence of fish in 2016 suggests early settlement. Increased energy densities in 2017 are consistent with cooler water temperatures.

For Chinook salmon, due to the diet items observed, impacts of warming conditions on Chinook salmon may be lagged due to higher trophic level feeding. In later years, energy density decreases may be reflective of a decrease in forage fish species as Chinook salmon are typically piscivorous.

For pink salmon, the two lowest energy densities for even brood year pinks were seen in 2011 and 2015 and coincided with two of the four lowest returns over the last 32 years. The two highest energy densities for odd brood year pinks were seen in 2010 and 2012 and coincided with the second and third highest returns over the last 32 years. Energy density was improved by 2015 and decreased to the lowest level in 2017. Samples from 2016 and subsequent years will be analyzed and added to the time series.

Herring

Prince William Sound Herring

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Last updated: September 2018

Description of indicator: Prince William Sound (PWS) Pacific herring (*Clupea pallasii*) population estimates are generated annually by *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) researchers with an age-structure-assessment (ASA) model using data collected by EVOSTC researchers and Alaska Department of Fish and Game (ADF&G). The original catch-age analysis for PWS herring, developed by Funk and Sandone (1990) for ADF&G stock assessment and management, was later adapted for research and described by Hulson et al. (2007). The results presented here are from a Bayesian version of the ASA model described by Muradian et al. (2017) (hereafter referred to as BASA) that was developed and run by the University of Washington as part of the *Exxon Valdez* Oil Spill Trustee Council sponsored Herring Research and Monitoring program. The model inputs include aerial surveys of mile-days of spawn, acoustic surveys of spawning biomass, age-sex-size, historical egg deposition, and disease prevalence data. The PWS surveys used by the model are conducted in the spring. The survey area covers traditional spawning regions within Prince William Sound and occasional surveys in the Kayak Island area, although Kayak Island is not included in the inputs to the ASA model.

The mile-days of milt surveys collected by ADF&G extend back to the early 1970s, but the approach was standardized in 1980. While the mile-days of milt survey is a relative index of abundance, it is the longest abundance time series used in the model. Acoustic surveys collected by the Prince William Sound Science Center started in the mid 1990s. ADF&G has collected herring age, sex, and size data from PWS commercial fisheries and fishery independent research projects since 1973. Egg deposition scuba surveys were conducted by ADF&G in 1983, 1984, and 1988–1997. In the BASA model, egg deposition are treated as values of absolute abundance. Historical harvests from commercial pound, seine, and gillnet fisheries from 1980–1998 are also included as inputs to the model, although there have been no commercial herring fisheries in PWS since 1998. An output of the model is the annual median estimate of the pre-fishery biomass.

Status and trends: A rapid rise in the estimated prefishery biomass of herring occurred in the 1980s and a subsequent decline in the 1990s (Figure 38). After that decline, the population remained fairly steady. Starting in 2014, the BASA model estimated a declining trend in herring biomass, but then an increase in 2017 (Figure 38). The estimated increase in 2017 is informed by both an increase in the acoustic biomass estimate and a higher proportion of age 3 recruits in the age composition, contrasting the decrease in the observed mile-days of milt (Figure 39). While no BASA estimate of the 2018 biomass is available yet, the observed mile-days of milt continued its decline to the lowest level on record in 2018.

Factors influencing observed trends: There was a peak in antibodies to the viral hemorrhagic septicemia (VHS) virus observed in 2015 that is consistent with an outbreak of that pathogen between 2014 and 2015. The warm waters associated with the “Blob” are likely to have caused nutritional stress that may have contributed to the outbreak of the VHS virus. There is not complete agreement about the cause of the decline in the early 1990s, but an outbreak of VHS is one mechanism thought to be possibly responsible for the decline.

Implications: It is possible that lower abundance of herring may have negative impacts on predators that rely on them. Population information on other forage species in PWS is not known.

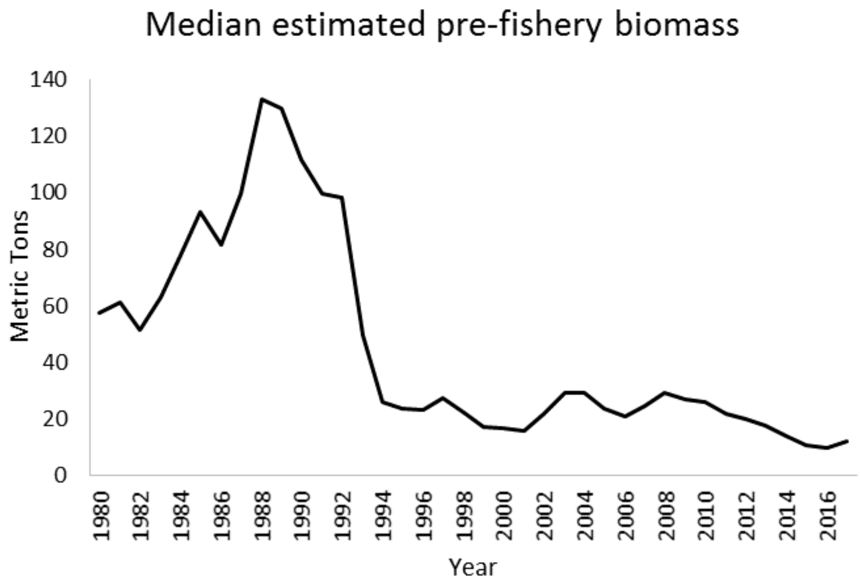

Figure 38: The Bayesian age-structured assessment model median estimate of the pre-fishery biomass.

Southeastern Alaska Herring

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Last updated: October 2018

Description of indicator: Pacific herring (*Clupea pallasi*) stocks that reside in southeastern Alaskan waters are defined on a spawning area basis. In recent decades there have been about nine spawning areas where spawning events have typically been annual and meaningful in size relative to potential for commercial exploitation. These areas include Sitka Sound, Craig, Seymour Canal, Hoonah Sound Hobart Bay-Port Houghton, Tenakee Inlet, Ernest Sound, West Behm Canal, and Kah Shakes-Cat Island (Figure 40). Stock assessments have been conducted at these areas for most years since at least the 1980s by the Alaska Department of Fish and Game, primarily through stock assessments that combine spawn indices with age and size information (Hebert, 2017). Starting in 2016, surveys and stock assessments were eliminated for many stocks in southeastern Alaska due to State of Alaska budget cuts. Although spawning at these areas accounts for a large proportion of the spawning biomass in southeastern Alaska in any given year, other areas with more limited spawning also exist throughout southeastern Alaska. However, little or no stock assessment activity occurs at these minor locations other than occasional and opportunistic aerial surveys to document the miles of spawn along shoreline.

Status and trends: Although industrial-scale herring oil reduction fisheries and foreign fisheries operated in Southeast Alaska, with catch peaking in 1935, reliable estimates of biomass exist only from those data collected since 1980, which are discussed here. For all monitored spawning areas combined, the biomass of Southeast Alaska herring has increased since 1980 (Figure 41). The combined biomass level remained relatively consistent until the late 1990s, at which time it began to increase. Age-structured assessment modeling for the Sitka Sound, Craig, and Seymour Canal herring stocks indicated an increase in adult (age 3+) herring survival in the late 1990s, which coincided with a period of climate change as described by a shift in the Pacific Decadal Oscillation (PDO) index (`http://jisao.washington.edu/pdo/`). However, since peaking around the early 2010s, several stocks have decreased substantially. Assessment modeling

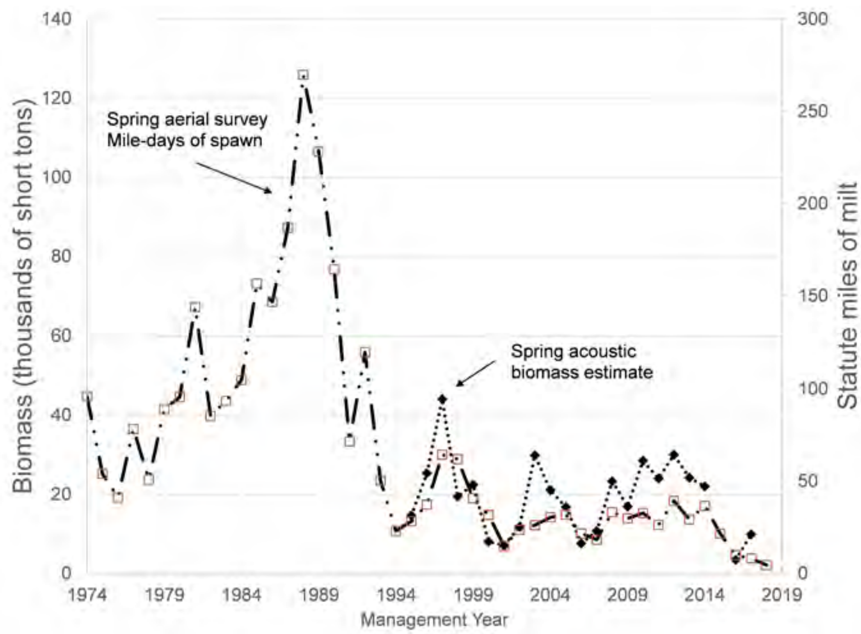

Figure 39: Mile-days of milt in Prince William Sound based on aerial surveys and biomass estimates from acoustic surveys. Includes preliminary results of the 2018 survey from Alaska Department of Fish and Game.

indicates that this may be attributed at least in part to lower survival rates over the past several years.

Current biomass for Southeast Alaskan herring is at a moderate level. Following a period of generally low biomass during the 1980s through mid-1990s, most stocks increased from the mid-1990s to their peaks between 2008–2011. These peak years represent the most productive period for herring in Southeast Alaska that has been documented since at least 1980. Although the two largest and most consistent stocks, Sitka Sound and Craig, have declined substantially from their peaks of 2009 and 2011, respectively, they continue to be at levels well above the thresholds necessary to allow commercial fisheries. Other, smaller stocks in the region have declined to low levels over the past several years and in some cases to small fractions of their peaks (e.g. Hoonah Sound, Seymour Canal, Ernest Sound). Current biomass levels for these areas are unknown because stock assessment surveys were suspended starting in 2016, due to budget cuts. At least two stocks, Hoonah Sound and Hobart Bay, have not rebounded despite fishery closures for several years.

Factors influencing observed trends: The underlying cause for the recent decline in herring survival and biomass in the region remains unknown. Multiple plausible factors may be contributing, including increasing populations of predatory marine mammals, such as humpback whales and Stellar sea lions (Sigler et al., 2009; Muto et al., 2016; Fritz et al., 2016), high levels of predatory fish such as salmon, or the recent shift to warmer sea surface temperatures as reflected in the PDO, which could affect herring prey or metabolism. The herring that spawn in all areas of Southeast Alaska are believed to be affected by the physical and chemical characteristics of Gulf of Alaska waters, though the spawning areas directly exposed to the open coast (Sitka Sound, Craig, Kah Shakes-Cat Island) may be affected the greatest or the most immediately.

Implications: Although it is possible that lower abundance of herring in the region may have short-term deleterious effects on predators that rely on herring, there is not enough information about populations of other forage species to understand the broader net impact on predators. The relatively short life-span of herring and the natural volatility of stock levels, particularly of smaller-sized stocks, make it difficult to speculate on long-term implications to the ecosystem.

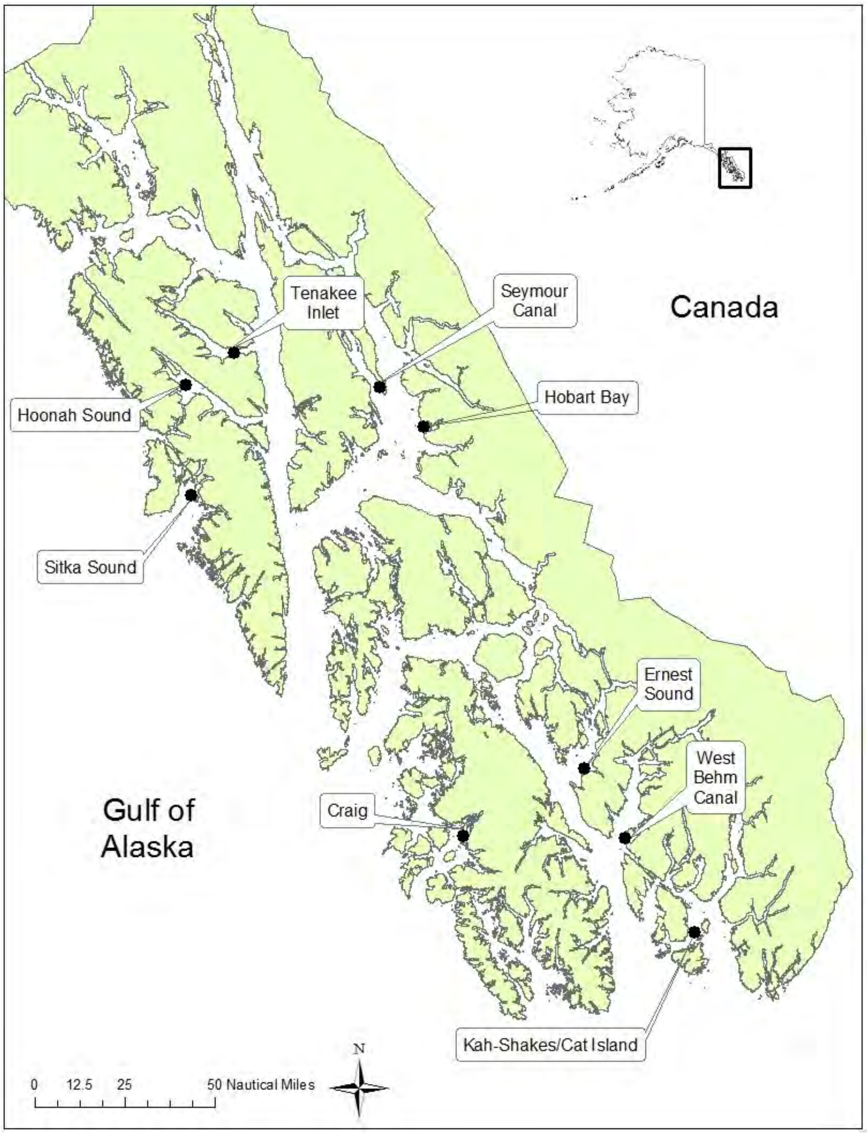

Figure 40: Location of nine important Pacific herring spawning locations in Southeast Alaska.

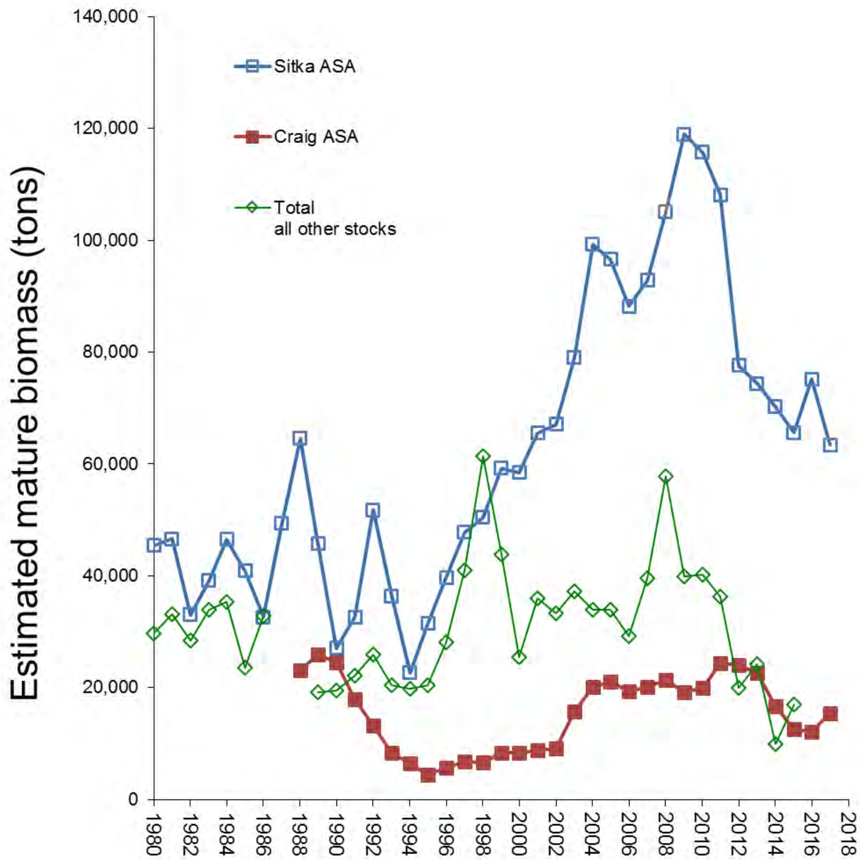

Figure 41: Estimated mature herring biomass (i.e. prefishery biomass) for nine important southeastern Alaska (SEAK) spawning areas, 1980-2017. Biomass estimates for Sitka and Craig are based on age-structured assessment (ASA) models and those for all other stocks, where ASA model estimates are not available, were calculated by converting total egg deposition estimates to biomass using an estimate of eggs per ton of spawners. For years 1987–1988 results were excluded for all other stocks because all stocks were not surveyed in those years. For years 2016–2017, data were excluded for all other stocks because starting in 2016 stock assessment surveys were suspended for most areas due to budget cuts.

Salmon

Salmon Trends in the Southeast Coastal Monitoring (SECM) Survey

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Last updated: August 2018

Description of indicator: The Southeast Coastal Monitoring (SECM) program has collected fish, zooplankton, and oceanographic samples in southeast Alaska since 1997 (Fergusson et al., 2013, 2018; Murphy et al., 2018). Sampling has been focused most consistently in Icy Strait, the primary northern migratory pathway to the Gulf of Alaska for juvenile salmon originating from over 2000 southeast Alaska (SEAK) streams and rivers. Research objectives of the SECM program are to provide insight into the production dynamics and early ocean ecology of SEAK salmon.

Surface trawls (0–20m) are used to sample epipelagic fish species, including all five commercial species of Pacific salmon (*Oncorhynchus* sp.) in SEAK. Juvenile pink salmon (*O. gorbuscha*) are, on average, the most abundant species in the epipelagic habitat in SECM surveys. We provide summaries of the annual catch rates for the five salmon species (pink; coho *O. kisutch*; sockeye, *O. nerka*; chum, *O. keta*; and Chinook, *O. tshawytscha*).

Status and trends: In 2018, juvenile salmon catch rates were among the lowest of the time series (Figure 42). Nominal catch rates of juvenile salmon were down for chum, coho, and pink salmon. There were slight upticks in the rates of juvenile sockeye and Chinook salmon catches but the scales of these slight improvements still leave catch rates at low levels. Our sampling does not typically include appreciable numbers of adult sockeye and coho salmon but the remaining species (pink, chum, Chinook) exhibited lower catch rates of adult fish than last year.

Factors influencing observed trends: Ocean conditions in 2018 were preceded by several anomalously warm years, though 2017 was cooler. Warm ocean conditions are likely to have influenced recruitment patterns through multiple years of altered community structure and stock dynamics and it may take a few more years like 2017 before the impacts of warm waters have fully stabilized.

In 2017, a record low number of out-migrating juvenile pink salmon were caught during our surveys, pointing to the expected low returns of adult pink salmon this year. Meanwhile, the unexpectedly low catches of adult salmon may be at least partially attributed to changes in the vessel used for the survey this year. Trawl speeds were slightly slower, potentially allowing faster adult salmon to avoid capture.

Juvenile pink salmon catch rates typically exhibit an even-odd year pattern, with higher catch rates of out-migrating juvenile pink salmon in even years (Figure 42). Thus, low juvenile pink salmon catch rates this year (an even year) were unexpected. The low number of juvenile pinks may point to lower freshwater survival of pinks between the hatching and out-migrating periods. Alternatively, it could suggest a shifted timing of out-migration such that our survey did not effectively capture out-migrating juveniles. Similarly, juvenile coho catch rates were lower than are historically seen which may be indicative of the same low freshwater survival or shifted migration timing.

Implications: While the small uptick in juvenile Chinook salmon catch rate this year is encouraging, the scale of Chinook salmon catches is still quite small and thus it is unclear if the increase is meaningful (note the small values of the y-axis in Figure 42). Catches of immature Chinook salmon in 2019 will help to determine whether we have seen a strong recruitment event for Chinook salmon. Meanwhile, the low catch rates of immature Chinook salmon this year are discouraging for return of adult Chinook in the near future.

Also discouraging is the observation of low juvenile pink and chum salmon catch rates this year despite

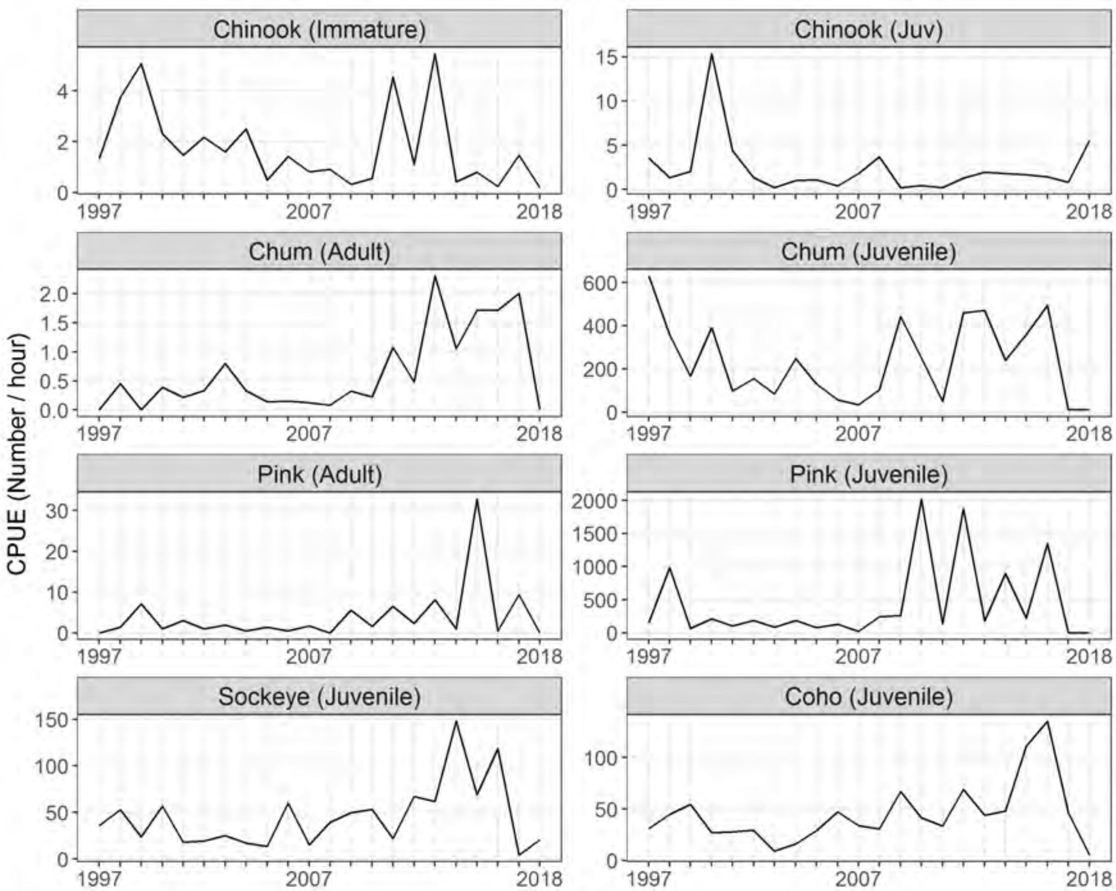

Figure 42: Time series of juvenile, immature (Chinook only), and adult salmon catch rates (number of fish per hour) during southeast Coastal Monitoring (SECM) surveys from 1997–2018.

sizable adult pink salmon returns last year. Early ocean mortality is often considered to be a primary driver of salmon cohort success but if the observed catches of juvenile pink and chum salmon this year are, in fact, indicative of poor freshwater survival as well, we may be entering a period of challenging stock dynamics. Such challenges could be indicative of a period of low recruitment events that can yield slow recoveries.

Juvenile Salmon Size and Condition Trends in Icy Strait, Southeast Alaska

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Last updated: September 2018

Description of indicator: The Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories, AFSC, has been investigating how climate change may affect Southeast Alaska (SEAK) nearshore ecosystems in relation to juvenile salmon (Oncorhynchus spp.) and associated biophysical factors since 1997 (Fergusson et al., 2018). Juvenile pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*) salmon size and condition data have been collected annually in Icy Strait during monthly (June to August) fisheries oceanography surveys. This report presents size data (length and weight) through 2018 and energy density data through 2017 for juvenile salmon in Icy Strait.

Status and trends: In 2018, juvenile salmon length and weight values declined from 2017 values. For all juvenile salmon, length and weight values were below the 21 year average (Figures 1-2). An overall decreasing trend in size has been observed since the 2015 and 2016 seasons which marked some of the largest sizes of juvenile salmon seen in the time series.

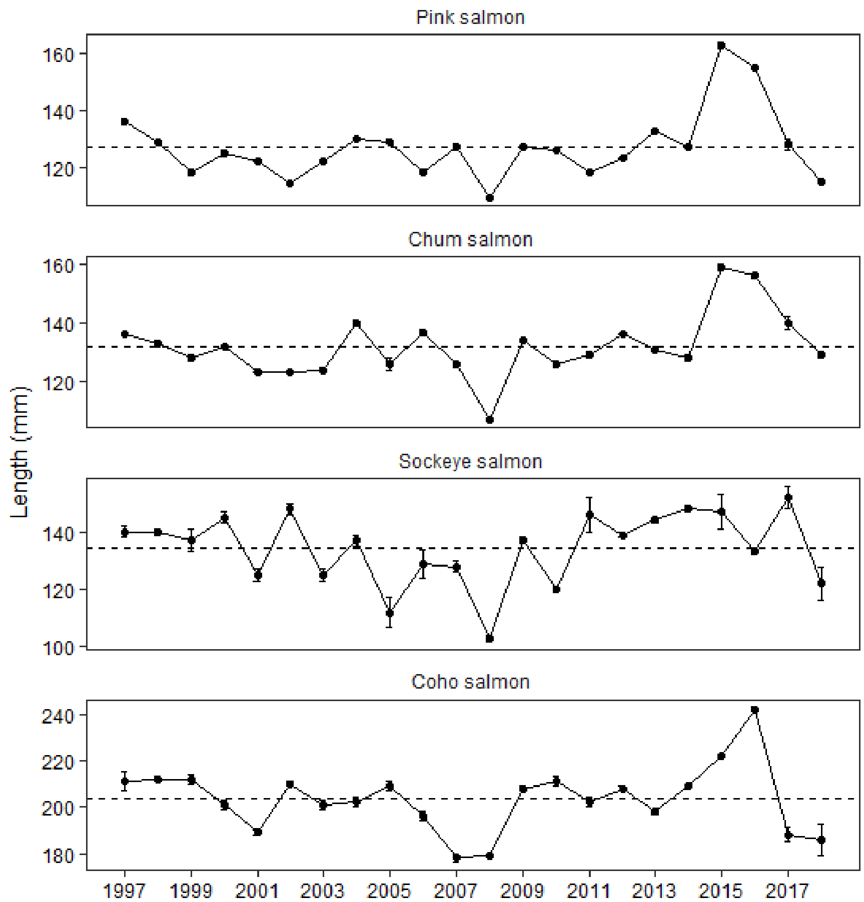

Figure 43: Average fork length (mm; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2018. Time series average is indicated by the dashed line.

In 2017, juvenile salmon energy density (kJ/g dry weight) values declined for all species except sockeye salmon which showed no change (Figure 3). Energy density for all species continued the above average trend that began during 2013–2014.

Factors influencing observed trends: Among-cohort variation in survival of Pacific salmon is strongly influenced by early marine residency with body size being an important factor driving survival (Parker, 1968; Mortensen et al., 2000)). During early marine residency, juvenile salmon must exhibit high growth to avoid predation while also acquiring enough lipid reserves to survive winter when food is limited (Beamish and Mahnken, 2001; Moss et al., 2005)).

Implications: The below average size values for all four species of juvenile salmon is concerning since this could lead to increased predation. However, the above average energy densities observed indicates that the fish are entering the Gulf of Alaska with high energy stores which may favor overwintering survival. With these contradictory size and energy density values, it is unclear how overall survival may be influenced.

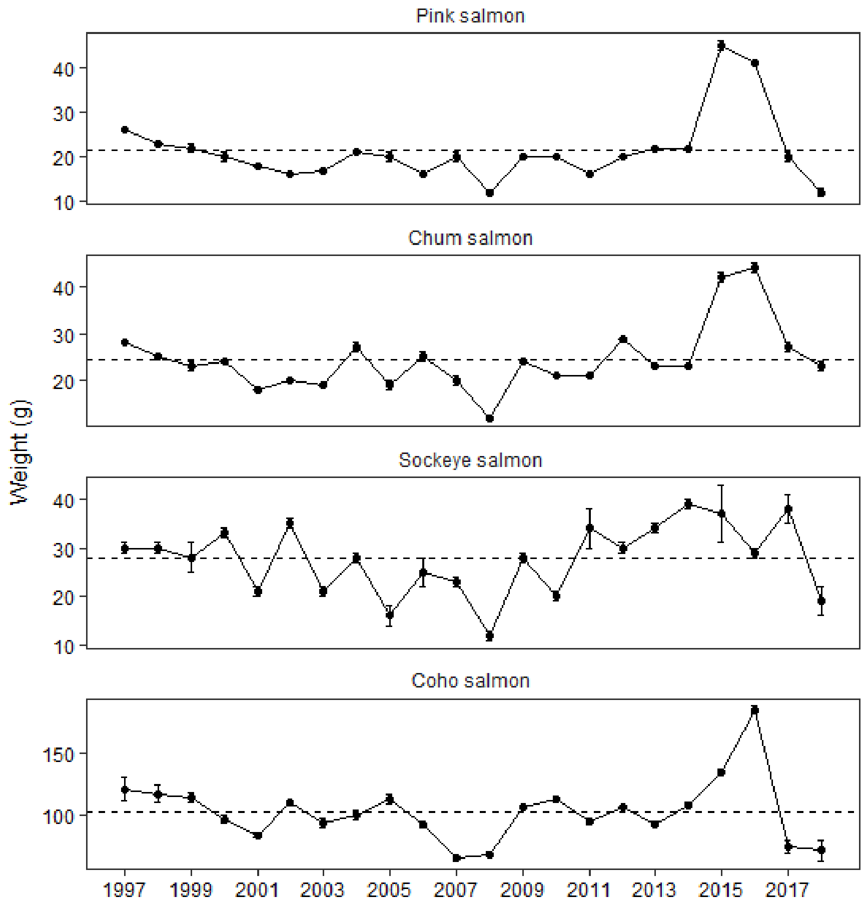

Figure 44: Average weight (g, frozen; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2018. Time series average is indicated by the dashed line.

Marine Survival Index for Pink Salmon from Auke Creek, Southeast Alaska

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Last updated: September 2018

Description of indicator: The time series of marine survival estimates for wild pink salmon from the Auke Creek Research Station in Southeast Alaska is the longest-running continuous series available in the North Pacific. The Auke Creek weir structure facilitates near-complete capture of all migrating pink fry and returning adults, and is the only weir capable of such on a wild system in the North Pacific. Marine survival is estimated as the number of adults (escapement) per fry. While no stock-specific harvest information is available for Auke Creek pink salmon, and there are possible influences of straying and intertidal production downstream of the weir structure, the precision of this long-term dataset is still unmatched and makes the series an excellent choice for model input relating to nearshore and gulf-wide productivity. The index is presented by fry ocean entry year.

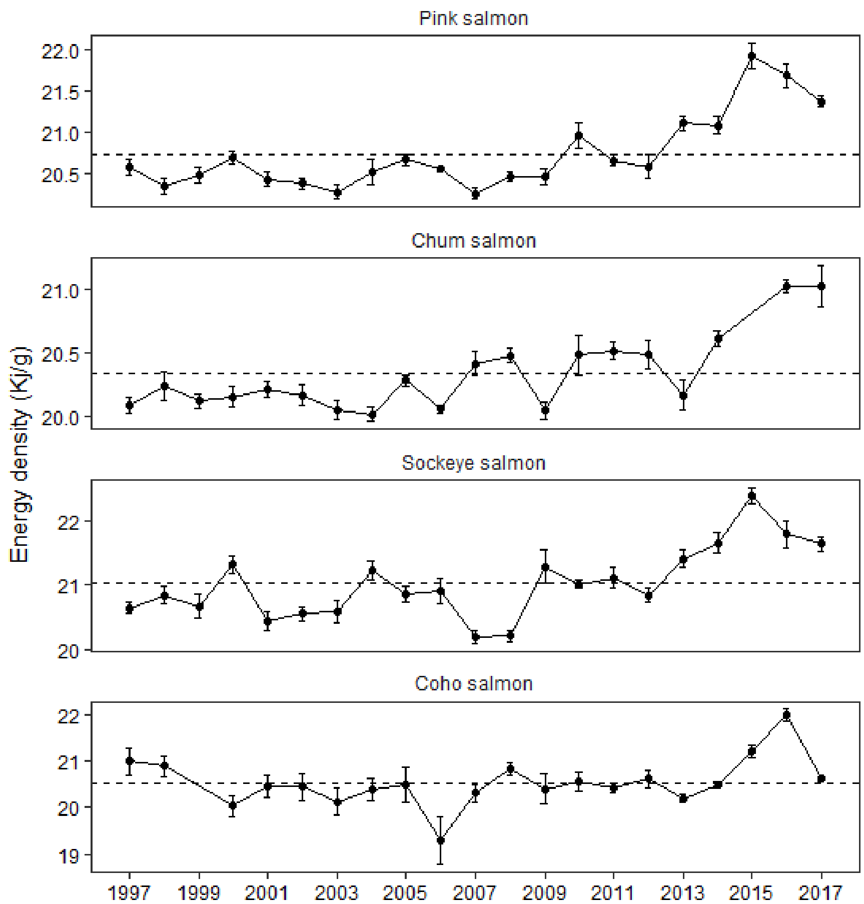

Figure 45: Average energy density (kJ/g, dry weight; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2017. Time series average is indicated by the dashed line.

Status and trends: The historical trend shows marine survival of wild pink salmon from Auke Creek varies from 1.2% to 53.3%, with an average survival of 11.0% from ocean entry years 1980-2017 (Figure 46). Marine survival for the 2017 ocean entry year was 1.9% and overall survival averaged 14.3% over the last 5 years and 15.2% over the last 10 years. 2018 saw the lowest return of pink salmon to Auke Creek with 351 returning adults (Figure 47).

The historical trend shows marine survival of wild pink salmon from Auke Creek varies from 1.2% to 53.3%, with an average survival of 11.2% from ocean entry years 1980–2016 (Figure 46). Marine survival for the 2016 smolt year was 10.6% and overall survival averaged 16.9% over the last 5 years and 15.4% over the last 10 years.

Factors influencing observed trends: Factors that have influenced these observed trends include: migration timing, fishery effort and timing, predation, growth rates, maintained genetic variation, and stream conditions. Within the Auke Creek system, a system undergoing rapid climatic change, climate-induced phenological shifts have been shown to influence the trend of earlier migration of both the early and late run of pink adults, as well as, juvenile fry migration (Kovach et al. 2013b, Shanley et al. 2015). The effect of fishing pressure on pink salmon has some obvious effects on marine survival as well as unapparent impacts including decreases in body weight, variations in length, increases in earlier-maturing fish, and increases in heterozygosity at PGM (Hard et al. 2008).

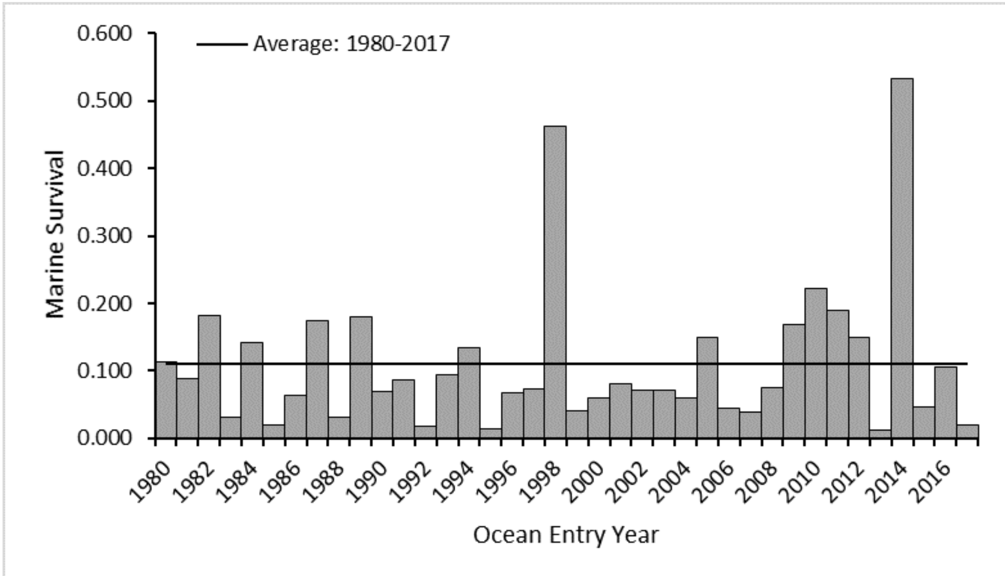

Figure 46: Auke Creek pink salmon marine survival index by ocean entry year.

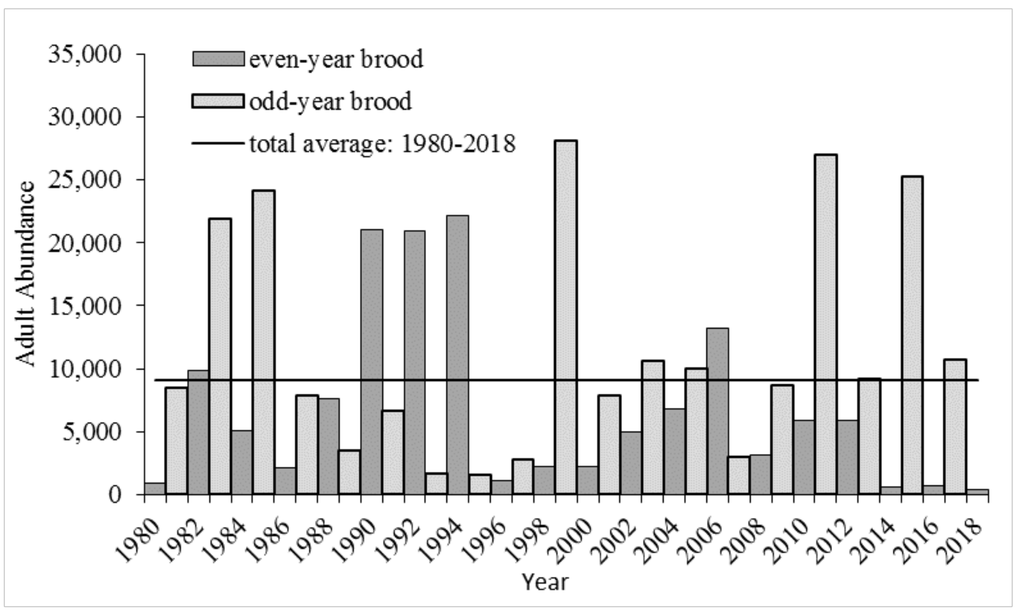

Figure 47: Auke Creek pink salmon adult returns by year.

