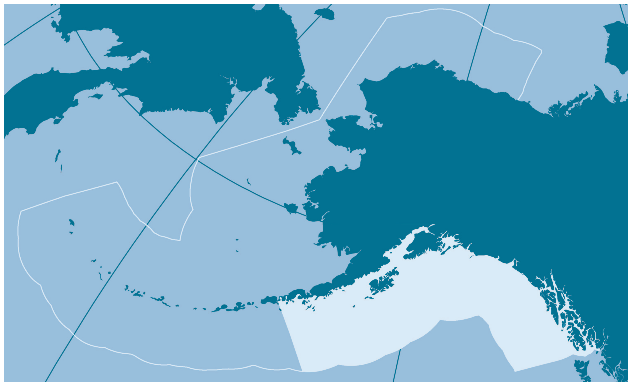
Ecosystem Status Report 2019

Gulf of Alaska



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Western Gulf of Alaska 2019 Report Card

- The western Gulf of Alaska remained **in heatwave conditions** for most of 2019. Summer sea surface temperatures were similar to the warmest temperatures during the 2014–2016 marine heatwave. The **PDO declined to neutral**, reflecting warm conditions across the NE Pacific (with no temperature contrast in the central Pacific that describes the positive or negative PDO pattern).
- **Mesozooplankton biomass** measured by the continuous plankton recorder **declined in 2018** ending a stretch of positive abundance anomalies seen from 2014–2017.
- **Copepod community size was larger in 2017 and 2018** than it had been during the 2014–2016 heatwave, indicating that there were more large species available. However, the lower biomass in 2018 indicates a **potential decline in foraging conditions for planktivorous predators** relative to that in 2017.
- Bottom trawl **survey biomass of motile epifauna increased from 2017 to 2019 (10%) and is above the long term mean**. The biomass of this guild is dominated by octopuses, hermit crabs, and brittle stars. Octopuses increased to their highest value over the time series, while both hermit crabs and brittle stars decreased to well below their long-term means.
- Trends in **capelin** as sampled by rhinocerous auklets at Middleton Island have indicated that capelin were abundant from 2008 to 2013, but**continue to be minimal in seabird chick diets in recent years**. Their apparent **decline coincided with the period of warm water temperatures** in the Gulf of Alaska.
- **Fish apex predator biomass during 2019 bottom trawl survey** increased from 2017 to 2019 (13%) but remains well below the long-term mean. **The trend is driven primarily by increases in Pacific cod and arrowtooth flounder** which are both at their second lowest abundance in the survey time series, and **increases in sablefish**, which is above their long-term mean and at its third highest abundance in the survey time series.
- **Black-legged kittiwakes experienced reproductive failure in 2019** at the Semedi Islands. The failure occurred during the chick-rearing period, **potentially indicating a rapid decline in prey availability** for these surface-feeding seabirds. In contrast, **diving, fish-eating seabirds in the western GOA had strong reproductive success** in 2019.
- Although Steller sea lion non-pups were counted in 2019, the data were not available in time for this report. 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, 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.

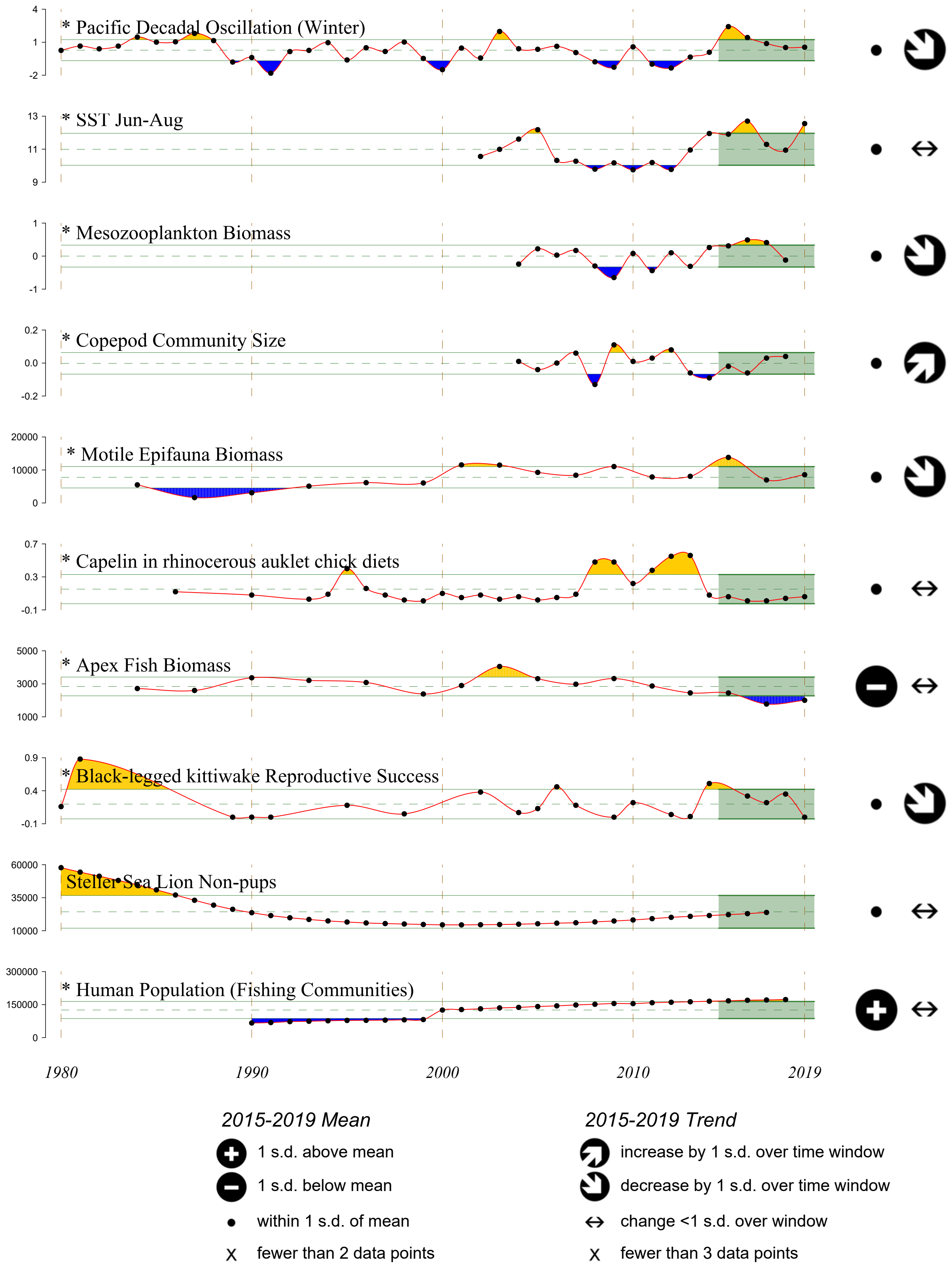

Figure 1: Western Gulf of Alaska report card indicators; see text for descriptions. * indicates time series updated in 2019

Eastern Gulf of Alaska 2019 Report Card

- There was a **weak-moderate El Niño last winter**. **Near-neutral El Niño expected for winter 2019–2020**.
- Total **zooplankton density in Icy Strait in 2019 was slightly below average** and represented a slight decline from 2017 and 2018. This suggests **about average foraging conditions for planktivorous fish, seabirds, and mammals** and an improvement relative to the below-average densities during 2013–2016.
- However, the **overall copepod community size remained low** due to below-average abundance of large copepods while small copepods were nearly average. This suggests below-average quality zooplankton prey, confirmed by **low lipid content in all measured zooplankton taxamonic groups**.
- Bottom trawl **survey biomass of motile epifauna remained well above the long-term mean in 2019** (2^{nd} highest over the time series). Brittle stars are the largest contributor to biomass in this guild and increased 9% from 2017. Other large increases in biomass from 2017 to 2019 were observed with hermit crabs (526%) and eelpouts (276%).
- 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 increased slightly (2%) from 2017 to 2019 but remains below the long-term mean**. Arrowtooth flounder are the dominant component of the biomass in this guild and increased 7% from 2017. Other groups contributing to the increase in guild biomass are sablefish, big skate, and Pacific cod.
- **Growth rates of piscivorous rhinoceros auklet chicks continue to be anomalously low, similar to the 2015–2016 heatwave years**, suggesting the adults were unable to find sufficent prey to support optimal chick growth. However, burrow residency indices (a proxy for reproductive success), suggests that there were some successful nesting attempts.
- Although Steller sea lion non-pups were counted in 2019, the data were not available in time for this report. Modelled estimates of eastern Gulf of Alaska **Steller sea lion non-pups counts were above the long term mean through 2017**. However, counts suggest that non-pup counts declined 12% in 2017 relative to 2015. This unusual 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 remained stable since 2000**, with minimal decadal changes. There were no significant population changes within large communities between 2010 and 2018.

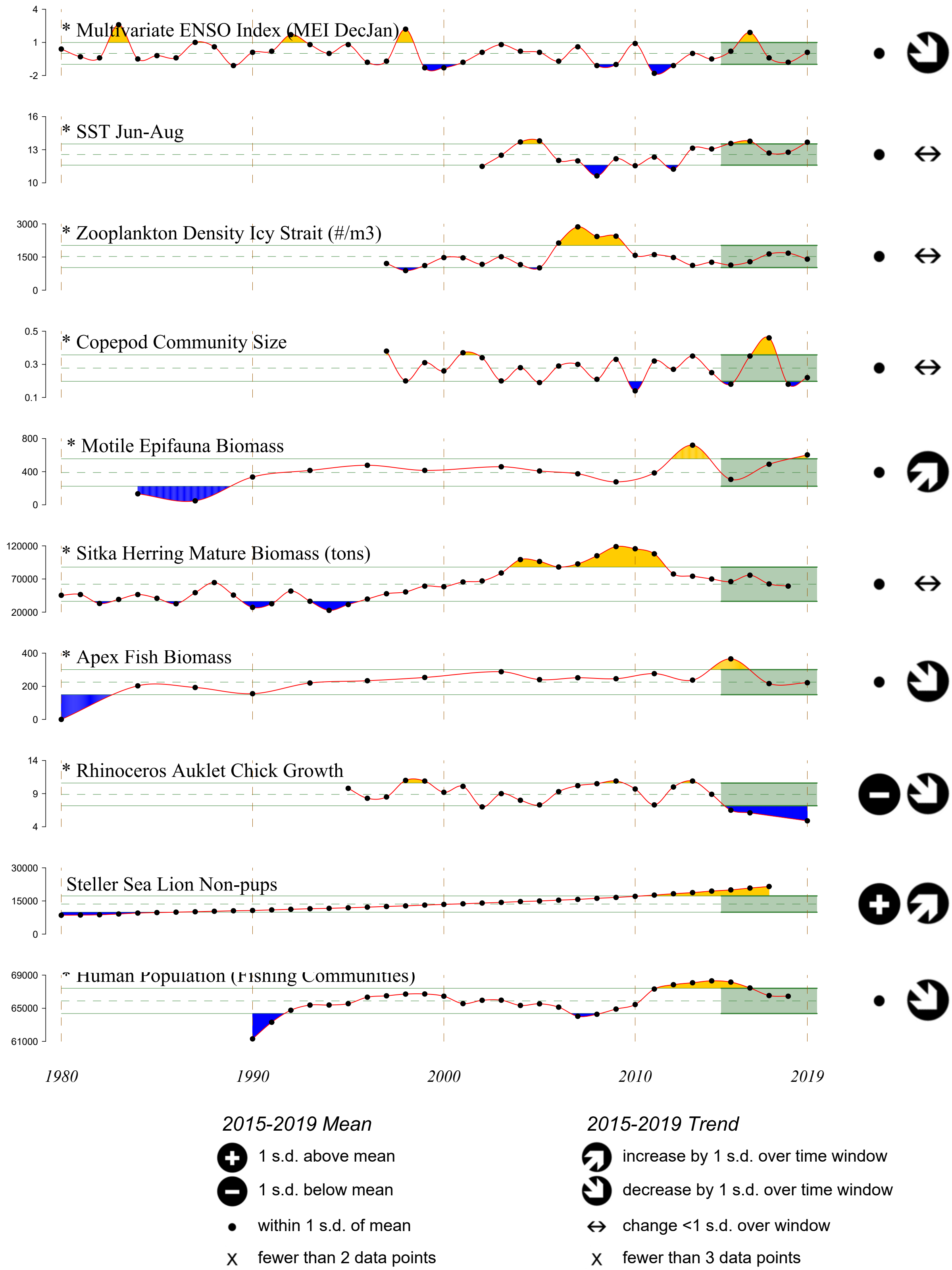

Figure 2: Eastern Gulf of Alaska report card indicators; see text for descriptions. * indicates time series updated in 2019.

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, several zooplankton indicators are available for the western GOA, while the only comparable indicators in the eastern GOA sample inside waters (Icy Strait). The report card indicators are described at the end of the Ecosystem Indicators section of this ESR. We will continue to revise and update these indicators in future editions of this report.

Complete Recap of the 2018 Ecosystem State

Some ecosystem indicators are updated to the current year (2019), while others can only be updated to the previous year (or earlier) due to the nature of the data collected, sample processing, or 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 2018 that includes information from both previous and current indicators. The next section (Current conditions: 2019) provides separate summaries of the 2019 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.

2018 marked the last year of a 2-year stretch of generally more "typical" conditions in the GOA following the 2014–2016 marine heatwave and before warm conditions returned in 2019 (see next section). Here we review our set of indicators for 2018 and attempt to distinguish which ecosystem components continued to show signs of lagged effects of the heatwave versus those that were more responsive to the generally cooler conditions.

The North Pacific atmosphere-ocean system in 2018 was similar to that of 2017, as seen in the continuation of largely average conditions in the western GOA 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 sea surface temperatures across the North Pacific. Across the GOA, 2018 sea surface temperatures were largely average with some warming during the spring and summer. At a local scale, 2018 sea temperatures within the top 100m along the Seward Line showed average to slightly cooler than average temperatures during May. However, in Auke Creek near Juneau, freshwater temperatures during summer 2018 were the warmest since 1980. Surface currents during winter 2017/2018 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 than in years with strong eddy activity. By late September 2018, temperatures within the western GOA shelf area crossed a threshold to be considered a heatwave. Climate models had forecast anomalously warm sea surface temperatures throughout winter 2017/2018 in the GOA; while the signs of the anomalies proved to be correct, actual temperatures exceeded the forecast.

During 2017–2018, phytoplankton blooms appeared to be earlier and with higher concentrations overall relative to the previous warm years. Satellite-derived chlorphyll estimates indicated that the spring phytoplankton bloom occurred early, in April, during 2017 and 2018, particularly in the western GOA. This differed from 2012–2014, when the peak occurred later, in May. Chlorophyll concentrations were high in 2017 and exceptionally high in 2018. The continuous plankton recorded showed higher diatom abundances overall in 2017, and to a lesser extent in 2018, and confirmed an earlier bloom in 2018. These patterns suggest increased availability of food for phytoplankton consumers such as zooplankton and larval fish.

Indicators of zooplankton abundance for 2018 showed mixed signals. The biomass of large copepods during May 2018 along the Seward line was above average and similar to that during 2015–2017. While this was the fourth spring of abundant copepods, it was the first for euphausiids since 2014, potentially indicating an increase in higher quality zooplankton prey for predators during spring. However, higher abundance of large copepods during spring can also reflect faster growth during warmer temperatures, not necessarily higher abundance for predators. In contrast, the decline in zooplankton biomass seen in the CPR in 2018, after the higher biomasses observed from 2014–2017, was mostly due to a drop in the numbers of small copepods, which had been numerous during the warm years. Zooplankton sampled in Icy Strait in 2018 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, the community consisted primarily of small calanoid copepods. Densities of larger zooplankton, which are prey items for small fish, were below average in 2018.

Another indicator of zooplankton availability to predators in 2018 is the reproductive success of planktivorous seabirds. Parakeet auklets had poor reproductive success in the Semidi Islands south of the Alaska Peninsula, where they feed mostly on euphausiids. This is notable because these auklets 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 early fall 2018, euphausiid biomass was among the highest in the Seward Line time series during September sampling, likely due to the cooler spring temperatures and indicating that euphausiid prey continued to be abundant over summer. If this represented a true record abundance of euphausiids in late summer, the 2018 year-class of pollock may have benefited from this high-quality forage going into winter.

With respect to forage fish, seabird-derived indicators suggested increases in abundance relative to the heatwave years. In 2018, piscivorous seabirds had above average reproductive success at the Semidi Islands, indicating that there were sufficient forage fish prey (possibly including age-0 gadids) to raise chicks. Kittiwakes and rhinoceros auklet chick diets at Middleton Island in 2018 showed notable increases in sand lance, an important forage fish, but few capelin, which disappeared from chick diets during the heatwave. In contrast, based on reproductive success, prey appeared to be limiting for the surface-foraging kittiwakes in 2018, 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. Given that the 2018 year-class of pollock appears to be strong as age-1s, we may assume that there were numerous age-0 pollock to support the seabird reproductive trends observed, particularly in the western GOA. Also, one may speculate that the reduced stock sizes of large piscivorous groundfish (e.g, Pacific cod and arrowtooth flounder) and cooler temperatures, which modulated their energetic demands relative to the heat wave years, may have decreased natural mortality on forage fish, leaving more for the seabirds.

Indicators suggest poor conditions for salmon survival in the Gulf of Alaska during 2017 and 2018. Juvenile chum, coho and pink salmon captured during the summer surface trawl surveys in Icy Strait were in low numbers and had small body sizes. Abundances in 2018 increased for juvenile Chinook salmon (2nd highest) and sockeye salmon (but still low) since 1997 for the 22-year time series, although sockeye body sizes remained low. 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 showed low adult returns and poor freshwater and marine survival of pink and coho 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 to Auke Creek as adults in 2018 had the second lowest marine survival for the weir since 1980. The 2018 outmigrating smolts experienced warm creek temperatures and low water depths due to lack of snowfall and snowmelt. Pink salmon had low marine survival, and adult returns were the lowest in 2018 since 1980.

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 in 2018 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 2017 was primarily due to increases in the pollock and arrowtooth flounder catch relative to 2017. Overall, and including the observations and assessments based on the 2017 bottom trawl surveys, large piscivorous groundfish such as Pacific cod and arrowtooth flounder (but not sablefish which are longer-lived and inhabit deeper depths) remain at low stock sizes relative to before the heatwave.

Marine birds and mammals appear to continue to show signs of negative impacts from the marine heatwave. The numbers of piscivorous murres breeding in the Semedis in 2018 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. 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 since 2015. In Glacier Bay, crude birth rates—number of calves per adult whale sighted—remained anomalously low from 2016–2018. During whale 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 survey window (June–August). Some whales had 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 changes in whale prey availability and/or quality, which may be negatively affecting maternal body condition and therefore reproductive success and/or overall juvenile survival.

Current Environmental State—Western Gulf of Alaska

The dominant physical signature of 2019 was the return to warm conditions following the largely average temperatures in 2017–2018. The western GOA shelf area sea surface temperatures remained largely above the 90% threshold over consecutive 5-day periods to qualify as a heatwave (see p.27). This was particularly the case during the summer, when the cumulative intensity (°C days) exceeded that of summer 2015. Despite that, the cumulative intensity for the entire year was very similar between 2015 and 2019. The winter of 2018/2019 was not as warm as those of 2014/2015 and 2015/2016, which may have modulated the negative impacts on the ecosystem relative to those previous heatwave winters, which had extensive impacts on populations of piscivorous predators such as Pacific cod and murres.

Several surveys confirmed that the warm waters at the surface during summer 2019 extended to depth. The thermal profile measured during the biennial bottom trawl survey suggests that water temperatures in 2019 may have been as warm or warmer than those observed in 2015 and 2017, particularly near the surface in the western Gulf of Alaska. Bottom temperatures observed during the biennial larval fish surveys were higher in summer 2019 relative to 2015. It is important to note that neither of these surveys took place during summer 2016, which we believe was the warmest of the 2014–2016 heatwave. The annual temperature profile of the top 100 m from the Seward Line indicates that temperatures during spring (May) 2019, while warmer than average, were not as warm as those from 2015 or 2016; summer temperature profiles were not available.

Chlorophyll concentrations during 2019 in the GOA indicated: (1) a late phytoplankton bloom that did not show up until June, and (2) low early season biomass, which could possibly affect phytoplankton consumers such as zooplankton and some larval fish populations, depending on their timing and location. Indeed, zooplantkon indicators suggested that only moderate to low abundances were available to predators. During May 2019, both large calanoid copepod and euphausiid biomasses were below average on the Seward Line. During the summer acoustic survey, euphausiid biomass was estimated to be slightly below average in this 7-year time series. Planktivorous parakeet auklets nesting at the Semedi Islands had above average reproductive success, suggesting that there were sufficient euphausiid or larval fish prey available to successfully rear chicks. However, planktivorous fork-tailed storm petrels nesting at the Barren Islands at the mouth of the Cook Inlet did not fare well reproductively, so zooplankton may not have been as available to them in that area. Also, record abundances of jellyfish were caught during the bottom trawl survey, across all regions. As jellyfish such as *Chrysaora melanaster* feed on zooplankton and small fish, high numbers could represent significant additional predation pressure on their prey.

Larval fish surveys during spring found few to no age-0 gadids, and their near-absence was confirmed during surveys at the end of summer. No age-0 pollock were found to the south and east of Kodiak Island, or near the Shumagin Islands in the southwest. The majority of fish found were in Shelikof Strait and near the Semedi Islands. Interestingly, black-legged kittiwakes, which have a mixed fish/invertebrate diet, failed reproductively at the Semedi Islands during the chick-rearing stage. The timing of failure suggests that they arrived in good condition in early summer but failed to find sufficient prey for their chicks. Kittiwakes are known to feed on age-1 pollock through late winter and early spring, when they become too big for kittiwakes to eat. It's reasonable to assume that kittiwakes had sufficient prey available to them at the surface prior to the breeding season, including age-1 pollock, but then suffered from the lack of age-0 pollock during the chick-rearing stage, when they had to abandon chicks. Surveys confirm that there appear to be abundant age-1 pollock (the 2018 year class). While the diving, piscivorous seabirds at the Semedi Islands did well reproductively, anecdotal data suggest that these birds were bringing in more diverse prey than the typical sand lance and age-0 gadids (pers. comm H. Renner). On Middleton Island, the occurrence of herring and other coastal species in seabird diets possibly reflect more use of nearshore/inner shelf habitat because of reduced availability of their offshore primary prey such as capelin. In fact, GPS-tracking of foraging seabirds conducted during chick-rearing revealed that birds from Middleton Island were commuting a considerable distance (~80 km one-way) and foraging principally in nearshore waters. Overall, these patterns suggest that forage fish were not abundant in 2019.

Groundfish condition, as measured by length-weight residuals, was once again below average for all groundfish in the bottom trawl survey except for Pacific cod. This was the same overall pattern that was seen during the last survey in 2017, and indicates that foraging conditions were not sufficient for optimal growth for most species of groundfish. However, when fish condition is analyzed at finer spatial scales, a few patterns are discernible. There appeared to be an east-to-west trend in condition with heavy age-2+ pollock and southern rock sole per length in the eastern areas of the GOA relative to the western areas. While the survey is prosecuted in a west-to-east direction, and pollock typically put on weight during the summer, this spatial pattern in condition is not persistent across years. The pattern in 2019 is not likely to be due solely to sampling error, but may reflect regional differences in foraging landscapes, with pollock in the western GOA experiencing more limitations in prey than those in the east. Further supporting evidence of below average foraging conditions is the negative anomalies in condition of Pacific Ocean perch, which have similarly planktivorous diets to pollock. Pacific cod biomass is currently at an extremely low level. Little density-dependent competitive effects in combination with their large growth potential may have enabled cod to build up their weight.

Seabirds and marine mammals continue to show lagged effects of the 2014–2016 heatwave. While the generally high reproductive success of murres indicated favorable foraging conditions in 2019, the numbers of birds on breeding cliffs at the Semedi Islands was still only a little more than half the number that was counted, on average, in years before the 2014–2016 heatwave, and specifically before the die-off in 2015/2016, which was estimated to comprise approximately 1 million individuals (Piatt et al., in review). While murres may defer breeding in some years, likely due to poor foraging conditions, the continuation of low numbers at colonies may indicate population-level impacts of the 2015/2016 murre die-off. More humpback whales were observed during September 2019 in Prince William Sound than had been observed in 2017 and 2018; however, they remain well below 2008–2014 numbers. One positive note is that unlike in 2017 and 2018, no whales in poor body condition were observed. There was a large unusual mortality event that included 48 dead grey whales found within Alaska waters, 19 of which were in the western GOA. Given that benthic prey (primarily ampelecid amphipods) in the Bering, Chukchi, and Beaufort Seas are considered the mainstay of gray whale foraging, it is reasonable to assume that the mortalities located in the GOA are linked to the extreme changes in their foraging grounds to the north (see EBS ESR).

Current Environmental State—Eastern Gulf of Alaska

Here we highlight those trends that are specific to the eastern GOA. However, separating an assessment of the current state of the eastern GOA ecosystem highlights the limited data relative to the western GOA. Data-limitations are highlighted further when we distinguish current indicators for inside waters from offshore waters.

Sea surface temperatures during summer 2019 in the eastern GOA, while not as warm as in the western GOA, were also elevated and similar to those during summer 2016. Warm temperatures were also recorded in inside waters in southeast Alaska. Inside waters, while not as warm as the outside waters, were similar to those in 2015 and 2016 overall. This pattern was confirmed by direct sampling in Icy Strait, where surface temperatures were warmer than those in 2015 and very similar to those in 2016.

In contrast to the western GOA, phytoplankton bloom timing was only slightly late (May), and chlorophyll concentrations were nearly average. Zooplankton density in Icy Strait dropped in 2019 relative to 2018, and lipid content was also low. However, planktivorous storm-petrels nesting on St. Lazaria Island had high reproductive success, suggesting that zooplankton prey were abundant in offshore waters. This is further supported by the positive anomalies in pollock condition in this region. The contrast among zooplankton indicators may reflect differences in zooplankton abundance in inside waters compared with outside waters. However, it is difficult to draw conclusions from such few indicators.

The lack of forage fish indicators for the eastern GOA limit assessments about their condition or abundance. Gulls and murres nesting at St Lazaria Island had very successful reproduction in 2019; as both are primarily forage fish eaters, this suggests that there were sufficient prey to support chick-rearing in offshore waters. In contrast, juvenile salmon catch rates in Icy Strait were among the lowest since the survey began in 1997, although their average length increased relative to 2017–2018. Adult pink salmon returns and marine survival rates at Auke Creek were very low, despite being an odd-year brood.

Humpback whale calving and juvenile return rates in Glacier Bay remained low in 2019, and mothers appeared to be in suboptimal condition, suggesting poor foraging conditions and continuation of negative impacts of the 2014–2016 heatwave. While only 3 of the 48 dead gray whales found throughout the state were found in the eastern GOA, this is not likely an indication of better foraging conditions relative to other Alaskan areas, but simply the lagged negative impacts of their foraging landscape in the Northern Bering Chukchi seas in 2018.

Executive Summary of Recent Trends in the Gulf of Alaska

This section summarizes highlights of those indicators that show noteworthy status or trends. 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

- Fall 2018 through summer 2019 included a range of atmospheric circulation patterns and generally warmer than normal temperatures for the North Pacific (p. 35).
- The climate models used for seasonal weather predictions are forecasting ENSO-neutral conditions for the winter of 2019–2020, and warmer than normal SSTs through early 2020 (p. 41).

Gulf of Alaska

- Sea level pressure patterns over the Gulf of Alaska resulted in suppressed storminess and contributed to the development of very warm sea surface temperatures (p. 36).
- The western Gulf of Alaska shelf area has largely remained in heatwave conditions since September 2018 (p. 27).
- Satellite-derived sea surface temperatures confirmed that the moderate temperatures of 2017–2018 ended during fall 2018 and that both the western and eastern Gulf of Alaska have been warm since (p. 48).
- The thermal profile suggests that water temperatures in 2019 may have been as warm or warmer than those observed in 2015 and 2017, particularly near the surface in the western Gulf of Alaska (p. 49).
- Bottom temperatures recorded during the summer larval fish surveys were higher in summer of 2019 relative to 2015 (p. 55).
- Ocean temperatures along the Seward Line were well above normal during May 2019, with increased stratification (p. 59).
- After returning to near-average temperatures in late 2017–early 2018, temperatures in Prince William Sound during 2019 again shifted towards strongly above average, with magnitudes exceeding those observed during the 2014–2016 heat wave (p. 62).

Ecosystem Trends

- Chlorophyll concentrations during 2019 in the GOA saw a late bloom overall, with low early season biomass, which could possibly affect some larval fish populations depending on their spawn timing and location (p. 73).
- In the Alaskan Shelf region sampled by the continuous plankton recorder, zooplankton biomass anomalies were negative, ending the run of positive values that had occurred from 2014–2017 (p. 74).
- Acoustic estimates of euphausiid biomass in 2019 increased slightly from the previous low estimate in 2017 (p. 81).
- Along the Seward Line, large calanoid copepod biomass in May 2019 was substantially lower than it was in 2015–2018. Euphausiid biomass during May 2019 was also below average, while biomass during September 2019 was among the highest in the time series (p. 83).
- In Icy Strait, the 2019 total density and lipid content of zooplankton were below 2018 values (p. 88 and 91).
- The 2019 relative catch per unit effort of jellyfish during the NOAA bottom trawl surveys was the highest ever observed during the survey time series (p. 92).
- Over the years, small numbers of market squid have been sporadically observed at Little Port Walter in Southeast Alaska. Sizable schools and spawning events occurred for the first time in 2015 and were observed again in 2016, 2018, and 2019 (p. 31).
- In 2019, the abundance of all assessed larval fishes within the main grid area of the spring larval survey was below average and low relative to 2017 (p. 97).
- Catches of age-0 pollock during late summer surface trawl surveys were second lowest on record, with the majority of fish found in Shelikof Strait and near the Semidis. No age-0 pollock were found at the majority of stations to the south and east of Kodiak as well as near the Shumagin Islands in the southwest (p. 102).
- In nearshore waters of Icy Strait in northern southeast Alaska during 2019, juvenile and adult salmon catch rates were among the lowest since the survey began in 1997 (p. 117).
- In 2019, groundfish condition sampled during the NOAA bottom trawl survey was below the time-series average for all species except Pacific cod. Northern and dusky rockfish had the lowest condition on record, and for Pacific Ocean perch was the second lowest on record (p. 126).
- Diving, fish-eating seabirds in the Gulf of Alaska had generally high reproductive success (and some highest on record) at monitored colonies in 2019, the exception was poor productivity for murres at East Amatuli (Barren Islands). Kittiwakes experienced complete breeding failure at Chowiet (Semedi Islands) but had a normal year at East Amatuli (Barren Islands). Storm-petrels had poor breeding success at East Amatuli but had higher than average breeding success at St. Lazaria (southeast Alaska)(p. 139).
- An unusual mortality event was declared for gray whales in May 2019. Between January 1–October 30, there were 48 strandings in Alaska and 213 total along the west coast between Mexico and Alaska (p. 30).
- Humpback whale calving and juvenile return rates in Glacier Bay and Icy Strait declined substantially beginning in 2015. Crude birth rates have remained anomalously low from 2016–2019 (p. 144).
- During September of 2019 in Prince William Sound more humpback whales were observed than in 2017 and 2018; however they remain well below 2008–2014 numbers. Unlike 2017 and 2018, no whales in poor body condition were observed (p. 143).

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. Discard biomass in the fixed gear (hook-and-line and pot) sector has generally declined from 2013 onward, though discard rates increased sharply in 2018 to 18% after remaining around 10% from 2013 to 2017 (p. 156).
- In 2017–2018, 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. 160).
- Stock composition of Chinook salmon bycatch in Gulf of Alaska trawl fisheries was relatively stable from 2010–2017, 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. 162).
- The numbers of seabirds estimated to be caught incidentally in Gulf of Alaska fisheries in 2018 increased from that in 2017 by 19%, and was above the 2007–2017 average of 655 birds, primarily due to increases in black-footed albatross, northern fulmar, and gulls (p. 164).
- 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. 175).
- Landings in the Gulf of Alaska remained stable through 2018. Landings are primarily composed of salmon, pelagic foragers, and apex predators. Pacific cod landings decreased in 2017 as a result of low abundance, and the TAC was substantially reduced in 2018 to conserve the stock (p. 180).
- Ex-vessel revenues have remained fairly stable over time but have been lower since 2003 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. In 2018, cod value decreased substantially with conservation-based reduction in the TAC (p. 182).
- As of 2018, the unemployment rate in the western GOA was 11.9% and in the eastern GOA was 5.97%, which are both higher than the national rate of 3.9% (p. 186).
- The total population of the western GOA (excluding Anchorage) has steadily increased since 2010. Small community populations decreased by 21.47% between 2010 and 2018, and larger communities increased by 5.86%. The total population of the eastern GOA has remained stable since 2000, with m no significant population changes within large communities between 2010 and 2018 (p. 189).
- As of 2019, there are three schools in the western GOA with enrollments under 10 students facing possible closure (p. 198).
- In eastern GOA municipalities with school enrollment between 100 to 500 students, enrollment appears to be steadying since 2016. Larger districts such as Sitka and Ketchikan have the lowest graduation rates (both remaining under 60%) for the 2015–2017 cohorts, consistently placing in the lower 1/3 of school districts analyzed (p. 198).

Contents

† indicates new contribution

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Introduction

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

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

The purpose of the first section, the Report Card(s), is to summarize the status of the top indicators selected by teams of ecosystem experts to best represent each ecosystem. Time series of indicators are presented in figures formatted similarly to enable comparisons across indicators. Recent trends in climate and the physical environment, ecosystems, and fishing and fisheries are highlighted in 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 adopted by the Council in December 2018. 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 communicate clearly the current status and possible future directions of ecosystems. In 2017 we expanded the Fishing and Human Dimensions section to reflect more broadly aspects of our role in the ecosystem. In doing so, we organized this new section around a proposed set of ecosystem-scale objectives derived from U.S. legislation and current management practices.

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

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

[1]The Arctic report is under development

1. Maintain, rebuild, and restore fish stocks at levels sufficient to protect, maintain, and restore food web structure and function;
2. Protect, restore, and maintain the ecological processes, trophic levels, diversity, and overall productive capacity of the system;
3. Conserve habitats for fish and other wildlife;
4. Provide for subsistence, commercial, recreational, and non-consumptive uses of the marine environment;
5. Avoid irreversible or long-term adverse effects on fishery resources and the marine environment; and
6. Provide a legacy of healthy ecosystems for future generations.

Ecosystem Indicators

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 2018–2019 marine heatwave

As of 1 November 2019, the western Gulf of Alaska shelf area largely remained in marine heatwave conditions from late September 2018 through mid-October 2019 (Figure 3). This implies that for most of the 2018/2019 winter and to an even greater extent during summer 2019 (Figure 4), temperatures have remained above the 90% threshold as defined by Hobday et al. (2016). While overall cumulative intensities (°C days) were similar for 2015 and 2019, a greater proportion of the heatwave took place during summer in 2019 relative to 2015. Summer 2019 temperatures were higher than those of 2016, but the anomalies were higher in 2016 because the highest temperatures were on days which are not on average the warmest days (Figure 5). The current heatwave dropped below the threshold on 12 October 2019 likely due to strong storms in early October that enhanced surface mixing. However, the threshold was exceeded again on 4 November. Also, SST forecast models are predicting the continuation of warmer than normal temperatures in the NE Pacific (see p.41). Together, these suggest that heatwave conditions may persist through the winter 2019/2020. Full impacts of this heatwave to the ecosystem are currently unknown, but will likely depend on whether it continues and if so, its extent and duration.

Methods The daily sea surface temperatures for 1981 through October 2019 were retrieved from the NOAA High-resolution Blended Analysis Data database (NOAA 2017) and filtered to include only 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 heatwave 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 for the dates involved. 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.

Contributed by Steve Barbeaux and Stephani Zador

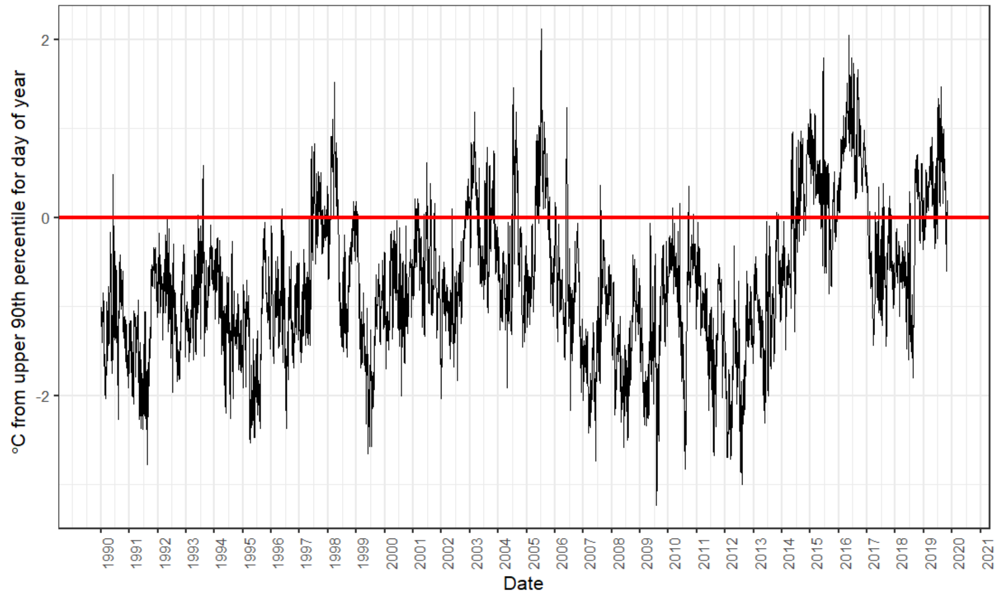


Figure 3: Gulf of Alaska temperatures with heatwave threshold (red line) as defined by Hobday et al. (2016). Temperatures are standardized to remove season signals. Time series updated 5 November 2019.

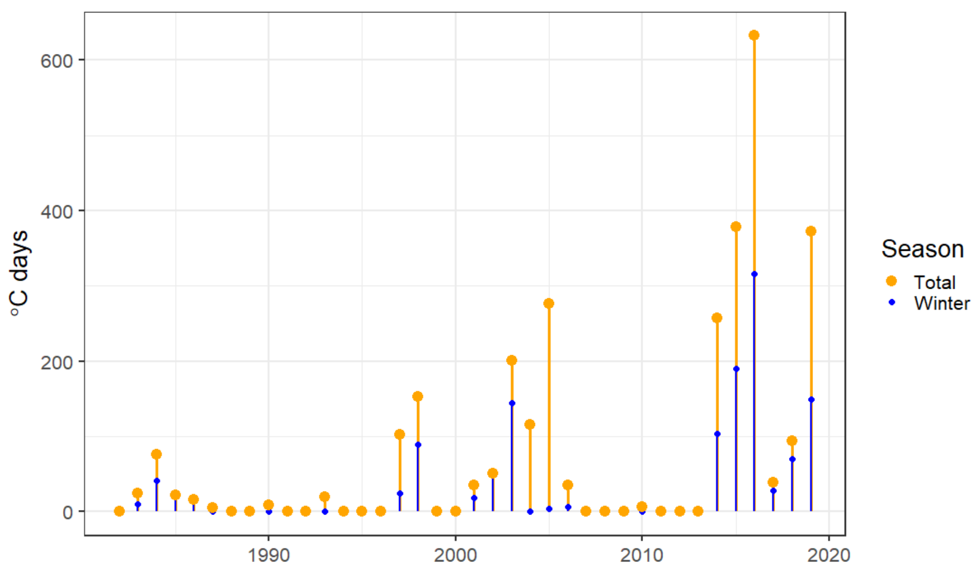


Figure 4: Index of the sum of the annual marine heatwave cumulative intensity (°C days) for 1981–2019 (larger red points) and index of the sum of the annual winter marine heatwave cumulative intensity for 1981–2019 (smaller blue points) from the daily mean sea surface temperatures NOAA high resolution blended analysis data for the Central Gulf of Alaska. The 2019 index value is the sum through 5 November 2019.

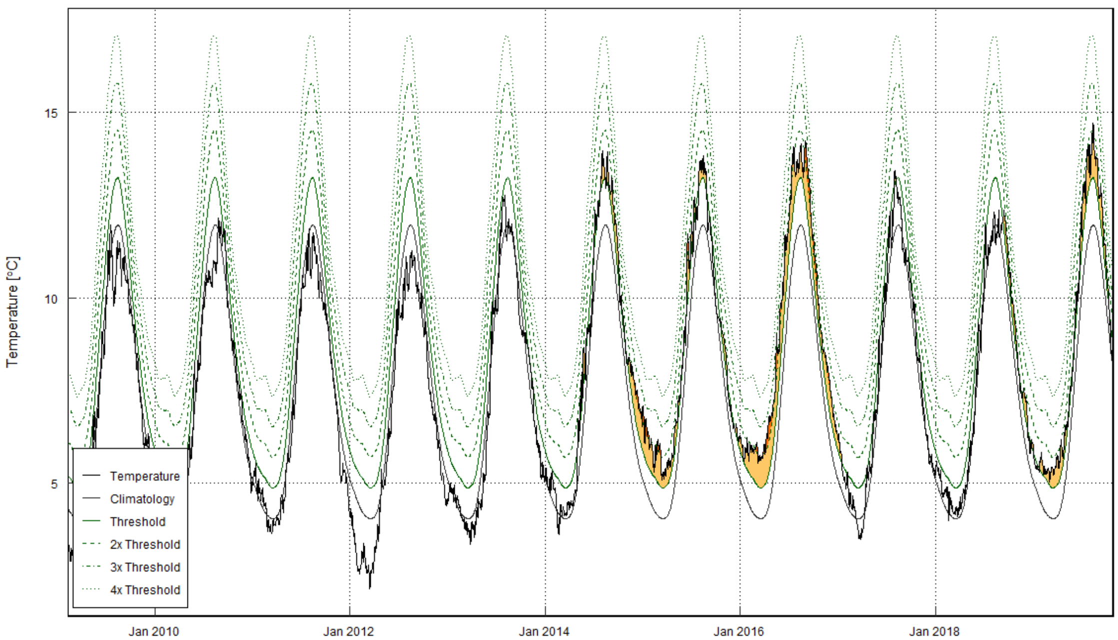


Figure 5: Gulf of Alaska temperatures with heatwave thresholds as defined by Hobday et al. (2016). Time series updated 1 November 2019.

Unusual Mortality Event: Gray Whales

Since January of 2019, elevated numbers of eastern North Pacific gray whale (*Eschrichtius robustus*) mortalities have occurred along the west coast of North America, stretching from Mexico to Alaska. In May of 2019, the increased strandings were declared an Unusual Mortality Event (UME) (Table 1, Figure 6).

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

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

Gray whale life history includes an annual round-trip migration of up to 20,000 km. The mortalities started off the western coast of the southern Baja California Peninsula where gray whales over-winter to mate and calve. Mortalities followed the late winter/spring migration up to Alaskan waters where foraging occurs before the fasting return journey south. The first Alaskan gray whale stranding occurred on May 9th in Turnagain Arm of Cook Inlet. Mortalities have continued throughout the summer with hotspots around Kodiak Island, Bristol Bay, and coastal waters of the Bering Strait and Chukchi Sea (Figure 7).

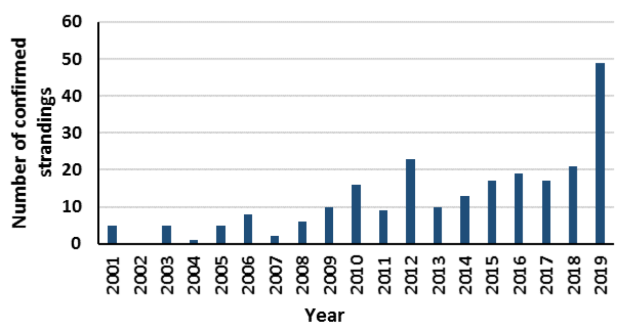


Figure 6: Number of gray whale strandings in Alaska by year, 2001–2019 (2019 numbers through October).

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

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

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

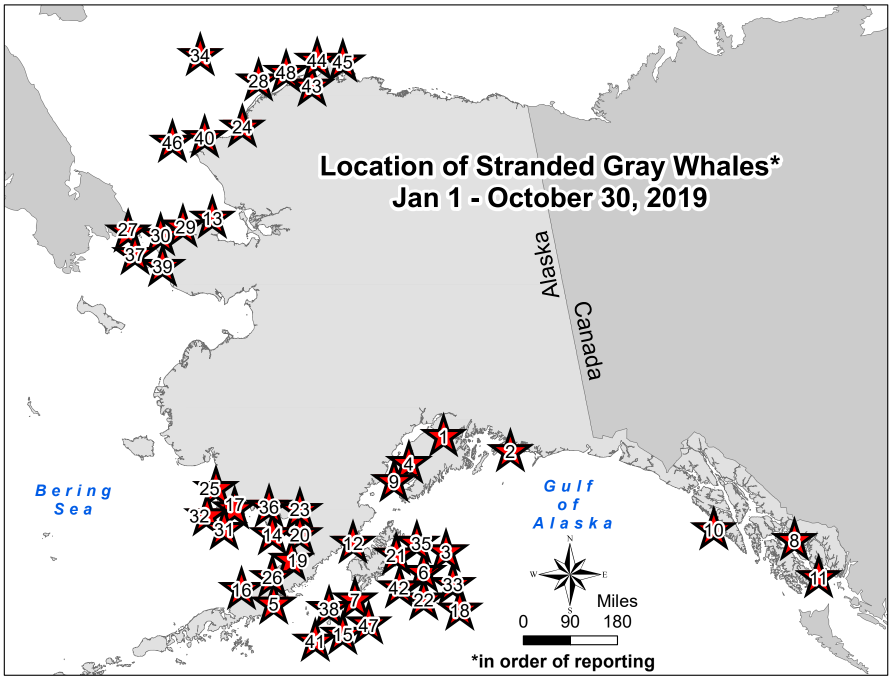


Figure 7: Locations of gray whale strandings in Alaska (NOAA/NMFS Alaska Region Marine Mammal Stranding Network unpublished data).

Contributed by Kate Savage, DVM
Protected Resources Division
NOAA Fisheries

Market Squid Spawning in Southeast Alaska

Market squid (*Doryteuthis opalescens*) are a small Myopsid squid (Figure 8) that typically inhabits nearshore waters along the Pacific coast of North America. They are an important commercial species, particularly in fisheries along the coast of California (Perretti et al., 2015) as well as an important prey species for many predators, including various fish, marine mammal, and seabirds. Although this species occurs from Baja California to southeast Alaska, it is most abundant from Baja to central California. Market squid historically spawn from Baja California to southern British Columbia. Water temperatures farther north were presumably too cold for spawning in the past.

Over the years, small numbers of market squid have been sporadically observed at Little Port Walter (Figure 8), a small fjord located on southern Baranof Island in southeast Alaska. Biologists at the Little Port Walter research station have been monitoring marine life and ocean conditions at the site since the 1930s. A notable

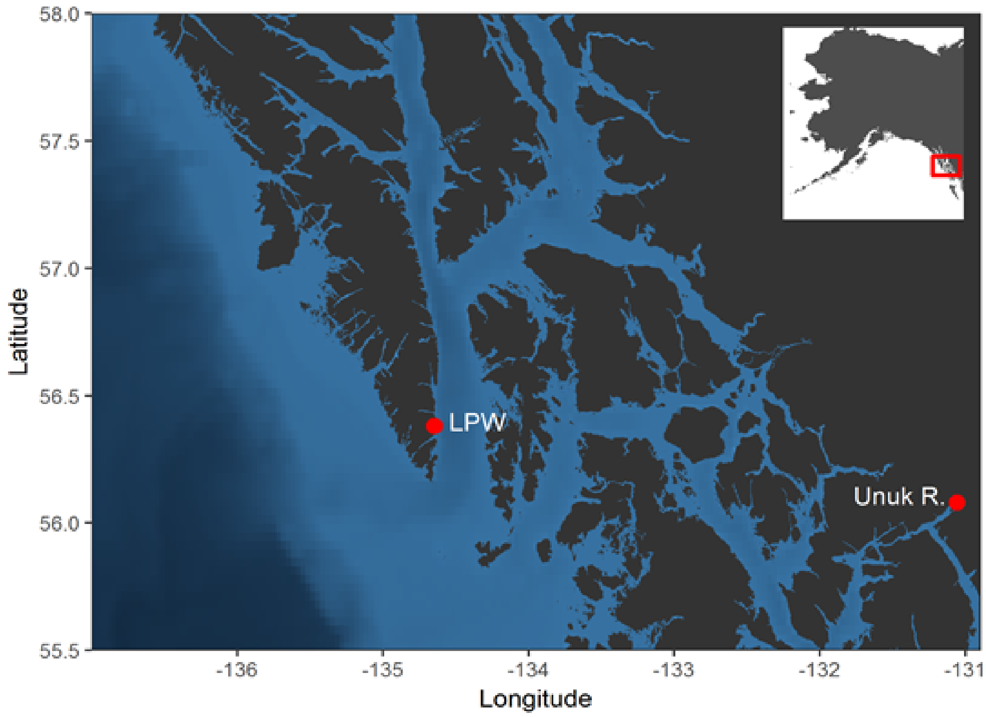


Figure 8: Map of Little Port Walter in southeast Alaska

change occurred in 2015 when hundreds of market squid were observed at the station. In addition to the increased number of individuals present, the squid were also spawning and laying eggs on mesh netting being used at the site (Figure 9). Sizable schools of market squid and subsequent spawning events occurred in 2016, 2018, and 2019. No squid were seen in the area during 2017.

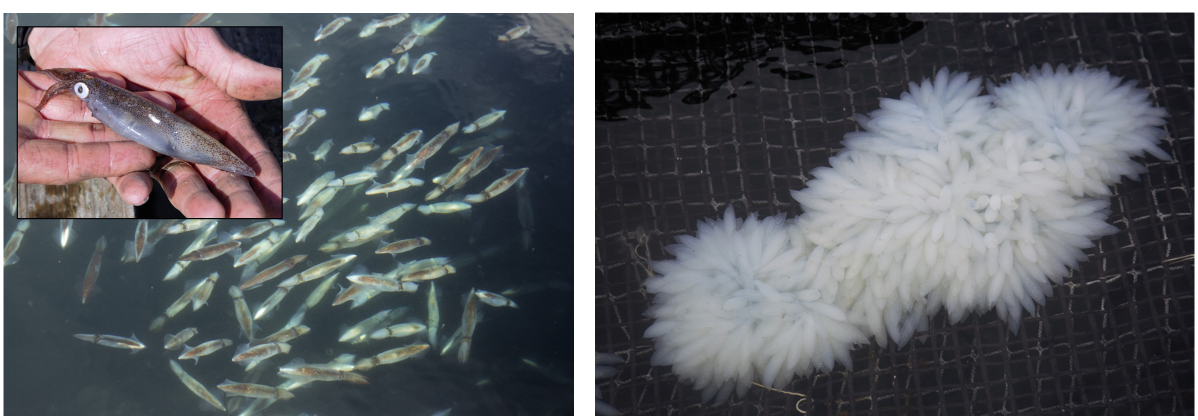


Figure 9: Market squid observed at the Little Port Walter research station (left panel) and market squid egg cases laid on netting at the station (right panel).

Contributed by John H. Eiler and Alexa L. Marinelli

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). The 2017 ESR identified the LEO Network as a potential platform for tracking these observations, and the authors were encouraged by the Council and SSC to continue exploring the utilization of this framework in future reports. Other citizen science efforts exist in Alaska, but to our knowledge these efforts are mostly project specific (e.g., bird spotting and identification) or community specific and do not provide sufficient breadth to cover the myriad of anomalous environmental observations relevant to the Council. While the LEO Network also suffers from this issue, it still appears to be the citizen science database with the most coverage across species and regions of the state.

The LEO Network was launched in 2012 by the Alaska Native Tribal Health Consortium (ANTHC) as a tool for local observers in the Arctic to share information about climate and other drivers of environmental change (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 10 shows the number of LEO Network observations from August 2, 2018 to August 14, 2019 in the Gulf of Alaska (GOA) with the frequency by category (dates were specified to include observations that were part of the ESR in 2018). These categories are based on analysis of the 110 total observations in 2018 and 2019 in the GOA and are not limited to the marine environment. The observations in Figure 11 were made in 30 total communities. Observations in 2018 were dominated by unusually large numbers of bear sightings and human interactions across Gulf of Alaska communities, which observers attributed to small salmon runs causing bears to change their behavior in search of food. In 2019, the observations were dominated by references to extreme weather events, especially the hot and dry summer across Southeast and Southcentral Alaska coupled with excessive haze from large wildfires in the Interior.

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

Contributed by Marysia Szymkowiak

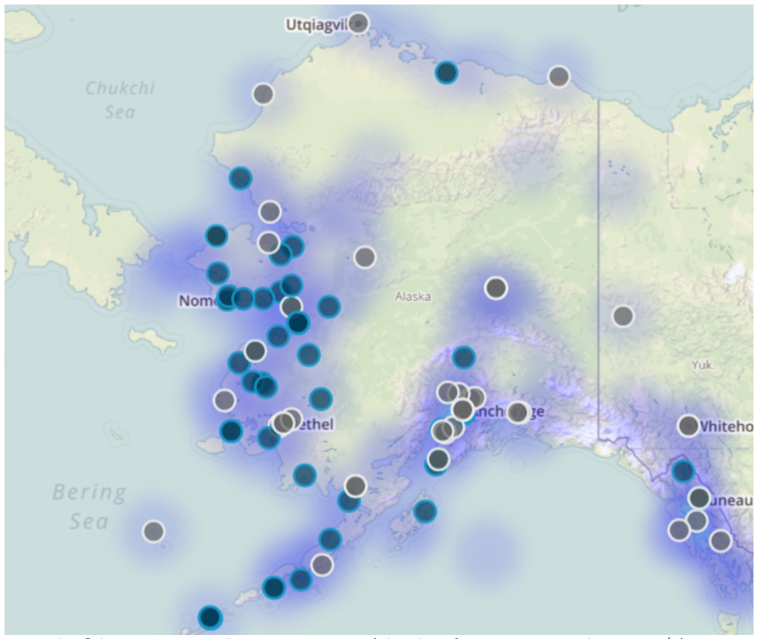


Figure 10: LEO Network Observation locations in Alaska for 2018 and 2019 (August to August) source: `https://www.leonetwork.org`

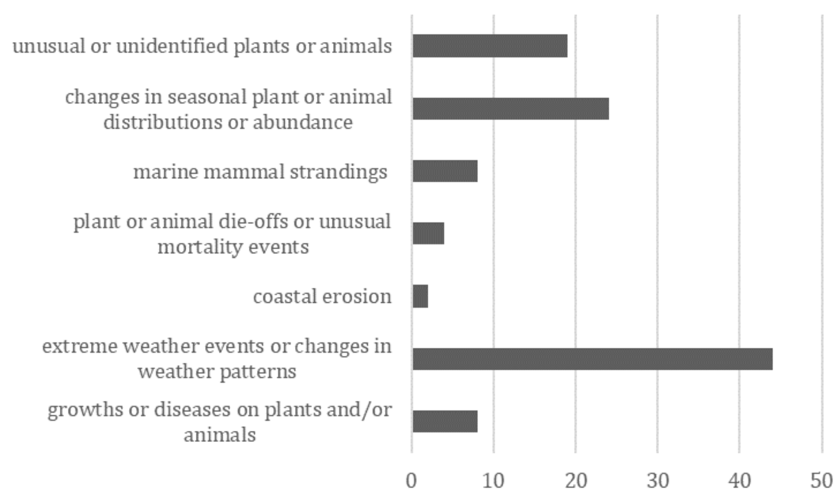


Figure 11: Numbers of LEO Network Observations in GOA communities, August 2018 through August 2019.

Ecosystem Status Indicators

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

Physical Environment

North Pacific Climate Overview

Contributed by Nick Bond (UW/JISAO), NOAA/PMEL, Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: nicholas.bond@noaa.gov
Last updated: August 2019

Summary: *The period of autumn 2018 through summer 2019 included a range of atmospheric circulation patterns and generally warmer than normal temperatures for the North Pacific. The winter of 2018-19 featured a weak Aleutian low (positive sea level pressure anomalies), which is unusual given the weak-moderate El Niño that was occurring at the same time. The sea surface temperature (SST) anomalies during 2018–2019 tended to be in the positive sense, with prominent warm anomalies in the Bering Sea, Gulf of Alaska, and by summer 2019, off the coast of the Pacific Northwest. The Pacific Decadal Oscillation (PDO) underwent a transition from near zero during autumn 2018 to +1 in the summer of 2019. The climate models used for seasonal weather predictions are indicating a 50–55% chance of neutral conditions in the equatorial Pacific, and a 30% chance of a weak-moderate El Niño, for the winter of 2019–2020. The consensus of the model projections is for a reduction in the magnitude of the SST anomalies in the middle to high latitudes of the North Pacific by early 2020.*

Regional Highlights:

Alaska Peninsula and Aleutian Islands. The weather of this region featured a tendency for a westward shift in the Pacific storm track into the western Bering Sea during the winter of 2018-19. The regional wind anomalies were from the south in an overall sense. Based on synthetic data from NOAA's Global Ocean Data Assimilation System (GODAS), the Alaska Stream appears to have been of typical strength on the south side of the eastern Aleutian Islands. It was generally stronger than that during the previous year of 2017–2018, but not as strong as indicated in 2015–2016. Based on the winds in the vicinity of Unimak Pass, it is assumed that the mass transport of Pacific water into the Bering Sea was of near-normal magnitude in 2018–2019.

Gulf of Alaska. The weather of the coastal GOA featured warmer than normal air temperatures from late fall 2018 through the winter of 2019. There was generally less precipitation than usual in the coastal watersheds of the eastern GOA from winter into summer 2019. The freshwater runoff in this region appears to have been somewhat suppressed during the spring into summer of 2019, with near-normal flows on the larger rivers and lower flows on the smaller streams. The GOA coastal wind anomalies were in a clockwise sense (upwelling-favorable) from late 2018 through summer 2019, especially along the southeast Alaska panhandle. The GOA winds are also reflected in the surface currents estimated with NOAA's Ocean Surface Current Simulator (OSCURS), which tended to indicate less northward, and more eastward, movements of water parcels originating at Station P at 50°N, 145°W. More on this subject is provided in the Ocean Surface Currents – PAPA Trajectory Index section (p. 45).

West Coast of Lower 48. This region experienced generally warm ocean temperatures (typically 0.5 to

1°C above normal) from late 2018 through spring 2019. The summer of 2019 featured the development of substantial anomalies (exceeding + 2°C) off the coast of the Pacific Northwest. Relatively warm water reached the coast at times, and tended to be accompanied by low surface chlorophyll concentrations. From a weather perspective, the winter of 2018–2019 had near normal temperatures for much of the western US. It included an above normal snowpack for the Sierra Nevada Mountains of California and the southern Cascade Mountains of Oregon; the snowpack in Washington state was not as healthy. As a result, there were abundant flows in the Sacramento/San Joaquin river system during spring 2019 and presumably good conditions for out-migrating salmon. On the other hand, the reduced snowpack in Washington state was followed by low and warm flows on many streams and rivers in the summer of 2019 and hence sub-par habitats for salmonids, especially returning adults. The coastal wind anomalies in the northern portion were more upwelling-favorable than usual in the late winter and early spring and downwelling-favorable in July of 2019, but otherwise were not too different from their seasonal norms in an overall sense. The large assemblages of pyrosomes in the coastal waters of the Pacific Northwest that were found in 2017 and 2018 were not observed in 2019. In this region herring appeared to be more abundant during the summer of 2019 than most recent years.

Sea Surface Temperature and Sea Level Pressure Anomalies

Contributed by Nick Bond (UW/JISAO), NOAA/PMEL, Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: nicholas.bond@noaa.gov
Last updated: September 2019

Description of indices: The state of the North Pacific climate from autumn 2018 through summer 2019 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981–2010. The SST data are from NOAA's Optimum Interpolation Sea Surface Temperature (OISST) analysis; the SLP data are from the NCEP/NCAR Reanalysis project. Both data sets are made available by NOAA's Earth System Research Laboratory (ESRL) at `http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl`.

Status and trends: During 2014–2016, the eastern portion of the North Pacific ocean experienced one of the most extreme marine heatwaves in the observational record (Scannell et al., 2016). While that event can be considered to have ended, most of the northern portions of the Pacific Ocean have tended to remain warm relative to their 1981–2010 climatological norms. More detail on the evolution of the SST and SLP from a seasonal perspective is provided directly below.

The SST during the autumn (Sep–Nov) of 2018 (Figure 12a) was warmer than normal across almost the entire Pacific Ocean north of 35°N. Greater positive (> 1°C) anomalies occurred in the Chukchi Sea and in the northern Bering Sea, resulting in a delayed onset of sea ice the following winter. Prominent positive SST anomalies were also observed in the central Gulf of Alaska (GOA). The SST anomalies were positive in the eastern equatorial Pacific in association with a weak Niño. The SLP pattern during autumn 2018 (Figure 13a) featured large positive anomalies over western Canada, with the ridging extending westward into the GOA. Lower than normal SLP was present over the central North Pacific with an anomaly center near 40°N and the dateline. This SLP distribution implies suppressed storminess for the GOA and helps explain the development of the relatively warm SSTs in that region.

The distribution of SST anomalies during winter (Dec–Feb) of 2018–2019 (Figure 12b) resembled those of the previous fall season, with some moderation of the magnitude of the positive anomalies in the north, particularly in the Bering Sea and GOA. The equatorial Pacific was characterized by very little change, with SST anomalies barely exceeding +1°C near the dateline and 120 to 100°W signifying a weak/moderate El Niño. A highly unusual atmospheric circulation pattern for the North Pacific accompanied this manifestation of El Niño as illustrated by the anomalous SLP pattern for winter 2018-19 shown in Figure 13b. El Niño generally results in a relatively strong Aleutian low that is displaced to the southeast of its mean position. Virtually the opposite happened, signified by the much higher than normal SLP for a broad region extending from 30°N west of the dateline to southern mainland Alaska. This anomalous ridging in combination with negative SLP anomalies over the Kamchatka Peninsula and western Bering Sea resulted in a pressure pattern that supported extremely strong wind anomalies ($\sim$ 3 to 4 m s^{-1}) from the south across the central and eastern Bering Sea for the second winter in a row. The magnitudes of these seasonal anomalies are particularly remarkable considering that an interval of strong winds from the north occurred in the Bering Sea during the latter half of December 2018.