As pink salmon are one of the most numerous and available food sources of larger migrating juvenile salmon and other marine species, their early marine survival can be heavily impacted by predation (Parker 1971, Landingham et al. 1998, Mortensen et al. 2000, Orsi et al. 2013). One resistance to this predation is that pink salmon fry are able to quickly outgrow their main predators of juvenile coho and sockeye salmon and become unavailable as a food resource due to their size (Parker 1971). During juvenile development, the local conditions of stream discharge and temperature are strong determinants of egg and fry survival. In addition, many of these influencing factors have been shown to have a genetic component that can strongly influence survival (Geiger et al. 1997, McGregor et al. 1998, Kovach et al. 2013a).

Implications: The low survival indices of the 2015 and 2016 outmigration year classes may indicate poor habitat quality, ocean conditions, and/or prey resources for predatory groundfish. The marine survival of

Auke Creek pink salmon is related to large-scale ocean productivity indices and to important rearing habitats of many southeast Alaska groundfish species. The marine survival of indices of Auke Creek pink salmon provide trends that allow for the examination of annual variation in habitat quality of rearing areas and general ocean conditions and productivity. Due to the one ocean year life history of pink salmon, we are able to use their marine survival as a proxy for the general state of the Gulf of Alaska. Additionally, as pink fry are such a numerous food resource in southeast Alaska, their abundance and rate of predation allow for insights into the groundfish fisheries. Pink fry have been shown to be an important food resource for juvenile sablefish, making up a large percentage of their diet (Sturdevant et al. 2009, 2012). The growth and marine survival of Auke Creek pink salmon provide valuable proxies for Gulf of Alaska and southeast Alaska productivity, as well as, the overwintering survival and recruitment of sablefish.

Marine Survival Index for Coho Salmon from Auke Creek, Southeast Alaska

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Last updated: September 2018

Description of indicator: The time series of marine survival estimates for wild coho salmon from the Auke Creek Weir in Southeast Alaska is the most precise and longest-running continuous series available in the North Pacific. Auke Bay Laboratories began monitoring wild coho salmon survival in 1980. All coho salmon smolts leaving the Auke Lake watershed have been counted, subsampled for age and length, and injected with coded wire tags (CWT). Research studies over the last 36 years have captured and sampled virtually all migrating wild juvenile and adult coho salmon. These migrating fish included those with both 1 and 2 freshwater annuli and 0 or 1 ocean annuli. Marine survival is estimated as the number of adults (harvest plus escapement) per smolt. The index is presented by smolt (outmigration) year. The precision of the survival estimate was high due to 100% marking and sampling fractions that minimized the variance in the survival estimate and made the series an excellent choice for model input relating to nearshore and gulf-wide productivity. It is the only continuous marine survival and scale data set in the North Pacific that recovers all returning age classes of wild, CWT coho salmon as ocean age 0 and 1

Status and trends: The historical trend shows marine survival of wild coho salmon from Auke Creek varies from 5.1% to 47.8%, with an average survival of 22.5% from smolt years 1980–2017 (Figure 48; top panel). Marine survival for 2017 was the second lowest on record at 6.0%, and overall survival averaged 11.7% over the last 5 years and 15.1% over the last 10 years. The survival index for ocean age-1 coho varies from 3.9% to 36.6% from smolt years 1980–2017 (Figure 48; middle panel) and for ocean age-0 coho varies from 0.5% to 11.2% from smolt years 1980–2017, with 2017 being the lowest on record (Figure 48; bottom panel). Return data for 2018 returns are included, despite the fact that the run is not completely finished. These data are included because the marine survival for ocean age-1 coho at Auke Creek will likely again be near the lowest on record at ∼6.0% (marine survival was at 5.6% as of 28 September 2018, with recent fishery and escapement counts indicating that a minimum amount of fish likely remain at large).

Factors influencing observed trends: Factors influencing observed trends include: smolt age, smolt size, migration timing, fishery effort and location, and marine environmental conditions (Kovach et al. 2013; Malick et al. 2009; Robins 2006; Briscoe et al. 2005). Coho salmon marine survival is influenced by a number of life history parameters such as juvenile growth rate and size, smolt age and smolt ocean entry timing (Weitkamp et al. 2011). Recent studies have shown that climate change has shifted the median date of migration later for juveniles and earlier for adults (Kovach et al. 2013). The marine survival of Auke Creek coho reflects nearshore rearing productivity and, as such, is utilized to infer regional trends in coho salmon productivity as one of four indicator stocks utilized by the Alaska Department of Fish and Game to manage coho salmon over all of southeast Alaska (Shaul et al. 2011). The marine survival of Auke Creek coho salmon and growth inferred by scales samples is influenced and reflective of broad scale oceanographic

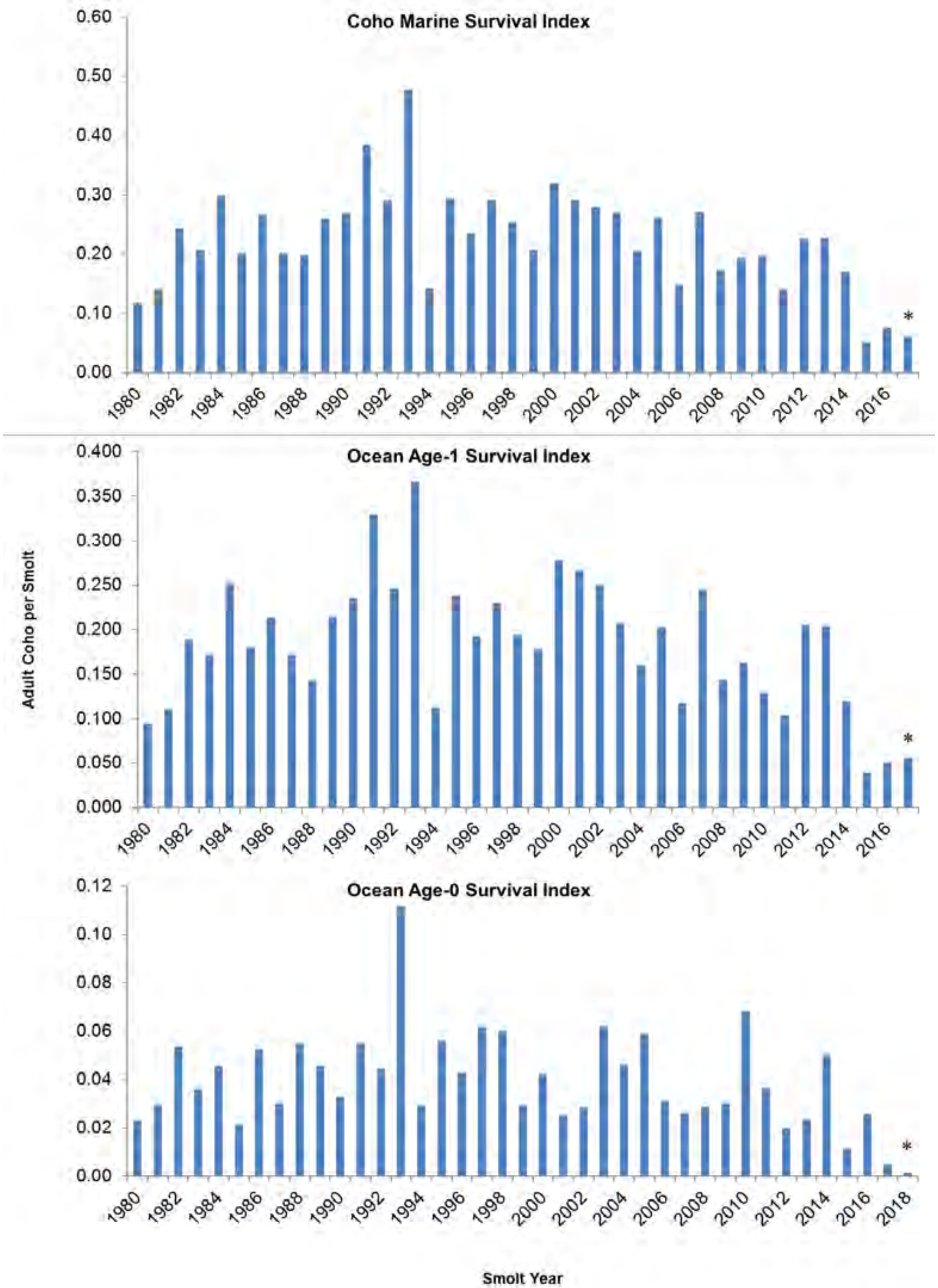

Figure 48: Auke Creek coho salmon marine survival indices showing total marine survival (ocean age-0 and age-1 harvest plus escapement; top panel), percentage of ocean age-1 coho per smolt (harvest plus escapement; middle panel), and percentage of ocean age-0 coho per smolt (escapement only; bottom panel) by smolt year. Return year 2018 data are denoted with an asterisk as these may change slightly by the end of the coho return.

indices in the Gulf of Alaska (Malick et al. 2005; Robbins 2006; Briscoe et al. 2005; Orsi et al. 2013).

Implications: The marine survival index of coho salmon at Auke Creek is related to ocean productivity indices and to important rearing habitats shared by groundfish species. The preliminary 2017 survival data indicate that recent conditions were not favorable for the Auke Creek coho. The trends in coho salmon marine survival indices from Auke Creek provide a unique opportunity to examine annual variation in habitat rearing areas and conditions because ocean age-0 coho adults occupy only nearshore and strait habitats prior to returning to the creek. Ocean age-0 coho leave freshwater in May through June and return in August through October, the same time sablefish are moving from offshore to nearshore habitats. In contrast, ocean age-1 coho salmon occupy those nearshore habitats for only a short time before entering the Gulf of Alaska and making a long migratory loop. They return to the nearshore habitats on their way to spawning grounds after the first winter that age-0 sablefish spend in nearshore habitats. The relative growth and survival of ocean age-0 and age-1 coho salmon from Auke Creek may provide important proxies for productivity, overwintering survival of sablefish, and recruitment of sablefish to age-1.

Groundfish

ADF&G Gulf of Alaska Trawl Survey

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Last updated: October 2018

Description of indicator: The Alaska Department of Fish and Game conducts an annual trawl survey for crab and groundfish in Gulf of Alaska targeting areas of crab habitat around Kodiak Island, the Alaska Peninsula, and the Eastern Aleutian Islands (Spalinger and Knutson, 2018). Parts of these areas have been surveyed annually since 1984, but the most consistent time series begins in 1988. In 2018, a total of 368 stations was sampled from June 14 through September 14. While the survey covers a large portion of the central and western Gulf of Alaska, results from Kiliuda and Ugak Bays (inshore) and the immediately contiguous Barnabas Gully (offshore) are generally representative of the survey results across the region (Figure 49). The trawl survey uses a 400-mesh eastern otter trawl constructed with stretch mesh ranging from 10.2 cm in the body, decreasing to 3.2 cm in the codend. Constructed ideally to sample crab, it can also reliably sample a variety of fish species and sizes, ranging from 15 cm to adult sizes, but occasionally capturing fish as small as 7 cm for some species. The survey catches (mt/km) from Kiliuda and Ugak Bays and Barnabas Gully were summarized by year for selected species groups (Figure 50). Using a method described by (Link et al., 2002), standardized anomalies, a measure of departure from the mean catch (kg) per distance towed (km), were also calculated for selected species; arrowtooth flounder *Atheresthes stomias*, flathead sole *Hippoglosoides elassodon*, Tanner crab *Chionoecetes bairdi*, Pacific cod *Gadus macrocephalus*, skates, walleye pollock *G. chalcogrammus* and Pacific halibut *Hippoglossus stenolepis* (Figure 51). Temperature anomalies were calculated using average bottom temperatures recorded for each haul from 1990 to present (Figure 52).

Status and trends: Arrowtooth flounder, flathead sole, and other flatfish continue to dominate the catches in the ADF&G trawl survey, but not to the same degree as seen in previous surveys. A sharp decrease in overall biomass is apparent from 2007 to 2017 from the years of record high catches occurring from 2002 to 2005 (Figure 50). Although still as relatively low levels, 2018 survey data showed a slight increase in overall biomass.

Prior to the start of our standard trawl survey in 1988, Ugak Bay was the subject of an intensive seasonal trawl survey in 1976–1977 (Blackburn 1977). Today, the Ugak Bay species composition is markedly different than in 1976. Red king crabs *Paralithodes camtschaticus* were the main component of the catch in 1976–1977, but now are nearly non-existent. Flathead sole, skate, and gadid catch rates have all increased roughly 10-fold. While Pacific cod made up 88% and walleye pollock 10% of the gadid catch in 1976-1977, catch compositions have reversed with Pacific cod making up 14% of catch and walleye pollock 86% in 2017. In 2018, Pacific cod increased to 29%, while Walleye pollock decreased to 71% of the overall gadid catches.

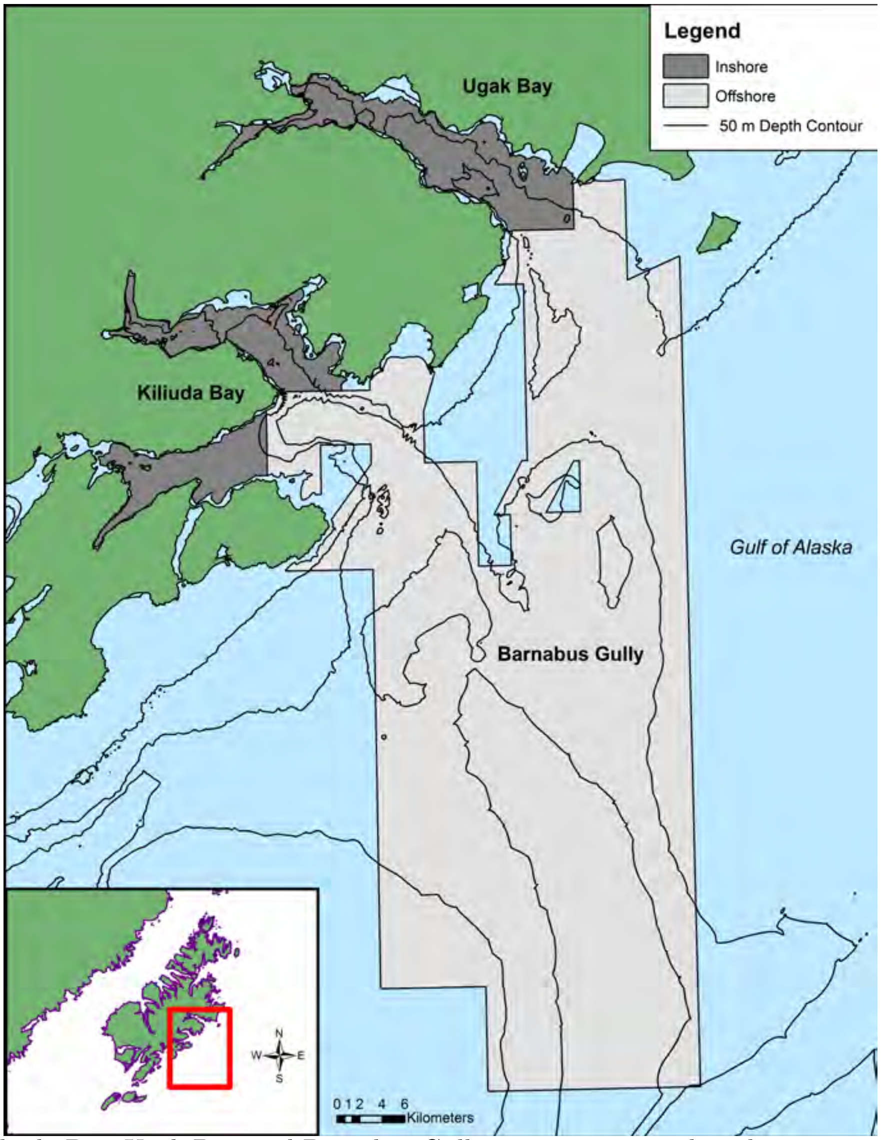

Figure 49: Kiliuda Bay, Ugak Bay, and Barnabus Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

Pollock catches remain below average in the inshore areas of Kiliuda and Ugak Bays, but increased to above average in the offshore area of Barnabus Gully, driven mainly by three large offshore tows that made up 74% of this total biomass (Figure 51).

Below average anomaly values for arrowtooth flounder and flathead sole were recorded again in 2018 for both inshore and offshore areas; along with Pacific cod, Pacific halibut, and skates (Figure 51). The above average anomaly values for Tanner crab in 2018 were due to a large increase in numbers of juvenile crab captured in both inshore and offshore areas that have not been observed for several years (Spalinger and Knutson, 2018).

Temperature anomalies for both inshore and offshore stations show significant decreases in 2017 and 2018 from the extremely warm temperatures recorded in 2016, aligning closer to the long term average (Figure 52). The higher than average temperature years frequently occur during moderate and strong El Niño years (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml).

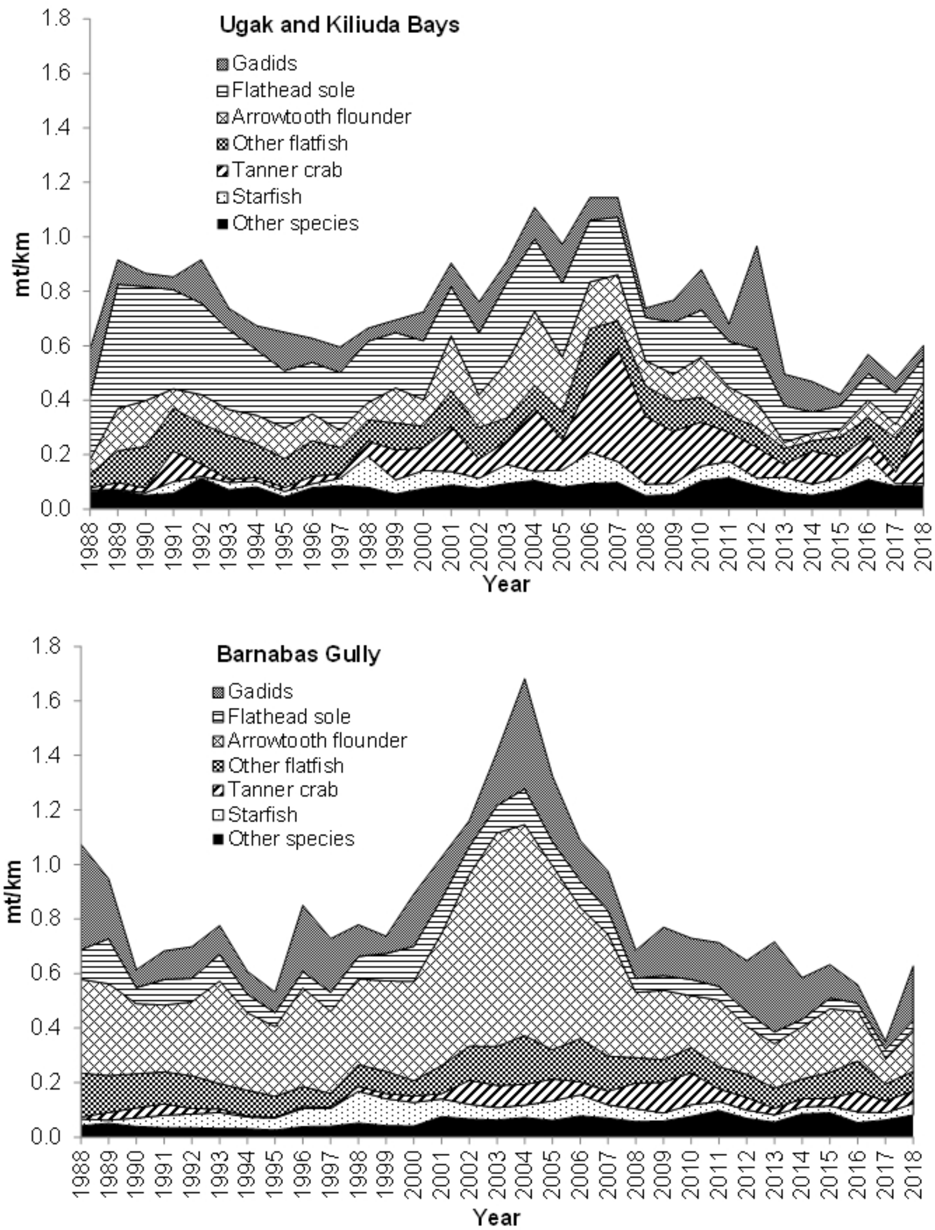

Figure 50: Total catch per km towed (mt/km) of selected species from Barnabus Gully and Kiliuda and Ugak Bay survey areas off the east side of Kodiak Island, 1987–2018

Factors influencing observed trends: It appears that significant changes in volume and composition of the catches on the east side of Kodiak are occurring, but it is unknown to what extent predation, environmental changes, and fishing effort are contributing. The lower overall catch from 1993 to 1999 (Figure 50) may be a reflection of the greater frequency of El Niño events on overall production, while the period of less frequent El Niño events, 2000 to 2003, corresponds to years of increasing production and corresponding catches. Lower than average temperatures have been recorded from 2006 to 2009 along with decreasing overall abundances in 2008 and 2009. This may indicate a possible lag in response to changing environmental conditions or some other factors may be affecting abundance that are not yet apparent.

Implications: Although trends in abundance in the trawl survey appear to be influenced by major oceano-

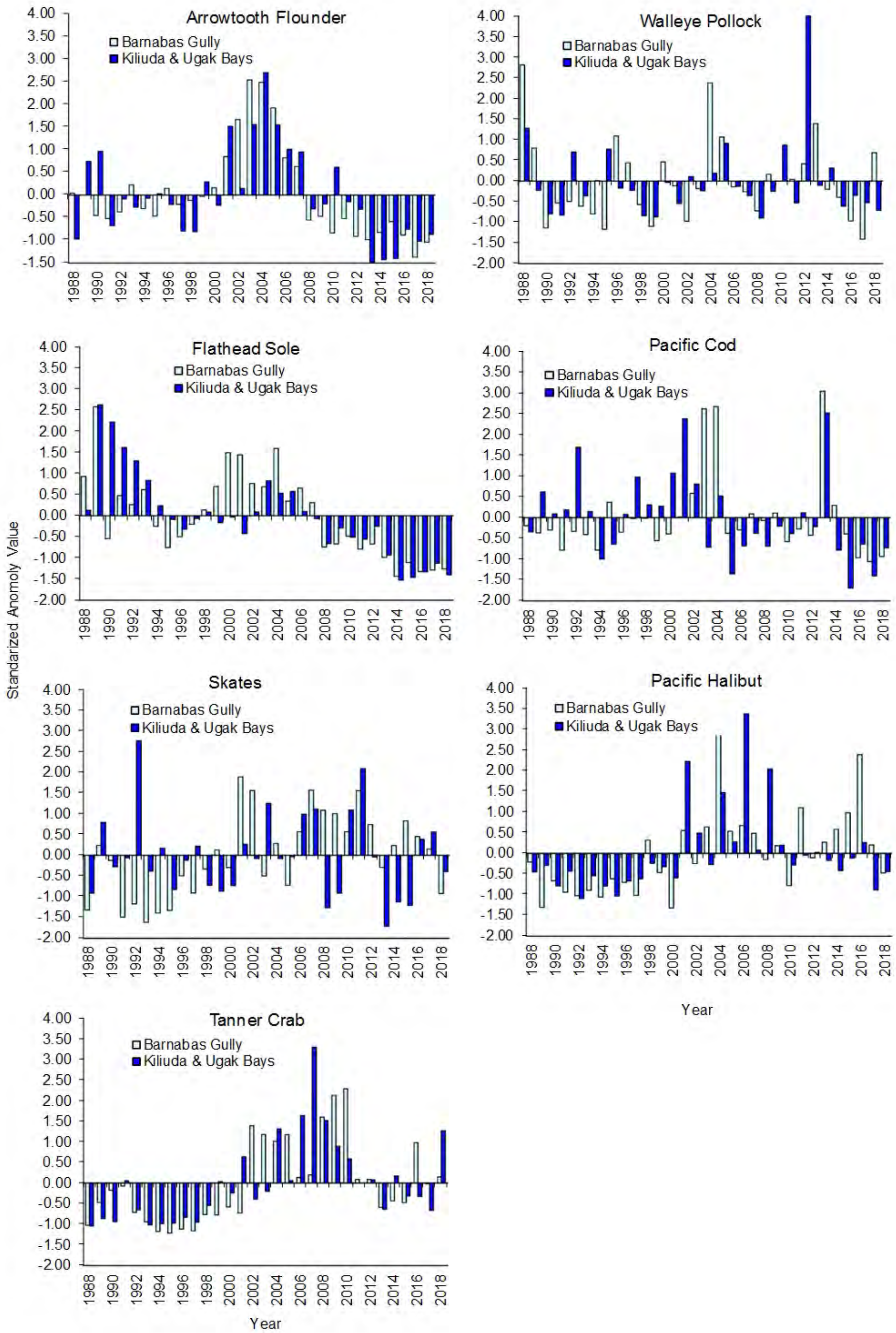

Figure 51: A comparison of standardized anomaly values, based on catch (kg) per distance towed (km) for selected species caught from 1988 to 2018 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

graphic events such as El Niño, local environmental changes, predation, movements, and fishery effects may influence species specific abundances. Monitoring these trends is an important process used in establishing

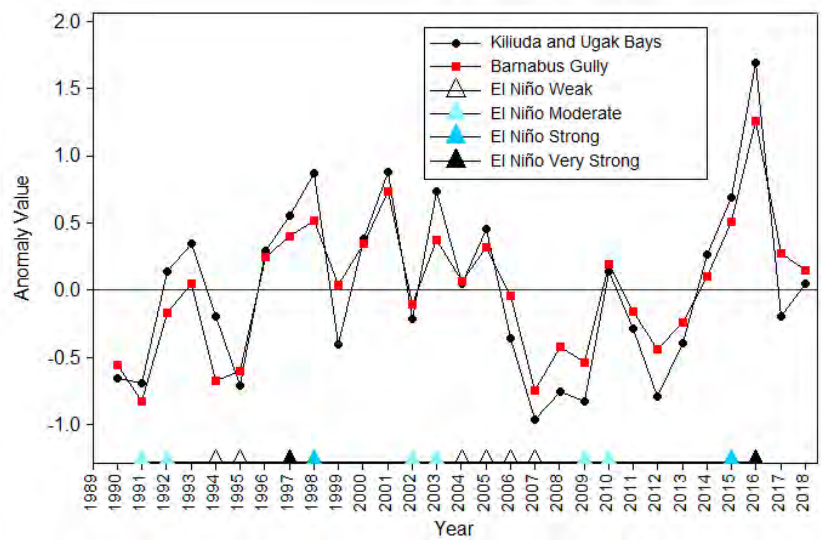

Figure 52: Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2018, with corresponding El Niño years represented.

harvest levels for state water fisheries. These survey data are used to establish guideline harvest levels of state managed fisheries and supply abundance estimates of the nearshore component of other groundfish species such as Pacific cod and pollock. Decreases in species abundance will most likely be reflected in decreased guideline harvest levels.

Seabirds

Seabird Monitoring Summary from Alaska Maritime National Wildlife Refuge

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Last updated: October 2018

Description of indicator: The Alaska Maritime National Wildlife Refuge has monitored seabirds at colonies around Alaska in most years since the early- to mid-1970s. Time series of annual breeding success and phenology (and other parameters) are available from over a dozen species at eight Refuge sites in the Gulf of Alaska, Aleutian Islands, and Bering and Chukchi Seas (Figure 53). Monitored colonies in the Gulf of Alaska include Chowiet (Semidi Islands, WGOA), East Amatuli (Barren Islands, WGOA), and St. Lazaria (Southeast Alaska, EGOA) islands. Reproductive success is defined as the proportion of nest sites with eggs (or just eggs for murres that do not build nests) that fledged a chick.

Status and trends: Fish-eating seabirds in the Gulf of Alaska had generally normal reproductive success in 2018 (Figure 54). Common murres, which showed rare widespread reproductive failure in 2015–2016 and improved success in 2017, had generally better colony attendance and fledging rates in 2018; still the number of birds breeding was low at most sites. Tufted puffin productivity was within 1 standard deviation (SD) of the long term mean at all monitored sites. Black-legged kittiwakes and storm-petrels (which consume a mix of fish and invertebrates) showed fledging rates within 1 SD of the mean; success of planktivorous auklets was low at Chowiet. Timing of breeding was normal for most species at Chowiet, late for murres at E Amatuli, and late for murres and gulls at St. Lazaria.

Factors influencing observed trends: In general, murres appear to have been negatively affected during the marine heatwave of 2015-2016, with widespread reproductive failures, die-offs, and low attendance at breeding colonies. Murre attendance is still lower than prior to the heatwave, but improvements in reproductive success in 2018 suggests environmental changes have returned back to more neutral conditions (see Bond, p. 41). Other species did not show broad-scale failures during this period; planktivorous seabirds were generally successful; however planktivorous auklets did poorly at Chowiet in 2018.

Implications: Reproductive activity of central-place foraging seabirds can reflect ecosystem conditions at multiple spatial and temporal scales. For piscivorous species that feed at higher trophic levels, continued reduced reproductive success may indicate that the ecosystem has not yet shifted back from warm conditions and/or there is a lagged response of the prey. However, the improvement in attendance and reproductive activity among murres during 2018 indicates continued improvement in foraging conditions for those species.

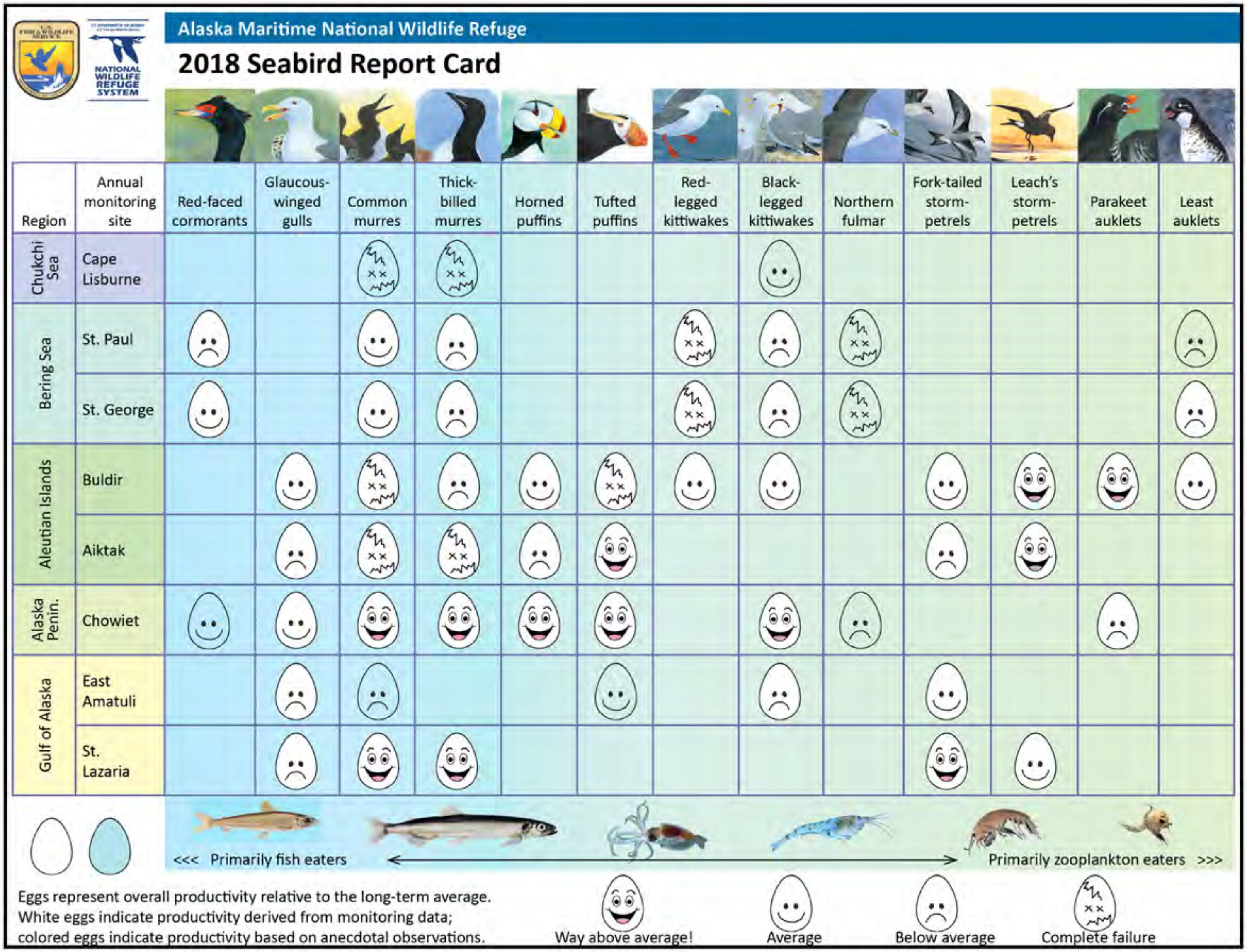

Figure 53: Summary of reproductive success in 2018 at long-term monitored sites on the Alaska Maritime National Wildlife Refuge. Figure created by AMNWR

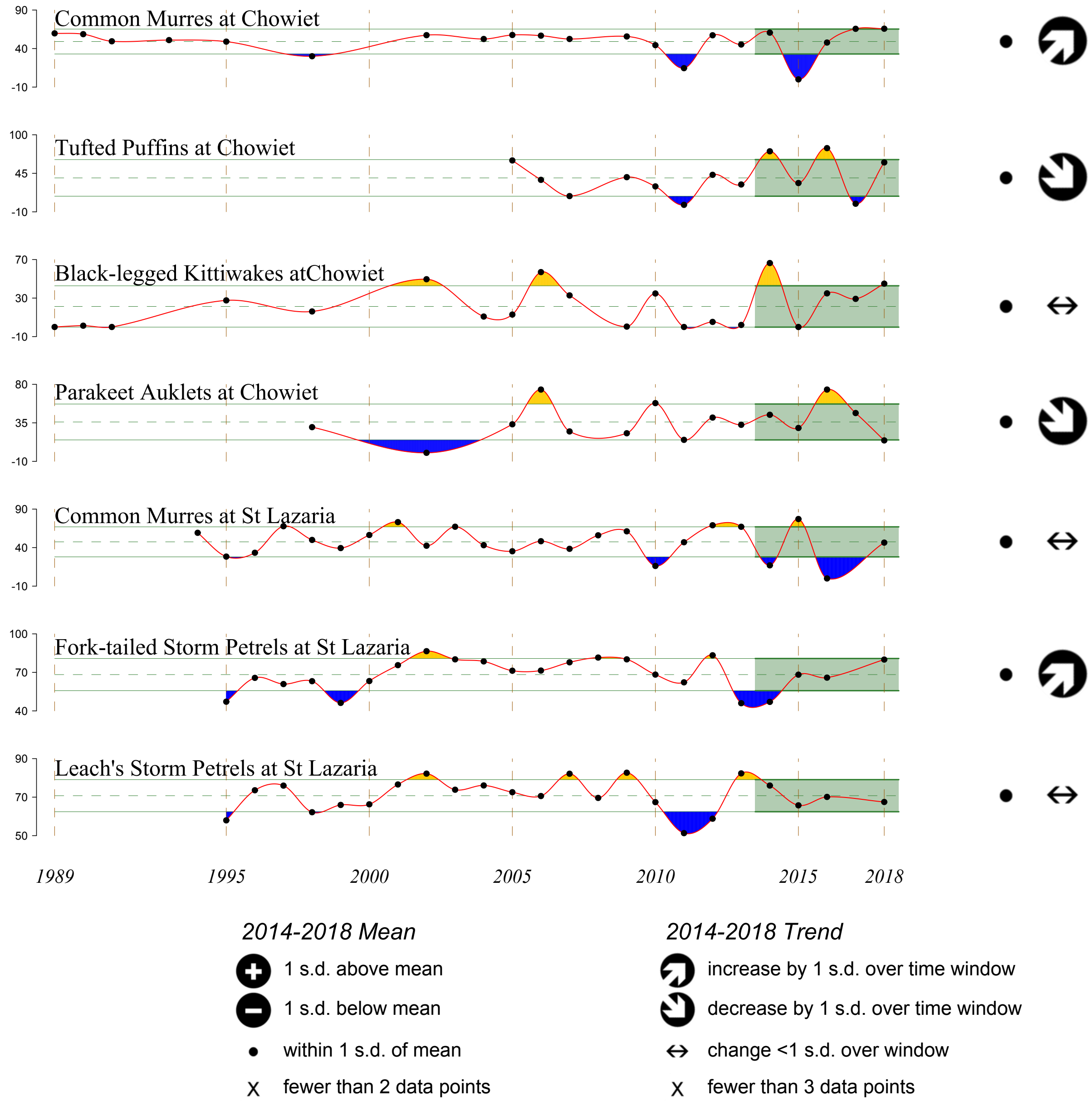

Figure 54: Summary of reproductive success of some seabird species at Chowiet (WGOA) and St Lazaria (EGOA)

Marine Mammals

Continued Decline of Humpback Whale Calving in Glacier Bay and Icy Strait

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Last updated: September 2018

Description of indicator: From 1985-2018, we used consistent methods and levels of effort to monitor individually-identified humpback whales annually from June 1–August 31 in Glacier Bay and Icy Strait (Gabriele et al., 2017). We photographically identified and counted the number of different whales and documented how many were calves of the year. We calculated the crude birth rate (CBR) as an annual reproductive index by dividing the number of calves by the total whale count for each year. Longitudinal data on individuals allows us to document the return of calves in subsequent years as juveniles and adults. Humpback whales and groundfish target the same lipid-rich prey (i.e., forage fish and euphausiids); therefore trends in whale reproductive success may indicate changes in prey quantity and/or quality available for both groundfish and humpback whales in the eastern Gulf of Alaska.

Status and trends: After many years of considerable reproductive success (Gabriele et al., 2017), we documented a sudden, sharp decline in humpback whale productivity and juvenile survival beginning in 2014 (see Neilson et al. 2017 in the 2018 Ecosystem Status Report). In 2018, we found continued evidence that humpback whale calving and juvenile return rates in Glacier Bay and Icy Strait are much lower than historic levels (Figure 55). Total whale abundance in 2018 (99 whales) declined for the fifth year in a row and we only observed one cow/calf pair. However, the only female documented to produce a calf in 2018 (#1470) lost her calf by early August. The CBR over the past five years (2014–2018 mean = 2.8%) is significantly lower than typical CBRs prior to 2014 (1985–2013 mean = 9.3%). Low numbers of whales and very few calves have been documented elsewhere in Southeast Alaska in the SPLISH program since at least 2016 (J. Moran, pers. comm.), indicating that these declines are not unique to the Glacier Bay–Icy Strait area.

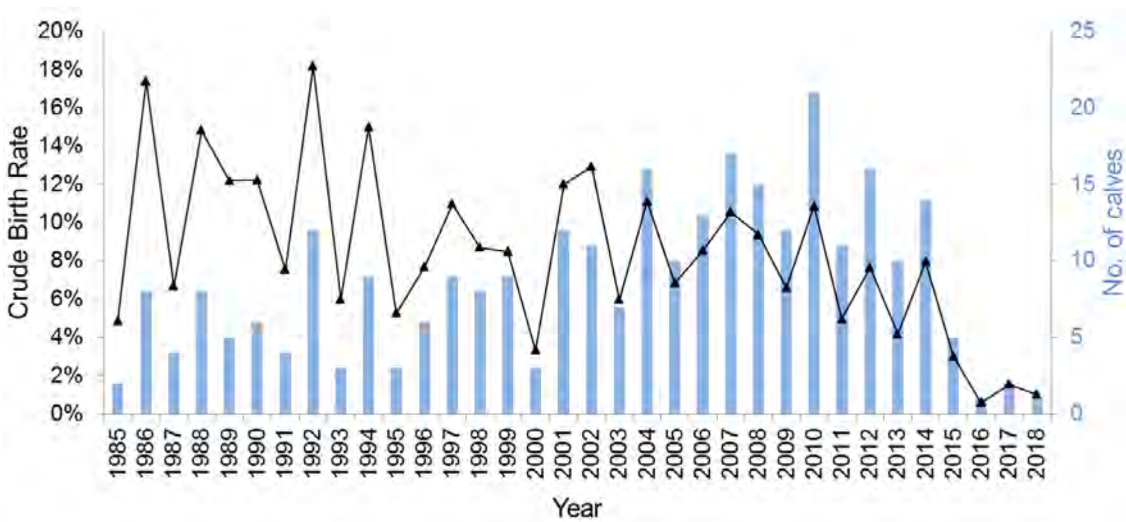

Figure 55: Crude birth rate (black line) (1985–2018) and annual number of calves (blue bars) (1985–2018) in Glacier Bay-Icy Strait.

In 2014–2018 (4.6 calves on average, range 1–14), we observed far fewer calves per year than we did in 1985–2013 (9.3 calves on average, range 2–21; Table 1). In 2014, the first year of the calving anomaly, a

Time Period	Number of Calves	Crude Birth Rate	Number of calves lost (%)
1985-2013	mean 9.3 (range 2–21)	mean 9.3 (range 3.3–18.2)	8 (4%)
2014	14*	8	5 (36%)
2015	5*	3	0
2016	1*	0.6	0
2017	2*	1.6	1 (50%)
2018	1	1.0	1 (100%)

typical number of calves was observed (n = 14) but an unprecedented number of them (n = 5) disappeared during the season (Neilson et al., 2015). In 2017, one of the years two calves was lost, and in 2018 the only calf documented was lost, marking total reproductive failure for the first time during this 34-year study. The rate of apparent calf mortality in 2014–2018 (n = 7) stands in stark contrast to the low rate of mid-season calf loss for the entire pre-anomaly period 1985–2013 (n = 8) during which no more than one case was observed per year (Neilson et al., 2015). Note that the calf mortality rate in the Alaska feeding grounds is biased low because it is presumed that some level of neonatal mortality occurs prior to arrival on the feeding grounds. In the mid-1990s, an estimated 1 of 5 calves documented in the Hawaii breeding ground were no longer with their mother after her migration to Alaska (Gabriele et al., 2001), but no recent estimates of neonatal mortality are available.

We did not document any juveniles (age 1–4 years) in 2017, and we observed very few small whales in 2018, in part due to the low number of calves in prior years. However, none of the 22 calves born in 2014–2017 have returned or been documented elsewhere in Southeast Alaska, to the best of our knowledge. While the mean age at which calves return to the study area is 3.2 years (Gabriele et al., 2017) and juvenile whales can be difficult to photo-identify because they are small and often behave erratically, this very low rate of juvenile return is notable.

Factors influencing observed trends: The proximate cause of declining humpback whale reproductive success is likely a decline in maternal body condition and calf/juvenile survival (Bradford et al., 2012; Fuentes et al., 2016; Seyboth et al., 2016) brought on by a dramatic decline in the quantity and/or quality of whale prey available. Ultimately, we suspect that the sustained decline in prey availability resulted from the combined effects the warm water "Blob" that dominated in the northeastern Pacific Ocean from late 2013–2016, the 2014 shift to the warm phase of the Pacific Decadal Oscillation, a very strong El Niño in 2015–2016, as well as ongoing climate change. Unusually warm waters were implicated in a wide variety of cascading effects on the marine ecosystem (Anderson and Piatt, 1999; Bond et al., 2015; Di Lorenzo and Mantua, 2016; Zador et al., 2017; Walsh et al., 2018).

Implications: The key driver of humpback whale population growth over the past 30 years in Glacier Bay and Icy Strait (Gabriele et al., 2017)) is reproduction and recruitment from within, as opposed to immigration from outside the population (Pierszalowski et al., 2016). Sustained low rates of calving and/or recruitment are therefore expected to have long-term effects on the humpback whale population in this area. If humpback whales are currently food-limited in northern Southeast Alaska, this might indicate that groundfish, which prey upon the same species, may also be food-limited.

Summer Survey of Population Level Indices for Southeast Alaska Humpback Whales and Fall Surveys of Humpback Whales in Prince William Sound

Contributed by John Moran[1]1, Janice Straley
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Last updated: October 2018

Description of indicator: Humpback whale populations have been monitored by various organizations in Northern Southeast Alaska since the 1970. The Survey of Population Level Indices for Southeast Alaska Humpback (SPLISH) survey assessed trends in abundance, calf production, spatial and temporal distribution, prey composition, and body condition for humpback whales in Northern Southeast Alaska during 2016, 2017, and 2018 (data from 2018 are not yet available). The 2016, 2017, and 2018 results can be compared to earlier studies to produce a decadal-scale time series (Straley et al., 2009; Calambokidis et al., 2008; Hendrix et al., 2012; Dahlheim et al., 2009; Neilson et al., 2017). For this report, we include the total number of juvenile/adult whales and calves estimated for Frederick Sound, Stephens Passage, Glacier Bay, and Icy Strait.

The *Exxon Valdez* Oil Spill trustee council has funded the monitoring humpback whales and their diets during the fall and winter months to understand predator prey interactions in the pelagic waters of Prince William Sound. The humpback whale population in the North Pacific has rebounded from near extinction in the late 1960s to over 22,000 individuals. This rapid recovery has coincided with major natural and anthropogenic perturbations in the marine ecosystem. Over much of the same period the abundance of the dominant forage fish, Pacific herring, shifted from an abundant state to a diminished state. The lack of commercial fishery has not restored this population to their former abundance. Humpback whales abundance and calf production within Prince William Sound can provide an index of forage fish abundance and ecosystem productivity.

Status and trends: Crude birth rates continue to drop in northern Southeast Alaska (Figure 56), and one of these is believed to have died. No calves were seen during the SPLISH survey window. We continued to see some whales in poor body condition but to a lesser extent than was observed in 2016 and 2017.

During September of 2018 in Prince William Sound we observed lower numbers of humpback whales, marine birds, herring, and forage fish relative to earlier surveys. Acoustic indices of fish and krill biomass in 2018 seemed much lower than 2017 and a lack of walleye pollock in the system was a noticeable change from previous years. This was our 8th fall survey, with the encounter rate for humpback whales (number of whales/NM traveled) only slightly higher than 2017, the lowest count since the project began in 2007 (Table 3). Ideal conditions while surveying known whale/herring hot spots failed to locate any significant concentrations of humpbacks or prey within Prince William Sound.

Factors influencing observed trends: It appears that the ecosystem has failed to recover from the recent warm water in the Gulf of Alaska, which has been linked to decreasing primary production/ forage species.

In Prince William Sound the decline in whales mirrors the decline in herring. Prior to 2015, adult over wintering and spawning herring were the preferred prey of humpback whales. Although the cause of the herring decline within the Sound remains unknown, lower whale numbers are likely the result of fewer herring.

Implications: We do not know what is causing the decrease in whale abundance in these areas (mortality or migration). Lower calf production and poor body condition suggest that the decline is related to prey. If prey is limiting and humpback whale populations have fully recovered to carrying capacity, there is potential for top-down forcing on forage species (Moran et al., 2017; Straley et al., 2017) and competition with fish, other marine mammals, and seabirds. Continued monitoring humpback whale indicators provides a useful method for assessing inter-annual productivity in the eastern GOA (i.e. shifts in whale distribution may reflect shifts in prey; changes in body condition and calf production may indicate changes in prey abundance

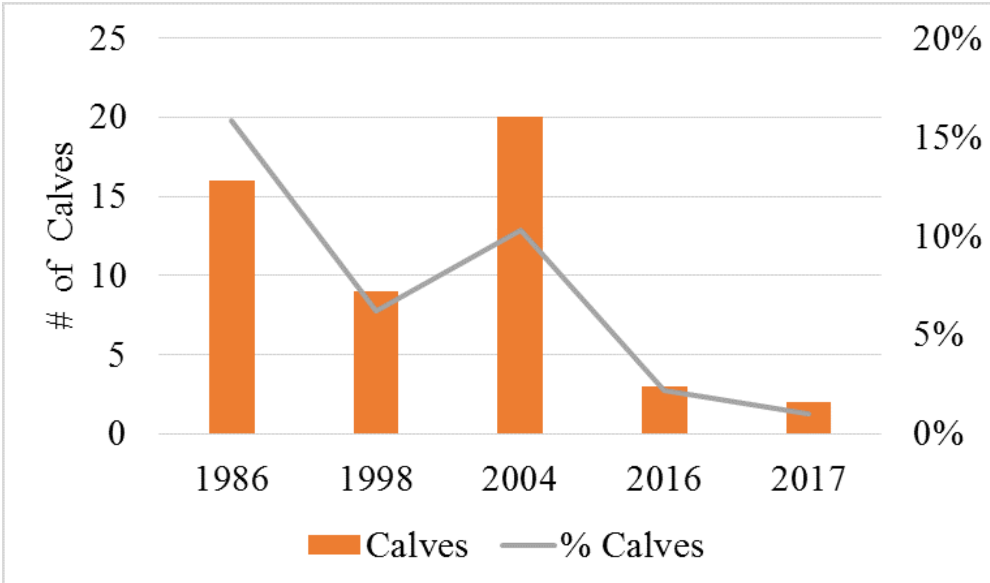

Figure 56: Numbers of calves and crude birth rate for humpback whales in northern Southeast Alaska (1986, 1998, and 2004 do not include Sitka Sound and Chatham Strait)

or availability). Since there is significant prey overlap between humpback whales and many ground fish species, these data may be useful for a coarse evaluation of ground fish prey.

Steller Sea Lions in the Gulf of Alaska

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Last updated: September 2018

Description of indicator: The Marine Mammal Laboratory (MML) uses the R package agTrend to model

Table 3: Index of PWS humpback whale abundance in PWS. *Note that the 2007 survey did not cover Montague Entrance, an area known for the highest concentration of whales and herring within the Sound in September.

Month/year	Counts of whales	Nautical miles surveyed	Encounter rate Whale/NM
Sep 2007*	24	370	0.06
Sep 2008	71	412	0.17
Oct 2011	62	441	0.14
Sep 2012	81	444	0.18
Sep 2013	113	355	0.32
Sep 2014	181	427	0.42
Sep 2017	12	543	0.02
Sep 2018	17	541	0.03

Steller sea lion (SSL) non-pup and pup counts and trend estimates (an index of population abundance and trends) within the bounds of the Gulf of Alaska (GOA) (Johnson and Fritz 2014). This region includes the GOA portion of the western Distinct Population Segment (DPS; known as the western, central and eastern GOA SSL regions and which together represent the western GOA ecoregion in this report) and the eastern DPS in Alaska (known as southeast Alaska, and as the eastern GOA ecoregion in this report)(Figure 57).

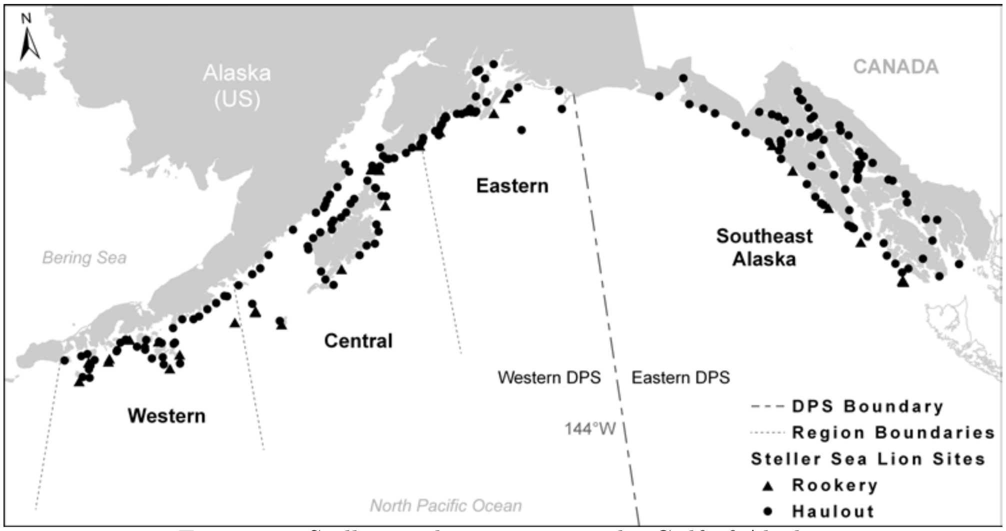

Figure 57: Steller sea lion regions in the Gulf of Alaska.

Status and trends: The western DPS in the GOA began to decline in the late-1970s, with the steepest decline occurring in the mid- to late-1980s, until it leveled out in 2001 and began to gradually increase an average of 3.47% per year (95% CI 2.64–4.34%; Figure 58; Merrick et al. 1987, Fritz et al. 2016). Between 1978 and 2017, the western DPS in the GOA has declined an average 2.84% per year (95% CI 3.14–2.54%). The survey counts from the most recent surveys of this region in 2015 and 2017 indicated that number of non-pups remained stable, despite having increased between 2001 and 2013 (Sweeney et al. 2017). Concurrently, 2017 pup counts in the eastern and central GOA declined from 2015 counts by 33 and 18%, respectively (Sweeney et al. 2017). Since regular surveys began in the eastern DPS in the early 1970s, southeast Alaska SSL abundance has been steadily increasing (Fritz et al. 2016). Between 1971 and 2017, the eastern DPS in the GOA increased 2.21% per year (95% CI 1.55–2.84%; Figure 59). Since 2013, the non-pup and pup count estimates appear to be oscillating around an apparent carrying capacity. However, more years of data are necessary to distinguish these changes from potential declines (Sweeney et al. 2017).

Factors influencing observed trends: Declines in pup counts in the eastern and central GOA occurred around the time of the 2014–2016 marine heatwave, which was linked to significant reduction in primary productivity, increased algal blooms, and an influx of warm-water species (Bond et al. 2015, Di Lorenzo and Mantua 2016). The increase in sea surface temperature was also linked to the 71% drop in abundance of Pacific cod in the area between 2015 and 2017 (Barbeaux et al. 2017).

Implications: SSL in the GOA began to gradually recover in 2000, but the recent decline in pup counts and stabilizing of non-pup counts indicate that this protected species is still susceptible to threats. Also, SSLs in the GOA prey on species that are target species for groundfish fisheries. Previous work using the frequency of occurrence (FO) of prey species identified by hard parts present in scat samples indicated that Steller sea lions in the GOA prey heavily on important target species of groundfish fisheries (Sinclair et al. 2013). Scats collected between 1999-2009 in the western GOA ecoregion indicated that Steller sea lions consumed predominantly walleye pollock and Pacific cod during the summer (34.3–64.2% and 2.9–37.7% FO, respectively) and winter (46.4–90.0% and 45.9–57.5% FO, respectively; Sinclair et al. 2013). Samples from the eastern GOA ecoregion (scat collected between 1997-1999), indicated that sea lions consumed predominantly walleye pollock (56.4–96.5% FO; Trites et al. 2007). SSL depredation on walleye pollock

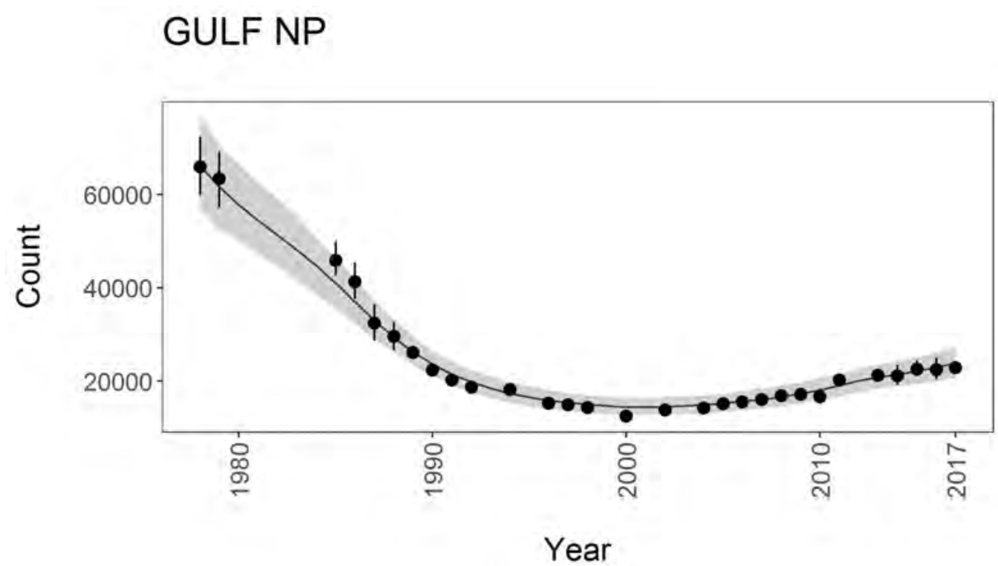

Figure 58: Steller sea lion trends in the western Gulf of Alaska ecoregion .

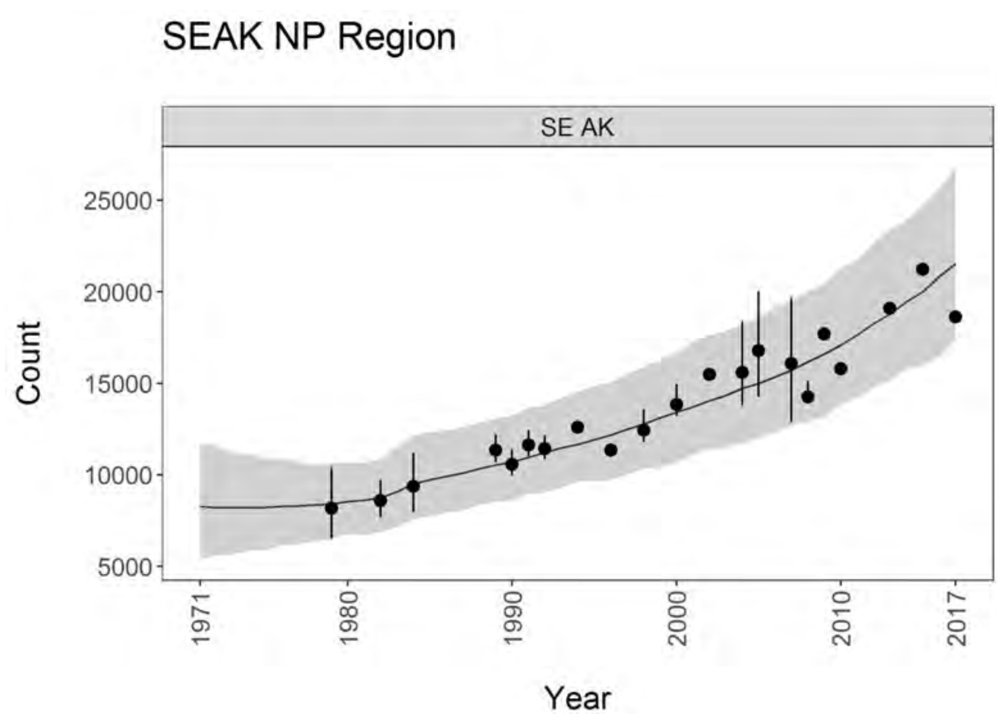

Figure 59: Steller sea lion trends in the eastern Gulf of Alaska ecoregion.

implies that changes in the abundance of SSLs in this region have the potential to influence GOA groundfish fisheries.

Ecosystem or Community Indicators

Stability of Groundfish Biomass in the Western Gulf of Alaska

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Last updated: September 2018

Description of indicator: The stability of the groundfish community total biomass is measured with the inverse biomass coefficient of variation (1 divided by the coefficient of variation of total groundfish biomass (1/CV[B])). This indicator provides a measure of the stability of the ecosystem and its resistance to perturbations. The variability of total community biomass is thought to be sensitive 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 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 biennial summer bottom-trawl survey of the Gulf of Alaska (GOA). Initially, the GOA ground fish survey was conducted on a triennial basis from 1984 through 1999. Starting in 2001 the survey has been conducted on a biennial basis. Since 10 years of data are required to calculate this metric, the indicator values start in 2007, the tenth time the western GOA was surveyed in the trawl survey time series (1984–2017). 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.

Status and trends: The stability of groundfish biomass in the western Gulf of Alaska has been relatively constant over the time period examined (Figure 60). There was a slight increase in stability from 2007 to 2015, followed by a decrease from 2015 to 2017.

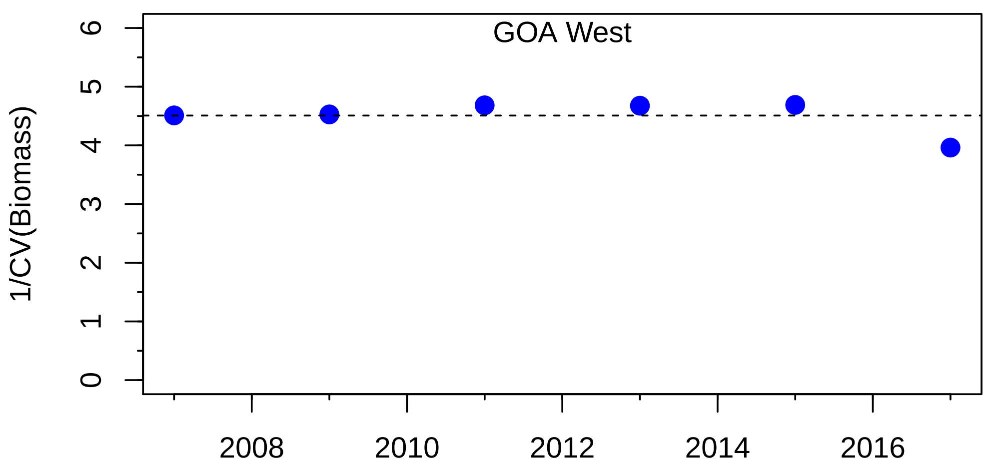

Figure 60: The stability of groundfish in the western GOA represented with the metric, one divided by the coefficient of variation of total groundfish biomass (1/CV[B]). Ten years of data are required to calculate this metric, so this time series begins in 2007 after the tenth occurrence of the NMFS/AFSC summer bottom-trawl survey. The dashed line represents the mean of the time series (2007–2017).

Factors influencing observed trends: The biomass index for the total groundfish community dropped to its lowest value over the trawl survey time series (1984–2017) in 2017. This reduced the recent ten year mean index and increased the standard deviation, resulting in a slight reduction in this indicator. 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, and 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 of the GOA summer bottom-trawl survey. In general, as total biomass decreases species spatial distribution may contract or have increasingly isolated patches, both of which may lead to increased CV (Shin et al. 2010).

Implications: The biomass of the groundfish community in the western GOA appears to be stable over the time period examined. Although the western GOA bottom trawl survey has only occurred 15 times and there are only six data points for this metric, there is no indication of a clear trend in the stability of the groundfish community biomass.

Mean Length of the Fish Community in the Western Gulf of Alaska

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

Description of indicator: The mean length of the groundfish community tracks fluctuations in the size of groundfish over time. This size-based indicator is thought to be sensitive to the effects of commercial fisheries because larger predatory fish are often targeted by fisheries and their selective removal would reduce mean size (Shin et al. 2005). Fish lengths are routinely recorded during the biennial bottom trawl survey of the Gulf of Alaska. Initially the survey was conducted on a triennial basis from 1984 to 1999 before switching to a biennial schedule in 2001.

Species-specific mean lengths are calculated for groundfish species from the length measurements collected during the trawl survey. The mean length for the groundfish community is calculated with the species-specific mean lengths, weighted by biomass indices (Shin et al. 2010) calculated from the bottom-trawl survey. This indicator specifically applies to the portion of the demersal groundfish community efficiently sampled with the trawling gear used by NMFS during the summer bottom-trawl survey of the GOA and have their lengths regularly sampled (for complete survey details see von Szalay and Raring 2018). This includes species of skates, flatfishes, and roundfishes (e.g., cods, sculpins, eelpouts). Species that are predominately found in the pelagic environment (e.g., capelin, pelagic smelts), over untrawlable habitat (e.g., rockfishes), or are otherwise infrequently encountered (e.g., sharks, grenadiers, myctophids) or not efficiently caught by the bottom-trawling gear are excluded from this indicator.

Status and trends: The mean length of the groundfish community in the western Gulf of Alaska in 2017 is 36.8 cm, which is slightly less than the long-term mean of 38.5 cm. This indicator has generally been stable over the years examined (Figure 61). Fluctuations in the mean length are largely the result of variation in the biomass indices of forage species not well sampled by the bottom-trawl. In 2001 and 2007 the mean length dropped to its two lowest values over the time series. This is attributable to the relatively high estimates of Pacific herring and other managed forage fish biomass indices in those years. Otherwise, the metric has remained close to the long-term mean.

Factors influencing observed trends: This indicator is specific to the fishes that are routinely caught

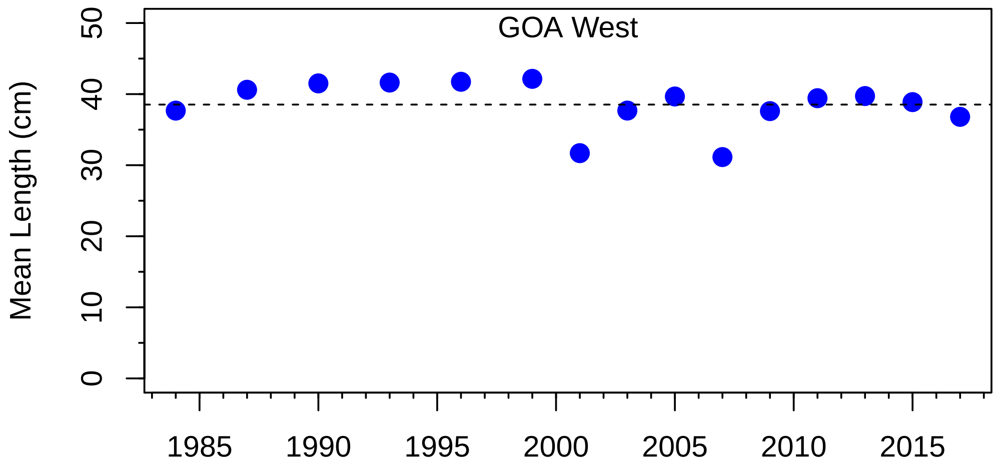

Figure 61: Mean length of the groundfish community sampled during the NMFS/AFSC summer bottom-trawl survey of the western Gulf of Alaska (1984–2017). The groundfish community mean length is weighted by the relative biomass of the sampled species. The dashed line represents the time series mean (1984–2017).

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 effecting the availability and quality of food, or by direct temperature effects on growth rate.

Implications: The mean length of the groundfish community in the western Gulf of Alaska has been stable over the bottom-trawl time series (1984-2017). There is no evidence at this time of an obvious trend in mean size or indication that an external pressure such as climate or fishing is affecting this indicator.

Mean Lifespan of the Fish Community in the Western Gulf of Alaska

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

Description of indicator: The mean lifespan of the community is defined by Shin et al. (2010) as, "a proxy for the mean turnover rate of species and communities" and is intended to reflect "ecosystem stability and resistance to perturbations." The indicator for mean lifespan of the groundfish community is modeled after the method for mean lifespan presented in Shin et al. (2010). Lifespan estimates of groundfish species regularly encountered during the NMFS/AFSC biennial summer bottom-trawl survey of the Gulf of Alaska were retrieved from the AFSC Life History Database (`https://access.afsc.noaa.gov/reem/LHWeb/Index.php`). Initially, the GOA bottom trawl survey was conducted triennially from 1984 to 1999, then switched to a biennial schedule beginning in 2001. The groundfish community mean lifespan is weighted by the relative biomass of groundfish species sampled during the summer bottom-trawl survey. This metric specifically applies to the demersal groundfish community that is sampled by the trawling gear employed in this survey.

Status and trends: The mean lifespan of the western GOA demersal fish community is 22.6 which is slightly less than the long-term mean of 24.6 over the years 1984–2017 (Figure 62). This metric has been largely stable over the time period examined with some interannual variation. Conspicuous drops in the mean valı ... ecies, including ... icates a negative

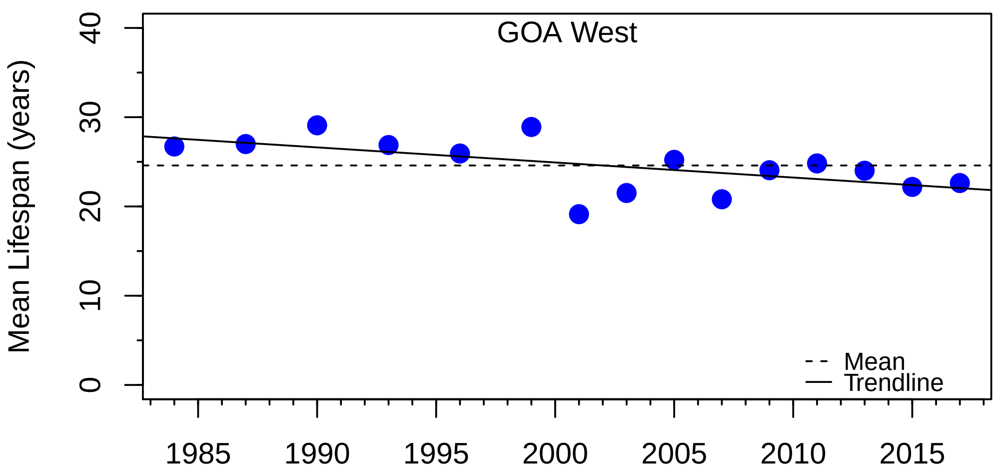

Figure 62: The mean lifespan of the western Gulf of Alaska demersal fish community (blue line), weighted by relative biomass calculated from the NMFS/AFSC summer bottom-trawl survey. The dashed line represents the mean of the time series (1984–2017) and the solid line is a trendline with slope = 0.169.

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 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. This seems to be the case in 2001 and 2007 when high biomass indices for Pacific herring and other forage species reduced the mean lifespan for the groundfish community.

Implications: The groundfish mean lifespan has been generally stable over the time series of the summer bottom trawl survey. The trendline indicates a slow decrease in mean lifespan over the time series. However, there is no indication 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).

Stability of Groundfish Biomass in the Eastern Gulf of Alaska

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Last updated: September 2018

Description of indicator: The stability of the groundfish community total biomass is measured with the inverse biomass coefficient of variation (1 divided by the coefficient of variation of total groundfish biomass (1/CV[B])). This indicator provides a measure of the stability of the ecosystem and its resistance to perturbations. The variability of total community biomass is thought to be sensitive 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 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 biennial summer bottom-trawl survey of the Gulf of Alaska (GOA). Initially, the GOA ground fish survey was conducted on a triennial basis from 1984 through 1999. Starting in 2001 the survey has been conducted on a biennial basis; however, the eastern GOA was not surveyed in 2001. Since 10 years of data are required to calculate this metric, the indicator values start in 2007, the tenth time the western GOA was surveyed in the trawl survey time series (1984–2017). 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.

Status and trends: The stability of groundfish biomass in the eastern Gulf of Alaska has been generally constant over the time period examined with only minor fluctuations between survey years (Figure 60).

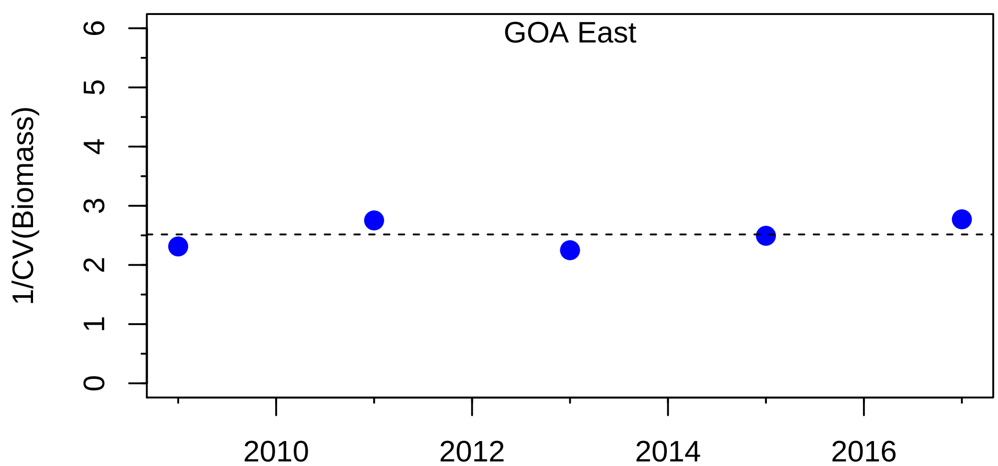

Figure 63: The stability of groundfish in the eastern GOA represented with the metric, one divided by the coefficient of variation of total groundfish biomass (1/CV[B]). Ten years of data are required to calculate this metric, so this time series begins in 2007 after the tenth occurrence of the NMFS/AFSC summer bottom-trawl survey. The dashed line represents the mean of the time series (2007–2017).

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, and 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 summer bottom-trawl survey. In general, as total biomass decreases species spatial distribution may contract or have increasingly isolated patches, both of which may lead to increased CV (Shin et al. 2010).

Implications: The biomass of the groundfish community in the eastern GOA appears to be stable over the time period examined. Although the eastern GOA bottom trawl survey has only occurred 14 times and there are only five data points for this metric, there is no indication of a clear trend in this indicator.

Mean Length of the Fish Community in the Eastern Gulf of Alaska

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Last updated: September 2018

Description of indicator: The mean length of the groundfish community tracks fluctuations in the size of groundfish over time. This size-based indicator is thought to be sensitive to the effects of commercial fisheries because larger predatory fish are often targeted by fisheries and their selective removal would reduce mean size (Shin et al. 2005). Fish lengths are routinely recorded during the biennial bottom trawl survey of the Gulf of Alaska. Initially the survey was conducted on a triennial basis from 1984 to 1999 before switching to a biennial schedule in 2001. However, the eastern Gulf of Alaska (east of 144°W) was not surveyed in 2001.

Species-specific mean lengths are calculated for groundfish species from the length measurements collected during the trawl survey. The mean length for the groundfish community is calculated with the species-specific mean lengths, weighted by biomass indices (Shin et al. 2010) calculated from the bottom-trawl survey. This indicator specifically applies to the portion of the demersal groundfish community efficiently sampled with the trawling gear used by NMFS during the summer bottom-trawl survey of the GOA and have their lengths regularly sampled (for complete survey details see von Szalay and Raring 2018). This includes species of skates, flatfishes, and roundfishes (e.g., cods, sculpins, eelpouts). Species that are predominately found in the pelagic environment (e.g., capelin, pelagic smelts), over untrawlable habitat (e.g., rockfishes), or are otherwise infrequently encountered (e.g., sharks, grenadiers, myctophids) or not efficiently caught by the bottom-trawling gear are excluded from this indicator.

Status and trends: The mean length of the groundfish community in the eastern GOA in 2017 is 29.5 cm, down from 36 cm in 2015 and below the long-term mean of 33.5 cm (Figure 64). Year-to-year variation in this indicator reflects interannual variation in the relative abundance of large and small species of groundfish. This indicator is generally stable over the survey time series and the slope of a trendline was not significantly different from zero ($p > 0.05$).

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 effecting the availability and

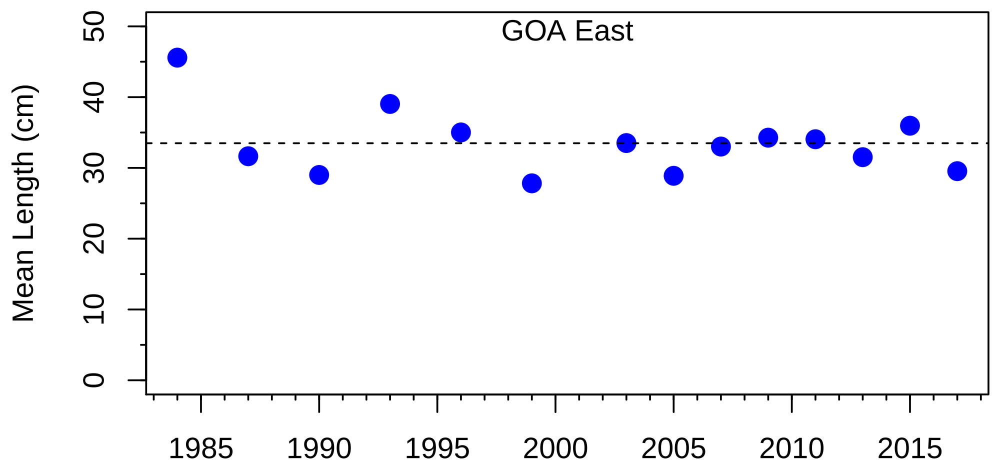

Figure 64: Mean length of the groundfish community sampled during the NMFS/AFSC summer bottom-trawl survey of the eastern Gulf of Alaska (1984–2017). The groundfish community mean length is weighted by the relative biomass of the sampled species. The dashed line represents the time series mean (1984–2017).

quality of food, or by direct temperature effects on growth rate.