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

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

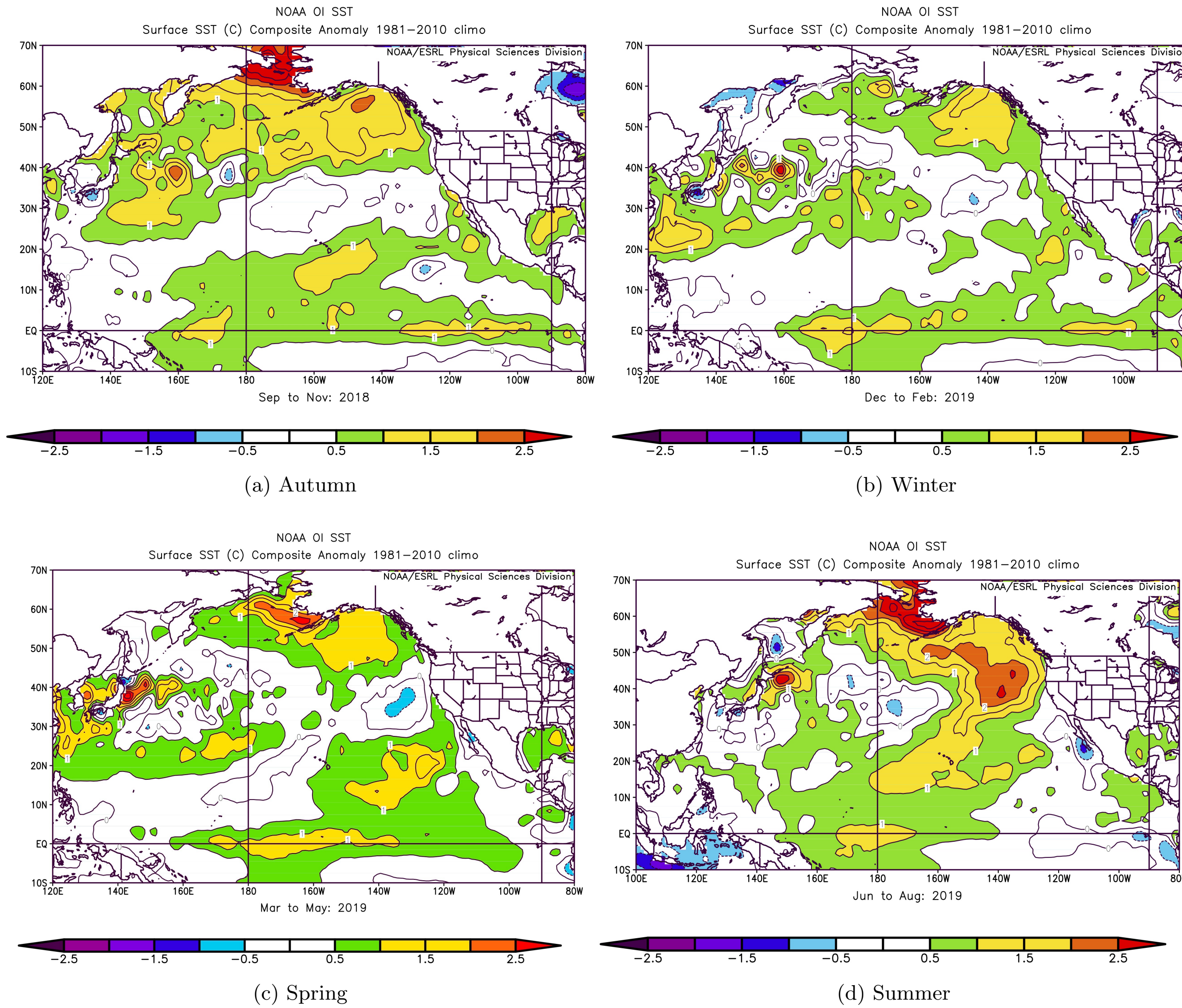
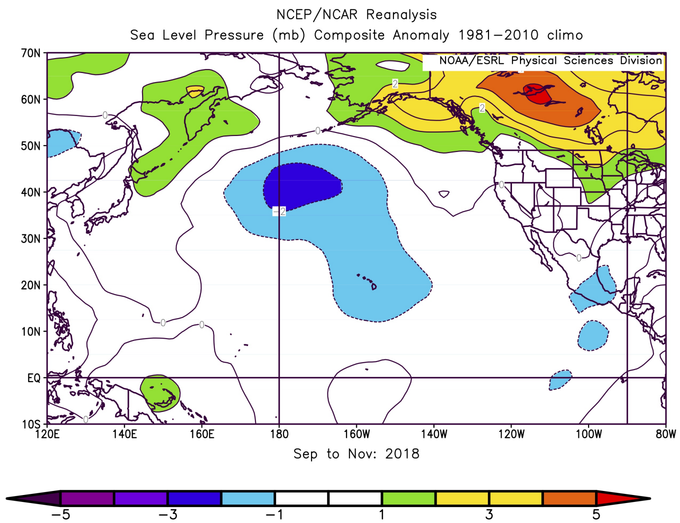
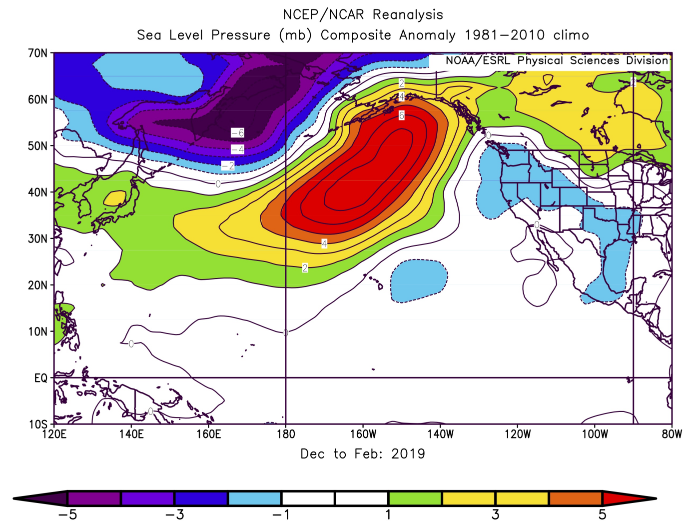


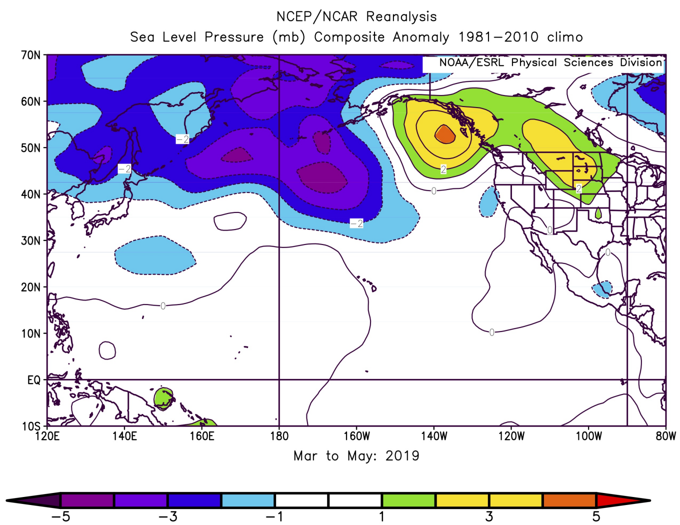
Figure 12: SST anomalies for autumn (September–November 2018), winter (December 2018–February 2019), spring (March–May 2019), and summer (June–August 2019).



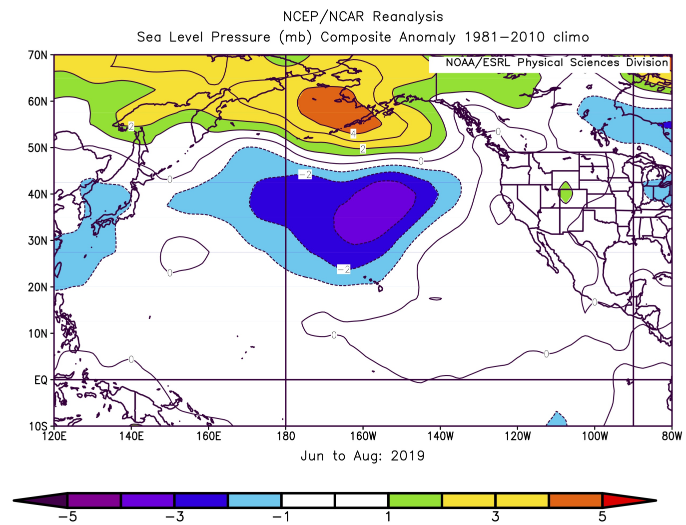
(a) Autumn



(b) Winter



(c) Spring



(d) Summer

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

Climate Indices

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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, PDO index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO) and Arctic Oscillation (AO). The time series of these indices from 2009 into spring/summer 2019 are plotted in Figure 14.

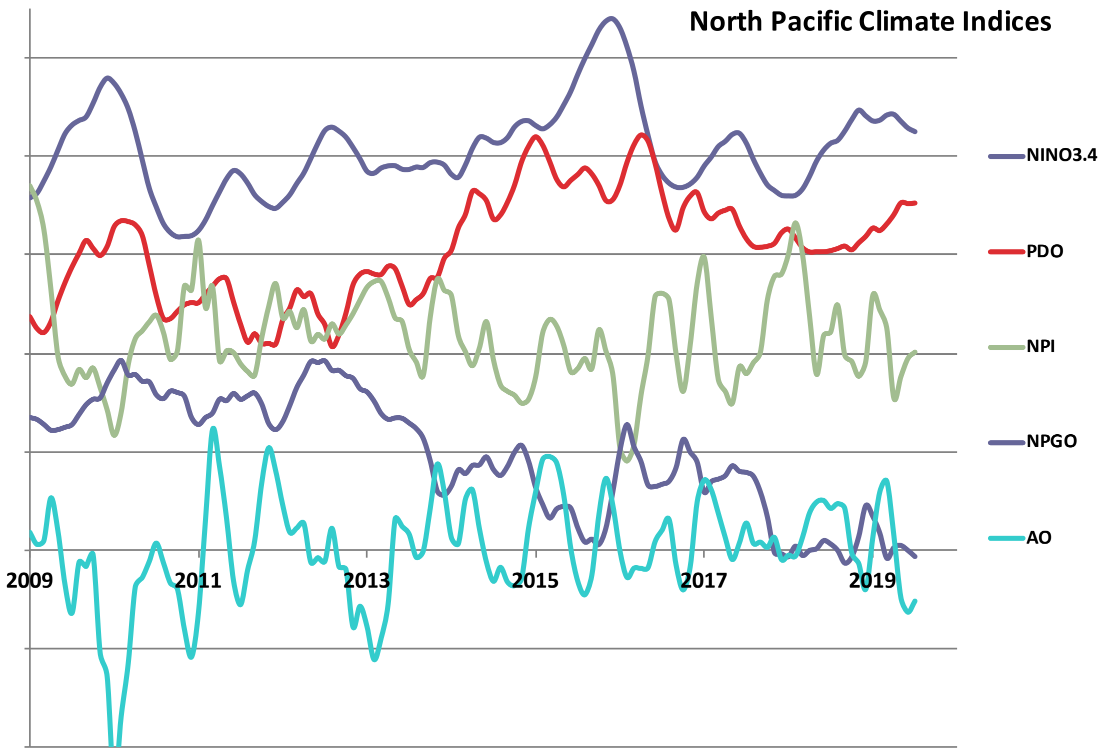

Figure 14: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices for 2009–2019. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Earth Systems Laboratory at `http://www.esrl.noaa.gov/psd/data/climateindices/`.

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

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

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

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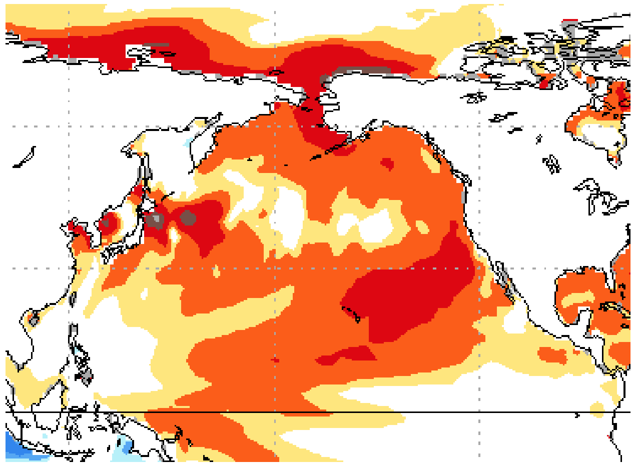
Last updated: September 2019

Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figures 15. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.

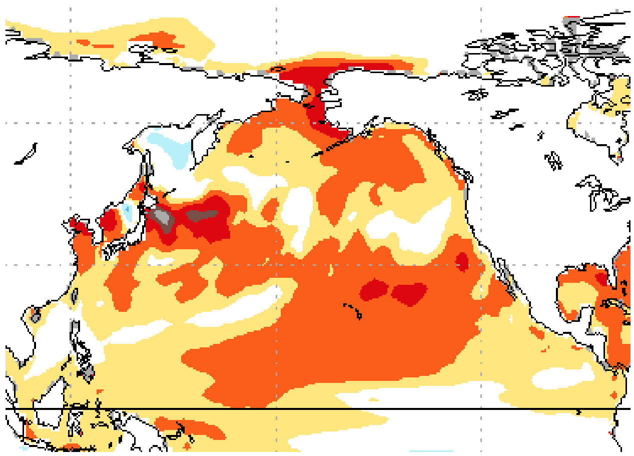
Status and trends: The projections from a year ago are first reviewed briefly. In general, the SST forecasts from late summer 2018 for the upcoming fall and winter indicated basin-scale anomaly patterns for the North Pacific that resembled those observed. The magnitudes of the observed anomalies in some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

These NMME forecasts of three-month average SST anomalies indicate a continuation of warm conditions across virtually all of the North Pacific north of about 40°N through the end of the year (Oct–Dec 2019), with a reduction in magnitude of the positive anomalies on the southern Bering Sea shelf, and offshore of the Pacific Northwest (Figure 15a). The magnitude of the positive anomalies is projected to be greatest (exceeding 2°C) north of the Kuroshio Extension in the far western North Pacific. Weak SST anomalies are projected in the equatorial Pacific. As of early September 2019, the probabilistic forecast provided by NOAA's Climate Prediction Center (CPC) in collaboration with the International Research Institute for Climate and Society (IRI) for the upcoming fall through winter indicates a 50–55% chance of neutral conditions and a 30% chance of El Niño. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2019–February 2020 (Figure 15b) and February–April 2020 (Figure 15c) with mostly a diminution in the magnitudes of the anomalies, especially in the eastern Bering Sea, GOA, and off the coast of the Pacific Northwest.

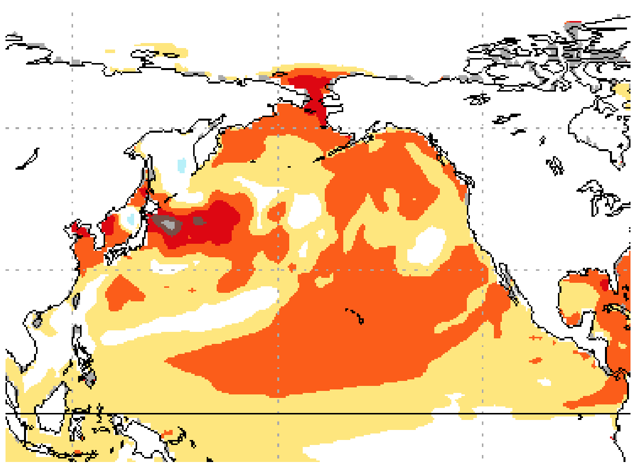
Implications: There is currently a lack of consensus among the climate models about the expected mean regional circulation anomalies associated with the variability of the Aleutian low during the upcoming autumn and winter. This result is consistent with the absence of predictability associated with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



(a) Months Oct–Nov–Dec



(b) Months Dec–Jan–Feb



(c) Months Feb–Mar–Apr

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

Eddies in the Gulf of Alaska

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Last updated: August 2019

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 16; region c), eddy energy in the years 2002–2004 was the highest in the altimetry record. The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS) (`http://www.marine.copernicus.eu`).

Since 1992, a suite of satellite altimeters has been monitoring sea surface height. Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (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 16). The first two regions are associated with the formation of the 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). By averaging EKE over the regions, we obtain an index of energy associated with eddies in these regions (Figure 17).

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, 2015 and 2017. Near-real-time data suggests that EKE was approximately average in both region (c) and region (d) in spring/summer 2019.

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 2019 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).

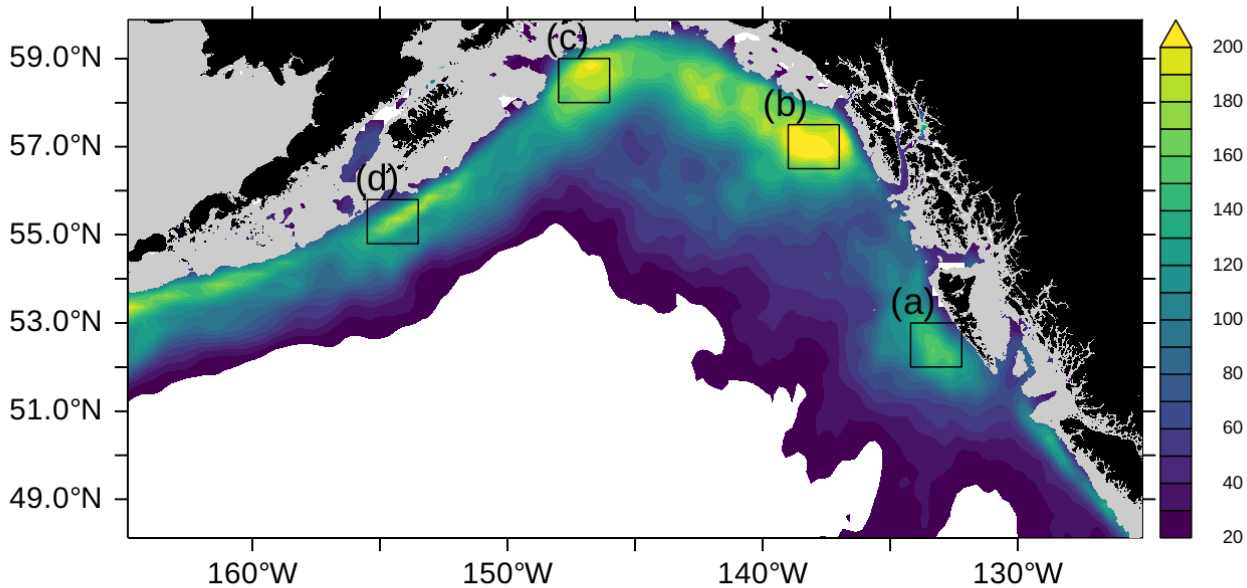

Figure 16: Eddy Kinetic Energy averaged over January 1993–December 2018 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 17.

Ocean Surface Currents—PAPA Trajectory Index

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Last updated: August 2019

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 18). 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 2018 (trajectory endpoints years 1902–2019).

Status and trends: In general, the trajectories fan out northeastwardly toward the North American continent (Figure 18). The 2009/2010 trajectory was an exception and resulted in the westernmost trajectory endpoint for the entire set of model runs (1902–2019 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

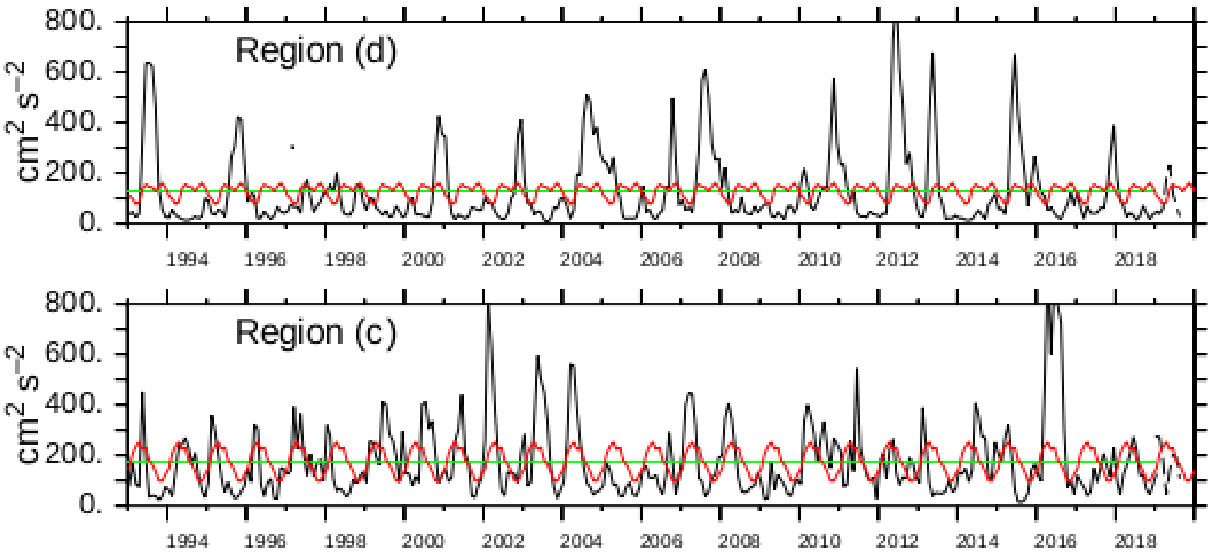

Figure 17: Eddy kinetic energy (cm^2 s^{-2}) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 16. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product), Red: seasonal cycle. Green (straight line): mean over entire time series.

northeastwardly path of most drifters, but was notable because its ending latitude was the northernmost of all trajectories since 1994 (Figure 18). 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 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 19). The 2017/18 trajectory was rather unremarkable, with positive sea-level pressure anomalies during early winter centered to the east of the Gulf of Alaska shifting to the west later in the winter, resulting in a latitudinal reversal of the trajectory such that the PTI for 2017/18 was close to zero. The 2018/19 trajectory was influenced by a shift in the pattern of sea level pressure anomalies between December and January such that winds shifted from westerly to southerly, resulting in a negative PTI for 2019.

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 were 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, although this cycle ended rather quickly, as the filtered PTI crossed the mean in the opposite direction in 2011. Since 2005, the PTI appears to be fluctuating on a much shorter time scale (∼5 years per mean crossing) than previously.

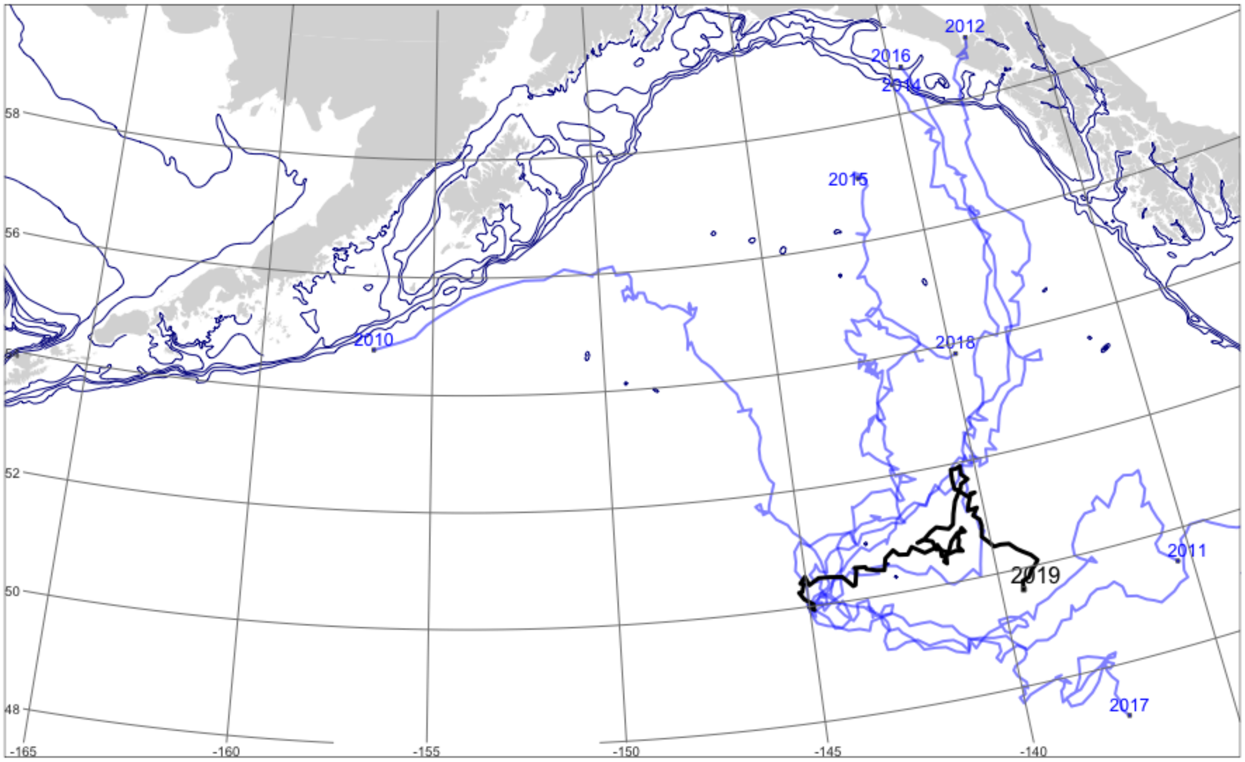

Figure 18: Simulated surface drifter trajectories for winters 2010–2019 (endpoint year). End points of 90-day trajectories for simulated surface drifters released on Dec. 1 of the previous year at Ocean Weather Station PAPA are labeled with the year of the endpoint (50°N, 145°W).

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 Alaska's 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 Alaska's 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).

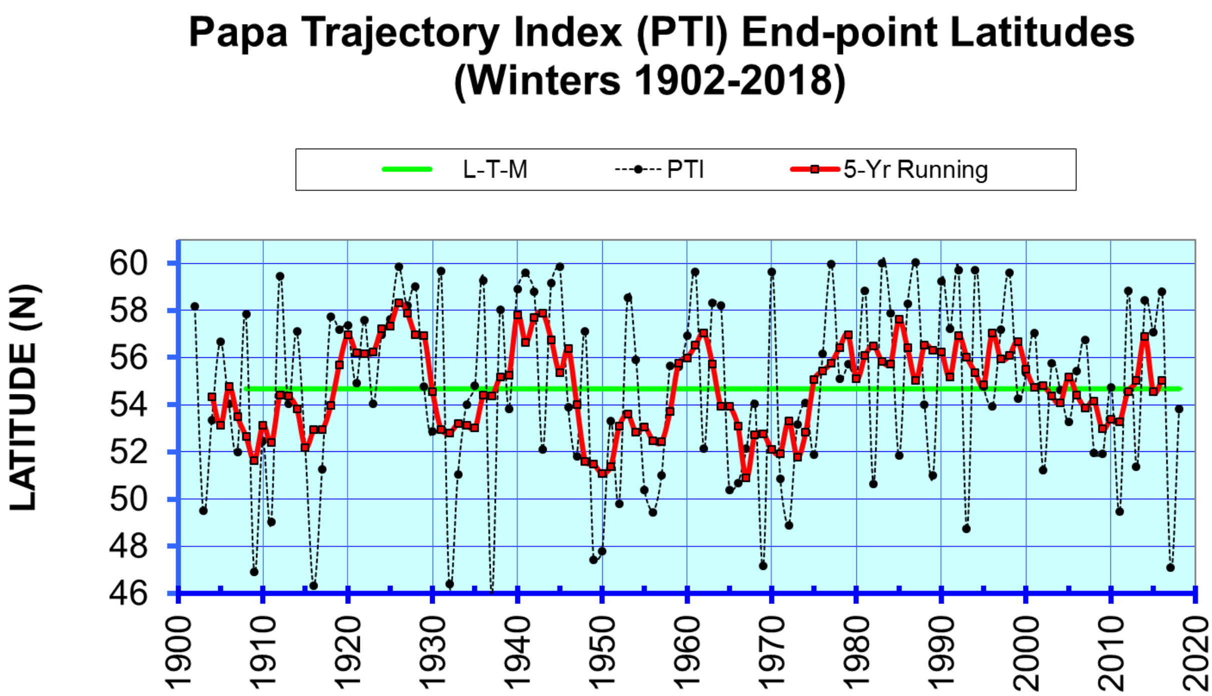

Figure 19: Annual, long-term mean (green line), and 5-year running mean (red line and squares) of the PAPA Trajectory Index time series (dotted black line and points) for 1902–2019 winters.

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

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

A limitation of SST records derived from satellites has been missing data as a result of cloud cover. Using the NASA multi-scale ultra-high resolution (MUR) SST dataset however, a combination of collection modalities creates a gap-free blend of data (`https://mur.jpl.nasa.gov/InformationText.php`). Daily SST data were accessed via the NOAA Coast Watch West Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/`). More detailed methods are available online (Watson, 2019).

For this indicator, the Gulf of Alaska (GOA) was divided into three regions. The western GOA (WGOA) was identified as ADF&G statistical areas that fell within 144°W–163°W; eastern GOA (EGOA), 133°W–144°W, and southeast Alaska (SEAK inside), inside waters east of 137°W. Figure 20 illustrates the boundaries of these areas.

Daily mean temperatures were averaged by month and anomalies were calculated by season for the WGOA, EGOA, and SEAK inside. The seasons (Dec–Feb, Mar–May, Jun–Aug, Sept–Nov) were chosen for consistency with other climatological ecosystem indicators in this report (Figure 21).

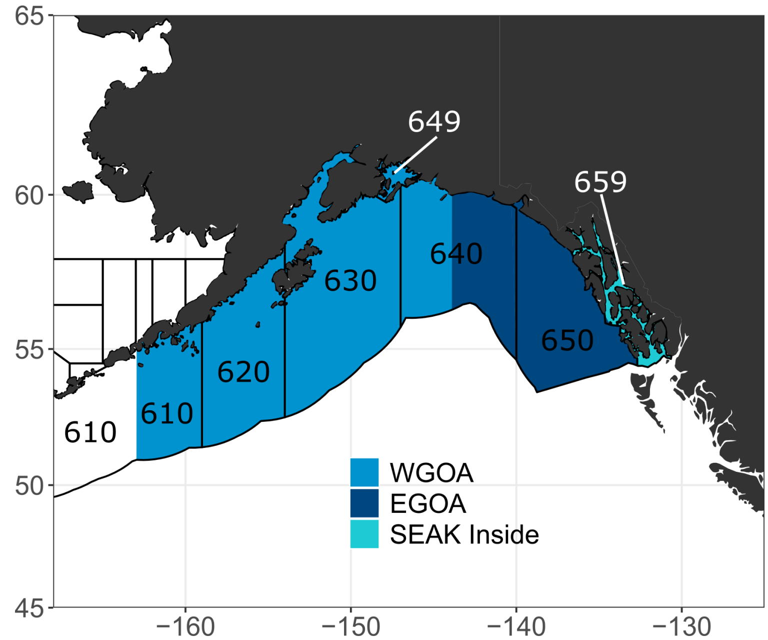

Figure 20: Map of the boundaries for the western (WGOA) and eastern (EGOA) Gulf of Alaska, and inside waters of southeast Alaska (SEAK Inside). Colored areas illustrated regions described by the SST indicator. Solid lines and numbers show boundaries of NMFS areas. Note that SST indicator areas span multiple NMFS areas.

Status and trends: The WGOA and EGOA demonstrated consistently similar trends within seasons and years, though, in several cases, the magnitude (and direction) of an anomaly was different for SEAK versus the GOA. The overall patterns of summer anomalies demonstrated a brief warm period during the summers of 2004 and 2005, with a broader cold stanza across seasons from 2006–2012. In the fall of 2014, surface waters began a warm period that continued through 2016. The outside waters of the EGOA and WGOA warmed again in the fall of 2018 and stayed warm into the recently concluded summer period. The inside waters of SEAK did not show as much warming; however, these waters were slightly warmer than average.

Factors influencing observed trends: The time period illustrated here includes the well-documented "Blob" period (Bond et al., 2015; Hu et al., 2016), which is identified by the anomalously warm winters, 2014–2016. In the early part of this time series, Mar–May temperatures scarcely exceeded half a degree above average. In four of the last six years however, Mar–May temperatures exceeded this threshold.

Implications: Spring in the GOA is an important season as this is when the larval stages of commercially important groundfish are present. As Rogers and Dougherty (Rogers and Dougherty, 2019) have demonstrated, such warming has been attributed with shifts in the spawning phenology of pollock populations. During the other seasons, shifts in the ecosystem may lead to impacts on predator-prey overlap and could have implications for a suite of species that forage and rear in this area.

Gulf of Alaska Survey Bottom Trawl Temperature Analysis

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Last updated: October 2019

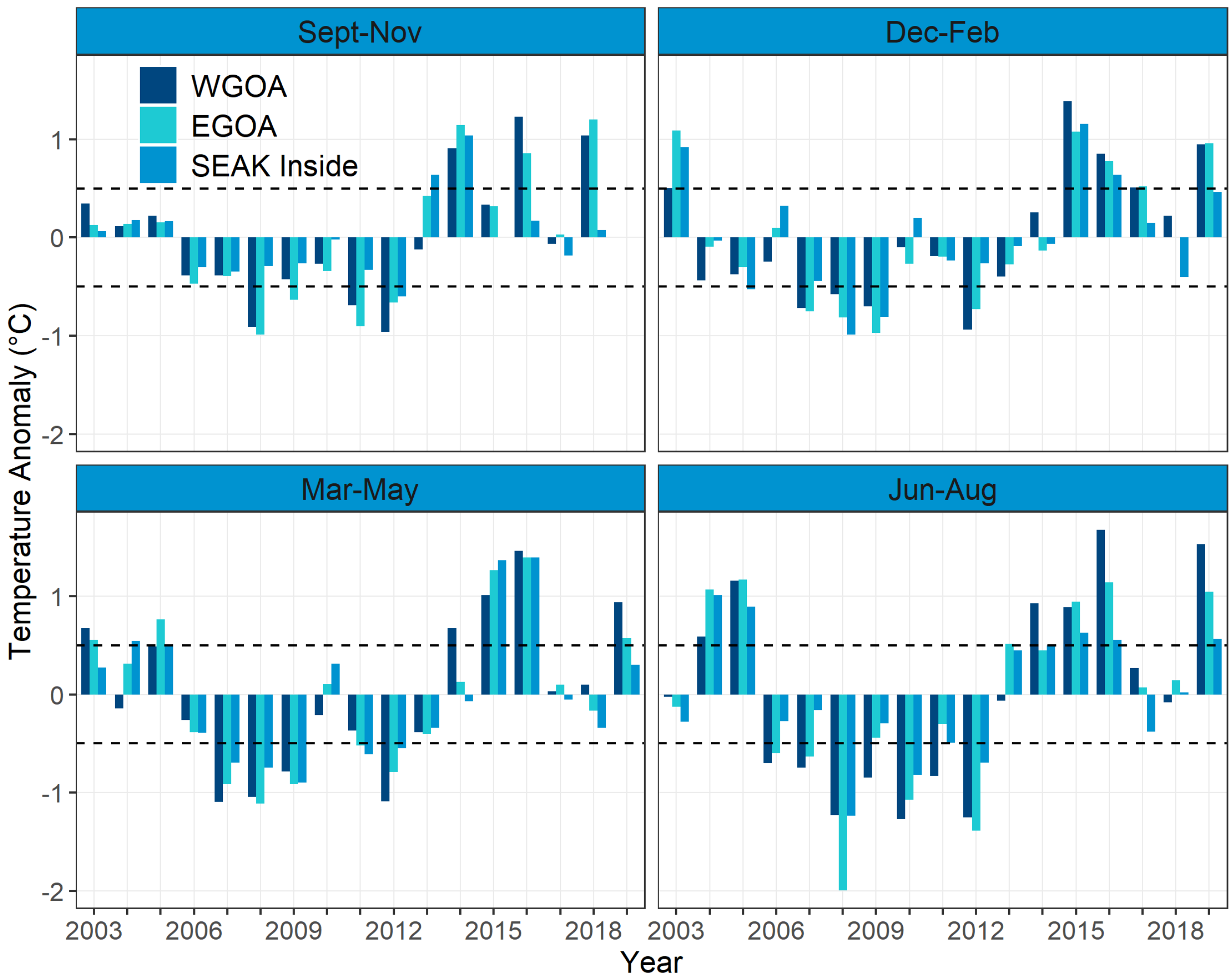

Figure 21: Seasonal sea surface temperature anomalies by Gulf of Alaska ecosystem region. The time series begins in December 2002 and ends in August 2019. The December data included in Dec–Feb are those from the previous year (e.g., Dec–Feb 2003 includes December 2002). Horizontal dashed lines are provided as a reference.

Description of indicator: Ocean circulation in the Gulf of Alaska (GOA) survey area (Figure 22) is dominated by two current systems, the Alaska Current and the Alaska Coastal Current (Stabeno et al., 2004). The Alaska Current is a typical eastern boundary current characterized by numerous eddies and meanders. It is driven by the West Wind Drift of the subarctic gyre in the North Pacific basin and flows to the north-northwest from the southeast GOA bottom trawl survey boundary at Dixon Entrance until it is diverted to the southwest around Prince William Sound, forming the origins of the Alaska Coastal Current (ACC). The majority of ACC water flows through Shelikof Strait. The remainder passes to the south of Kodiak Island, forming the origins of the Alaska Stream which continues to flow to the west along the Aleutian Islands (Stabeno et al., 1995). In addition, tidal forces dominate local circulation in Cook Inlet and in many of the bays along the Alaska Peninsula.

Since 1993, water column temperatures have been routinely recorded during Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) GOA bottom trawl surveys using bathythermograph data loggers attached to the headrope of the bottom trawl net. In 2003, a SeaBird (SBE-39) microbathythermograph (Sea-Bird Electronics, Inc., Bellevue, WA) replaced the Brancker XL200 data logger (Richard Brancker Research, Ltd., Kanata, Ontario, Canada) which had been in use from 1993–2001 (Buckley et al., 2009). The analyses presented here combine these two types of bathythermic data; the downcast data from each RACE-GAP trawl haul were isolated and used to inform our models.

Spatial and temporal coverage of the GOA RACE-GAP summer bottom trawl surveys has varied from year to year. Starting dates have ranged from the middle of May to the first week in June, and survey end dates ranged from the third week in July to the first week in September. The number of vessels employed, the areal extent, and the maximum depth of the GOA survey have all varied among survey years (e.g., water temperatures were not collected from the eastern GOA in 1993 and 2001, stations in the deepest GOA stratum [700–1000 m] have been sampled in just 5 of the last 13 surveys). Since the GOA survey sweeps from west to east over the late spring and summer, the expectation is a trend toward warmer water temperatures collected late in the summer in southeast Alaska compared with those collected in the western GOA in late spring; this anticipated trend is expected to be particularly pronounced in the upper layers of the water column.

To account for the spatio-temporal variations that were a consequence of the survey design, we removed the effect of collection date on water temperature by standardizing all RACE-GAP GOA bottom trawl collection dates to a median survey date of July 10. We formulated a generalized additive model (GAM) to estimate the effects of collection date on temperature at depth across survey areas and years; the GAM accounted for 81% of the total deviance in the temperature data. The resulting model was used to predict water temperature on the median survey day at depth and station from survey trawl haul downcasts. Model residuals were added to the predicted median day temperature-at-depth to produce temperature anomaly estimates for each station and depth during each survey year. To facilitate visualization, these estimates were averaged over systematic depth bins in ½-degree longitude increments. Depth gradations were set finer in shallower depths (e.g., 5 m bins between 0 and 100 m, 10 m bins between 100 and 300 m) to capture the anticipated rapid water temperature changes in surface waters with increasing depth. To further stretch the color ramp and enhance the visual separation of the near-surface temperature anomalies (between ~ 4 and 10°C and < 100 m), predicted temperature anomalies ≥ 9.5°C and ≤ 3.5°C were fixed at 9.5 and 3.5°C (e.g., a 12.5°C temperature anomaly was recoded as 9.5°C for the graphic representation) and the y-axis (depth) was truncated (0–400 m) relative to the deepest depths sampled (ca. 1000 m).

Status and trends: The thermal profile suggests that water temperatures in 2019 may have been as warm or warmer than those observed in 2015 and 2017, particularly near the surface in the western Gulf (Figures 23 and 24). The last three GOA surveys appear to be the warmest in our record. In 2019, the warmest water penetrated more deeply into the upper 100 m in the western and central Gulf than in any previous years and elevated temperature anomalies were commonly observed down to 200 m across the entire survey area in 2019. This year's anomaly profiles were most similar to 2015 profiles with warmer anomalies ($\geq$ 7.0°C) consistently observed across the entire survey area and penetrating to 200 m depths. While among the warmest years in our record, 2017 appears to be slightly cooler than either 2015 or 2019. These warm years contrast starkly with the cooler years (e.g., 2007–2013) in our record.

Factors influencing observed trends: Temperature data we collected during RACE-GAP bottom trawl surveys in the GOA represent a temporally brief and spatially constrained snapshot of water column conditions. In the data summarized in the figure, each temperature bin represents data that were collected over a relatively short time as the vessels moved through the area. It is difficult to draw general conclusions about longer term trends from this type of data, especially since these temperature observations can be affected by short term events such as storms, tidal currents, and changes in freshwater discharge. More persistent medium-term phenomena like seasonal changes in solar heat flux, El Niño Southern Oscillations, and shifts in the Alaska Coastal Current also play an important role in determining water column temperatures. In addition, the strength and persistence of eddies are believed to have a large impact on the transport of both heat and nutrients across the continental shelf in the GOA (Ladd, 2007). The data reported here depict the variation in water column temperatures observed amongst GOA bottom trawl survey years, but do not inform the mechanisms or processes driving these differences.

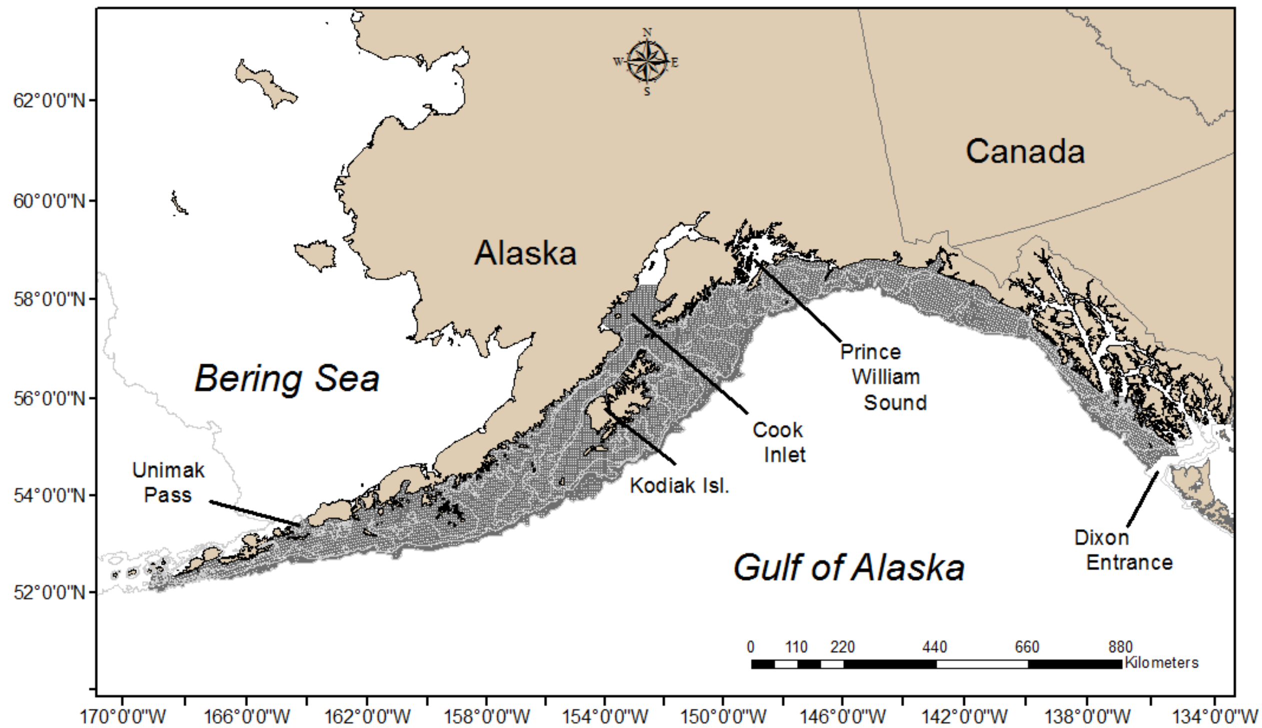

Figure 22: Map of the AFSC/RACE GAP Gulf of Alaska survey area and survey grid.

Implications: Water column temperatures influence the distribution, assemblage membership, abundance, and growth rates of phytoplankton and zooplankton species. Ichthyoplankton distribution and growth rates are also related to location of the warm core eddies that are a prominent feature of the central GOA (Atwood et al., 2010). Adult and juvenile fish distribution can also be influenced by water temperatures (Kotwicki and Lauth, 2013; Rooney et al., 2018; Li et al., 2019; Yang et al., 2019). Inter-annual differences in water column temperatures, their implications, and their possible effects on fish populations in the GOA require more study to be better understood.

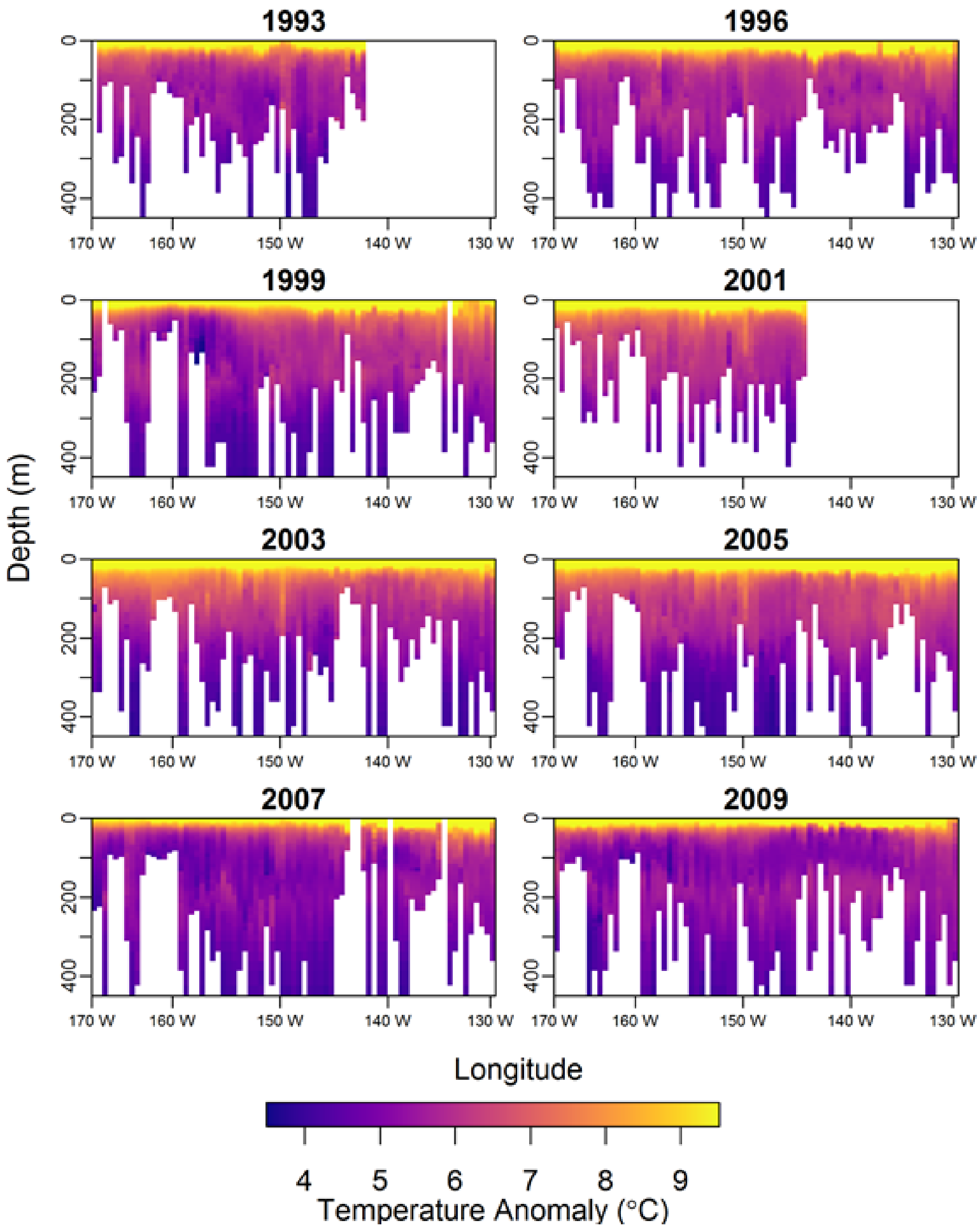

Figure 23: Temperature (°C) anomaly profiles derived from RACE-GAP Gulf of Alaska bottom trawl survey bathythermograph casts (1993–2019) and predicted from a generalized additive model at systematic depth increments and ½-degree longitude intervals; to visually enhance near-surface temperature changes, values ≤ 3.5°C or ≥ 9.5°C were fixed at 3.5 or 9.5°C and the y-axis (depth) was truncated at 400 m (relative to maximum collection depth ca 1000 m), 2011–2019.

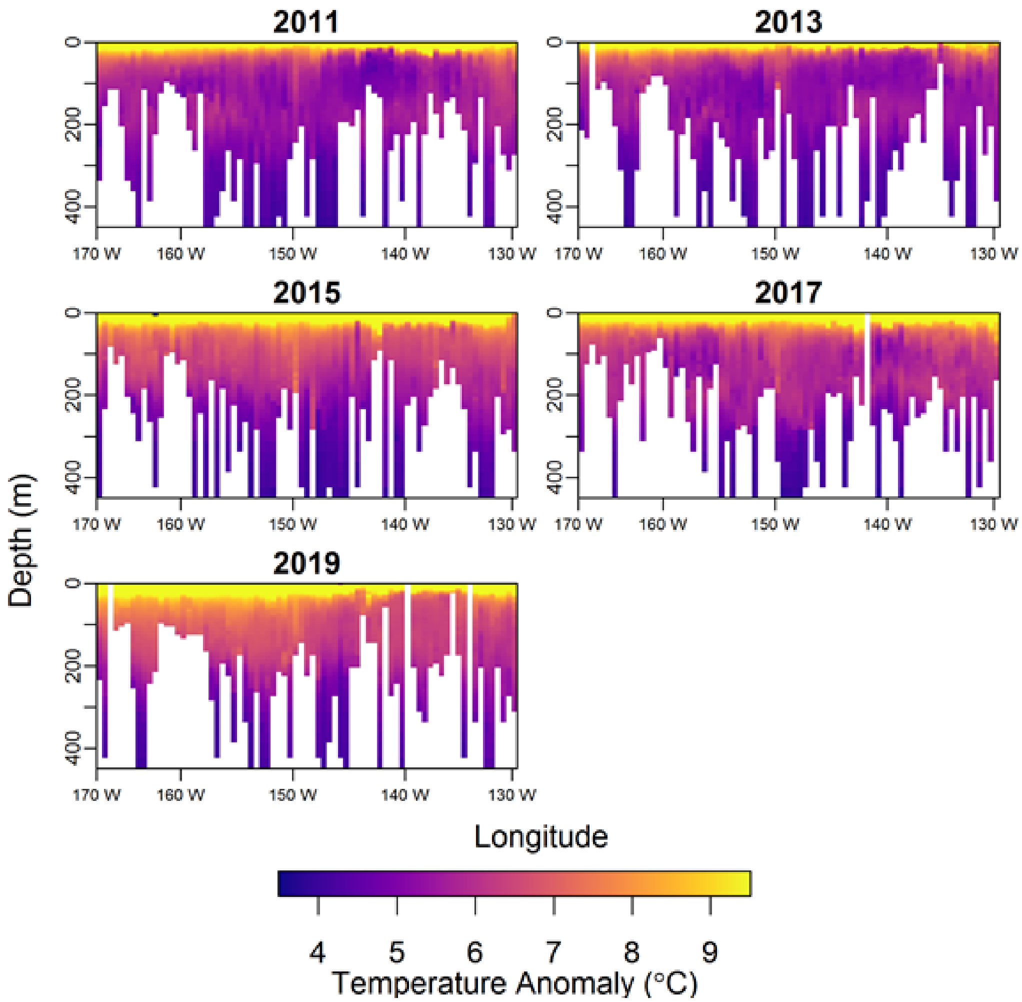

Figure 24: Temperature (°C) anomaly profiles derived from RACE-GAP Gulf of Alaska bottom trawl survey bathythermograph casts (1993–2019) and predicted from a generalized additive model at systematic depth increments and ½-degree longitude intervals; to visually enhance near-surface temperature changes, values ≤ 3.5°C or ≥ 9.5°C were fixed at 3.5 or 9.5°C and the y-axis (depth) was truncated at 400 m (relative to maximum collection depth ca 1000 m), 1993–2009.

Spring and Summer Water Column Temperatures in the Western Gulf of Alaska

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Last updated: October 2019

Description of indicator: EcoFOCI conducts biennial surveys in spring (May-June) and summer (August-September) in the Western Gulf of Alaska, targeting early life stages of fishes and their prey. At each sampling station, a bongo net array is towed obliquely from surface to 100m (spring) or 200m (late summer), or to 10m off bottom in shallower waters. Attached to the wire above the bongo frame is a Seabird FastCAT profiler which measures temperature, salinity, and depth. Up casts were processed and used to generate maps and time-series of temperatures at the surface and at maximum tow depth using the custom R package FastrCAT (`https://github.com/Copepoda/FastrCAT`).

Status and trends: Springtime temperatures in 2019 averaged 6.8°C at the surface and 6.1°C at depth. Temperatures were warmer around Kodiak Island, and cooler towards the southwest, a typical pattern observed in the springtime (Figure 25). Sea surface temperatures were relatively average when compared with the three prior years with spatially-extensive sampling reported here; however, temperatures at maximum depth were warm, similar to those observed during the marine heatwave in 2015 (Figure 26). Conditions remained warm through the summer, with average surface temperatures of 13.3°C and temperatures at maximum depth of 7.3°C (Figure 26). Shallow banks were especially warm in 2019, with cooler waters in the depths of the Shelikof Sea Valley (Figure 27). Especially notable is the warming trend in bottom temperatures, which were even higher in summer 2019 relative to 2015 (Figure 26).

Factors influencing observed trends: These observations confirm that the 2019 marine heatwave extended beyond the surface waters and is characterized by warming throughout the water column in the Western Gulf of Alaska.

Implications: The ecological implications of warming at depth are typically greater than surface warming as it means that cooler thermal habitat is not available in the water column, which makes warming an inescapable change for the shelf community. In 2015, a year with similar water column temperatures, recruitment of pollock and Pacific cod was sharply reduced. Observations of pollock and Pacific cod early life stages in 2019 suggest a similar pattern (see p.97 and p.102).

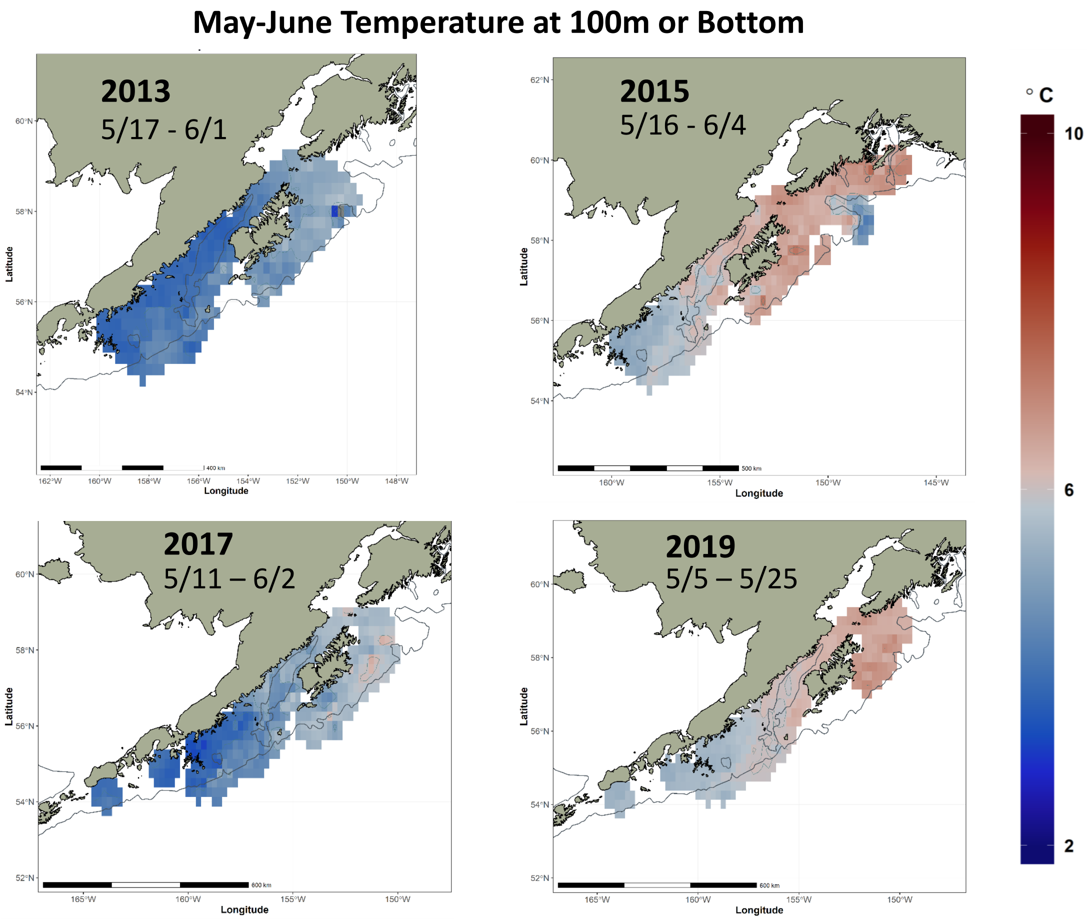

Figure 25: Measured temperatures at maximum gear depth, which was 100m or 10m off bottom in shallower waters, during the biennial spring larval survey. Sampling dates are indicated in each panel.

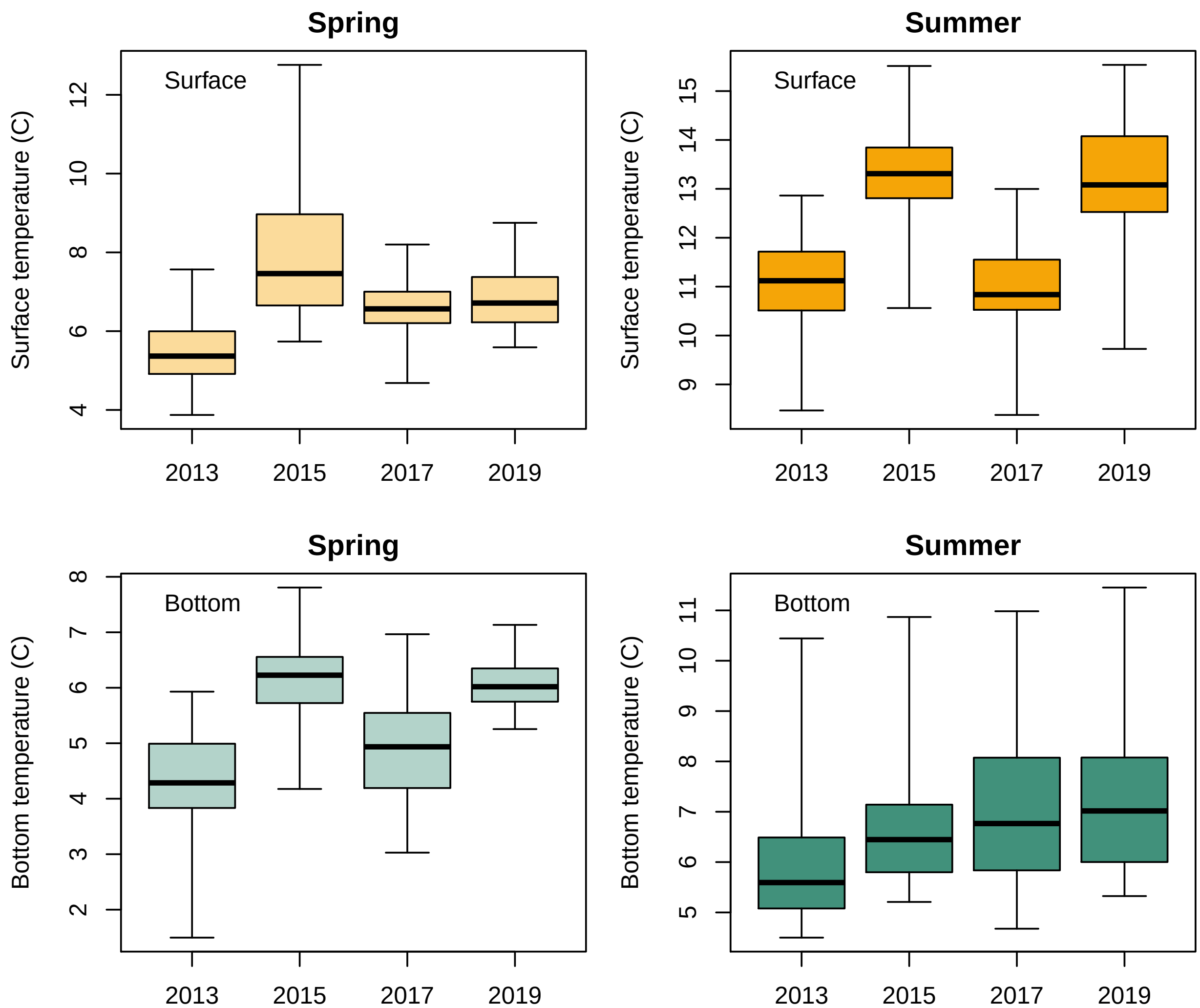

Figure 26: Distributions of observed surface and bottom temperatures across all stations sampled during spring and summer EcoFOCI surveys. Bottom temperatures refer to temperature at maximum gear depth. Boxes show the median, 25th and 75th percentiles, and whiskers show the full range.

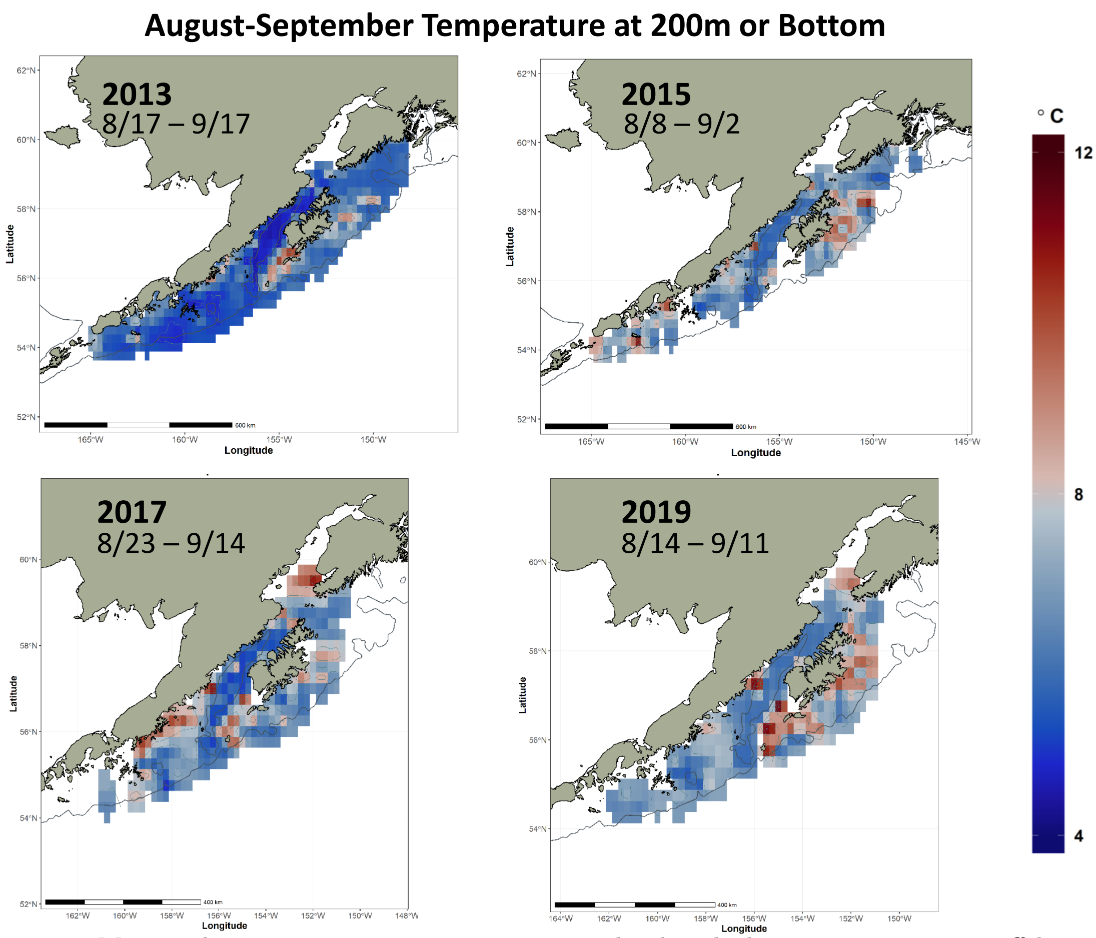

Figure 27: Measured temperatures at maximum gear depth, which was 200m or 10m off bottom in shallower waters, during the biennial late-summer YOY groundfish survey. Sampling dates are indicated in each panel.

Seward Line May Temperatures

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Last updated: August 2019

Description of indicator: Since 1998, hydrographic transects have been completed in May (typically during the first 10 days of the month) along a sampling line that extends from the mouth of Resurrection Bay near Seward to the outer continental slope of the northern Gulf of Alaska. Data analyzed here is water column profile data that has been averaged over the top 100m of the water column to provide an index of upper water column heat content on the northern Gulf of Alaska shelf. The spring bloom is strongly influenced by water temperature, with colder years typically having greater productivity. Growth rates of all cold-blooded marine organisms 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.

Status and trends: The northern most station, GAK1 has been occupied for nearly 50 years, show long-term warming and surface freshening of the Gulf of Alaska Coastal Current (see the GAK1 indicator time series for details). The Seward Line data (Figure 28) shows that in most years the upper water column warms and cools in synchrony from the coast (60°N) to the continental slope (58°N). Although May temperatures were closer to the long-term mean during 2017 and 2018, for 2019 they were 0.64 ˚C above the 22-year mean.

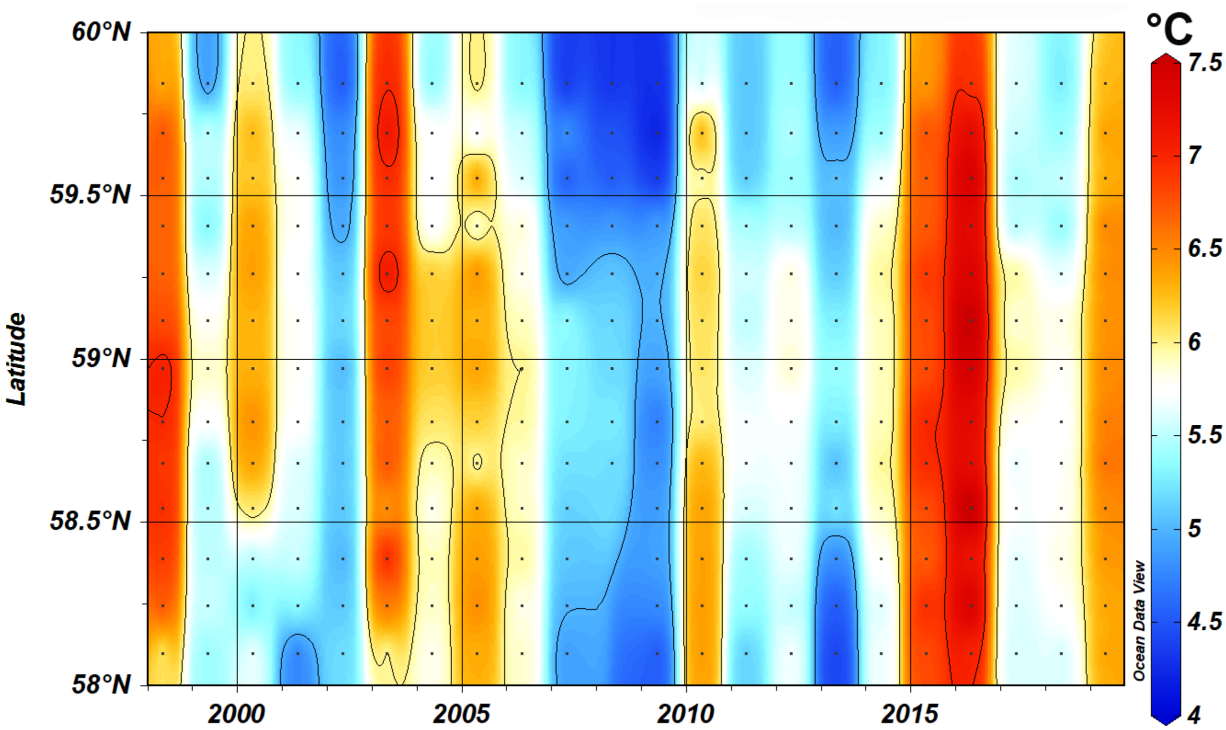

Figure 28: May sea temperatures averaged over the top 100m along the Seward Line in the northern Gulf of Alaska, 1998–2019.