Implications: The mean length of the groundfish community in the eastern Gulf of Alaska has been stable over the bottom-trawl time series (1984-2017). There is no evidence at this time of an obvious trend in mean size or indication that an external pressure such as climate or fishing is affecting this indicator.

Mean Lifespan of the Fish Community in the Eastern Gulf of Alaska

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Last updated: September 2018

Description of indicator: The mean lifespan of the community is defined by Shin et al. (2010) as, "a proxy for the mean turnover rate of species and communities" and is intended to reflect "ecosystem stability and resistance to perturbations." The indicator for mean lifespan of the groundfish community is modeled after the method for mean lifespan presented in (Shin et al. 2010). Lifespan estimates of groundfish species regularly encountered during the NMFS/AFSC biennial summer bottom-trawl survey of the Gulf of Alaska were retrieved from the AFSC Life History Database (`https://access.afsc.noaa.gov/reem/LHWeb/Index.php`). Initially, the GOA bottom trawl survey was conducted triennially from 1984 to 1999, then switched to a biennial schedule beginning in 2001. However, the eastern GOA (east of 144°W) was not surveyed in 2001. The groundfish community mean lifespan is weighted by the relative biomass of groundfish species sampled during the summer bottom-trawl survey. This metric specifically applies to the demersal groundfish community that is sampled by the trawling gear employed in this survey.

Status and trends: The mean lifespan of the eastern GOA demersal fish community is 24.4 which is slightly less than the long-term mean of 26 over the years 1984–2017. This metric has been generally stable over the time period examined with some interannual variation that reflects fluctuations in abundance of the dominant groundfish species in this region (Figure 65). High values for this indicator in 1984 and 1993 reflect relatively high biomass indices for long-lived species such as sablefish, Pacific halibut, and dover sole. In contras ıorter lived speci ıdline was not si

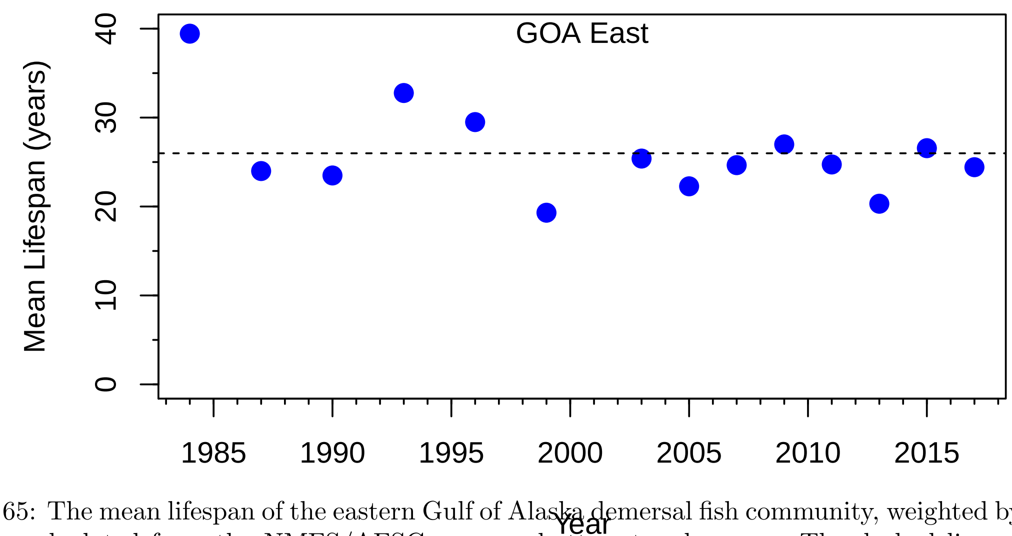

Figure 65: The mean lifespan of the eastern Gulf of Alaska demersal fish community, weighted by relative biomass calculated from the NMFS/AFSC summer bottom-trawl survey. The dashed line represents the time series mean (1984–2017).

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 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.

Implications: The groundfish mean lifespan has been generally stable over the time series of the summer bottom trawl survey. There is no indication 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).

Disease Ecology Indicators

Temporal Trends in Ichthyophonus Infection Prevalence in Pacific Halibut

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Last updated: October 2018

Description of indicator: *Ichthyophonus* (spp.) is a globally distributed mesomycetozoan fish parasite, which has caused epizootic events among economically important fish stocks, including herring and salmon. The parasite has been documented in at least 145 fish species, and infection can result in reduced growth, stamina, and overall health. In some cases, individuals show gross clinical signs including black papules, white nodules on heart tissue, muscle ulcers, and roughening of the skin.

Here we report: 1) *Ichthyophonus* infection prevalence in sport-caught fishes assessed by sampling sport-caught specimens at municipal fish processing stations in the ports of Homer, Seward, Valdez, Whittier, and Deep Creek/ Ninilchik (Central Cook Inlet, CCI) in 2011 and 2) *Ichthyophonus* infection prevalence in Pacific halibut *Hippoglossus stenolepis* sampled in the port of Homer between 2011 and 2017. The parasite load and body condition effects are also explored.

Status and trends: Sampling in 2011 detected *Ichthyophonus* in fishes from all 5 ports and in 5 of the 10 species examined, including yelloweye rockfish *Sebastes ruberrimus* (5%, n = 20), lingcod *Ophiodon elongates* (16%, n = 45), black rockfish *S. melanops* (9%, n = 56), Pacific cod *Gadus macrocephalus* (9%, n = 58), and Pacific halibut (35%, n = 334). The parasite was not detected in dusky rockfish S. ciliates (n = 46), canary rockfish *S. pinniger* (n = 2), copper rockfish *S. caurinus* (n = 2), silvergray rockfish *S. brevispinis* (n = 4), or quillback rockfish *S. malinger* (n = 18). The combined infection prevalence in all species varied by port (17–44%) and was strongly influenced by the proportion of Pacific halibut in each sample. Samples from CCI had the highest *Ichthyophonus* prevalence (44% ±10.1%). In Pacific halibut—the only species examined in all 5 ports—infection prevalence varied (26–45%). This work is reported in Harris et al. (2018)

The prevalence of *Ichthyophonus* infections in sport-caught Pacific halibut landed at Homer, AK increased from 19–59% from 2011–2017 (Figure 66). Despite the high infection prevalence, there was no indication that the parasite caused serious damage to the host, as significant relationships were not detected between host infection status and sex, age, length-at-age, or fish condition. All metrics of infection severity, including histopathology, bioelectrical impedance, and parasite load assessment, indicated uniformly low levels among infected individuals. These results, when combined with analogous observations of rapid changes in infection prevalence throughout the NE Pacific Ocean (Hershberger et al. 2018) provide evidence for a stable host/pathogen paradigm characterized by recurring prey-based exposures, resulting in light infections that are fully or partially resolved by an effective host immune response. This work is reported in Sitkiewicz et al. (in review).

Factors influencing observed trends: *Ichthyophonus* infections in the sport-caught fishes in all five southcentral Alaska ports and similarity in their piscivorous dietary habits together suggests that the parasite has regional distribution and is likely present in forage fishes. In addition to the increasing temporal trend in infection prevalence in Pacific halibut, we see preliminary evidence of decreases in the infection prevalence in old-age females. The causes of this decline are currently under exploration.

Implications: This research has found no indication of high intensity infections or clinically diseased individuals. These results support the hypothesis that under typical conditions, *Ichthyophonus* can occur at high infection prevalence with concomitant low infection intensities in Pacific halibut. This differs from reports from other species, in which *Ichthyophonus* infection severity increases concomitantly with infection

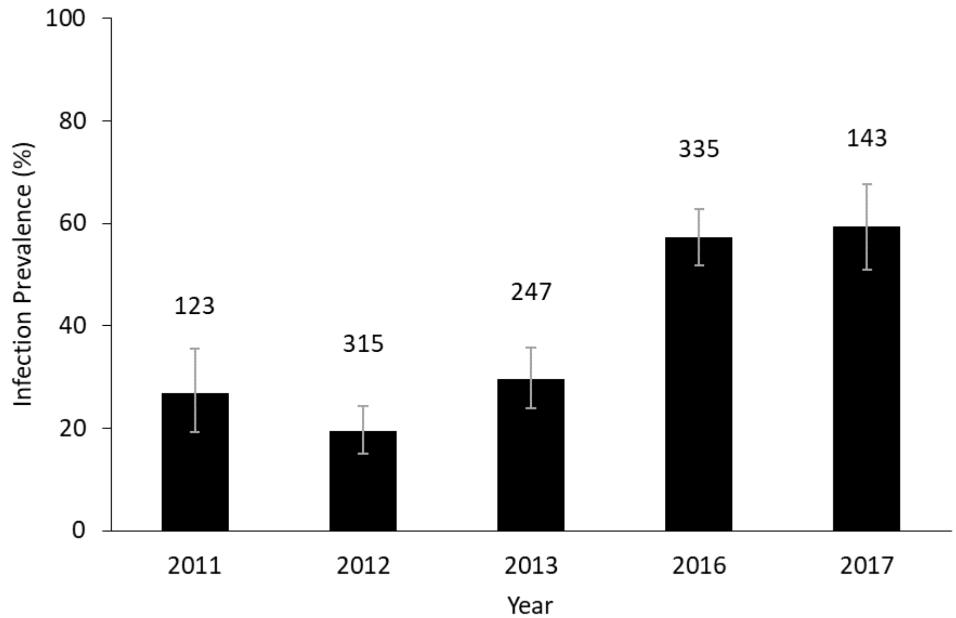

Figure 66: Ichthyophonus infection prevalence in Pacific halibut sampled from 2011-17 at the Port of Homer, AK. Error bars represent 95% confidence intervals, and total sample size (n) is indicated by the numerals above each bar.

prevalence. This project lays important methodological groundwork for the expansion of groundfish condition research to the Bering Sea–Aleutian Islands and Gulf of Alaska.

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:

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

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

Time Trends in Groundfish Discards

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Last updated: September 2018

Description of indicator: Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Regions' blend data, while estimates for 2003 and later come from the Alaska Region's Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards. Discard rates as shown in the figures 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 Fishery Management Plan (FMP)-managed groundfish species within the FMP groundfish fisheries: not included are groundfish discards in the halibut fishery and discards of non-FMP groundfish species, such as forage fish and species managed under prohibited species catch limits.

Status and trends: Since 1993 discard rates of groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in both pollock and non-pollock trawl fisheries in the Gulf of Alaska (GOA) (Figure 67 and 68). In the non-pollock trawl sector, discard rates dropped from 40% in 1994 to 21% in 1998, trended upwards from 1998 to 2003, and generally declined to a low of 8% in 2015 and 2016 before increasing slightly to 11% in 2017. Discard rates in the GOA pollock trawl sectors declined from over 10% in 1993 to about 1% in 1998 and have since fluctuated between 1% and 3%. Rates in the GOA fixed gear (hook-and-line and pot) sector have varied between a low of 6% in 2012 and a high of 14% in 1993 and 2000 and have fluctuated between 9% and 11% over the last 5 years. Due to a significant reduction in the 2018 GOA Pacific cod TAC, discard biomass in the fixed gear sector is trending lower to date in 2018 relative to the last 5 years.

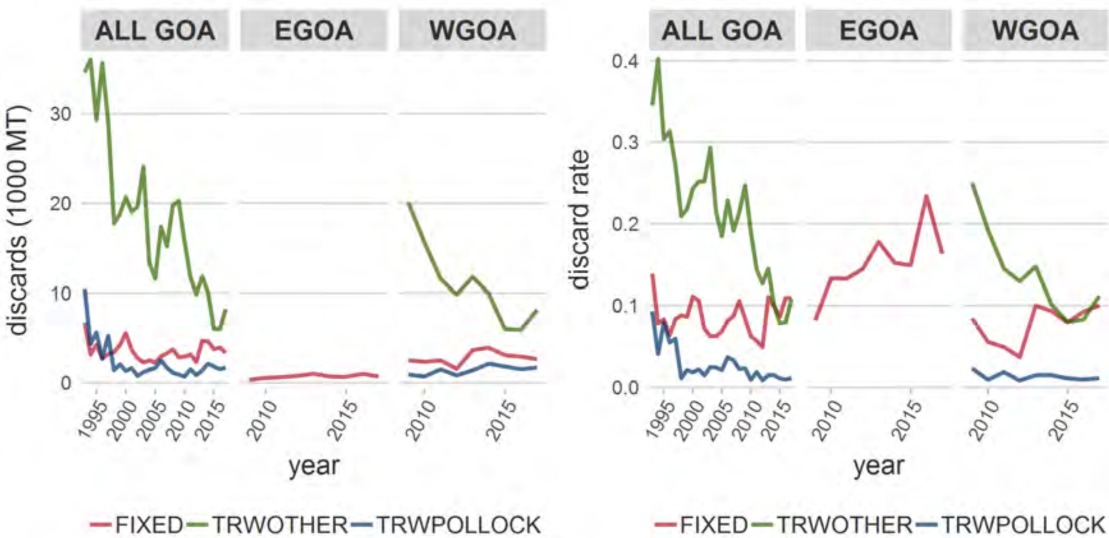

Figure 67: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear, pollock trawl, and non-pollock trawl sectors, 1993–2017, for the Gulf of Alaska (GOA) and eastern and western GOA subregions (data by subregion available only for 2009 and forward). Discard rates are calculated as total discard weight of FMP groundfish divided by total retained and discarded weight of FMP groundfish for the sector (includes only catch counted against federal TACs).

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

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

In the Gulf of Alaska LME management and conservation measures aimed at reducing bycatch have contributed to an overall decline in groundfish discards since the early 1990s (NPFMC 2016). Pollock roe stripping, wherein harvesters discard all but the the highest value pollock product, was prohibited in 1991 (56 Federal Register 492). In 1997 arrowtooth flounder was added as a basis species for retention of pollock and Pacific cod (62 Federal Register 11109), and in 1998 full retention requirements for pollock and cod were implemented for federally-permitted vessels fishing for groundfish, leading to overall declines in pollock and

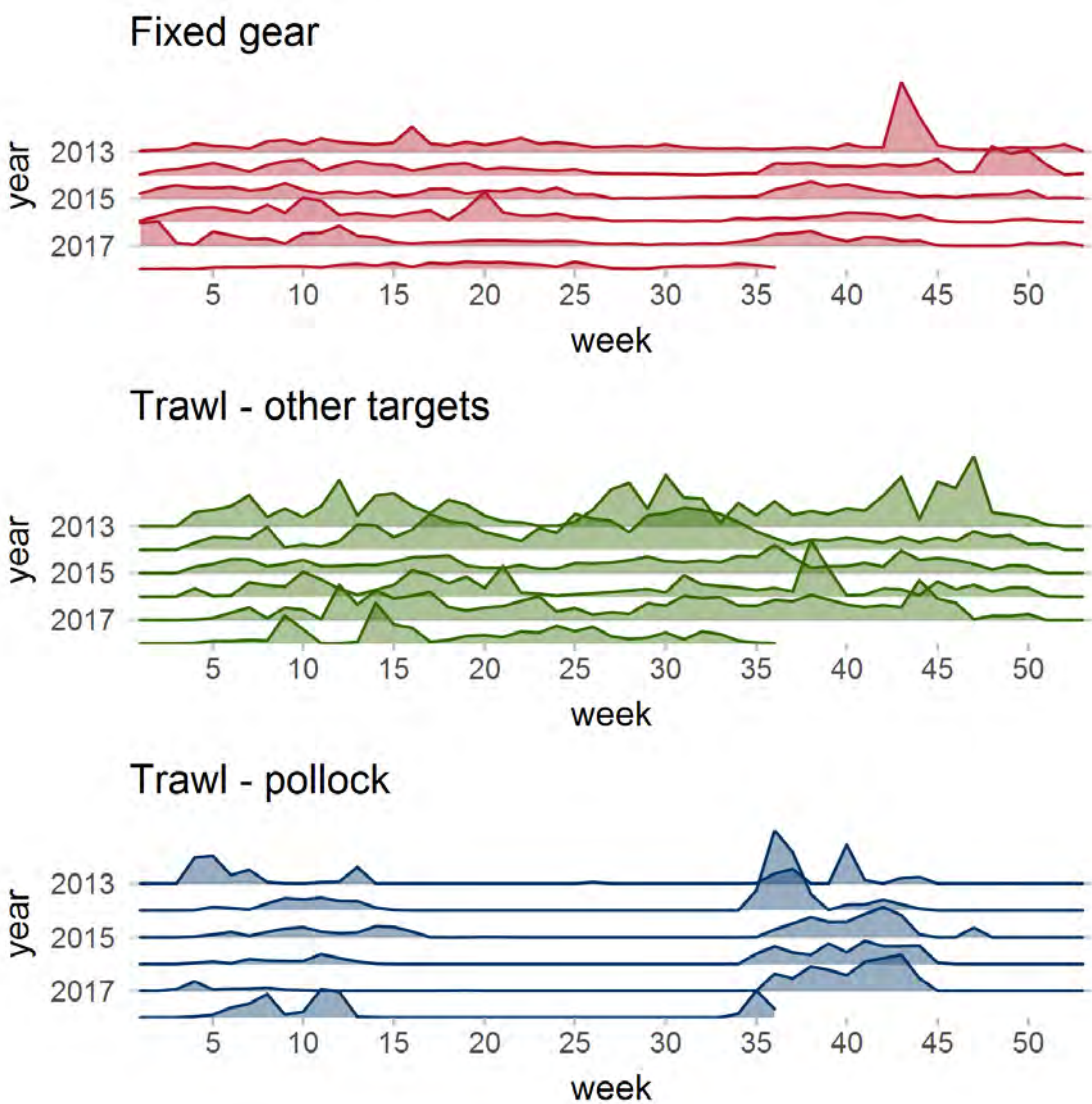

Figure 68: Total biomass of FMP groundfish discarded in the Gulf of Alaska by sector and week of the fishing season, 2013–2018 (data for 2018 is shown through week 36). Plotted heights are not comparable across fisheries.

cod discards in the GOA (62 Federal Register 65379). Additional retention requirements went into effect in 2003 for shallow-water flatfish species across the entire GOA (62 Federal Register 65379) and in 2004 for demersal shelf rockfish in the Southeast Outside district of the Eastern Gulf (69 Federal Register 68095). In 2009, NMFS revised the MRA for groundfish caught in the Gulf of Alaska arrowtooth flounder fishery, including an increase from 0 to 20 percent for flatfish species (74 Federal Register 13348). Under the GOA groundfish FMP, fisheries with discard rates over 5% for shallow-water flatfish are subject to annual review by the North Pacific Council. Reductions in flatfish discards account for most of the general decline in discards and discard rates for the non-pollock trawl sector.

Two LAPPs in the Gulf of Alaska, the Pacific Halibut and Sablefish Individual Fishing Quota (IFQ) Program, implemented in 1995, and the Central Gulf of Alaska (CGOA) Rockfish Program, piloted in 2007 and fully implemented in 2012, include measures to minimize discards by program participants. In the IFQ program, retention of sablefish and halibut is required as long as the harvester has catch quota available, which restricts the practice of high grading. Additionally, all Pacific cod and rockfish must be retained when IFQ halibut or sablefish are on board, subject to other regulations. Vessels participating in cooperatives with CGOA Rockfish Program catch quota are prohibited from discarding catch of allocated target species (Pacific ocean perch and northern, dusky, and thornyhead rockfish) and bycatch species (Pacific cod, sablefish, and rougheye and shortraker rockfish).

In recent years the species historically comprising the "other groundfish" assemblage (skate, sculpin, shark, squid, octopus) have overtaken flatfish as the largest source of discards in the GOA. Most discards of these species currently occur in the longline fishery, although expanded observer coverage of smaller hook and line vessels beginning in 2013 may account for some of the recent increase in fixed gear sector discards. Retention rates for skate and octopus have fluctuated over time, in part due to changing market conditions for these species (Conners and Conrath 2015, Ormseth 2015). Interest in retention of skates and directed fishing for skates (despite management under "bycatch-only" status beginning in 2005) resulted in annual overages of longnose and big skate TACs from 2007 to 2013. Discards and discard rates of skate increased between 2013 and 2016 as NMFS took action to prevent such overages, including regulatory discard requirements for big skate in the Central GOA, imposed at progressively earlier dates during the year from 2013 to 2015, and, in 2016, a reduction in the MRA for GOA skates from 20% to 5% (Ormseth 2015).

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

Time Trends in Non-Target Species Catch

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Last updated: August 2018

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

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

Total catch of non-target species is estimated from observer species composition samples taken at sea during fishing operations, scaled up to reflect the total catch by both observed and unobserved hauls and vessels operating in all Fishery Management Plan 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.

The catch of non-target species/groups from the GOA includes the reporting areas 610, 620, 630, 640, 649, 650, and 659 (https://alaskafisheries.noaa.gov/sites/default/files/fig3.pdf). Within reporting area 610, the GOA and Aleutian Islands (AI) Large Marine Ecosystems are divided at 164°W. Non-target species caught east of 164°W is within the GOA LME and the catch west of 164°W is within the AI LME.

Status and trends: The catch of Scyphozoan jellies in the GOA has been variable from 2011-2017, with the highest catch in 2016 (Figure 69). Other years of elevated catch were 2012 and 2015 and were preceded by years of reduced catch. The catch in 2017 was the second lowest over this time period. Scyphozoan jellies are primarily caught in the pollock fishery. The catch of structural epifauna in the GOA dropped slightly from 2011 to 2012 and trended upward through 2016. In 2017, the catch dropped down to level equivalent to 2013. Sea anemones comprise the majority of the structural epifauna catch and they are primarily caught in the flatfish, Pacific cod, and sablefish fisheries. The catch of assorted invertebrates in the GOA has been variable and shown little trend. The catch increased from 2012 to a peak in 2015 then decreased from 2015 to a low in 2017. Sea stars dominate the assorted invertebrate catch, accounting for more than 90% of the total assorted invertebrate catch in each year. Sea stars are caught primarily in the Pacific cod and halibut fisheries.

Factors influencing observed trends: The catch of non-target species may change if fisheries change, or ecosystems change, or both. Because non-target species catch is unregulated and unintended, if there have been no large-scale changes in fishery management in a particular ecosystem, then large-scale signals in the non-target catch may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, wind-mixing, ocean currents, and prey abundance (Purcell, 2005; Brodeur et al., 2008).

Implications: The catch of structural epifauna and assorted invertebrates is very low compared with the catch of target species. The lack of a clear trend in the catch of scyphozoan jellyfish may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries. Abundant jellyfish may have a negative impact on fishes as they compete with planktivorous fishes for prey resources (Purcell and Sturdevant, 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).

Stock Compositions of Chinook Salmon Bycatch in Gulf of Alaska Trawl Fisheries

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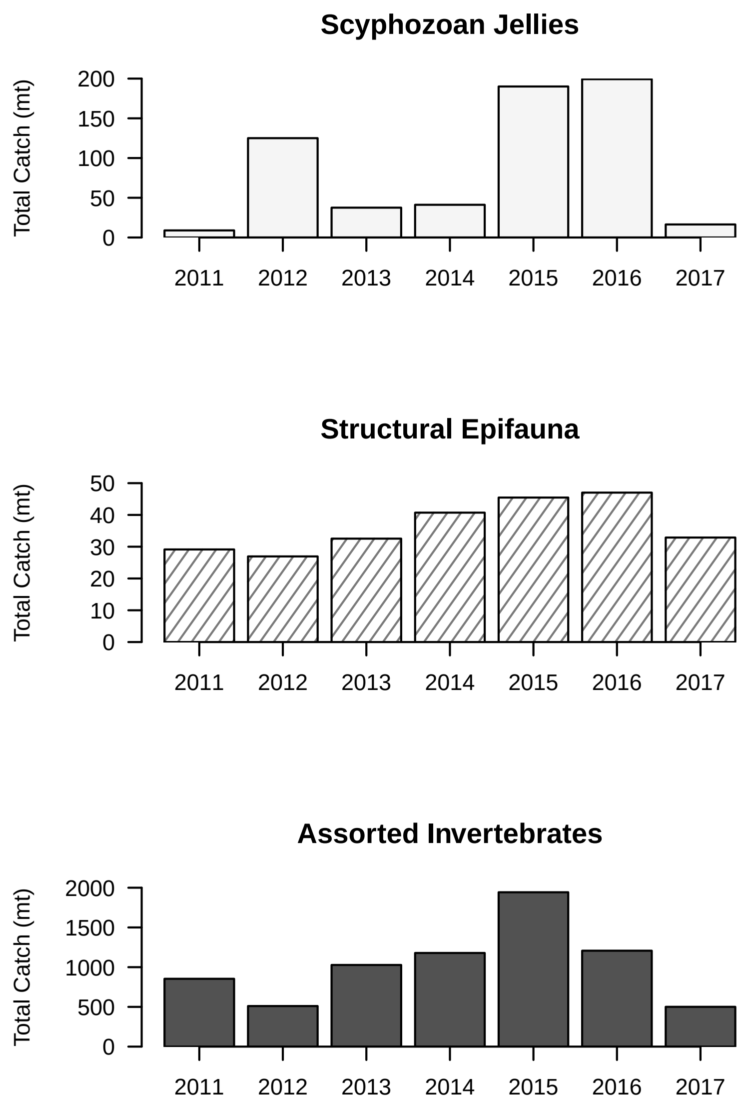

Figure 69: Total catch of non-target species (tons) in the GOA groundfish fisheries (2003–2017). Note the different y-axis scales between species groups.

Last updated: August 2018

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

Observers from the North Pacific Groundfish Observer Program monitor at least 30% of the trips targeting walleye pollock (*Gadus chalcogrammus*) in the Gulf of Alaska each year, and during these trips, they enumerate all Chinook salmon bycatch. Among these, they sample ∼10% of the total estimated Chinook salmon bycatch for genetic analysis. The Genetics Program at the Auke Bay Laboratories analyzes Chinook salmon bycatch samples for genetic stock identification (Guthrie III et al., 2017), apportioning catches to clusters of geographic regions (West Coast U.S., British Columbia (BC), Coastal Southeast Alaska (Coast SE AK), Copper River, Northeast Gulf of Alaska, Northwest Gulf of Alaska (NW GOA), North Alaska Peninsula, Coastal Western Alaska, Middle Yukon River, Upper Yukon River, and Russia). We present the proportional composition of the bycatch for each of these reporting groups.

Status and trends: Stock composition has been relatively stable during the short duration of this time series, with British Columbia stocks dominating the bycatch, and West Coast U.S. stocks either similar to British Columbia stocks, or less, in most years (Figure 70). Coastal Southeast Alaska and Northwest Gulf of Alaska stocks typically represent substantially less of the bycatch while the remainder of stocks were negligible. In 2016 relative to 2015, slight increases were seen in the proportion of west Coast and southeast Alaska Chinook salmon and a reduction in British Columbia stocks in the trawl fisheries of the Gulf of Alaska.

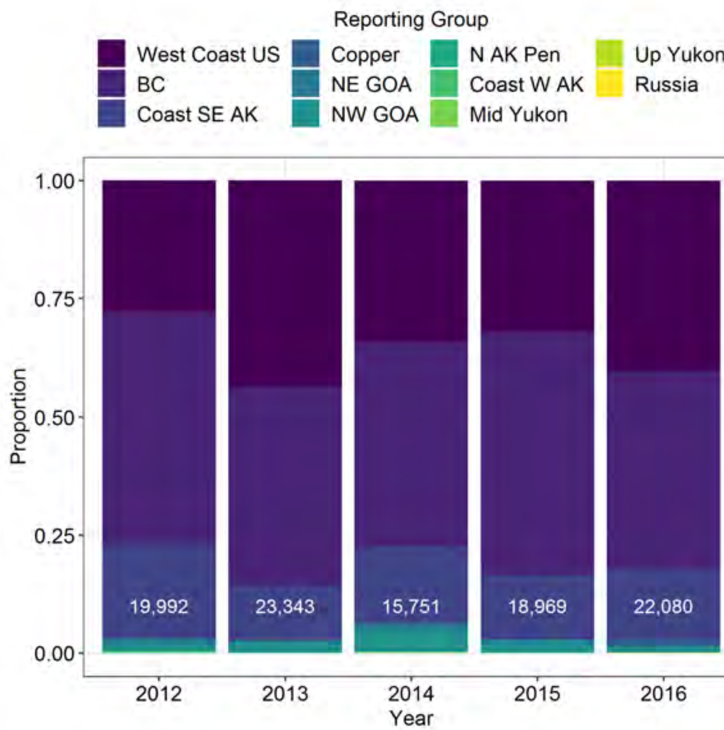

Figure 70: Stock composition (proportion) of Chinook salmon bycatch by year from the Gulf of Alaska (GOA) pollock trawl fishery with total numbers of GOA trawl fishery catches of Chinook salmon provided in the lower portion of each bar, 2012–2016.

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

Factors influencing observed trends: Two primary factors dictate the observed trends in genetic stock composition of trawl fishery bycatch in the Gulf of Alaska. First, British Columbia and West Coast U.S. systems produce orders of magnitude more Chinook salmon each year than Alaska systems, yielding the much greater proportion of these stocks. Second, the timing of the fisheries may also drive some of the observed signals. British Columbia and West Coast U.S. stocks have both spring and fall runs of Chinook salmon, which may lead to the presence of greater overlap with trawl fisheries in the Gulf of Alaska, as compared to Alaskan stocks which are dominated by a spring out-migration of smolts, reducing periods of potential overlap with trawl fleets.

Implications: Understanding the dynamics of Chinook salmon bycatch in trawl fisheries is critical to groundfish management because Chinook salmon represent a prohibited species catch that can drive fisher behavior and lead to significant economic impacts on the fleet. The coarse spatial resolution of the reporting groups makes it difficult to resolve the impacts of Chinook salmon bycatch on any particular stock, as has been done in the Bering Sea (Ianelli and Stram, 2014). However, despite the coarse resolution, changes in the relative compositions from year to year may serve as an indicator of altered dynamics in the fishery interaction with Chinook salmon. A shift in compositions could be indicative of a change in timing of either Chinook salmon migration patterns or fishing patterns (Watson and Haynie, 2018), both of which could be related to environmental changes. Alternatively, a change in genetic stock structure could be indicative of a change in population dynamics (e.g., higher or lower juvenile mortality) of a particular stock, altered hatchery production scales or schedules, or the recovery or failure of dominant regional runs. Any such factors could affect groundfish fleets or salmon fisheries and may warrant further investigation.

Seabird Bycatch Estimates for Groundfish Fisheries in the Gulf of Alaska, 2007–2017

Contributed by Anne Marie Eich[1], Stephani Zador[2], Shannon Fitzgerald[2] and Jennifer Mondragon[1]
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Last updated: August 2018

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

Estimates are based on two sources of information, (1) data provided by NMFS-certified fishery observers deployed to vessels and floating or shoreside processing plants (AFSC, 2011), and (2) industry reports of catch and production. The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2014, 2010). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. It is also used for the provision of estimates of non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. The CAS produces estimates based on these two current data sets, which may change over time. Changes in the data from one reporting year to another are due to errors that were discovered through additional data quality checks, 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.

Status and trends: The numbers of seabirds estimated to be caught incidentally in Gulf of Alaska fisheries in 2017 increased from that in 2016 by 138%, and was above the 2007–2016 average of 1,066 by 41% (Table 4; Figure 71). Black-footed albatross, northern fulmars, and gulls were the most common species caught incidentally. In 2017, the number of black-footed albatross increased by 293% compared to 2016 and was well above the 2007–2016 average of 220 by 259%. In 2017, the number of northern fulmars increased by

89% compared to 2016 but remained below the 2007–2016 average of 426 by 12%. In 2017, the number of gulls increased by 21% compared to 2016 and was above the 2007–2016 average of 258 by 19%. For only the second time in this time series (2007–2017) no Laysan albatross were estimated to be caught incidentally in Gulf of Alaska fisheries. The estimated numbers of albatrosses caught incidentally in the Gulf of Alaska is more than in each the eastern Bering Sea and the Aleutian Islands, as has been the case in all years in this time series (Figure 72). The estimated numbers of birds caught incidentally in the Gulf of Alaska are generally far lower than the numbers caught in the Bering Sea, but are generally higher than the number caught in the Aleutian Islands with the exception of two years (2010 and 2015; Figure 71).

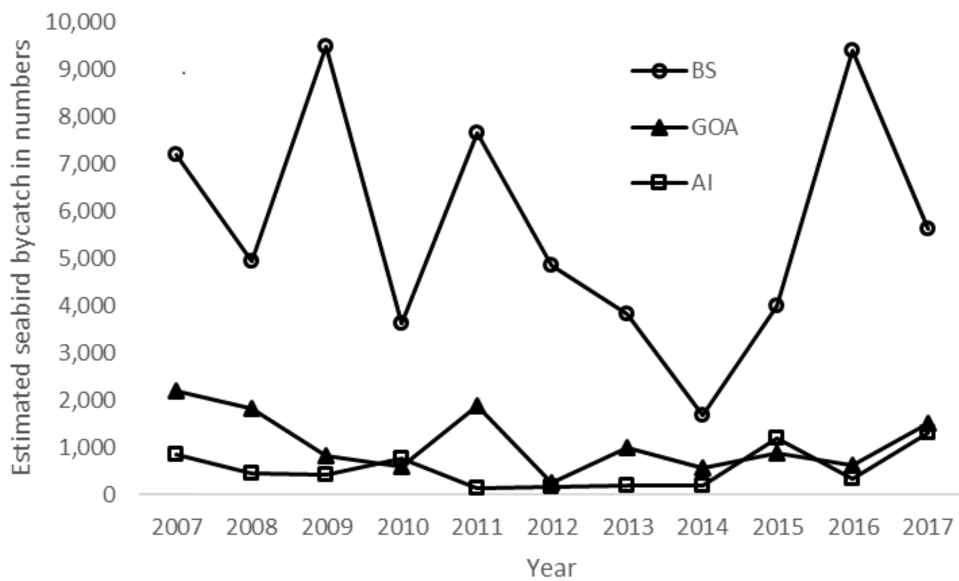

Figure 71: Total estimated seabird bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007 to 2017.

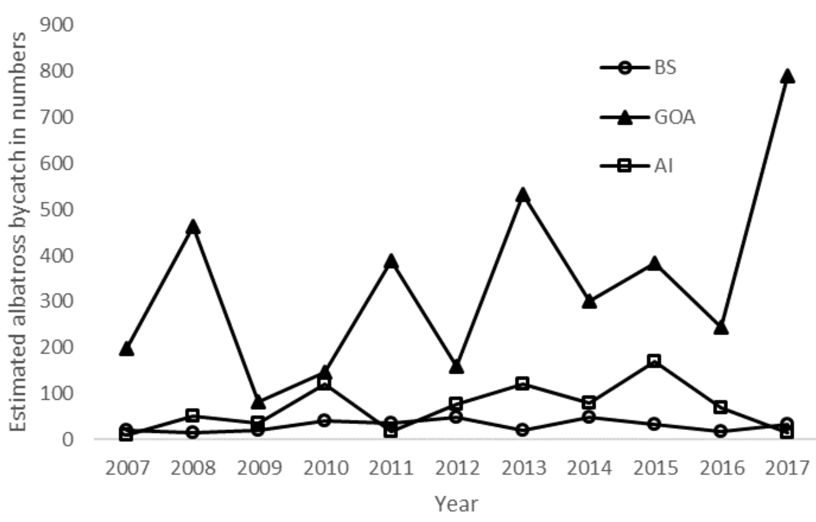

Figure 72: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007 to 2017.

Factors influencing observed trends: There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. For

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

Species Group	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Unidentified Albatrosses	17	0	0	0	10	0	28	0	0	0	0
Laysan Albatross	0	168	31	85	164	17	69	32	41	44	0
Black-footed Albatross	182	295	51	63	216	142	436	269	343	201	790
Northern Fulmar	1,466	893	236	175	877	19	260	51	88	198	375
Shearwaters	32	0	0	0	61	0	57	0	5	20	27
Gulls	461	183	320	280	555	51	137	157	287	149	308
Auklets	0	0	0	0	0	0	0	6	49	0	0
Other Alcids	0	0	0	0	0	0	0	39	0	0	0
Cormorants	0	0	0	0	0	0	0	0	28	0	0
Unidentified Birds	48	274	188	0	9	33	7	0	33	19	0
Grand Total	2,206	1,813	826	603	1,892	262	994	554	874	631	1,500

example, a marked decline in overall numbers of birds caught after 2002 reflected the increased use of seabird mitigation devices. A large portion of the freezer longline fleet adopted these measures in 2002, followed by regulation requiring them for the rest of the fleet beginning in February 2004. Since 2002, seabird bycatch estimates have varied annually but have not returned to the level seen prior to the use of seabird mitigation devices. Since 2004, work has continued on developing new and refining existing mitigation gear (Dietrich and Melvin, 2008).

The longline fleet has traditionally been responsible for about 90% of the overall seabird bycatch in Alaska, as determined from the data sources noted above. However, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates are biased low. 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 (Fitzgerald et al., 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 (Eich et al., 2017).

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

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

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

Areas Closed to Bottom Trawling in the BSAI and GOA

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Last updated: October 2018

Description of indicator: Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Figure 73, Table 5). Some of the trawl closures are in effect year-round while others are seasonal. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high.

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

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

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

Steller Sea Lion closure maps are available here:

`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/atka_pollock.pdf`

`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/pcod_nontrawl.pdf`

`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/cod_trawl.pdf`

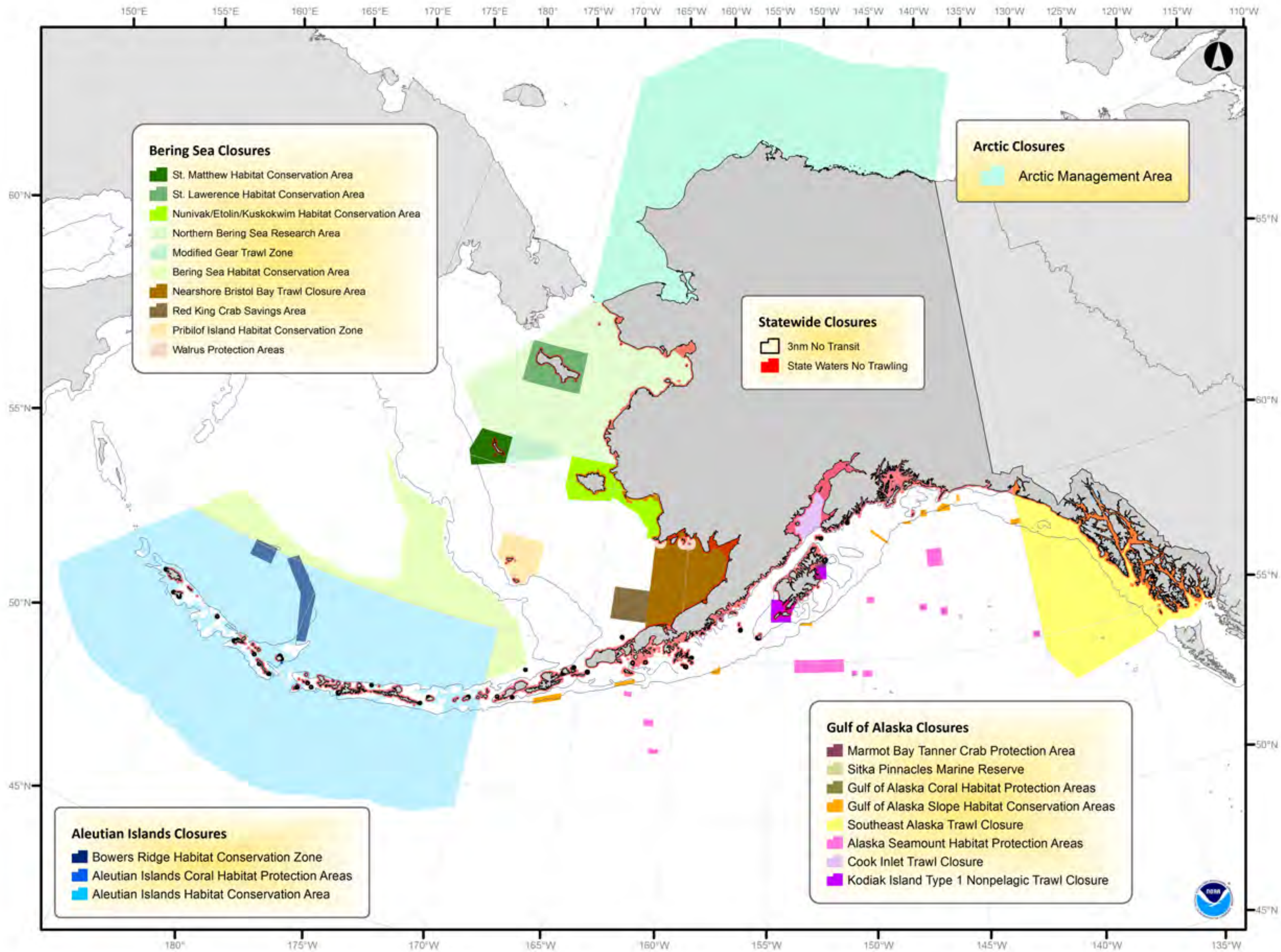

Figure 73: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Area Disturbed by Trawl Fishing Gear in Alaska

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Last updated: October 2018

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

Status and trends: The percent of area disturbed due to commercial fishing interactions (pelagic and non-pelagic trawl, longline, and pot) decreased steadily from 2008 to the present in the Bering Sea, with slightly decreasing or steady trends in the Gulf of Alaska and Aleutian Islands (Figures 74 and 75).

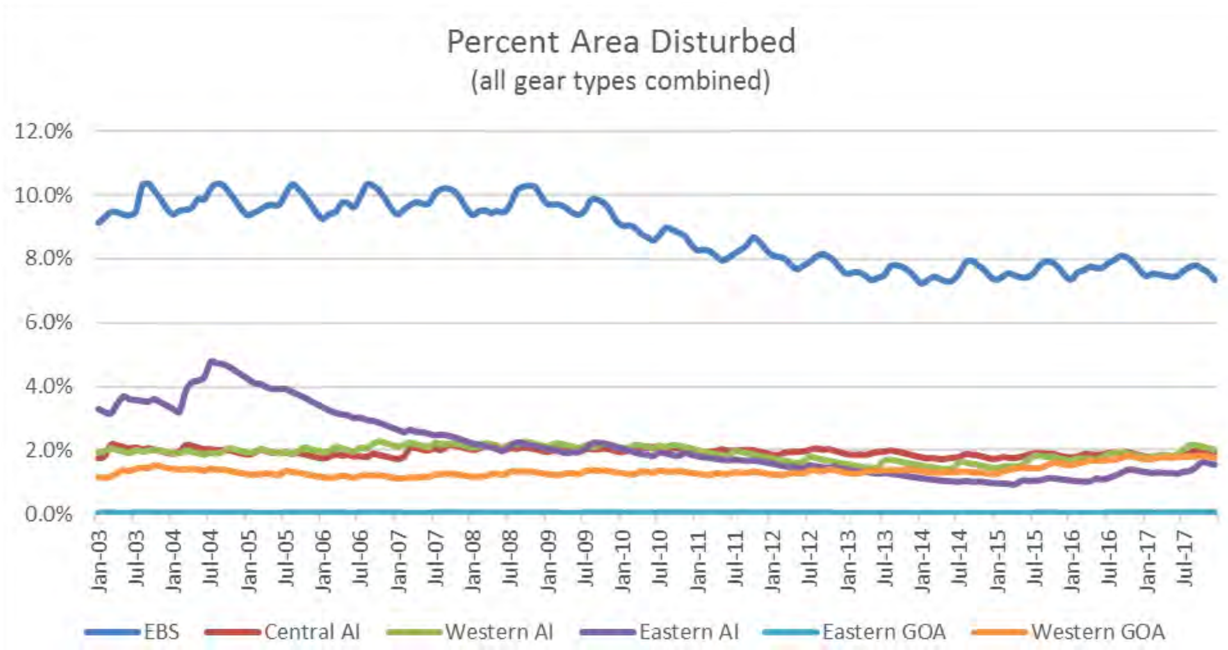

Figure 74: Percent habitat reduction, all gear types combined, from 2003 through 2017.

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

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

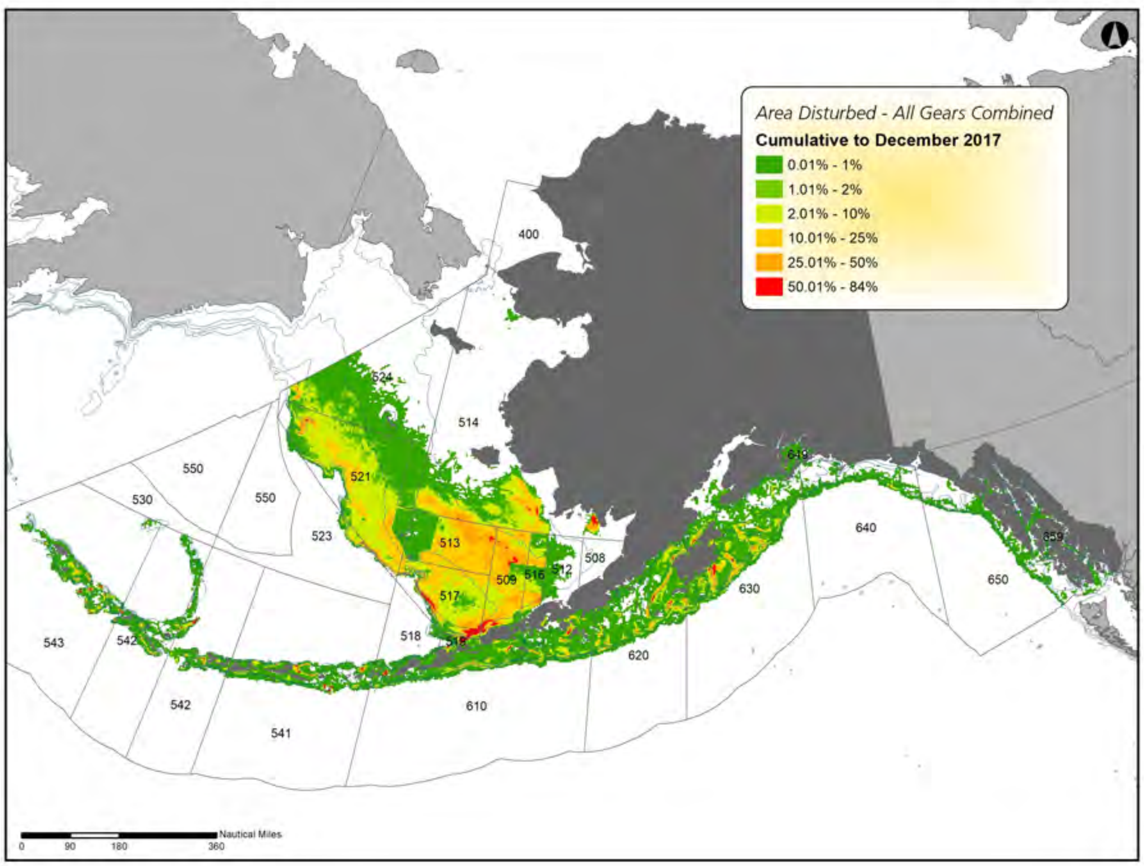

Figure 75: Map of percentage area disturbed per grid cell for all gear types. Effects are cumulative, and consider impacts and recovery of features from 2003 to 2017.

Implications: The effects of changes in fishing effort on habitat are largely unknown, 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 (`ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/TM_NMFS_AFKR/TM_NMFS_FAKR_15.pdf`). The 2005 EFH FEIS, 2010 EFH Review, and 2015

EFH Review concluded that fisheries do have long term effects on habitat, and these impacts were determined to be minimal and not detrimental to fish populations or their habitats. These previous EFH analyses indicated the need for improved fishing effects model parameters. With the FE model, our ability to analyze fishing effects on habitat has grown exponentially. Vessel Monitoring System data provides a much more detailed treatment of fishing intensity, allowing better assessments of the effects of overlapping effort and distribution of effort between and within grid cells. The development of literature-derived fishing effects database has increased our ability to estimate gear-specific susceptibility and recovery parameters. The distribution of habitat types, derived from increased sediment data availability, has improved. The combination of these parameters has greatly enhanced our ability to estimate fishing impacts.

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

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

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

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

Sustainability (for consumptive and non-consumptive uses)

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

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Last updated: July 2018

Description of indicator: The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of fish stocks selected for their importance to commercial and recreational fisheries (https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updat 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 total Alaska FSSI as a percentage of the maximum possible score (i.e., 100%). Additionally, there are 29 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement. None of the non-FSSI stocks are known to be overfished, approaching an overfished condition, or subject to overfishing. For more information on non-FSSI stocks see the Status of U.S. Fisheries webpage.

Within the GOA region there are 14 FSSI stocks. The assessment for sablefish is based on aggregated data from the GOA and BSAI regions. In FSSI contributions prior to 2017, the sablefish FSSI score was included among BSAI species. Starting with last years contribution sablefish was removed from the BSAI contribution and placed in the GOA FSSI.

Status and trends: As of June 30, 2018, no GOA groundfish stock or stock complex is subjected to overfishing, is known to be overfished, or known to be approaching an overfished condition (Table 6).

Table 6: Summary of status for GOA FSSI stocks managed under federal fishery management plans, updated through June 2018.

GOA FSSI (14 stocks)	Yes	No	Unk	Undef	N/A
Overfishing	0	14	0	0	0
Overfished	0	12	2	0	0
Approaching Overfished Condition	0	12	2	0	0

The current overall Alaska FSSI is 135 out of a possible 144, or 93.75%, based on updates through June 2018 and is the highest score observed over the time period examined (Figure 76). The Alaska FSSI increased 2.5 points from last years score and is the net result of increased scores for two king crab stocks in the EBS and a lower score for snow crab in the EBS. The overall Alaska FSSI has generally trended upwards from 80% in 2006 to 93.75% in 2018.The GOA FSSI is 51 out of a maximum possible 56 (Table 6). Two and a half points are deducted from both the Demersal Shelf Rockfish Complex and the Thornyhead Rockfish complex for unknown status determinations and not estimating B/BMSY. Since 2006 the GOA FSSI has been generally steady, increasing from 90% in 2006 up to 91% in 2018 (Figure 77). There were minor drops in the FSSI in 2008–2009 and again in 2012–2013. In 2008 and 2009 a point was lost each year for B/BMSY walleye pollock in the western/central GOA dropping below 0.8. In 2009 an additional 2.5 points were lost for the Rex sole stock having unknown status determinations and for not estimating B/BMSY. In 2012 and 2013 2.5 points were lost for having unknown status determinations and not estimating B/BMSY for the deep water flatfish complex.

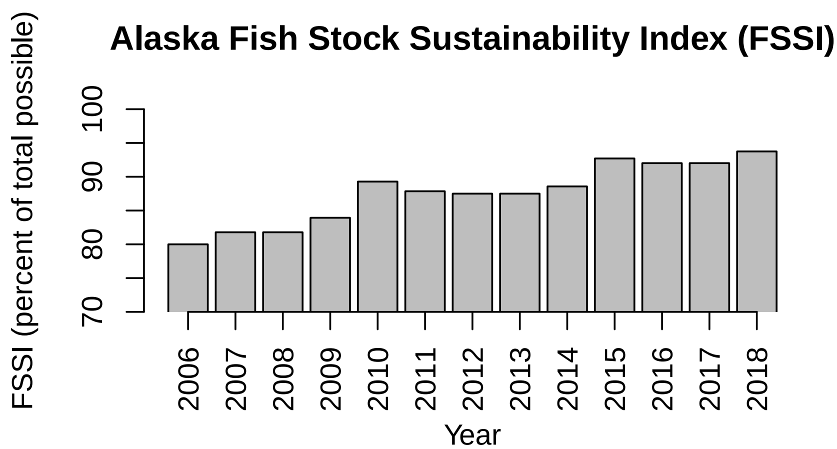

Figure 76: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2018. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 on it is 144. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Factors influencing observed trends: The GOA FSSI is unchanged from last year. GOA stocks that had low FSSI scores (1.5) are the thornyhead rockfish complex (shortspine thornyhead rockfish as the indicator species) and the demersal shelf rockfish complex (yelloweye rockfish as the indicator species). The low scores for these groups are because the overfished status determinations are not

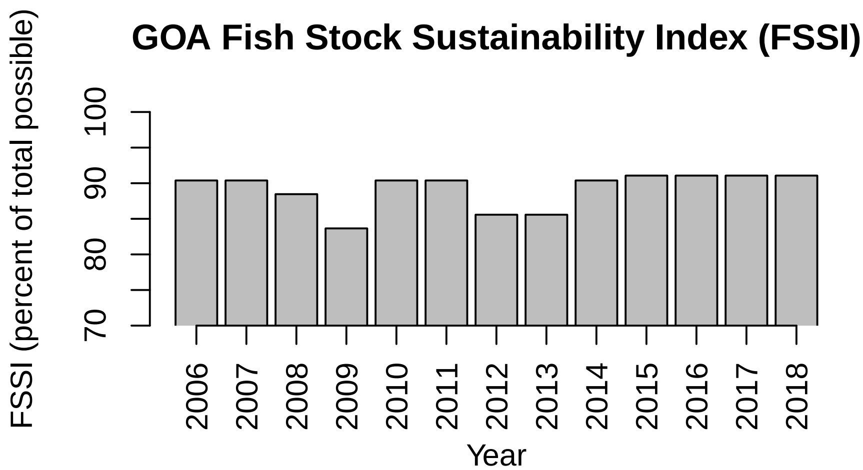

Figure 77: The trend in FSSI from 2006 through 2018 for the GOA region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

defined and it is therefore unknown if the biomass is above the overfished level or if biomass is at or above 80% of BMSY.

Implications: The majority of Alaska groundfish fisheries appear to be sustainably managed, including GOA groundfish fisheries. Until the overfished status determinations are defined for the Demersal Shelf Rockfish complex and the Thornyhead Rockfish complex, it will be unknown whether these stocks are overfished or approaching an overfished condition.

Table 6: GOA FSSI stocks under NPFMC jurisdiction updated June 2018 adapted from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`. See Box B for endnotes and definition of stocks and stock complexes. (continued)

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/B_{MSY}	FSSI Score
GOA Arrowtooth flounder	No	No	No	N/A	N/A	3.38	4
GOA Flathead sole	No	No	No	N/A	N/A	2.55	4
GOA Blackspotted and Rougheye Rockfish complex[a]	No	No	No	N/A	N/A	1.92	4
GOA Deepwater Flatfish Complex[b]	No	No	No	N/A	N/A	2.43	4
GOA Shallow Water Flatfish Complex[c]	No	No	No	N/A	N/A	2.02	4
GOA Demersal Shelf Rockfish Complex[d]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
GOA Dusky Rockfish	No	No	No	N/A	N/A	1.46	4
GOA Thornyhead Rockfish Complex[e]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Northern rockfish - Western / Central GOA	No	No	No	N/A	N/A	1.28	4
GOA Pacific cod	No	No	No	N/A	N/A	1.32	4
GOA Pacific Ocean perch	No	No	No	N/A	N/A	1.57	4
GOA Rex sole	No	No	No	N/A	N/A	2.20	4
Walleye pollock - Western / Central GOA	No	No	No	N/A	N/A	0.93	4
GOA BSAI Sablefish[f]	No	No	No	N/A	N/A	1.02	4

Box B. Endnotes and stock complex definitions for FSSI stocks listed in Table 6, adapted from the Status of U.S. Fisheries website: `www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

(a) GOA 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.

(b) The Deep Water Flatfish Complex consists of the following stocks: Deepsea Sole, Dover Sole, and Greenland Turbot. Dover Sole is the indicator species for determining the status of this stock complex.

(c) The Shallow Water Flatfish Complex consists of the following stocks: Alaska Plaice, Butter Sole, C-O Sole, Curlfin Sole, English Sole, Northern Rock Sole, Pacific Sanddab, Petrale Sole, Sand Sole, Slender Sole, Southern Rock Sole, Speckled Sanddab, Starry Flounder, and Yellowfin Sole. The overfishing determination is based on the OFL, which is computed by using abundance estimates of the complex. A single, assemblage-wide OFL is specified, but overfishing was not defined for the other shallow-water flatfish stocks per se, because they are part of the overall shallow-water flatfish assemblage. SAFE report indicates that the shallow water flatfish complex was not subjected to overfishing and that neither of the indicator species (northern and southern rock sole) is overfished or approaching a condition of being overfished.

(d) The Demersal Shelf Rockfish Complex consists of the following stocks: Canary Rockfish, China Rockfish, Copper Rockfish, Quillback Rockfish, Rosethorn Rockfish, Tiger Rockfish, and Yelloweye Rockfish. The overfishing determination is based on the OFL, which is computed by using estimates of Yelloweye Rockfish and then increased by 10% to account for the remaining members of the complex.

(e) The Thornyhead Rockfish Complex consists of the following stocks: Longspine Thornyhead and Shortspine Thornyhead. The overfishing determination is based on the OFL, which is computed using abundance estimates of Shortspine Thornyhead.

(f) Although Sablefish is managed separately in the Gulf of Alaska, Bering Sea, and Aleutian Islands, with separate overfishing levels, ABCs, and TACs based on the proportion of biomass in each respective region, separate assessments are not conducted for each of these three regions; the assessment is based on aggregated data from the Gulf of Alaska, Bering Sea, and Aleutian Islands regions. Therefore, it is not appropriate to list separate status determinations for these three regions.

Total Annual Surplus Production and Overall Exploitation Rate of Groundfish, Gulf of Alaska

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Last updated: Oct 2018

Description of indices: Total annual surplus production (ASP) of 10 groundfish on the Gulf of Alaska (GOA) shelf from 1978–2017 was estimated by summing annual production across major commercial groundfish stocks for which Tier 3 assessments are available (Table 7). These species represent at least 75% of the total catch in bottom trawl surveys. Annual surplus production in year t can be estimated as the change in total adult groundfish biomass across species from year t (Bt) to year t+1 ($Bt + 1$) plus total catches in year t (Ct):

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

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

$$ut = Ct/Bt$$

Table 7: Species included in computing annual surplus production in the Bering Sea and Gulf of Alaska.

Stocks
Walleye Pollock (*Gadus chalcogrammus*)
Pacific Cod (*Gadus macrocephalus*)
Arrowtooth Flounder (*Atheresthes stomias*)
Northern Rock Sole (*Lepidopsetta polyxystra*)
Southern Rock Sole (*L.bilineata*)
Flathead Sole (*Hippoglossoides spp.*)
Pacific Ocean Perch (*Sebastes alutus*)
Northern Rockfish (*S. polyspinus*)
Rougheye Rockfish (*S. melanostictus*)
sablefish (*Anoplopoma fimbria*)

Status and trends: The resulting indices suggest high interannual variability in groundfish production in the GOA (Figure 78), with very high ASP in 1979/1980 associated with a number of strong recruitment events for multiple groundfish species after the 1976/77 oceanographic regime shift. ASP was lowest (negative) in the mid-1990s and in the most recent years except 2015, which had one of the largest values for surplus production due to a large increase in pollock biomass. Because of large fluctuations in pollock biomass, ASP was also computed without pollock included, which shows a significant, long-term decline in ASP with the lowest (negative) value in 2017 (Figure 2). Total exploitation rates for the groundfish complex ranged from 2.5–7.2% in the GOA (Figure 78)). Overall exploitation rates were relatively stable over recent decades with peaks in 1984/1985 and in the last three years.

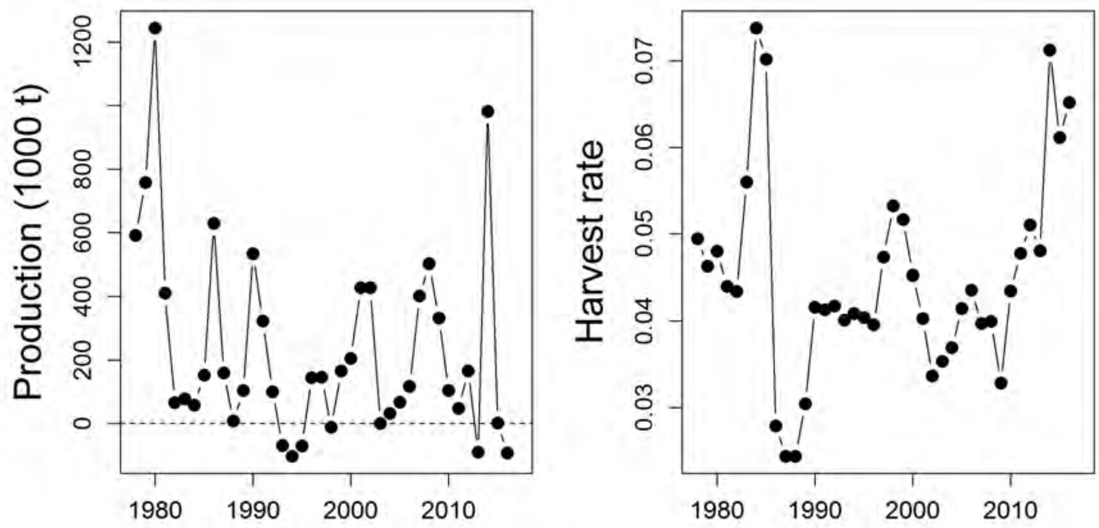

Figure 78: Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and total harvest rate (total catch / beginning-of-year biomass, each summed across all major groundfish species).

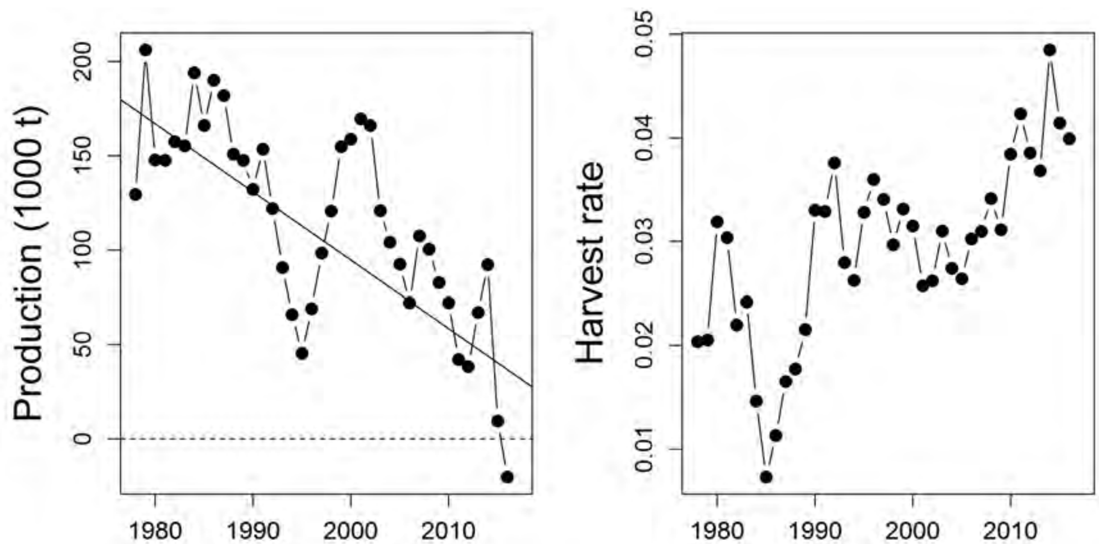

Figure 79: Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and total harvest rate (total catch / beginning-of-year biomass, each summed across all major groundfish species, **excluding walleye pollock).**

Factors causing trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e. mortality from all non-fishery sources) during a given year. It is highest during periods of increasing total biomass (e.g., 2007–2008, 2015) and lowest during periods of decreasing biomass (e.g., 1993–1995, 2016/17). In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Theory suggests that surplus production of a population will decrease as biomass increases much above BMSY, which is the case for many species in the GOA management area. Exploitation rates are primarily determined by management and reflect a relatively precautionary management regime with rates that have mostly averaged less than 5% for the total groundfish complex. Low overall exploitation rates are largely a result of the fact that arrowtooth flounder dominate biomass in the GOA and have very low exploitation rates.

Implications: Under certain assumptions, aggregate surplus production can provide an estimate of the long-term maximum sustainable yield of these groundfish complexes (Mueter and Megrey 2006, Figure 80). Although there is relatively little contrast in total biomass over time, it appears that biomass was generally above the level that would be expected to yield maximum surplus production under a Graham-Schaefer model fit to aggregate ASP (Figure 80). The estimated maximum sustainable yield for the groundfish complex (12 species) was 378,870 t.

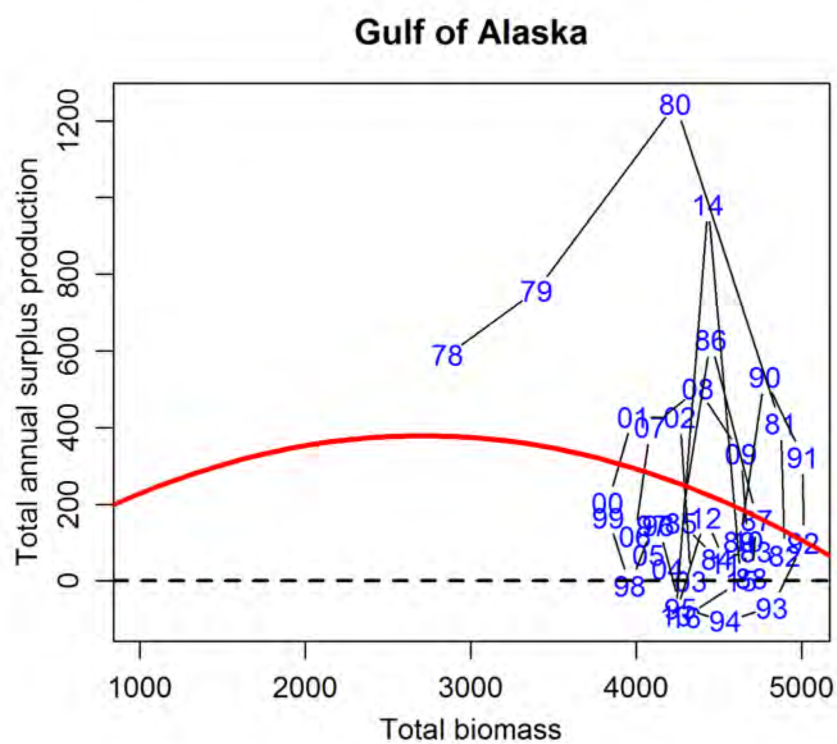

Figure 80: Estimated annual aggregated surplus production against total biomass of major commercial species with fitted Graham-Schaefer curve. Units on both axes are in 1000 t.

Seafood Production

Economic Indicators in the Gulf of Alaska Ecosystem: Landings

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Last updated: September 2018

Description of indicator: Landings are a baseline metric for characterizing commercial economic production in the Gulf of Alaska. Landings are the retained catch of fish. Landings 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, Pacific halibut, sablefish, and arrowtooth flounder. The primary target species in the pelagic foragers functional group are walleye pollock, Pacific ocean perch, northern rockfish and dusky rockfish. The primary species caught in the benthic foragers functional group are flathead sole, and rex sole. The primary target species in the salmonid functional group are Chinook, sockeye, and pink salmon. The primary species caught in the motile epifauna functional group are tanner and dungeness crab. Because of significant differences in the relative scale of landings across functional group landings are plotted in logs.

Status and trends: Landings in the Gulf of Alaska are primarily comprised of catch from three functional groups: salmon, pelagic foragers, and apex predators (Figure 81). Salmon landings display a stable cycle driven by large returning year classes in odd years. The primary species landed within the pelagic forager functional group is pollock whose landings have been fairly stable till 2012 when they began to increase with the Total Allowable Catch (TAC). Pacific ocean perch, northern rockfish and dusky rockfish are also caught in significant quantities in the Gulf, but landings are roughly one half to one fifth the volume of pollock landings.

Within the apex predator functional group, Pacific cod, arrowtooth flounder, halibut and sablefish all have significant target fisheries. For the functional group as a whole landings have been stable, but the distribution of landings across species within this group has changed over time. Halibut and sablefish landings have declined significantly over roughly the last decade with conservation reductions in the allowable catch. Pacific cod landings are also determined by the TAC which has been significantly higher since 2010 than before, though landings decreased in 2017 as a result of low abundance, a trend which is expected to continue through 2018.

Relative to the preceding three functional groups, benthic forager and motile epifauna are caught in significantly smaller quantities. Rex sole and flathead sole have target fisheries and total landings are well below the annual TACs for these species. State managed fisheries exist for tanner and Dungeness crab. Landings of both of these functional groups has remained fairly stable over time.

Factors influencing observed trends: Landings depict one aspect of the raw stresses from harvesting imposed on the Gulf of Alaska ecosystems 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. Salmonids

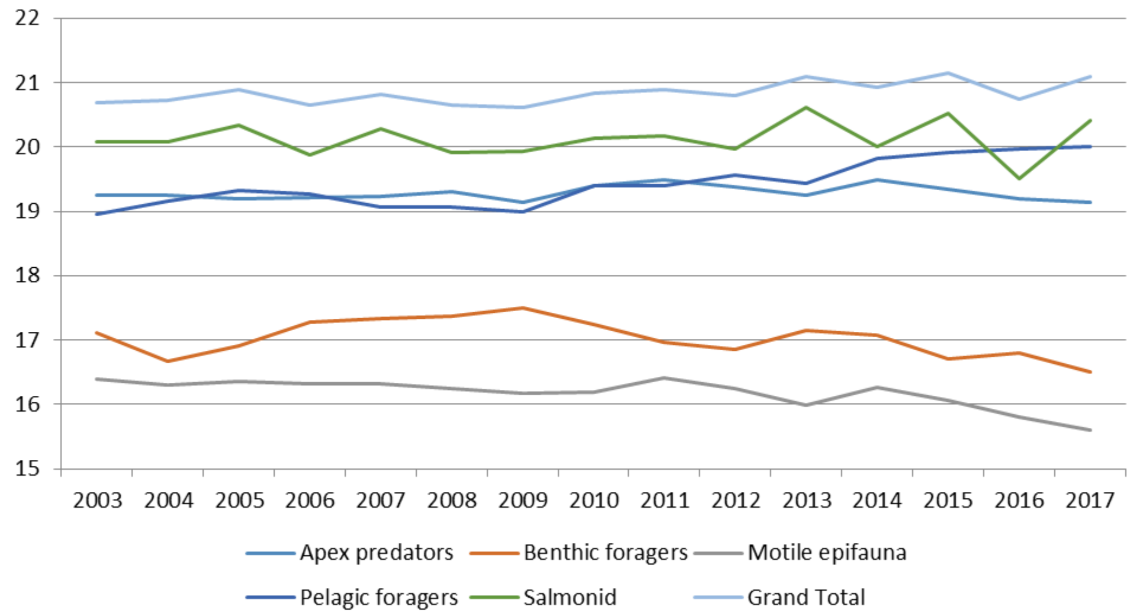

Figure 81: Gulf of Alaska landings by functional group (pounds in log scale).

have on average been the largest functional group landed over this period, followed by pelagic foragers and apex predators which have been roughly equivalent over time but have experienced some divergence in recent years. Relative to other functional groups, benthic foragers and motile epifauna make up a smaller share of total landings in the Gulf of Alaska.

Implications: 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.

Halibut and Salmon Subsistence Trends in the Gulf of Alaska

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Last updated: August 2018

Description of indicator: Subsistence uses of wild resources are defined as "noncommercial, customary and traditional uses" for a variety purposes including, nutritional, trade, and cultural purposes (ADF&G, http://www.adfg.alaska.gov). Following the IPHC and NMFS regulations in 2003, the subsistence halibut fishery allows the use of halibut by rural residents and members of federally-recognized Alaska native tribes for non-commercial use, for food, or customary trade

(Gilroy). Subsistence fishery harvests produces an average of 155 pounds of food per person per year in rural Alaska.

The Western Gulf of Alaska (WGOA) is a mixtures of urban and rural communities. Subsistence use varies and regulations depend on the area and time fished. All five salmon species are important subsistence fisheries, as well as halibut, herring, bottomfish, and shellfish (ADF&G 2017; Fall et al. 2017). In Eastern Gulf of Alaska (EGOA), all five salmon species are important subsistence fisheries, as well as halibut, shellfish, and other finfish (ADF&G 2018; Fall et al 2017). Marine resources used for subsistence purposes in the EGOA include salmon, halibut, herring spawn-on-kelp, shellfish, groundfish, eulachon, Dolly Varden, trout, and smelt. Salmon is heavily targeted using a variety of gear (depending on area fished) such as set gillnets, drift gillnets, gaffs, spears, beach seines, dip nets, cast nets and hand purse seines. In addition to subsistence, the GOA also supports personal use fisheries. For these reasons, subsistence harvests of two focal species—salmon and halibut—were considered informative.

Harvest data were collected from the ADF&G Division of Subsistence for years 1994 to 2016 (ADF&G: http://www.adfg.alaska.gov/index.cfm?adfg=subsistence.harvest). ADF&G reports that 1990 was the first year data from all subsistence fisheries was available and comparable to current collections. Subsistence data are largely collected from household surveys.

Status and trends: *Salmon* The WGOA represents 47% of the total subsistence salmon harvest statewide in 2016; this number includes Anchorage. Sockeye salmon harvest estimates appear to increase from an average of 121,602 fish a year from 1990-2009, to an average of 651,801 (2010–2016) fish a year (Figure 82). Records indicate a dramatic increase in harvest levels in 2010.

The EGOA represents 5% of the total subsistence salmon harvest statewide in 2016, which is considerably less than other regions. Records indicate a significant decrease of total salmon harvest (for all species) in the EGOA starting in 2004 and continuing to 2016 (Figure 83). The most dramatic decreases are evident in sockeye and chum salmon. Sockeye salmon has remained the main harvest, ranging from 79 to 87% of the total catch. The historical average since 1990 is 95,527 salmon, with the 2016 harvest estimated at 57,776 fish. The number of subsistence salmon permits jumped from 22 in 1995 to 8,290 in 1996; however the number of permits began a steady decline in 2000. A total of 3140 permits were issued in 2016 (Figure 84).