Factors influencing observed trends: Warm years are often associated with El Niño events (1998, 2003, and 2016) and other marine heatwaves (2015). Cool conditions observed are often related to complex winter balances between heat loss, coastal runoff and stratification (Janout et al., 2010).

Implications: Ocean temperatures in the Gulf of Alaska have been well above normal for 2019, with

Table 2: Statistics of the near surface (0–50m) and near seafloor (200–250m) salinity and temperature trends over the period of record at GAK1.

Parameter (units)	Date range	Depth Range	N (months)	Slope	r^2	P
Temperature (°C)	1970–2019	0–50	411	0.235 +/- 0.061	0.120	2.05E-13
Temperature (°C)	1970–2019	200–250	409	0.167 +/- 0.036	0.170	8.40E-18
Salinity	1970–2019	0–50	411	-0.071 +/- 0.032	0.040	1.48E-05
Salinity	1970–2019	200–250	407	0.025 +/- 0.017	0.020	4.75E-03

increased stratification. This coincides with reduced chlorophyll and smaller, less lipid-rich zooplankton in the Northern Gulf that will likely reduce the transfer of energy to high trophic levels

Oceanographic station GAK1 water column conditions

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Description of indicator: Located at the mouth of Resurrection Bay near Seward, Alaska, temperature and salinity versus depth profiles have been taken at oceanographic station GAK1 since December, 1970. This time series is one of the longest running oceanographic time series in the North Pacific.

Status and trends: With the exception of a few months in 2017 and 2018, GAK1 monthly mean temperatures have remained above the 1970–2019 long-term mean since early 2014 (Figure 29).

A summary of the GAK1 period of record trends for the near surface and near-bottom temperature and salinity (Table 2).

The data show that surface waters are warming faster than subsurface waters. The near-surface has a significant long-term trend of freshening. The near-bottom has a significant long-term trend of salinization. The temperature and salinity trends both force the system into greater stratification.

Factors influencing observed trends: The long-term 1970–2019 warming trend reflects the Northern Gulf of Alaska manifestation of climate warming due to increased atmospheric concentrations of greenhouse gases. Punctuated warm and cool phases are related to global-scale atmospheric dynamics such as El Niño and La Niña oscillations, shifts in the Pacific Decadal Oscillation, and alterations of the strength and location of Aleutian Low storms. Warming air temperatures are contributing to net ablation of Gulf of Alaska glaciers (Jacob et al., 2012; Hill et al., 2015); we attribute the near-surface freshening to the effects of this increased ice melt.

Implications: Thermal conditions impact energetic balances of all marine species. Increased temperatures elevate metabolic costs to organisms. Stratification, which is driven by both salinity and temperature in the Gulf of Alaska, controls the impact of wind-induced mixing on the replenishment of subsurface nutrients into the surface mixed layer. Greater stratification will generally lead to a reduction of nutrients in the euphotic zone, thereby impacting primary production. A smaller nutrient pool also generally favors smaller phytoplankton and a lengthening of the trophic cascade. Hence, both warming and stratification increases suggest an oceanic environment with a longer cascade of trophic exchanges and a greater competition for available resources.

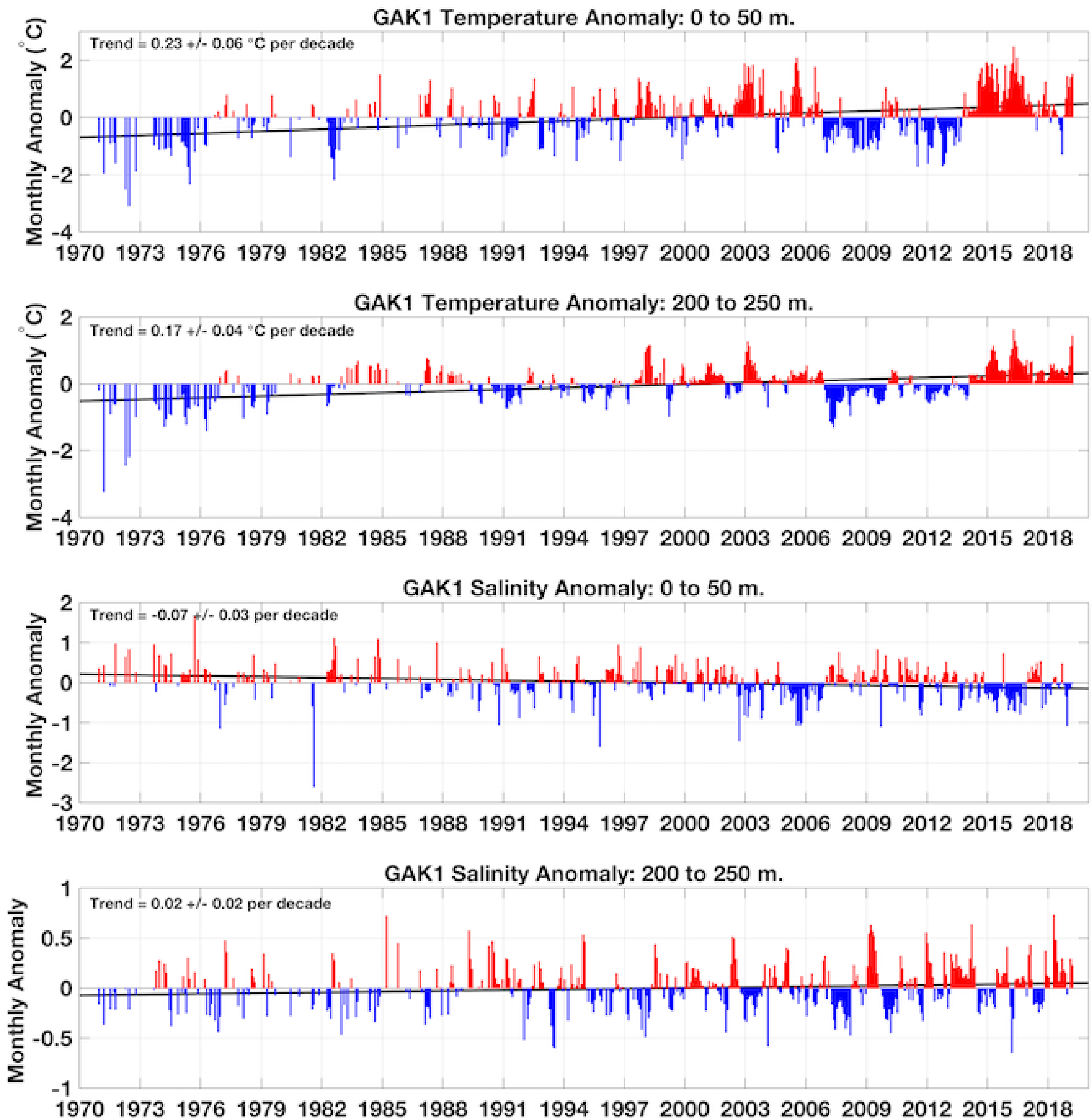

Figure 29: GAK1 monthly anomaly time series for the 1970–2019. Temperature (upper two panels) and salinity (lower two panels) anomalies represent averages over the uppermost and lowermost 50 m of the water column. The data exhibit a long-term trend in warming punctuated by signals associated with the cycles of El Niño/ and other phenomena. Black lines show the least squares best fit trend over the period of record. Text provides trend statistics (best fit least squares linear) over the record length.

Temperature trends in the surface waters of Prince William Sound

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Last updated: September 2019

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, 1974–2019. 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 30), 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). After returning to near-average temperatures in late 2017–early 2018, temperatures in 2019 again shifted towards strongly above average, with magnitudes exceeding those observed during the 2013–2017 heatwave.

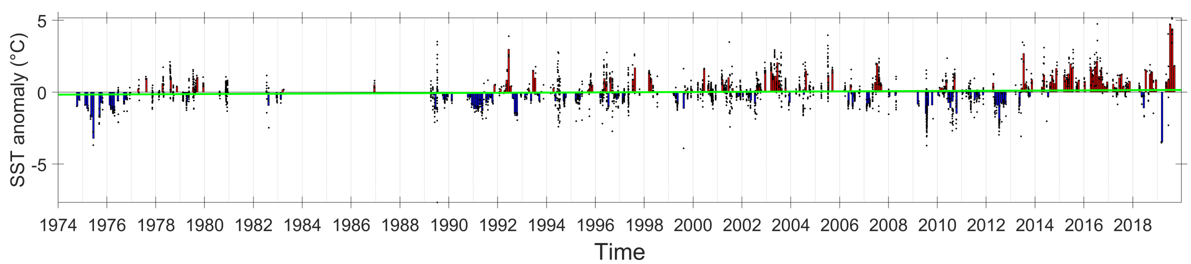

Figure 30: Near surface (2 m) temperature anomalies in central Prince William Sound, 1974–2019. Black dots indicate observations, and bars are monthly averages; the green line is the long term trend. Anomalies were calculated as the residuals of a second order cosine curve fit to all years data (to remove seasonality).

Factors influencing observed trends: Temperatures in PWS generally track those of the Gulf of Alaska, with a lag of about 12 months which is driven by circulation within the region (Campbell, 2018). In PWS, the onsets of the marine heatwave in 2013–2014 and 2019 warm anomalies were concurrent with increases in temperatures basin-wide, because the driver of the onset of the heatwave was atmospheric (a prolonged period of calm weather where heat may be retained in the surface layer and not mixed out). 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 these species. The increase in their relative abundance during the marine heatwave years may have been in part because these species 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 2019

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. Forty years of temperature data are available (1980–2019), and 14 years of creek height data (2006–2019). 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 2018 was 10.7°C and 12.3°C for 2019. From 2006–2019, average yearly creek height varied from 21.3 ft to 21.9 ft, with an average of 21.7 ft. The average gauge height for 2018 was 21.5 ft and 21.3 ft for 2019. Historical trends and the most recent two years are shown for creek temperature (Figure 31) and gauge height (Figure 32).

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 32). This

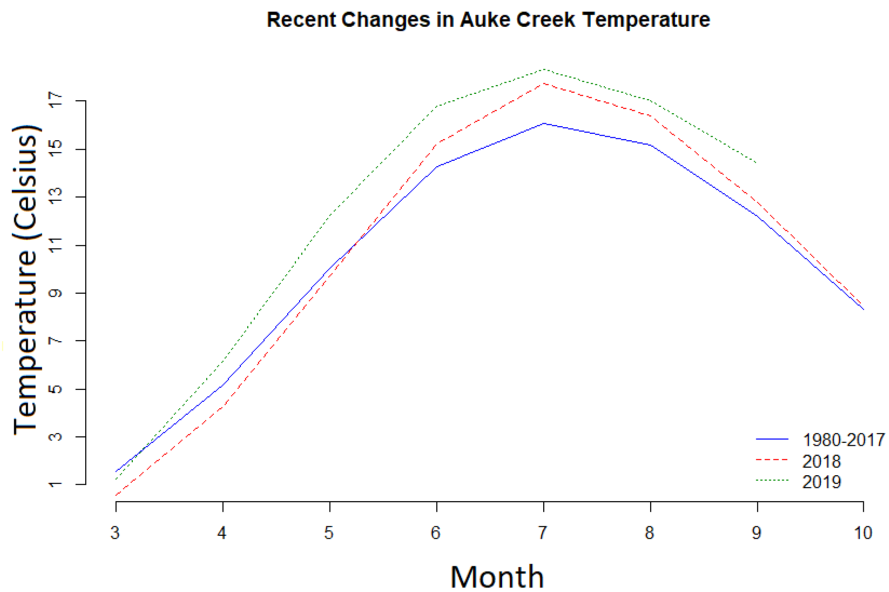

Figure 31: Auke Creek average temperature by months of operation for 1980–2019.

lack of snowfall, and subsequent lack of snowmelt, contribute to warmer creek temperatures earlier in the year (Figure 31).

Implications: These changes in stream conditions and climate have been shown to influence 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 nearshore 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).

Habitat

Structural Epifauna—Gulf of Alaska

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Description of indicator: Structural epifauna groups considered to be Habitat Area of Particular Concern (HAPC) biota include sponges, corals (both hard and soft) and anemones. NOAA collects data on structural epifauna during the biennial RACE summer surveys in the Gulf of Alaska. For each species group, the catches for each year were scaled to the largest catch over the time

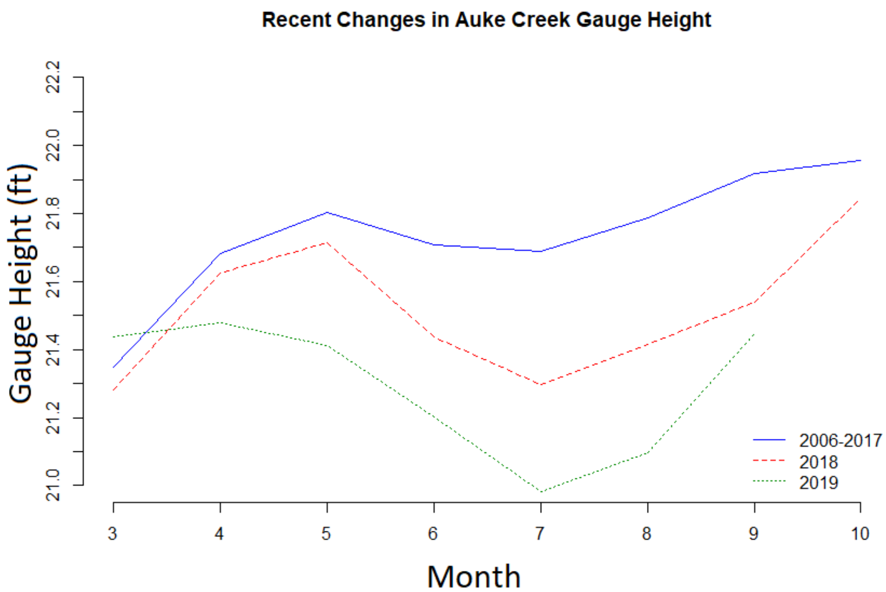

Figure 32: Auke Creek average gauge height by months of operation for 2006–2019.

series (which was arbitrarily scaled to a value of 100). The standard error (±1) was weighted proportionally to the CPUE to get a relative standard error. The percentage of positive catches in the survey bottom trawl hauls was also calculated.

Status and trends: A few general patterns are clearly discernible (Figure 33). Sponges are caught in about 50% of bottom trawl survey hauls in all areas of the GOA when combined across areas. This percentage has been increasing in the Yakutat (to about 30% of hauls) and Southeastern (to about 60% of hauls) regions. However, the CPUE is generally highest in the Shumagin area and lower to the east. Sponge CPUE has declined in the Kodiak area, while CPUE has remained fairly constant in the four other areas. Anemones are caught in low abundance in the eastern GOA, while they are common (occur in ∼50% of tows) at a relatively constant abundance in the Shumagin, Chirikof and Kodiak regions. Gorgonian corals show an opposite pattern, as they are in highest abundance in the southeastern GOA, although they are relatively uncommon in catches for all areas. The peak abundance occurred in 1999 in the eastern GOA, and catches have declined in recent surveys. The sea pen time series is dominated by large CPUE's in 2005 and 2015 in the Chirikof area, but they occur uncommonly in bottom trawl tows (< 10% occurrence). Stony coral catches are rare. Soft coral CPUE has been uniformly low with the exception of a large catch in the western GOA in the 1984 survey.

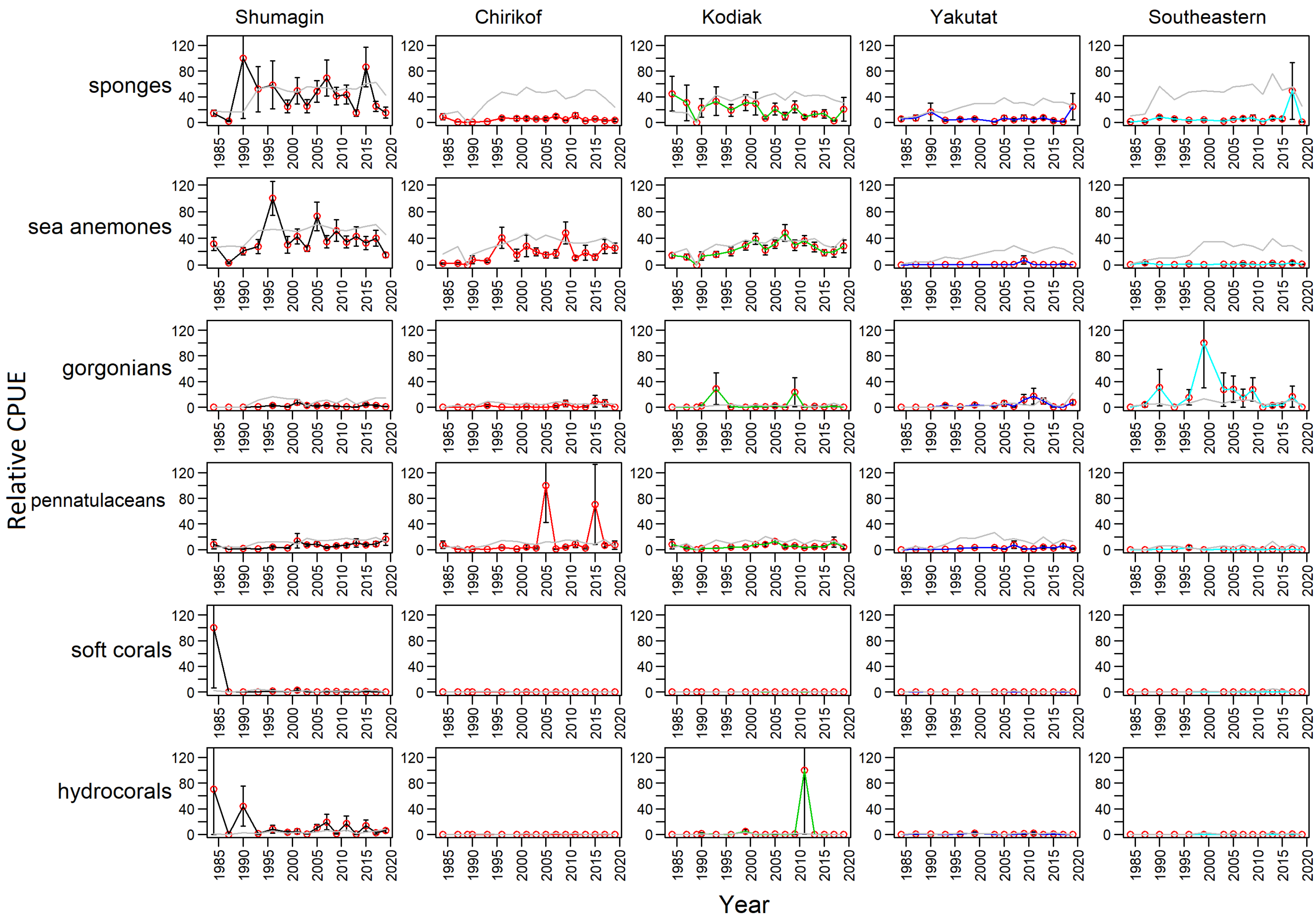

Figure 33: Mean CPUE of HAPC species groups by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2019. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

Factors influencing observed trends: The Gulf of Alaska Bottom Trawl Survey does not sample any of these fauna well, so some caution is recommended in interpreting these trends in CPUE. Overall, most area-species combinations do not show trends in either catches or frequency of occurrence. However, the decline in sponge catches in the Kodiak area may indicate that sponges are decreasing here, whereas the increases in frequency of occurrence of sponges in the Yakutat and Southeastern areas may indicate an expansion of sponge populations.

Implications: Changes in structural epifauna CPUE may indicate changes in habitat, but at present no research has demonstrated definitive links. In future ecosystem contributions an overall biomass for these species groups for the Gulf of Alaska will be computed using geospatial methods. Preliminary results (Figure 34) show that overall coral and sponge biomass estimates have remained consistently variable throughout the history of the bottom trawl survey, whereas pennatulaceans seemed to peak in the 2005 survey before falling off and recovering to a high level in 2017. These are preliminary results and need further examination and exploration.

Intertidal Ecosystem Indicators in the Northern Gulf of Alaska

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Last updated: September 2019

Description of indicator: Nearshore monitoring in the Gulf of Alaska (GOA) provides ongoing evaluation of 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), Kenai Fjords National Park (KEFJ), Kachemak Bay (KBAY), and Katmai National Park (KATM). 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). First, we present water temperature at the 0.5 m tide level in the intertidal to evaluate whether the following biological indicators changed in concert with widespread physical forcing in the Gulf of Alaska. We have selected three biological indicators that represent key nearshore ecosystem components of primary production (algal cover), prey abundance (mussel density), and predator abundance (sea star density). 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. All biological indicators are presented as annual anomalies compared to the long term mean of the data record by site.

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 35). These results confirm that the 2014–2016 marine heatwave

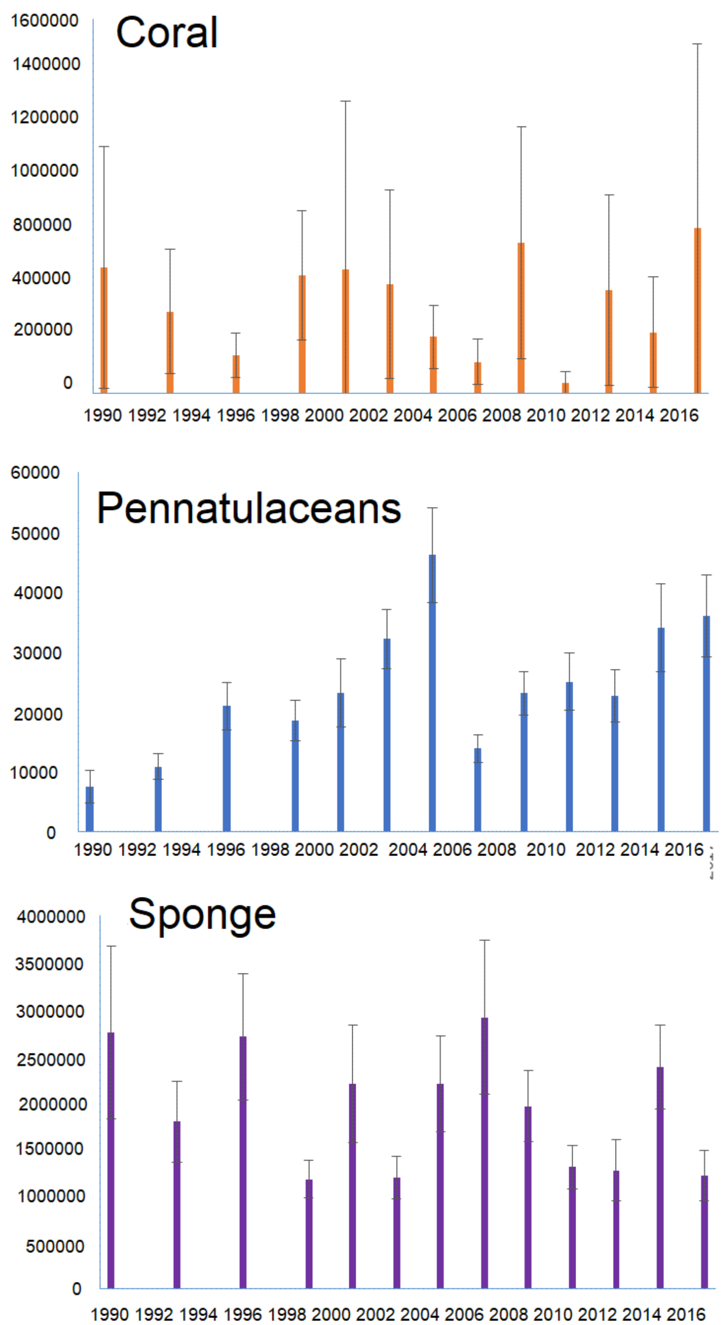

Figure 34: Time series of structure forming invertebrate biomass estimates for the Gulf of Alaska. Estimates (and standard deviations) were produced using a multispecies VAST model that included combined coral groups, combined pennatulaceans and combined sponge groups.

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, KATM and KEFJ sites showed consistently negative trends during the recent

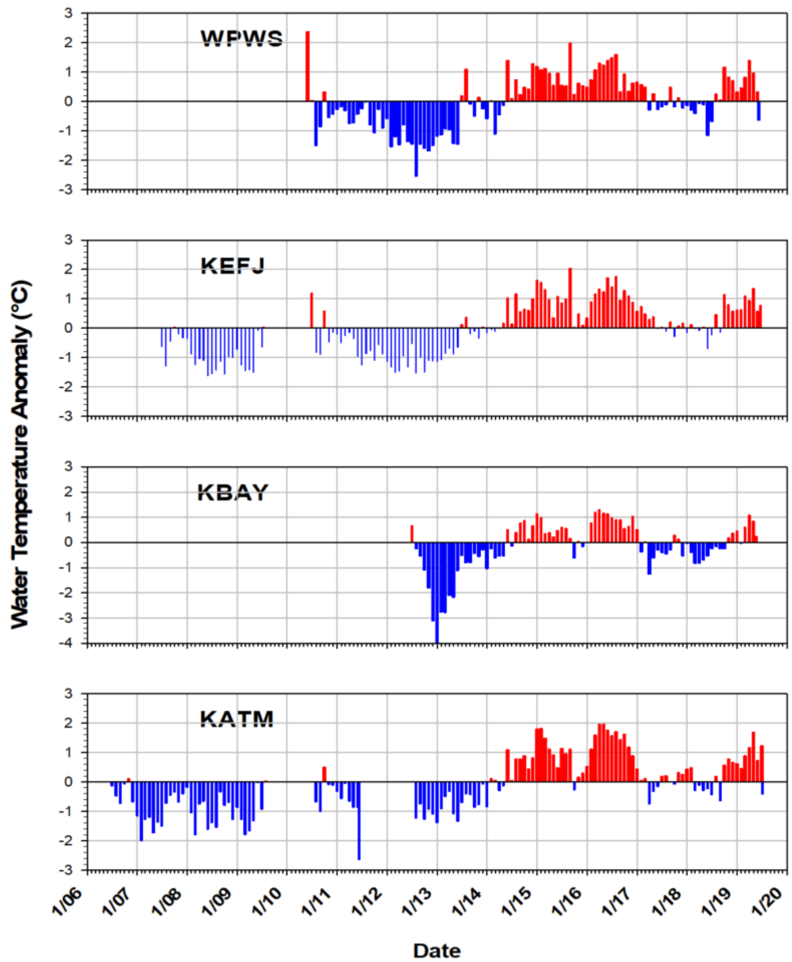

Figure 35: Intertidal temperature anomalies at the 0.5 m tide level four regions of the western Gulf of Alaska (west of 144°W), western Prince William Sound (WPWS; 2011–2019), Kenai Fjords National Park (KEFJ; 2008–2019), Kachemak Bay (KBAY; 2013–2019), and Katmai National Park adjacent to Shelikof Strait (KATM; 2006–2019).

marine heatwave and continuing through 2019 (Figure 36). KBAY has continued to have average Fucus cover without a noticeable response to the heatwave. Anomalies in WPWS became positive in 2019 and may indicate recovery from the heatwave effects after temperatures cooled in 2018.

Large mussel densities ($\geq$20 mm) show an overall strong positive trend across all sites consistent with the timing of the marine heatwave, in this case switching from generally negative to positive anomalies after 2014 – an opposite response compared to sea stars (Figure 37). Also, in comparison to other indicators, there seems to be higher across-site variability in 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 density, diversity and dominance of individual sea star species varied greatly among regions through 2015 (Figure 38). In 2016, abundance began to decline and remained strongly negative across all regions through 2018. In 2019, there was some recruitment and recovery in WPWS and to a lesser degree in KEFJ and KATM, although still negative. However, KBAY continues to show no signs of recovery yet. There could be some lag in recovery in KBAY

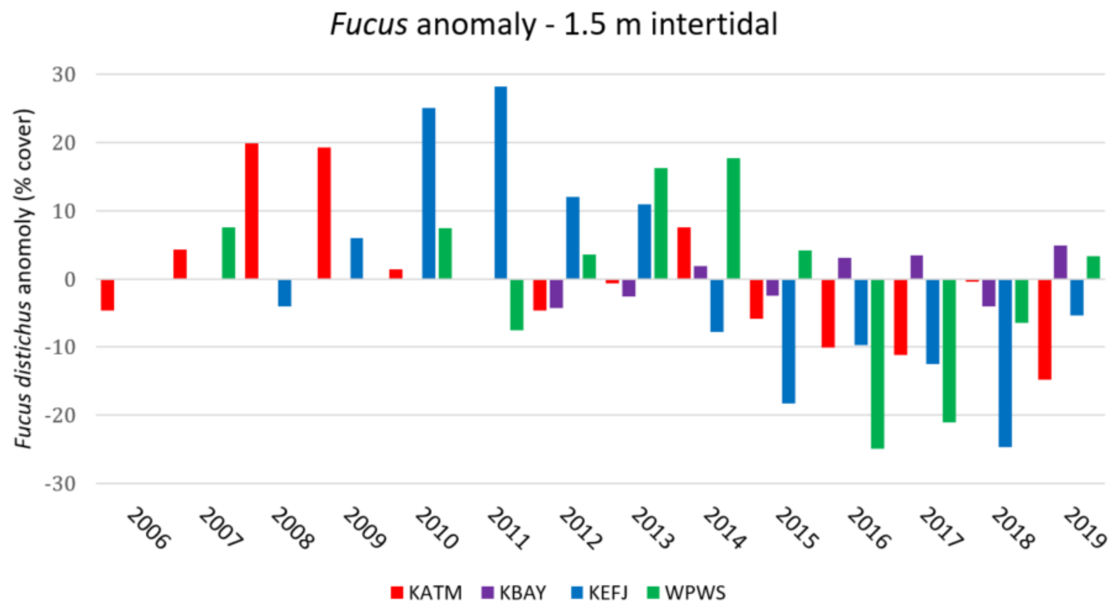

Figure 36: Percent cover anomalies for rockweed (*Fucus distichus subsp. evanescens*) in four regions of the western Gulf of Alaska, WPWS (2007, 2010–2019), KEFJ (2008–2019), KBAY (2012–2017), and KATM (2006–2010, 2012–2019).

as sea star wasting disease seemed to move across the Gulf of Alaska from east to west, with first records in WPWS, then KEFJ, and then KBAY (Konar et al., 2019).

Factors influencing observed trends: The negative anomalies of rockweed in three of the four regions and sea stars across all regions are coincident with warm water temperatures in nearshore areas. The decline in sea star abundance was likely due to sea star wasting disease (Konar et al., 2019), first detected south of Alaska in 2014 and generally associated with warm water temperature anomalies (Eisenlord et al., 2016). The positive anomalies during 2015–2019 for large mussels are possibly in part a response to the reduced predation pressure given the synoptic decline of sea stars. Continued positive anomalies of large mussels, particularly in KATM, coincide with continued negative anomalies of sea stars in this region.

Implications: Collectively, these indicators demonstrate consistent, large scale perturbations of nearshore ecosystems throughout much of the western Gulf of Alaska, including areas both inside (WPWS, KBAY) and outside (KEFJ and KATM) of protected marine waters. The three indicators signal community level effects correlated with changing water temperatures and ecological processes. The decline in *Fucus distichus* suggests habitat loss for settlement of new mussel recruits but also decreased competition for space with larger mussels. *Fucus* trends also reflect a reduction in nearshore sources of primary productivity.

An array of nearshore predators, including invertebrates, seabirds and terrestrial and marine mammals, utilize mussels as habitat and prey. As predatory sea stars decline and mussels increase in size and abundance, we expect nearshore predators like sea otters, black oystercatchers and sea ducks will benefit from this increase in prey.

Intertidal and nearshore ecosystems provide valuable habitat for early life stages of various commercially important species in the Gulf of Alaska, including Dungeness crab, Pacific cod, salmonids and

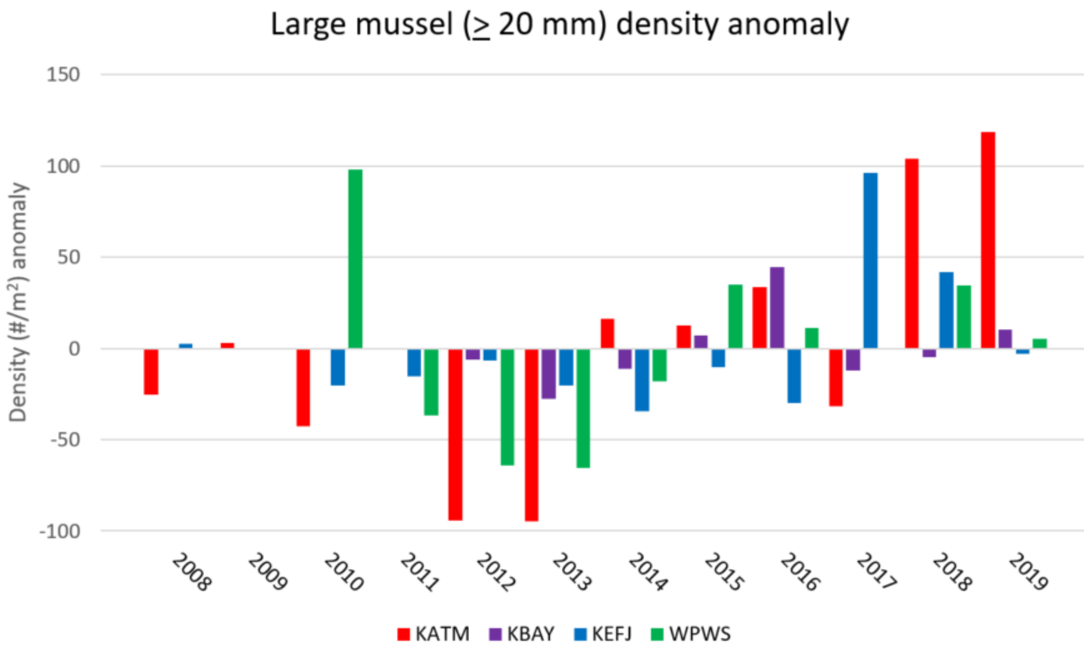

Figure 37: Density anomalies for large mussels (>20 mm) in four study regions spanning the northern Gulf of Alaska. WPWS (2010–2019), KEFJ (2008–2019), KBAY (2012–2019), and KATM (2008–2010, 2012–2019).

several species of rockfish. Our indicators suggest that some nearshore biological responses to the heatwave appear to continue into 2019, and could possibly affect future recruitment and survival of species whose life stages rely on nearshore habitat. A new marine heatwave is forming in the Pacific that will likely impact these coastal ecosystems (Cornwall, 2019), which our data supports With these perturbations, we also expect to see responses of nearshore-reliant species (such as sea otters and sea ducks) to shifts in prey availability from changing ocean conditions across the Gulf of Alaska.

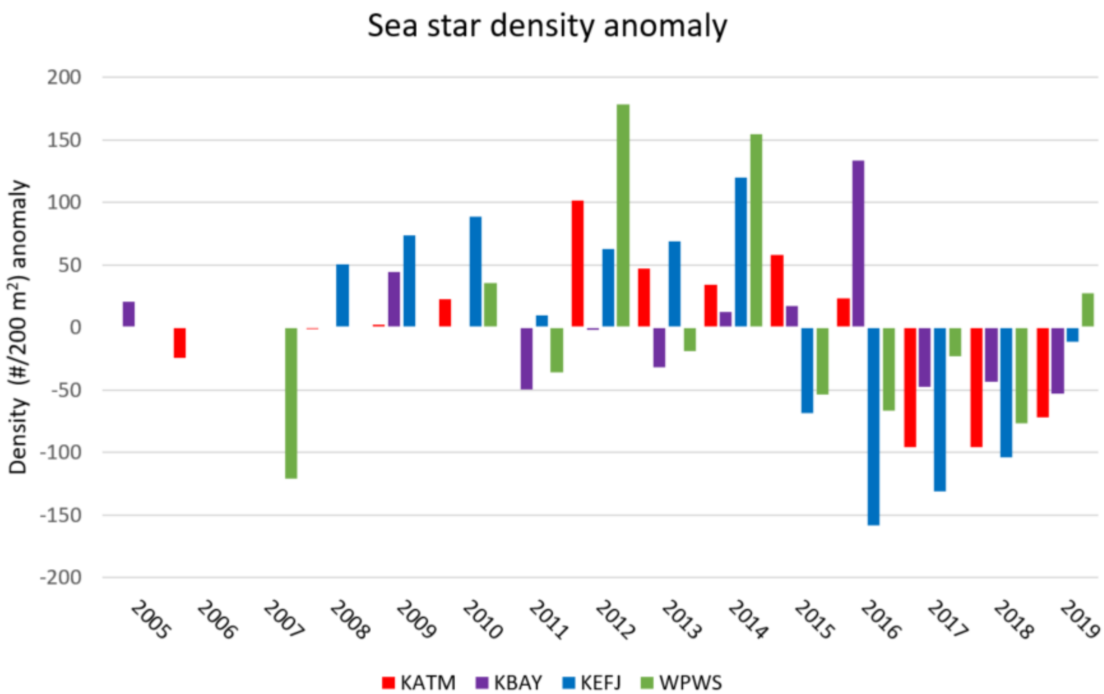

Figure 38: Abundance of sea stars (*Dermasterias imbricata*, *Evasterias troschelii*, *Pisaster ochraceus*, and *Pycnopodia helianthoides*) in four study areas spanning the northern Gulf of Alaska. WPWS (2007, 2010–2019), KEFJ (2008–2019), KBAY (2005, 2009, 2011–2019), and KATM (2006, 2008–2010, 2012–2019).

Primary Production

Satellite-derived Chlorophyll *a* Trends in the Gulf of Alaska

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Last updated: September 2019

Description of indicator: We viewed 14 day composites of satellite chlorophyll *a* (chla) data (MODIS, accessed via `http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMBchla14day.html` for the eastern, central and western Gulf of Alaska (GOA) throughout the growing season (March–August) of 2006 through 2019. Each composite was averaged within each month and each National Marine Fisheries Service (NMFS) statistical area for the western GOA (WGOA), 610; eastern GOA (EGOA), 640–650; and central GOA (CGOA), 620–630 `https://alaskafisheries.noaa.gov/maps`. Chla (used as a proxy for phytoplankton biomass) generally represents available food to secondary consumers like zooplankton and larval fish. Satellite data, while often hampered by cloud cover in this region, can still help reveal big picture trends in production. During spring, a large bloom occurs once the upper surface of the water column stratifies, and light intensity becomes strong enough to support it. This bloom takes advantage of higher nutrient stores remaining in surface waters after winter storms when phytoplankton activity is low.

Status and trends: Chla is highly variable on both monthly and annual time scales, with timing of the spring chla maximum usually occurring during April or May. The spring maximum during 2018 occurred during April across all regions, with a particularly significant bloom in the CGOA. By contrast, chla activity during early (March–May) 2019 seems to be low overall (Figure 39), with a particularly late bloom for the CGOA and WGOA that did not show up until about June. The EGOA bloom occurred earlier during May, but was still particularly low (Figure 40). The standardized anomaly is about average during both spring and summer for the EGOA region, while the central and western regions were below average during spring, (relative to the 2007–2019 run), and above average in mid-late summer (Figure 39).

Factors influencing observed trends: During summer, the strength and frequency of summer storm events and water column stratification will influence the amount of nutrients that are brought to surface waters from depth. Diminished nutrient stores leading to lower production in the upper water column may directly affect food stores for higher trophic levels and lead to slowed growth of larval fish during summer months.

Implications: Chlorophyll can be viewed as a proxy of energy available at the base of the food web. Concentrations of chla collected during NOAA surveys during late August have shown a strong relationship with age-2 recruitment of sablefish (Yasumiishi et al., 2015). Despite the fact that satellite data comes with some caveats (i.e. cloud cover issues, and unknown species or harmful algal bloom status), chla may be helpful in identifying years and months when food is plentiful for young fish. Chla conditions during 2019 in the GOA saw a late bloom overall, with low early season biomass, which could possibly affect some larval fish populations depending on their spawn timing and location (CGOA chla biomass was about average throughout the growing season, although bloom timing was later than normal).

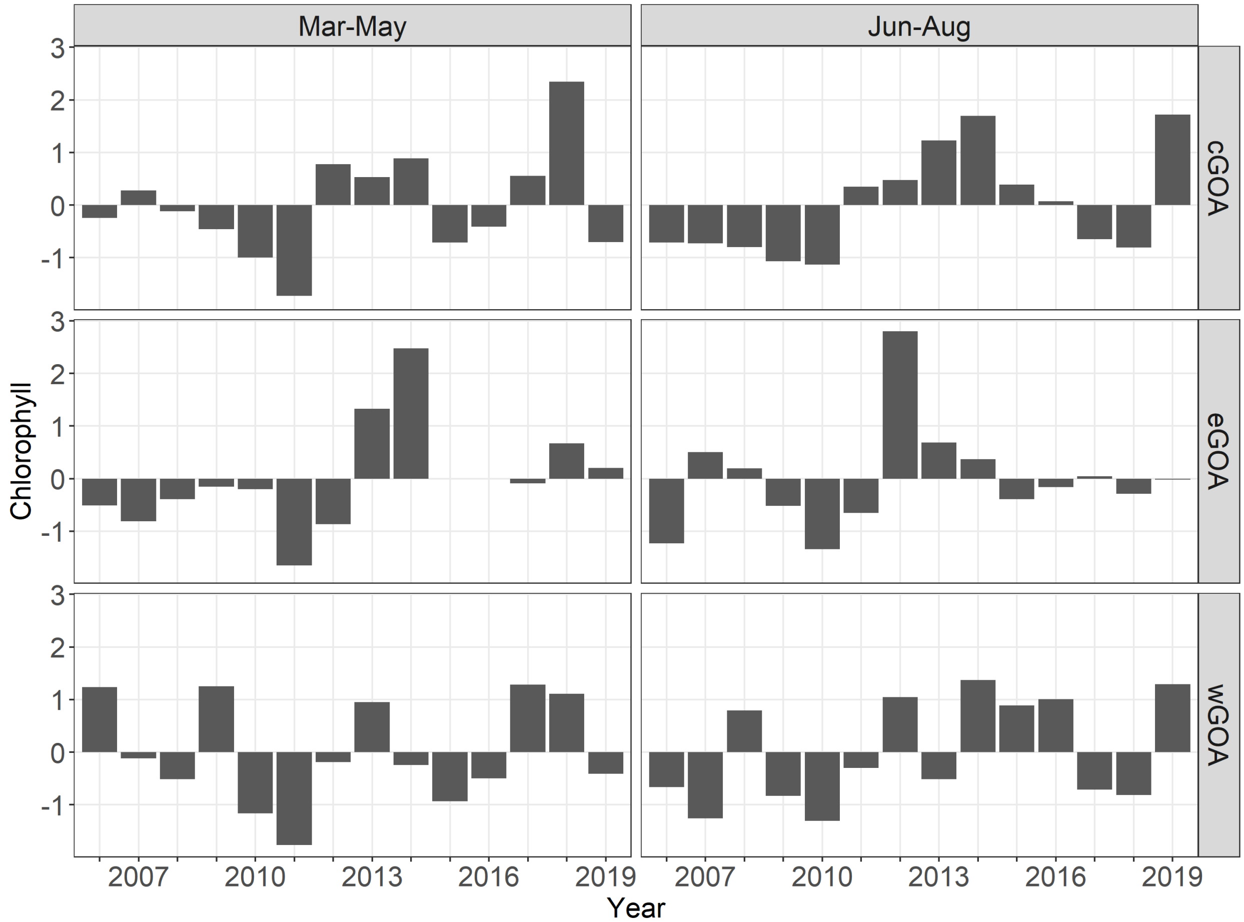

Figure 39: Standardized anomaly plot of chlorophyll biomass in the eastern, central, and western Gulf of Alaska during spring (Mar–May), and summer (Jun–Aug).

Zooplankton

Continuous Plankton Recorder Data from the Northeast Pacific, 2000–2018

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Last updated: August 2019

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 two regions

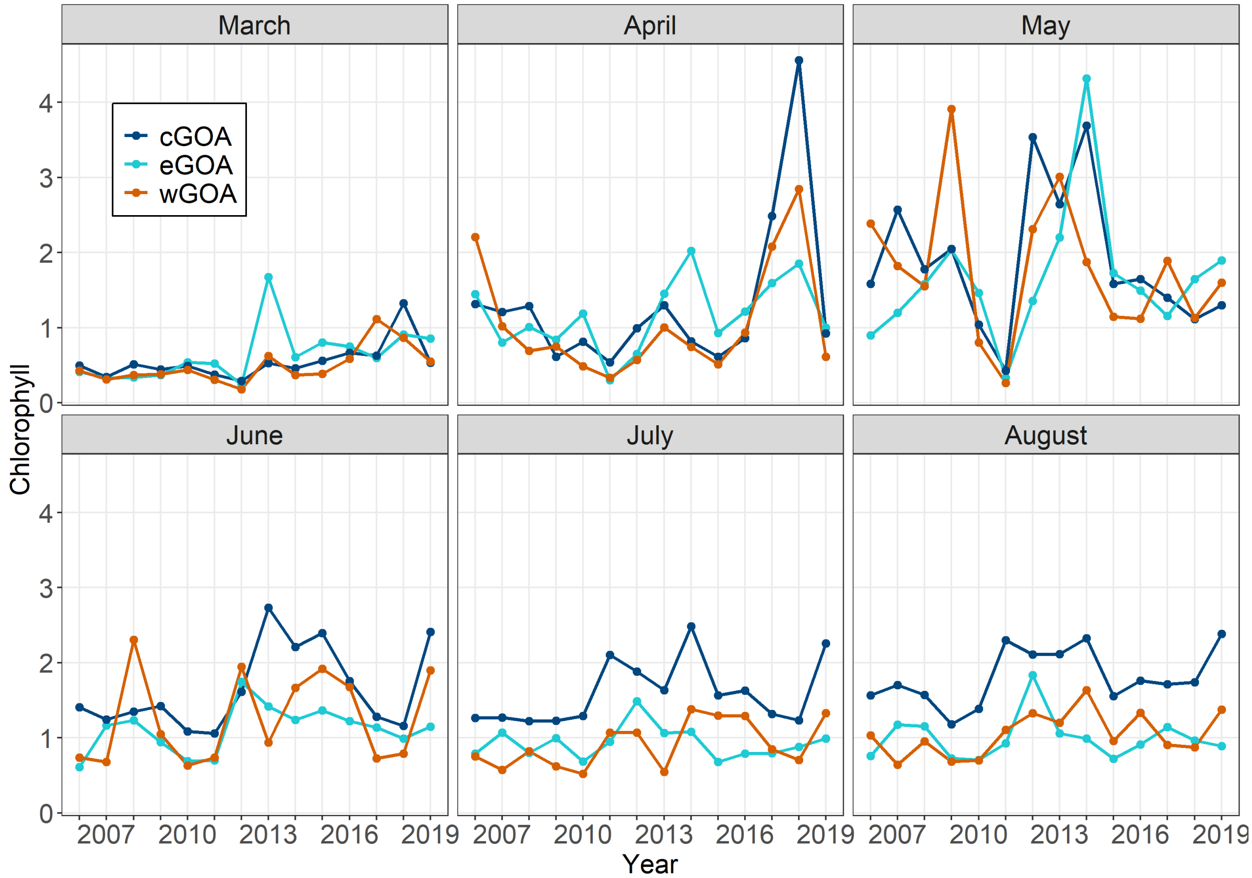

Figure 40: Chlorophyll concentrations for the eastern, central, and western Gulf of Alaska for the months of March through August.

(Figure 41); 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 month's 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 41). 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.

Status and trends: The diatom abundance anomaly for the shelf region was still positive in 2018,

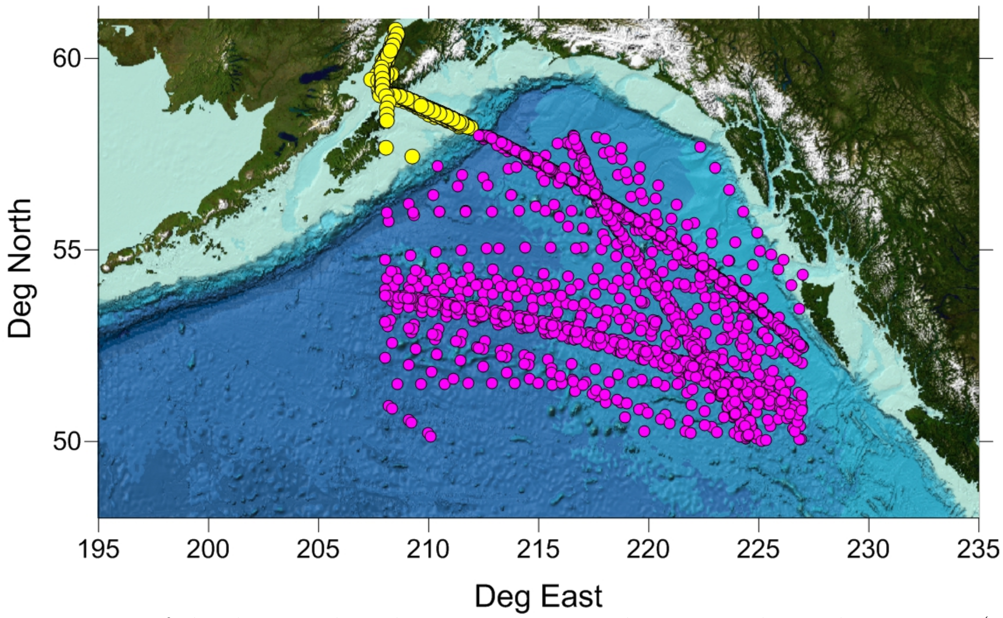

Figure 41: Location of the data used in this report. Dots indicate actual sample positions (note that for the shelf region the multiple transects overlay each other almost entirely).

but not as strongly so as in 2017 (Figure 42). The spring peak in 2018 was early, in April, and there were also higher than average abundances in July and September. In the open ocean the diatom abundance anomaly was still negative across most months, as it has been for most of the recent years. The copepod community size anomaly was slightly positive in the shelf region in 2018 and almost average in the open ocean. Zooplankton biomass anomalies were negative in both regions (strongly so in the open ocean), ending the run of positive values that had occurred.

Factors influencing observed trends: The Pacific Decadal Oscillation (PDO) monthly values were often negative in 2018 causing a lower annual mean value compared to the preceding years of 2014–2016, which had experienced a marine heatwave (Di Lorenzo and Mantua, 2016). 2017 was a transition year from positive to negative values. A particularly clear response in the lower trophic levels to this reversion was the return to a larger mean copepod community size. In warm conditions smaller species are more abundant; the community size index was negative throughout the marine heatwave period of 2014–2016, but turned positive in 2017, and remained so on the shelf in 2018 but neutral offshore. Somewhat of concern is the decline in zooplankton biomass in 2018, particularly in the open ocean. The main group affected here was the large copepods, which had their most negative abundance anomaly of the time series in 2018. Euphausiid numbers were also slightly negative, while other groups were near average abundance and pteropods were slightly positive. Large subarctic copepods have an annual life cycle and it may be that several successive years of lower than average diatoms in the offshore, and warmer than average conditions, have caused this reduction in numbers. Abundances were also lower than average in 2016 and 2017, though not as low as in 2018. On the Alaskan shelf, the decline in zooplankton biomass is mostly due to a drop in the numbers of small copepods to below average numbers (they had been numerous during the warmer years).

Implications: Each of these variables is important to the way that ocean climate variability is passed though the phytoplankton to zooplankton and up to higher trophic levels. Changes in

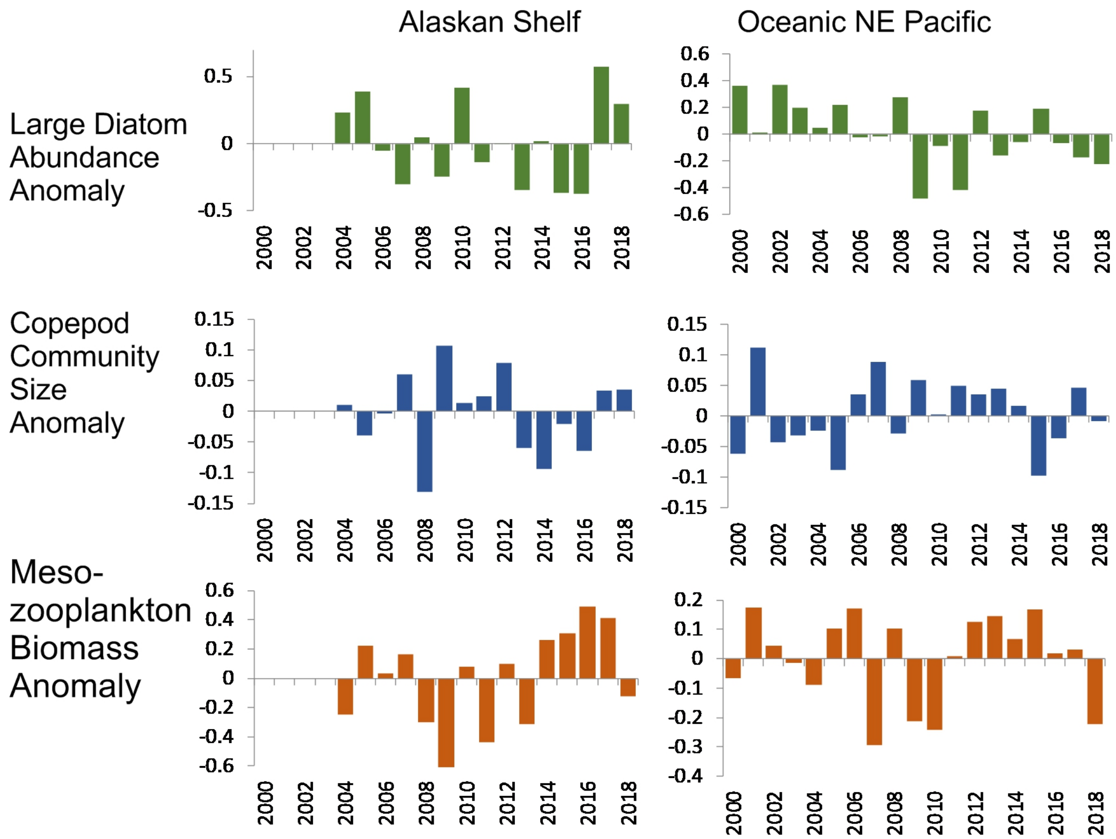

Figure 42: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for both regions shown in Figure 41. Note that sampling of the shelf region did not begin until 2004.

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 organisms to their predators. Changes in abundance or biomass, together with size, influences availability of prey to predators. The Alaskan shelf communities were closer to average in 2018 than in recent years, while the low zooplankton biomass in the offshore, particularly in the large copepod fraction which store lipids, suggests poor prey conditions for higher trophic levels which forage there.

Rapid Zooplankton Assessment in the Western Gulf of Alaska

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Last updated: September 2019

Description of indicator: In 2015, EcoFOCI implemented a method for an at sea Rapid Zooplankton Assessment (RZA) to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20/60 cm oblique bongo tows from 10 m from bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories are small copepods (< 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp. and *Oithona* spp.), large copepods (> 2mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids (< 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 μm mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 μm mesh, 60 cm bongo net. In 2016, the method was refined and personnel counted a minimum of 100 organisms per sample at sea to improve zooplankton estimates. Other, rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method. RZA abundance estimates should not be expected to closely match historical estimates of abundance as methods differ between laboratory processing and ship-board RZA. Rather, RZA abundances should be considered estimates of relative abundance trends overall. A detailed comparison of RZA data versus historical, laboratory processed data will be forthcoming in the next year. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1+ years post survey). The GOA RZA was conducted on two surveys: 1) from 5 May to 25 May 2019 (spring) and 2) from 13 Aug to 14 Sep 2019 (summer).

To provide comparisons for yearly RZA data, a long-term time series was developed from archived data. The mean, annual abundance of each RZA category was plotted for "Line 8" (an area approximately bounded by 57.46–57.73°N and 154.67–155.30°W) in the Shelikof Strait, Gulf of Alaska from 1990–2017 and represented May/June sampling (spring). For summer, mean, annual abundance of each RZA category was plotted for the primary grid area southwest of Kodiak Island (an area approximately bounded by 54–58°N and 155–160°W) from 2000–2017 (where data were available) and represented Aug/Sep sampling.

Status and trends: In 2019, large copepods had high abundances in the SW area of the survey grid and near Kodiak Island in spring (Figure 43). Large copepod abundances remained similar in summer and large zooplankton abundances were patchy (Figure 43). Compared to historical abundances of large copepods at Line 8, 2019 abundances were lower in magnitude compared to the long-term estimates and were similar to 2013 (Figure 44). Small copepods were abundant throughout the sampling area in spring, and their abundances increased during summer (Figure 43).

Small copepods showed very little interannual variability in spring and summer abundance and 2019 values were similar to the long-term estimates (Figure 44). Euphausiid juvenile stages had low abundances during spring, with areas near Kodiak Island having higher numbers. Euphausiid abundances were low overall during summer, but were more widespread than the spring (Figure 43). Euphausiid abundances in 2019 appeared to be much lower than historical estimates in spring in general, similar to what was seen in 2013 (Figure 44).

Factors influencing observed trends: Large zooplankton abundances were similar to those observed in 2015, suggesting that the increased warming present in the system again affected large copepod numbers. Specifically, the warmer temperatures may have accelerated the entry into diapause for the larger copepods *Neocalanus cristatus* and *N. plumchrus/flemingeri* lowering overall large copepods numbers. We also observed low abundances of the other large copepod, *Calanus marshallae*, in contrast to 2017 when high abundances of this copepod were observed. Overall decline in *C. marshallae* could also be a result of a switch in phenology or a response to changes in system productivity. The exact mechanism remains unclear. Small copepod numbers remained high

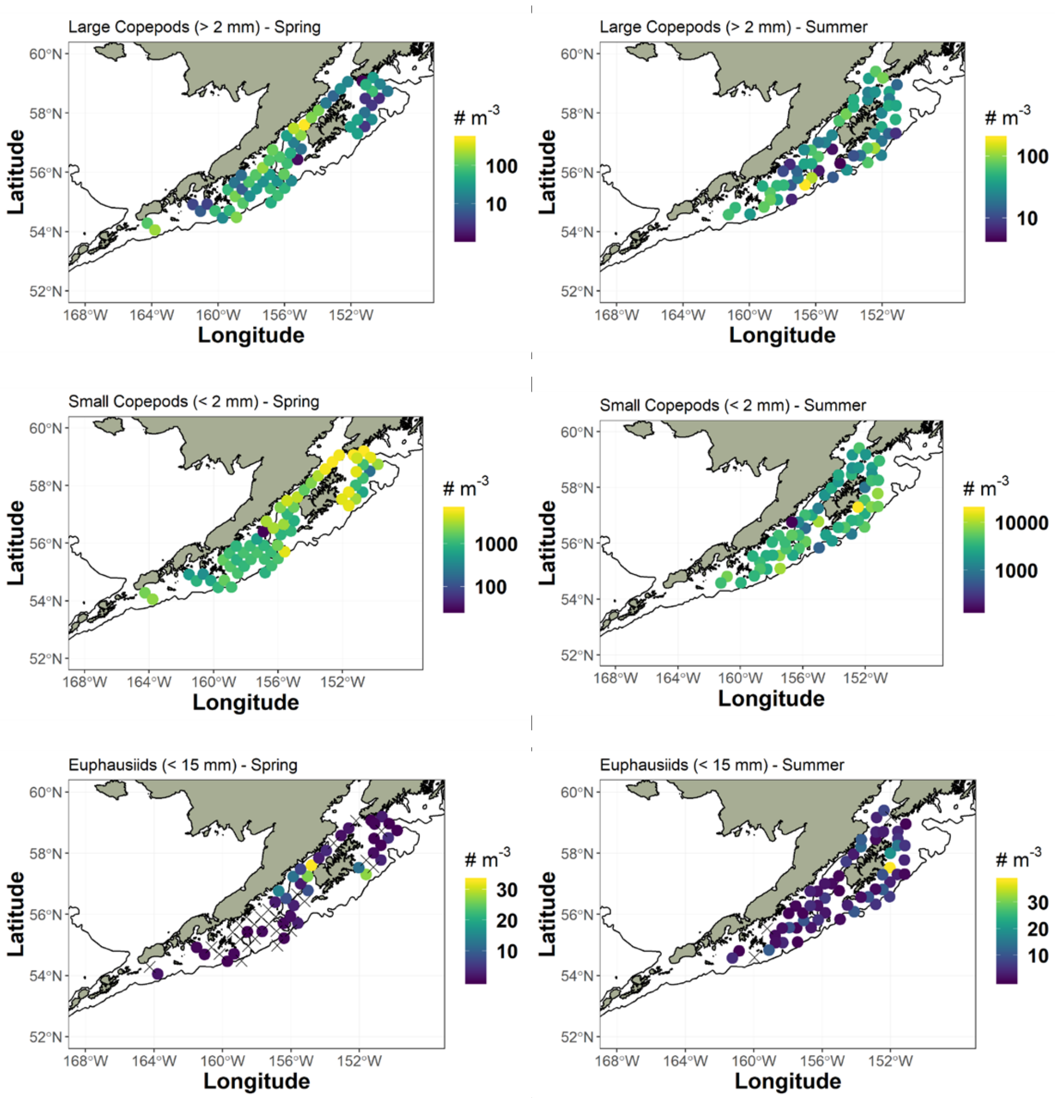

Figure 43: Maps show the spring (left) and summer (right) abundance of large copepods, small copepods, and euphausiid larvae/juveniles estimated by the rapid zooplankton assessment. Note all maps have a different abundance scales (No. m^{-3}). X indicates a sample with abundance of zero individuals m^{-3}.

during both spring and summer. Small copepod abundances appear to be less impacted by warming as opposed to the larger copepods. This makes sense with respect to life history characteristics of small copepods, e.g. multiple generations per year, faster turnover times, and metabolic rates that

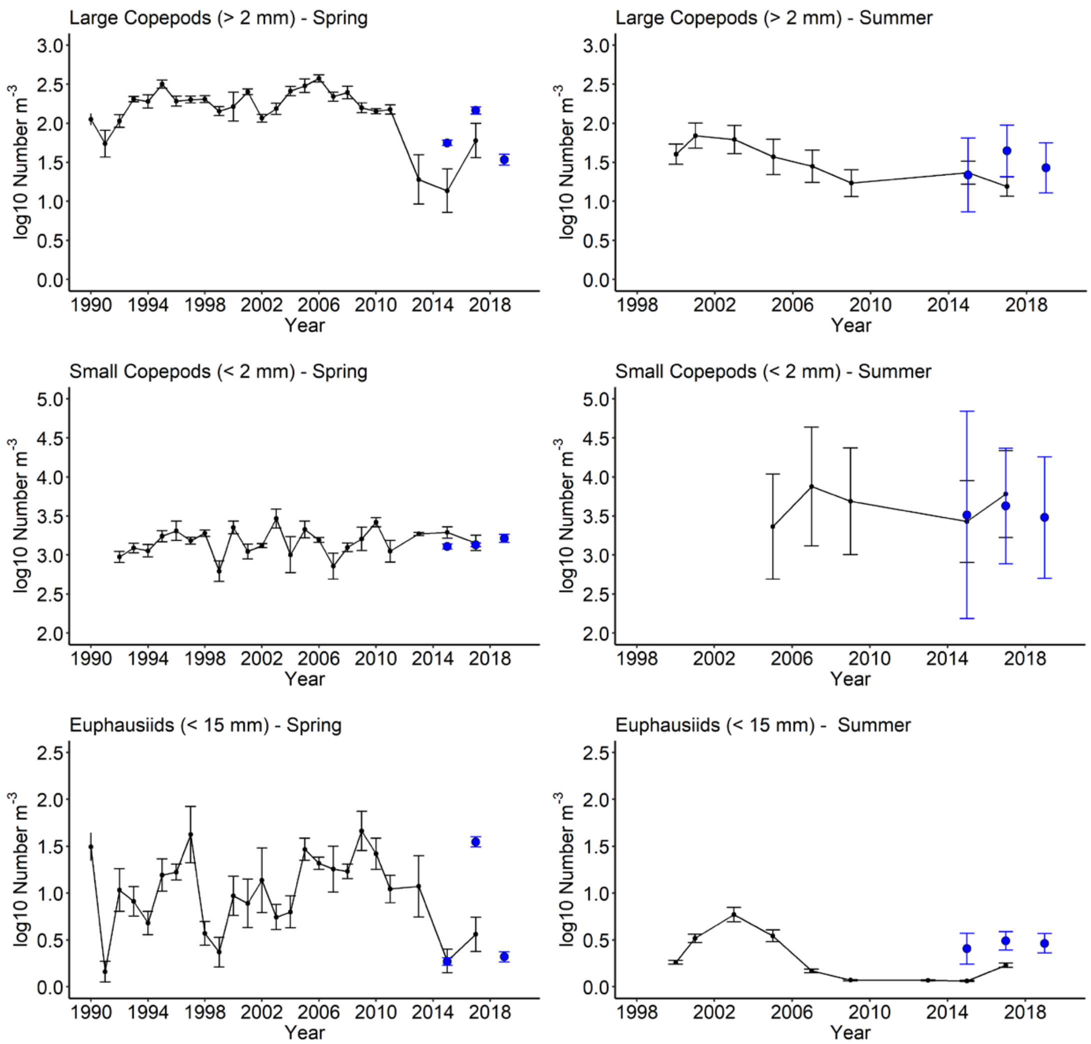

Figure 44: Spring (left) and summer (right), annual, mean abundance of large copepods, small copepods, and euphausiids in the Gulf of Alaska, FOCI sampling region. Black points and lines represent FOCI archived data from the Line 8 region, blue points represent RZA data from spring sampling across the Gulf of Alaska in 2015 and 2017. Error bars represent standard error of the mean.

scale less dramatically with temperature. The significant decline in euphausiid numbers during the spring can be partially explained by the development of euphausiids resulting in larger sized individuals that can effectively avoid the 60 cm bongo net. Further comparison with the acoustically determined euphausiid estimates may determine if low euphausiid numbers in spring are correlated to summer, adult abundances.