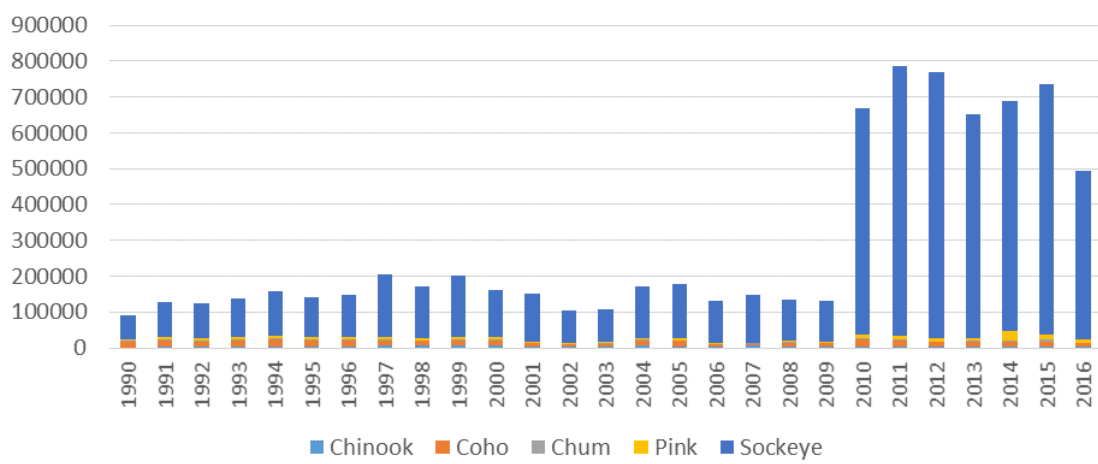

Figure 82: Historical subsistence salmon harvest in the Western GOA

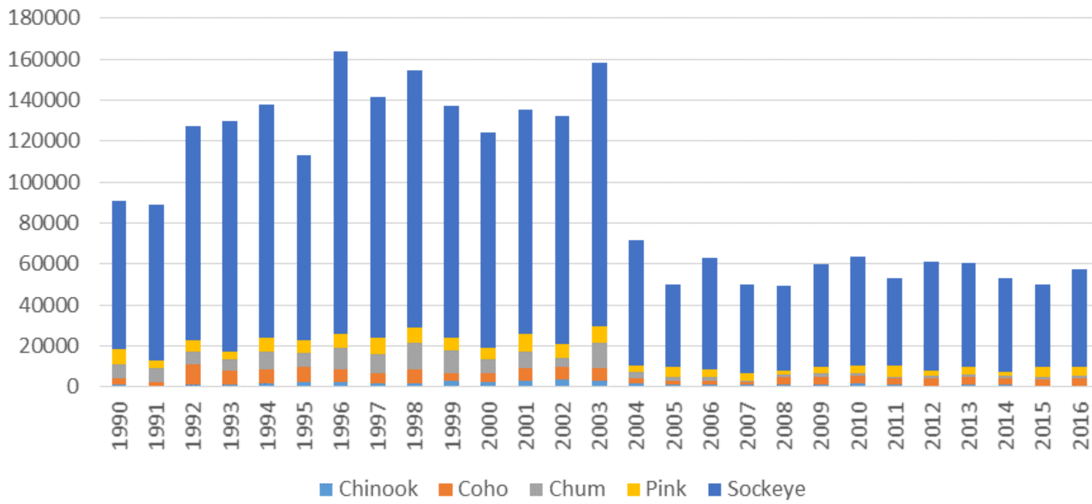

Figure 83: Historical subsistence salmon harvest in the Eastern GOA

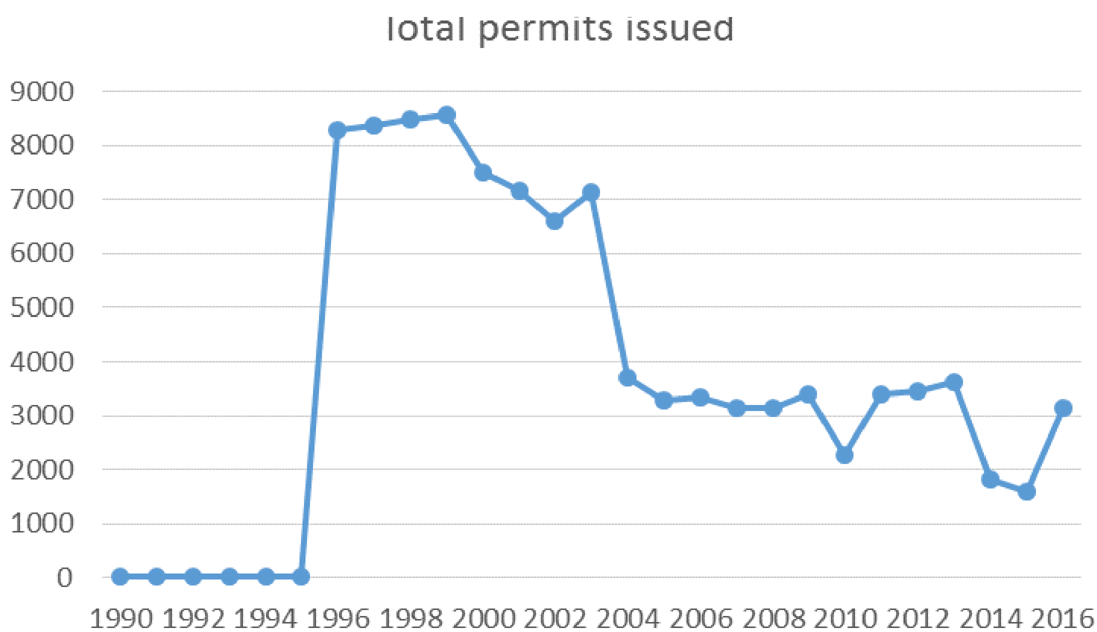

Figure 84: Total number of subsistence salmon permits issued in Eastern GOA.

Halibut According to ADF&G, statewide subsistence halibut harvest (in pounds) declined substantially between the years 2004 to 2010, with a slight uptick in 2010–2012. There were approximately 8,847 subsistence permits issued Alaska-wide, harvesting an estimated 36,467 halibut in 2016. The WGOA represented 30% of the total halibut pounds harvested in 2016. There is a steady decline in the amount of reported halibut catch in the Western GOA since 2004 (Figure 85).The number of SHARC permits issued has decreased since 2007 (4340 permits) to 2016 (2786 permits). The EGOA represented the largest amount (65%) of the total halibut pounds harvested in 2016. There is a steady decline in the amount of reported halibut catch in the EGOA from 2004–2010, with a slight increase in 2011–2016 (Figure 86). The number of SHARC permits issued has decreased from 7267 permits issued in 2003 to 5607 permits issued in 2016.

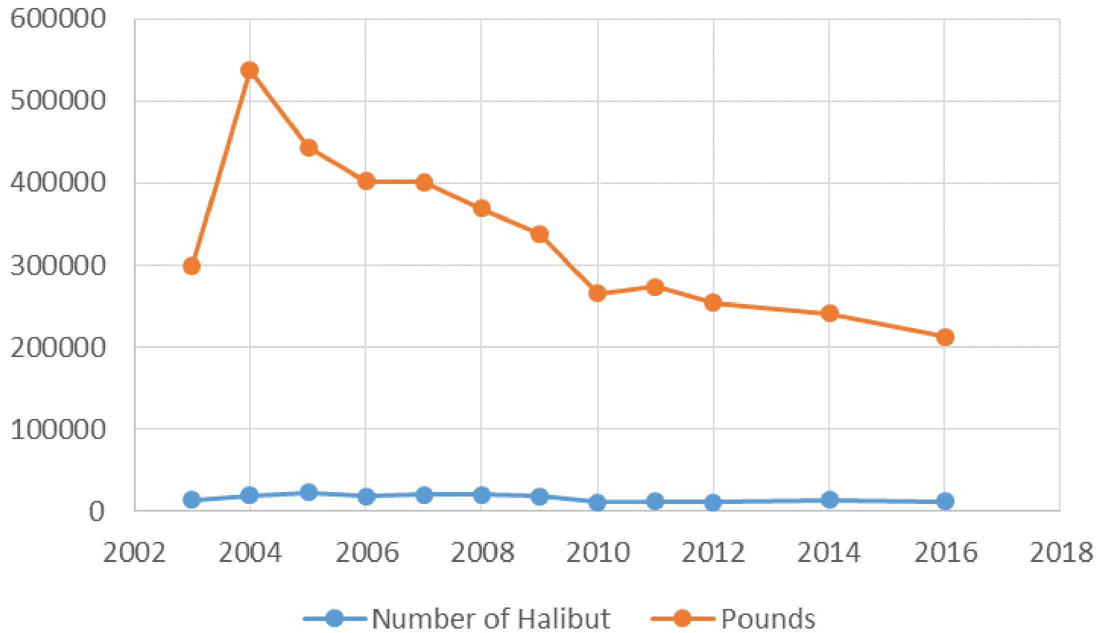

Figure 85: Estimated subsistence harvests of halibut in the Western GOA, 2003–2012, 2014 and 2016 (lbs. net weight)

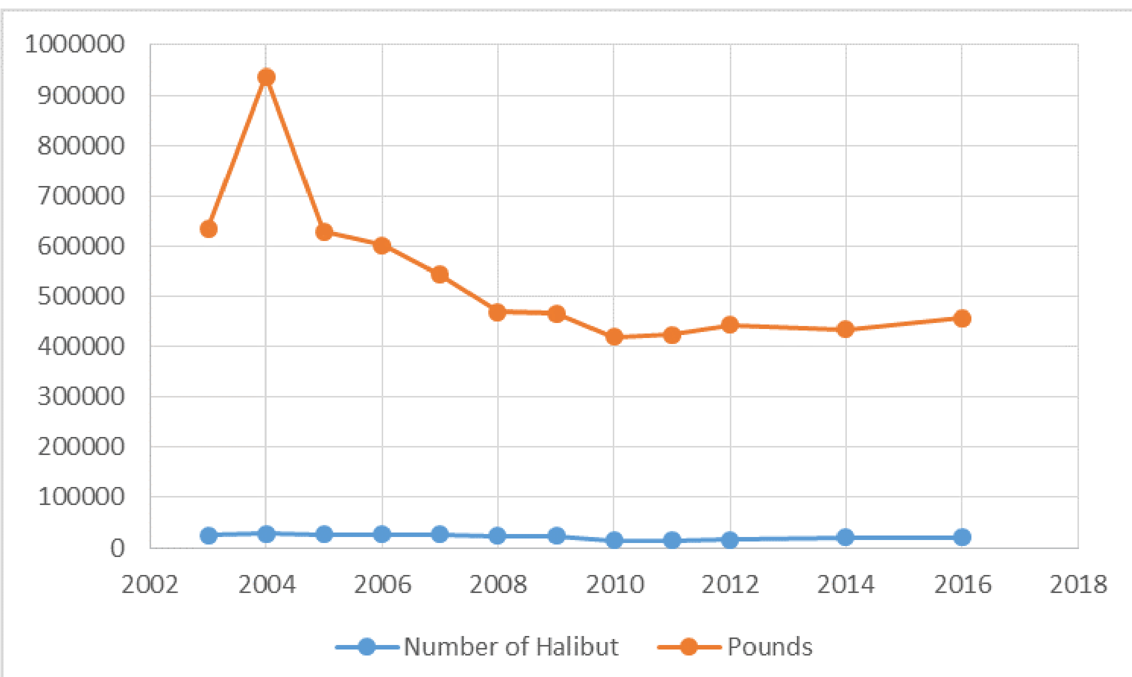

Figure 86: Estimated subsistence harvests of halibut in the Eastern GOA, 2003–2012, 2014 and 2016 (lbs. net weight)

Factors influencing observed trends: The reasons for the decline in subsistence halibut harvest are complex, and in large part believe to be related to participation in the survey and methodology (Fall and Lemons, 2015). Due to budgetary constraints, data collection efforts were reduced in size and scope, which is consistent with the decrease in reported harvests, suggesting that some of the decrease in halibut harvest is a result of a lower participation in the survey. In certain regulatory areas, there is a downturn in renewal of halibut permits (SHARCs) after the initial rise in participation after the start of the SHARC program (Fall and Lemons, 2015). Postal survey methodology differed in some regions. The decrease could suggest survey fatigue. In 2014, an effort was made to follow up with non-participants to complete the survey, increasing the reported harvest estimates. After the fieldwork, concerns were raised in certain areas about the decrease in available harvest, suggesting one cause may be bycatch from commercial cod fishing. In addition, a decrease in average halibut size over time may contribute to this trend.

Implications: Subsistence fishing and hunting represent a major source of food security and cultural identity for rural Alaskans. Rural households rely on subsistence resources to supplement food during the winter when other sources of food may be unavailable or prohibitively expensive (Loring and Gerlach, 2009). In addition, gathering of subsistence resources represents a way of life to many rural Alaskans that connects them to their land, heritage and establishes community bonds of sharing and networking (Picou et al., 1992). The decline in halibut subsistence may indicate increased vulnerability for subsistence communities. The decline in salmon permits indicates fewer people are getting permits. The reasons for the downward trend could indicate a decrease in the number of people eligible for subsistence permits or that fewer people are getting permits in order to subsistence fish. Additional research is required to address some of these uncertainties.

Profits

Economic Indicators in the Gulf of Alaska Ecosystem: Value and Unit Value

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Last updated: September 2018

Description of indicator: Three metrics are used to characterize economic value in an ecosystem context for the Gulf of Alaska: ex-vessel value, first-wholesale value, and ratio of first-wholesale value to total catch. Ex-vessel value is the un-processed value of the retained catch. 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. First-wholesale value is thus 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. The measure of biomass included 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 two metrics 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, Pacific halibut, sablefish, and arrowtooth flounder. The primary target species in the pelagic foragers functional group are walleye pollock, Pacific ocean perch, northern rockfish and dusky rockfish. The primary species caught in the benthic foragers functional group are flathead sole, and rex sole. The primary target species in the salmonid functional group are chinook, sockeye, and pink salmon. The primary species caught in the motile epifauna functional group are tanner and dungeness crab. Because of significant differences in the relative scale of value across functional group value is plotted in logs.

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 salmon and apex predator functional groups (Figure 87). Ex-vessel revenues have remained fairly stable over time but have been lower since 2013 as the relative share of landings have shifted away from the more highly priced sablefish and halibut species towards the more moderately priced Pacific cod. Despite large catch volumes pollock prices are comparatively lower than apex predators or salmon. A combination of catch and price increases account for the increasing trend in up to 2012. Since 2013 depressed pollock prices have resulted in flat or decreasing revenue despite increased landings. Changes in benthic forager flatfish revenues have largely tracked changes in landings of rex sole and flathead sole. Value in the motile epifauna group has generally increased with crab ex-vessel prices.

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

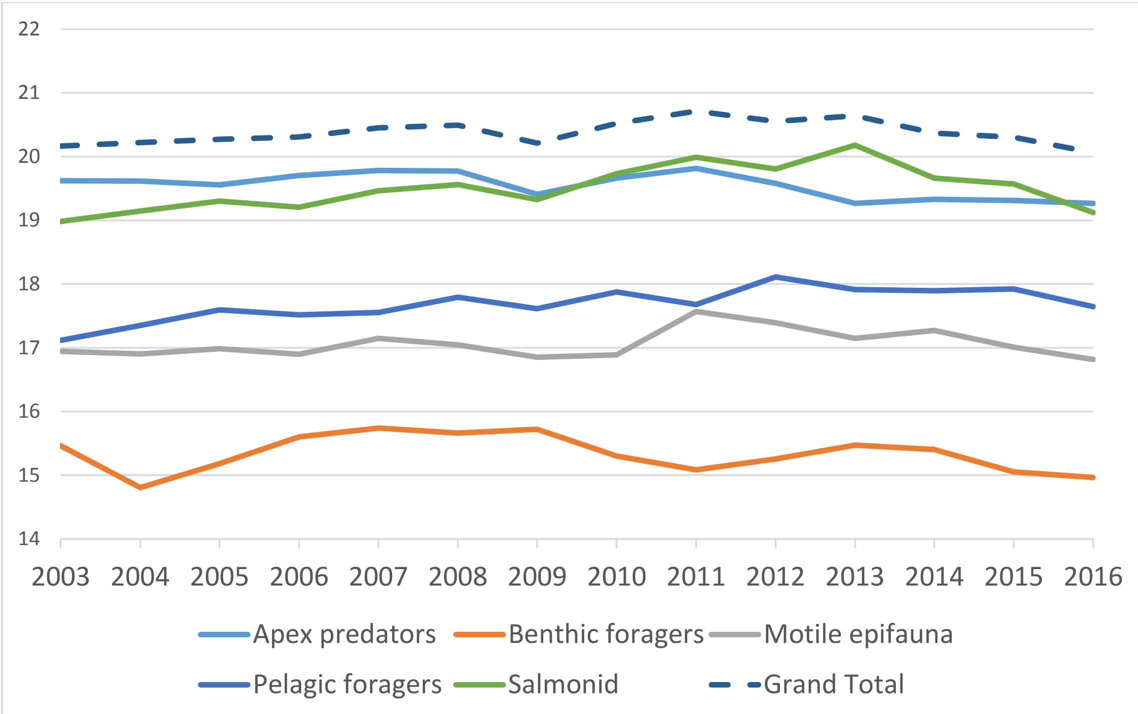

Figure 87: Gulf of Alaska real ex-vessel value by functional group (2017 dollars logged).

of revenue. First-wholesale was generally increasing for each of the functional groups up to about
wholesale indices compared to the ex-vessel indices are influenced by differences in the amount
2008-2010 with stable or increasing landings and gradually increasing prices after which variation in landings and prices have had differential responses (Figure 88). Over the long-term both salmon prices and revenue show an increasing trend. First-wholesale value in the apex predator group decreased with Pacific cod prices in 2009 and declined after 2011. The value of the pelagic forager
have had differential impacts. Salmon first-wholesale prices are affected by the annual cycles in
group shows a gradual increasing trend up to 2012 when prices for pollock decreased with high global pollock supply. Benthic forager first-wholesale value has remained fairly stable and changes in value largely reflect changes in landings. First-wholesale value in the motile epifauna group has remained fairly stable, crab prices increased through 2012, dipped in 2013–2014 and have been increasing through 2016.

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 value of salmon and apex predators, the unit value index is more heavily weighted towards these groups. The unit value index increased from 2003–2008 with generally increasing prices across all functional groups (Figure 89). After 2008 shifts in the relative share of landings from halibut and sablefish to the more moderately-priced cod resulted in a decrease in the average price of the apex predator group. Salmon prices continued to rise through 2012. The net effect of these changes is that the trend in the aggregate unit value index leveled out from 2009–2012. Pollock prices fell somewhat starting in 2013. Apex predator prices continued to decline after 2013.

Factors influencing observed trends: Sablefish and halibut are high valued whitefish, and price increases resulting from the reduced supply of these species have helped to offset the impact on revenues from reduced landings. Differences in the relative level of the indices between the landings

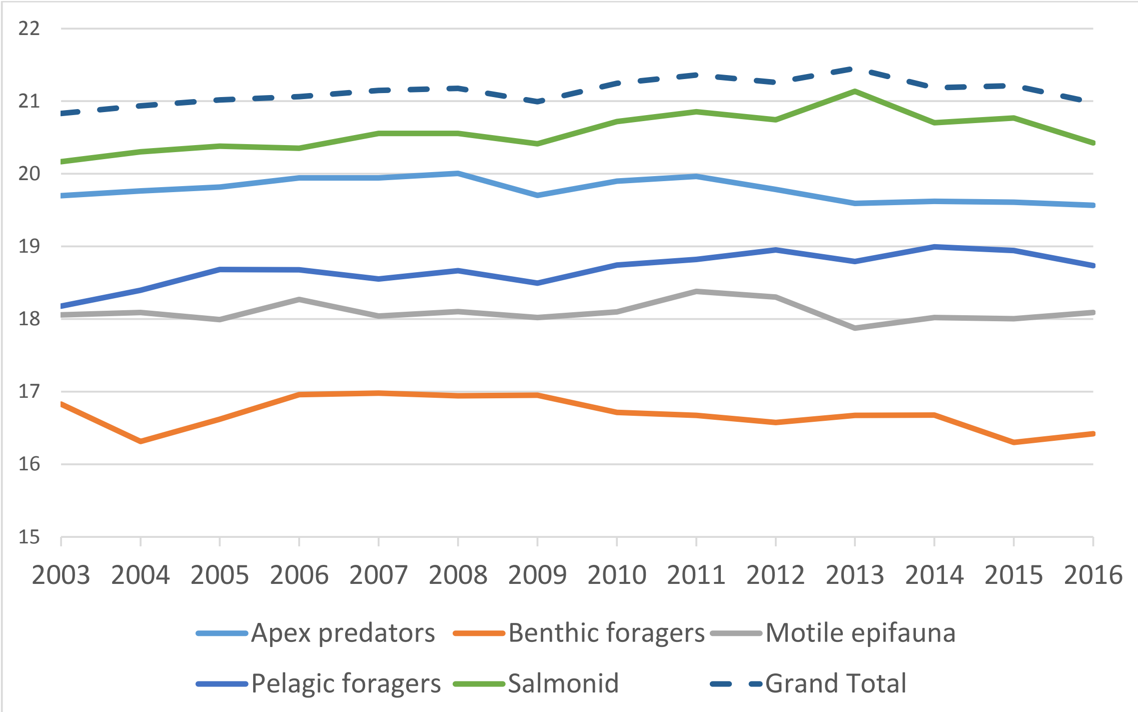

Figure 88: Gulf of Alaska real first-wholesale value by functional group (2016 dollars logged).

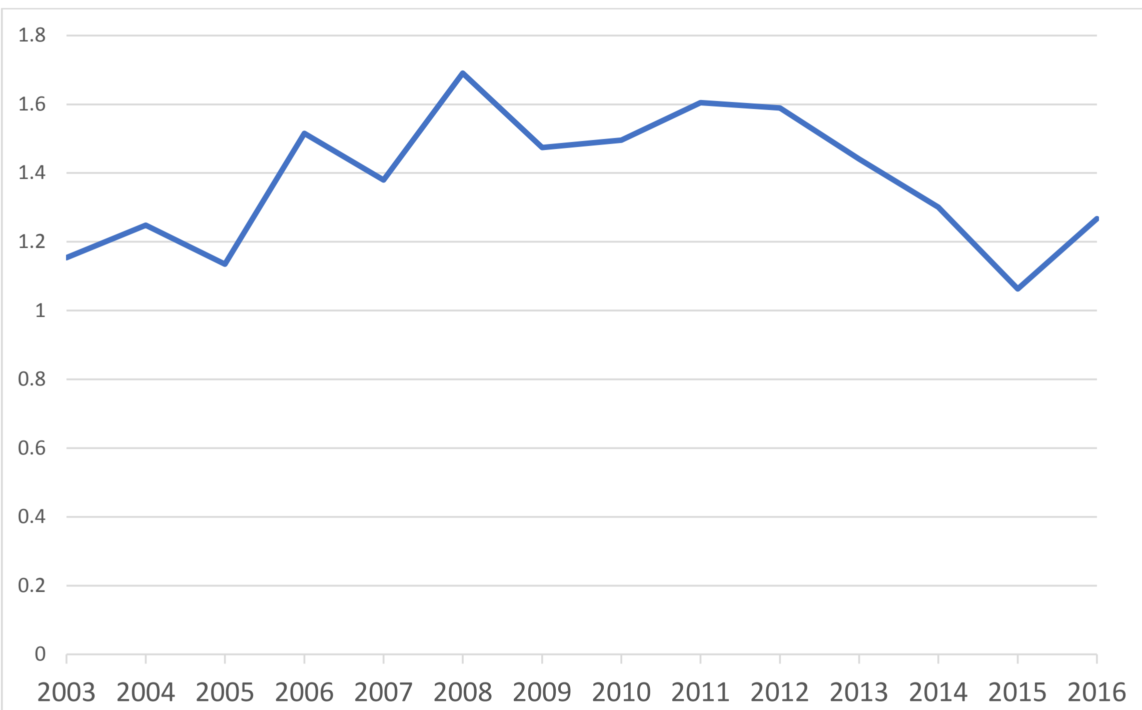

Figure 89: Real first-wholesale to total catch unit value in the Gulf of Alaska (2017 dollars).

and ex-vessel value in Figure 88 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 those of the motile epifauna group, but motile epifauna ex-vessel value is higher because it commands a higher price. 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 trends are the influence of a trend of increasing value in the first-wholesale market as well as inflation.

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. Salmon first-wholesale prices are affected by the annual cycles in landings and tend to display a counter-cyclic relationship with lower prices when landings volumes are high and higher prices when volumes are low. This relationship tends to smooth out revenues over time. Declines since 2011 are largely the result of a shift in the relative share of landings from the more highly priced sablefish and halibut species towards the more moderately priced Pacific cod.

Significant global pollock supply contributed to the decline in pollock prices starting in 2013. The decline in apex predator prices after 2013 occurred with shifts in catch composition. These features combined with volatility in salmon prices account for the decreasing unit value trend since 2012.

Implications: The economic metrics displayed here provide perspective on how the human component of the ecosystem feeds off of and receives value from the Gulf of Alaska 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. While salmon and apex predators are relatively equally important to the ex-vessel sector, the salmonid functional group consistently makes up a larger share of first wholesale revenue. Pelagic foragers also make up a relatively similar share of landings as apex predators, but are substantially lower in terms of ex-vessel and first wholesale revenue due to their high volume and relatively low prices. Similarly, while the landings trends are diverging for the pelagic foragers (increasing) and apex predators (declining), trends in first wholesale and ex-vessel revenues have remained fairly flat for apex predators while declining slightly for pelagic foragers. 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

Saltwater Recreational Fishing Participation in the Gulf of Alaska: Number of Anglers and Fishing Days

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Last updated: August 2018

Description of indicator: Federal fisheries management objectives include managing healthy ecosystems in part to provide recreational fishing opportunities. We use saltwater fishing participation to represent trends in recreational fishing in Alaska. The magnitude of recreational saltwater fishing participation is captured by (a) the days fished and (b) the number of anglers. The Alaska Department of Fish and Game (ADF&G) conducts an annual survey of anglers to collect information on participation, catch, and harvest (Jennings et al., 2015; Romberg, 2016). The ADFG Division of Sport Fish Alaska Sport Fishing Survey database has public data available at https://www.adfg.alaska.gov/sf/sportfishingsurvey/. Data provided by Alaska Fisheries Information Network. Annual estimates of the total number of saltwater anglers are available from 1996 to 2016. Estimates of the total number of saltwater fishing days are available from 1981 through 2016. For the purposes of this indicator, ADF&G Sport Fishing Areas A to H and J to Q correspond to the Gulf of Alaska (GOA), while Areas R–Z comprise the Eastern Bering Sea (EBS) (see `http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=main.home`).

Status and trends: In the GOA the total number of days fished in saltwater has increased since the early 1980s when almost a half million fishing days were taken (Figure 90). Annual saltwater fishing days reached its peak in 1995 at about 1.06 million fishing days. In recent years the annual number of fishing days has been between 800,000 and 1 million. Total days fished decreased from 2015 to 2016. The annual number of saltwater anglers fishing in the GOA has fluctuated since the mid-1990s between 350,000 and 442,000 anglers (Figure 91). Since 2009, the annual number of saltwater anglers has generally been below 400,000. The total number of saltwater anglers decreased from 2015 to 2016.

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

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

Figure 90: Total number of days fished by saltwater sport anglers in the Gulf of Alaska, 1996–2016.

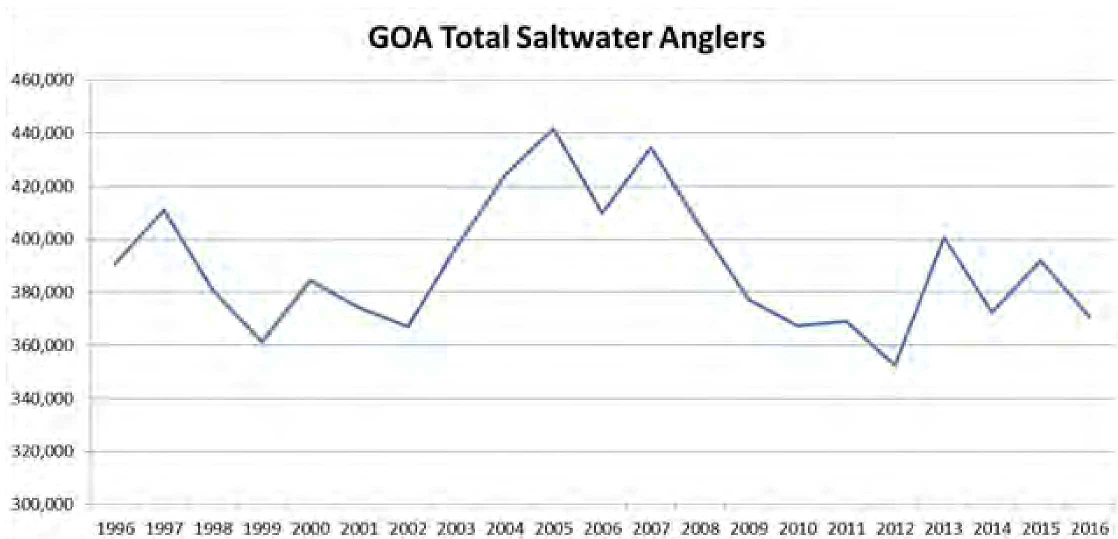

Figure 91: Total number of saltwater sport anglers in the Gulf of Alaska, 1996–2016

changed significantly over the years in the GOA (Meyer, 2010). Starting in 2007, more restrictive bag and size limit regulations were imposed for halibut caught on charter boat fishing trips in Southeast Alaska (74 Federal Register 21194). Beginning in 2014, southcentral Alaska charter boat anglers began facing the same types of charter-specific bag and size limit and other restrictions (see `https://alaskafisheries.noaa.gov/fisheries/2c-3a-halibut-regs`). Under the Halibut Catch Sharing Plan (CSP), which went into effect during 2014, the management tools used to regulate harvest of Pacific halibut in the recreational sport sector are evaluated annually (79 Federal Register 13906).

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

Macroeconomic factors such as economy-wide recessions likely affect participation patterns in saltwater fishing in Alaska. Due to the expense of traveling to and from Alaska, it is likely that during times of economic hardship, there will be fewer non-resident saltwater anglers, resulting in fewer trips and days fished. Dips in annual saltwater fishing days and number of anglers during the period 2001 and 2002 and the period 2008 and 2012 can be seen, which may be a result of the brief 2001 Recession and the Great Recession (that began at the end of 2007). The relatively larger numbers of anglers and fishing days in years after 2012 may be related to an improving national economy. Population growth in Alaska and the U.S. may also impact fishing trends. While conditions in the larger state, national, and international economy are likely to explain some of the observed trends, the statistics generally reflect micro-level decisions made by individual anglers (Lew and Larson, 2011, 2012, 2015, 2017).

Implications: Monitoring the number of saltwater anglers and fishing days provides a general measure of fishing effort and participation in the saltwater sport fishery and can reflect changes in ecosystem conditions, target stock status, management, economic factors, demographic trends, and other economic, social, and cultural factors. Alaska is well-known for its sport fishing opportunities and draws anglers both from within and from outside Alaska. Saltwater recreational fishing can be a non-trivial source of extraction of several species (including Pacific halibut, Pacific salmon, and rockfish). Studies have indicated saltwater fishing in Alaska is valuable to anglers (Lew and Larson, 2011, 2012, 2015, 2017) and contributes to the economy by creating jobs and generating sales to fishing and non-fishing businesses and income to households (Lovell et al., 2013; Lew and Seung, 2018). Although there has been some variation over the past 15 years in annual fishing days and total saltwater anglers, the overall trends in recent years appear to be relatively stable. Thus, without significant changes in the ecological, economic, management, or socio-cultural factors that are likely to influence GOA-level participation in saltwater recreational fishing, it is likely that saltwater recreational fishing will remain at or near currently observed levels.

Saltwater Recreational Fishing in the Gulf of Alaska: Sport Fishing Harvest by Functional Group

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

The Alaska Department of Fish and Game (ADF&G) conducts an annual survey of anglers to collect information on participation, catch, and harvest (Jennings et al., 2015; Romberg, 2016, e.g.,). ADF&G Division of Sport Fish Alaska Sport Fishing Survey database. Public data available at `https://www.adfg.alaska.gov/sf/sportfishingsurvey/`. Data provided by Alaska Fisheries Information Network. Annual estimates of the total harvest of Pacific salmon, Pacific halibut, rockfish, and smelt are available from 1977 to 2016. Estimates of the total harvest of lingcod are available from 1990 to 2016, while Pacific cod and shark estimates are available for 1996 to 2016. Sablefish harvest estimates are available for 2010 to 2016. For the purposes of this indicator, ADF&G Sport Fishing Areas A to H and J to Q correspond to the Gulf of Alaska (GOA), while Areas R-Z comprise the Eastern Bering Sea (EBS) (see `http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=main.home`).

Status and trends: In the GOA, annual salmonid harvest has exceeded the harvest of other functional groups except for during a few years in the 1980s (1981, 1983–1984), when pelagic species were harvested in greater numbers, and in 2012 when a slightly larger number of apex predators (mostly Pacific halibut) were harvested (Figure 92). The total annual harvest of salmonids (Chinook, coho, pink, sockeye, and chum salmon) has been over 200,000 fish since the mid-1980s, with harvest levels being consistently over 500,000 fish since the mid-1990s, except for in 2012 when it dropped to 440,000. Annual recreational harvest of apex predators (Pacific halibut, Pacific cod, sharks, sablefish, and lingcod) has generally increased over time with recent years' harvest being between 480,000 and 540,000 fish. Apex predator harvest is predominantly Pacific halibut, which appears in the time series for all years. Note that lingcod does not appear in the apex predator harvest estimates until 1990, Pacific cod and sharks do not appear until 1996, and sablefish do not appear until 2010. This means that the pre-1990 apex predator harvest estimates are composed solely of Pacific halibut harvest. The pelagic functional group includes rockfish and smelt. Since the early 1990s, the harvest of pelagic species has generally increased, and in recent years has been between 340,000 and 390,000 fish.

Factors influencing observed trends: Saltwater recreational fishing harvests in Alaska are influenced by a number of factors, including fishing regulations for target species, social and economic factors affecting anglers and their households, and expected fishing conditions (e.g., stock abundance, timing and size of runs, weather, etc.). Pacific halibut (apex predator) and Pacific salmon (salmonids) are the most common targets in the GOA, with other species less frequently being the principal target but being caught on trips targeting these species. Fishing regulations for these fish influence decisions about whether or not to fish, where to fish, what species to fish for, and by what means to fish (e.g., unguided or guided fishing).

Fishing regulations in the Pacific halibut sport fishery were first established in 1973, but have changed significantly over the years in the GOA (Meyer, 2010). Starting in 2007 more restrictive bag and size limit regulations were imposed for halibut caught on charter boat fishing trips in Southeast Alaska (74 Federal Register 21194). Beginning in 2014, southcentral Alaska charter boat anglers began facing the same types of charter-specific bag and size limit and other restrictions (see `https://alaskafisheries.noaa.gov/fisheries/2c-3a-halibut-regs`). Under the Halibut Catch Sharing Plan (CSP), which went into effect during 2014, the management tools used to regulate harvest of Pacific halibut in the recreational sport sector are evaluated annually (79 Federal Register 13906).

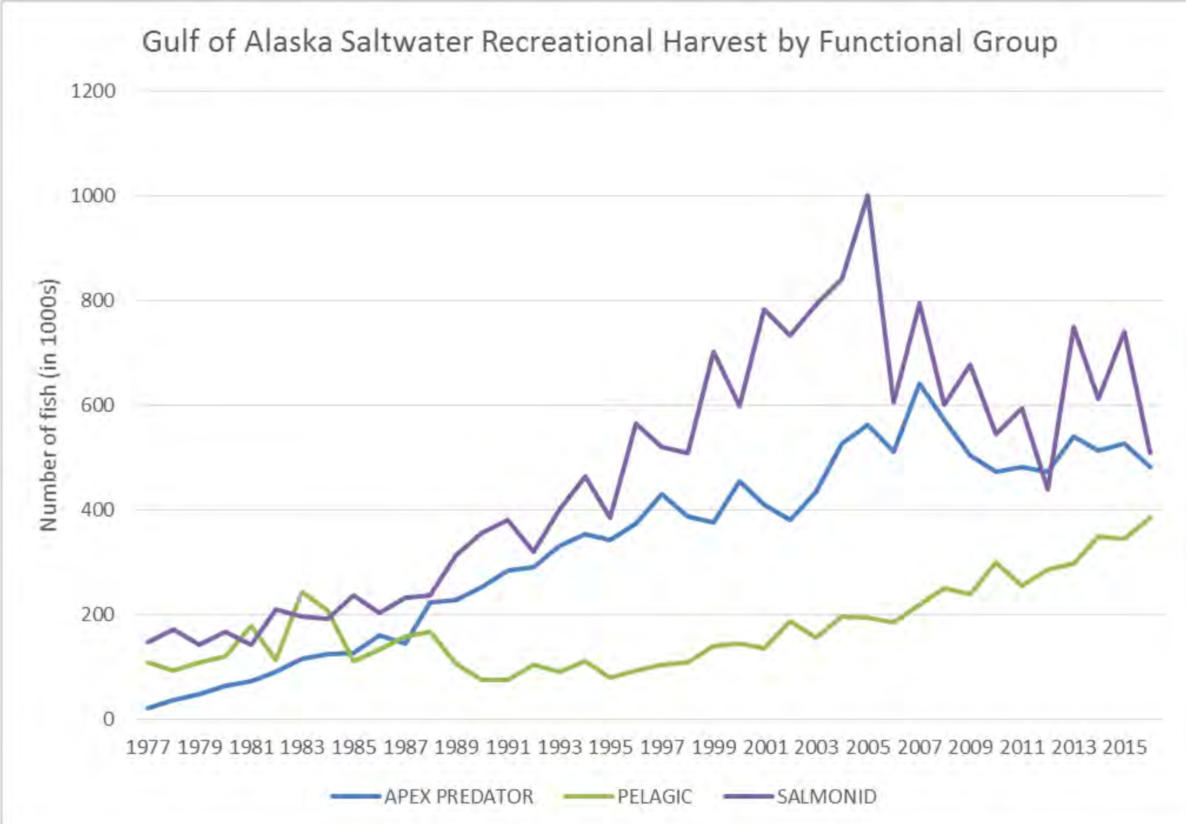

Figure 92: Number of fish harvested by functional group in recreational fisheries in the Gulf of Alaska, 1977-2016.

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

Macroeconomic factors such as economy-wide recessions likely affect participation patterns, and hence harvest levels, in GOA recreational saltwater fishing. Due to the expense of traveling to and from Alaska, it is likely that during times of economic hardship, there will be fewer non-resident saltwater anglers, resulting in fewer trips and days fished being taken by non-residents. Further, the increased popularity of, and opportunities for, marine recreational fishing could impact the increased harvest. More restrictive regulations on Pacific salmon and Pacific halibut in recent years may also contribute to increased harvest of other species. Population growth in Alaska and the U.S. may also impact harvesting trends (insofar as this growth leads to overall increased fishing participation). While conditions in the larger state, national, and international economy are likely to explain some of the observed trends, the statistics generally reflect micro-level decisions made by individual anglers about both fishing effort and targeting behavior (e.g., Lew and Larson 2011, 2012, 2015, 2017).

Note that one micro-level decision that many Pacific salmon anglers face is whether to fish in saltwater or freshwater. While the focus here is on saltwater harvest, it is important to recognize that a majority of the total Pacific salmon harvest in GOA from 1996–2016 has been from freshwater fishing, not saltwater. The proportion of the total salmon harvest attributable to saltwater fishing has ranged from 33 to 50 percent across these years.

Implications: Monitoring the amount of saltwater sportfish harvests provides a general measure of saltwater sport fisheries' impacts on fish stocks and can reflect changes in ecosystem conditions, target stock status, management, demographic trends, and other economic, social, and cultural factors. Generally, Alaska is well-known for its sport fishing opportunities and draws anglers both from within and from outside Alaska. Saltwater recreational fishing can be a non-trivial source of extraction of salmonid, pelagic, and apex predator functional group species. Studies have indicated saltwater fishing in Alaska is valuable to anglers (Lew and Larson, 2011, 2012, 2015, 2017, e.g.,) and contributes to the economy by creating jobs and generating sales to fishing and non-fishing businesses and income to households (**?**Lew and Seung, 2018). Without significant changes in the ecological, economic, management, or socio-cultural factors that are likely to influence GOA-level participation in saltwater recreational fishing, it is likely that saltwater recreational fishing will remain at or near currently observed levels.

Employment

Trends in Unemployment in the Gulf of Alaska

Contributed by Anna Lavoie, Resource Ecology and Fishery Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: September 2017

Description of indicator: Unemployment is a significant factor in the Gulf of Alaska (GOA) ecosystem, as it is an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems research has demonstrated the importance of incorporating social variables in ecosystem management and monitoring, and unemployment reflects economic settings of a socio-ecological system (Turner et al., 2003; Ostrom, 2007).

This section summarizes trends in unemployment rates over time in the Gulf of Alaska (including Southeast Alaska, Cook Inlet, and Prince William Sound). The 132 GOA fishing communities included in analysis comprise most of the population that resides along Gulf of Alaska coast. Trends in population is presented for eastern (between 164°W and 144°W) and western (144°W to the Canadian border) GOA communities. Communities were included: if they were within 50 miles of the coast, based on their historical involvement in Gulf of Alaska fisheries, and if they were included in one of the North Pacific Fishery Management Councils GOA fishery programs, such as the Community Quota Entity program. Communities were further divided into two categories as part of this analysis; small (population <1,500); and large (population ≥1,500). Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2017 (ADLWD, 2018).

Status and trends: In the eastern GOA, unemployment rates from 1990 to 2017 were lower than statewide and national rates (Figures 93–94). As of 2017, the unemployment rate in eastern GOA was 4.95% which was slightly higher than the national rate of 4.1%. Eastern GOA unemployment rates reflect State and national trends overall as unemployment peaked in the early 1990s, in 2003 and 2010. The unemployment rate increased 57.79% between 1990 and 2017.

In the western GOA, unemployment rates from 1990 to 2017 were higher than statewide and national rates (Figures 1-2). As of 2017, the unemployment rate was 13.11% which was higher than the national rate of 4.1%. With Anchorage rates excluded, western GOA had a slightly higher rate of 13.27%. The unemployment rates reflect statewide and national trends overall as unemployment peaked in the early 1990s, in 2003 and 2010. However, the increase was significantly greater for western GOA. The unemployment rate (including Anchorage) decreased 13.30% between 1990 and 2017, and decreased 0.82% excluding Anchorage.

Factors influencing observed trends: Alaska 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 peak occurred following completion of the pipeline, during the oil bust of the late 1980s, and during the great recession of 2007-2009 (ADLWD 2016) . 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). With oil and construction industry headquarters and workers largely located in Anchorage, the

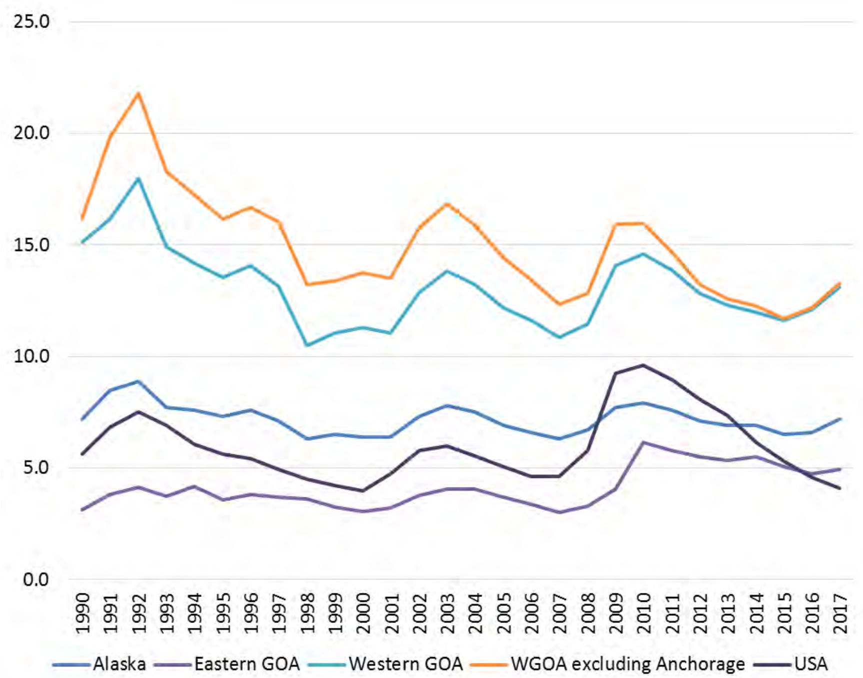

Figure 93: Unemployment rates for the eastern and western Gulf of Alaska (GOA), Alaska and USA, 1990–2017.

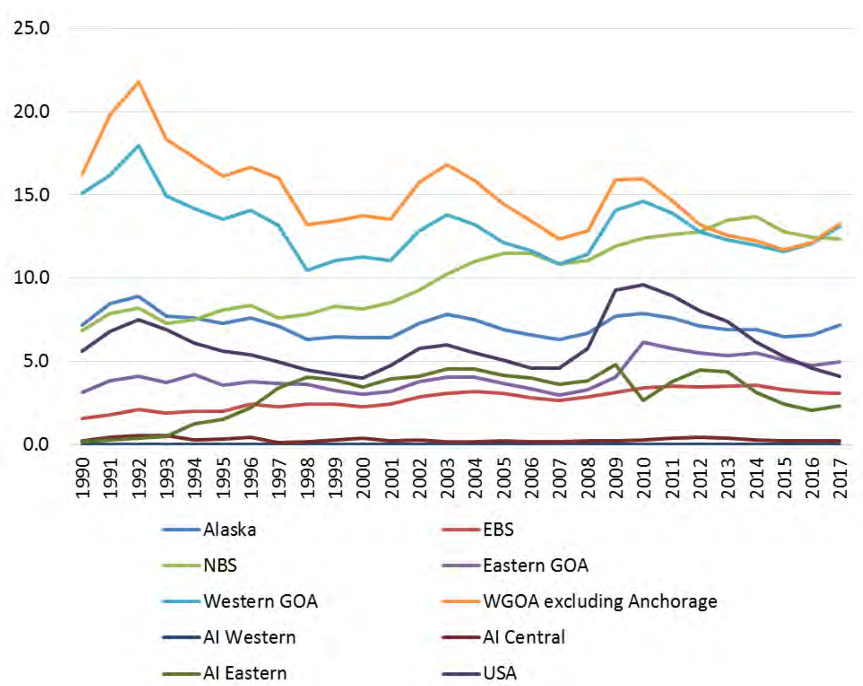

Figure 94: Unemployment rates for all regions, Alaska and USA, 1990–2017.

western GOA region would be most impacted by job loss in these industries. The western GOA region had the second highest unemployment rates (Arctic region had highest) between 1990 and

2017. In the GOA, seafood processing is a major contributor of jobs along the coast.

The eastern GOA region has among the lowest unemployment rates in Alaska. This low rate is partly due to a stable tourism economy, government jobs based in Juneau, and commercial fishing and seafood processing industries. However, the eastern GOA region is forecasted to experience job loss, similar to State trends since 2015, due to reduced oil revenues (ADLWD, 2018).

Implications: Fisheries contribute to community vitality of the GOA, 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). Many larger communities of the GOA region are highly engaged in fisheries and depend upon fish processing industries to support their economies, such as in Kodiak, with both a resident and transient labor force. Changes in groundfish policy and management may have implications for GOA community economies in both remote and urban areas.

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 Fishery and 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 Fisheries Conservation 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, St. 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 (St. Martin and Hall-Arber, 2008). In an effort to acknowledge women's role in fisheries, Calhoun, Conway, and Russel (2016) discuss fishing community in terms of participation in the broader industry (Calhoun et al., 2016). Acknowledging power dynamics and the issue of scale when describing "fishing community", Clay and Olson (2008) complicate the MSA definition, bringing forward the importance of "political, social, and economic relationships".

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

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

Contributed by Sarah P. Wise

Trends in Human Population in the Gulf of Alaska

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Last updated: September 2018

Description of indicator: Human population is a significant factor in the Gulf of Alaska (GOA) ecosystem, as many communities in the region rely upon fisheries to support their economies and to meet subsistence and cultural needs. As with areas neighboring the Arctic, population is an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems research have demonstrated the importance of incorporating social variables in ecosystem management and monitoring (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 GOA (including Southeast Alaska, Cook Inlet, and Prince William Sound). The 132 GOA fishing communities included in analysis comprise most of the population that resides along Gulf of Alaska coast. Trends in population is presented for eastern (between 164°W and 144°W) and western (144°W to the Canadian border) GOA communities. Communities were included: if they were within 50 miles of the coast, based on their historical involvement in Gulf of Alaska fisheries, and if they were included in one of the North Pacific Fishery Management Councils GOA fishery programs, such as the Commu-

Table 8: Gulf of Alaska (GOA) population 1880–2017. Percent change rates are decadal until 2017.

Year	Alaska	% change	Eastern GOA	% change	Western GOA	% change	Western GOA excluding An
1880	33426		2125		1026	168.71	1026
1890	32052	-4.11	4712	121.74	2757	-27.60	2757
1900	63592	98.40	8503	80.45	1996	137.17	1996
1910	64356	1.20	8660	1.85	4734	22.60	4734
1920	55036	-14.48	11404	31.69	5804	16.56	3948
1930	59278	7.71	14896	30.62	6765	47.51	4488
1940	72524	22.35	19258	29.28	9979	113.50	6484
1950	128643	77.38	20655	7.25	21305	358.36	10051
1960	226167	75.81	26557	28.57	97653	50.61	14820
1970	302583	33.79	34925	31.51	147080	43.01	22538
1980	401851	32.81	45665	30.75	210338	39.28	35907
1990	550043	36.88	61306	34.25	292955	168.71	66617
2000	626932	13.98	66455	8.40	385634	31.64	125351
2010	710231	13.29	65449	-1.51	446356	15.75	154530
2017	737080	3.78	66535	1.66	468623	4.99	171140

nity Quota Entity program. Communities were further divided into two categories as part of this analysis; small (population $<$1,500); and large (population $\geq$1,500). Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2017 (ADLWD, 2018).

Status and trends: Eastern GOA is comprised of 45 coastal communities with a total population of 66,535 as of 2017. The total population of small communities (population less than 1,500) was 10,372, and large communities 54,425. The total population of eastern GOA has remained stable since 1990, with small community populations ranging between 10,372 and 10,544, and larger communities 49,288 and 54,425 (Table 8 and Figure 95). Population change between 1990 and 2017 for small communities is -1.63%, and large communities 10.42%. Large communities with the greatest decrease in population between 1990 and 2017 include Petersburg (-9.70%), and Wrangell (-3.71%). The population of Haines increased 40.39% and Juneau 20.63% during this time period.

Small communities in the eastern GOA with the greatest decreases in population between 1990 and 2017 were Hobart Bay, a census designated place (CDP) (-99.47%), Elfin Cove CDP (-74.55%), Game Creek CDP (-70.49%), Pelican (-69.82%), Point Baker CDP (-66.67%), Port Alexander (-53.78%), and Edna Bay (-50.0%). The communities of Hobart Bay, Annette CDP, Meyers Chuck CDP, Cube Cove CDP had zero population or had no population data as of 2010. Loring CDP and Excursion Inlet CDP had populations between ranging between 2 and 15 between the years 2000 and 2017. On the contrary, Mosquito Lake CDP and Gustavus has population increases of 231.25% and 110.85%, respectively, between 1990 and 2017.

Western GOA is comprised of 87 coastal communities with a total population of 468,623 as of 2017. The total population excluding Anchorage was 171,140. The total population of small communities (population less than 1,500) was 19,334, and large communities 151,806 (excluding Anchorage). The total population of western GOA has steadily increased since 1990, with small community populations increasing 65.90% between 1990 and 2017, and larger communities 176.20% (Table 8 and Figure 96). This increase in population is consistent with State trends as population peaked

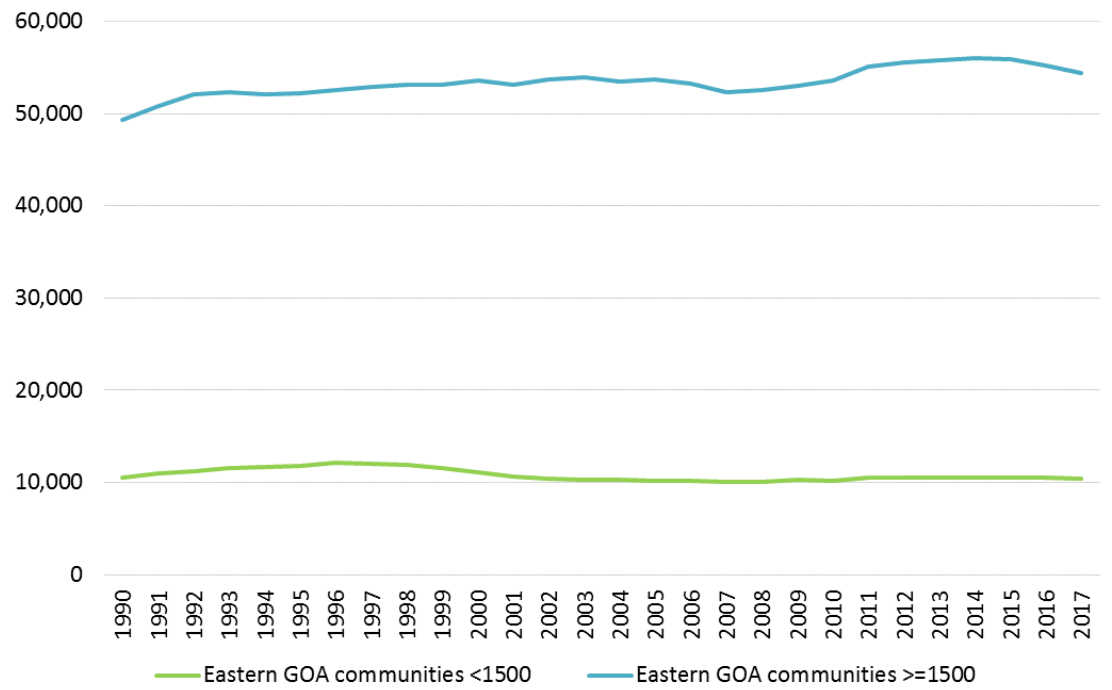

Figure 95: Eastern Gulf of Alaska population 1990–2017.

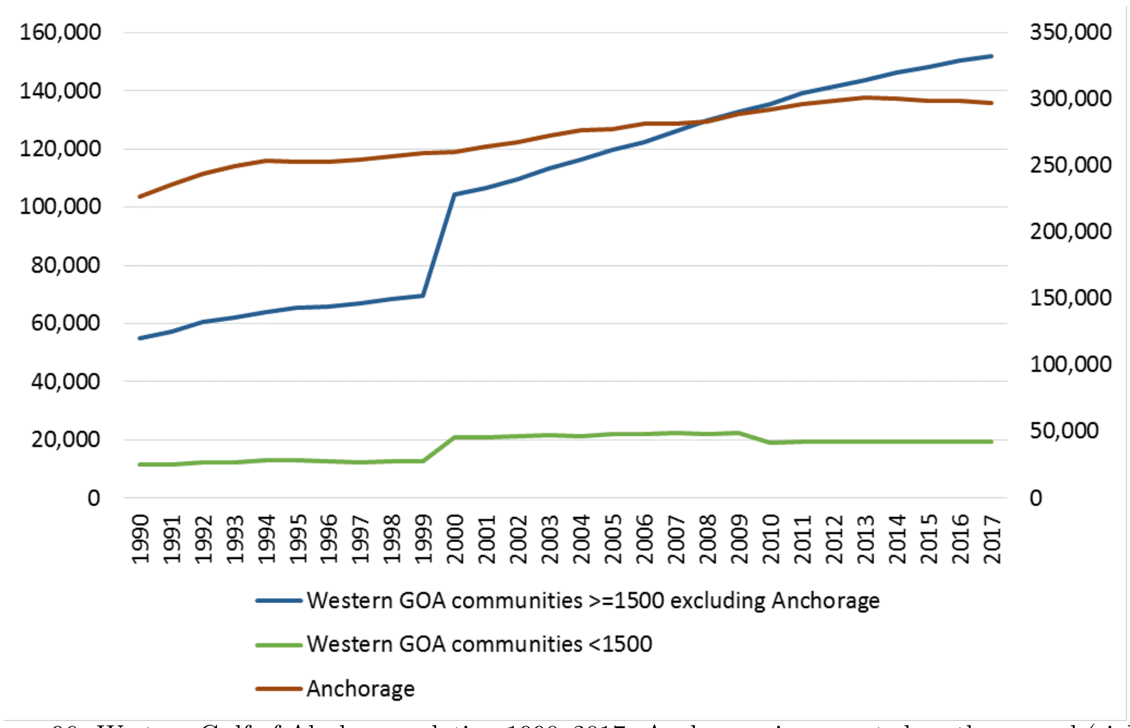

Figure 96: Western Gulf of Alaska population 1990–2017. Anchorage is presented on the second (right) axis.

during the 1990s. Population increase leveled off after 1990 for smaller communities but continued to increase for larger communities in western GOA.

Of the western GOA small communities only Kodiak Station experienced population decrease between 1990 and 2017 (-35.65%). Only three large communities experienced population decrease (Seward -6.71%, Kodiak -6.49%), and Valdez -3.22%). The majority of large communities experienced significant population increases during this time period with Kalifornskys population increasing 2904.91%.

Factors influencing observed trends: Population growth in the eastern GOA between 1990 and 2017 (8.53%) was lower than state trends, whereas population increase in the western GOA (59.96% including Anchorage and 156.90% excluding Anchorage) was much higher than state trends (34.0%). Anchorage and its surrounding Metropolitan Statistical Area is where the majority of population increase has occurred and where 40% of Alaska's population currently resides (ADLWD, 2016). Alaska has high rates of population turnover because of migration, and population growth has occurred mainly in urban areas (ADLWD, 2016). The main factors that affect population growth are natural increase (births minus deaths) and migration, with the latter being the most unpredictable aspect of population change (Williams, 2004; ADLWD, 2016). In 2010, 61% of Alaska's population was born out of State (Rasmussen et al. 2015). In terms of natural growth, from 2010 to 2014 the average annual birth rate in Alaska was 1.6 per 100 people which was higher than the national rate of 1.3 (ADLWD, 2016). The natural growth rates of the GOA had a range of 0.0–1.5% (ADLWD 2016). In regard to migration, the highest net migration occurs in the GOA region, and the Matanuska-Susitna Borough has the highest growth rate in the State (ADLWD, 2016).

Population trends in Alaska and the GOA region are the result of changes in resource extraction and military activity (Williams, 2004). Historically, the gold rush of the late 19th century doubled the states population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD2016c). However, certain areas have experienced population shifts at various periods, particularly those with military bases. For example, the population of Kodiak declined in the 1990s because of Coast Guard cut-backs (Williams 2006). The fishing industry also influences community population. Kodiak and the Aleutian Islands have the most transient populations because of the seafood processing industry (Williams, 2004). Some GOA communities that experienced fishery permit loss subsequently experienced population decline (Donkersloot and Carothers, 2016). Also, reduction of jobs in the lumber industry have caused population decrease. For example, the Whitestone Logging Camp population fluctuated from 164 to 0 between 1990 and 2006, increased to 17 in 2010 and was zero in subsequent years (ADLWD, 2017).

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. As stated earlier, the majority of population increases in the GOA are due to increased net migration rather than natural increase, and they have mainly occurred in urban areas as populations in many small communities are declining. Fisheries contribute to community vitality of the GOA. 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). Many larger communities of the GOA region are highly engaged in fisheries and depend upon fish processing industries to support their economies, such as in Kodiak, with both a resident and transient labor force. Changes in groundfish policy and management, such as increased regulations, may have implications for GOA community economies in both remote and urban areas.

With a large concentration of Alaskas population in Anchorage, it has become the major hub for goods and services, trade, and travel. Services such as medical, business and technology support and entertainment attract people to the area seeking services, and employment and education opportunities. The population growth of Anchorage has also contributed to sprawl into the Matanuska-Susitna valley. According to the U.S. Census Bureau of 2010, the population density of the Matanuska-Susitna borough was 3.6, whereas the state as a whole was 1.2. This regional growth has increased regional hunting and fishing pressures, recreational demand, and reduced available agricultural land because of high speculative land values (Fischer, 1976). Rapid development of the Matanuska-Susitna valley may have impacts on the local watersheds fish stocks and habitat, which should be monitored over time.

Trends in School Enrollment in the Western Gulf of Alaska

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

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. Enrollments trends are of particular relevance due to the value of schools to community cohesion and identity.

Public school enrollment was analyzed in the Western Gulf of Alaska (WGOA) by borough and community level in order to examine broader regional trends as well as the social and economic vitality of individual rural communities. Enrollment statistics for K-12 grades by school and region were compiled for the years 1996–2018 from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`). Current school locations and names were verified using the EPA EJ mapping tool (`https://ejscreen.epa.gov/mapper/`). School graduation rates are based off of the four year adjusted cohort graduation rate, which was implemented in Alaska starting with the 2011–2012 school year. Graduation rates are reported for 2015–2017 cohorts based upon school district. Dropout rates are reported by school district from 1990–2017. All data originate from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`)

Status and trends: In the WGOA, school enrollment patterns vary considerably depending on whether in rural or urban areas and the population of the municipality. Within municipalities where school enrollment is over 500 students, school enrollment has decreased slightly with the exception of Homer and Soldotna (Figure 97). School enrollment in Homer has decreased by 55.1 % since 1996 (from 2,543 to 1,401 students).

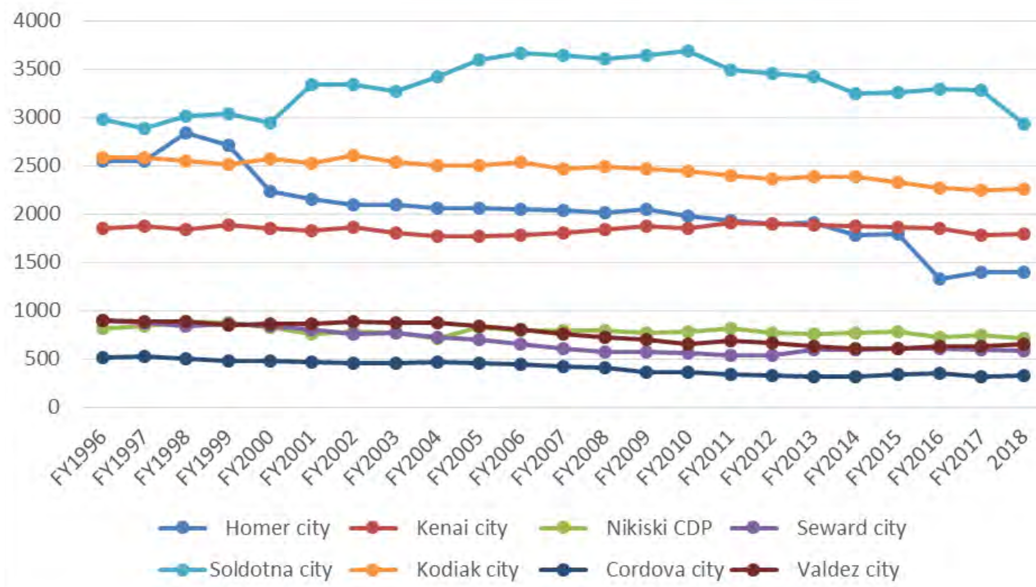

Figure 97: GOA fishing community schools with enrollment over 500 students.

In municipalities with school enrollment between 100 and 500 students, there is a downward trend for all schools with the exception of Nanwalek; many schools have declined by at least 50% since 1996. There have been five school closures. As of 2018, there are three schools with enrollments under 10 students facing possible closure. The majority of schools have enrollment under 100 students. Schools in smaller communities tend to have more variable enrollment trends. To illustrate, Figure 98 depicts Kodiak Island Borough schools, with enrollments currently ranging from 6 to 27.

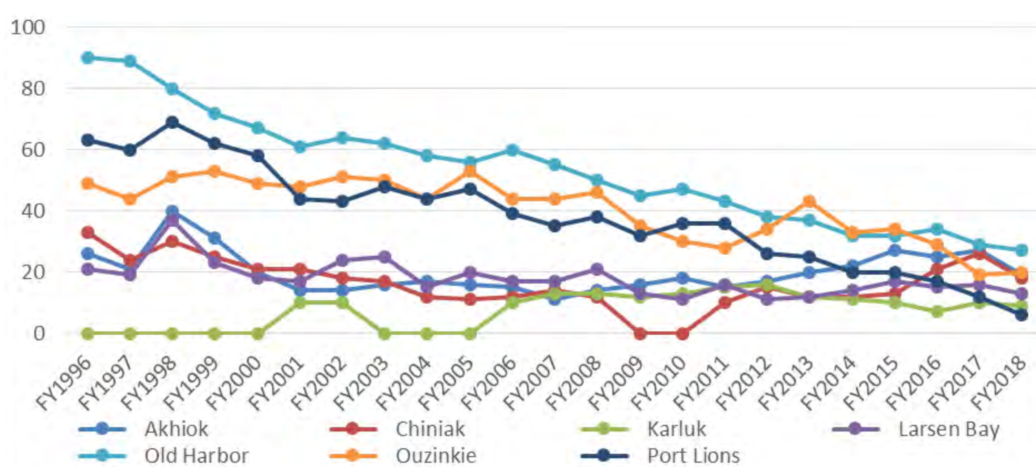

Figure 98: School enrollment in the Kodiak Island Borough.

There is some fluctuation in enrollment, but an overall downward trend. Two schools dropped in enrollment forcing periodic school closures. The Karluk School first opened in 2001 with 10 students, closed in 2003, and re-opened in 2006 with 10. As of October 2018, Karluk was slated for closure again. Chiniak School closed in 2009 when enrollment dipped below the 10 student threshold, and re-opening in 2011. In contrast to rural areas in WGOA, school enrollment in the urban municipality of Anchorage has been relatively stable, with a slight decrease in enrollment starting in 2010. The Mat-Su Borough school district has continued to grow, suggesting movement away from rural communities to urban centers.

There is some variation in the graduation rates of WGOA school districts; all but Valdez have maintained at least a 60% graduation rate for the 2015–2017 cohorts (Figure 99). The State graduation average was 75.6% (2015), 76.1% (2016) and 78.2% (2017). Dropout rates vary for Western GOA school districts, but typically stay below 6%. The Chugach School district has the most amount of outliers, with a dropout rate of almost 20% in 1999.

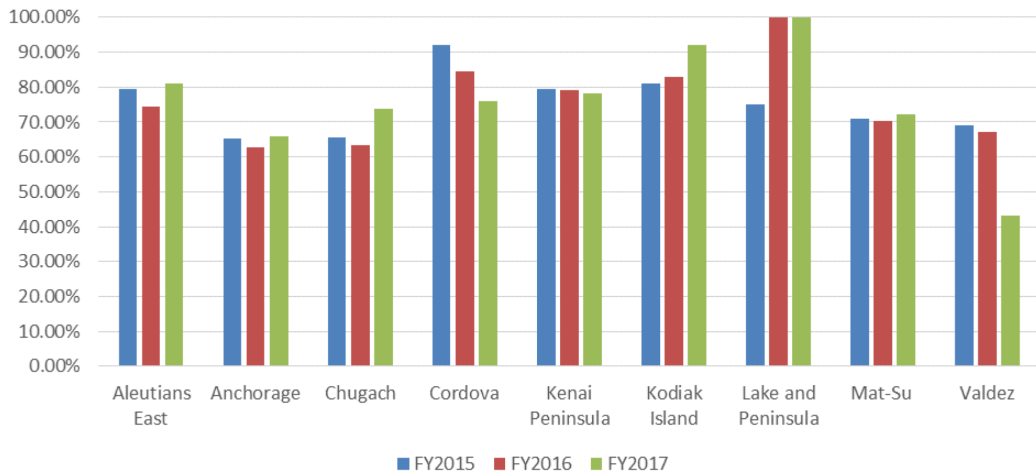

Figure 99: Graduation rates for Western GOA school districts, 2015–2017

Factors influencing observed trends: The GOA ecoregion varies substantially in population and community structure and vitality. The GOA holds several larger municipalities, with larger school enrollment, compared to other regions of Alaska. As people migrate to other areas, populations increase in adjacent communities. Enrollment may shift to the larger communities; however other factors should be considered including economic opportunity and infrastructure (such as functional ports, airports, or medical facilities) which provide needed services for a viable community. Those schools with enrollment under 30 students experience the greatest uncertainty in terms of educational stability. As of 2018, there have been six school closures (with Larsen Bay and Port Lions pending), 18 schools have enrollment under 30, and eight schools have enrollments under 15 students (Table 9). With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and possible community disruption. The reasons for decreasing enrollment likely involve complex social and economic drivers including migratory patterns, resource availability, and employment.

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 (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

Table 9: WGOA fishing community schools with enrollment of 30 or fewer students.

Enrollment	Number of Schools	Schools
Now closed	6	Bartlett School ; Danger Bay; Icy Bay CDP; Ivanof Bay CDP; Karluk CDP; Two Moon Bay CDP
16–30 students	10	Akhiok; Chignik Lake CDP; Chiniak CDP; Larsen Bay; Old Harbor; Ouzinkie; Perryville CDP; Tatitlek CDP; Tyonek CDP; Whittier
<15 students	8	Chenega CDP; Chignik Bay CDP; Chignik Lagoon CDP; Cooper Landing CDP; Larsen Bay; Marathon School; Moose Pass CDP; Port Lions

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 and viability, possibly leading to less vibrant and sustainable communities.

Trends in School Enrollment in the Eastern Gulf of Alaska

Contributed by Sarah P. Wise[1] and Kim Sparks[2]
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[2] Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA; and Alaska Fisheries Information Network, Pacific States Marine Fisheries Commission
Contact: sarah.wise@noaa.gov
Last updated: October 2018

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. Enrollments trends are of particular relevance due to the value of schools to community cohesion and identity.

Public school enrollment was analyzed in the Eastern Gulf of Alaska (EGOA) by borough and community level in order to examine broader regional trends as well as the social and economic vitality of individual rural communities. Enrollment statistics for K-12 grades by school and region were compiled for the years 1996–2018 from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`). Current school locations and names were verified using the EPA EJ mapping tool (`https://ejscreen.epa.gov/mapper/`). School graduation rates are based off of the four year adjusted cohort graduation rate, which was implemented in Alaska starting with the 2011–2012 school year. Graduation rates are reported for 2015–2017 cohorts based upon school district. Dropout rates are reported by school district from 1990–2017. All data originate from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`)

Status and trends: School enrollment patterns vary considerably in the EGOA depending on whether in rural or urban areas and the population of the municipality. Within municipalities where school enrollment is over 500 students, school enrollment is relatively stable with the exception of Juneau (Figure 100). School enrollment in Juneau has decreased by 19% since 1996 (from 5,502 students in 1996 to 4,471 in 2018).

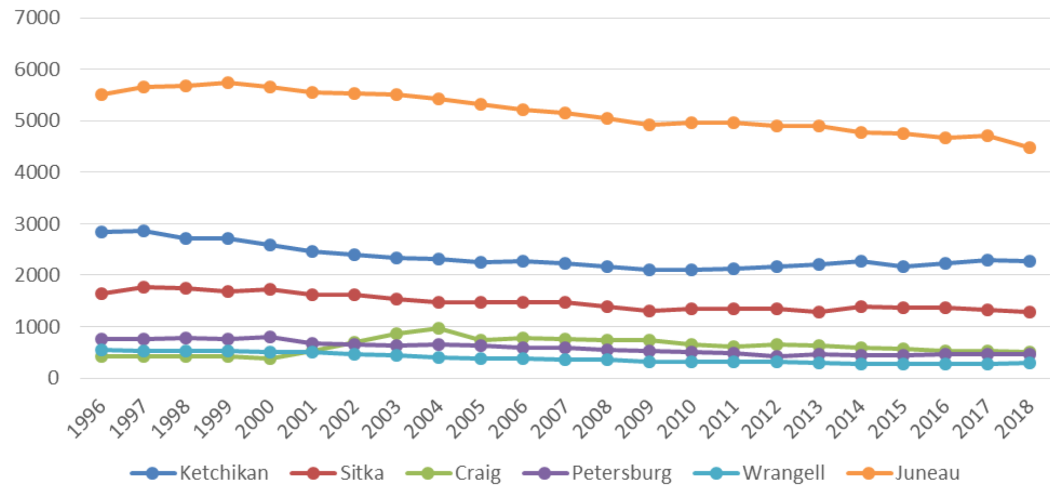

Figure 100: EGOA fishing community schools with enrollment over 500 students.

In municipalities with school enrollment from 100 to 500 students, there is a downward trend for most school districts, with a slight increase in enrollment in some districts since 2016 (Figure 101). There have been nine school closures, three of which have consolidations of Junior/Senior High schools into one K–12 school (Table 10).

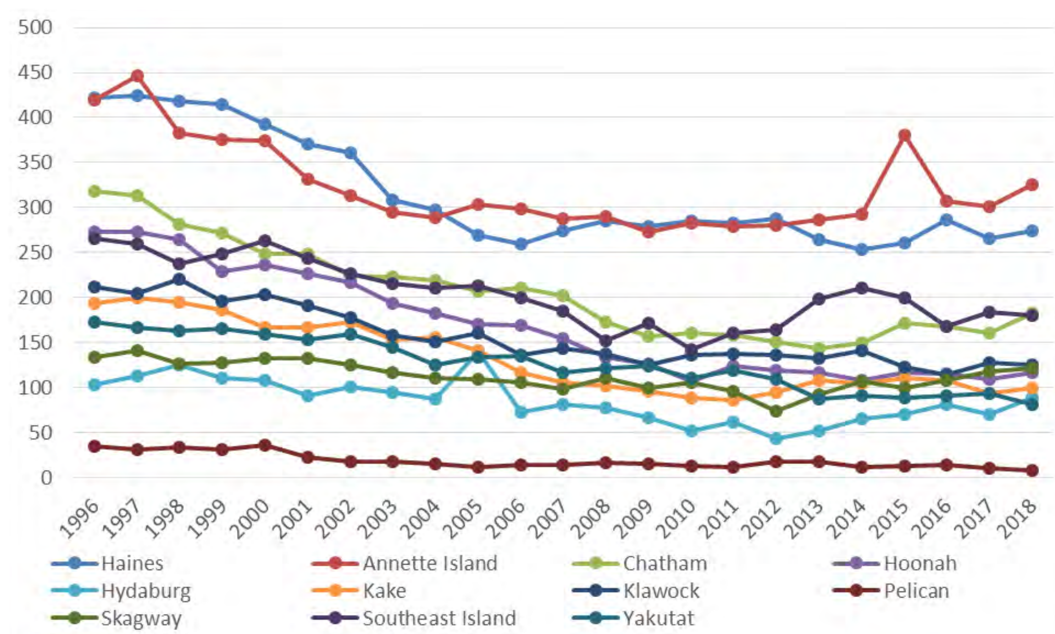

Figure 101: Eastern GOA School Districts with enrollment between 100 and 500 students

Table 10: EGOA fishing community schools with enrollment of 30 or fewer students.

Enrollment	Number of Schools	Schools
Now closed	9	Cube Cove CDP; Edna Bay CDP; Elfin Cove CDP; Haines Jr High; Hydaburg Jr/Sr High School; Klawock Jr/Sr High; Port Protection CDP; Tenakee Springs CDP; Yakutat Jr/Sr High School
16–30 students	4	Hollis CDP; Klukwan CDP; Naukati Bay CDP; Whale Pass CDP
<15 students	5	Coffman Cove CDP; Hyder CDP; Kasaan CDP; Pelican CDP; Port Alexander CDP

There is a large variation in the graduation rates of EGOA school districts. Larger districts such as Sitka and Ketchikan have the lowest graduation rates (both remaining under 60%) for the 2015–2017 cohorts (Figure fig.egoagrad), consistently placing in the lower 1/3 of school districts analyzed within this document. The State graduation average in was 75.6% (2015), 76.1% (2016), and 78.2% (2017). Dropout rates vary for EGOA school districts, but typically stay below 10%.

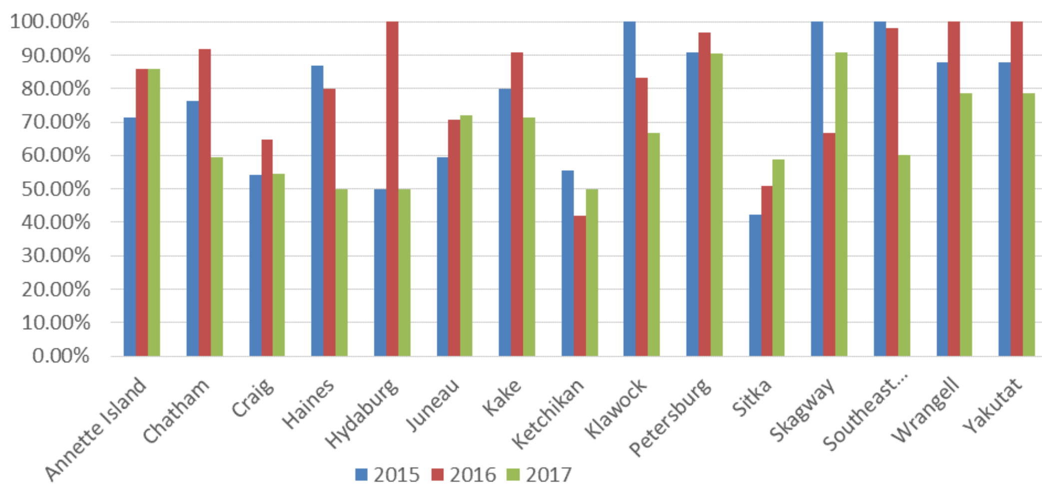

Figure 102: Graduation rates for Eastern GOA school districts, 2015–2017

Factors influencing observed trends: The GOA ecoregion varies substantially in population and community structure and vitality. The GOA holds several larger municipalities, with larger school enrollment, compared to other regions of Alaska. As people migrate to other areas, populations increase in adjacent communities. Enrollment may shift to the larger communities; however other factors should be considered including economic opportunity and infrastructure (such as functional ports, airports, or medical facilities) which provide needed services for a viable community. Those schools with enrollment under 30 students experience the greatest uncertainty in terms of educational stability. As of 2018, there have been six school closures (with Larsen Bay and Port Lions pending), 18 schools have enrollment under 30, and eight schools have enrollments under 15 students (Table tab.egoaschool). With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and possible community disruption. The reasons for decreasing enrollment likely involve complex social and economic drivers including migratory patterns, resource availability, and employment.

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 (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 and viability, possibly leading to less vibrant and sustainable communities.