Implications: Zooplankton are an important prey base for larval and juvenile fish in spring and summer. Small copepod numbers remained high during spring and this indicates that there is likely significant number of nauplii and smaller copepods available as prey for larval fish. The lack of large copepods is less relevant in spring for larval fish; however, it may indicate that the system timing for larger copepods is changing or may indicate shifts in overall productivity. Finally, small euphausiid numbers are variable in the spring, but both 2015 and 2019 had very low numbers overall, suggesting that warming results in reduced euphausiid abundances during spring. The stable large copepod abundances over time in summer suggest the standing stock of primarily *C. marshallae* remains unchanged regardless of spring conditions. Similarly, despite high variability over time in spring, euphausiid numbers in the summer remain low, suggesting that the larger euphausiid index derived from acoustics is more applicable as an indicator in summer.

Gulf of Alaska Euphausiid ("krill") Acoustic Survey

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Last updated: October 2019

Description of indicator: The Gulf of Alaska survey of the abundance and distribution of euphausiids ("krill", principally *Thysanoessa* spp.) has been developed (Simonsen et al., 2016) based on methods used by Ressler et al. (2012) in the Bering Sea. The survey incorporates both acoustic and Methot trawl data from summer Gulf of Alaska acoustic-trawl surveys for pollock conducted in 2003, 2005, 2011, and biennially since 2013 by NOAA-AFSC. Acoustic backscatter per unit area (s_A at 120 kHz, m^2 nmi^{-2}) classified as euphausiids was integrated over the water column and then across the surveyed area to produce an annual estimate of acoustic abundance (s_A * area, proportional to the total abundance of euphausiids). Approximate 95% confidence intervals on these estimates were computed from geostatistical estimates of relative estimation error (Petitgas, 1993). Though surveys since 2013 have covered the shelf from the Islands of Four Mountains to Yakutat (Figure 45), the index reported here is limited to areas around Kodiak that have been consistently sampled in all years of the time series (Figure 46). In those years since 2013 with consistent survey coverage, interannual changes in mean krill s_A in the consistently sampled area were positively correlated with those in the whole surveyed area (r^2= 0.37, n= 4 surveys). Net collections from euphausiid scattering layers in 2011, 2013, and 2015 have been numerically dominated by euphausiids and show that *Thysanoessa inermis*, *T. spinifera*, and *Euphausia pacifica* with average length ~19 mm are the most commonly encountered species (Simonsen et al. 2016, Ressler unpublished data).

Status and trends: Results indicate that highest abundance of euphausiids in the time series was observed in 2011 and the lowest in 2003 (Figure 47). There was a modest increase in 2019 from the previous update in 2017, but the 2019 value is the third lowest in the time series. Barnabas Trough appears to be a local hotspot, as observed in previous surveys (Simonsen et al., 2016). Final species and length composition data from summer 2019 Methot trawls are not yet available.

Factors influencing observed trends: Factors controlling annual changes in euphausiid abun-

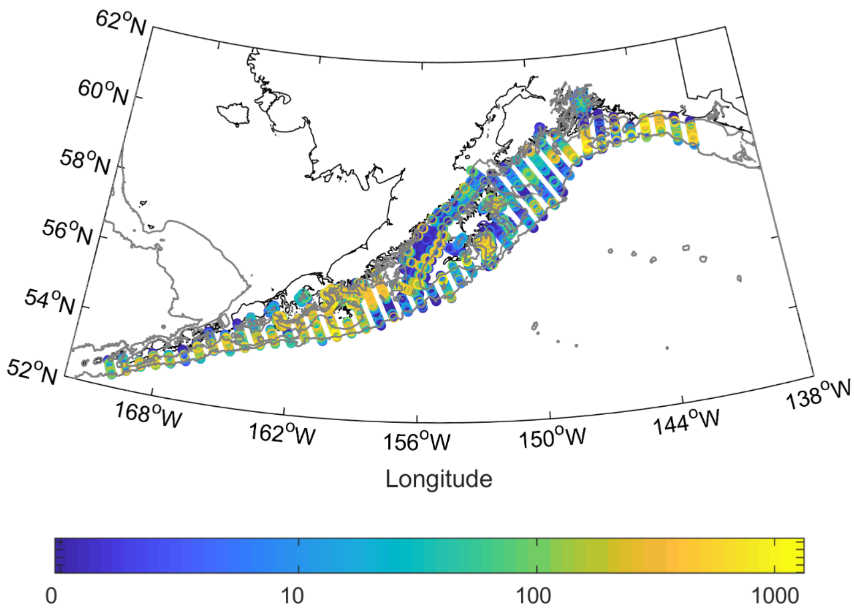

Figure 45: Spatial distribution of acoustic backscatter density (s_A at 120 kHz, m^2 nmi^{-2}) attributed to euphausiids in the entire GOA survey area during the 2019 Gulf of Alaska summer acoustic-trawl survey.

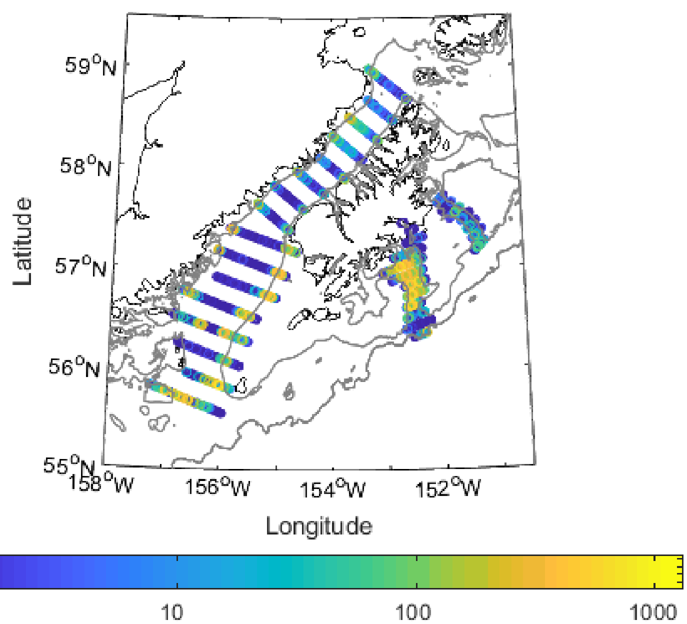

Figure 46: Spatial distribution of acoustic backscatter density (s_A at 120 kHz, m^2 nmi^{-2}) attributed to euphausiids in the consistently sampled areas around Kodiak Island (Shelikof Strait, Barnabas Trough, and Chiniak Trough) during the 2019 Gulf of Alaska summer acoustic-trawl survey.

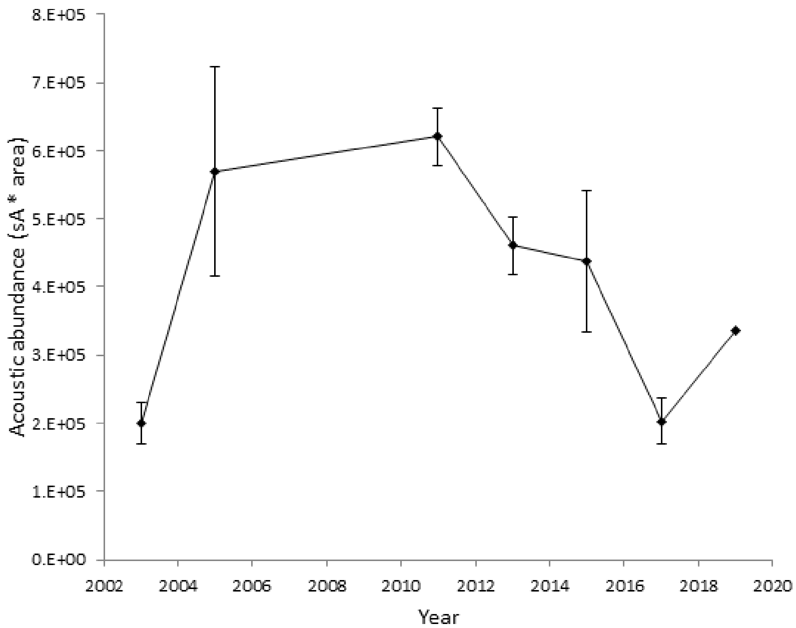

Figure 47: Acoustic backscatter estimate of euphausiid abundance from NOAA-AFSC Gulf of Alaska summer acoustic-trawl survey. Error bars are approximate 95% confidence intervals computed from geostatistical estimates of relative estimation error (Petitgas, 1993).

dance are not well understood; possible candidates include bottom-up forcing by temperature and food supply, and top-down control through predation (Hunt et al., 2016). When factors including temperature, pollock abundance, primary production, and spatial location have been considered in spatially-explicit multiple regression models, increases in euphausiid abundance have been strongly correlated with cold temperatures in the eastern Bering Sea (Ressler et al., 2014), but not in the GOA (Simonsen et al., 2016). Euphausiid abundance is not strongly correlated with the abundance of pollock (a major predator) in statistical models of observations from either system.

Implications: The results presented here suggest an increase in euphausiid prey availability since 2017, though the value is still low relative to the mean of the time series. Euphausiids are a key prey species for fish species of both ecological and economic importance in the Gulf of Alaska, including walleye pollock (*Gadus chalcogrammus*), Pacific Ocean perch (*Sebastes alutus*), arrowtooth flounder (*Atheresthes stomias*), capelin (*Mallotus villosus*), eulachon (*Thaleichthys pacificus*), and as well as many species of seabirds and marine mammals.

Spring and Fall Large Copepod and Euphausiid Biomass along the Seward Line

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Last updated: October 2019

Description of indicator: Transects have been completed south of Seward Alaska typically during the first 10 days of May and during mid-September for over 2 decades to determine species composition, abundance and biomass of the zooplankton community. Data are 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 (a.k.a. krill) retained by a 0.5 mm mesh net. These categories represent key prey for a variety of fish, marine mammals and seabirds.

Status and trends: Large calanoid copepod biomass in May 2019 was substantially lower than it has been 2015–2018. Euphausiid biomass during May 2019 was also below average, while euphausiid biomass during September 2018 was among the highest in the time series (Figures 48 and 49).

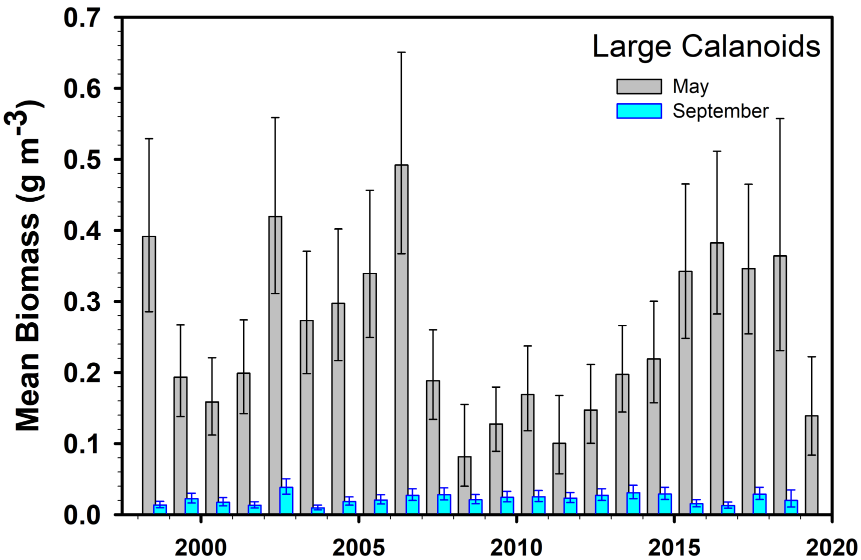

Figure 48: Biomass of Calanoid copepods along the Seward Line sampled using a 0.5 mm mesh at night. Transect means and 95% confidence intervals are calculated on power-transformed data.

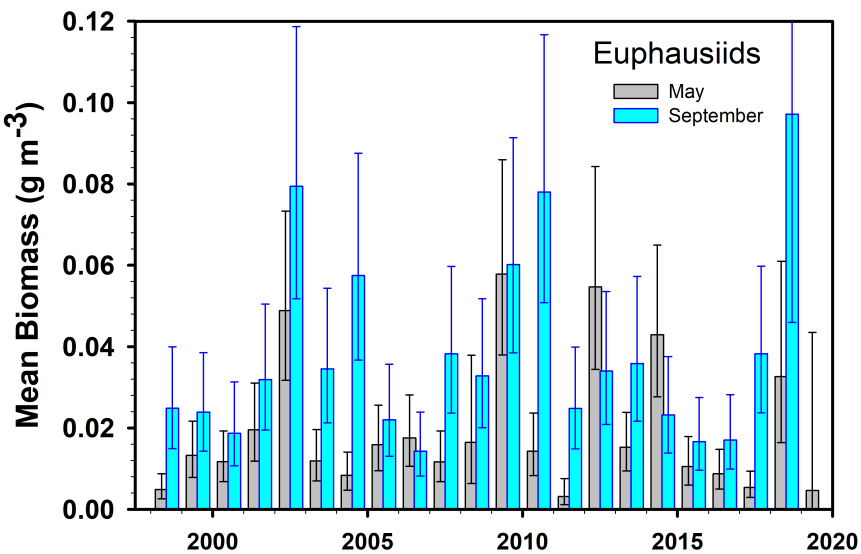

Figure 49: Biomass of Euphausiids along the Seward Line sampled using a 0.5 mm mesh at night. Transect means and 95 confidence intervals are calculated on power-transformed data.

Factors influencing observed trends: May of 2019 was $\tilde{0}.6$°C above the 20-year mean along the Seward Line and remained well above average for the entire summer (see p.59). Large copepod biomass during May often 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. By September most large calanoids have descended into offshore waters, and their biomass is greatly reduced. 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. Preliminary May data for 2019 suggests low calanoid biomass despite above average temperatures.

In contrast, May euphausiid biomass appears to be negatively impacted by warm springs, with peaks in May often driven by high abundances of their larval stages when conditions are favorable (as was the case in 2018). Continued growth and recruitment often leads to higher biomass by September. The warm springs of 2015 and 2016 corresponded with low euphausiids biomass, that began to recover during 2017 and 2018, but once again appears to have been impacted by the warm spring temperature during 2019.

Implications: 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 below average during May 2019, one might expect prey resources to be limiting to vertebrate predators for the remainder of 2019.

Zooplankton trends in Prince William Sound

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Last updated: August 2019

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 more expensive. Observations were $\log_{10}$+1 transformed and averaged by month and subtracted from the monthly average to produce an anomaly.

Status and trends: Zooplankton abundance was extremely variable. Nine years is not a particularly long time series, but 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 50, top panel), species assemblages shifted, with warm water copepod species becoming much more prevalent during the marine heatwave years (Figure 50, bottom panel), while the abundance of cool water species was lower than average (Figure 50, middle panel). In 2018, generally higher than average abundances of zooplankton were observed in Prince William Sound (Figure 50), and zooplankton assemblages returned to conditions more similar to those prior to the marine heatwave, with cool water species predominating and warm water species more rare.

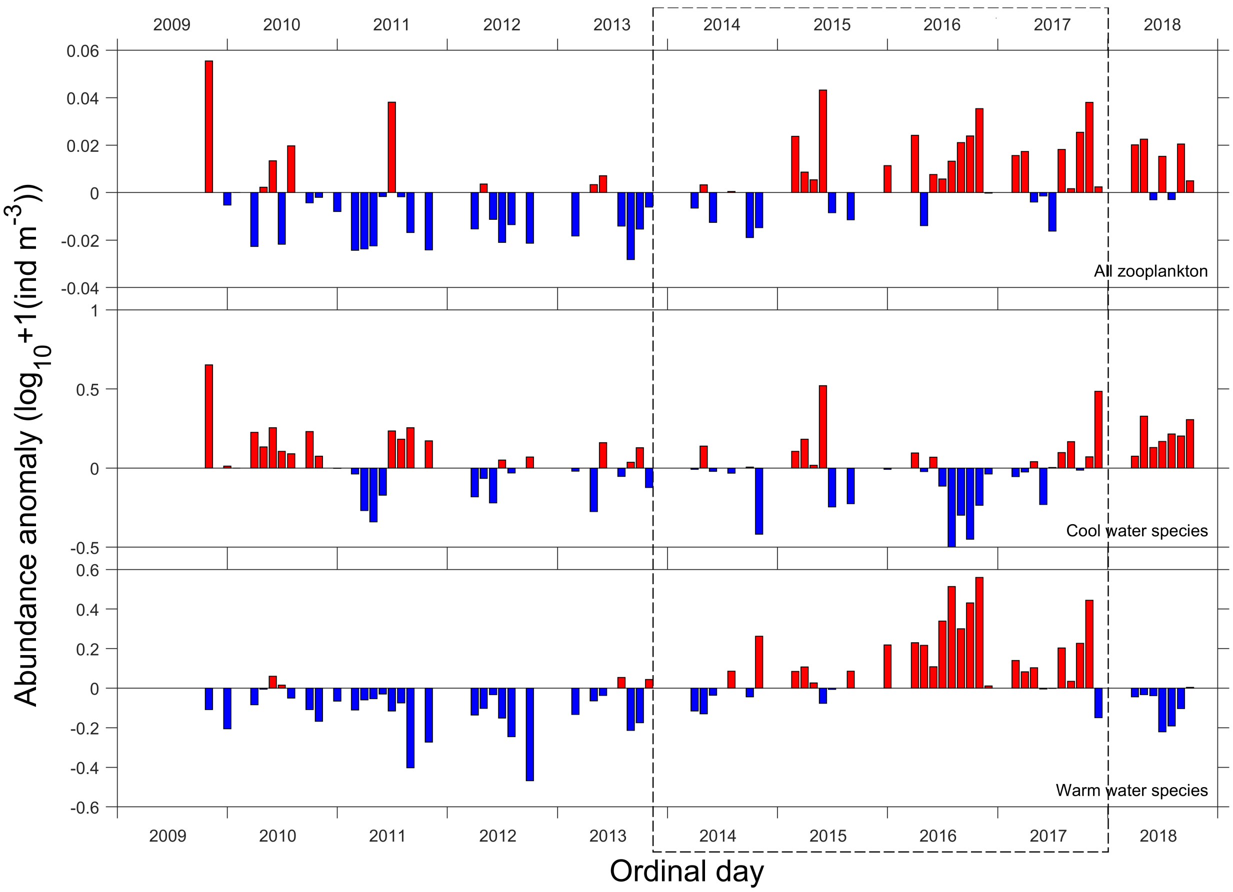

Figure 50: Abundance anomalies of all zooplankton (top panel), warm water copepod species (bottom panel) and cool water copepod species (middle panel) in PWS, 2010–2018. The dashed box includes the 2014–2016 heatwave. Observations were $\log^{10}+1$ transformed and averaged by month and subtracted from the monthly average to produce an anomaly; no detrending was done. Warm water and cool water species were those identified as indicative by Fisher 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*.

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, which influences what species are present in PWS and therefore, influences the prey field for predators. Warm-preferring copepod species are generally more common within PWS than on the adjacent shelf and PWS may act as a "refuge" for those species. The increase in the relative abundance of warm water copepods during the marine heatwave years may have been in part because those species may have subsisted in low numbers in PWS and then grew and reproduced better during the marine heatwave years. Early copepodid stages of the warm water copepod species were also observed, indicating that local reproduction (as opposed to transport) was involved. Conversely, cool water species may have been at a competitive disadvantage during those years.

Implications: Abundance of copepod species have been identified as characteristic of warmer or cooler waters. “Warm” water species are generally common in the southern portion of the Gulf of Alaska and are smaller bodied, and possess smaller lipid reserves. “Cool” water species are more common in 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 fishes and juvenile groundfish. Zooplankton species assemblages change much more slowly than temperature, and lag temperature changes by several years. The continued warming trend (and likelihood of heatwave events in future) in the PWS region will likely result in the plankton assemblage of the region shifting towards smaller-bodied forms with lower lipid content, which will represent a lower quality food source to larval and juvenile fishes of many types.

Zooplankton and Temperature Trends in Icy Strait, Southeast Alaska

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Last updated: September 2019

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 2019 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 12 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 ±1.0°C (Figure 51). The ISTI in 2019 was well-above average (10.0°C), the second warmest in the 23 year time series, only 0.01°C below the 2005 ISTI.

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 52). The 2019 total density of zooplankton was below average and showed a decrease from the 2018 total density. 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 = 0.2, P = 0.06).

Overall, the zooplankton community was numerically dominated by small ($\leq$2.5 mm length; $\leq$72% 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$3%). For 2019, small and large calanoid copepods and hyperiid amphipods decreased from 2018 densities and all were below average. Euphausiids and gastropods increased from 2018 densities. The euphausiids increased from below to above average, to the 5$^{\text{th}}$ highest density in the time series, and were mostly late stage larval euphausiids. A similar increase in euphausiid densities was observed in 2015 when water temperatures also dramatically increased, and increased in the consumption of euphausiids by juvenile was also noted in 2015.

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,

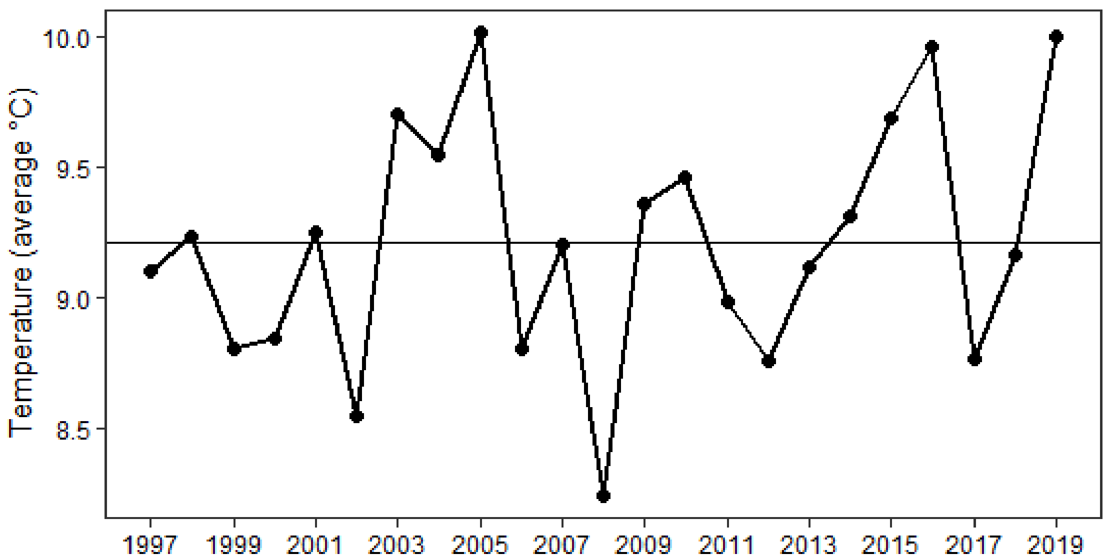

Figure 51: Mean annual Icy Strait Temperature Index (ISTI, °C, 20 m integrated water column, May–August) and 23-year mean ISTI (dashed line), for the northern region of SEAK from the Southeast Coastal Monitoring project time series, 1997–2019

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 reflect critical trophic interactions with respect to climate change more accurately, an analysis at the species level would be needed and should include a prey quality measure, such as % lipid.

Implications: The increase in euphausiids is beneficial to larval and juvenile fish that depend on these zooplankton as prey. The decrease in densities of the other zooplankton, especially small and large calanoid copepods indicates 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.

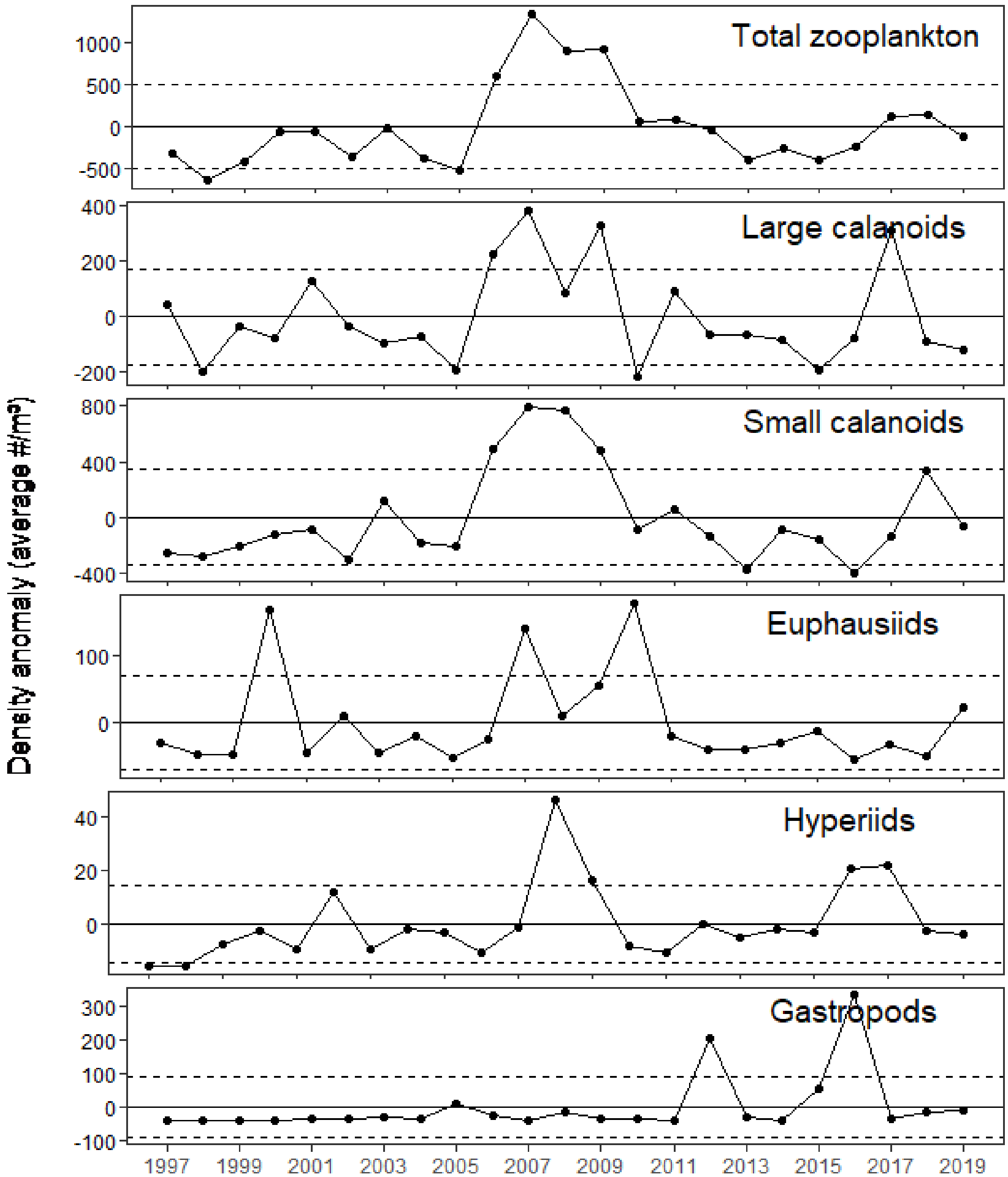

Figure 52: Average annual total zooplankton and taxa specific density anomalies for the northern region of SEAK (Icy Strait) from the Southeast Coastal Monitoring project time series, 1997–2019. One standard deviation above and below the mean is indicated by the dashed lines. Annual densities are composed 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 2019

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 2019 annual values of zooplankton lipid content for specific taxa in relation to the past 6 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 2019 decreased from 2018 lipid values (Figure 53). Trends from 2013 to 2019 for all taxa showed mean percent lipids ranging from ¡0.01% to 38%. In 2019, percent lipids for all zooplankton taxa decreased from above to below average. This decrease in lipid content indicates a decrease in the nutritional quality of the prey field utilized by larval and juvenile fish in Icy Strait. Additionally, the lipid content has decreased to the low lipid levels observed during the El Niño/Blob period of anomalously warm temperatures from 2014–2016 (Fergusson et al., 2017).

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 community's copepod population was observed after the 1990's 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 decrease in nutritional quality of zooplankton indicates unfavorable feeding conditions for larval and juvenile stages of many commercially and ecologically important species of fish that reside in Icy Strait, which may directly or indirectly affect fish growth and recruitment.

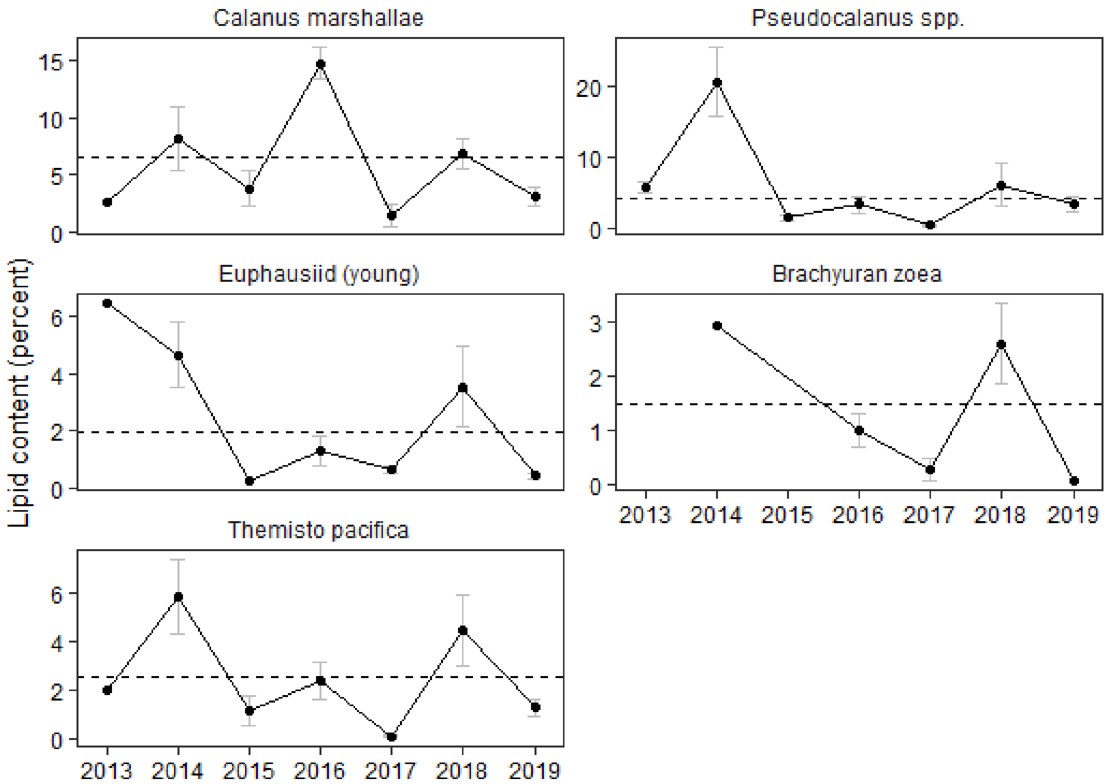

Figure 53: Average annual zooplankton lipid content (percent) from zooplankton collections in Icy Strait, AK by the Southeast Coastal Monitoring project, 2013–2019. Time series average is indicated by the dashed line.

Jellyfish

Jellyfish—Gulf of Alaska Bottom Trawl Survey

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Last updated: October 2019

Description of indicator: RACE bottom trawl surveys in the Gulf of Alaska (GOA) are designed primarily to assess populations of commercially important fish and invertebrates. However many other species are identified, weighed and counted during the course of these surveys and these data may provide a measure of relative abundance for some of these species. Jellyfish are probably not sampled well by the gear due to their fragility and potential for catch in the mid-water during net deployment or retrieval. Therefore jellyfish encountered in small numbers which may or may not reflect their true abundance in the GOA. The fishing gear used aboard the Japanese vessels that participated in all GOA surveys prior to 1990 was very different from the gear used by all vessels since. This gear difference almost certainly affected the catch rates for jellyfish. For jellyfish, the catches for each year were scaled to the largest catch over the time series (which was arbitrarily scaled to a value of 100). The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The percentage of positive catches in the survey bottom trawl hauls was also calculated.

Status and trends: The 2019 relative catch per unit effort (CPUE) of jellyfish was the highest ever observed during the survey time series in each of the five GOA regions (Figure 54). Compared to Kodiak and occasionally Yakutat, jellyfish are relatively in low abundance in the Shumagin, Chirikof, and Southeastern regions. However, there was a two to three fold increase in relative abundance in 2019 in these regions than during any previous survey. Relative abundance is typically higher in the Kodiak region and was again in 2019, however, the relative abundance in the Yaktat region was almost as great as the abundance in Kodiak. Prior to 2019, 1990 had the greatest relative cpue in the Kodiak, Chirikof, and Yakutat regions, but the cpue is two times greater in 2019 than in 1990. The frequency of occurrence in trawl catches is generally high but variable among all areas. However, 2019 has had the greatest percentage in all but the Southeastern region.

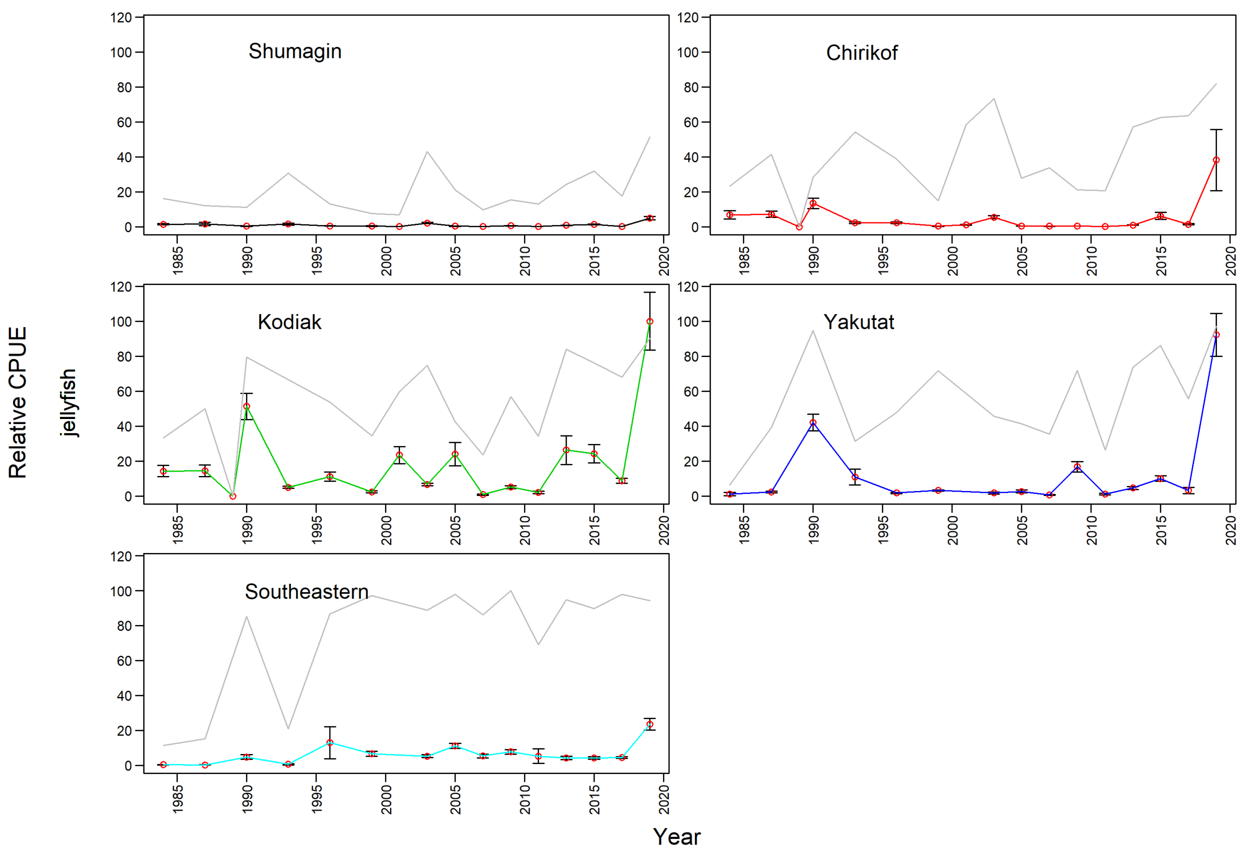

Figure 54: Relative mean CPUE of jellyfish species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2019. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

Factors influencing observed trends: Unknown

Implications: GOA survey results show a strong signal of high abundance in the GOA during 2019, and this trend is consistent among all regions. A similar high abundance was observed in

1990 but did not lead to a consistent high abundance during subsequent surveys.

Ichthyoplankton

Rapid Larval Assessment in the Gulf of Alaska

Contributed by Annette Dougherty, Alison Deary, and Lauren Rogers, EcoFOCI Program, Resource Assessment and Conservation Engineering, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: September 2019

Description of indicator: The 2019 EcoFOCI spring larval survey was conducted from May 6 to May 22 (approximately 7 days earlier than the 2017 survey). A total of 232 stations were sampled using the 60 cm bongo with 0.505 mm mesh. From the 60 cm bongos, net 1 was preserved in 1.5% formaldehyde for later identification, quantification, and length measurement of all larval fish species. Net 2 was used to acquire a rough count of larval fishes while at sea, known as the Rapid Larval Assessment (RLA), to determine a rough estimate of abundance and geographic distribution. In addition to providing a rough count for pollock larvae, which has been provided in past Ecosystem Status Report contributions, an additional five species were added to the RLA protocol including Pacific cod, southern rock sole, northern rock sole, rockfishes, and arrowtooth flounder to provide early data for more commercially important fish species. Initial rough counts were acquired by pouring the codend contents into a 4 liter beaker and removing a 10% subsample for sorting. Due to the low abundance of larval fishes, especially walleye pollock, in 2019, the entire codend was sorted at all stations for all larval fishes.

At-sea rough counts of larval walleye pollock have provided a rapid indicator of larval abundance (Dougherty and Rogers, 2017) and their utility for forecasting was one of the motivators to expand the RLA to include other commercially important fishes. For pollock, a comparison of abundance estimates using at-sea rough counts and laboratory counts from 2000–2015 indicate a strong correlation (r = 0.99). This comparison between the at-sea rough counts and the laboratory-based counts is not yet possible for the other species included in the RLA but will be assessed as these data become available in the future.

The larval walleye pollock samples removed from net 2 were preserved in alcohol or frozen for later determination of age, growth, hatch date distributions and cell cycle analysis. On every other survey line, a rapid zooplankton assessment (RZA) was conducted to determine prey abundance available to larval fish (see p.77). A Sea-Bird FastCat was used in conjunction with the bongos to acquire temperature and salinity profiles at all stations.

Status and trends: In 2019, the abundance of all assessed larval fishes within the main grid area (see polygon in map figures) was below average and low relative to 2017 (Figure 55). Overall, abundance and geographic distribution of larval fishes in 2019 was similar to that of 2015 (a "Blob" year) with the exception of larval rockfishes, which had decreased abundance in 2019 compared to 2015 especially along the shelf edge (Figure 56). Counts of larval walleye pollock from 2019 in the western Gulf of Alaska were below average throughout the entire survey grid with frequent zero catches and a distribution similar to that of 2015 (Figure 57). This is in contrast to 2017 when larval catches were average within the main grid area. Pacific cod were encountered in low abundances within the main grid, with a distribution similar to that of 2015 (Figure 58).

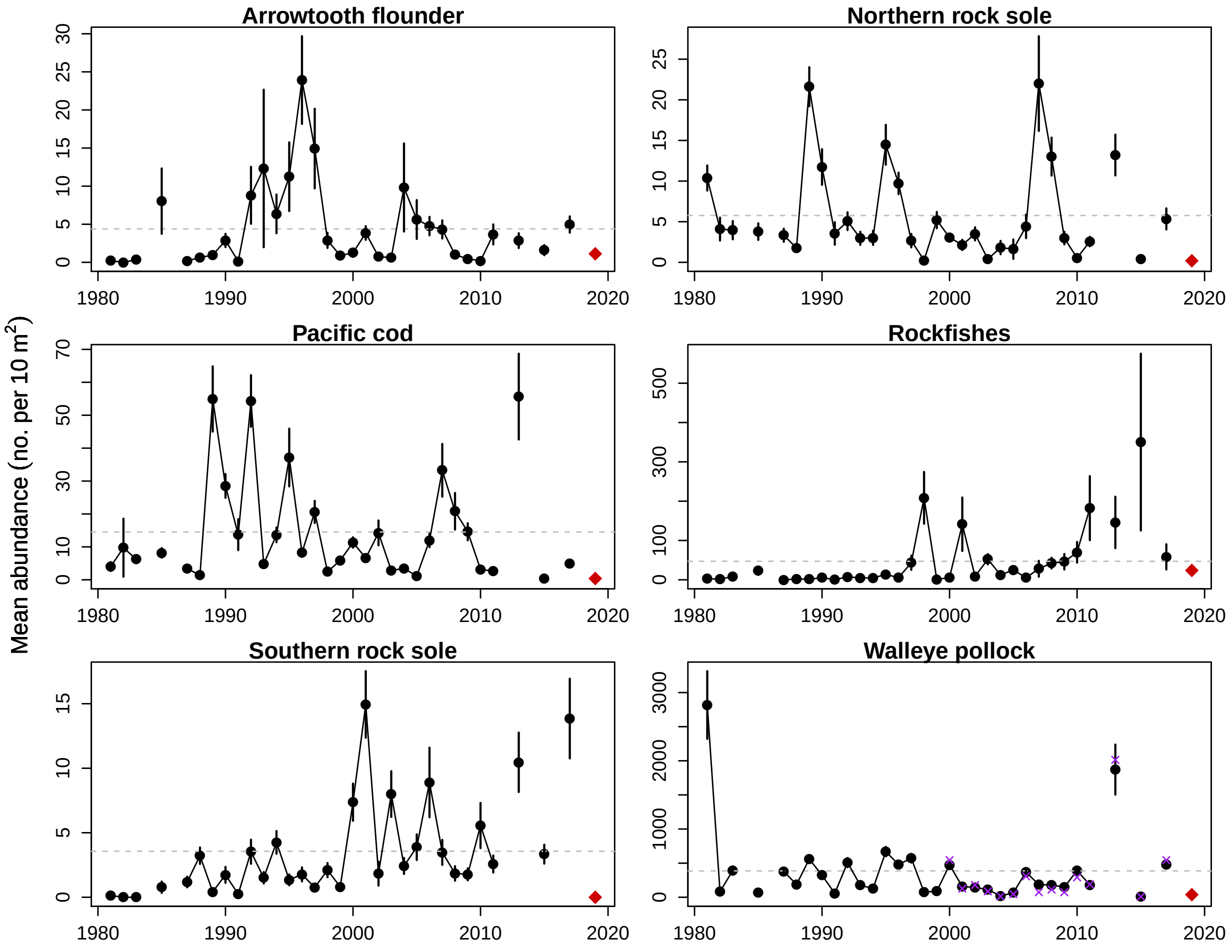

Figure 55: Interannual variation in late spring larval fish abundance in the Gulf of Alaska 1981–2019. Time-series of mean abundance within the main grid area for species included in the Rapid Larval Assessment (RLA) for 2019. Laboratory counts are denoted by black circles; the RLA estimate is the red diamond. Purple x's denote historical at-sea rough count estimates for pollock. 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, 2016, or 2018. Time-series may differ slightly from previous versions due to updating the spatial polygon used for selecting historical data.

Arrowtooth flounder larvae were typically encountered along the shelf edge in the southern part of the main grid. The abundance of larval arrowtooth flounder was lower in 2019 relative to 2015 and 2017, with no individuals encountered outside of the main survey grid (not shown). Northern rock sole and southern rock sole tended to have similar geographic distributions and abundances throughout the main grid until 2019 when southern rock sole were absent from the main grid (not shown).

Factors influencing observed trends: Thermal conditions during the spring larval survey were warmer than average at the surface, but more surprisingly, were warm at depth, similar to the warming at depth observed during the "Blob" in 2015. As in 2015, these warm conditions appear

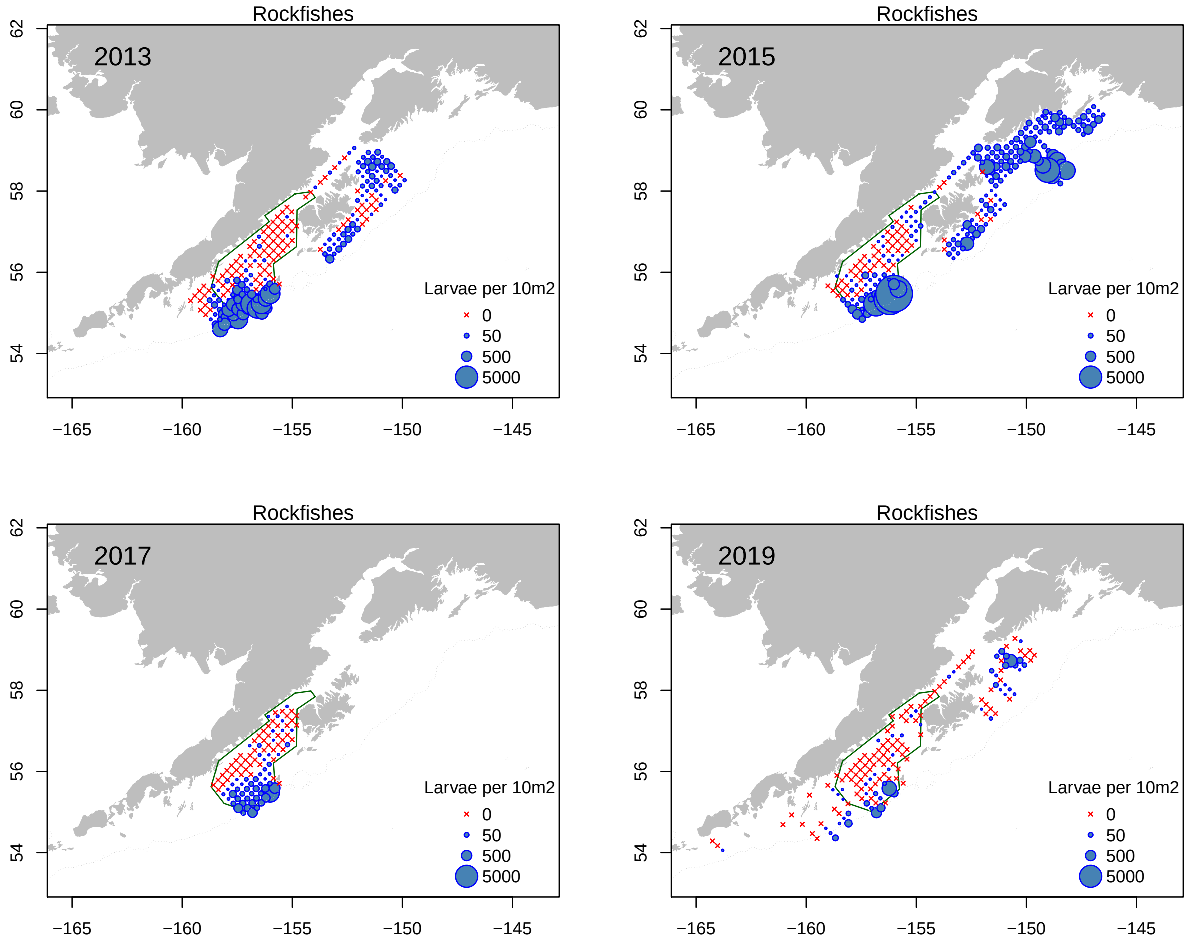

Figure 56: Abundance of larval rockfishes on the EcoFOCI spring larval survey for 2013–2019. The at-sea rough counts were used to generate the distribution for 2019 whereas laboratory data are shown for previous years. The polygon shows the main grid area, which has historically been the most consistently sampled area.

to have had an adverse effect on early life stages of many fishes including walleye pollock and Pacific cod. Depending on species-specific physiological constraints, high bottom temperatures may reduce egg viability or early survival due to physiological stress in species that utilize the water near the benthos for spawning, such as Pacific cod (Laurel and Rogers in review). Warmer temperatures could also result in match-mismatch dynamics depending on the thermal sensitivity of spawning, development and prey production. Results of the RZA revealed a reduced abundance of large copepods and euphausiids and only an average abundance of small copepods (see contribution by David Kimmel), which may indicate poor conditions for growth of larval fishes. However, all larval pollock examined in 2019 were observed to be in good condition and feeding well, suggesting that the prey field was appropriate to support good foraging conditions for larval pollock in the spring.

Implications: The decreased abundance of all six taxa assessed in the RLA suggests that ecosystem conditions were not conducive for the survival of eggs and larvae of a range of species, similar to the "Blob" conditions of 2015. Lower abundance of larvae suggests weak 2019 year classes, and

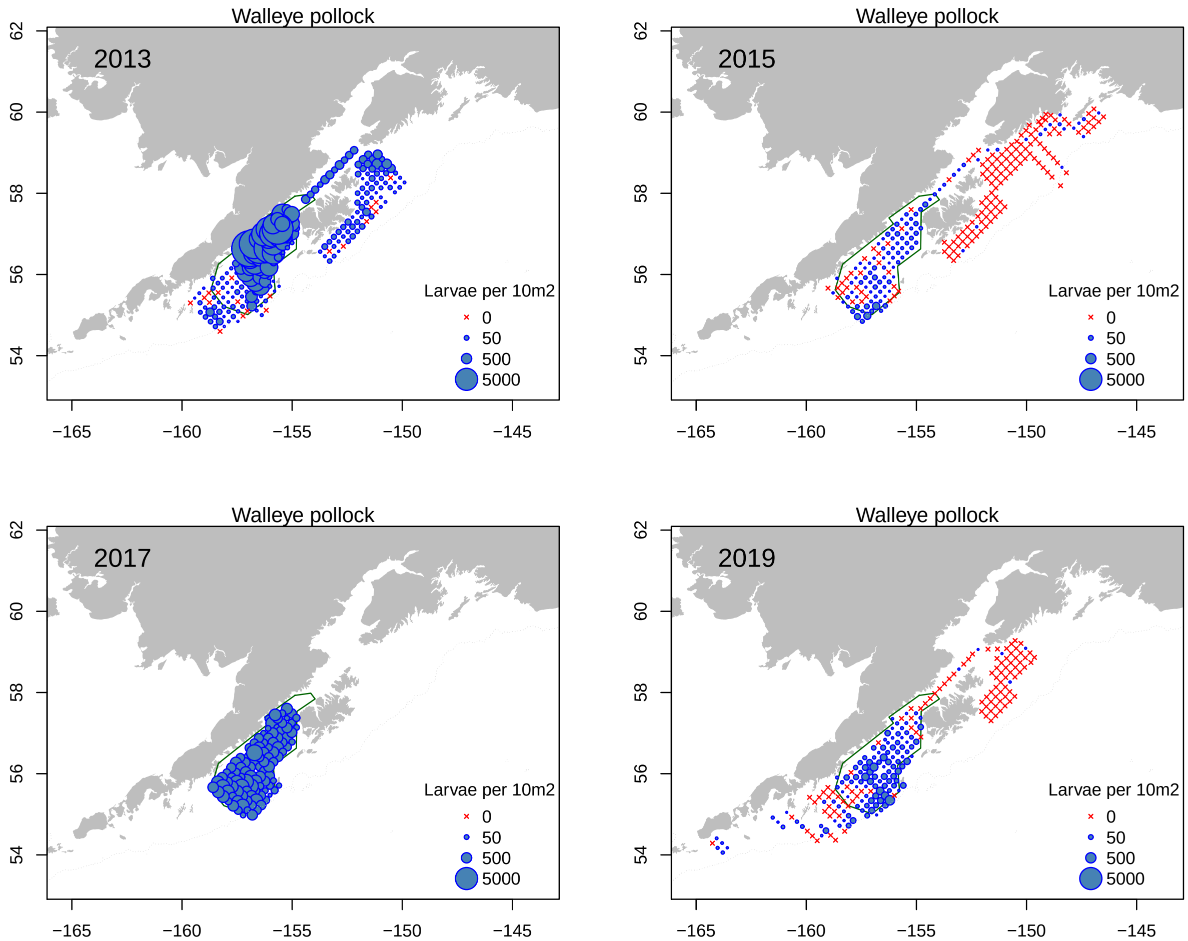

Figure 57: Abundance of larval walleye pollock on the EcoFOCI spring larval survey for 2013–2019. The at-sea rough counts were used to generate the distribution for 2019 whereas laboratory data are shown for previous years.

reduced future recruitment to the fishery. In addition, a paucity of small fishes indicates reduced prey availability for piscivorous predators, including seabirds and fishes, through 2019.

Multispecies Larval Indicator for the Gulf of Alaska

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Last updated: September 2019

Description of indicator: Ichthyoplankton sampling in the Gulf of Alaska (GOA) has been conducted by the Alaska Fisheries Science Center (AFSC) Ecosystems and Fisheries Oceanography Coordinated Investigations Program (EcoFOCI) annually from 1981–2011 and biennially during

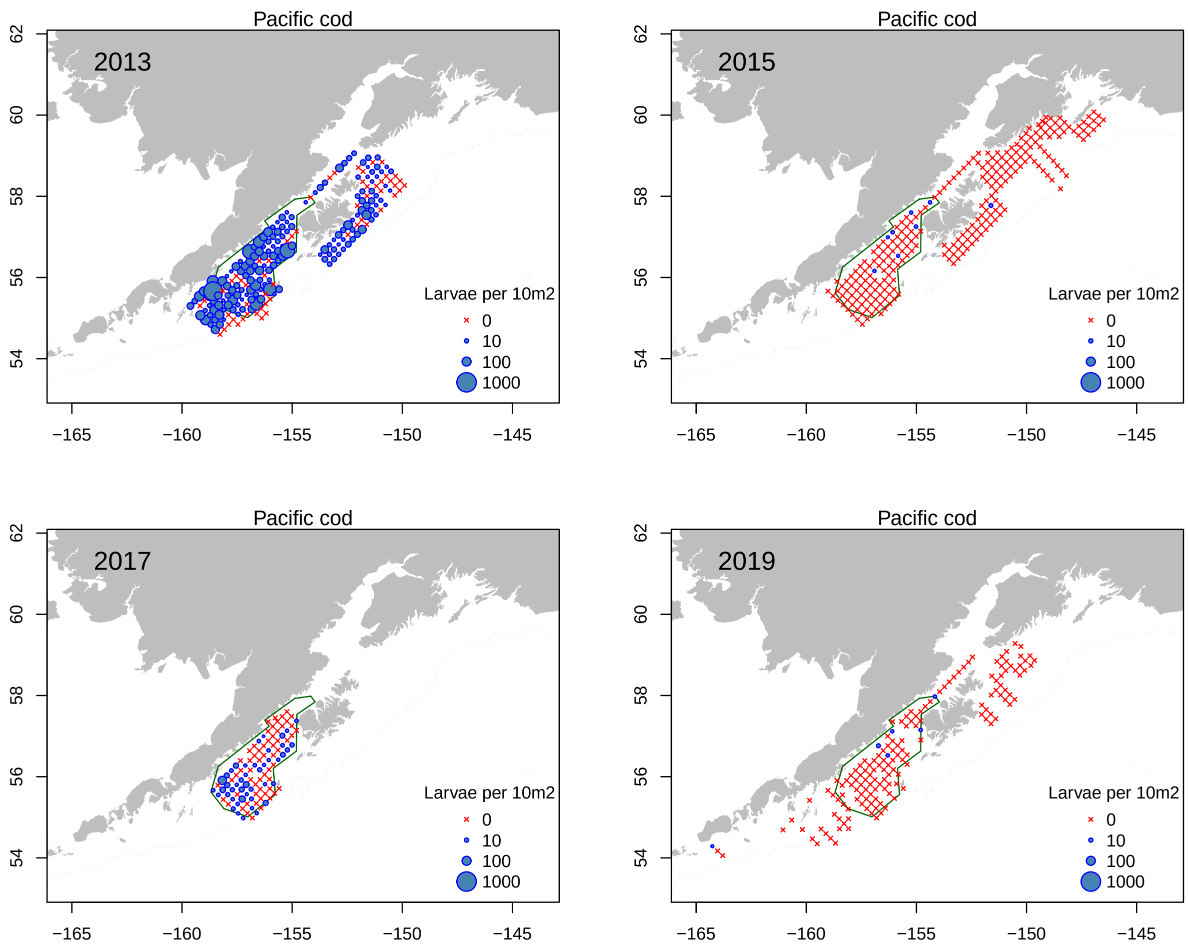

Figure 58: Abundance of larval Pacific cod on the EcoFOCI spring larval survey for 2013–2019. The at-sea rough counts were used to generate the distribution for 2019 whereas laboratory data are shown for previous years.

odd-numbered years thereafter. The most consistent sampling has been conducted in the region of Shelikof Strait and Sea Valley from mid-May to early June providing consistent time series data (Rogers et al., 2018). Here, a multispecies larval indicator was developed aimed at capturing the annual dynamics of the ichthyoplankton fauna. Because early life stages of single species often exhibit high variability, a multispecies approach may be advantageous in capturing general dynamics of the larval community, and could provide an indicator and link to recruitment and ecosystems conditions. Ichthyoplankton were analysed using dynamic factor analysis which is a multivariate time series technique useful for estimating common trend(s) from multiple timeseries data (Ward et al., 2019). Loading estimates for each individual species time series denote if a species is positively or negatively correlated to the common trend. We developed a multispecies larval Dynamic Factor Analysis (DFA) analyses based on 6 common and commercially important species: walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), northern rock sole (*Lepidopsetta polyxystra*), southern rock sole (*Lepidopsetta bilineata*), rockfishes (Sebastes spp.) and arrowtooth flounder (*Atheresthes stomias*). We specified the DFA model to estimate one common trend. Starting in 2019, a Rapid Larval Assessment has been conducted for these 6 species, which provides immediate information on species abundances (see p.97). Rough counts are subsequently replaced with the quantitative data once laboratory work is complete, about a year after sampling. Previous rough counts for walleye pollock align closely with the quantitative data suggesting that this method provides a valuable and rapid assessment of abundance levels.

Status and trends: The analysis showed that walleye pollock, Pacific cod and northern rock sole co-vary over time and all loaded positively to the larval DFA, i.e. these species have higher abundance when the common trend is positive (Figure 59B). Contrarily, rockfishes and to a lesser extent southern rock sole loaded negatively to the trend (i.e. negative trend values indicative of higher abundance). Arrowtooth flounder was poorly explained by the model. The larval dynamic factor analysis showed that the estimated common trend was at the lowest in 2019 (Figure 59A), similar to previous years such as 1998, 2003–2005 and 2015. The years with low DFA trend values reflect low abundances of pollock and Pacific cod and higher abundance of rockfish species.

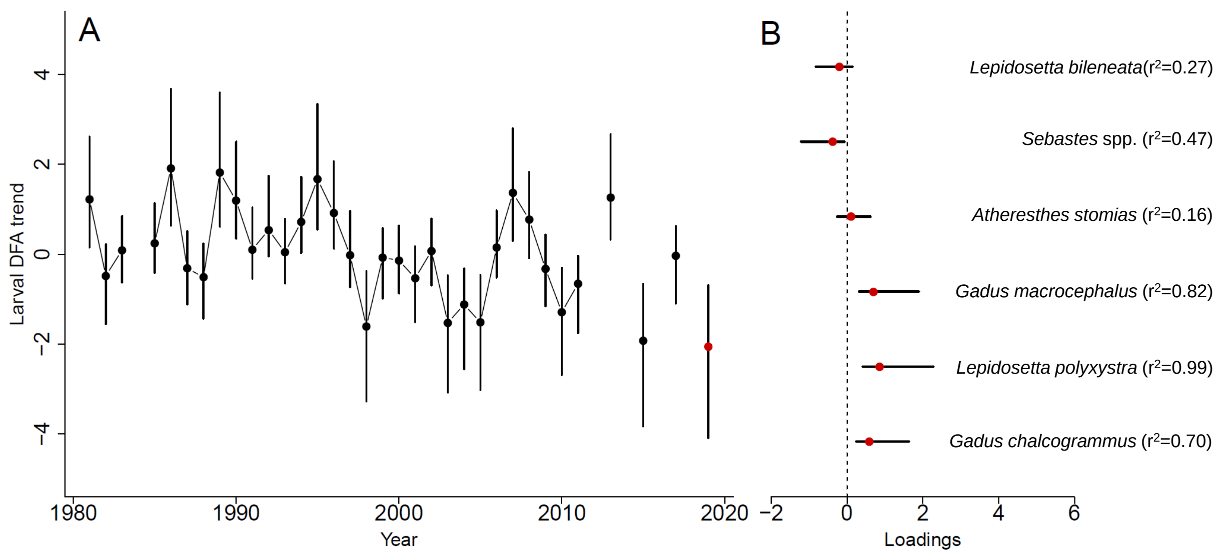

Figure 59: A) Time trend of the multispecies larval DFA trend, with the 2019 value based on the Rapid Larval Assessment in red. B) Loading of the 6 larval fish taxa on the time trend shown in A.

Factors influencing observed trends: The multispecies larval indicator supports the idea that ichthyoplankton respond rapidly to environmental changes. Negative values of the larval DFA, indicative of low abundance of walleye pollock, Pacific cod and northern rock sole, were particularly pronounced in the years 1998, 2003–2005, and in particular 2015 and 2019; all warm years. This suggests that the ichthyoplankton in 2019 responded similarly as in the past to warm conditions, including the recent 2014–2016 marine heatwave which had major impacts on the GOA ecosystem. This pattern is also supported by a significant relationship between spring temperatures and the larval DFA trend (data not shown).

Implications: Ichthyoplankton are good indicators of ecosystem dynamics (Boeing and Duffy-Anderson, 2008). The multispecies larval indicator developed here appears to capture well the dynamics of several of the most common ichthyoplankton species in the Gulf of Alaska. In addition, the larval DFA based on the 6 species, aligns closely with a larval DFA using 20 of the most common species suggesting that the Rapid Larval Assessment represents the general ichthyoplankton dynamics well. The low values of the common trend in 2019 suggest that walleye pollock, Pacific cod and northern rock sole all experienced high mortality rates and thus suggests potentially low recruitment to the fishery at a magnitude similar to the marine heatwave year of 2015. Poor larval recruitment of the 6 species considered here is likely to have impacts on both commercial fisheries of these species, and may influence survival of higher trophic level predators, such as seabirds and mammals that forage on larger individuals of these species. Preliminary analyses also suggest that the multispecies larval indicator is correlated to chla levels, temperature and abundance of *Pseudocalanus spp.* (a smaller but abundant copepod and potential prey species), indicating that the larval DFA analyses have value as indicators of ecosystem dynamics in the Gulf of Alaska.

Forage Fish and Squid

Body Condition of age-0 pollock in the Western Gulf of Alaska

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Last updated: September 2019

Description of indicator: Body condition of fishes is an integrated indicator, reflecting conditions for growth, such as prey availability and temperature, as well as stock resilience, as fish in better condition (i.e. with greater energetic reserves) can survive longer under poor prey conditions. This may be particularly true for juvenile pollock as they transition into their first winter; when food becomes scarce, sufficient energy stores may be critical for overwinter survival (Sogard and Olla, 2000).

The AFSC EcoFOCI juvenile groundfish survey is a midwater trawl survey that has sampled age-0 walleye pollock throughout the Western Gulf of Alaska in late summer (August–September) since 2000 (Figure 60). Individual age-0 pollock were frozen at sea and later measured for length and weight in the laboratory. Body condition was measured as residuals from a regression of log(weight) on log(length), with positive residuals indicating “fatter” fish having larger body mass per unit length. Because body condition can vary with season (Buchheister et al., 2006), and survey timing varied by up to a month between years, we included an additional term in the regression model to account for the day of year fish were collected. In 2011, the survey occurred in October, a month later than other years, and data from that year have been excluded. Only a subset of fish from each station were measured, thus residuals were weighted by station CPUE when constructing an annual average. Fish collected in the consistently sampled Semidi bank region (Figure 60) were used to construct the index.

Status and trends: Average body condition of age-0 pollock was low in the two most recent years sampled (2015 and 2017) as well as 2005 (Figure 61). Good body condition was observed in 2001, 2003, 2007 and 2009. There was no significant long-term trend in condition. Fish from the 2019 survey will be processed and analyzed in early 2020.