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

December 2017 SSC Comments

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

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

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

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

There are expanded analyses of abundance and distribution shifts of groundfish and jellyfish from AFSC bottom trawl surveys. New indicators for groundfish from these surveys (mean length, lifespan and total biomass) have remained relatively stable over the time series. The SSC appreciates the inclusion of these new indicators, but suggests that even small changes could have far reaching implications as these are relatively gross-scale indicators. The SSC requests further development *of these indicators as anomalies to better discern long-term trends. The SSC looks forward to the eventual inclusion of comparisons of events in the different LMEs, and how events in one LME may affect another LME.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Gulf of Alaska Chapter

The Ecosystem Considerations Chapter for the Gulf of Alaska is still expanding and developing, and the SSC wishes to recognize the hard work of the editors and the contributors in developing this valuable management product. The SSC looks forward to further development of the GOA chapter, including the development of additional indicators. The need remains to finalize indicators for the regional report cards and to make progress in the development of predictive capacity as in the EBS Ecosystem report. The division of the GOA into eastern and western sub regions emphasizes data gaps, such as the lack of forage fish indicators in both regions, and the role of freshwater input.

This edition of the GOA ESR represents a substantial expansion, particularly in a year without the NOAA summer bottom trawl survey. There are 19 new indicator contributions. As in the past, we will monitor the efficacy and utility of these new indicators to inform the ecosystem assessment and ecosystem considerations of the fisheries management cycle. We continue to strive for balanced suite of indicators that are informative even if not comprehensive.

We continue to pursue a freshwater input indicator. The best available freshwater input data are from a model by David Hill and Jordan Beamer. They have produced regional scale 1 km gridded runoff products for the western and eastern GOA. Hill and Beamer recently updated their model to output a variety of products in formats that are more user friendly, including: 1) 1 km x 1 km; domain is 500,000 km^2, 2) daily runoff at all grid cells (80 GB files), 3) daily runoff at only coastal grid cells (2 GB files), 4) historic (1980–2015) runs for CFSR, MERRA, NARR reanalysis products, 5) future (2070–2100) runs for 5-model mean for RCP 4.5, 6, 8.5, and 6) netcdf format containing runoff values and lon / lat locations of grid cells.

An exceptionally valuable addition this year is a thoughtful examination of the impact that the warm "blob" that arrived in late 2013 had on the dynamics of Pacific cod in the Gulf of Alaska. This *exposition provides not only a way to understand what happened and why, but also provides the tools for rethinking how we might have detected the decline of cod two to three years before it happened. It would be valuable to develop a protocol for how to detect and respond to a potent ecosystem change in the future that could negatively, or positively, affect harvest specifications (See above discussion).*

This year for the first time, some stock assessments are include a risk matrix table that formerly incorporates ecosystem information along with uncertainties about model structure and population dynamics. If successful, this would allow contextual ecosystem information, such as what was noted during the marine heatwave, even if not directly included in the stock assessment model. These tables are included in the GOA pollock and cod 2018 stock assessments.

The SSC welcomes new contributions including: multiple oceanographic indicators, forage fish from Middleton Island auklet and kittiwake diets (which show a lack of capelin in their diets during heat wave years), ADFG herring biomass in EGOA, spring larval pollock from the EcoFOCI survey in western GOA, humpback whales in Glacier Bay, and the new suite of socio-economic indicators. The disease ecology indicators may prove particularly important. The SSC expects to see prevalence of these factors shift with changes in environment, e.g., emerging novel pathogens, or expansion of distribution with changes in the environment, such as an increase in Vibrio in warming waters.

This edition includes 19 new indicators. See discusion above.

The report on the station Papa trajectory index was interesting and the SSC appreciated having the full retrospective dataset for comparison to the southward trajectory in 2017. It would be useful to explore how variations in this index translate into changes in zooplankton abundance or species composition. A unique feature of the GOA is the number of tidewater glaciers in Kenai Fjords, Prince William Sound and SE Alaska that contribute freshwater to the marine environment. How are these inputs changing, and what are the potential impacts on the productivity of the GOA?

This is indeed an interesting topic that we are continuing to pursue, but don't have results to report at present.

The SSC suggests that results from the AFSC GOA bottom trawl survey be further investigated as a strong data source. Biomass estimates for the apex predator and the motile epifauna guilds are included in the report cards for the subregions, but more detail on these results included in the executive summaries and the current state sections would be useful. As shown by the editor in the presentation to the SSC, there were differences in what drove recent changes in the apex predator biomass by subregion, in this case, the large increase in the eastern GOA in 2015 was driven by arrowtooth flounder. It would also be useful to have data on acidification (pH) as an additional indicator to complement temperature and salinity. The SSC noted that Qiong Yang (PMEL/JISAO, NPRB 1509) has developed a new index of fish distribution by size, which should be considered for the 2018 report.

There was no bottom trawl survey this year, but we will pursue these suggestions next year. We continue to pursue ocean acidification indicators. There are some sources that may prove informative for the purposes of the ESR. The Alaska Ocean Acidification Network (https://www.aoos.org/alaska-ocean-acidification-network/). Moorings with OA sensors: (1) GAKOA (mouth of Resurrection Bay, Seward, near GAK1) 2011-present, contact UAF Ocean Acidification Research Center (OARC). Shore stations (1) wGOA Alutiiq Pride Shellfish Hatchery, Seward, 2014-present, contact Wiley Evans Hakai Institute, Kodiak NOAA facility, 2017-present, contact Wiley Evans Hakai Institute, (2) eGOA Oceans Alaska facility, Ketchikan, contact Wiley Evans Hakai Institute, 2016-present,

(3) eGOA Sitka, 2017-present, contact Wiley Evans Hakai Institute. Routine vessel sampling (1) wGOA Seward Line, 2008-present, sampled twice per year; May & September. contact Russ Hopcroft, University of Alaska Fairbanks, (2) eGOA Alaska Marine Highway Ferry: Columbia, 2017–present. Also citizen science and manual sample collection in GOA villages 2015-presetn and Kachemak Bay (KBNERR) 2016-present.

A few notable trends in the GOA: As noted in the Hot Topics section, pyrosomes were noted in the GOA for the first time in 2017. It appears that they were quite widespread and abundant, but it is not clear what their presence means for commercially important fish stocks. To the extent possible, their potential role in the ecosystem and potential impact on fish in the GOA needs to be addressed.

We did not receive reports of pyrosomes this year.

Zooplankton/jellyfish The shift in the size of zooplankton from large (Calanus, Neocalanus) to smaller species, and the scarcity of the larger species is an important observation. This shift may reflect changes in the advection of large species from the south and/or onto the shelf or an ecosystem response to the recent warming events.

In general, we have observed abundant, but smaller sized copepods during the warm years in the GOA. Large copepod and euphausiid are more energy rich prey than smaller copepods for small fish. Understanding how the strength of the Alaska Coastal Current and the availability of large zooplankton would be an interesting focus study in the eastern Gulf of Alaska shelf region.

The size distribution of jellyfish species has shifted toward smaller species; it would be interesting to determine whether this shift is a reflection of the size spectrum of zooplankton available.

We have not updated data on jellyfish this year. *Groundfish The arrowtooth flounder stock has declined recently, potentially indicating a response to the marine heat wave similar to Pacific cod. Presumably, this would result in decreased predation pressure on pollock, as well.*

This is a reasonable assumption, but we do not have data to show this at present.

Larval walleye pollock at-sea rough counts were above average in the WGOA EcoFOCI survey throughout grid, in contrast to 2015, when the survey encountered lots of zero stations and low rough counts. Larval pollock abundances were also high in late summer during the Oscar Dyson survey. The SSC requests that this survey be further investigated to evaluate its utility for other groundfish species.

Current plans for EcoFOCI survery in the GOA in 2019 includes rough counts for pollock, Pacific cod, arrowtooth flounder, Northern rock sole, Southern rock sole, and Sebastes spp. This expanding rough count protocol was implemented in the EBS in Spring 2018.

In 2017, all groundfish species excepting Pacific cod had below average condition. The lack of a consistent temporal and spatial trend might be indicative of highly dynamic productivity with local hotspots that influence condition. The SSC requests these data be split out into juvenile and adult samples, as suggested by the contributors to evaluate further spatial and temporal patterns.

We will request this in the 2019 ESR when we have new bottom trawl survey data.

Based on 2016 environmental data, model-based predictions are for an above average abundance of age-2 sablefish (68 million) in 2018 (2016 year-class). However, based on 2017 environmental data, *there may be below average abundance of age-2 sablefish in 2017 (2015 year-class). Recruitment is modeled from chlorophyll a, sea temperatures and pink salmon returns in Southeast Alaska. The large 2018 prediction appears to be primarily driven by a high chlorophyll a value, and the author notes the relatively high error associated with this estimate. These data are from the Southeast Coastal Monitoring survey. This raises the question whether there are other data that could be available from this survey.*

Yes, there are other oceanographic, zooplankton, and nutrient metrics. However, SST and chlorophyll a are made available soon after the survey for this sablefish model and prediction. With the new rapid zooplankton assessment by Fergusson, indices of abundance, density, and composition from the SECM survey in icy Strait could be included in the model in the year sampled.

Salmon: Estimated biomass of juvenile salmon present on the EGOA shelf decreased in 2017. Abundances were low for Chinook, coho, and pink salmon, and moderate for chum salmon. This implies a decline in marine conditions encountered for growth and survival of salmon from Southeast Alaska, British Columbia, and the Pacific Northwest stocks.

No survey was conducted in the EGOA in 2018. Currently, efforts are being made to link CPUE of juvenile salmon species to adult returns of salmon (Moss et al. in prep).

Marine mammals Preliminary non-pup counts of Steller sea lions declined 12% in 2017 compared to 2015. Both the eastern and western population were on an upward trajectory through 2015. It will be important for management to see if the latest decline was a short-term response to the heat wave or if it becomes a persistent trend.

We agree, but do not know yet.

Given the marked changes observed in the Gulf of Alaska in response to the marine heat wave, the SSC encourages the ecosystem considerations authors to examine methods to estimate the carrying capacity of the Gulf of Alaska. The SSC recognizes that some consideration of ecoregions (perhaps nearshore, banks and troughs) and zoogeography (perhaps an eastern and western/central spilt) may be needed.

This is an active area of research.

References

ADLWD. 2016. Alaska Population Overview: 2015 Estimates. Report, Alaska Department of Labor and Workforce Development.

ADLWD. 2017. Cities and Census Designated Places (CDPs), 2010 to 2016. Report, Alaska Department of Labor and Workforce Development.

ADLWD. 2018. Cities and census designated places (CDPs), 2010 to 2017. Report, Alaska Department of Labor and Workforce Development, Research and Analysis Section. `http://live.laborstats.alaska.gov/pop/index.cfm`

Alvarez-Fernandez, S., H. Lindeboom, and E. Meesters. 2012. Temporal changes in plankton of the North Sea: community shifts and environmental drivers. Marine Ecology Progress Series **462**:21–38.

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

Anderson, P. J. 2003. Gulf of Alaska small mesh trawl survey trends, In: J.L.Boldt (Ed.), Ecosystem Considerations for 2004. Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Reports. Report, North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Anderson, P. J., and J. F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series **189**:117–123.

Atwood, E., J. K. Duffy-Anderson, J. K. Horne, and C. Ladd. 2010. Influence of mesoscale eddies on ichthyoplankton assemblages in the Gulf of Alaska. Fisheries Oceanography **19**:493–507.

Batten, S. D., and D. W. Welch. 2004. Changes in oceanic zooplankton populations in the northeast Pacific associated with the possible climatic regime shift of 1998/1999. Deep Sea Research Part II: Topical Studies in Oceanography **51**:863–873.

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

Beaugrand, G. 2004. The North Sea regime shift: evidence, causes, mechanisms and consequences. Progress in Oceanography **60**:245–262.

Bodkin, J. L., H. A. Coletti, B. E. Ballachey, D. H. Monson, D. Esler, and T. A. Dean. 2018. Variation in abundance of Pacific Blue Mussel (Mytilus trossulus) in the Northern Gulf of Alaska, 20062015. Deep Sea Research Part II: Topical Studies in Oceanography **147**:87–97.

Bond, N. A., M. F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters **42**:3414–3420.

Bond, N. A., and L. Guy. 2010. North Pacific Climate Overview In: S. Zador and S. Gaichas (Ed.), Ecosystem Considerations for 2010. Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Report. Report, North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Bradford, A. L., D. W. Weller, A. E. Punt, Y. V. Ivashchenko, A. M. Burdin, G. R. VanBlaricom, and R. L. Brownell Jr. 2012. Leaner leviathans: body condition variation in a critically endangered whale population. Journal of Mammalogy **93**:251–266.

Brickley, P. J., and A. C. Thomas. 2004. Satellite-measured seasonal and inter-annual chlorophyll variability in the Northeast Pacific and Coastal Gulf of Alaska. Deep-Sea Research Part Ii-Topical Studies in Oceanography **51**:229–245.

Brodeur, R., and D. M. Ware. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fisheries Oceanography **1**:32–37.

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

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

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

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

Calambokidis, J., E. A. Falcone, T. J. Quinn, A. M. Burdin, P. Clapham, J. Ford, C. Gabriele, R. LeDuc, D. Mattila, and L. Rojas-Bracho. 2008. SPLASH: Structure of populations, levels of abundance and status of humpback whales in the North Pacific. Report.

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

Campbell, R. W. 2018. Hydrographic trends in Prince William Sound, Alaska, 19602016. Deep Sea Research Part II: Topical Studies in Oceanography **147**:43–57.

Catchpole, T., C. Frid, and T. Gray. 2006. Importance of discards from the English Nephrops norvegicus fishery in the North Sea to marine scavengers. Marine Ecology Progress Series **313**:215–226.

Combes, V., and E. Di Lorenzo. 2007. Intrinsic and forced interannual variability of the Gulf of Alaska mesoscale circulation. Progress in Oceanography **75**:266–286.

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

Crusius, J., A. W. Schroth, J. A. Resing, J. Cullen, and R. W. Campbell. 2017. Seasonal and spatial variabilities in northern Gulf of Alaska surface water iron concentrations driven by shelf sediment resuspension, glacial meltwater, a Yakutat eddy, and dust. Global Biogeochemical Cycles **31**:942–960.

Dahlheim, M. E., P. A. White, and J. M. Waite. 2009. Cetaceans of Southeast Alaska: distribution and seasonal occurrence. Journal of Biogeography **36**:410–426.

DCCED. 2016. State of Alaska Department of Commerce, Community and Economic Development. Community and Regional Analysis, Community Database Online. Report. `https://www.commerce.alaska.gov/dcra/DCRAExternal`

Di Lorenzo, E., and N. Mantua. 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Clim. Change **advance online publication**.

Di Lorenzo, E., D. Mountain, H. Batchelder, N. Bond, and E. Hofmann. 2013. Advances in marine ecosystem dynamics from US GLOBEC: The horizontal-advection bottom-up forcing paradigm. Oceanography **26**:2233.

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

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

Dougherty, A., and L. Rogers. 2017. Larval Walleye Pollock Assessment in the Gulf of Alaska, Spring 2017. In Zador, S., and Yasumiishi, E., 2017. Ecosystem Considerations 2017: Status of the Gulf of Alaska Marine Ecosystem. Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Doyle, M., and K. Mier. 2012. A new conceptual framework for evaluating the early ontogeny phase of recruitment processes among marine fish species. Canadian Journal of Fisheries and Aquatic Sciences **69**:2112–2129.

Doyle, M. J., S. J. Picquelle, K. L. Mier, M. Spillane, and N. bond. 2009. Larval fish abundance and physical forcing in the Gulf of Alaska, 1981-2003. Progress in Oceanography **80**:163–187.

Ducet, N., P. Y. Le Traon, and G. Reverdin. 2000. Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and-2. Journal of Geophysical Research-Oceans **105**:19477–19498.

Fall, J. A., and T. Lemons. 2015. Subsistence harvests of Pacific halibut in Alaska, 2014. Report.

Fergusson, E., J. T. Watson, A. Gray, and J. Murphy. 2018. Annual Survey of Juvenile Salmon, Ecologically-Related Species, and Biophysical Factors in the Marine Waters of Southeastern Alaska, MayAugust 2016 .

Fergusson, E. A., M. V. Sturdevant, and J. A. Orsi. 2013. Trophic relationships among juvenile salmon during a 16-year time series of climate variability in Southeast Alaska. Report.

Fischer, V. 1976. Regional effects of Anchorage metropolitan growth. Fairbanks: Institute of Social, Economic and Government Research, University of Alaska.

Fritz, L. W., K. Sweeney, R. G. Towell, and T. W. Gelatt. 2016. Aerial and ship-based surveys of Steller sea lions (Eumetopias jubatus) conducted in Alaska in June-July 2013 through 2015, and an update on the status and trend of the western distinct population segment in Alaska. Report.

Fuentes, M. M., S. Delean, J. Grayson, S. Lavender, M. Logan, and H. Marsh. 2016. Spatial and Temporal Variation in the Effects of Climatic Variables on Dugong Calf Production. PloS one **11**:e0155675.

Funk, F., and G. J. Sandone. 1990. Catch-age analysis of Prince William Sound, Alaska, herring, 1973-1988. Alaska Department of Fish and Game, Division of Commercial Fisheries.

Gabriele, C. M., J. L. Neilson, J. M. Straley, C. S. Baker, J. A. Cedarleaf, and J. F. Saracco. 2017. Natural history, population dynamics, and habitat use of humpback whales over 30 years on an Alaska feeding ground. Ecosphere **8**.

Gabriele, C. M., J. M. Straley, S. A. Mizroch, C. S. Baker, A. S. Craig, L. M. Herman, D. Glockner-Ferrari, M. J. Ferrari, S. Cerchio, and O. v. Ziegesar. 2001. Estimating the mortality rate of humpback whale calves in the central North Pacific Ocean. Canadian Journal of Zoology **79**:589–600.

Gilroy, H. L. The Pacific halibut fishery, 2004. in International Pacific Halibut Commission Eighty-First Annual Meeting, page 1907 .

Greene, K. 2002. Coastal cool-down. Science **295**:1823–1823.

Guthrie III, C., H. T. Nguyen, A. E. Thomson, and J. Guyon. 2017. Genetic stock composition analysis of the Chinook salmon bycatch from the 2015 Gulf of Alaska trawl fisheries. Report.

Hatch, S. A. 2013. Kittiwake diets and chick production signal a 2008 regime shift in the Northeast Pacific. Marine Ecology Progress Series **477**:271–284.

Heard, W. R. 2009. Alaska Salmon. Unit 13 in Our Living Oceans, 6th edition. Report.

Hebert, K. P. 2017. Southeast Alaska 2016 herring stock assessment surveys. Report, Alaska Department of Fish and Game, Fishery Data Series No. 17-01.

Heintz, R. A., E. C. Siddon, E. V. Farley Jr, and J. M. Napp. 2013. Correlation between recruitment and fall condition of age-0 pollock (Theragra chalcogramma) from the eastern Bering Sea under varying climate conditions. Deep Sea Research Part II: Topical Studies in Oceanography .

Hendrix, A., J. Straley, C. Gabriele, and S. Gende. 2012. Bayesian estimation of humpback whale (Megaptera novaeangliae) population abundance and movement patterns in southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences **69**:1783–1797.

Hobday, A. J., L. V. Alexander, S. E. Perkins, D. A. Smale, S. C. Straub, E. C. Oliver, J. A. Benthuysen, M. T. Burrows, M. G. Donat, and M. Feng. 2016. A hierarchical approach to defining marine heatwaves. Progress in Oceanography **141**:227–238.

Hulson, P.-J. F., S. E. Miller, T. J. Quinn, G. D. Marty, S. D. Moffitt, and F. Funk. 2007. Data conflicts in fishery models: incorporating hydroacoustic data into the Prince William Sound Pacific herring assessment model. ICES Journal of Marine Science **65**:25–43.

Ianelli, J. N., and D. L. Stram. 2014. Estimating impacts of the pollock fishery bycatch on western Alaska Chinook salmon. ICES Journal of Marine Science **72**:1159–1172.

Janout, M. A., T. J. Weingartner, T. C. Royer, and S. L. Danielson. 2010. On the nature of winter cooling and the recent temperature shift on the northern Gulf of Alaska shelf. Journal of Geophysical Research: Oceans **115**.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2015. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2011. Report.

Kelleher, K. 2005. Discards in the world's marine fisheries: an update. Food & Agriculture Org.

King, J. 2005. Report of the Study Group on Fisheries and Ecosystem Responses to recent regime shifts. PICES Scientific Report No. 28. Report.

Kline, J., T. C. 2010. Stable carbon and nitrogen isotope variation in the northern lampfish and Neocalanus, marine survival rates of pink salmon, and meso-scale eddies in the Gulf of Alaska. Progress in Oceanography **87**:49–60.

Kovach, R. P., J. E. Joyce, J. D. Echave, M. S. Lindberg, and D. A. Tallmon. 2013. Earlier Migration Timing, Decreasing Phenotypic Variation, and Biocomplexity in Multiple Salmonid Species. PLoS ONE **8**:e53807.

Ladd, C. 2007. Interannual variability of the Gulf of Alaska eddy field. Geophysical Research Letters **34**.

Ladd, C., and W. Cheng. 2016. Gap winds and their effects on regional oceanography Part I: Cross Sound, Alaska. Deep Sea Research II .

Ladd, C., W. R. Crawford, C. Harpold, W. Johnson, N. B. Kachel, P. Stabeno, and F. Whitney. 2009. A synoptic survey of young mesoscale eddies in the Eastern Gulf of Alaska. Deep-Sea Research Part II **56**:2460–2473.

Ladd, C., N. B. Kachel, C. W. Mordy, and P. J. Stabeno. 2005. Observations from a Yakutat eddy in the northern Gulf of Alaska. Journal of Geophysical Research-Oceans **110**.

Ladd, C., C. W. Mordy, N. B. Kachel, and P. J. Stabeno. 2007. Northern Gulf of Alaska eddies and associated anomalies. Deep-Sea Research Part I-Oceanographic Research Papers **54**:487–509.

Landingham, J. H., M. V. Sturdevant, and R. D. Brodeur. 1998. Feeding habits of juvenile Pacific salmon in marine waters of southeastern Alaska and northern British Columbia. Fishery Bulletin **96**:285–302.

Langdon-Pollock, J. 2004. West coast marine fishing community descriptions. Report, Pacific State Marine Fisheries Commission, Economic Fisheries Information Networks.

Levitus, S., J. I. Antonov, J. Wang, T. L. Delworth, K. W. Dixon, and A. J. Broccoli. 2001. Anthropogenic warming of Earth's climate system. Science **292**:267–270.

Lew, D. K., and D. M. Larson. 2011. A repeated mixed logit approach to valuing a local sport fishery: the case of Southeast Alaska salmon. Land Economics **87**:712–729.

Lew, D. K., and D. M. Larson. 2012. Economic values for saltwater sport fishing in Alaska: A stated preference analysis. North American journal of fisheries management **32**:745–759.

Lew, D. K., and D. M. Larson. 2015. Stated preferences for size and bag limits of Alaska charter boat anglers. Marine Policy **61**:66–76.

Lew, D. K., and D. M. Larson. 2017. Stated preferences of Alaska resident saltwater anglersfor contemporary regulatory policies. Marine Fisheries Review **79**:12–25.

Lew, D. K., and C. Seung. 2018. Measuring the Economic Contribution of the Saltwater Charter Fishing Sector in Alaska. Alaska Fisheries Science Center, NMFS-NOAA page working paper .

Link, J. S., J. K. T. Brodziak, S. F. Edwards, W. J. Overholtz, D. Mountain, J. W. Jossi, T. D. Smith, and M. J. Fogarty. 2002. Marine ecosystem assessment in a fisheries management context. Canadian Journal of Fisheries and Aquatic Sciences **59**:1429–1440.

Loring, P. A., and S. C. Gerlach. 2009. Food, culture, and human health in Alaska: an integrative health approach to food security. Environmental Science & Policy **12**:466–478.

Lovell, S. J., S. R. Steinback, and J. R. Hilger. 2013. The economic contribution of marine angler expenditures in the United States, 2011 .

Lyson, T. 2005. The importance of schools to rural community viability. A Mathematics Educators Introduction to Rural Policy Issues **48**.

Lyson, T. A. 2002. What Does a School Mean to a Community? Assessing the Social and Economic Benefits of Schools to Rural Villages in New York .

Mackas, D. L., W. Greve, M. Edwards, S. Chiba, K. Tadokoro, D. Eloire, M. G. Mazzocchi, S. Batten, A. J. Richardson, C. Johnson, E. Head, A. Conversi, and T. Peluso. 2012. Changing zooplankton seasonality in a changing ocean: Comparing time series of zooplankton phenology. Progress in Oceanography **97100**:31–62.

Matarese, A. C., D. M. Blood, S. J. Picquelle, and J. L. Benson. 2003. Atlas of abundance and distribution patterns of ichthyoplankton from the northeast Pacific Ocean and Bering Sea ecosystems based on research conducted by the Alaska Fisheries Science Center (1972-1996). Report.

McKinstry, C. A., and R. W. Campbell. 2018. Seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska, 20092016. Deep Sea Research Part II: Topical Studies in Oceanography **147**:69–78.

Meyer, S. 2010. Changes coming for Alaska's charter halibut fishery. Report.

Moran, J., R. Heintz, J. Straley, and J. Vollenweider. 2017. Regional variation in the intensity of humpback whale predation on Pacific herring in the Gulf of Alaska. Deep Sea Research Part II: Topical Studies in Oceanography .

Mortensen, D., A. Wertheimer, C. Taylor, and J. Landingham. 2000. The relation between early marine growth of pink salmon, Oncorhynchus gorbuscha, and marine water temperature, secondary production, and survival to adulthood. Fishery Bulletin .

Moss, J. H., D. A. Beauchamp, A. D. Cross, K. W. Myers, E. V. Farley Jr, J. M. Murphy, and J. H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. Transactions of the American Fisheries Society **134**:1313–1322.

Muradian, M. L., T. A. Branch, S. D. Moffitt, and P.-J. F. Hulson. 2017. Bayesian stock assessment of Pacific herring in Prince William Sound, Alaska. PloS one **12**:e0172153.

Murphy, J. M., E. Fergusson, J. Watson, and A. Gray. 2018. Southeast Alaska coastal monitoring survey plan for 2018. Report, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center, Auke Bay Laboratories, Ted Stevens Marine Research Institute. `http://www.npafc.org`

Muto, M., V. Helker, R. Angliss, B. Allen, P. Boveng, J. Breiwick, M. Cameron, P. Clapham, S. Dahle, M. Dahlheim, B. S. Fadely, M. C. Ferguson, L. W. Fritz, R. C. Hobbs, Y. V. Ivashchenko, A. S. Kennedy, J. M. London, S. A. Mizroch, R. R. Ream, E. L. Richmond, K. E. W. Shelden, R. G. Towell, P. R. Wade, J. N. Waite, and A. N. Zerbini. 2016. Alaska Marine Mammal Stock Assessments, 2016. Report.

Neilson, J. L., C. M. Gabriele, and L. F. Taylor-Thomas. 2017. Humpback whale monitoring in Glacier Bay and adjacent waters 2016: Annual progress report. Report.

Neilson, J. L., C. M. Gabriele, and P. B. S. Vanselow. 2015. Results of humpback whale monitoring in Glacier Bay and adjacent waters 2014: Annual progress report. Report.

Okkonen, S. R., G. A. Jacobs, E. J. Metzger, H. E. Hurlburt, and J. F. Shriver. 2001. Mesoscale variability in the boundary currents of the Alaska Gyre. Continental Shelf Research **21**:1219–1236.

Okkonen, S. R., T. J. Weingartner, S. L. Danielson, D. L. Musgrave, and G. M. Schmidt. 2003. Satellite and hydrographic observations of eddy-induced shelf-slope exchange in the northwestern Gulf of Alaska. Journal of Geophysical Research-Oceans **108**.

Olson, J. 2005. Development in Theory: Re-Placing the Space of Community: A Story of Cultural Politics, Policies, and Fisheries Management. Anthropological Quarterly **78**:247–268.

Oncescu, J. M., and A. Giles. 2014. Rebuilding a sense of community through reconnection: The impact of a rural school's closure on individuals without school-aged children. Journal of Rural and Community Development **9**.

Orsi, J., A. Wertheimer, M. Sturdevant, E. Fergusson, D. Mortensen, and B. Wing. 2004. Juvenile chum salmon consumption of zooplankton in marine waters of southeastern Alaska: a bioenergetics approach to implications of hatchery stock interactions. Reviews in Fish Biology and Fisheries **14**:335–359.

Orsi, J. A., E. A. Fergusson, E. M. Yasumiishi, E. V. Farley, and R. A. Heintz. 2015. Southeast Alaska Coastal Monitoring (SCEM) survey plan for 2015. Report, Auke Bay Lab., Alaska Fisheries Science Center, NOAA, NMFS. `http://www.npafc.org`

Ostrom, E. 2007. A diagnostic approach for going beyond panaceas. Proceedings of the national Academy of sciences **104**:15181–15187.

Park, W., M. Sturdevant, J. Orsi, A. Wertheimer, E. Fergusson, W. Heard, and T. Shirley. 2004. Interannual abundance patterns of copepods during an ENSO event in Icy Strait, southeastern Alaska. ICES Journal of Marine Science: Journal du Conseil **61**:464–477.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. Journal of the Fisheries Board of Canada **25**:757–794.

Peshkin, A. 1978. Growing Up American; Schooling and the Survival of Community .

Peshkin, A. 1982. The Imperfect Union. School Consolidation & Community Conflict. ERIC.

Peterson, G. D., S. R. Carpenter, and W. A. Brock. 2003. Uncertainty and the management of multistate ecosystems: an apparently rational route to collapse. Ecology **84**:1403–1411.

Peterson, W. T., J. L. Fisher, P. T. Strub, X. Du, C. Risien, J. Peterson, and C. T. Shaw. 2017. The pelagic ecosystem in the Northern California Current off Oregon during the 20142016 warm anomalies within the context of the past 20 years. Journal of Geophysical Research: Oceans **122**:7267–7290.

Piatt, J. F., and P. J. Anderson. 1996. Response of Common Murres to the Exxon Valdez oil spill and long-term changes in the Gulf of Alaska marine ecosystem. American Fisheries Society Symposium **18**:720–737.

Picou, J. S., D. A. Gill, C. L. Dyer, and E. W. Curry. 1992. Disruption and stress in an Alaskan fishing community: Initial and continuing impacts of the Exxon Valdez oil spill. Industrial Crisis Quarterly **6**:235–257.

Pierszalowski, S. P., C. M. Gabriele, D. J. Steel, J. L. Neilson, P. B. Vanselow, J. A. Cedarleaf, J. M. Straley, and C. S. Baker. 2016. Local recruitment of humpback whales in Glacier Bay and Icy Strait, Alaska, over 30 years. Endangered Species Research **31**:177–189.

Purcell, J. E. 2005. Climate effects on formation of jellyfish and ctenophore blooms: a review. Journal of the Marine Biological Association of the United Kingdom **85**:461–476.

Purcell, J. E., and M. N. Arai. 2001. Interactions of pelagic cnidarians and ctenophores with fish: a review. Hydrobiologia **451**:27–44.

Purcell, J. E., and M. V. Sturdevant. 2001. Prey selection and dietary overlap among zooplanktivorous jellyfish and juvenile fishes in Prince William Sound, Alaska. Marine Ecology Progress Series **210**:67–83.

Queirolo, L. E., L. Fritz, P. Livingston, M. Loefflad, D. Colpo, and Y. DeReynier. 1995. Bycatch, utilization, and discards in the commercial groundfish fisheries of the Gulf of Alaska, eastern Bering Sea, and Aleutian Islands. NOAA Technical Memorandum NMFS-AFSC **58**:148.

Rasmussen, R. E., G. K. Hovelsrud, and S. Gearheard. 2015. Community Viability. Nordic Council of Ministers.

Ream, R. R., J. T. Sterling, and T. R. Loughlin. 2005. Oceanographic features related to northern fur seal migratory movements. Deep-Sea Research Part Ii-Topical Studies in Oceanography **52**:823–843.

Richardson, A. J., A. W. Walne, A. G. J. John, T. D. Jonas, J. A. Lindley, D. W. Sims, D. Stevens, and M. Witt. 2006. Using continuous plankton recorder data. Progress in Oceanography **68**:27–74.

Robinson, K. L., J. J. Ruzicka, M. B. Decker, R. D. Brodeur, R. J. Hernandez, J. Quinones, E. M. Acha, S.-i. Uye, H. Mianzan, and W. M. Graham. 2014. Jellyfish, Forage Fish, and the Worlds Major Fisheries. Oceanography **27**:104–115.

Romberg, W. J. 2016. Alaska Statewide Sport Fish Harvest Survey, 2016. Alaska Department of Fish and Game, Regional Operational Plan SF.4A.2016.04,, Anchorage.

Royer, T. C., and C. E. Grosch. 2006. Ocean warming and freshening in the northern Gulf of Alaska. Geophysical Research Letters **33**.

Rykaczewski, R. R., W. T. Peterson, and J. L. Fisher. 2015. The impact of El Nio events on the pelagic food chain in the northern California Current .

Scannell, H. A., A. J. Pershing, M. A. Alexander, A. C. Thomas, and K. E. Mills. 2016. Frequency of marine heatwaves in the North Atlantic and North Pacific since 1950. Geophysical Research Letters **43**:2069–2076.

Schnaittacher, G. M., and R. E. Narita. 2013. Incidental catches of salmonids by US groundfish fisheries in the Bering Sea/Aleutian Islands and the Gulf of Alaska, 1990-2012. NPAFC Doc **1476**.

Sell, R. S., and F. L. Leistritz. 1997. Socioeconomic impacts of school consolidation on host and vacated communities. Community Development **28**:186–205.

Seyboth, E., K. R. Groch, L. Dalla Rosa, K. Reid, P. A. Flores, and E. R. Secchi. 2016. Southern right whale (Eubalaena australis) reproductive success is influenced by krill (Euphausia superba) density and climate. Scientific reports **6**:28205.

Shanley, C. S., S. Pyare, M. I. Goldstein, P. B. Alaback, D. M. Albert, C. M. Beier, T. J. Brinkman, R. T. Edwards, E. Hood, and A. MacKinnon. 2015. Climate change implications in the northern coastal temperate rainforest of North America. Climatic Change **130**:155–170.

Shin, Y.-J., L. J. Shannon, A. Bundy, M. Coll, K. Aydin, N. Bez, J. L. Blanchard, M. d. F. Borges, I. Diallo, E. Diaz, J. J. Heymans, L. Hill, E. Johannesen, D. Jouffre, S. Kifani, P. Labrosse, J. S. Link, S. Mackinson, H. Masski, C. Mllmann, S. Neira, H. Ojaveer, K. ould Mohammed Abdallahi, I. Perry, D. Thiao, D. Yemane, and P. M. Cury. 2010. Using indicators for evaluating, comparing, and communicating the ecological status of exploited marine ecosystems. 2. Setting the scene. ICES Journal of Marine Science **67**:692–716.

Sigler, M., D. Tollit, J. J. Vollenweider, J. F. Thedinga, D. J. Csepp, J. N. Womble, M. A. Wong, M. J. Rehberg, and A. W. Trites. 2009. Steller Sea Lion Foraging Response to Seasonal Changes in Prey Availability. Marine Ecology Progress Series **388**.

Spalinger, K., and M. Knutson. 2018. Large-mesh bottom trawl survey of crab and groundfish: Kodiak, Chignik, South Peninsula, and Eastern Aleutian Management Districts, 2017, Alaska Department of Fish and Game, Fishery Management Report No. 18-15. Report.

St. Martin, K., and M. Hall-Arber. 2008. The missing layer: Geo-technologies, communities, and implications for marine spatial planning. Marine Policy **32**:779–786.

Straley, J. M., J. R. Moran, K. M. Boswell, J. J. Vollenweider, R. A. Heintz, T. J. Quinn II, B. H. Witteveen, and S. D. Rice. 2017. Seasonal presence and potential influence of humpback whales on wintering Pacific herring populations in the Gulf of Alaska. Deep Sea Research Part II: Topical Studies in Oceanography .

Straley, J. M., I. Quinn, J. Terrance, and C. M. Gabriele. 2009. Assessment of markrecapture models to estimate the abundance of a humpback whale feeding aggregation in Southeast Alaska. Journal of biogeography **36**:427–438.

Stram, D. L., and J. N. Ianelli. 2014. Evaluating the efficacy of salmon bycatch measures using fishery-dependent data. ICES Journal of Marine Science **72**:1173–1180.

Sturdevant, M., J. Orsi, and E. Fergusson. 2012. Diets and trophic linkages of epipelagic fish predators in coastal Southeast Alaska during a period of warm and cold climate years, 19972011. Marine and Coastal Fisheries **4**:526–545.

Sturdevant, M., M. Sigler, and J. Orsi. 2009. Sablefish predation on juvenile Pacific salmon in the coastal marine waters of Southeast Alaska in 1999. Transactions of the American Fisheries Society **138**:675–691.

Turner, B. L., R. E. Kasperson, P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, and M. L. Martello. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the national academy of sciences **100**:8074–8079.

Van Handel, E. 1985. Rapid determination of total lipids in mosquitoes. J Am Mosq Control Assoc **1**:302–304.

Walsh, J. E., R. L. Thoman, U. S. Bhatt, P. A. Bieniek, B. Brettschneider, M. Brubaker, S. Danielson, R. Lader, F. Fetterer, and K. Holderied. 2018. The High Latitude Marine Heat Wave of 2016 and Its Impacts on Alaska. Bulletin of the American Meteorological Society **99**:S39–S43.

Watson, J. T., and A. C. Haynie. 2018. Paths to resilience: the walleye pollock fleet uses multiple fishing strategies to buffer against environmental change in the Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences **75**:1977–1989.

Weitkamp, L. A., J. A. Orsi, K. Myers, and R. Francis. 2011. Contrasting early marine ecology of Chinook salmon and coho salmon in Southeast Alaska: insight into factors affecting marine survival. Marine and Coastal Fisheries **3**:233–249.

Wespestad, V. G., L. W. Fritz, W. J. Ingraham, and B. A. Megrey. 2000. On relationships between cannibalism, climate variability, physical transport, and recruitment success of Bering Sea walleye pollock (Theragra chalcogramma). Ices Journal of Marine Science **57**:272–278.

Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. 2002. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography **55**:235–247.

Williams, J. 2004. Alaska population overview: 2001-2002 estimates and census 2000. Alaska Department of Labor and Workforce Development, Research and Analysis Section, Juneau .

Witherell, D., and D. Woodby. 2005. Application of marine protected areas for sustainable production and marine biodiversity off Alaska. Marine Fisheries Review **67**:1–28.

Zador, S. G., and S. Fitzgerald. 2008. Seabird Attraction to Trawler Discards. Report, Alaska Fisheries Science Center, NOAA, NMFS.

Zador, S. G., E. M. Yasumiishi, and K. Holsman. 2017. Ecosystem Assessment. In: Ecosystem Considerations 2017: Status of the Gulf of Alaska Marine Ecosystem. Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99301.