Factors influencing observed trends: Body condition of age-0 pollock is likely influenced by

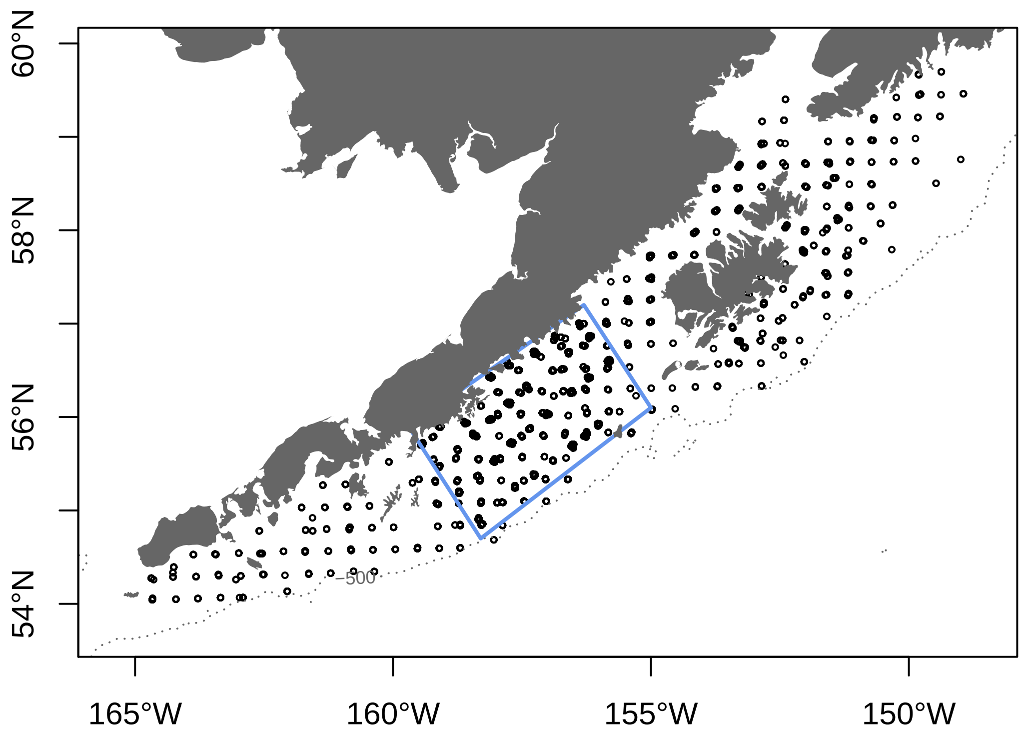

Figure 60: Map showing all sample locations (2000–2017), and the core Semidi area (blue box) used for constructing the condition index.

temperature, which increases metabolic demands, and prey quality and quantity, which determine their ability to meet those demands. In 2015, during the "Blob" heatwave, temperatures were warm and prey quality and quantity were likely reduced, resulting in poor body condition. Warm temperatures were also observed in 2005. In 2017, body condition was somewhat improved from 2015, but still poor, matching observations for older stages of groundfishes in the GOA (Boldt et al., 2017). Krill, an important prey for age-0 pollock which has been associated with improved body condition (Wilson et al., 2013), were relatively scarce in 2017 (Ressler, 2017).

Implications: Juvenile pollock rapidly increase their energy storage in late summer, presumably to increase their survival chances during winter, when prey are scarce (Siddon et al., 2013). In the Bering Sea, low energy storage prior to the first winter has been associated with poor year-class strength for juvenile pollock. Whether this relationship holds for the Gulf of Alaska is yet to be seen, but poor body condition in 2015 and 2017 reflects suboptimal ecosystem conditions for pollock growth both during and after the "Blob", which may have had adverse effects on overwinter survival. Poor condition of age-0 pollock also results in reduced quality of these fish as prey for seabirds and other piscivorous predators.

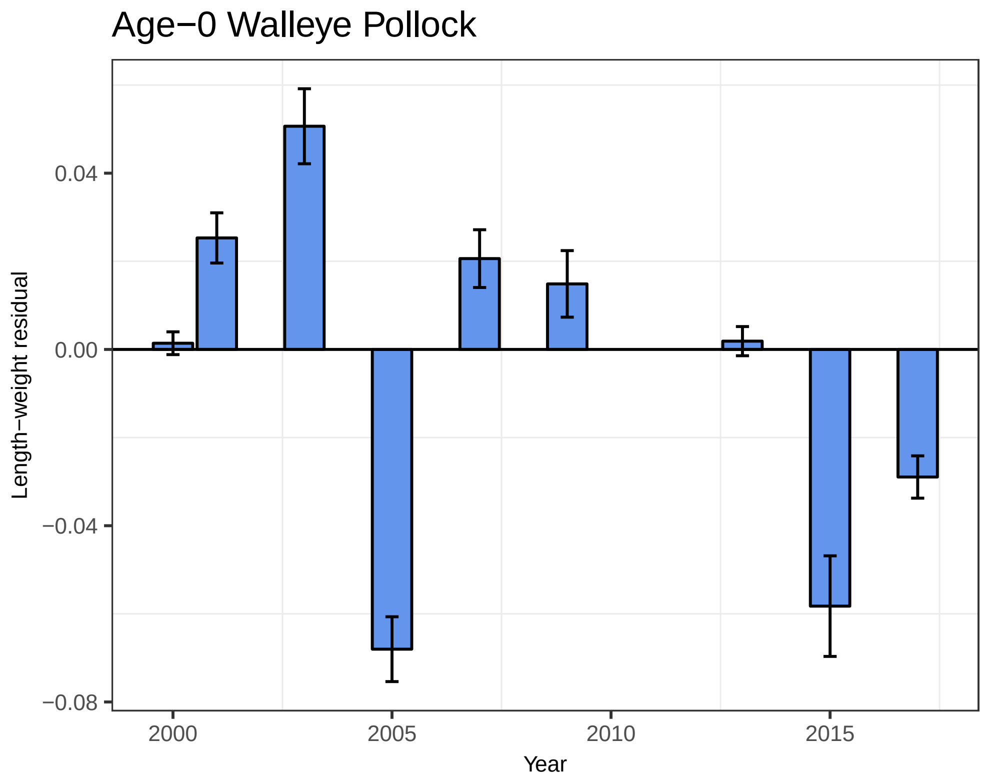

Figure 61: Average CPUE-weighted body condition of age-0 pollock in the core Semidi area (+/- 1 standard error).

Abundance of YOY pollock and capelin in Western Gulf of Alaska

Contributed by Lauren Rogers, Matthew Wilson, Steven Porter, EcoFOCI Program, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, NOAA
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Last updated: October 2019

Description of indicator: The Ecosystems & Fisheries Oceanography Coordinated Investigations (EcoFOCI) Program monitors and researches small neritic fishes to improve our understanding and management of the Gulf of Alaska (GOA) ecosystem and fisheries. Small neritic fishes include the juvenile stages of economically and ecologically important species (e.g., walleye pollock, Pacific cod, Pacific ocean perch and other rockfishes, sablefish, and arrowtooth flounder). They also include species managed exclusively as forage fishes (e.g., capelin and eulachon) that support the fishes, seabirds, and marine mammals that characterize the piscivore-dominated GOA ecosystem. Longstanding objectives of EcoFOCI late-summer field work in the western Gulf of Alaska are to extend a time series of age-0 walleye pollock abundance estimates, monitor the neritic environment including zooplankton and abiotic conditions, and collect samples for research (e.g., trophic and spatial ecology, bioenergetics, age and growth).

During 13 August–14 September, the NOAA vessel *Oscar Dyson* sampled the western Gulf of Alaska from Cook Inlet to the Shumagin Islands, including Shelikof Strait, the east side of Kodiak Island,

and spanning the shelf out to the shelf break. The survey grid west of the Shumagin Islands was truncated due to weather. At each of 130 stations, water temperature and salinity were profiled and zooplankton samples were collected with 20 cm (153 μm mesh) and 60 cm (505 μm mesh) bongos towed obliquely through the upper 200 m of the water column (see p.77). Target fishes were collected using a Stauffer trawl (aka anchovy trawl) equipped with a small-mesh (2x3 mm) codend liner towed obliquely to a maximum depth of 200 m.

Time series of abundance for age-0 pollock and for capelin were constructed based on catches from late-summer surveys since 2000 (only odd years since 2001) for the consistently sampled region between Kodiak Island and the Shumagin Islands (Figure 62). Mean catch per unit area was calculated using an area-weighted mean. Due to significant differences in catches of capelin during day versus night, mean CPUE for the night stations only is also shown.

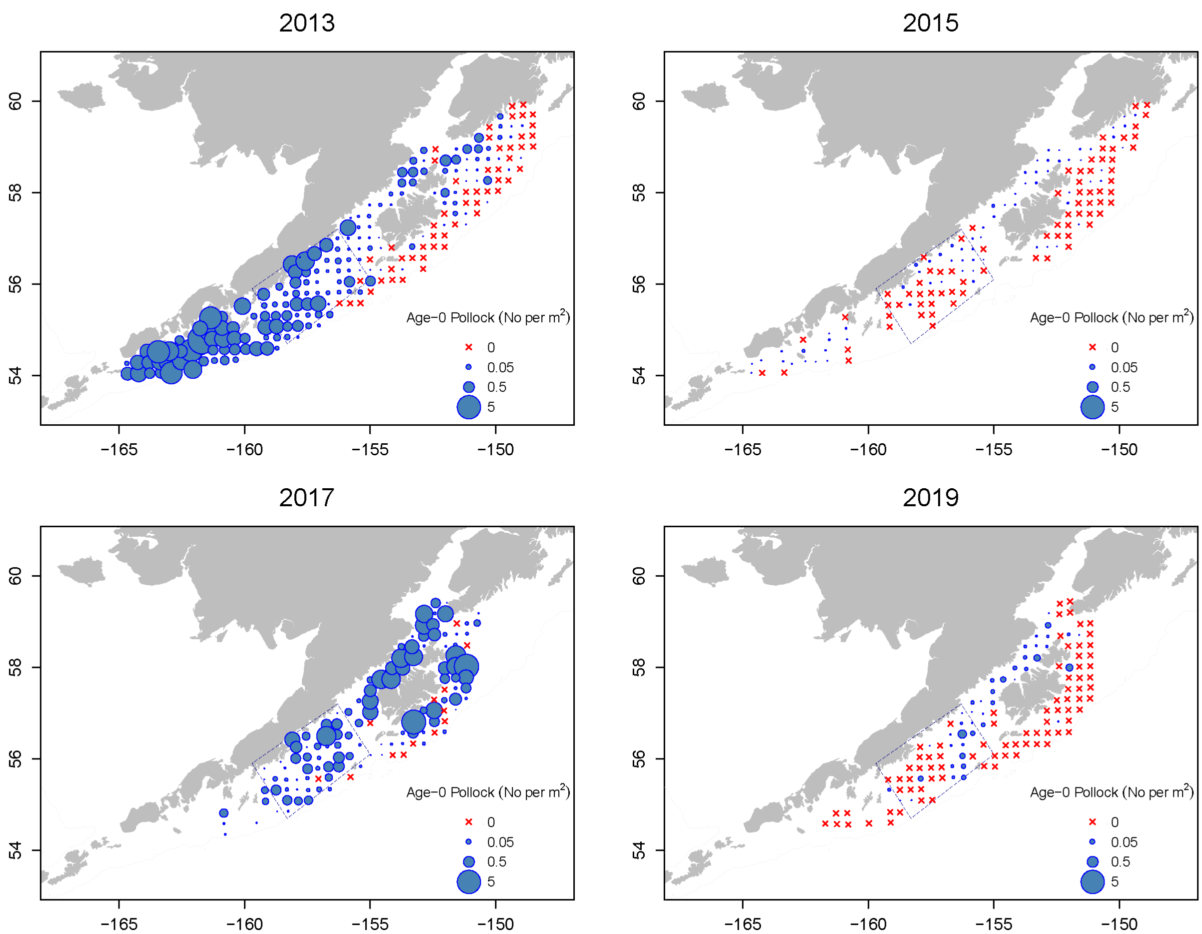

Figure 62: Catches of age-0 walleye pollock in the EcoFOCI late-summer small-mesh trawl survey for 2013, 2015, 2017, and 2019.

Status and trends: Catches of age-0 pollock were second lowest on record, with the majority of fish found in Shelikof Strait and near the Semidis (Figures 62 and 63). No age-0 pollock were found at the majority of stations to the south and east of Kodiak as well as near the Shumagin Islands in the southwest. This spatial distribution is in contrast to a previous high abundance year (2013) when catches were highest southwest of the Shumagin Islands. Capelin abundance remained low in 2019, although up slightly from 2017 (Figure 63). However, note that no sampling occurred in even years and the time-series estimate does not include catches from near Kodiak, where capelin catches are typically higher.

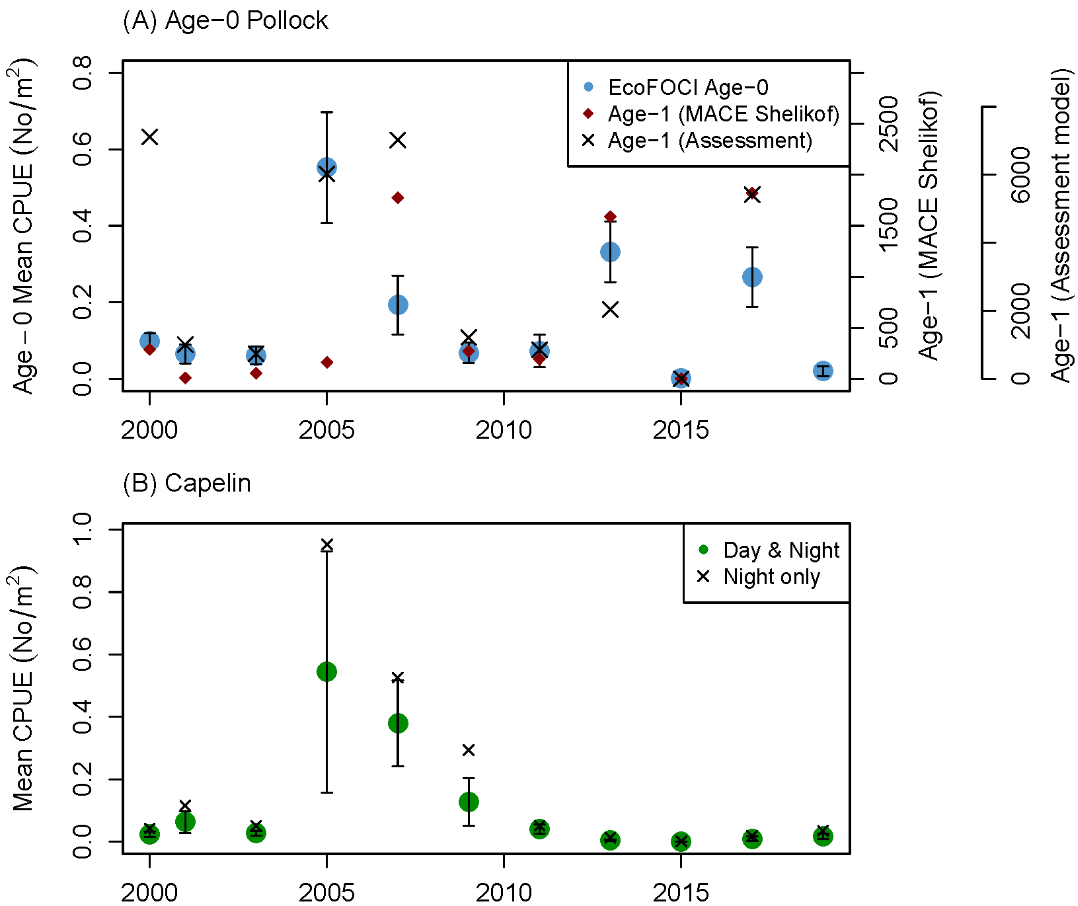

Figure 63: Estimated indices (+/- 1 standard error) of abundance for a) pollock and b) capelin. For pollock, the EcoFOCI age-0 estimate is shown relative to subsequent indicators of year-class strength, including an estimate of age-1 abundance in winter from the MACE acoustic survey in Shelikof Strait (Table 1.10 in (Dorn et al., 2018)) and the estimated age-1 abundance from the stock assessment for GOA pollock (Table 1.21 in (Dorn et al., 2018)).

Factors influencing observed trends: The abundance of age-0 pollock in late summer reflects the number of surviving larvae from spawning in the spring and survival processes through the summer. In spring of 2019, catches of larval pollock were very low (see p.97). Warm conditions have returned to the Gulf of Alaska, including at depth, reminiscent of the marine heatwave that occurred from 2014–2016. The 2015 year class, hatched during the height of the heatwave, was the smallest observed for GOA pollock in the historical record (Dorn et al., 2018). Based on current observations, it appears that the current warm anomaly will have similar (although possibly less severe) impacts. The observed spatial distribution of pollock may result from transport processes and/or reflect production from different spawning groups. Capelin experienced widespread declines in the GOA associated with the 2014–2016 heatwave, but beyond this, capelin dynamics don't appear to have a clear link with temperature in the western GOA (McGowan et al. in review).

Implications: Capelin and young-of-year pollock are key forage fish species in the Gulf of Alaska, providing prey for seabirds, fishes, and mammals. This late-summer survey also provides an assessment of the abundance, size, and condition of young-of-year pollock before entering their first winter, giving an early indicator of potential year-class strength. Low catches of juvenile pollock, together with previously observed low larval abundance, suggest a weak 2019 year class, similar to, although not as severe as was observed during the "Blob" heatwave in 2014–2016. Capelin abundances remain relatively low, suggesting limited forage food for piscivorous predators.

Seabird-Derived Forage Fish Indicators from Middleton Island

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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), Middleton's 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.

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 64) shows general agreement between a sustained decline of sand lance and, beginning in 2007, the emergence of capelin as a dominant forage species. 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 in respect to prey-switching to alternate species such as mytophids, salmon, and greenlings.

Auklet data plotted separately by prey type highlight the interannual dynamics of individual species (Figure 65). 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 65).

In 2019, sand lance declined slightly as compared with the previous year, the difference being countered by a modest increase capelin—seemingly a more or less direct and predictable trade-off that is evident throughout these datasets. Greenlings were prominent in the auklet (but not kittiwake) diet during 2019, to a degree not seen in fact since 1994 (Figure 64). The occurrence of herring and other coastal species in seabird diets from Middleton possibly reflect more use of nearshore/inner shelf habitat because of reduced availability of their offshore primary prey such as capelin. Indeed, GPS tracking of foraging seabirds conducted during chick-rearing (albeit a few days prior to the diet sampling reported here) revealed that birds from Middleton were commuting a considerable distance (∼80 km one-way) and foraging principally in nearshore waters, including the south end of Montague Island.

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 2013 (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 64). 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 also 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.

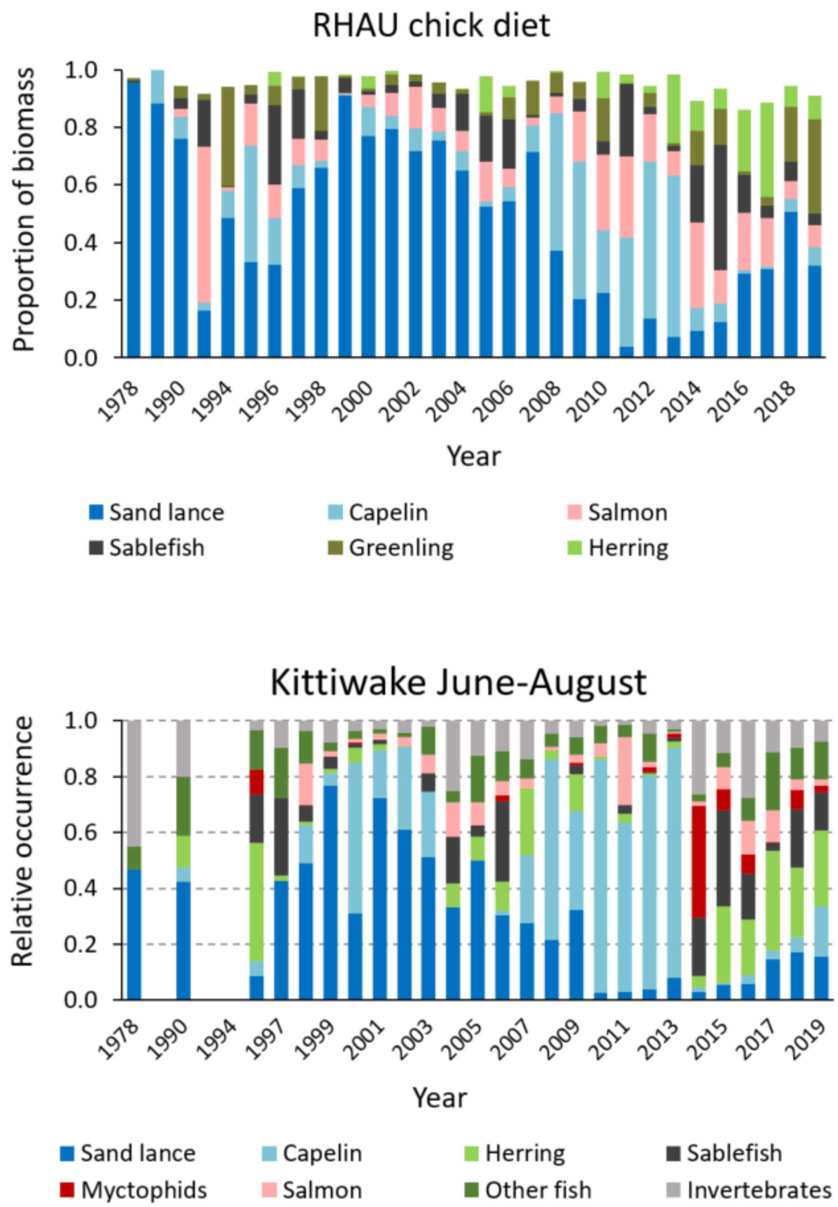

Figure 64: Interannual variation in diet composition of chick-rearing rhinoceros auklets (upper panel) and black-legged kittiwakes (lower panel) on Middleton Island, 1978–2019.

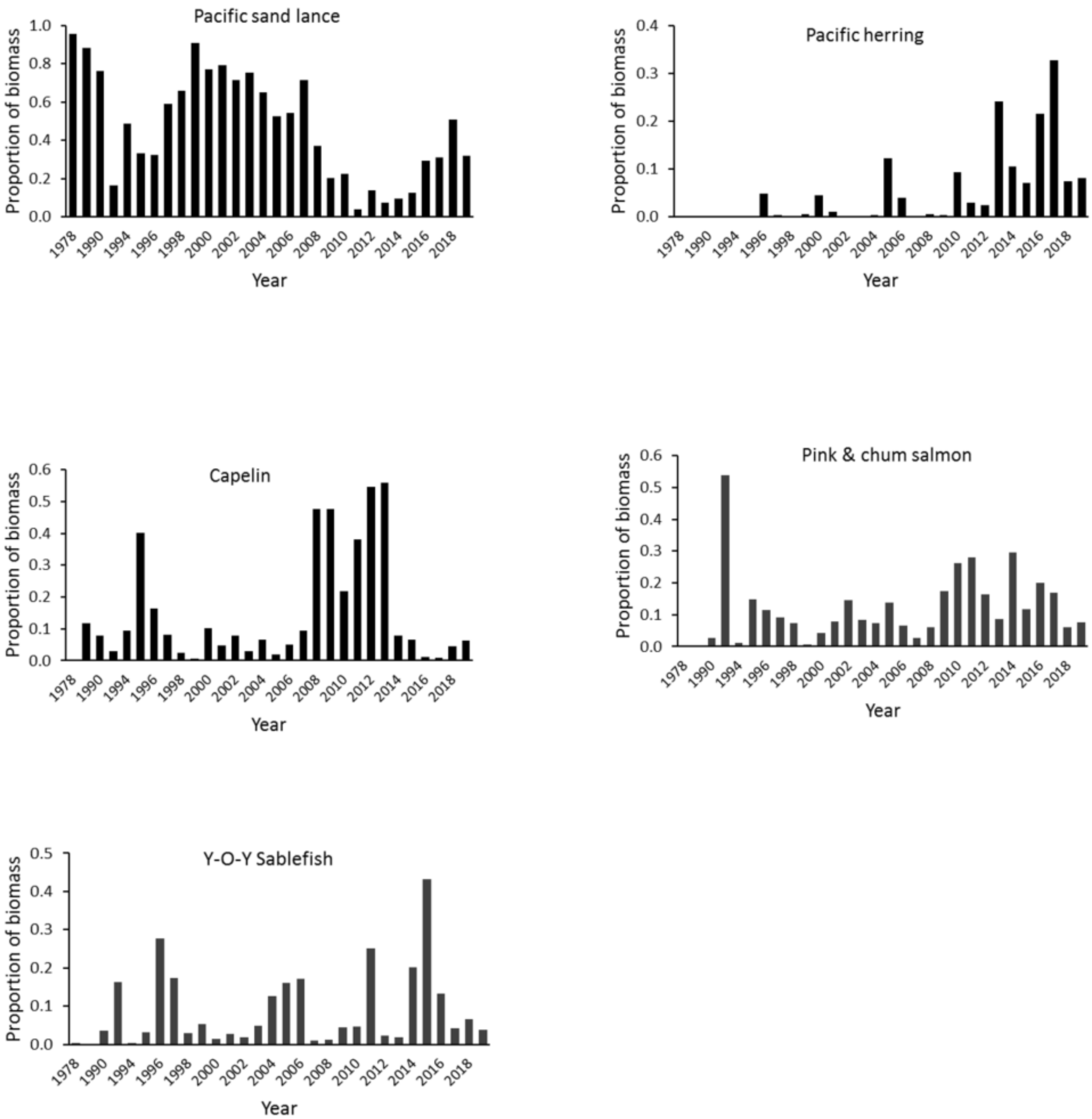

Figure 65: Prey species occurrence in the nestling diet of rhinoceros auklets on Middleton Island from 1978–2019.

Herring

Prince William Sound Herring

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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 pre-fishery biomass of herring occurred in the 1980s and a subsequent decline in the 1990s (Figure 66). 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 66). 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 67). While no BASA estimate of the 2019 biomass is available yet. While observed mile-days of milt in 2019 is still very low, it was nearly triple that of 2018 (Figure 67).

Factors influencing observed trends: There was a peak in antibodies to the VHS virus ob-

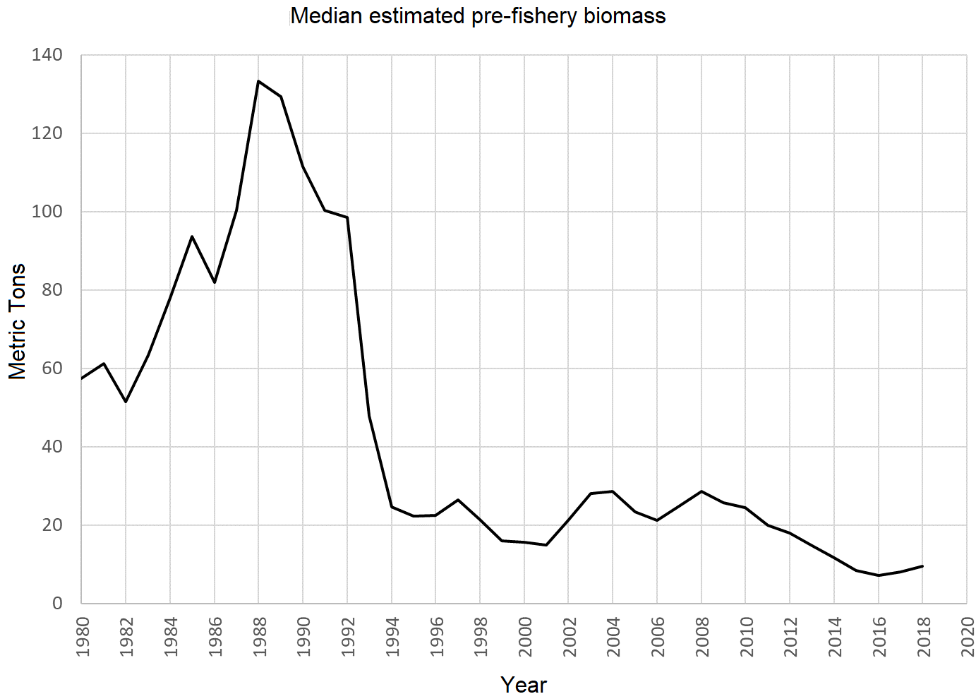

Figure 66: The Bayesian age-structured assessment model median estimate of the pre-fishery biomass.

served 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. We are awaiting the age information on the spawning stock to determine if the increased mile-days of milt in 2019 was caused by recruitment or potentially older herring that had not been observed the previous two years.

Implications: It is possible that lower abundance of herring may have negative impacts on predators that rely on them.

Southeastern Alaska Herring

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Last updated: August 2019

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 68). 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

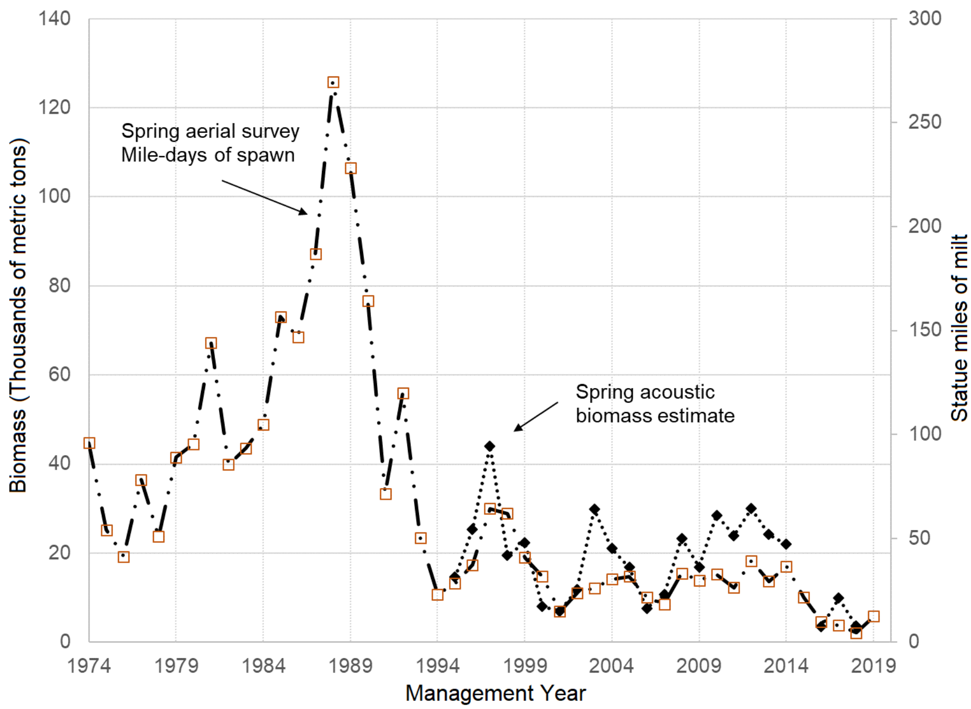

Figure 67: Mile-days of milt in Prince William Sound based on aerial surveys and biomass estimates from acoustic surveys. Includes preliminary results of the 2019 survey from Alaska Department of Fish and Game.

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. 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.

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 69). 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 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 reductions. Based on spawn observations from aerial surveys it is clear that at least two stocks, Hoonah Sound and Hobart Bay, have not rebounded despite fishery closures for several years. However, other areas have declined dramatically in the absence of commercial fishing (e.g. West Behm Canal) and have also not rebounded for reasons unknown, but possible due to shifts in spawning areas. Although estimates for 2019 were not available at the time of publication, preliminary results indicate that spawning for Sitka and Craig stocks was strong and dive surveys indicated high egg deposition.

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 (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.

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.

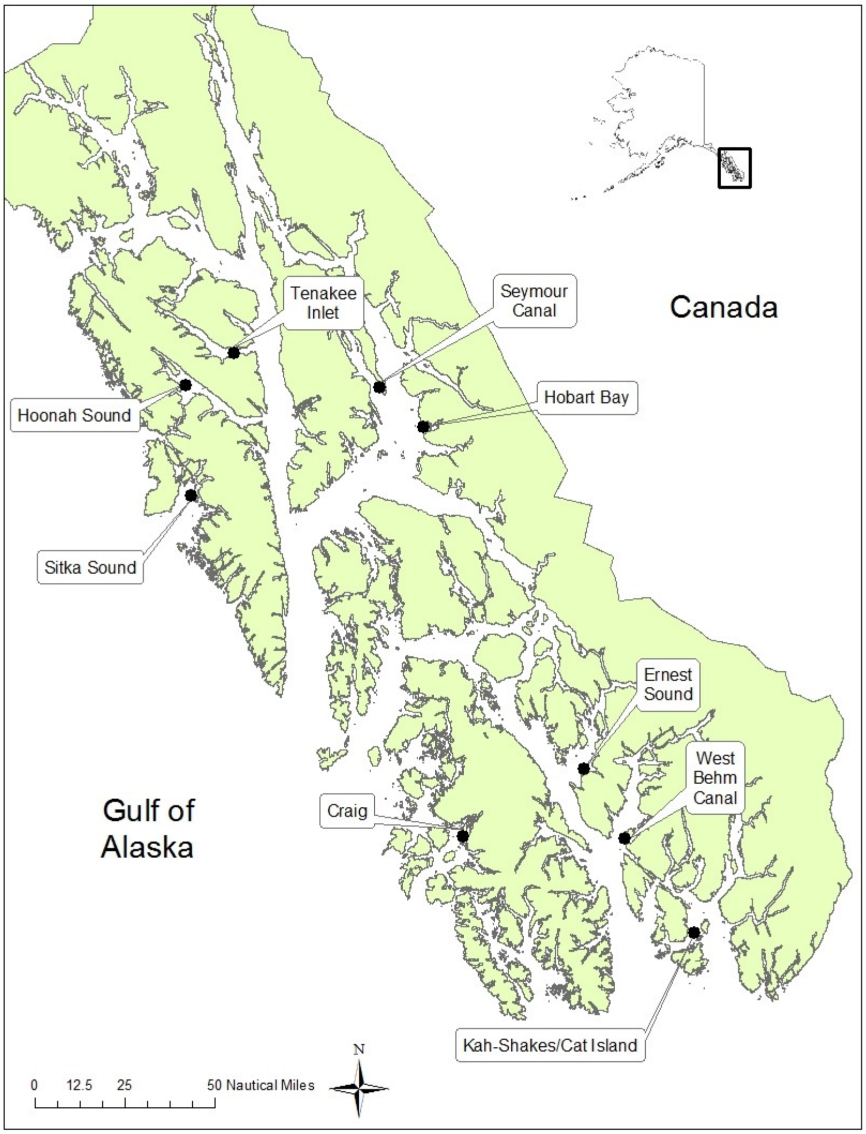

Figure 68: Location of nine important Pacific herring spawning locations in Southeast Alaska.

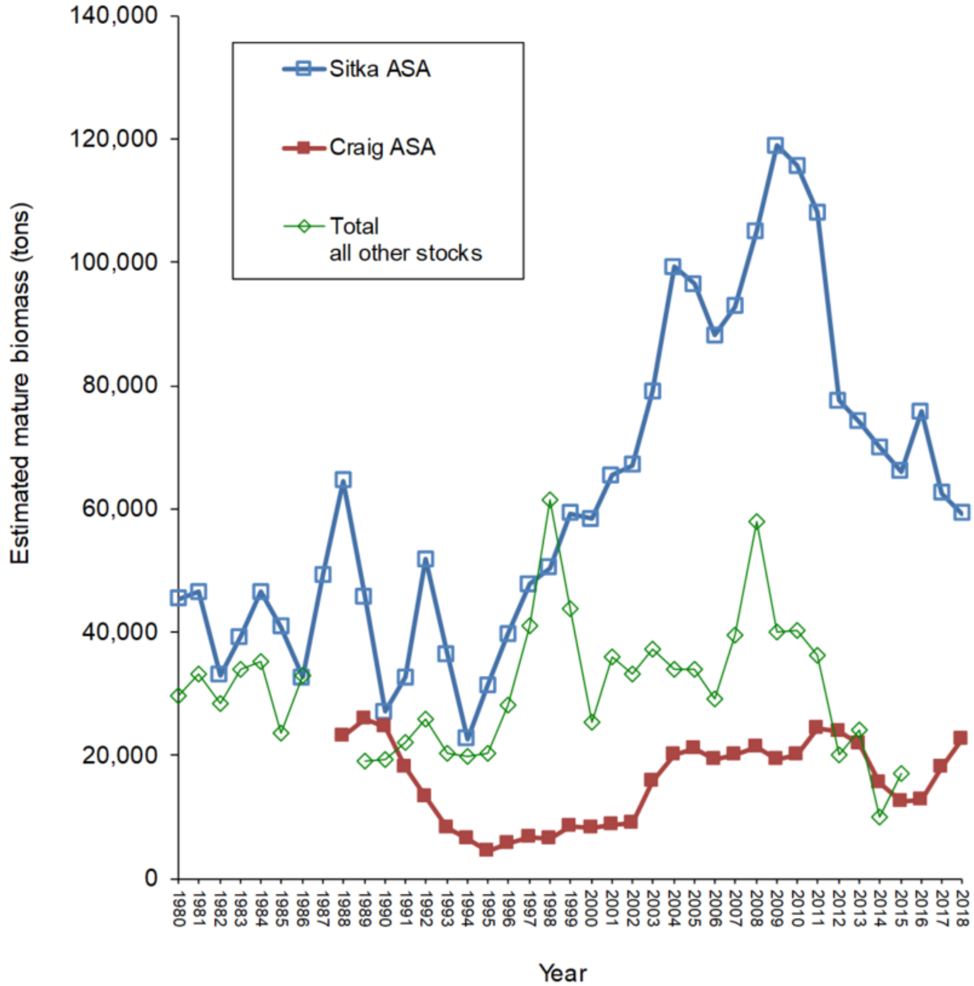

Figure 69: Estimated mature herring biomass (i.e. prefishery biomass) for nine important southeastern Alaska (SEAK) spawning areas, 1980–2018. Biomass estimates for Sitka and Craig are based on age-structured assessment (ASA) models and those for all other stocks, where ASA model estimates are not available, 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 2016–2019, data were excluded for all other stocks because starting in 2016 stock assessment surveys were suspended for most areas due to budget reductions.

Salmon

Historical and Current Alaska Salmon Trends—Gulf of Alaska

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Last updated: August 2019

Description of indicator: This contribution provides historic and current catch information for salmon in the Gulf of Alaska. This contribution summarizes available information that is included in current Alaska Department of Fish and Game (ADF&G) agency reports (Brenner and Munro, 2016).

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

Status and trends: *Statewide* Catches from directed fisheries on the five salmon species have fluctuated over recent decades (Figure 70) but in total have been generally strong. According to ADF&G, total salmon commercial harvests from 2018 totaled 115.7 million fish, which was about 31.6 million less than the preseason forecast of 147.3 million. The 2018 total salmon harvest was less than the 2017 total harvest of 225.7 million which was bolstered by the catch of 141.6 million pink salmon. In 2019 ADF&G is projecting an increase in the total commercial salmon catch to 213.2 million fish, due to expected increases in the number of pink and chum salmon.

Gulf of Alaska In the Southeast region, 2018 salmon harvests totaled 22 million, which was 42% of the recent 10-year average harvest and 54% of the long-term average harvest. Pink salmon comprised 37% of the total number of salmon harvested in 2018. Since 2006 pink salmon returns have followed a cycle of strong odd years and weak even years and that pattern continued in 2018 with one of the lowest harvests since 1962.

In the Southeast region, the harvest of Chinook salmon and sockeye salmon were both below their long-term average harvests and recent 10-year average harvests. The Chinook salmon harvest of 160,000 was the lowest since 1962. The coho salmon harvest of 1.6 million was less than both the long-term average harvest and the recent 10-year average. In contrast, the harvest of 11.5 million chum salmon in the Southeast region was 112% the recent 10-year average harvest and 189% the long-term average.

In the Kodiak management area the 2018 sockeye salmon commercial harvest of 1.8 million was below the recent 10-year average of 2.3 million and less than the preseason forecast of 2.6 million. The 2018 pink salmon harvest of 5.9 million was below the 10-year average harvest of 18.1 million and was below the forecast of 8.7 million.

In the Prince William Sound Area of the Central region, the 2018 total commercial salmon harvest was 29.37 million fish, of which 24.06 million were pink salmon. The pink salmon harvest was 29% below the preseason forecast and more than 14 million less than the recent 5-year even-year average. The catch of other salmon species in the Prince William Sound Area included 1.3 million sockeye, 3.47 million chum, 523,000 coho, and 8,000 Chinook.

Factors influencing observed trends: Historically, pink salmon catches increased in the late 1970s to the mid-1990s and have generally remained high in all regions in the last decade (Figure 70). While both natural and hatchery populations return to Prince William Sound, a large majority of the returning fish are hatchery fish, upwards of up to one half billion are released from four hatcheries (Kline et al., 2008). Pink salmon have an abbreviated life cycle, consisting of three phases 1) brood year, 2) early marine year, and 3) return year (Kline et al., 2008).

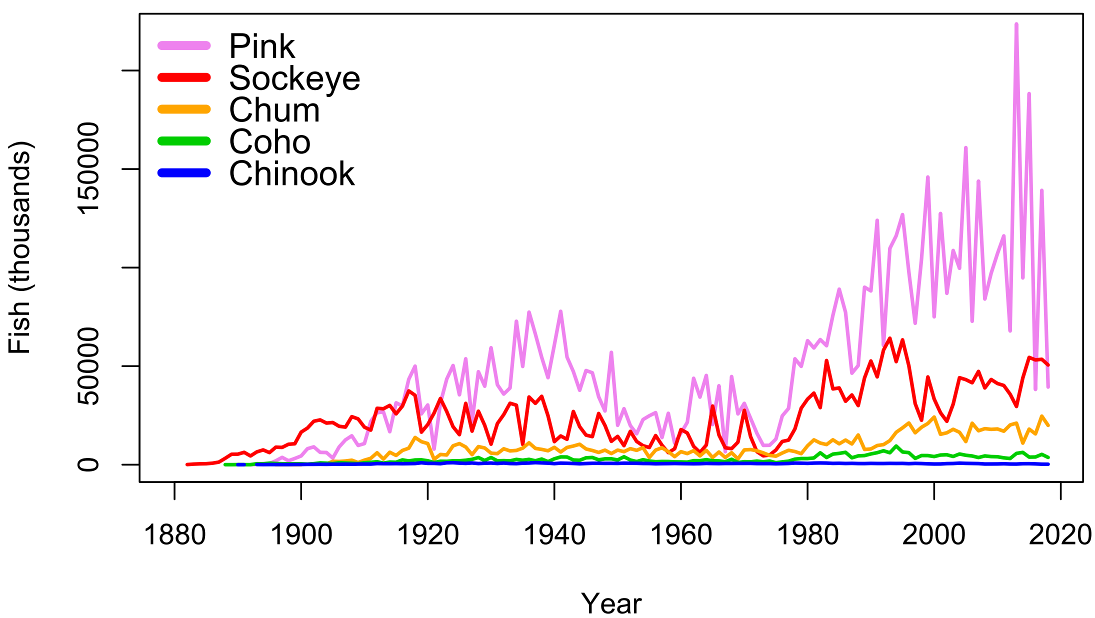

Figure 70: Alaska historical commercial salmon catches, 2018 values are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.)

Pink salmon run strength is established during early marine residence and may be influenced by diet and food availability (Cooney and Willette, 1997). Survival rates of Alaska pink salmon are positively related to sea surface temperatures and may reflect increased availability of zooplankton prey during periods with warmer surface temperatures (Mueter and Norcross, 2002). Interannual variation in Alaska statewide total salmon abundance is partly due to the even-year, odd-year cycle in pink salmon, which typically have larger runs in odd years. Pink salmon run strength is established during early marine residence and may be influenced by diet and food availability (Cooney and Willette, 1997). Survival rates of Alaska pink salmon are positively related to sea surface temperatures and may reflect increased availability of zooplankton prey during periods with warmer surface temperatures (Mueter and Norcross, 2002). Chinook runs have been declining statewide since 2007. Size-dependent mortality during the first year in the marine environment is thought to be a leading contributor to low Chinook run sizes (Beamish and Mahnken, 2001; Graham et al., 2019).

Implications: Salmon have important influences on Alaska marine ecosystems through interactions with marine food webs as predators on lower trophic levels and as prey for other species such as Steller sea lions. In years of great abundance, salmon may exploit prey resources more efficiently than their competitors, affecting the body condition, growth, and survival of competitors (Ruggerone et al., 2003; Toge et al., 2011; Kaga et al., 2013). A negative relationship between seabird reproductive success and years of high pink salmon abundance has recently been demonstrated (Springer and van Vliet, 2014). Directed salmon fisheries are economically important for the state of Alaska. The overall abundance of salmon in Alaska has been high in recent decades and despite annual fluctuations, the trend in total salmon catch in recent decades has been for generally strong harvests.

Trends in Salmon Abundance in Icy Strait, Southeast Alaska

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Last updated: September 2019

Description of indicator: The Southeast Coastal Monitoring (SECM) survey has assessed the status of the pelagic ecosystem in Southeast Alaska (SEAK) annually since 1997 using fish, zooplankton, and oceanographic samples (Fergusson et al., 2013, 2017; Murphy et al., 2018). Research objectives of the SECM program are to provide insight into the early ocean ecology and production dynamics of SEAK salmon. Understanding production dynamics, including recruitment processes, is an important aspect of managing fish stocks, particularly during periods of substantial environmental variability. Juvenile abundance and oceanographic data collected during SECM have provided reliable forecasts of pink salmon returns to SEAK and are used for preseason fisheries management decisions in the purse seine and drift gillnet fisheries of SEAK (Wertheimer et al., 2018). As of 2018, these forecasts are jointly developed by NOAA and the Alaska Department of Fish and Game (`http://www.adfg.alaska.gov/static/applications/dcfnewsrelease/1002259599.pdf`).

SECM sampling has focused most consistently in Icy Strait, the primary northern migratory pathway to the Gulf of Alaska for juvenile salmon originating from over 2,000 SEAK streams and rivers. Surface trawls (0–20m) are used to sample epipelagic fish species, including juveniles and adults of all five commercially-important species of Pacific salmon *(Oncorhynchus spp.)*. Juvenile pink salmon *(O. gorbuscha)* are, on average, the most abundant species in the epipelagic habitat in SECM surveys. Here, we provide summaries of the annual catch rates for juveniles of the five salmon species(pink; coho *O. kisutch*; sockeye, *O. nerka*; chum, *O. keta*; and Chinook, *O. tshawytscha*). Catch rates have been calibrated to account for differences in fishing power between survey vessels (Wertheimer et al., 2010).

Status and trends: In 2019, vessel-calibrated juvenile catch rates were among the lowest of the time series across all species (Figure 71). Compared to 2018, catch rates increased slightly for juvenile chum, coho, pink, and sockeye. However, despite these slight improvements, catch rates for these species remained at low levels compared to previous years. Vessel-calibrated catches of juvenile Chinook salmon were the second-lowest in the 23-year time series.

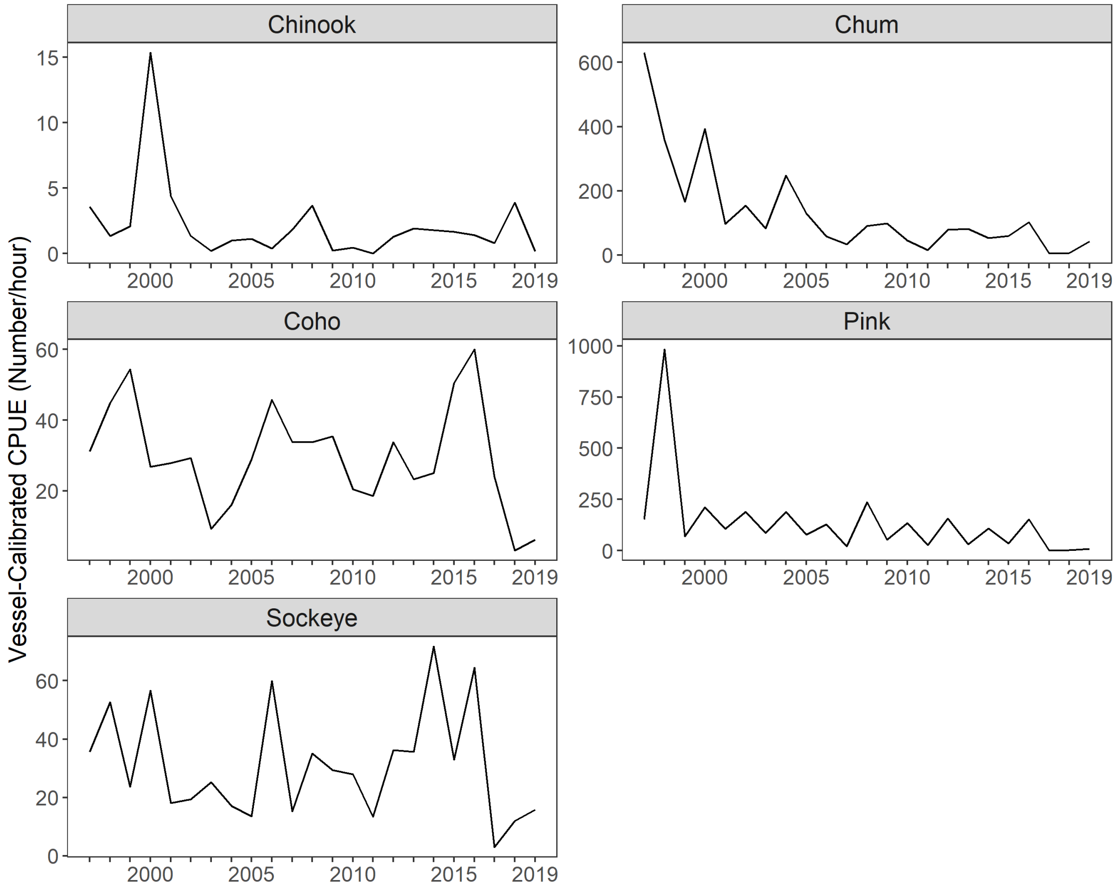

Figure 71: Time series of juvenile, immature (Chinook only), and adult salmon catch rates (number of fish per hour) during southeast Coastal Monitoring (SECM) surveys from 1997–2019.

Factors influencing observed trends: Sea surface waters in 2019 in Icy Strait (upper 20m integrated) were among the warmest of the time series. Further, open ocean conditions in 2019, like 2014–2016, continued to be anomalously warm. The persistent, warm marine conditions are likely to have influenced recruitment patterns through multiple years of altered community structure and stock dynamics. Lower catch rates could also be caused by reduced freshwater survivals, although this has not yet been investigated using SECM data. A final possible explanation of the low catch rates is a phenological shift in the out-migration timing of juvenile salmon, which could affect the survey's ability to capture them. Changes in both the median date and duration of migration has been documented across multiple species of salmon in Southeast Alaska (Kovach et al., 2013). The low numbers of juvenile pink salmon caught this year was not unexpected, as adult pink salmon escapement in 2018 was one of the lowest on record.

Implications: We have observed a significant and temporally-stable relationship between juvenile catch rates and adult harvest of pink salmon in SEAK. As a result, juvenile catch rates obtained from SECM are integral to produce accurate harvest forecasts of pink salmon in SEAK for the following year. The low pink salmon catches in 2019 indicate another year of low adult harvest in 2020.

Connections between juvenile catch rates and adult returns have not yet been identified for Chinook, chum, coho, and sockeye salmon. However, the development of production models for these species is an active area of research. SECM data are also being coupled with data from open ocean surveys to better understand mechanisms that may regulate the abundance of salmon, including early ocean and overwinter mortality.

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

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Last updated: September 2019

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) through 2019 and energy density data through 2018 for juvenile salmon in Icy Strait.

Status and trends: In 2019, juvenile salmon length values increased from 2018 values. For juvenile pink, chum, and sockeye salmon, length values increased from below to above the 23 year average (Figure 72). Although juvenile coho salmon size did increase, it was still below the 23 year average. The larger sizes of juvenile pink, chum, and sockeye salmon are very similar to those observed during the marine heatwave of 2014–2016, which were the largest of the time series.

In 2018, juvenile salmon energy densities (ED, kJ/g dry weight) were all above the 23 year average. However, juvenile pink and sockeye salmon EDs declined from 2017 values while juvenile chum and coho salmon EDs increased from 2017 (Figure 73). The above average EDs for all species continues a trend of good condition since 2013–2014.

Factors influencing observed trends: During early marine entry and residency, juvenile salmon must grow quickly to avoid predation while also acquiring enough lipid reserves to survive winter when food is limited (Beamish and Mahnken, 2001; Moss et al., 2005). Record low numbers of out-migrating juvenile pink and coho salmon in 2017 may have resulted from low escapement in 2015 and 2016 and/or low freshwater survival (Watson et al. 2018).

Implications: The above average size values observed for juvenile pink, chum, and sockeye salmon is favorable for survival as larger fish generally have increased foraging success and decreased predation risk. The above average energy density indicates that these fish entered the Gulf of Alaska in 2018 with above average energy stores which may contribute to higher survival.

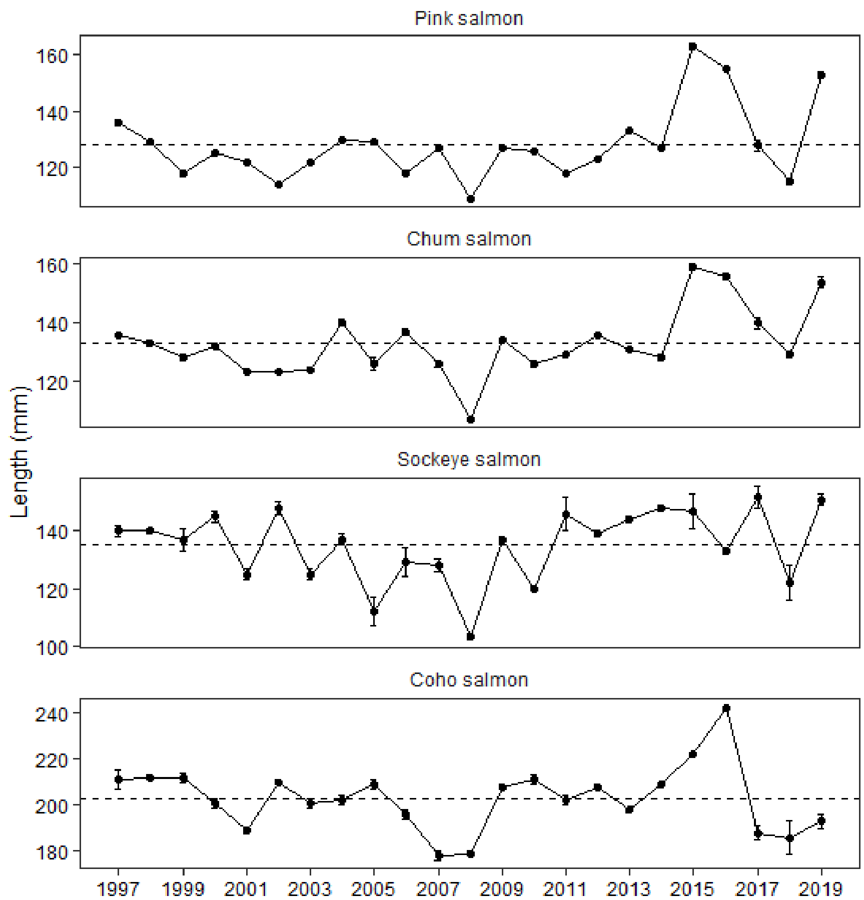

Figure 72: Average fork length (mm; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2019. Time series average is indicated by the dashed line.

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

Contributed by Scott C. Vulstek, Joshua R. Russell, Auke Bay Laboratories Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: September 2019

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

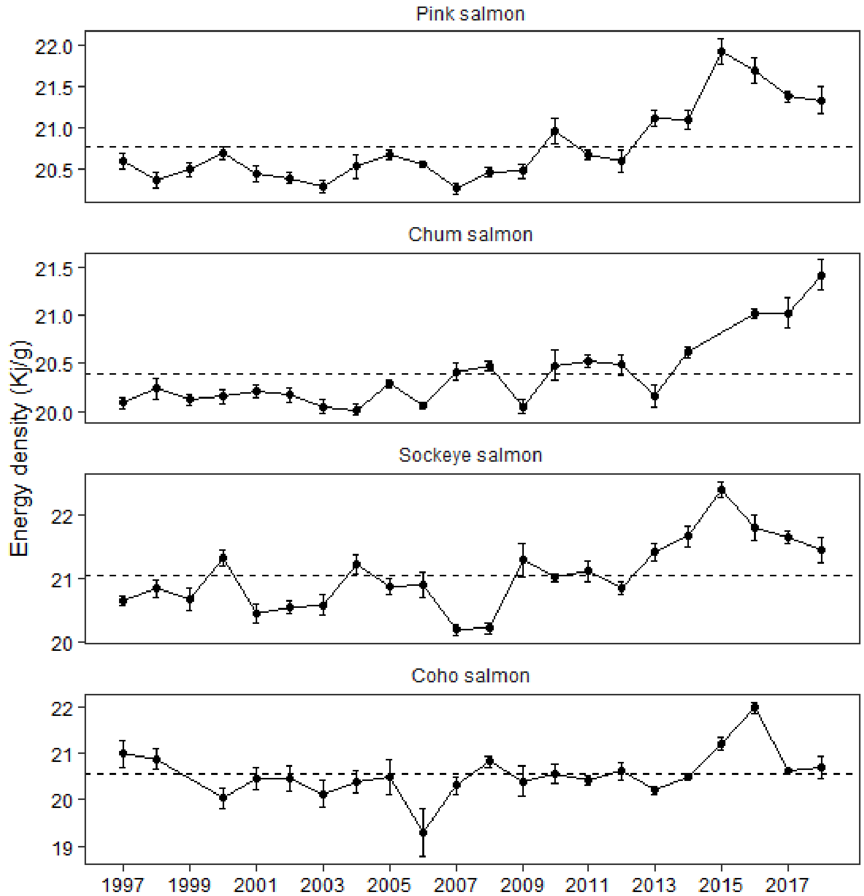

Figure 73: Average energy density (kJ/g, dry weight; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2018. Time series average is indicated by the dashed line.

model input relating to nearshore and gulf-wide productivity. The index is presented by fry ocean entry year.

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 1980–2018 (Figure 74). Marine survival for the 2016 ocean entry year was 6.6% and overall survival averaged 15.4% over the last 5 years and 15.1% over the last 10 years. 2019 saw the 9th lowest return of pink salmon to Auke Creek with 2093 returning adults (Figure 75).

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 74). 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 cli-

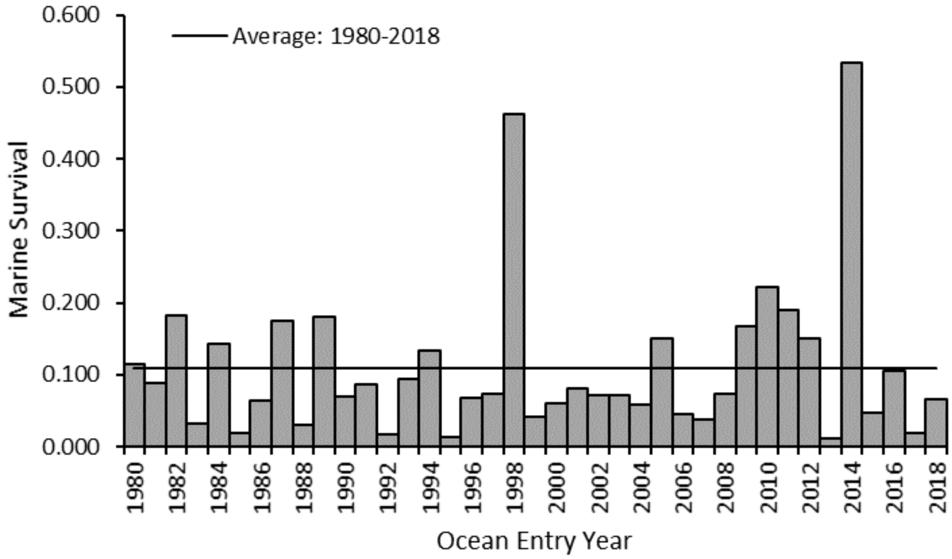

Figure 74: Auke Creek pink salmon marine survival index by ocean entry year.

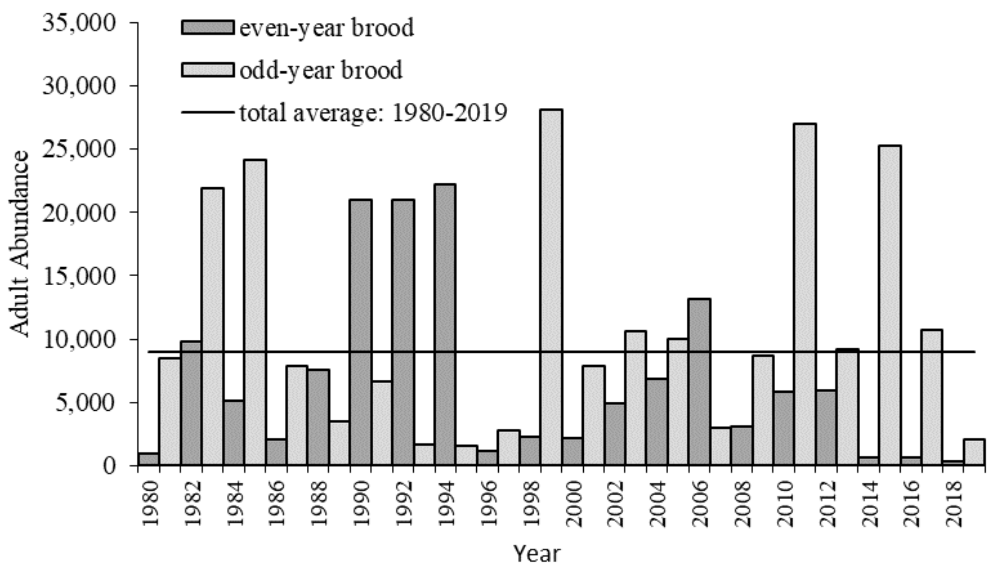

Figure 75: Auke Creek pink salmon adult returns by year.

matic 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).

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 2019

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 22.8% from smolt years 1980–2018 (Figure 76; top panel). Marine survival for 2018 was the fourth lowest on record at 8.0%, and overall survival averaged 9.0% over the last 5 years and 14.3% over the last 10 years. The survival index for ocean age-1 coho varies from 3.9% to 36.6% from smolt years 1980–2018 (Figure 76; middle panel) and for ocean age-0 coho varies from 0.5% to 11.2% from smolt years 1980–2018, with 2018 being the lowest on record (Figure 76; bottom panel). Return data for 2019 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 ∼8.0% (marine survival was at 7.8% as of 27 September 2019, 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 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.

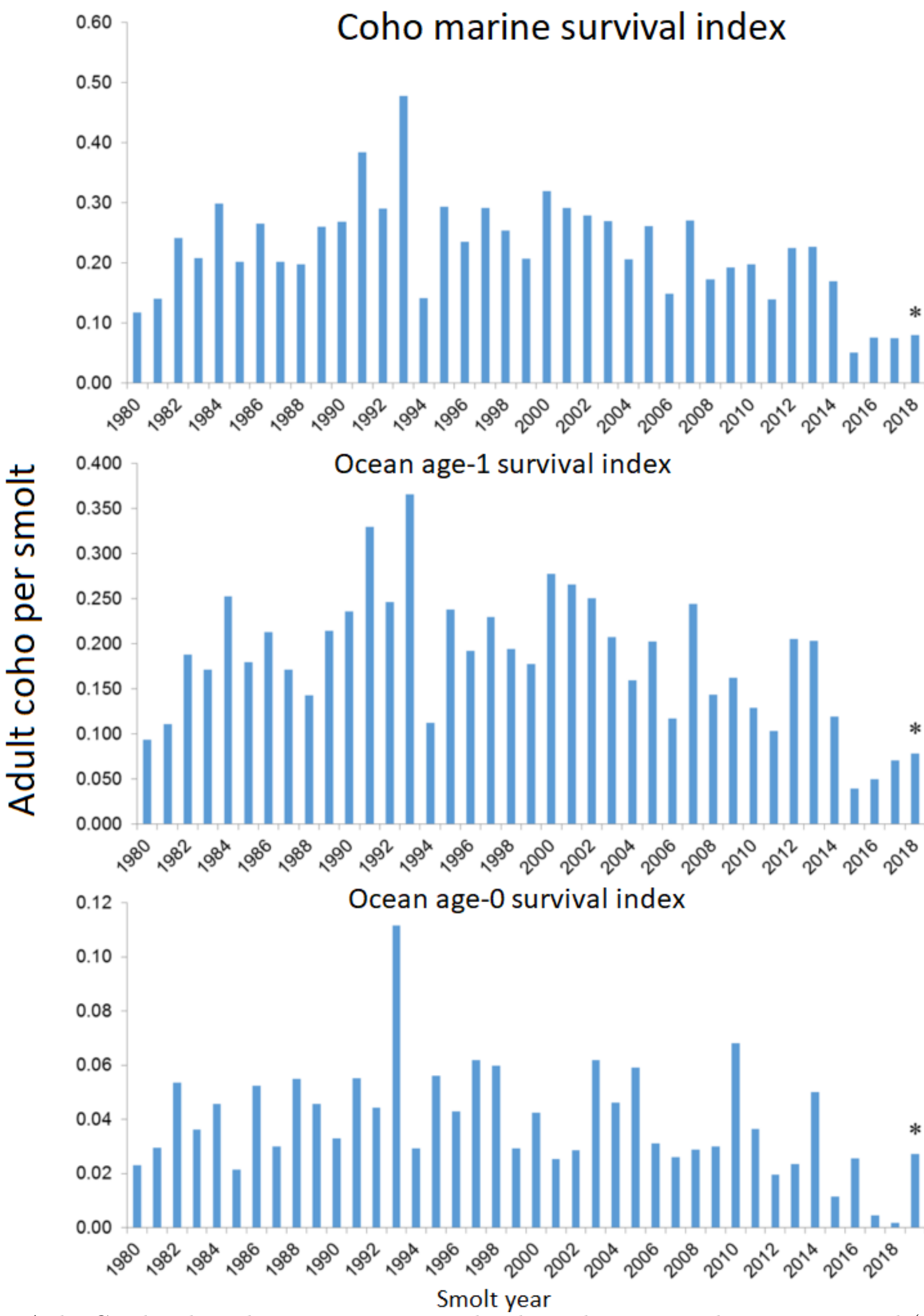

Figure 76: Auke Creek coho salmon marine survival indices showing total marine survival (ocean age-0 and age-1 harvest plus escapement; top panel), percentage of ocean age-1 coho per smolt (harvest plus escapement; middle panel), and percentage of ocean age-0 coho per smolt (escapement only; bottom panel) by smolt year. Return year 2019 data are denoted with an asterisk as these may change slightly by the end of the coho return.

Groundfish

Gulf of Alaska Groundfish Condition

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Last updated: October 2019

Description of indicator: Length-weight residuals are an indicator of somatic growth (Brodeur et al., 2004) and, therefore, a measure of fish condition representing how heavy a fish is per unit body length. As such, it may be an indicator of ecosystem productivity and fish survival. Positive length-weight residuals indicate better condition (i.e., heavier per unit length) than negative residuals indicating poorer condition (i.e., lighter per unit length). Overall condition of fishes likely affects their growth and can have implications for their subsequent survival (Paul et al., 1997; Boldt and Haldorson, 2004).

Paired lengths and weights of individual fishes were examined from the Alaska Fisheries Science Center biennial Resource and Conservation Engineering (AFSC/RACE)-Groundfish Assessment Program's (GAP) bottom trawl survey of the Gulf of Alaska (GOA). Analyses focused on walleye pollock, Pacific cod, arrowtooth flounder, Southern rock sole, dusky rockfish, Northern rockfish, and Pacific ocean perch collected in trawls with satisfactory performance at standard survey stations. Data were combined by International North Pacific Fisheries Commission (INPFC) area; Shumagin, Chirikof, Kodiak, Yakutat and Southeast (Figure 77). Length-weight relationships for each of the seven species were estimated from a linear regression of log-transformed values over all years where data were available (1984–2019); length-weight relationships for age-1 walleye pollock (fork length = 100–250 mm) were calculated independent of the adult life history stages caught. Predicted weights for all life stages and species were calculated and subtracted from observed weights to calculate residuals for each fish. Length-weight residuals were averaged across GOA surveys and within years for the 5 INPFC areas sampled in the standard AFSC/RACE GAP summer bottom trawl survey. Temporal and spatial patterns in residuals were examined.

Status and trends: Length-weight residuals varied over time for all species with a few notable patterns (Figure 78). Residuals for most species where there were data were positive in the first three years of the survey (1985–1990) and have been mixed since then. Age 1 pollock have more often displayed better than average condition over the survey time period, but have been consistently at or below average condition in recent survey years. Condition has increased over the last few surveys for several species (i.e., walleye pollock, Pacific cod, Southern rock sole, and arrowtooth flounder), but only for Pacific cod has fish condition increased above the long-term average. For Northern and dusky rockfishes, 2019 fish condition was the lowest in the record and was the second lowest in the record for Pacific ocean perch. Overall for the GOA species examined, Pacific cod is the only species with a trend toward better than average condition.

Spatial patterns in residuals were apparent for several species (Figure 79). For the gadids and flatfishes examined, fish condition improved in some areas in 2019 (e.g., adult walleye pollock and Southern rock sole in Southeastern or Pacific cod in all but Yakutat) or remained about the same across areas (e.g., age-1 walleye pollock). For the rockfishes, condition remains below average where they occur and continues declines begun in 2015 in some areas (e.g., Northern rockfish in the Shumagins and Chirikof, dusky rockfish in Southeastern). Fish condition varies widely between surveys within INPFC areas indicating that local conditions may be strong influencers of fish growth and production.

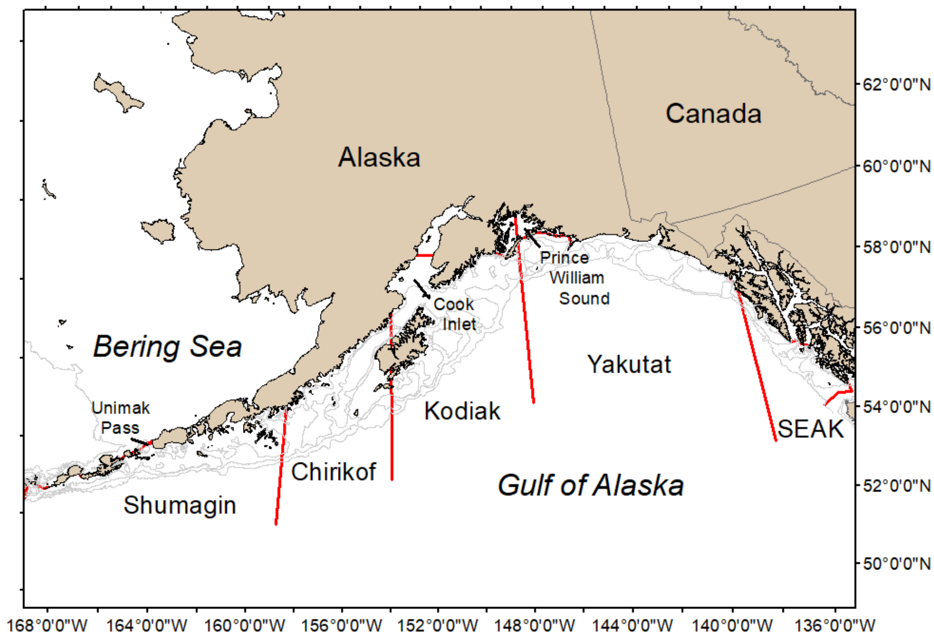

Figure 77: AFSC/RACE Groundfish Assessment Program summer bottom trawl survey area in the Gulf of Alaska; red lines demarcate International North Pacific Fisheries Commission (INPFC) statistical fishing Areas.

Factors influencing observed trends: Water temperatures and local production are potential factors that can affect spatio-temporal variability in the length-weight residuals. Trends in fish condition (up and down) over the last three Gulf of Alaska surveys correspond to warmer than usual water temperatures that have been attributed to the "Blob" (Bond et al., 2015) and continued elevated temperatures (Laman et al., 2017), and Laman in this issue. The observed spatial variability, which somewhat confounds temporal trends in the length-weight residuals, may reflect additional local environmental features (e.g., warm core eddies in the central Gulf of Alaska; (Atwood et al., 2010)) which can influence fish condition in the areas surveyed.

Other factors that could affect length-weight residuals include fish emigration/immigration and survey timing. The earliest length-weight data collected in GOA are typically recorded in late May or early June. The bottom trawl survey then progresses from late spring through the summer months as it sweeps from west to east. Because of the confounding of time and space as a necessity of our sampling design and logistics, it is likely impossible to separate in-season time trends from the spatial trends in these data. Is is also important to note that the data and analyses reported here depict spatial and temporal variation in length-weight residuals of a subset of the fish species collected in the AFSC/RACE GAP summer bottom trawl surveys of the Gulf of Alaska, but do not inform the mechanisms or processes creating the observed patterns.

Implications: Fish condition has implications for fish survival. For example, in Prince William

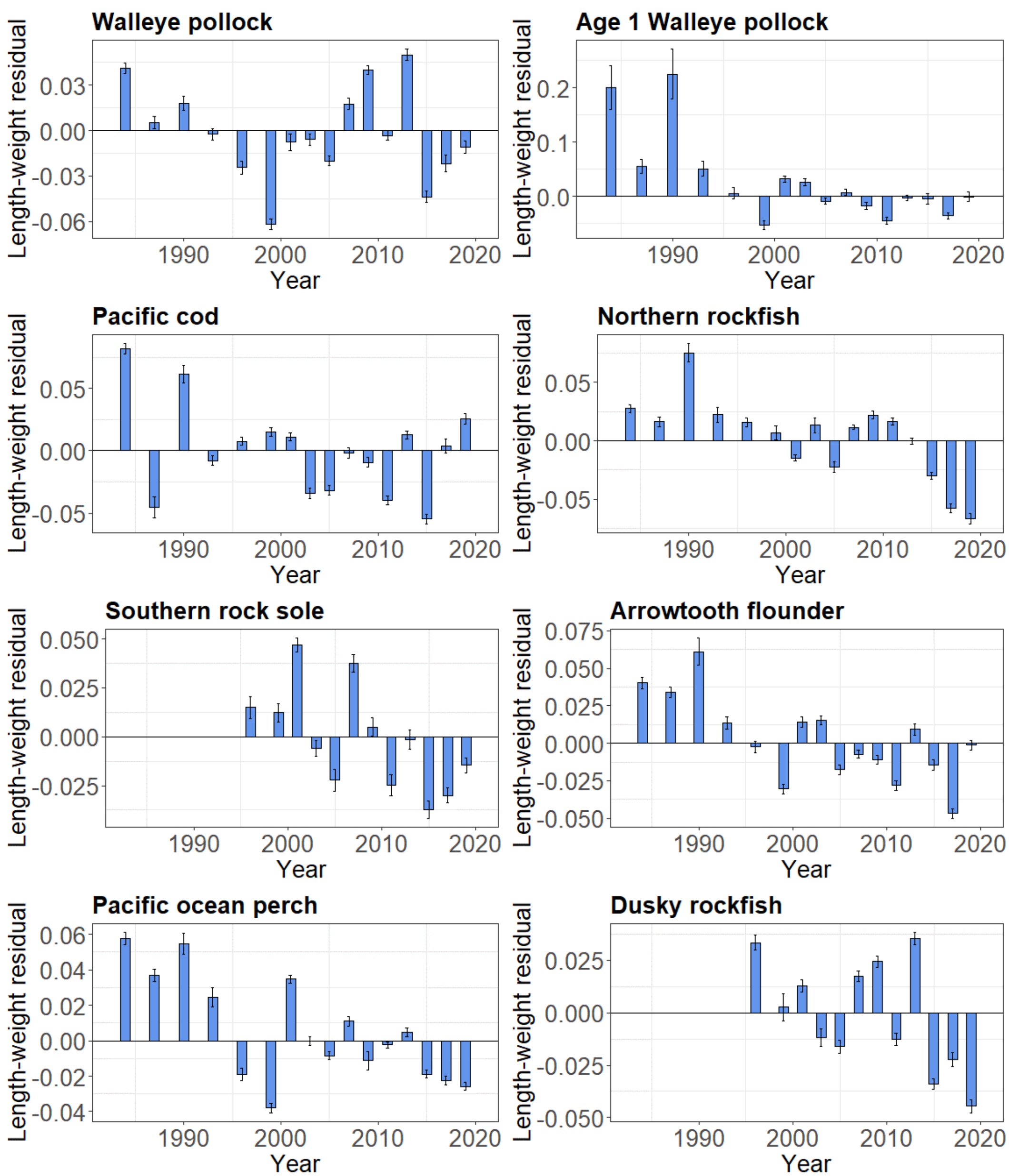

Figure 78: Length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985–2019.

Sound, the condition of herring prior to the winter may determine their subsequent survival (Paul and Paul, 1999). Thus, the condition of GOA groundfishes may provide us with insight into their survival and population health. However, it is likely that survivorship is affected by many factors in addition to fish condition. We also must consider that, in these analyses, fish condition was computed for all sizes of fishes combined. The examination of condition of early juvenile stage fishes not yet recruited to the fishery, or the condition of adult fishes separately, could provide greater insight into the value of length-weight residuals as an indicator of individual health or survivorship. Research on this topic is currently under way and will examine correlative relationships between length-weight residuals and survivorship for early and late juvenile stages as well as for adults

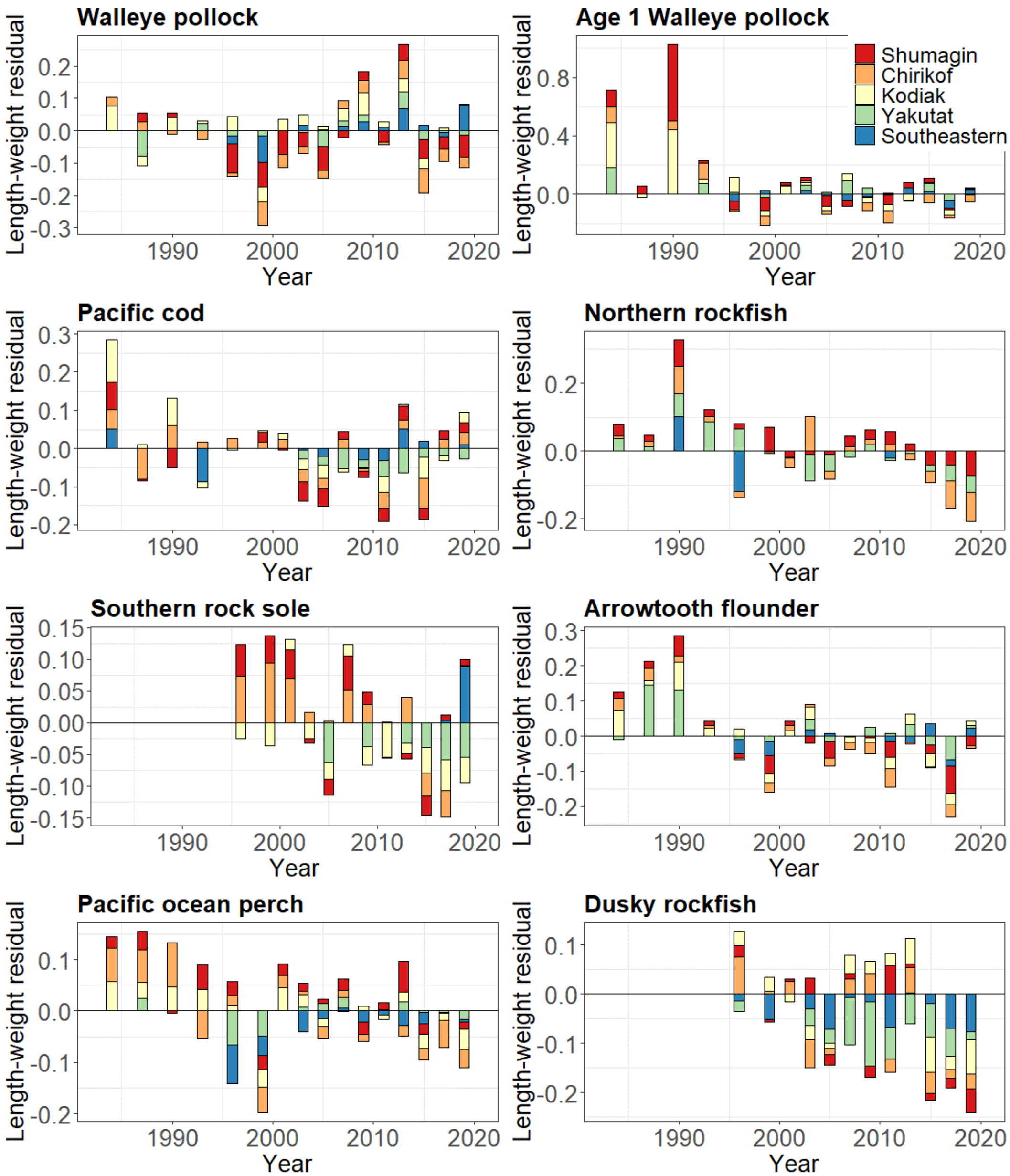

Figure 79: Length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985–2019, by INPFC area.

(Rooper et al. in prep.). The trend toward lowered fish condition for many species over the last 3–4 RACE/AFSC GAP Gulf of Alaska bottom trawl surveys is a potential cause for concern. It could indicate poor overwinter survival or may reflect the influence of locally changing environmental conditions depressing fish growth, local production, or survivorship. Indications are that the "Blob" documented in 2015 (Bond et al., 2015) has been followed by subsequent years with elevated water temperatures in the Gulf of Alaska (Laman et al., 2017), and Laman in this issue, which may be related to changes in fish condition in the species examined. As we continue to add years of fish condition to the record and expand on our knowledge of the relationships between condition, growth, production, and survival, we hope to gain insight into the overall health of fish populations in the Gulf of Alaska.

ADF&G Gulf of Alaska Trawl Survey

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Last updated: September 2019

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 80). 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 81). 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 82). Temperature anomalies were calculated using average bottom temperatures recorded for each haul from 1990 to present (Figure 83).

Status and trends: Tanner crab have dominated the catches in the ADF&G trawl survey in the last two years. Arrowtooth flounder, flathead sole, and other flatfish only slightly increased in 2019, from historically low catches in recent years. Similarly, starfish catches have significantly decreased in the inshore areas since 2017. 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 81). Although still at relatively low levels, 2019 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 29% of catch and walleye pollock 71% in 2018. In 2019, Pacific cod decreased to 19%, while walleye pollock increased to 88% of the overall gadid catches. Pollock catches remain well below average in the inshore areas of Kiliuda and Ugak Bays and only slightly above average in the offshore area of Barnabus Gully(Figure 81).

Below average anomaly values for arrowtooth flounder and flathead sole were recorded again in 2019 for both inshore and offshore areas; along with Pacific cod, Pacific halibut, and skates only in the offshore areas (Figure 82). The above average anomaly values for Tanner crab continue in

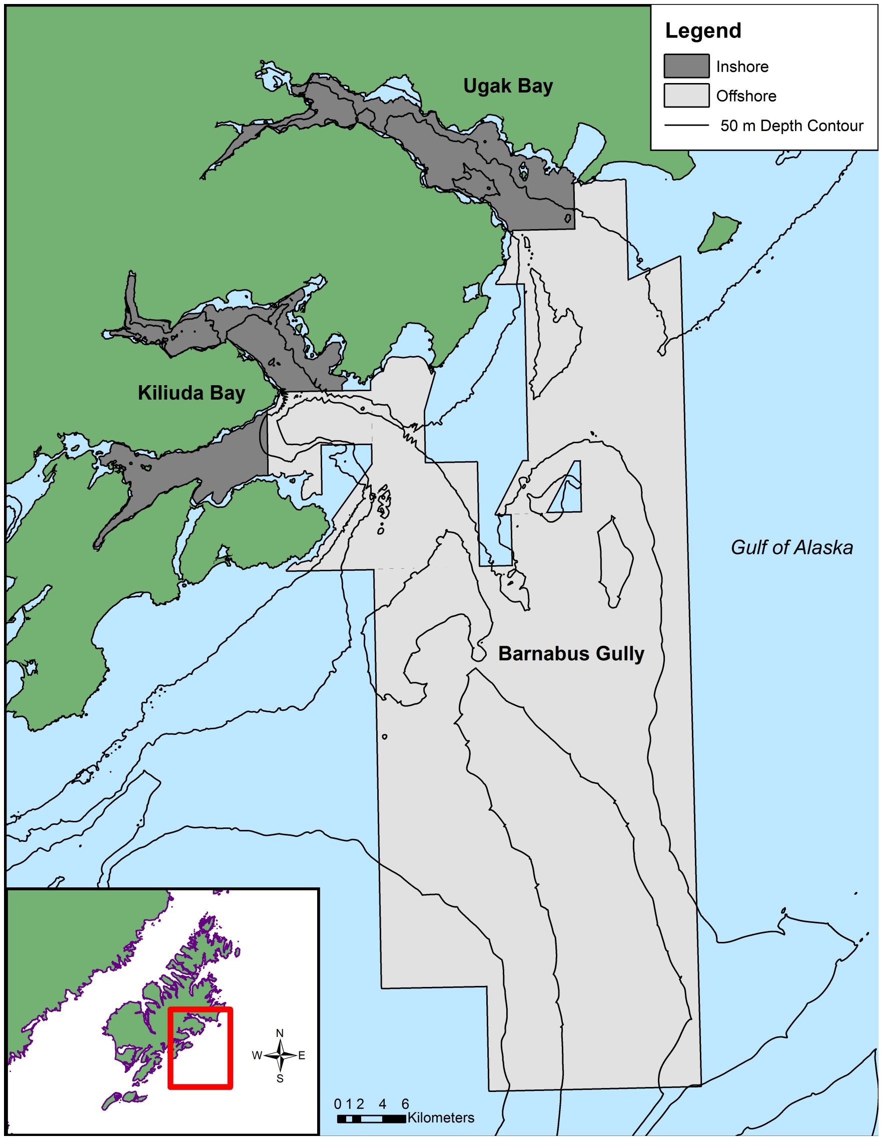

Figure 80: Kiliuda Bay, Ugak Bay, and Barnabus Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

2019 (Figure 81) were due to a large recruitment event occurring in both inshore and offshore areas (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 83). 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`).

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

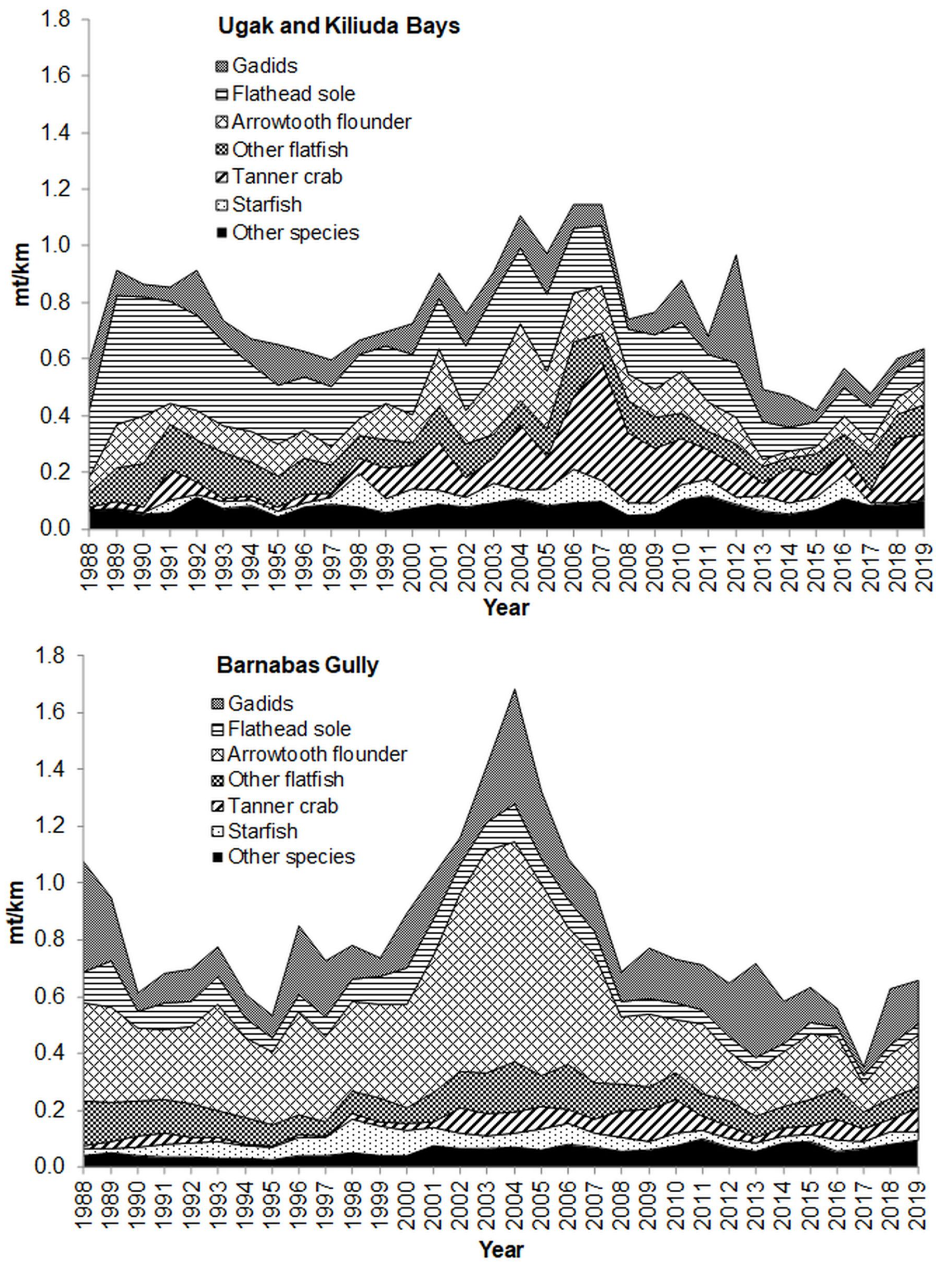

Figure 81: Total catch per km towed (mt/km) of selected species from Barnabus Gully and Kiliuda and Ugak Bay survey areas off the east side of Kodiak Island, 1987–2019.

1993 to 1999 (Figure 82) 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

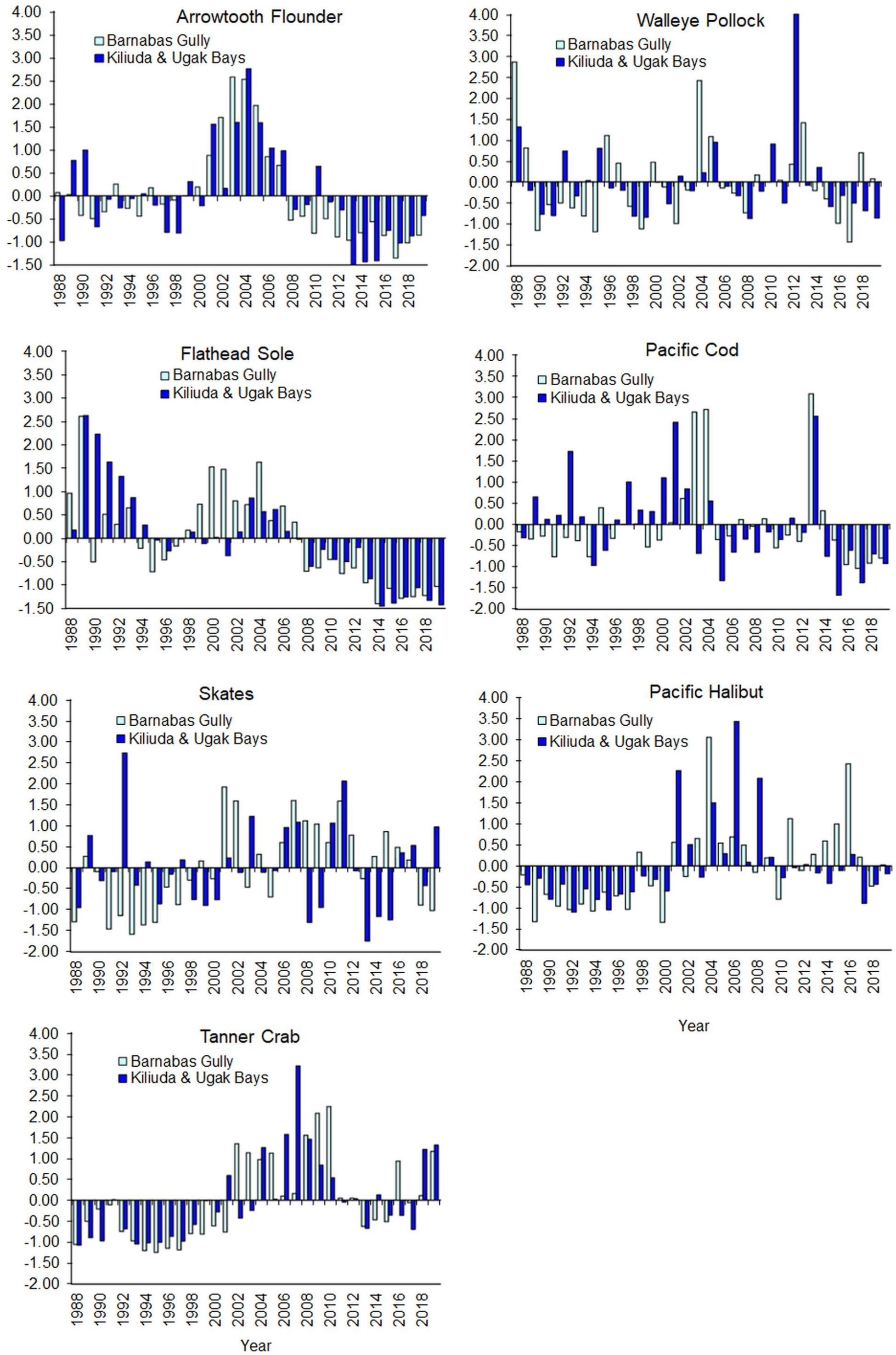

Figure 82: A comparison of standardized anomaly values, based on catch (kg) per distance towed (km) for selected species caught from 1988 to 2019 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

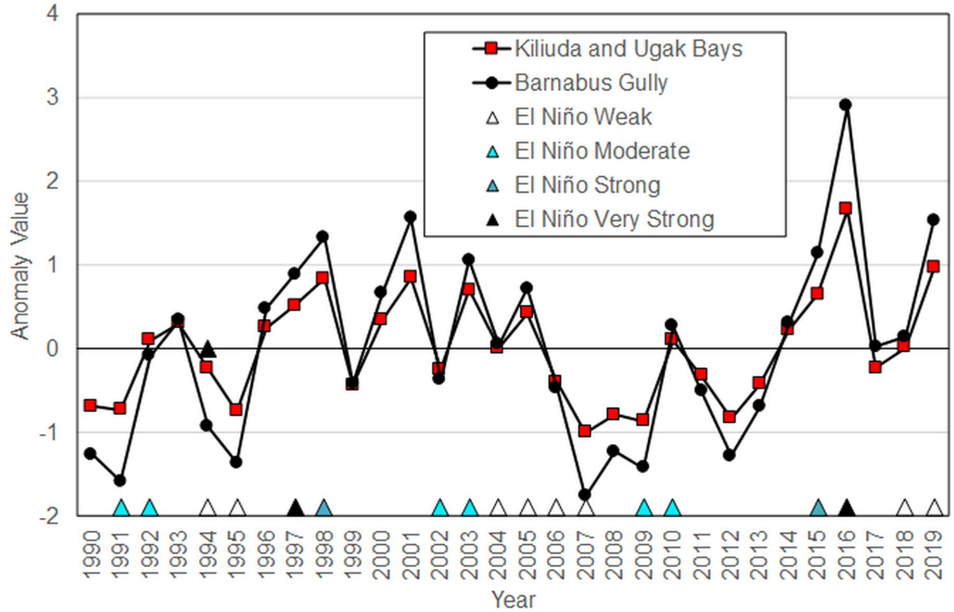

Figure 83: Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2019, with corresponding El Niño years represented.

oceanographic 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 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.

Benthic Communities and Non-target Fish Species

Miscellaneous Species—Gulf of Alaska Bottom Trawl Survey

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Last updated: October 2019

Description of indicator: RACE bottom trawl surveys in the Gulf of Alaska (GOA) are designed primarily to assess populations of commercially important fish and invertebrates. However many other species are identified, weighed and counted during the course of these surveys and these data may provide a measure of relative abundance for some of these species. Many of these species are not sampled well by the gear or occur in areas that are not well sampled by the survey (hard, rough areas, mid-water etc.); thus they are encountered in small numbers which may or may not reflect their true abundance in the GOA. The fishing gear used aboard the Japanese vessels that participated in all GOA surveys prior to 1990 was very different from the gear used by all vessels since. This gear difference almost certainly affected the catch rates for some of these species groups. For each species group, the catches for each year were scaled to the largest catch over the time series (which was arbitrarily scaled to a value of 100). The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The percentage of positive catches in the survey bottom trawl hauls was also calculated.

Status and trends: Echinoderm catches have been highest in the Kodiak and Chirikof regions of the GOA, and they are consistently captured in ∼80% of bottom trawl hauls in all areas (Figure 84). Echinoderms have declined in the Shumagin and Chirikof areas during 2019 but appear relatively stable in the other regions. Shrimp CPUE have been increasing in the Kodiak, Chirikof, and Yakutat areas over the last few surveys, while they have remained fairly constant and low relative abundance in the other areas. Eelpout CPUE has been variable, with peak abundances occurring in 1993, 2001 and 2009 in the Shumagin area but were at their lowest observed level in 2019. High abundances of eelpouts were observed in 2003 in the central GOA (Kodiak and Chirikof areas), however the Yakutat area had the highest ever abundance in 2019. Poacher CPUE's peaked in 1993 and 2015 in the Shumagin area. Poachers have been uniformly in low abundance in the Chirikof, Yakutat and Southeastern areas and have been variable, but somewhat higher in the Kodiak areas with the highest ever abundance during 2019 after a very low abundance in 2017.

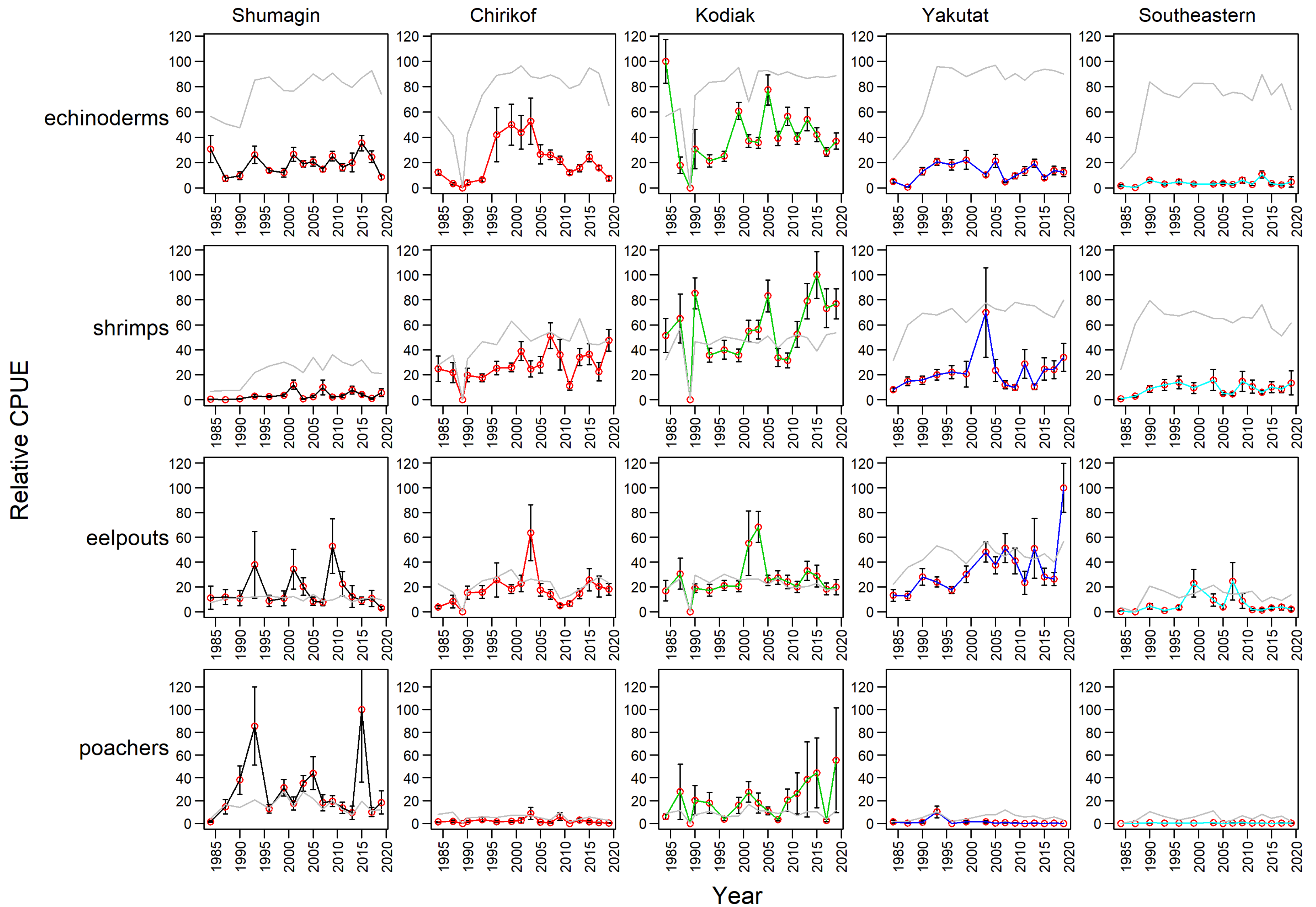

Figure 84: Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2019. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

Factors influencing observed trends: Unknown

Implications: The trends in other species in the bottom trawl survey do not appear consistent over time, with the possible exception of decreases in recent echinoderm and eelpout catches in the Shumagin region.

Seabirds

Seabird Monitoring Summary from Alaska Maritime National Wildlife Refuge

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Last updated: October 2019

Description of indicator: The Alaska Maritime National Wildlife has monitored seabirds at colonies around Alaska in most years since the early to mid-1970's. 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. Monitored colonies in the Gulf of Alaska include Chowiet (Semidi Islands), East Amatuli (Barren Islands), and St. Lazaria (southeast Alaska) islands. Reproductive success at colonies during 2019 is shown in Figure 85. Egg icons are determined using a nonparametric bootstrap approach. For each species and location, using all previous years' data, mean bootstrap quartiles were generated using 1000 bootstrap samples and delineated as follows:

- Current year's values above the mean 75th percentile received "big smiley" faces;
- Current year's values between the mean 25th–75th percentile received "smiley" faces;
- Current year's values below the mean 25th percentile received "frowny" faces;
- Current year's values below .01 received "broken" faces.

Status and trends: Diving fish-eating seabirds (common and thick-billed murres, rhinoceros auklets, and tufted puffins) generally had high reproductive success in 2019 (Figure 85). Success was well above the long-term average at most sites and was the highest ever recorded in some cases; the exception was poor productivity for murres at East Amatuli. Attendance of common murres at Chowiet continued to increase in 2019, but is still only a little more than half the average number counted in all years prior to 2014. Success of black-legged kittiwakes and storm-petrels (which consume a mix of fish and invertebrates at the surface) varied by site. Kittiwakes experienced complete breeding failure at Chowiet but had a normal year at East Amatuli. Storm-petrels had poor breeding success at East Amatuli but had higher than average breeding success at St. Lazaria in southeast Alaska. Planktivorous auklets breeding at Chowiet showed within-normal breeding success.

Factors influencing observed trends: In general, during the past few years murres appeared to be negatively affected by the 2014–2016 marine heatwave, with widespread reproductive failures, die-offs, and low attendance at breeding colonies (Figure 86). Other species did not show broad-scale failures during this period; planktivorous seabirds were generally successful during those years. Generally high reproductive success of murres and a slow increase in attendance in 2019 may indicate that environmental changes returned to more favorable conditions. Reproductive failure of black-legged kittiwakes at Chowiet during the chick rearing period in 2019 may reflect poor prey availability during the breeding season, supported by NOAA surveys that found few age-0 pollock, age-0 cod, and capelin in the Shelikof Straits and Semidi Islands area.

Implications: Reproductive activity of seabirds can reflect ecosystem conditions at multiple spatial and temporal scales. For diving piscivorous species that feed at higher trophic levels, widespread high reproductive success suggests improved foraging conditions for those species across the whole region in 2019. However, complete failure of surface-feeding kittiwakes in the western Gulf indicates localized foraging conditions in the upper water column may have been inadequate in 2019.

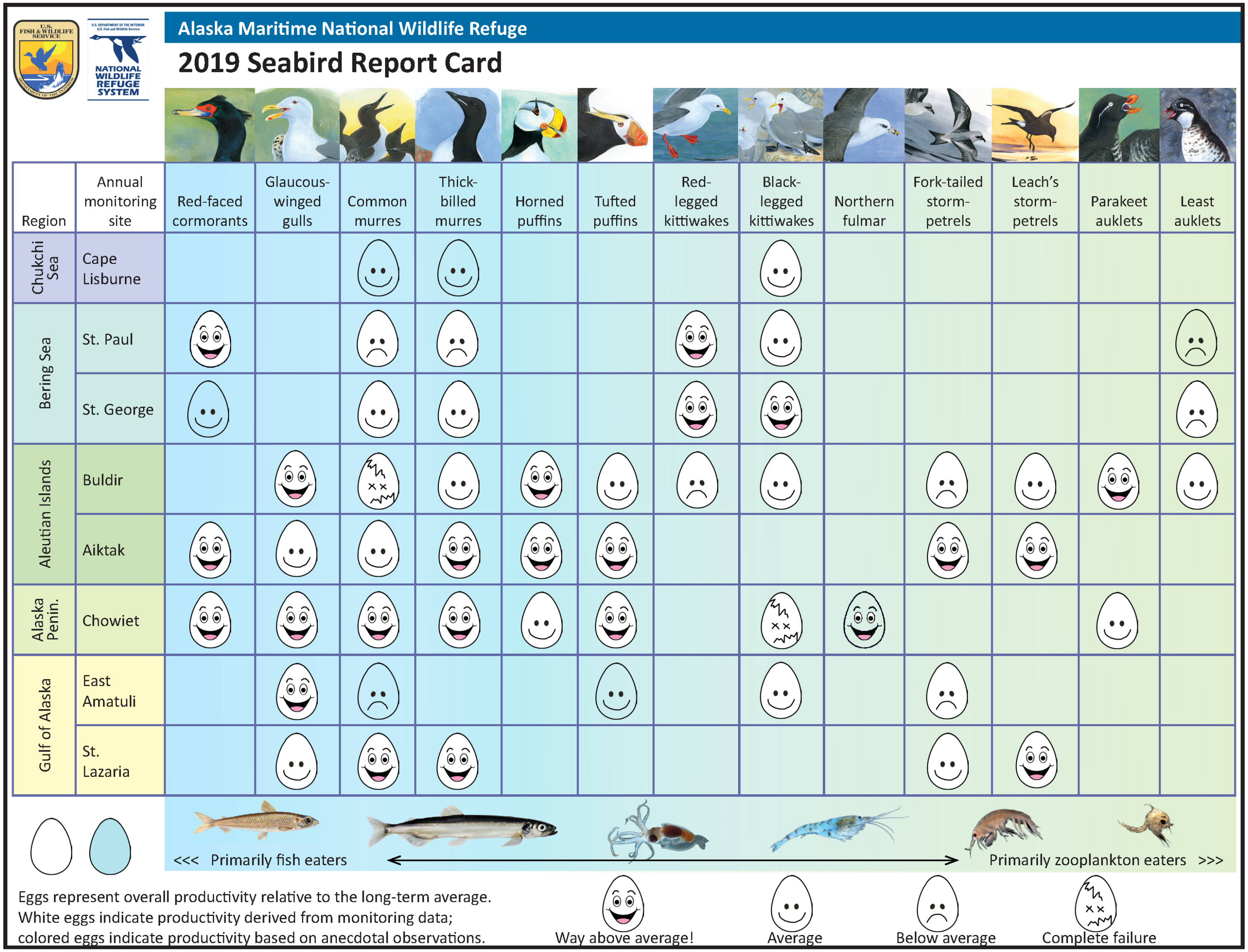

Figure 85: Summary of reproductive success in 2019 at long-term monitored sites on the Alaska Maritime National Wildlife Refuge. Figure created by AMNWR.

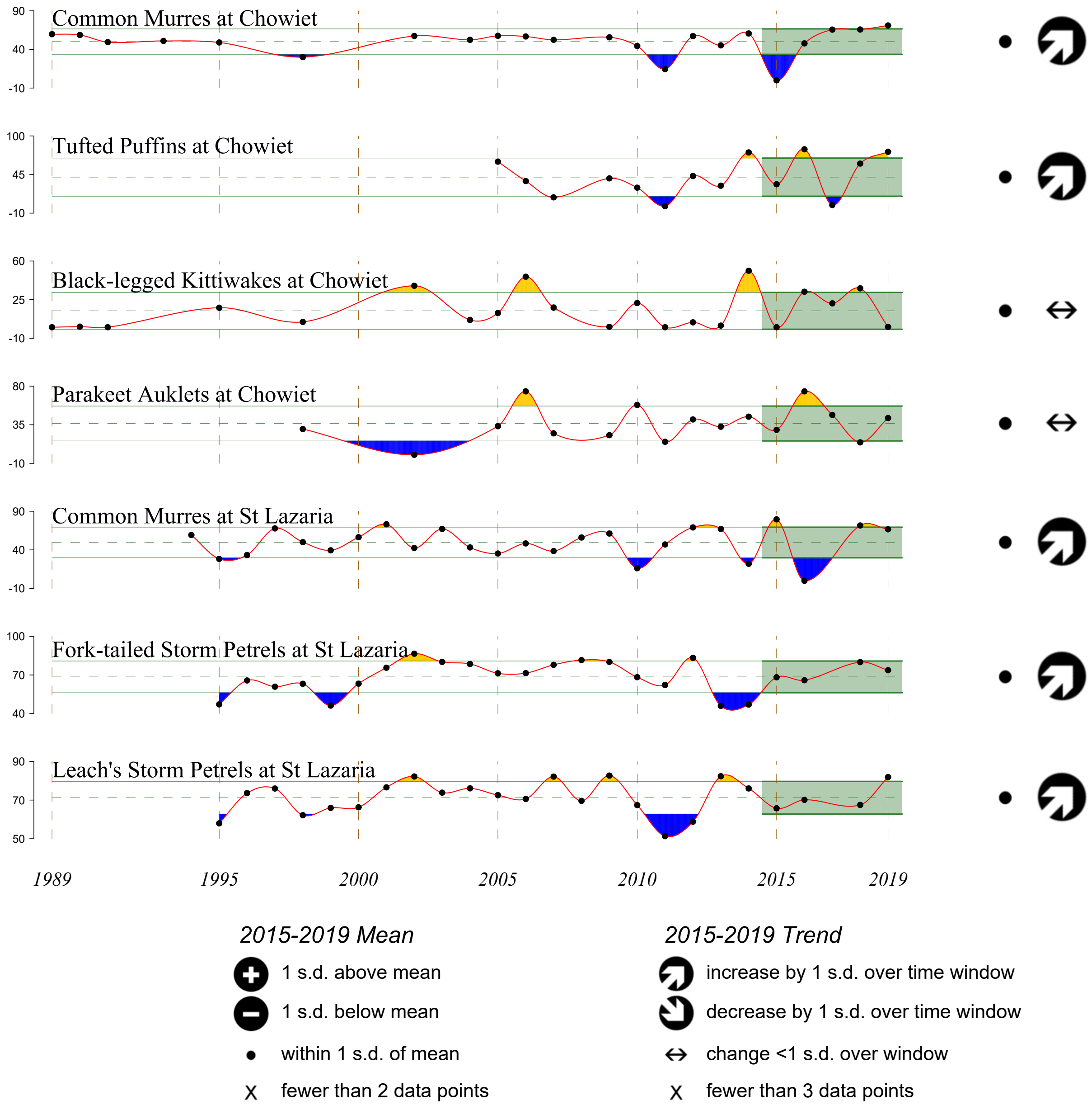

Figure 86: Summary of reproductive success of some seabird species at Chowiet (WGOA) and St Lazaria (EGOA).

Marine Mammals

Fall Surveys of Humpback Whales in Prince William Sound

Contributed by John Moran and Janice Straley, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2019

Description of indicator: 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 the ability of the ecosystem to support populations of large vertebrate predators.

Status and trends: During September of 2019 in Prince William Sound we observed more humpback whales than in 2017 and 2018, however they remain well below 2008–2014 numbers. The encounter rate for humpback whales (number of whales/nm traveled) was twice the rate seen in 2018 (Table 3). Calf production in the Sound continues to remain low, no calves were identified in 2019. Unlike 2017 and 2018, we did not see whales in poor body condition. Whale numbers continue to parallel the abundance of prey species. Acoustic indices of fish and krill biomass in 2019 was higher than 2017 and 2018, but still well below surveys conducted prior to the 2014–2016 heatwave. We also are seeing dietary shifts in Prince William Sound humpback whales. Prior to the 2014-2016 heatwave, adult herring dominated the fall diet. In 2019, the majority of whales were feeding on euphausiids. A few whales were feeding on juvenile herring which were abundant throughout the Sound. No adult herring were encountered during the September 2019 survey.

Factors influencing observed trends: In 2019 we saw a slight recovery in the Prince William Sound ecosystem. The primary prey of humpbacks switched from adult herring (prior to the heatwave) to euphausiids in 2019. Abundant juvenile herring and juvenile black cod were associated with some whales, but based on our observations the black cod were competitors for herring rather than prey for the whales. The cause of the herring decline within the Sound remains unknown, but

Table 3: Index of PWS humpback whale abundance and counts of calves in PWS.

Month/year	Whale counts	Calves counts	Nautical miles surveyed	Encounter rate whale/nm
Sep-08	71	17	412	0.17
Oct-11	62	2	441	0.14
Sep-12	81	5	444	0.18
Sep-13	113	6	355	0.32
Sep-14	181	1	427	0.42
Sep-17	12	0	543	0.02
Sep-18	17	1	541	0.03
Sep-19	35	0	573	0.06

lower whale numbers are likely the result of fewer herring.

Implications: Adult herring are still missing from whale diets in the Sound. In the fall herring are rich in fat and aggregate in large shoals prior to overwintering, making them the preferred food for humpbacks and many other piscivorous predators. The lack of calf production implies that prey resource have not fully recovered. If prey is limiting and humpback whale populations are at 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 of humpback whale indicators provides a useful method for assessing spatial variability in productivity and energy transfer to upper trophic level species in the WGOA (e.g., shifts in whale distribution may reflect shifts in prey; changes in body condition and calf production may indicate changes in prey abundance).

Caveat to observations of improved foraging conditions: We saw an influx of offshore predators (shearwaters, one albatross, fin whales, and minke whales), suggesting it is possible that poor conditions off shore were driving these species into the Sound. Juvenile black cod and juvenile herring were abundant throughout the Sound. We saw a similar occurrence in September of 2014, which may have been a precursor to the unusual mortality events and population declines that occurred during the 2014-2016 marine heatwave.

Trends in Humpback Whale Calving in Glacier Bay and Icy Strait

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Last updated: September 2019

Description of indicator: 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. From 1985–2019, 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 the number of calves-of-the-year. From these data we can document 1) number of calves; 2) crude birth rate (CBR) (defined as the number of calves divided by the total whale count for each year); 3) within-season calf survival; and 4) return rate of calves in subsequent years as juveniles and adults.

Status and trends: Humpback whale productivity and juvenile survival in Glacier Bay and Icy Strait declined sharply beginning in 2014 (Neilson et al., 2017), (Gabriele and Neilson, 2018) in Ecosystem Considerations) after many years of steady reproductive success (Gabriele et al., 2017), likely due to ecological disruptions brought on by warm ocean conditions including the "Blob" marine heatwave (Cornwall, 2019). In 2019, humpback whale calving and juvenile return rates remained lower than would be expected compared to 1985–2013 (Table 4).

We observed two cow/calf pairs in 2019; one in Glacier Bay (mother # 1906) and one in Icy Strait (mother # 219). Both mothers appeared to be in sub-optimal body condition (1906 at least through

Table 4: Humpback whale observations from Glacier Bay, Alaska. *None have been re-sighted as juveniles. Crude birth rate is calculated by dividing the number of calves by the total number of whales. The total number of whales is not yet available for 2019**. ***Overall calf mortality rate for 2014–2019 is 7 out of 25 (28%).

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%)
2019	2	<2.0**	0

mid-July and # 219 through mid-September) with visible scapulae and/or postcranial depressions (Figure 87). Female # 1906's body condition appeared to improve over the course of the summer, while # 219's did not. The total whale count in 2019 is not yet available, therefore we cannot yet compute a CBR, but with only two calves the CBR is expected to be less than 2%. 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%). When available, the 2019 CBR is not likely to depart from this trend of significantly reduced reproductive success in recent years (Figure 88).

Both calves appeared to be in relatively good physical condition when last sighted with their mothers (# 219 and calf in early September; # 1906 and calf in late July), which bodes well, but is no guarantee, for their continued survival. This is an improvement over the rate of apparent mid-season calf mortality in 2014–2019 (28%) which was sharply higher than the rate in the pre-anomaly period 1985–2013 (4%), and during which we observed no more than one apparent calf mortality per year (Table 4) (Neilson et al., 2015).

We did not document any juveniles (age 1–4 years) in 2019 and we observed only one unfamiliar small whale, which is not unexpected given very low calf production in recent years. None of the 23 Glacier Bay/Icy Strait calves born in 2014–2018 have returned or been documented elsewhere in Southeast Alaska, to the best of our knowledge. Along with fluke matching to the Southeast Alaska catalog and database that we share with our collaborator Jan Straley (University of Alaska Southeast), we have recently begun a collaboration with Murdoch University Ph.D. candidate Ted Cheeseman, founder of HappyWhale.com, a system that allows automated fluke-matching to a large photo collection from throughout the North Pacific. To date, this geographically expanded matching effort has not revealed any additional juvenile survivals.

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 4). In 2014, the first year of the calving anomaly, a 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 year's 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,

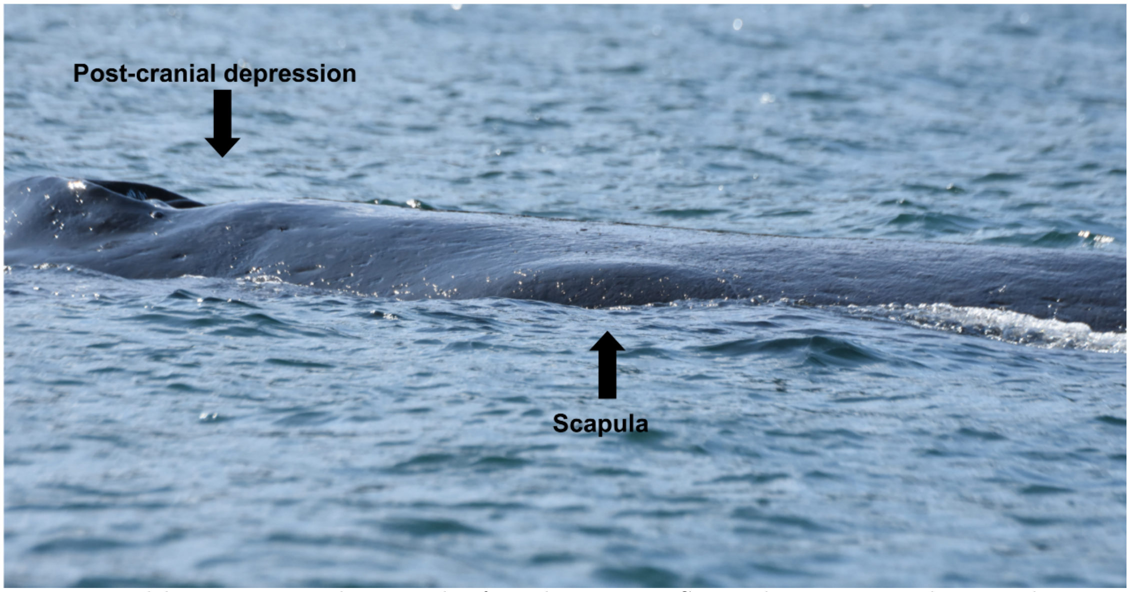

Figure 87: Health assessment photograph of mother 219 on September 10, 2019 showing the postcranial depression behind the blowholes (arrow at left) and protruding scapula (arrow at center) that characterize poor body condition.

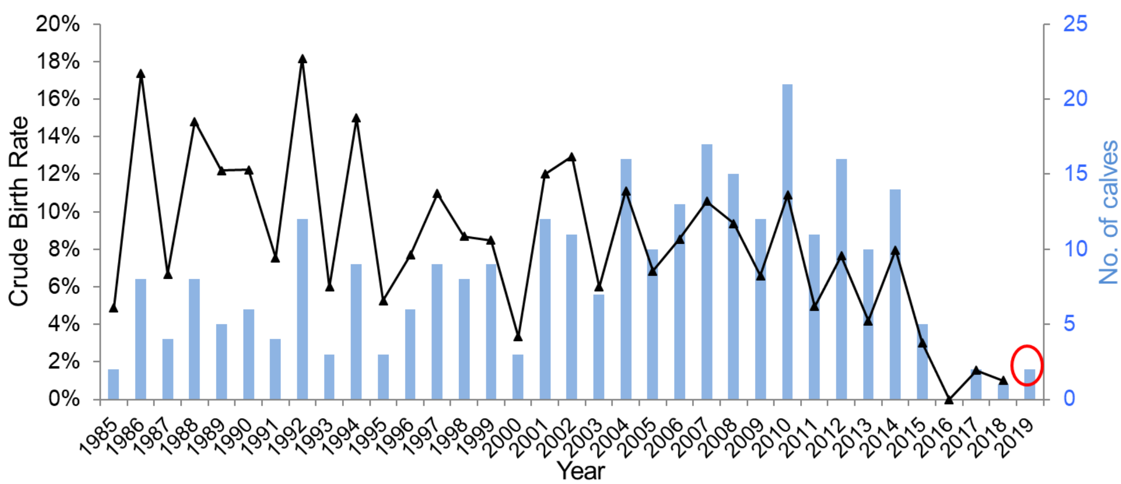

Figure 88: Crude birth rate (black line) (1985–2019) and annual number of calves (blue bars) (1985–2019) in Glacier Bay-Icy Strait. Red circle for 2019 indicates that the CBR is unknown but expected to be less than 2% (see text).

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: Unusually warm waters have been implicated in a wide variety of cascading effects on the marine ecosystem in 2014–2018 (Anderson and Piatt, 1999; Bond et al., 2015; Di Lorenzo and Mantua, 2016; Zador et al., 2017; Walsh et al., 2018; Cornwall, 2019). Although ocean temperatures were still notably above normal throughout Alaska in 2019 (https://aoos.org/ or https://www.fisheries.noaa.gov/feature-story/new-marine-heatwave-emerges-west-coast-resembles-blob), humpback whale feeding conditions appear to have improved somewhat in Glacier Bay this summer, based on an apparent increase in whale abundance in 2019 compared to 2018 (data analysis in progress), non-quantitative visual assessment of prey patches observed on our depth-sounder during whale surveys, visual observations of forage fish schooling near the surface, and an increase in whale group sizes. In the 2014–2018 period, pairs, trios and larger group sizes were conspicuously absent, whereas in 2019, we often saw whales feeding together, suggesting an improvement in feeding conditions. Pairing our long-term monitoring of the humpback whale population with a sustained, quantitative monitoring effort for forage species in Glacier Bay and Icy Strait would provide great explanatory power enabling a deeper understanding of the root causes of observed changes in whale population parameters.

Implications: Reproduction and recruitment from within, as opposed to immigration from outside the population, has been a key driver of humpback whale population growth in Glacier Bay and Icy Strait over the past 30 years (Pierszalowski et al., 2016). In addition to the slight improvement in productivity and survival (Table 4) and apparent improvement in feeding conditions, in 2019 we documented the return of several reproductive females (defined as females sighted with calves in previous years) who had not been seen in the past several years. In addition, sightings in Hawaii and elsewhere in Alaska found through HappyWhale matching have documented the survival of a few reproductive females that have been missing from the Glacier Bay area for several years. The survival and return of reproductive females are the first visible steps toward rebuilding a whale population with a more typical rate of calf production and survival, but only if oceanographic conditions support a prey base that promotes whale health and reproduction. If humpback whale feeding conditions in Glacier Bay (and potentially northern Southeast Alaska in general) improved somewhat in 2019 compared to recent years, this may indicate that groundfish may also have experienced better feeding conditions.

Ecosystem or Community Indicators

Stability of Groundfish Biomass in the Gulf of Alaska

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Last updated: October 2019

Description of indicator: The stability of the groundfish community total biomass is measured with the inverse biomass coefficient of variation (1 divided by the coefficient of variation of total groundfish biomass (1/CV[B])). This indicator provides a measure of the stability of the ecosystem and its resistance to perturbations. The variability of total community biomass is thought to be sensitive fishing and is expected to increase with increasing fishing pressure (Blanchard and Boucher, 2001). This metric is calculated following the methods of 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 time (Figure 89). There was a slight increase in stability from 2007 (4.5) to 2019 (4.7), with a series low in 2017 (4.0). Similarly, in the eastern Gulf of Alaska this indicator has been stable over the time series with only minor fluctuations between survey years and a long term mean of 2.6.

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 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).

The index of groundfish stability in the western GOA reached its highest level in 2019, reflecting the relative stability of the groundfish biomass index in the most recent ten survey years. 2017 was

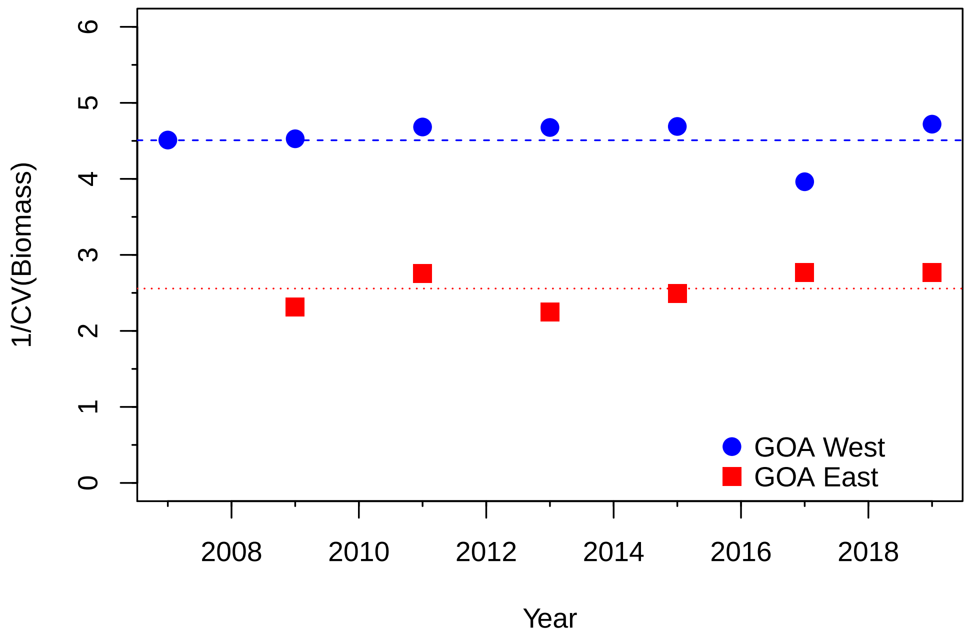

Figure 89: The stability of groundfish in the western and eastern GOA represented with the inverse biomass coefficient of variation (1/CV[B]). Ten years of data are required to calculate this metric, so this time series begins in 2007 for the western GOA and in 2009 for the eastern GOA (no survey in 2001) after the tenth occurrence of the NMFS/AFSC summer bottom-trawl survey. The dashed line represents the indicator mean for the western GOA (2007–2019) and the dotted line the mean for the eastern GOA (2009–2019).

the lowest value over the trawl survey time series (1984–2019) for the western GOA. That low was partly due to the low biomass index in 1999. In 2019, the 1999 index is no longer included in the recent 10 year average, reducing the CV, and increasing the indicator value.

In the eastern GOA this indicator is unchanged from 2017. Overall, this indicator has lower values than the eastern GOA (2.6) than in the western GOA (4.5). This is largely due to the prevalence of smaller, shorter-lived forage species (e.g., Pacific herring) in the eastern GOA which have greater interannual variation in their biomass index than the larger, longer-lived groundfish species (e.g., arrowtooth flounder, Pacific cod, walleye pollock) which are more prevalent in the western GOA. Although the species composition is similar between the eastern and western GOA, the relative abundance of the species is different between regions which has resulted in the difference in indicator values between the two regions. Despite the greater variability in biomass index in the eastern GOA, this indicator has been stable over the time period examined.

Implications: The stability of groundfish biomass in the eastern and western GOA appears constant over the time period examined and there is no indication that the communities are experiencing unusually high variability.

Mean Length of the Fish Community in the Gulf of Alaska

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Last updated: October 2019

Description of indicator: The mean length of the groundfish community tracks fluctuations in the size of groundfish over time. This size-based indicator is thought to be sensitive to the effects of commercial fisheries because larger predatory fish are often targeted by fisheries and their selective removal would reduce mean size (Shin et al. 2005). This indicator is also sensitive to shifting community composition of species with different mean sizes. Fish lengths are routinely recorded during the 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 catch data. 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 et al. (2017)). 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 is 31.6 cm, which is down from 36.2 cm in 2017. The 2019 value is less than the long-term mean of 37.7 cm and is the third lowest over the time series. In the eastern Gulf of Alaska the mean length of the groundfish community is 25.4 cm, which is down from 29.5 cm in 2017, and is the lowest over the time series. Despite declines in this indicator in both regions from 2015 to 2019, this indicator has generally been stable over the years examined (Figure 90) and the slopes of trendlines are not different from zero.

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 quality of food, or by

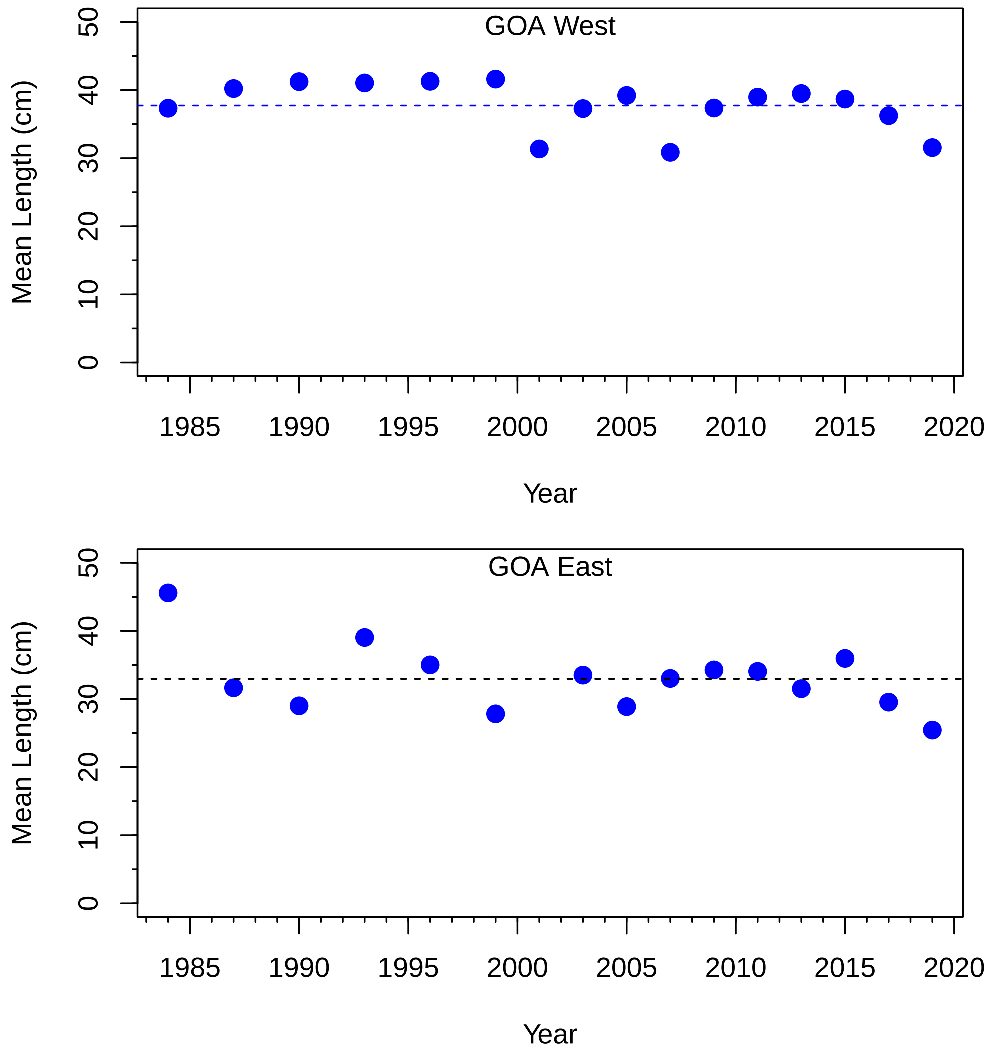

Figure 90: Mean length of the groundfish community sampled during the NMFS/AFSC summer bottom-trawl survey of the western Gulf of Alaska (1984–2019). The groundfish community mean length is weighted by the relative biomass of the sampled species. The dashed line represents the time series mean (1984–2019).

direct temperature effects on growth rate. Additionally, density dependent factors could contribute to size reductions.

Fluctuations in in this indicator are largely the result of variation in the biomass indices of forage species who have shorter mean lengths and are not well sampled by the bottom-trawl. In the Western GOA in 2001 and 2007 the mean length dropped to its two lowest values over the time series. This is attributable to the relatively high biomass indices for Pacific herring and other managed forage fish in those years. The low value in 2019 is in part due to relatively high biomass indices for smaller forage species and lower than average biomass indices for some larger commercial species (e.g., pollock, arrowtooth flounder). Additionally, the 2019 mean lengths for arrowtooth flounder, Pacific cod, Pacific halibut, and walleye pollock were all below their long-term mean length.

In the eastern GOA, previous lows in 1999, 2005, and 2013 corresponded to years where the biomass index of Pacific herring and other managed forage fish peaked. In 2019 the biomass index for Pacific herring reached its highest value over the time series which has contributed to the low indicator value.

Implications: The mean length of the groundfish community in the western and eastern GOA has been generally stable over the bottom-trawl time series (1984–2019). Low indicator values are broadly attributed to peaks in the biomass index of smaller, shorter-lived forage species. However, the mean of lengths collected during the 2019 survey for some groundfish species in the western GOA were below their long-term mean lengths. These lower than average values may be within the bounds of normal variation, but warrants continued monitoring.

Mean Lifespan of the Fish Community in the Gulf of Alaska

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Last updated: October 2019

Description of indicator: The mean lifespan of the community is defined by Shin et al. (2010) as, "a proxy for the mean turnover rate of species and communities" and is intended to reflect "ecosystem stability and resistance to perturbations." The indicator for mean lifespan of the groundfish community is modeled after the method for mean lifespan presented in Shin et al. (2010). Lifespan estimates of groundfish species regularly encountered during the NMFS/AFSC 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 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 (for complete survey details see Von Szalay et al. (2017)). 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 lifespan of the western GOA demersal fish community is 20.3, which is down from 22.6 in 2017, and is the second lowest from 1984–2019 (Figure 91). A trendline indicates a negative slope ($p = 0.006$) for this indicator over the time period examined. In the eastern GOA the mean lifespan in 2019 dropped to its second lowest value (18.4) over the time series (Figure 91). While this indicator has shown interannual variation, it has been generally stable over most of the period examined. However, after adding the 2019 value the slope of a trendline is negative (p=0.039) indicating a gradual decline.

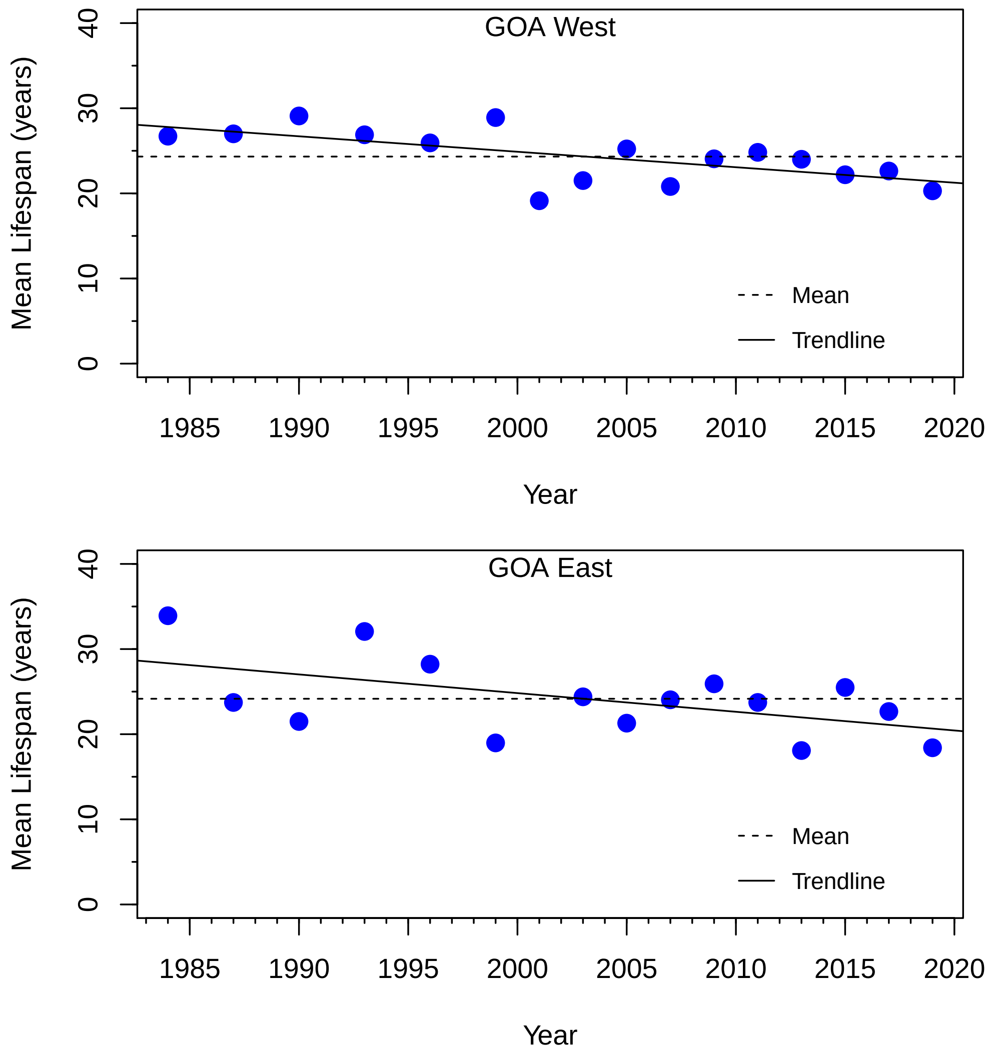

Figure 91: The mean lifespan of the western Gulf of Alaska demersal fish community (blue line), weighted by relative biomass calculated from the NMFS/AFSC summer bottom-trawl survey. The dashed line represents the mean of the time series (1984–2019) and the solid line is a trendlines (p¡0.05).

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 also 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, in part, be the case in 2001, 2007, and 2019 in the western GOA when biomass indices for the relatively shorter-lived Pacific herring and other managed forage species were high and reduced the mean lifespan for the groundfish community. Additionally, the mean lifespans in 2017 and 2019 were partly reduced by lower than average biomass indices for prominent longer-lived groundfish species, including walleye pollock, Pacific cod, and arrowtooth flounder.

In the eastern GOA, previous low values in 1999, 2005, and 2013 corresponded to years with high biomass indices for smaller, shorter-lived species Pacific herring and other managed forage fish. Similarly, 2019 was a year of peak biomass index for Pacific herring which has resulted in the low indicator value.

Implications: The groundfish mean lifespan in the western and eastern GOA has shown interannual variability over the time series and trendlines indicates a slow decrease in this indicator in both regions. Species that are short-lived are generally smaller and more sensitive to environmental variation than larger, longer-lived species (Winemiller and Sciences, 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). The low values in 2017 and 2019 in the western GOA are in part due to lower biomass indices for some commercial groundfish species. If the biomass of these commercial groups continues to decrease in the future, the groundfish community could be shifting in favor of smaller, shorter-lived species.

Disease Ecology Indicators

Temporal Trends in *Ichthyophonus* Infection in Pacific Halibut

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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. Recent work examining groundfish species in Southcentral Alaskan ports detected *Ichthyophonus* in yelloweye rockfish (*Sebastes ruberrimus*), lingcod (*Ophiodon elongates*), black rockfish (*S. melanops*), Pacific cod (*Gadus macrocephalus*), and Pacific halibut (*Hippoglossus stenolepis* (Harris et al., 2018).

Here we update our 2011–2017 dataset on *Ichthyophonus* infection prevalence in Pacific halibut sampled in the port of Homer with data from 2018 and consider potential mechanisms to explain observed temporal trends.

Status and trends: The prevalence of *Ichthyophonus* infections in sport-caught Pacific halibut landed at Homer, AK increased from 19–63% from 2011–2018 (Figure 92). Despite the high infection prevalence, there was no indication that the parasite caused serious damage to the host, as all metrics of infection severity, including histopathology, bioelectrical impedance, and parasite load assessment, indicated uniformly low levels among infected individuals.

Significant relationships were not detected between host infection status and sex or length-at-age. However, model-averaged coefficients from binomial generalized linear models identified year and age as significant predictors of *Ichthyophonus* infection status. Increases in infection probability were predicted to occur with each subsequent year, and decreases in infection probability predicted to occur with age for 2017 and 2018.

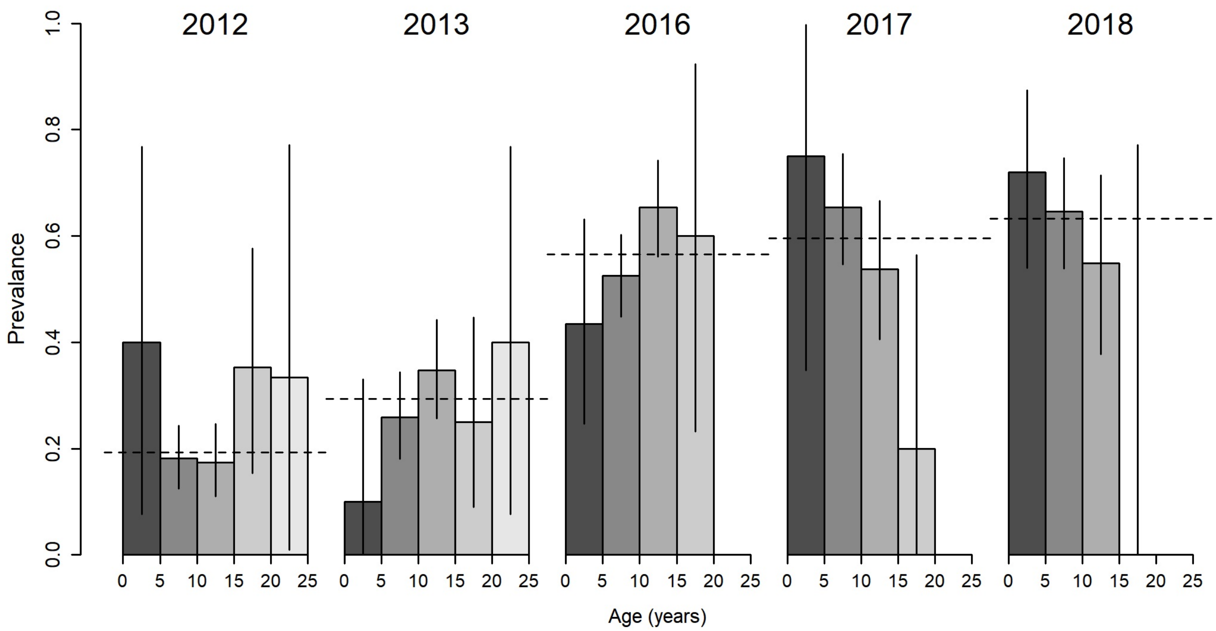

Figure 92: *Ichthyophonus* infection prevalence in halibut for each 5-year age bin, separated by year. Error bars represent 95% confidence intervals. Dashed lines represent annual means. No error bar is present for the 20–25 year bin in 2018 due to zero individuals.

Factors influencing observed trends: Despite observing increasing infection prevalence, this research found no indication of high intensity infections or clinically diseased individuals. This differs from reports from other species, in which *Ichthyophonus* infection severity increases concomitantly with infection prevalence. This, coupled with the sudden demographic shift in infection prevalence with lower infection rates observed in older fish in 2017–2018 suggest a stable host/pathogen paradigm in which Pacific halibut are capable of mounting an effective immune response that resolves low-level *Ichthyophonus* infections. This scenario would account for the rapid changes in infection prevalence as halibut experience shifts in their available prey base, whereby infection prevalence increases after consumption of infected fish, and decreases after a prey shift to squid or other non-*Ichthyophonus* hosts.

Implications: When combined with analogous observations of rapid changes in infection prevalence throughout the NE Pacific Ocean (Hershberger et al., 2018), these results 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).

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 2019

Description of indicator: Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Region's blend data, while estimates for 2003 and later come from the Alaska Region's Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards in the North Pacific. Discard rates as shown in Figure 93 below are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area-gear-target sector. Where rates are described below for species or species groups, they represent the total discarded weight of the species/species group divided by the total catch weight of the species/species group for the relevant area-gear-target sector. These estimates include only catch of FMP-managed groundfish species within the FMP groundfish fisheries. Discards of groundfish in the halibut fishery and discards of forage fish and species managed under prohibited species catch limits, such as halibut, are not included.

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 93). 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%. Discard biomass in the fixed gear (hook-and-line and pot) sector has generally declined from 2013 onward, though discard rates increased sharply in 2018 to 18% after remaining around 10% from 2013 to 2017. For 2019, discard biomass in both the pollock and non-pollock trawl sectors appears consistent relative to the previous 5 years (2014–2018) through week 34 (Figure 94). As in 2018, discard biomass in the fixed gear sector is tracking lower in 2019 relative to 2014–2017, consistent with recent reductions in the GOA P. cod allowable catch.

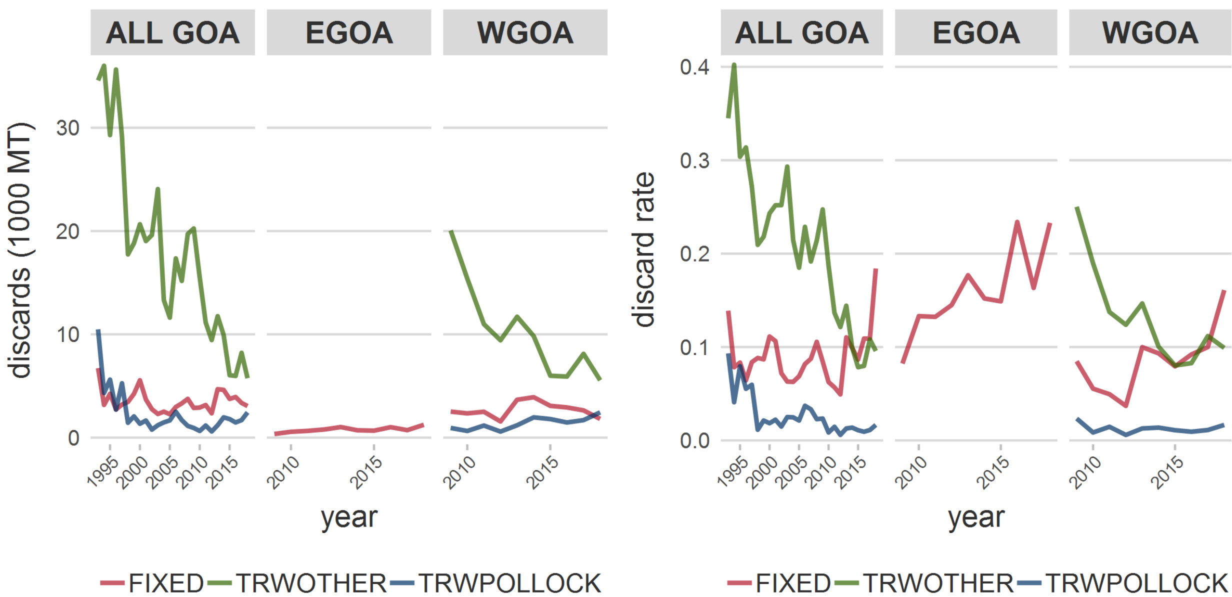

Figure 93: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear (FIXED), pollock trawl (TRWPOLLOCK), and non-pollock trawl sectors (TRWOTHER) for the Gulf of Alaska (ALL GOA) region, 1993–2018; and for and eastern (EGOA) and western (WGOA) subregions, 2009–2018. Discard rates are calculated as total discard weight of FMP groundfish divided by total retained and discarded weight of FMP groundfish for the sector (includes only catch counted against federal TACs).

Factors influencing observed trends: Fishery discards may occur for economic or regulatory reasons. Economic discards include discarding of lower value and unmarketable fish, while regulatory discards are those required by regulation—for example, upon reaching an allowable catch limit for a species. Minimizing discards is recognized as an ecological, economic, and moral imperative in various multilateral initiatives and in National Standard 9 of the Magnuson-Stevens Fishery Conservation and Management Act (Alverson, 1994; FAO, 1995; Karp et al., 2011). In the North

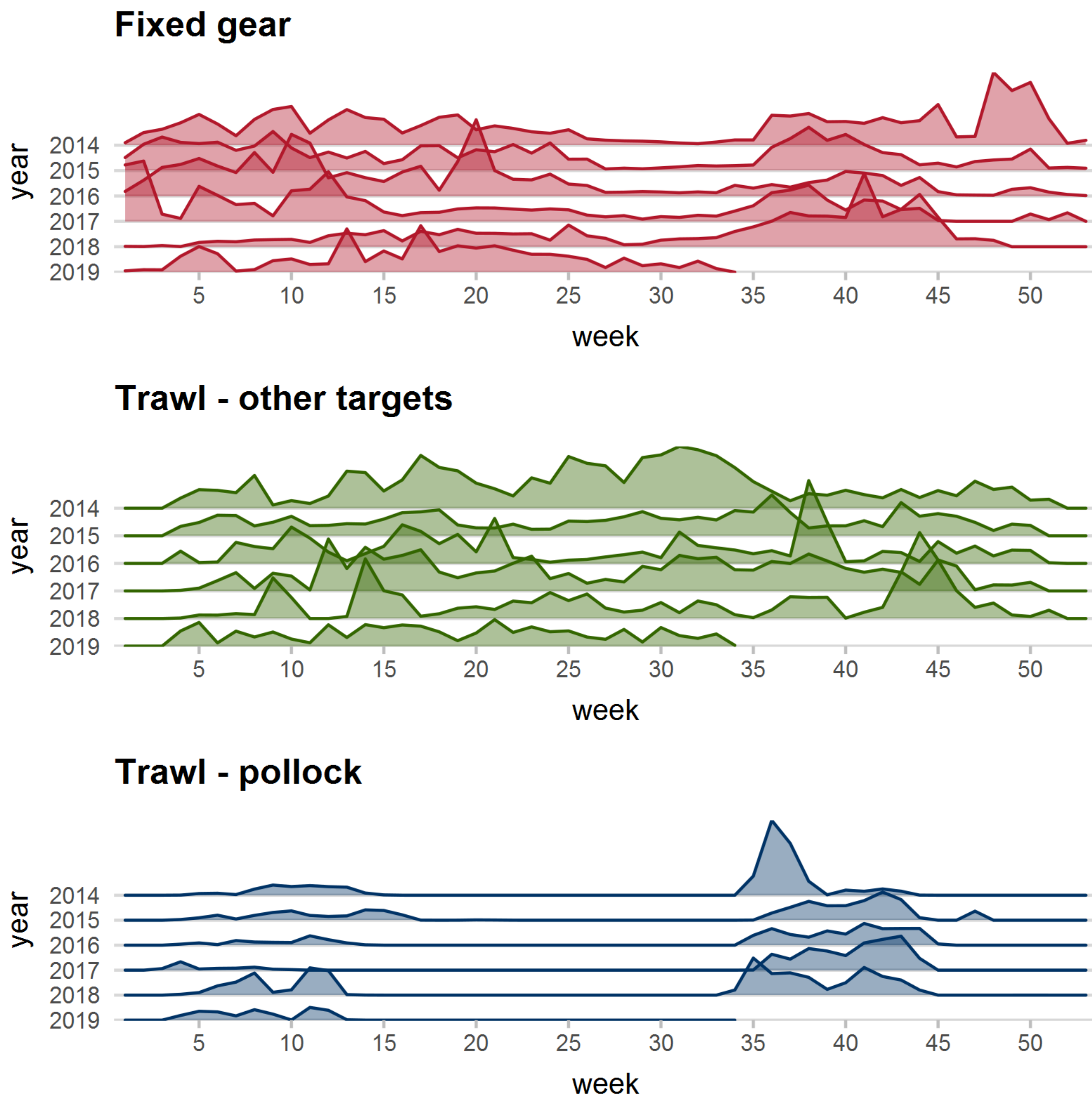

Figure 94: Total biomass of FMP groundfish discarded in the Gulf of Alaska by sector and week of the fishing season, 2014–2019 (data for 2019 is shown through week 34). Plotted heights are not comparable across fisheries.

Pacific groundfish fisheries, mechanisms to reduce discards include limited access privilege programs (LAPPs), which allocate catch quotas and may reduce economic discards by slowing down the pace of fishing; in-season closure of fisheries once target or bycatch species quotas are attained; minimum retention and utilization standards for certain fisheries; and maximum retainable amounts (MRAs), which allow 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 groundish, leading to overall declines in pollock and 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.

Measures for reducing discards are included in 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. 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, 2017; Ormseth, 2017). 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 2013to 2015, and, in 2016, a reduction in the MRA for GOA skates from 20% to 5% (Ormseth, 2017).

Implications: Fishery bycatch adds to the total human impact on biomass without providing a benefit to the Nation and as such is perceived as "contrary to responsible stewardship and sustainable utilization of marine resources" (Kelleher, 2005). Bycatch may constrain the utilization of target species and increases the uncertainty around total fishing-related mortality, making it more difficult to assess stocks, define overfishing levels, and monitor fisheries for overfishing (Alverson, 1994; Karp et al., 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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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 `https://www.fisheries.noaa.gov/alaska/population-assessments/2018-north-pacific-groundfish-stock-assessments`). 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 2011–2018, with the highest catch in 2016 (Figure 95). The catch of jellies in 2018 and 2017 were the second and third lowest over this time period, respectively. 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 to a peak in 2016. In 2017, the catch dropped 30% to level equivalent to 2013. In 2018 the catch of structural epifauna increased 12% from 2017. 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 since 2011. The catch increased from 2012 to a peak in 2015 then decreased each year since to a low in 2018. 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.

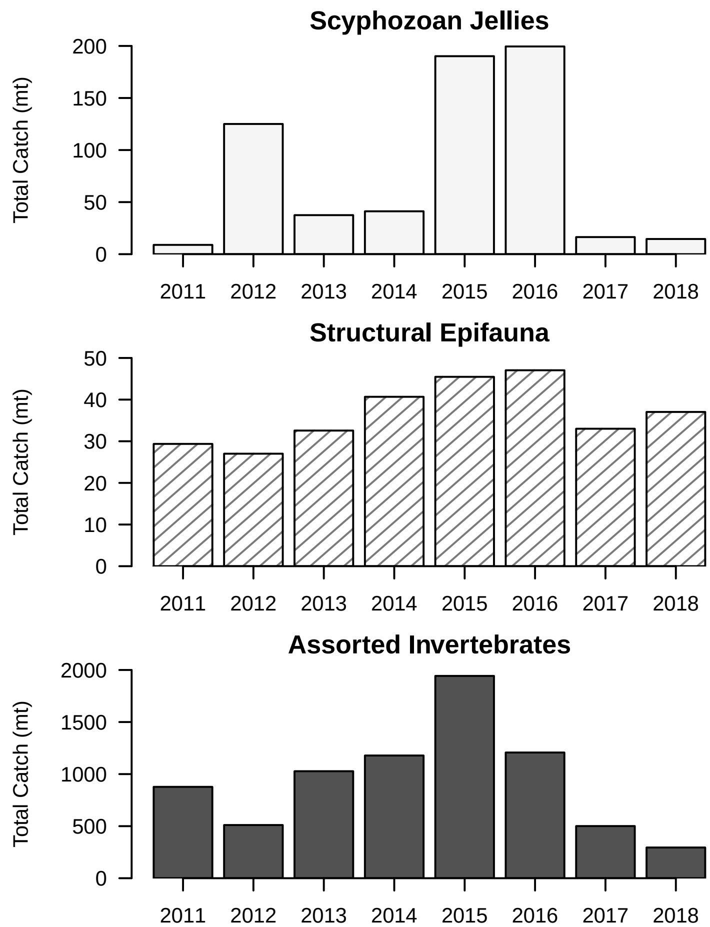

Figure 95: Total catch of non-target species (tons) in the GOA groundfish fisheries (2011–2018). Note the different y-axis scales between species groups.

Factors influencing observed trends: The catch of non-target species may change if fisheries change, if ecosystems change, or both. Because non-target species catch is unregulated and unintended, if there have been no large-scale changes in fishery management in a particular ecosystem, then large-scale signals in the non-target catch may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish 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). The lack of a clear trend in the catch of scyphozoan jellies may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries.

Implications: The catch of structural epifauna 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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Last updated: August 2019

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 and genetically sample all Chinook bycatch (Faunce, 2015). The Genetics Program at the Auke Bay Laboratories analyzes Chinook salmon bycatch samples for genetic stock identification (Guthrie et al., 2019), 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 during the years 2012–2017.

Status and trends: Stock composition has been relatively stable during the short duration of this time series, with British Columbia (45% [mean] ± 0.04% [1 SD]), West Coast U.S. (36.1% [mean] ± 0.03% [1 SD]), and Coastal Southeast Alaska (14.9% [mean] ± 0.06% [1 SD]) stocks accounting for an average of 96% of bycatch from 2012–2017. (Figure 96). We present the proportional composition of the bycatch for each of these predominant reporting groups (Figure 96); there are no statistical trends in any of the groups. Additional stock groups have accounted for negligible proportions of the bycatch.

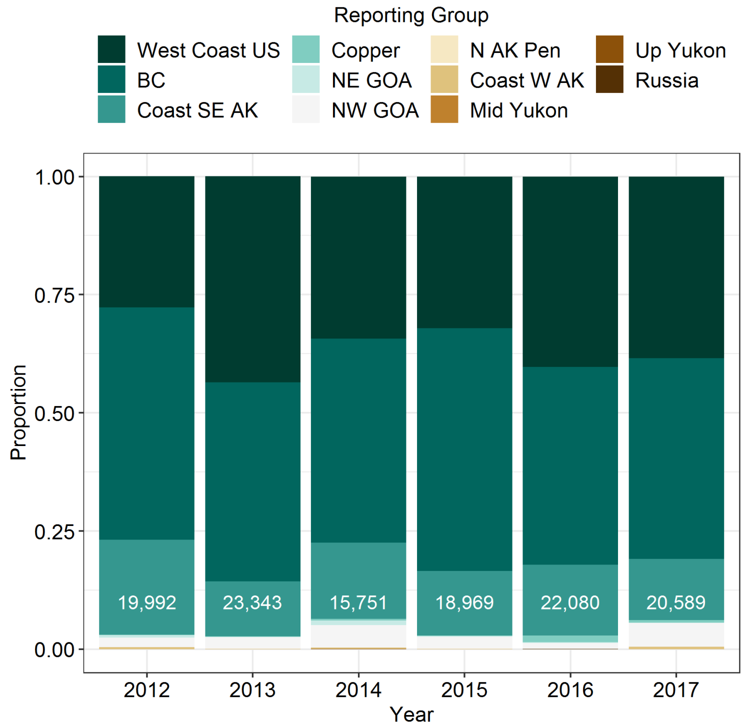

Figure 96: Stock composition (proportion) of Chinook salmon bycatch by year from the Gulf of Alaska (GOA) pollock trawl fishery with total numbers of GOA trawl fishery catches of Chinook salmon provided in the lower portion of each bar, 2012–2016.

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 each year than Alaska systems, driving the much greater proportion of these stocks. Second, the timing of the fisheries may also affect some of the observed signals. British Columbia and West Coast U.S. stocks have both spring and fall runs of Chinook, 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 bycatch dynamics in trawl fisheries is critical to groundfish management because Chinook represent a prohibited species catch that can drive fleet behaviors and economics. This is particularly important during periods of downward Chinook production across the Pacific Rim. The coarse spatial resolution of the reporting groups makes it difficult to resolve the impacts of Chinook 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. A shift in compositions could be indicative of a change in timing of either Chinook migration patterns or fishing patterns (Watson and Haynie, 2018), both of which could be related to environmental changes. Alternatively, a change in genetic stock structure could be indicative of a change in population dynamics (e.g., higher or lower juvenile mortality) of a particular stock, altered hatchery production scales or schedules, or the recovery or failure of dominant regional runs. Over the next few years, Washington State is expected to drastically increase hatchery production of salmon, for example. The increased hatchery production is expected to occur primarily for stocks that do not typically migrate north but if even a small proportion of these additional fish are caught as bycatch in trawl fisheries, this baseline will be valuable for comparison.

Seabird Bycatch Estimates for Groundfish Fisheries in the Gulf of Alaska

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Description of indicator: This report provides estimates of the numbers of seabirds caught as bycatch in commercial groundfish fisheries operating in federal waters of the U.S. Exclusive Economic Zone in the Gulf of Alaska for the years 2009 through 2018. Estimates of seabird bycatch from earlier years using different methods are not included here. Fishing gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic trawl. These numbers do not apply to gillnet, seine, or troll fisheries. Data collection on the Pacific halibut longline fishery began in 2013 with the restructured North Pacific Observer Program, although some small amounts of halibut fishery information were collected in years previous 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), and (2) industry reports of catch and production. Observer deployment plans are reviewed and updated annual in the Annual Deployment Plan (the 2019 plan is available at: `https://www.fisheries.noaa.gov/resource/document/2019-annual-deployment-plan-observers-groundfish-and-halibut-fisheries-alask` The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2014), (Cahalan et al., 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. CAS also estimates non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. The CAS produces estimates based on these two current data sets, which may have changed over time. Changes in data from one reporting year to another are due to errors that were discovered during observer debriefing, through additional data quality checks, and use of data for analysis, or issues with the data that come to light. Examples of the possible changes in the underlying data are include: changes in species identification; deletion of data sets where data collection protocols were not properly followed; and changes in the landing or at-sea production reports where data entry errors were found.

This report delineates and separately discusses estimates of seabird bycatch in the eastern Gulf of Alaska and the western Gulf of Alaska. Estimates of seabird bycatch from the eastern Gulf of Alaska include reporting areas 650, 659, and 640 (east of 144°W). Estimates from the western Gulf of Alaska include reporting areas 640 (west of 144°W), 649, 630, 620, and 610 (east of 164°W) (https://www.fisheries.noaa.gov/alaska/commercial-fishing/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones).

Status and trends: The number of seabirds estimated to be caught incidentally in western Gulf of Alaska fisheries in 2018 increased from that in 2017 by 19%, and was above the 2009–2017 average of 655 birds by 51% (Table 5; Figure 97). Black-footed albatross, northern fulmars, and gulls were

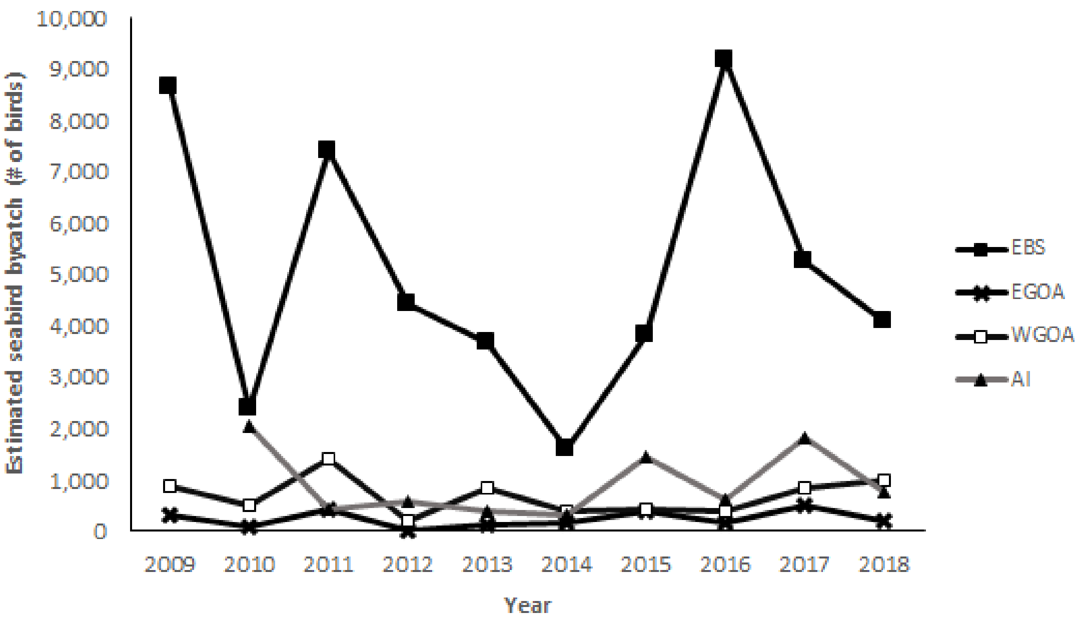

Figure 97: Total estimated seabird bycatch in eastern Bering Sea (EBS), Eastern Gulf of Alaska (EGOA), Western Gulf of Alaska (WGOA), and Aleutian Islands (AI), groundfish fisheries, all gear types combined, 2009 through 2018.

the most common species group caught incidentally. In 2018, the number of black-footed albatross decreased by 51% compared to 2017, but was still above the 2009–2017 average of 179 birds by 37%. In 2018, the number of gulls increased by 271% compared to 2017 and was well above the 2009–2017 average of 154 birds by 53%. The estimated number of northern fulmars also increased from 2017 to 2018 by 13% and was above the 2009–2017 average of 238 birds by 11%. There was also a large increase in the number of incidental takes of unidentified birds in 2018.

The numbers of seabirds estimated to be caught incidentally in eastern Gulf of Alaska fisheries in 2018 (207 birds) decreased from that in 2017 (501 birds) by 59%, and was below the 2009–2017 average of 248 birds by 17% (Table 6; Figure 97). Black-footed albatross, unidentified albatross, and gulls were the most common species or species groups caught incidentally. In 2018, the number of black-footed albatross decreased by 58% compared to 2017, but was still above the 2009–2017 average of 89 birds by 16%. In 2018, the number of gulls decreased by 85% compared to 2017 and was below the 2009–2017 average of 97 birds by 66%. The estimated number of unidentified albatross in 2018 was the highest reported in this time series for the eastern Gulf of Alaska. The only other year with unidentified albatross takes was 2013.

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 98). The estimated numbers of birds caught incidentally in the Gulf of Alaska are generally

Table 5: Estimated seabird bycatch in the western Gulf of Alaska groundfish fisheries for all gear types, 2009 through 2018. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Unidentified Albatross	0	0	9	0	3	0	0	0	0	10
Laysan Albatross	63	59	99	6	57	25	30	39	0	21
Black-footed Albatross	24	45	144	120	390	190	120	82	500	245
Northern Fulmars	457	168	741	18	239	47	63	174	235	265
Shearwaters	0	0	29	0	51	0	4	18	12	49
Gulls	266	218	375	45	91	77	155	73	87	236
Auklets	0	0	0	0	0	2	45	0	0	0
Other Alcids	0	0	0	0	0	37	0	0	0	0
Cormorants	0	0	0	0	0	0	4	0	0	0
Unidentified Birds	82	0	6	32	7	0	17	16	0	164
Grand Total	892	490	1403	221	838	378	438	402	834	990

Table 6: Estimated seabird bycatch in the eastern Gulf of Alaska groundfish fisheries for all gear types, 2009 through 2018. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Unidentified Albatross	0	0	0	0	26	0	0	0	0	44
Laysan Albatross	26	19	38	4	9	3	6	4	0	4
Black-footed Albatross	25	16	60	19	39	76	221	94	252	106
Northern Fulmars	137	5	126	0	13	4	19	6	33	19
Shearwaters	0	0	16	0	0	0	1	2	2	1
Gulls	103	42	203	5	43	77	124	63	214	33
Auklets	0	0	0	0	0	0	1	0	0	0
Cormorants	0	0	0	0	0	24	1	0	0	0
Unidentified Birds	13	0	3	1	0	0	16	2	0	0
Grand Total	304	82	446	29	130	160	412	171	501	207

far lower than the numbers caught in the eastern Bering Sea, but are generally higher than the number caught in the Aleutian Islands with the exception of two years (2010 and 2015; Figure 97). Examining the three fisheries responsible for the majority of seabird bycatch in federal waters off

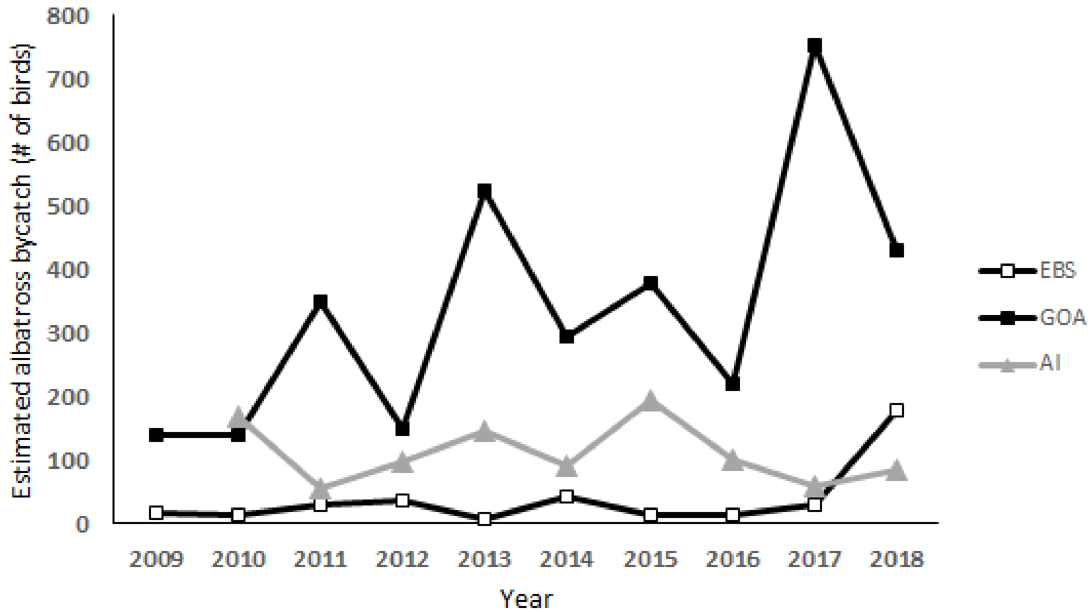

Figure 98: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2009 through 2018.

Alaska —Pacific cod, sablefish, and halibut demersal longline—the average annual seabird bycatch for 2010–2018 was 4,522, 717, and 231 birds per year, respectively (Table 13 in (Krieger et al., 2019)). In 2018, the Pacific cod, sablefish, and halibut demersal longline estimated seabird bycatch was similar with 4,209, 506, and 256 birds, respectively (Table 13 in (Krieger et al., 2019)).

Factors influencing observed trends: There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. For example, a marked decline in overall numbers of birds caught after 2002 reflected the increased use of seabird mitigation devices. A large portion of the freezer longline fleet adopted these measures in 2002, followed by regulation requiring them for the entire fleet beginning in February 2004 (69 RF 1930, January 13, 2004). Since 2002, seabird bycatch estimates have varied annually but have not returned to the level seen prior to the use of seabird mitigation devices. Since 2004, work has continued on developing new and refining existing mitigation gear (Dietrich and Melvin, 2008).

The longline fleet has traditionally been responsible for about 90% of the overall seabird bycatch in Alaska, as determined from the data sources noted above. However, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates may be 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, unpub. data). Observers now record the additional mortalities they see on trawl vessels and the AFSC Seabird Program has contracted an analyst to work on how these additional numbers can be folded into an overall estimate. The challenge to further reduce seabird bycatch is great given the rare nature of the event. For example, (Dietrich and Fitzgerald, 2010) found in an analysis of 35,270 longline sets from 2004 to 2007 that the most predominant species, northern fulmar, only occurred in 2.5% of all sets. Albatross, a focal species for conservation efforts, occurred in less than 0.1% of sets. However, given the vast size of the fishery, the total estimated bycatch can add up to hundreds of albatross or thousands of fulmars (Krieger et al., 2019).

Implications: The decrease in the number of estimated seabirds caught incidentally in the eastern Gulf of Alaska in 2018 relative to the year before was primarily attributed to decreased numbers of black-footed albatross and gulls. In contrast, the increase in the number of estimated seabirds caught incidentally in the western Gulf of Alaska was primarily attributed to increased numbers of gulls and unidentified birds. Estimated seabird bycatch decreased from 2017 to 2018 in the eastern Bering Sea, but 2018 had an unusually large number of Laysan albatross caught incidentally. Estimated seabird bycatch decreased from 2017 to 2018 in the Aleutian Islands; this was primarily attributed to decreased numbers of shearwaters and northern fulmars. These differences indicate localized changes in the Bering Sea, Gulf of Alaska, and Aleutian Islands regarding seabird distribution, fishing effort, and/or seabird prey supply, all of which could impact bycatch.

The effects of the "Blob", that resulted in an extreme marine heatwave from 2014–2016, appeared to be dissipating in 2017 and continued to be moderating 2018 (Zador and Yasumiishi, 2018). The warm temperatures caused variability in prey availability for seabirds. Over the last few years, seabird die-offs appear to have increased, presumably linked to the extreme marine heatwave from 2014–2016. Numerous seabirds have been reported dead, in poor body condition, or in reproductive failure (Zador and Yasumiishi, 2018) (Siddon and Zador, 2018) (K. Kuletz, pers comm.), though improvements in reproductive success were evident in 2018. Afflicted seabirds include northern fulmars, murres, storm petrels, short-tailed shearwaters, black-legged kittiwakes, auklets, gulls, and horned puffins. Examined birds ultimately died of starvation or drowning, but underlying factors contributing to the die-off have yet to be determined (K. Kuletz, pers comm.).

It is difficult to determine how seabird bycatch estimates and trends are linked to changes in ecosystem components because seabird mitigation gear is used in the longline fleet. There does appear to be a link between poor ocean conditions and the peak bycatch years, on a species-group basis. Fishermen have noted in some years that the birds appear starved and attack baited longline gear more aggressively. This probably indicates changes in food availability rather than distinct changes in how well the fleet employs mitigation gear. A focused investigation of this aspect of seabird bycatch is needed and could inform management of poor ocean conditions if seabird bycatch rates (reported in real time) were substantially higher than normal.

Maintaining and Restoring Fish Habitats

Areas Closed to Bottom Trawling in the BSAI and GOA

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Last updated: October 2019

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 99, Table 7). 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 Fishery 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 (FMP). This additional closure adds 148,300 nm^2 to the area closed to bottom trawling year-round.

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

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

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

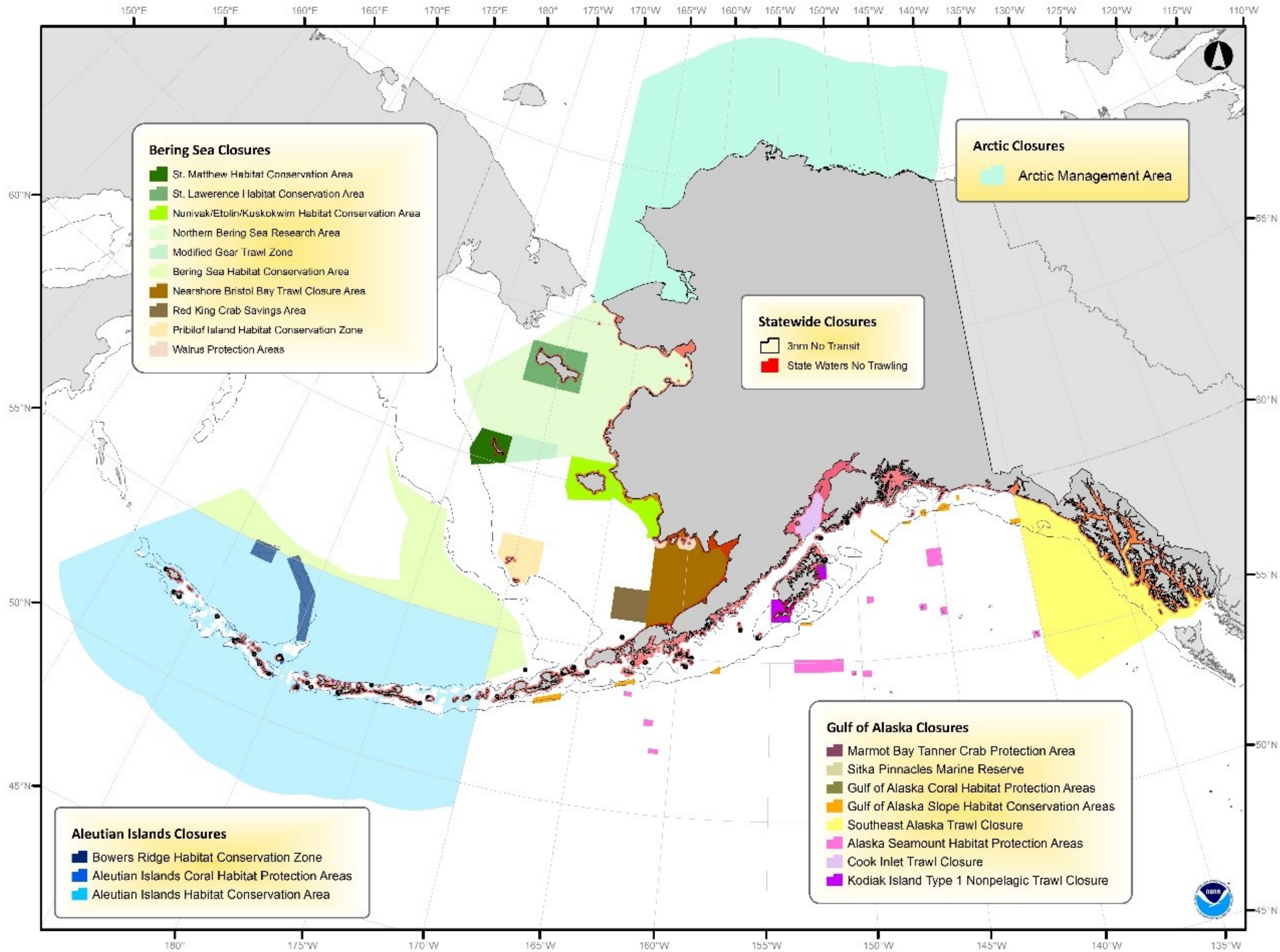

Figure 99: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Area Disturbed by Trawl Fishing Gear in Alaska

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

Status and trends: The percent of area disturbed due to commercial fishing interactions (pelagic and non-pelagic trawl, longline, and pot) decreased steadily from 2008 to the present in the Bering Sea, with slightly decreasing or steady trends in the Gulf of Alaska and Aleutian Islands (Figure 100).

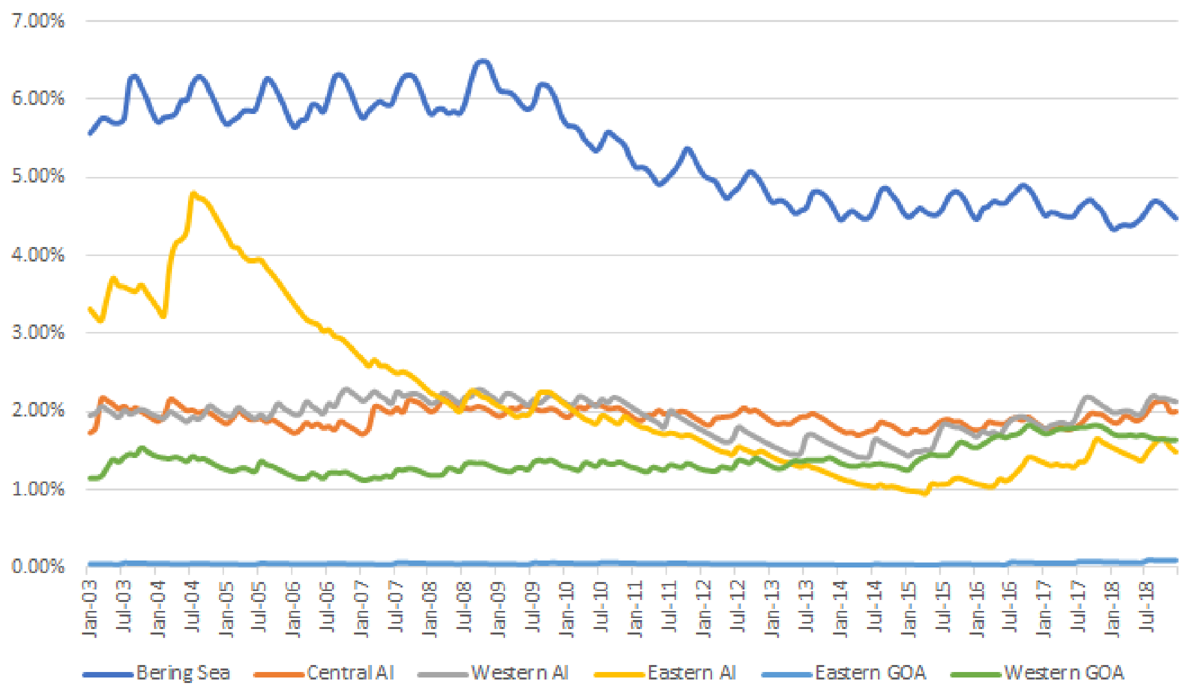

Figure 100: Percent habitat disturbance, all gear types combined, from 2003 through 2018.

Factors influencing observed trends: Trends in seafloor area disturbed can be affected by numerous variables, such as fish abundance and distribution, management actions (e.g., closed areas), changes in the structure of the fisheries due to rationalization, increased technology (e.g., increased ability to find fish), markets for fish products, and changes in vessel horsepower and fishing gear. Intensive fishing in an area can result in a change in species diversity by attracting opportunistic fish species which feed on animals that have been disturbed by fishing activity, or by reducing the suitability of habitat used by some species. It is possible that increased effort in fisheries that interact with both living and non-living bottom substrates could result in increased habitat loss/degradation due to fishing gear effects. The footprint of habitat damage varies with gear (type, weight, towing speed, depth of penetration), the physical and biological characteristics of the areas fished, recovery rates of living substrates in the areas fished, and management changes that result in spatial redistribution of fishing effort (Figure 101).

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

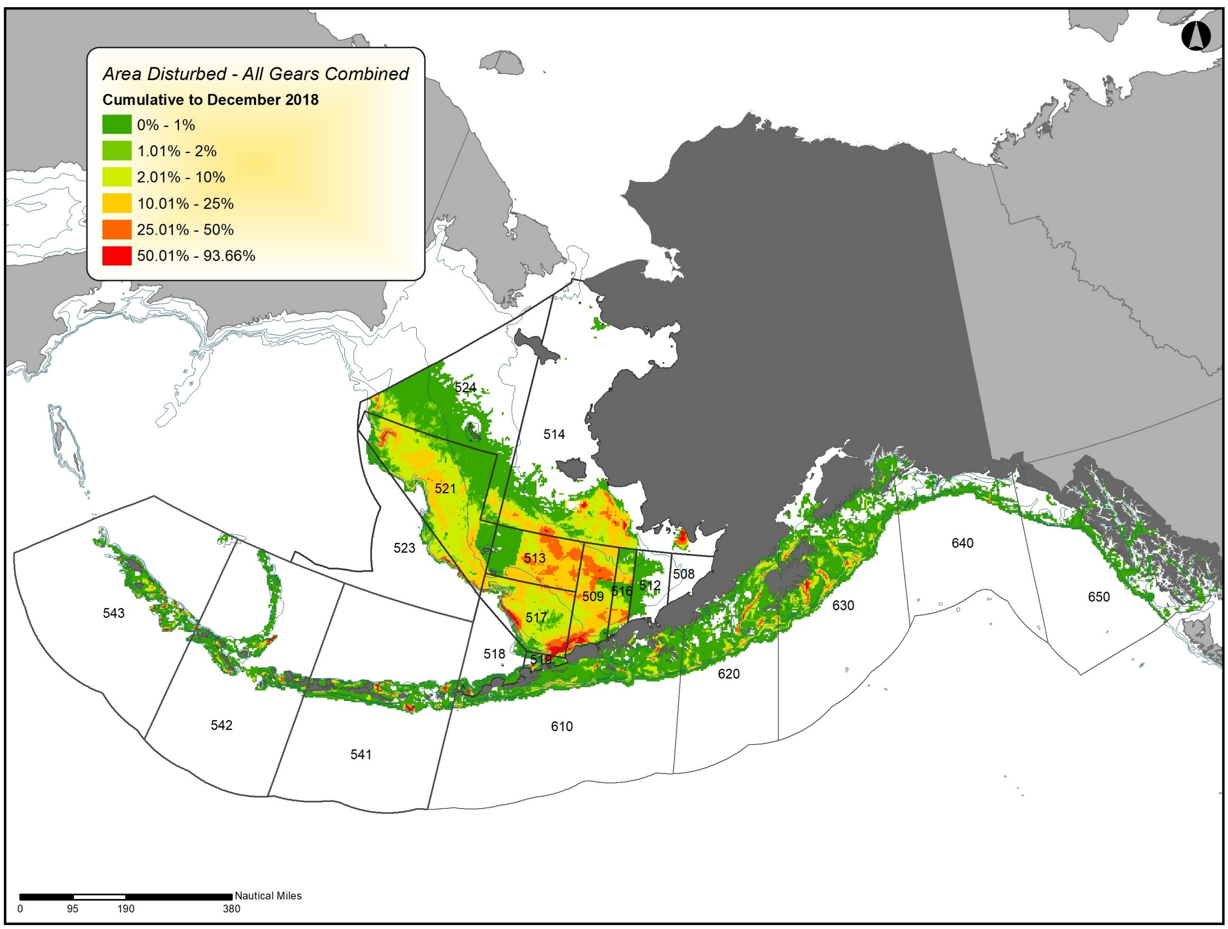

Figure 101: Map of percentage area disturbed per grid cell for all gear types. Effects are cumulative and consider impacts and recovery of features from 2003 to 2018.

Implications: The effects of changes in fishing effort on habitat are largely unknown, although our ability to quantify those effects has increased greatly with the development of a Fishing Effects model as a part of the 2015 Essential Fish Habitat (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 7: Time series of groundfish trawl closure areas in the BSAI and GOA, 1995–2018. LLP= License Limitation Program; HCA = Habitat Conservation Area; HCZ = Habitat Conservation Zone.

Area	Year	Location	Season	Area size	Notes
BSAI	1995	Area 512	Year-round	8,000 nm^2	Closure in place since 1987
		Area 516	3/15–6/15	4,000 nm^2	Closure in place since 1987
		Chum Salmon Savings Area	8/1–8/31	5,000 nm^2	Re-closed at 42,000 chum salmon
		Chinook Salmon Savings Area	Trigger	9,000 nm^2	Closed at 48,000 Chinook salmon
		Herring Savings Area	Trigger	30,000 nm^2	Trigger closure
		Zone 1	Trigger	30,000 nm^2	Trigger closure
		Zone 2	Trigger	50,000 nm^2	Trigger closure
		Pribilofs HCA	Year-round	7,000 nm^2	
		Red King Crab Savings Area	Year-round	4,000 nm^2	Pelagic trawling allowed
		Walrus Islands	5/1–9/30	900 nm^2	12 mile no-fishing zones
		SSL Rookeries	Seasonal ext.	5,100 nm^2	20 mile extensions at 8 rookeries
	1996	Nearshore Bristol Bay Trawl Closure	Year-round	19,000 nm^2	Expanded area 512 closure
		C. opilio bycatch limitation zone	Trigger	90,000 nm^2	Trigger closure
	2000	Steller Sea Lion protections			
		Pollock haulout trawl exclusion zones for EBS, AI * areas include GOA	* No trawl all year	11,900 nm^2	
			No trawl (Jan–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 for Groundfish, Crab, Salmon, and Scallop Stocks—Gulf of Alaska

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Last updated: August 2019

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 FSSI as a percentage of the maximum possible score (i.e., 100%). Within the GOA region there are 14 FSSI stocks (See FSSI Endnotes for stock definitions). The assessment for sablefish is based on aggregated data from the GOA and BSAI regions.

Additionally, in Alaska 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 `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

Status and trends: As of June 30, 2019, no GOA groundfish stock or stock complex is subjected to overfishing, is known to be over fished, or known to be approaching an overfished conditions

(Table 8). The overall Alaska FSSI is 133 out of a possible 144, or 92.36%, based on updates through June 2019 and is down two points from last year (Figure 102). The overall Alaska FSSI has generally trended upwards from 80% in 2006 to 93.75% in 2018. The overall Alaska FSSI has generally trended upwards from 80% in 2006 to 93.75% in 2018.

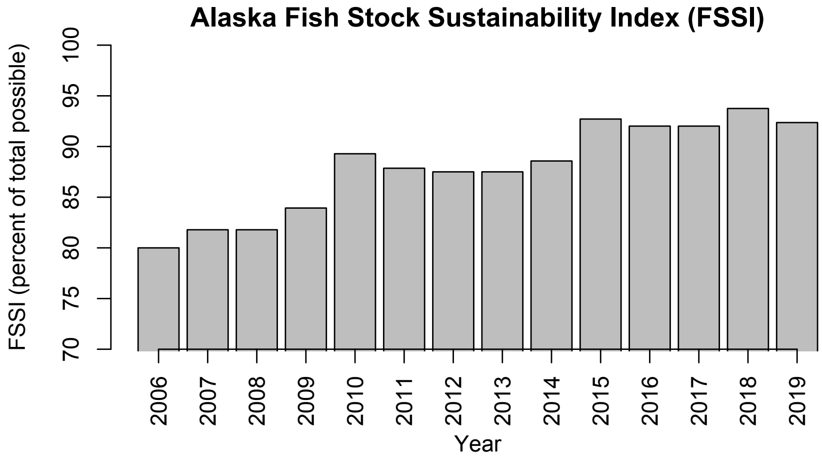

Figure 102: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2019. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 on it is 144. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

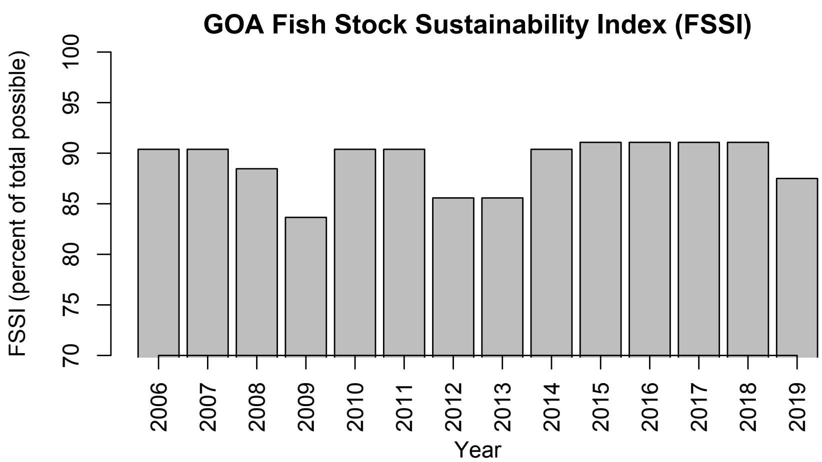

Figure 103: The trend in FSSI from 2006 through 2019 for the GOA region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

The GOA FSSI is down two points from last year at 49 out of a maximum possible 56, or 87.5% (Figure 103). GOA Pacific cod and GOA/BSAI sablefish each lost a point this year for having biomass drop below 80% of B_{MSY} (Table 9). 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/B_{MSY}. Since 2006 the GOA FSSI has been generally steady, ranging from a low of 83.7% in 2009 to a high of 91% from 2015–2018 (Figure 103). There were

Table 8: Status summary for GOA FSSI stocks managed under federal fishery management plans, updated through June 2019.

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

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/B_{MSY} 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/B_{MSY}. In 2012 and 2013 2.5 points were lost for having unknown status determinations and not estimating B/B_{MSY} for the deep water flatfish complex.

Factors influencing observed trends: The two point drop in the GOA FSSI is due to biomass dropping below 80% B_{MSY} for Pacific cod and sablefish. These two points also explain the two point drop in the overall Alaska FSSI. Other 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 defined and it is therefore unknown if the biomass is above the overfished level or if biomass is at or above 80% of B_{MSY}.

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 9: GOA FSSI stocks under NPFMC jurisdiction updated June 2019 adapted from the Status of U.S. Fisheries website: https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates. See FSSI Endnotes stock complex definitions.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/B_{MSY}	FSSI Score
GOA Arrowtooth flounder	No	No	No	N/A	N/A	2.85	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	2.48	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	1.14	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	1.16	4
GOA Pacific cod	No	No	No	N/A	N/A	0.66	3
GOA Pacific Ocean perch	No	No	No	N/A	N/A	1.75	4
GOA Rex sole	No	No	No	N/A	N/A	2.36	4
Walleye pollock-Western / Central GOA	No	No	No	N/A	N/A	1.68	4
GOA BSAI Sablefish[f]	No	No	No	N/A	N/A	0.77	3

FSSI Endnotes and stock complex definitions for FSSI stocks listed in Table 9, 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.

Seafood Production

Economic Indicators in the Gulf of Alaska: Landings

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Last updated: September 2019

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 (Figure 104). 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. 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 composed of catch from three functional groups salmon, pelagic foragers, and apex predators. Salmon landings display a stable cycle driven by large returning year classes in odd years. The primary species by volume 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). Pollock landings decreased in 2018 resulting a drop in the index for its functional group. 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 were relatively stable through 2017, 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 decreased in 2017 as a result of low abundance, and the TAC was substantially reduced in 2018 to conserve the stock.

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 ecosystem's functional group through fishing. This information can be useful in identifying areas where harvesting may be impacting different functional groups in times where the functional groups within the ecosystem might be constrained. Salmonids

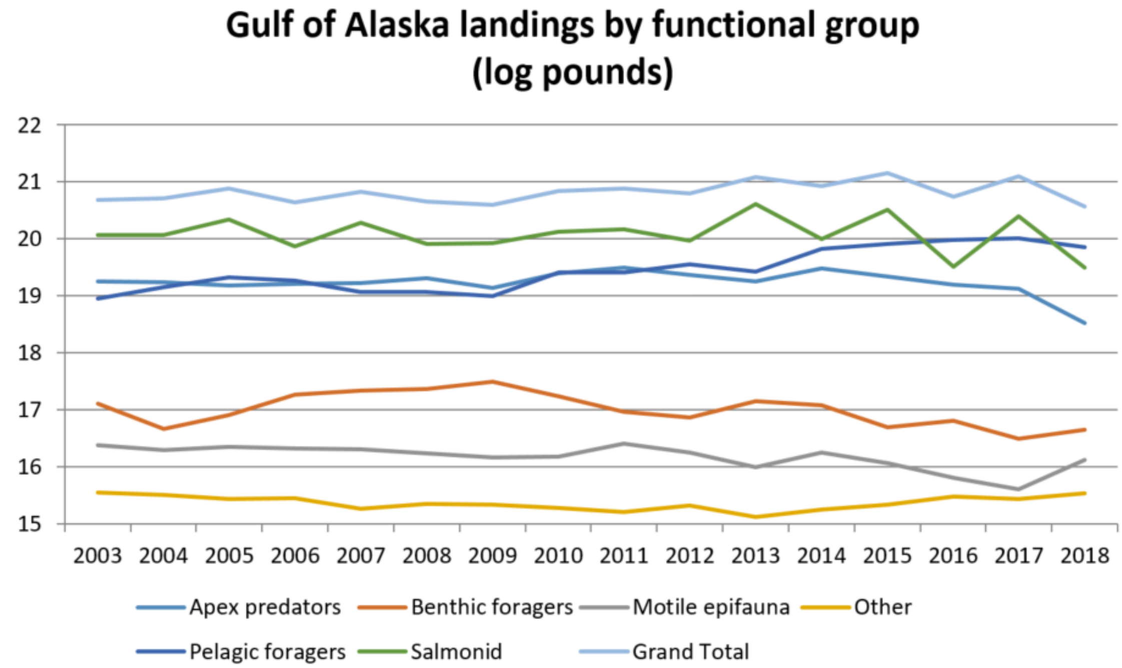

Figure 104: Gulf of Alaska landings by functional group (pounds in log scale).

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.

Profits

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

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Last updated: September 2019

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 predator's 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 105). Aggregate ex-vessel value decreased in 2018, largely the result of decreased revenues from cod and salmon. Ex-vessel value is highest in the salmon and apex predator functional groups. Ex-vessel revenues have remained fairly stable over time but were lower since 2013 than before 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. In 2018, cod value decreased substantially with conservation-based reduction in the TAC. 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. In 2018, pollock prices began to rebound contributing to an increase in the pelagic forager index. 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.

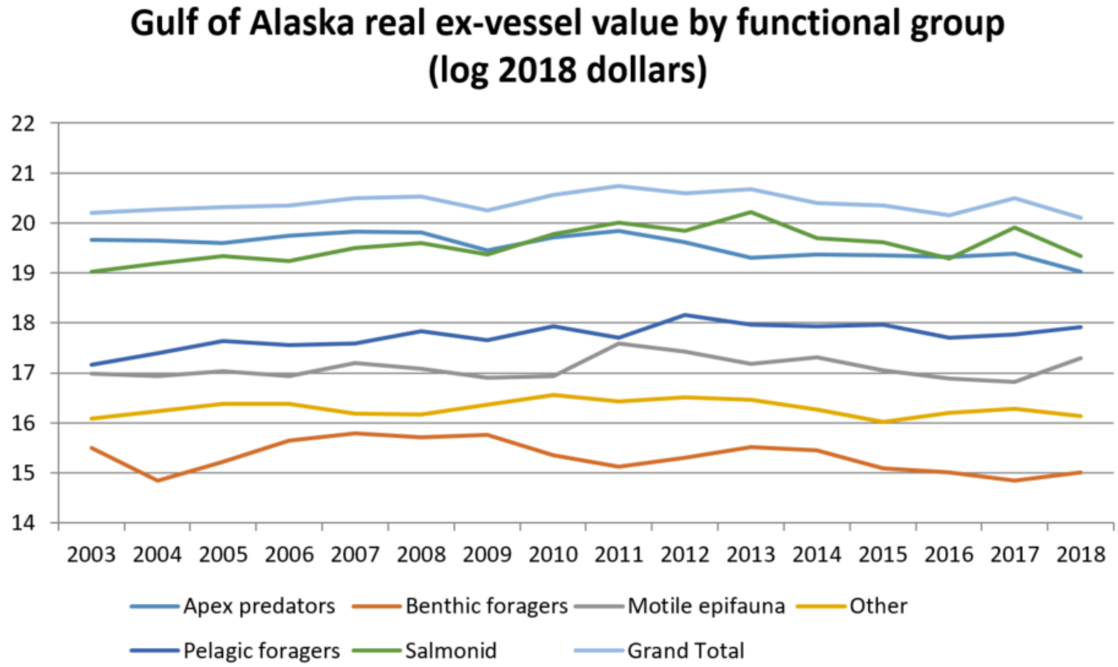

Figure 105: Gulf of Alaska real ex-vessel value by functional group (2018 dollars logged).

First-wholesale value is the revenue from the sale of processed fish (Figure 106). Some fish, in particular pollock and Pacific cod, are processed in a numerous product forms which can influence the generation of revenue. First-wholesale was generally increasing for each of the functional groups up to about 2008–2010 with stable or increasing landings and gradually increasing prices, after which landings and prices have had differential responses.Over the long-term both salmon prices and revenue show an increasing trend. Revenue for the salmonid group decreased in 2018 which is an off year in the salmon cycle. First-wholesale value in the apex predator group decreased with Pacific cod prices in 2009 and declined after 2011. Apex predator revenues decreased in 2018 with decreased landings of cod and lower average sablefish prices. The value of the pelagic forager group shows a gradual increasing trend up to 2012 when prices for pollock decreased with high global pollock supply. Pollock prices increased in 2018 which contributed to an increase in the pelagic forager unit value index. 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 (Figure 107). However, discards represent a relatively small fraction of total catch. Because of the comparatively larger value from of salmon and apex predators the unit value index is more heavily weighted towards these groups. The unit value index is increasing from 2003–2008 with generally increasing prices across all functional groups. 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

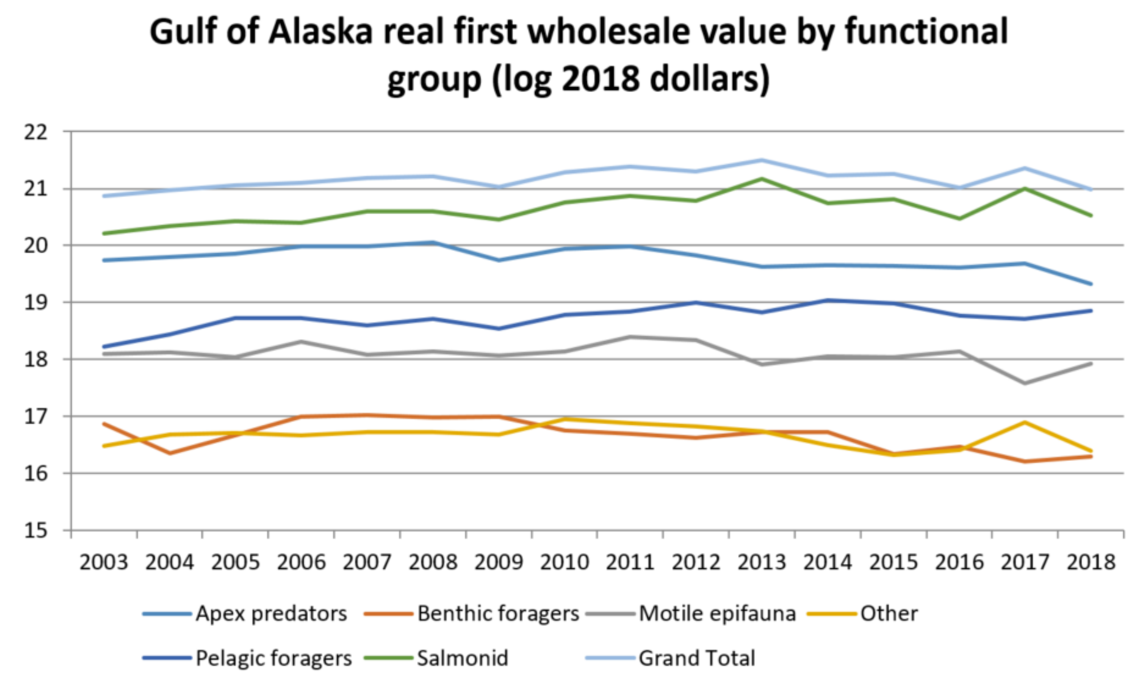

Figure 106: Gulf of Alaska real first-wholesale value by functional group (2018 dollars logged).

in 2013 with significant global pollock supply. Apex predator prices continued to decline after 2013 with shifts in catch composition. These features combined with volatility in salmon prices account for the decreasing unit value trend from 2012–2015. Since 2015 unit values have been increasing and decreased global whitefish supply put upward pressure on prices of cod and pollock in 2018.

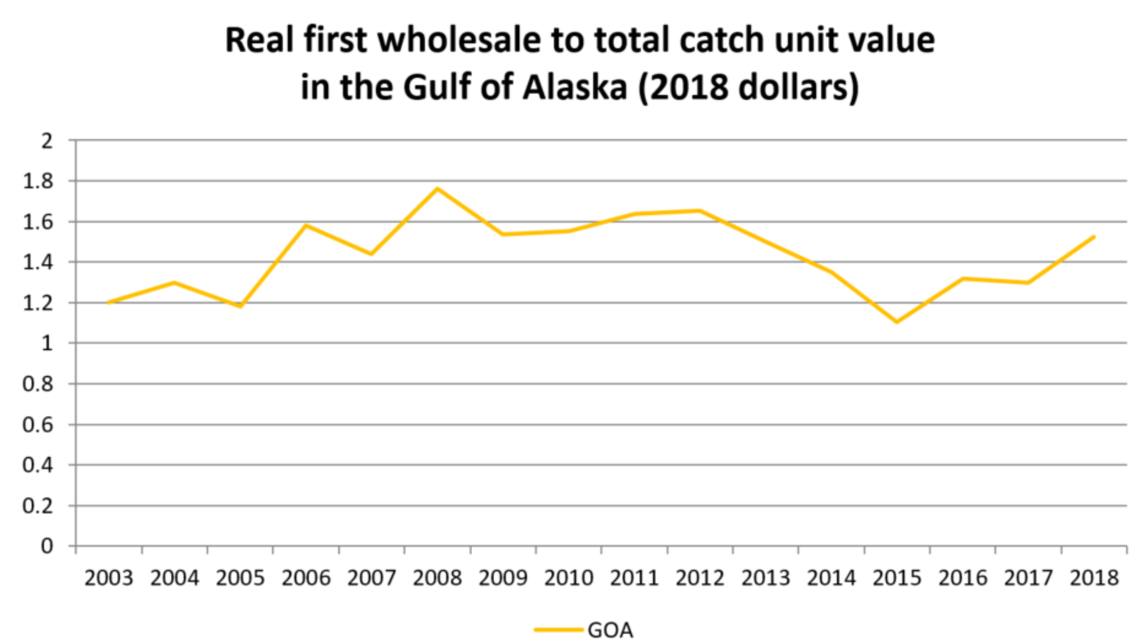

Figure 107: Real first-wholesale to total catch unit value in the Gulf of Alaska (2018 dollars).

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 and ex-vessel value in Figure 106 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.

Employment

Trends in Unemployment in the Gulf of Alaska

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Last updated: August 2019

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 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 Council's GOA fishery programs, such as the Community Quota Entity program. Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2018 (ADLWD, 2018).

Status and trends: In the eastern GOA, unemployment rates from 1990 to 2018 were lower than statewide and national rates (Figures 108–109). As of 2018, the unemployment rate in the eastern GOA was 5.97% which was slightly higher than the national rate of 3.9%. 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 by 90.24% between 1990 and 2018.

In the western GOA, unemployment rates from 1990 to 2018 were higher than statewide and national rates (Figures 108 and 109). As of 2018, the unemployment rate was 11.9% which was substantially higher than the national rate of 3.9%. With Anchorage rates excluded, western GOA had an even slightly higher rate of 15.3%. 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 the western GOA. The unemployment rate (including Anchorage) decreased 21.3% between 1990 and 2017, and decreased 10.76% 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*a*)). 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*a*)). With oil and construction industry headquarters and workers largely located in Anchorage, the western GOA region would be most impacted by job loss in these industries. Although Anchorage has experienced a recession from 2016-2018, in 2019 new military projects,

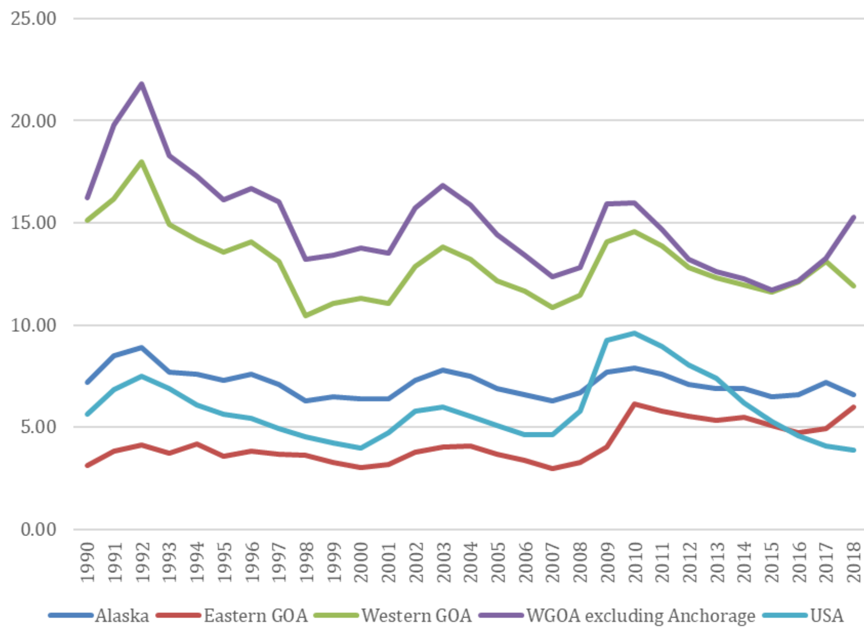

Figure 108: Unemployment rates for the eastern and western Gulf of Alaska (GOA), Alaska and USA, 1990–2018.

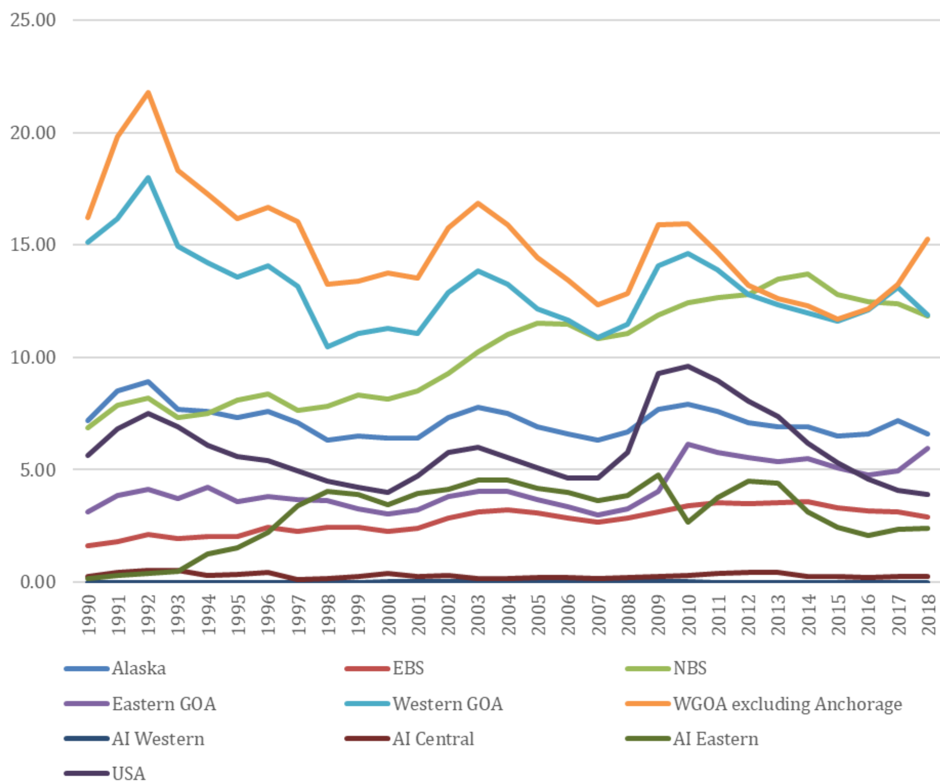

Figure 109: Unemployment rates for all regions(E is east, W is west, BS is Bering Sea, GOA is Gulf of Alaska, AI is Aleutian Islands), Alaska and USA, 1990–2018.

increased oil and gas activity and tourism are projected to increase job growth, mainly in Anchorage and the Matanuska-Susitna Borough ((ADLWD, 2019)). These impacts may have begun to be felt in 2018 as the unemployment trends for western GOA excluding Anchorage experienced an increase in unemployment while the rate for western GOA including Anchorage fell, which is the first major divergence between these two time series presented in Figure 109.

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. The divergence in trends in unemployment between western GOA with and without Anchorage as shown in Figure 1 is worthy of consideration and tracking over time to understand how the economic conditions are changing differentially between Anchorage and the rest of the western GOA region.

Socio-Cultural Dimensions

Trends in Human Population in the Gulf of Alaska

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Last updated: September 2019

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. 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 128 GOA communities. 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 Council's 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: The western GOA (WGOA) is composed of 87 coastal communities with a total population of 468,450 as of 2018. The total population excluding Anchorage was 173,085. The total population of small communities (population less than 1,500) was 19,551, and large communities 153,534 (excluding Anchorage). The total population of the WGOA (excluding Anchorage) has steadily increased since 2010. Small community populations decreased by 21.47% between 2010 and 2018, and larger communities increased by 5.86% (Table 10 and Figure 110). This decrease in population is consistent with State trends as the population of Alaska has been decreasing since the early 2010's (Sandberg, 2018).

The eastern GOA (EGOA) is composed of 41 coastal communities with a total population of 66,452 as of 2018. There are 35 small communities with a combined total population of 10,267, and six large communities with a combined total population of 56,185. The total population of EGOA has remained stable since 2000, with minimal decadal changes (Table 10). There were no significant population changes within large communities between 2010 and 2018 (Figure 111).

Factors influencing observed trends: 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*a*; ADLWD, 2016*a*). Between 2012–2016, 59% of Alaska's population was born outside of State (USCensus, 2018). In terms of natural growth, from 2013 to 2017 the average annual birth rate in Alaska was 1.5 per 100 people which was higher than the national rate of 1.2 (HAVR, 2018; Martin et al., 2018).

Table 10: Gulf of Alaska (GOA) population 1880–2018. Percent change rates are decadal until 2017.

Year	Alaska	% change	EGOA	% change	WGOA	% change	WGOA (excl. Anchorage)
1880	33,426		2,125		1,026	168.7	1,026
1890	32,052	-4.1	4,712	121.7	2,757	-27.6	2,757
1900	63,592	98.4	8,503	80.4	1,996	137.2	1,996
1910	64,356	1.2	8,660	1.8	4,734	22.6	4,734
1920	55,036	-14.5	11,404	31.7	5,804	16.6	3,948
1930	59,278	7.7	14,896	30.6	6,765	47.5	4,488
1940	72,524	22.3	19,258	29.3	9,979	113.5	6,484
1950	128,643	77.4	20,655	7.3	21,305	358.4	10,051
1960	226,167	75.8	26,557	28.6	97,653	50.6	14,820
1970	302,583	33.8	34,925	31.5	147,080	43.0	22,538
1980	401,851	32.8	45,665	30.8	210,338	39.3	35,907
1990	550,043	36.9	61,306	34.3	292,955	168.7	66,617
2000	626,932	14.0	66,455	8.4	385,634	31.6	125,351
2010	710,231	13.3	65,449	-1.5	446,356	15.8	154,530
2018	736,239	3.7	66,452	1.5	468,450	4.9	173,085

Population trends in Alaska and the GOA region have been largely attributed to changes in resource extraction and military activity (Williams, 2004*a*). Historically, the Gold Rush of the late 19th century doubled the State's population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD, 2016*b*). 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, 2004*b*). 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*a*). 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).

Population growth in the EGOA between 2010 and 2018 (-1.53%), and the WGOA (-4.95% including Anchorage and 12.01% excluding Anchorage) was lower than state trends (1.91%) When examining the WGOA, it is important to take into account the significant population differences between Anchorage and the Matanuska-Susitna Borough and the rest of Alaska. The population of Alaska in 2018 was 736,239 and 401,108 (54%) of residents resided in Anchorage and the Matanuska-Susitna Region. Migration of residents can be tracked through individuals who receive the Alaska Permanent Fund Dividend (PFD) to the census area. It is important to note that the majority of Alaskan residents receive the PFD (87% in 2018) but there are eligibility requirements that restrict some individuals from being included. The 87% PFD recipient rate is considered a reliable source of population estimates as Alaska's response rate for the 2010 U.S. Decennial Census was 64% (USCensus, 2018).

Between 2010 and 2018 the majority of individuals moving from both the eastern and western GOA moved out of state (Figures 112 and 113). The EGOA experienced negative net migration (-539) from 2010–2018 while the WGOA experienced a positive net migration (10,469) (Sandberg, 2018). Both regions' migration patterns are consistent with current state trends (Sandberg, 2018). As of 2018, all but five boroughs in the state are experiencing a negative net migration trend with the exception of the Matanuska-Susitna Borough where net migration has remained high (average 1,200 a year) (Sandberg, 2018). In addition to most migration being out of state, the majority of in migration to GOA communities is from individuals moving from out of state (Figures 114 and 115).

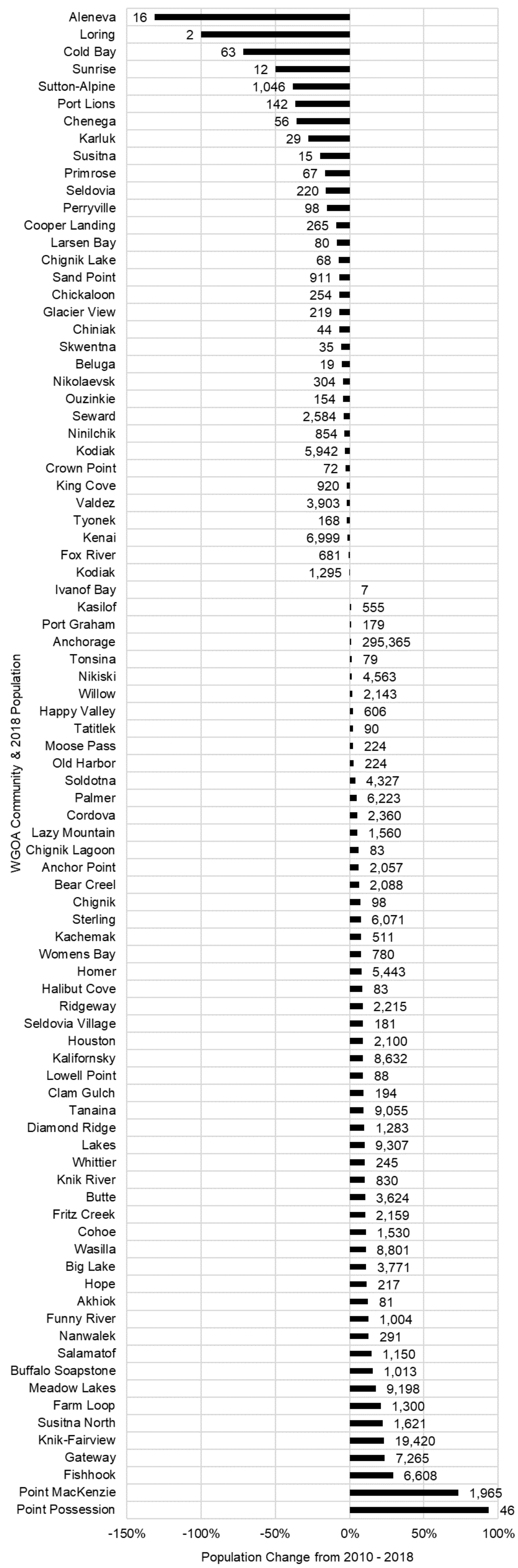

Figure 110: Population and population change of WGOA communities 2010–2018. Bars represent the percentage change and the number represents the 2018 population.

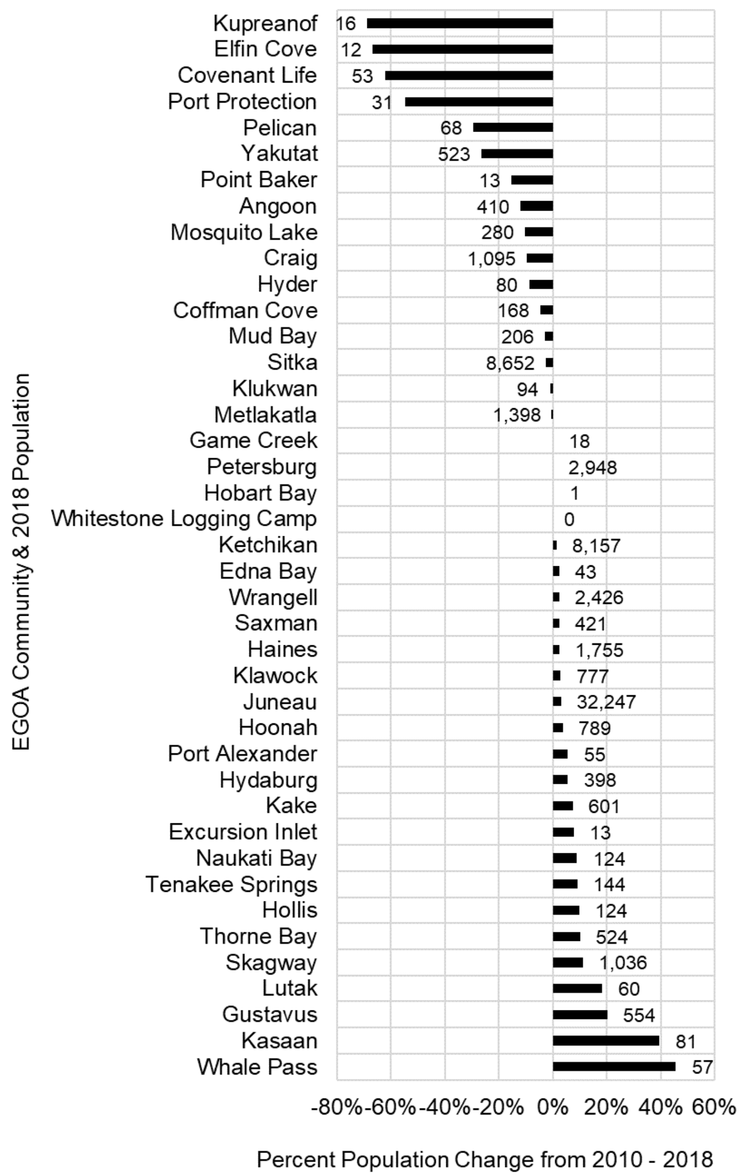

Figure 111: Population and population change of EGOA communities 2010–2018. Bars represent the percentage change and the number represents the 2018 population.

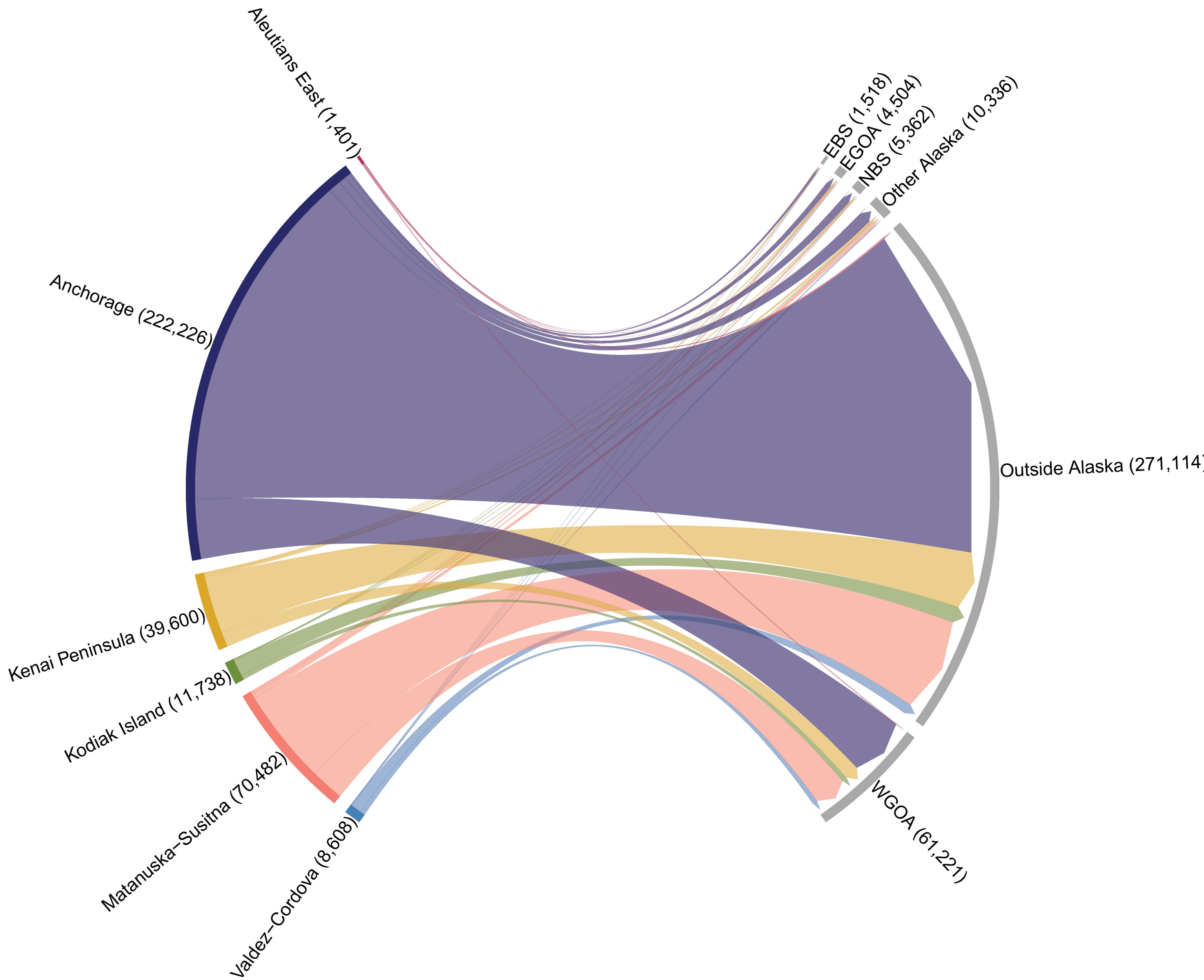

Figure 112: Total number of individuals that migrated from WGOA boroughs (left hand side of figure) from 2010–2018 and the region they migrated to (right hand side of figure).

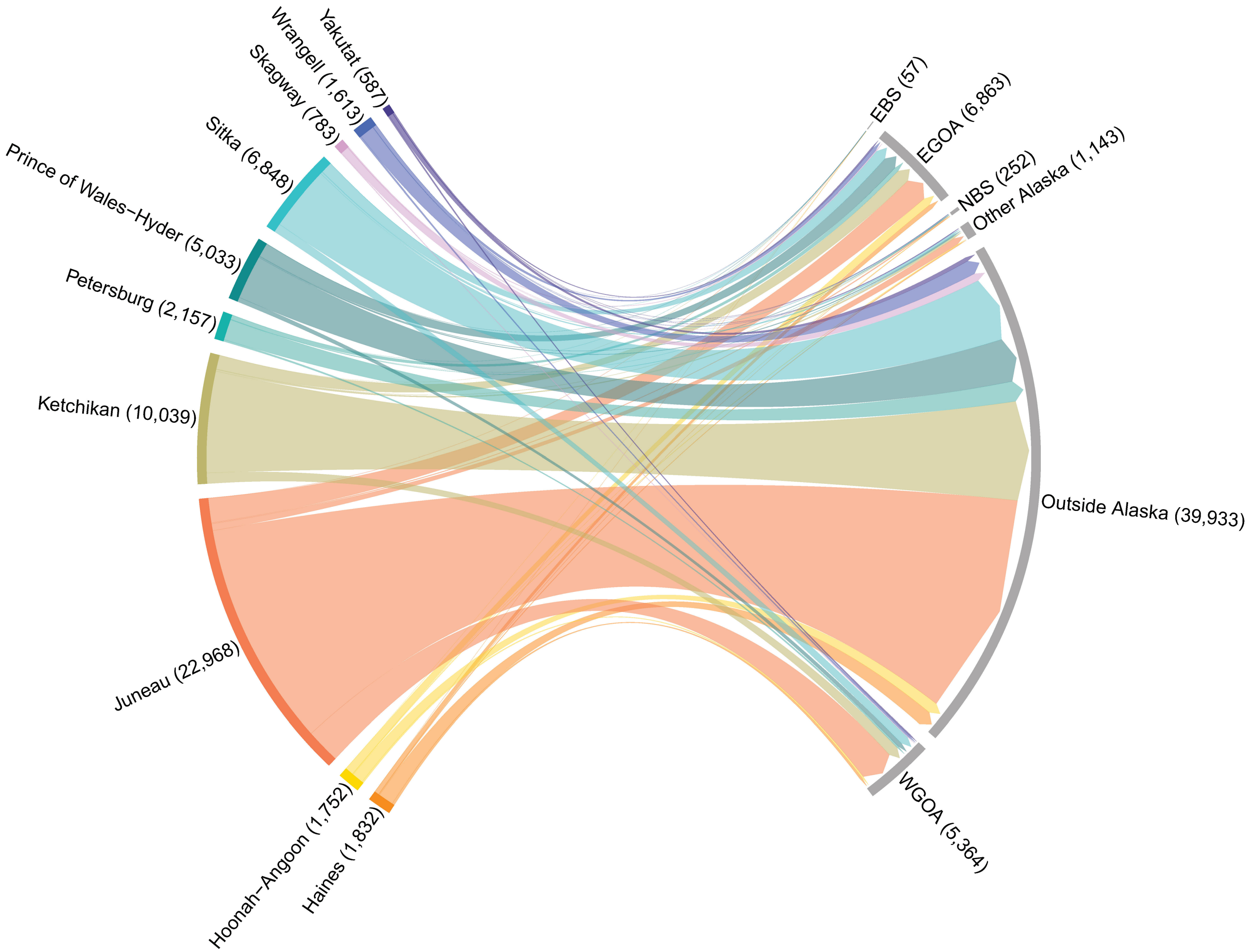

Figure 113: Total number of individuals that migrated from EGOA boroughs (left hand side of figure) from 2010–2018 and the region they migrated to (right hand side of figure).

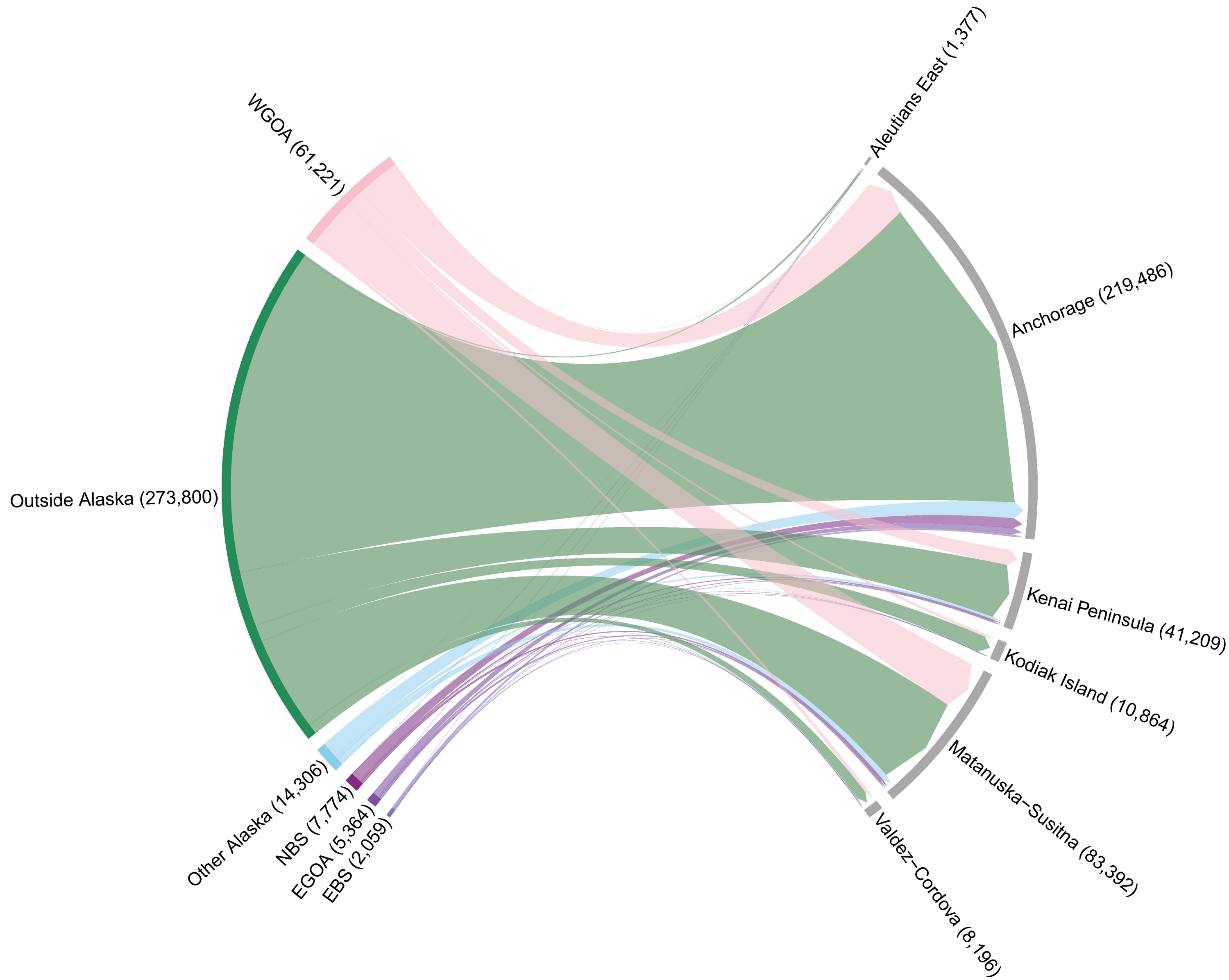

Figure 114: Total number of individuals that migrated to WGOA boroughs (right hand side of figure) from 2010–2018 and the region they migrated from (left hand side of figure).

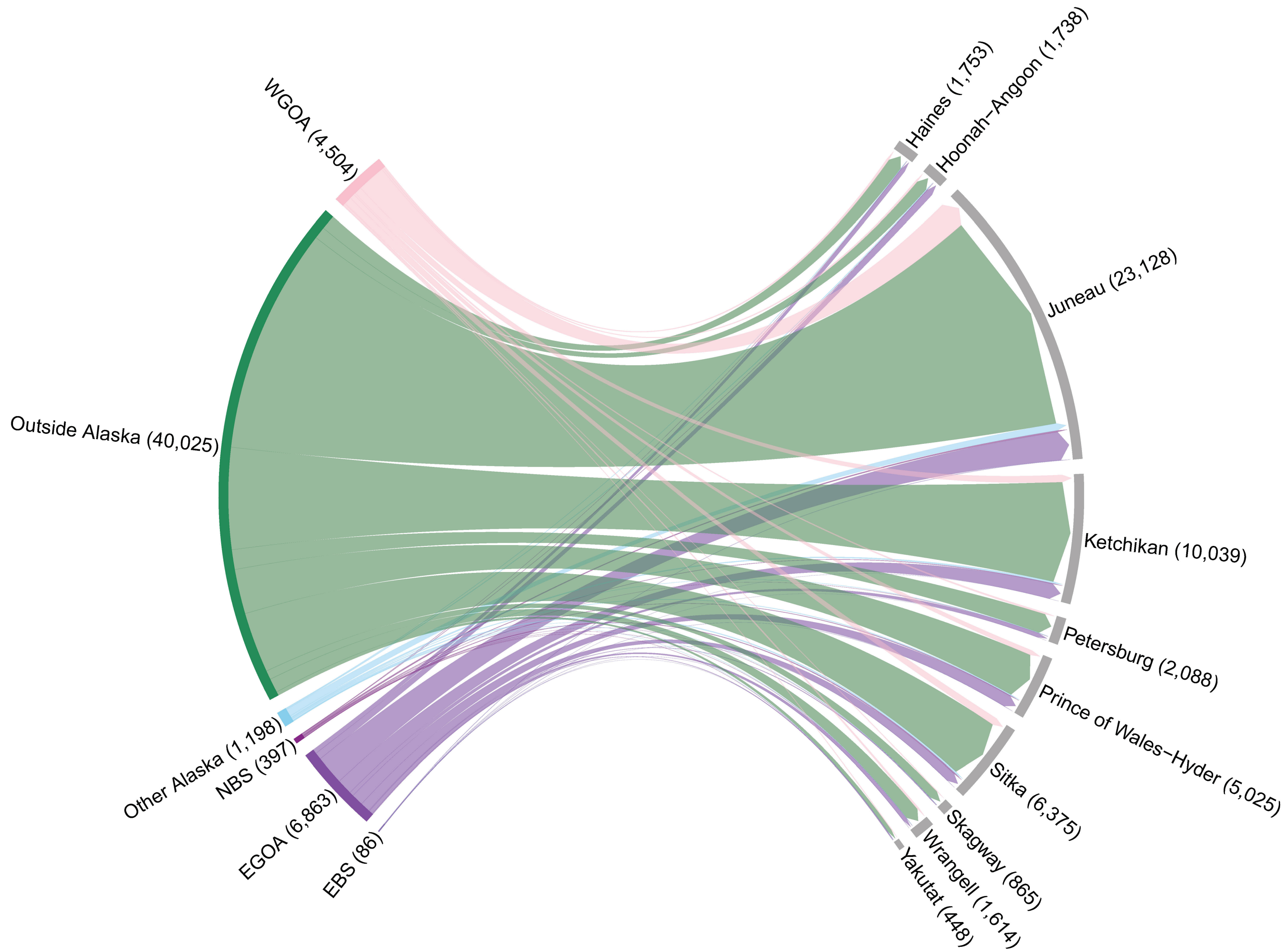

Figure 115: .
Total number of individuals that migrated to EGOA boroughs (right hand side of figure) from 2010–2018 and the region they migrated from (left hand side of figure).

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

Implications: Population shifts may be associated with perceived livelihood opportunities, including within fisheries, and can in turn affect pressures on fisheries resources. However inferences about human impacts on resources should account for overall capitalization of the fleet, economic shifts and global market demand for seafood and other extractive resources of the ecoregion. Consolidation in fishing fleets has not generally reduced the full utilization of TACs in fisheries in the past. 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.

School Enrollment and Graduation Rates, Western Gulf of Alaska Communities

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Last updated: September 2019

Description of indicator: Ensuring the productivity and sustainability of fishing communities is a core mandate of Federal fisheries management. One indicator to evaluate community vitality is K-12 public school enrollment. 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 1996–2019 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 2015–2018 cohorts based upon school district. 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 shown a slight steady decrease overall with few exceptions. Soldotna enrollment increased reaching a peak in 2010. Enrollment then began to decline until 2019 when enrollment jumped up by 10%. School enrollment in Homer has decreased substantially since it height in 1998 (over 50% from 2,842 to 1,406 students), taking a slight uptick in 2019 (Figure 116).

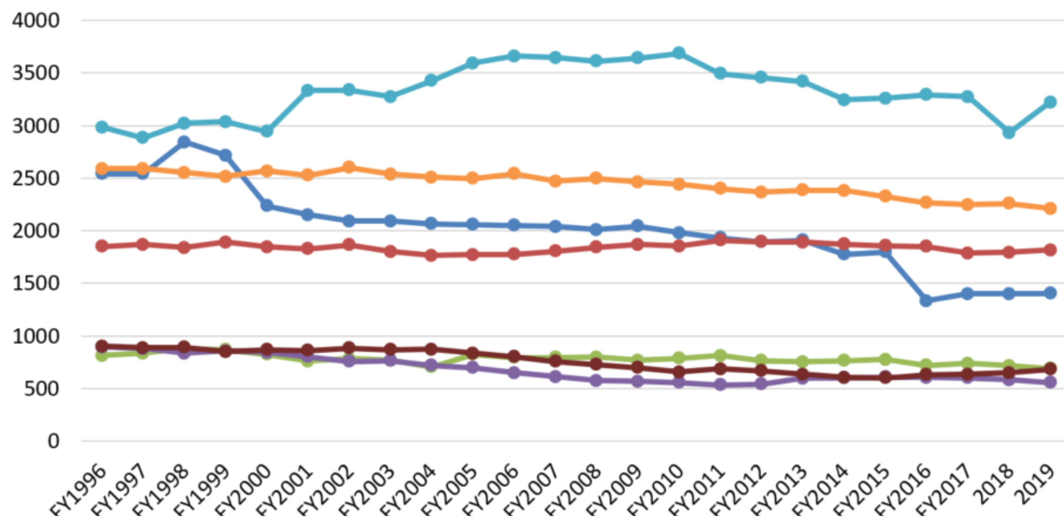

Figure 116: GOA fishing community schools with enrollment over 500 students.

In smaller municipalities with student enrollment between 100 and 500 students, there is an overall downward trend with many schools declining by at least 50% since 1996. Figure 117 depicts the overall downward trend of Kodiak Island Borough schools; however most schools showed a slight uptick in the past year. The exceptions were the Larsen Bay school which closed in 2018 and Akhiok which decreased by 26% from 19 to 15 students. The remaining school enrollment range from 7 to 30 students. Karluk has the lowest enrollment on Kodiak Island at 7 students and is threatened with closure (Figure 117).

School enrollment in the urban municipality of Anchorage has been relatively stable, with a slight decrease in enrollment starting in 2010. Enrollment declined by 966 students (2%) in the last year. The Mat-Su Borough school district remained constant. There is variation in graduation rates among WGOA school districts and across years (Figure 118).

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 func-

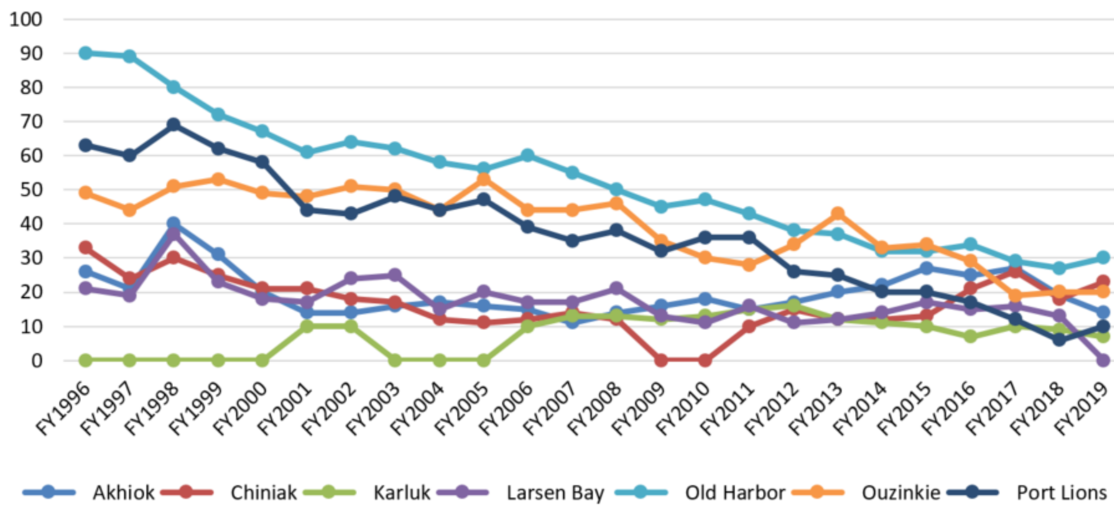

Figure 117: School enrollment in the Kodiak Island Borough.

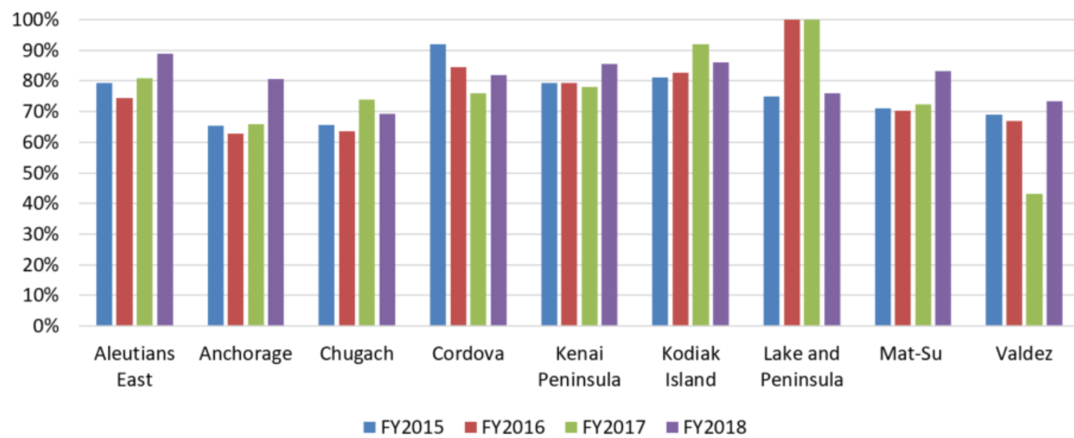

Figure 118: Graduation rates for western GOA school districts, 2015–2018.

tional 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. There has been one school closure (Larsen Bay in Kodiak Island), 17 schools have enrollment under 30, and 11 schools have enrollments under 15 students (Table 11). With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and possible community disruption. The reasons for decreasing enrollment likely involve complex social and economic drivers including migratory patterns, resource availability, and employment. Additional research into the specific reasons for diminishing school enrollment in rural areas, as well as the impacts on these communities would inform and benefit management decisions.

Implications: Community residents are closely tied to the ecosystem through sense of place and daily experience and activity. Schools are cultural centers and serve as important indicators of social and economic viability, and community well-being (Lyson, 2002, 2005). Within rural communities in particular, schools are valuable symbols for community identity, autonomy, and shared social values (Peshkin, 1978, 1982; Lyson, 2005). Research indicates that school closures negatively affect communities and student achievement (Buzzard, 2016; Thorsen, 2017). Closed school buildings

Table 11: WGOA fishing community schools with enrollment of 30 or fewer students.

Enrollment	Number of Schools	Schools
Now closed	1	Larsen Bay
16–30 students	6	Tatitlek CDP; Hope CDP; Moose Pass CDP; Ouzinkie; Chiniak CDP; Old Harbor; Perryville CDP;
<15 students	11	Akhiok; Chignik Lagoon CDP; Chenega CDP; Chignik Lake CDP; Chignik City; Cooper Landing CDP; Marathon School; Port Lions

can be a drain on community and school district resources (Barber 2018). Patterns of diminishing enrollment and school consolidation suggest a decrease in property values and taxes, fragmented community, and lost business, as well as declines in reported quality of life scores (Sell and Leistritz, 1997; Lyson, 2002). Some research finds the rate of participation in community organizations decreases in communities experiencing school closures (Oncescu and Giles, 2014; Sell and Leistritz, 1997). These finding suggests that reduced enrollments and school closures may flag disruptions in social cohesion, possibility leading to less vibrant and sustainable communities.

School Enrollment and Graduation Rates, Eastern Gulf of Alaska Communities

Contributed by Sarah P. Wise[1] and Kim Sparks[1,2]
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Contact: sarah.wise@noaa.gov
Last updated: October 2019

Description of indicator: Ensuring the productivity and sustainability of fishing communities is a core mandate of Federal fisheries management. One indicator to evaluate community vitality is K-12 public school enrollment. 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 1996–2019 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 2015–2018 cohorts based upon school district. 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 in rural or urban areas and the population of the municipality. Within municipalities where school enrollment is over 500 students, school enrollment remains relatively stable. Student enrollment increased slightly in Craig from 497 to 514 students (up 3.4%). Juneau's enrollment showed a small increase from 4,471 to 4,567 students (up 2%) since 2018; however other schools saw slight declines in enrollment. Sitka's enrollment fell from 1284 to 1243 (down 3%) (Figure 119).

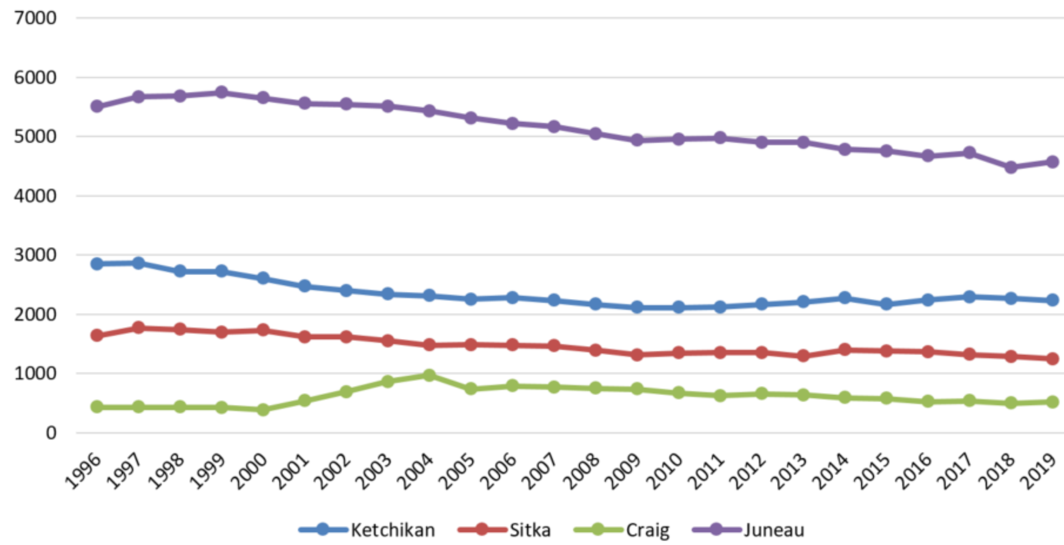

Figure 119: EGOA fishing community schools with enrollment over 500 students.

In municipalities with school enrollment between 100 to 500 students, enrollment appears to be steadying since 2016, although there appears to be a modest increase in some areas (Skagway and Southeast Island increased enrollment by 6% and 5% respectively), while other schools declined, such as Klawock (down by 9%) and Haines (down by 4%) (Figure 120).

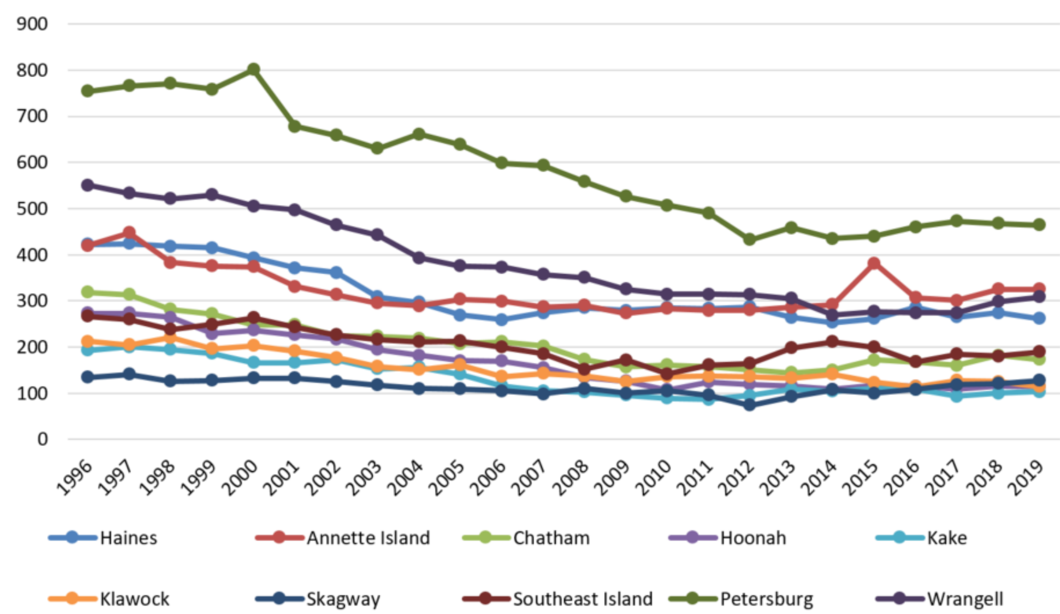

Figure 120: EGOA school districts with enrollment between 100 and 500 students.

Table 12: EGOA fishing community schools with enrollment of 30 or fewer students.

Enrollment	Number of Schools	Schools
16–30 students	16	Hollis CDP; Klukwan CDP; Naukati Bay CDP; Whale Pass CDP; Hydaburg city; Juneau; Port Alexander; Angoon; Sitka
<15 students	6	Coffman Cove CDP; Hyder CDP; Kasaan CDP; Pelican CDP; Hydaburg City; Angoon

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 121), 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%.

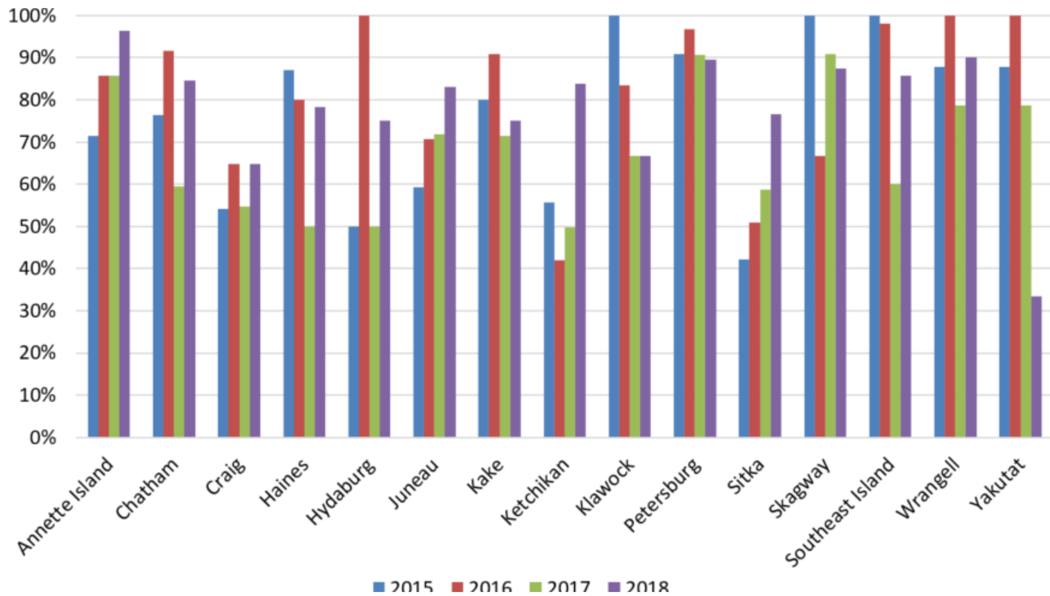

Figure 121: Graduation rates for Eastern GOA school districts, 2015–2018.

Factors influencing observed trends: The GOA ecoregion varies substantially in population, community structure, and vitality. The GOA holds several larger municipalities, with generally larger school enrollment than other regions of Alaska. As people migrate throughout the state, 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 2019, 16 schools (up from nine in 2018) in the EGOA have enrollment under 30, students of which six schools (up from five in 2018) have enrollments under 15 (Table 12).

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

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.

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 `https://oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_OC_PDO.htmlTable?time,PDO`.

Contact: nicholas.bond@noaa.gov

Summer Sea Surface Temperature The NASA multi-scale ultra-high resolution (MUR) SST dataset, using a combination of collection modalities, creates a gap-free blend of SST data (`https://mur.jpl.nasa.gov/InformationText.php`). Daily SST data were accessed via the NOAA Coast Watch West Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/`). Daily mean temperatures were averaged for June–August and anomalies were calculated within the western GOA (144°W–163°W). See contribution on p. 48. More detailed methods are available online (Watson, 2019).

Contact: jordan.watson@noaa.gov

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.

Contact: Sonia.Batten@mba.ac.uk

Motile epifauna biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. 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.

Contact: andy.whitehouse@noaa.gov

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 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. .

Contact: andy.whitehouse@noaa.gov

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 were built. 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).

Contact: kathryn.sweeney@noaa.gov

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 Council's GOA fishery programs, such as the Community Quota Entity program.

Contact: melissa.rhodes-reese@noaa.gov

Eastern Gulf of Alaska

Multivariate ENSO Index (MEI) The bi-monthly Multivariate El Niño/Southern Oscillation (ENSO) index (MEI.v2) is the time series of the leading combined Empirical Orthogonal Function (EOF) of five different variables (sea level pressure (SLP), sea surface temperature (SST), zonal and meridional components of the surface wind, and outgoing longwave radiation (OLR)) over the tropical Pacific basin (30°S-30°N and 100°E-70°W). The EOFs are calculated for 12 overlapping bi-monthly "seasons" (Dec-Jan, Jan-Feb, Feb-Mar,..., Nov-Dec) in order to take into account ENSO's seasonality, and reduce effects of higher frequency intraseasonal variability. We include the Dec-Jan value in the East Gulf of Alaska report card, with the year corresponding to January.

Key features of composite positive MEI events (warm, El Niño) include (1) anomalously warm SSTs across the east-central equatorial Pacific, (2) anomalously high SLP over Indonesia and the western tropical Pacific and low SLP over the eastern tropical Pacific, (3) reduction or reversal of tropical Pacific easterly winds (trade winds), (4) suppressed tropical convection (positive OLR) over Indonesia and Western Pacific and enhanced convection (negative OLR) over the central Pacific. Key features of composite negative MEI events (cold, La Niña) are of mostly opposite phase. For any single El Niño or La Niña situation, the atmospheric articulations may depart from this canonical view. Data are from `http://www.esrl.noaa.gov/psd/enso/mei/table.html`.

Contact: nicholas.bond@noaa.gov

Summer Sea Surface Temperature The NASA multi-scale ultra-high resolution (MUR) SST dataset, using a combination of collection modalities, creates a gap-free blend of SST data (`https://mur.jpl.nasa.gov/InformationText.php`). Daily SST data were accessed via the NOAA Coast Watch West Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/`). Daily mean temperatures were averaged for June–August and anomalies were calculated within the eastern GOA (133°W–144°W). See contribution on p. 48. More detailed methods are available online (Watson, 2019).

Contact: jordan.watson@noaa.gov

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.

Contact: emily.fergusson@noaa.gov

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.

Contact: emily.fergusson@noaa.gov

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.

Contact: andy.whitehouse@noaa.gov

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.

Contact: andy.whitehouse@noaa.gov

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.

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 eastern Distinct Population Segment known as southeast Alaska.

Contact: kathryn.sweeney@noaa.gov

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 Council's GOA fishery programs, such as the Community Quota Entity program.

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Appendices

History of the ESRs

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

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

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

Each year since 1999, the Ecosystem Status Reports have included 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 indicator, summarize the historical trends and current status of the indicator, and identify potential factors causing those trends. Beginning in 2009, contributors were also asked to describe why the indicator is important to groundfish fishery management and implications of indicator trends. In particular, contributors were asked to briefly address implications or impacts of the observed trends on the ecosystem or ecosystem components, what the trends mean and why they are important, and how the information can be used to inform groundfish management decisions. Answers to these types of questions will help provide a "heads-up" for developing management responses and research priorities.

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

[2]The Arctic report is under development

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

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

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 122). 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.

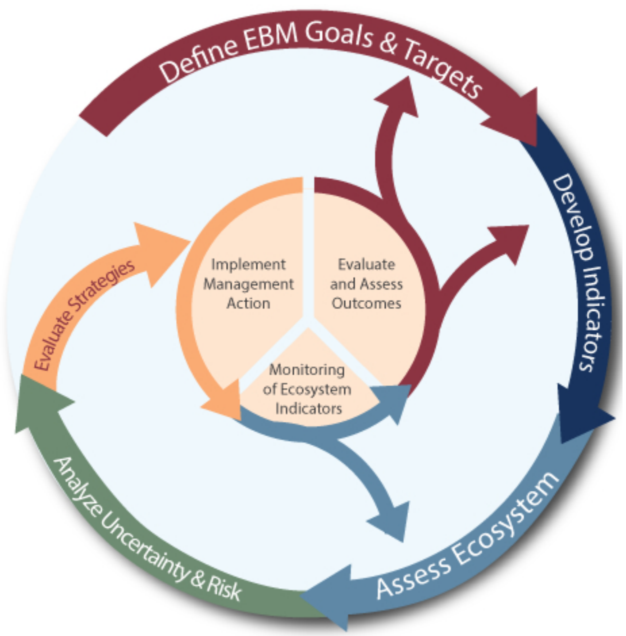

Figure 122: The IEA (integrated ecosystem assessment) process.

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

Past reports and all groundfish stock assessments are available at: `https://www.fisheries.noaa.gov/alaska/population-assessments/north-pacific-groundfish-stock-assessment-and-fishery-evalua`

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

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

December 2018 SSC Comments

General comments for all Ecosystem Status Report sections.

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

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

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

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

The SSC commends the ongoing efforts to expand the treatment of the Human Dimensions portion of the ESRs. In particular, a number of new indicators have been incorporated. The SSC notes that development of indicators on the health of fishing communities lags behind that of indicators for the health of the fish stocks and that the latter were developed and refined over a long time period. ***The SSC encourages the continued development of these Human Dimensions sections and, in particular, the development of indicators on which the Council might be able to act in the advent of evidence of a problem.*** *Specific to the human population indicators, regional characterizations mask rural trends relative to urban centers, and it is good to see that efforts have been made to identify changes in the smaller communities. Now, there is need to develop "implications" sections that go beyond stating all the factors that might be responsible* *for the trends and to suggest, however tentatively, what these trends imply about the futures of the communities described.*

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

Last year the SSC again raised the issue of how well report authors have managed to address the implications of their indicator findings for the current year. Overall, there appears to be improvement with respect to this issue, though room for further improvement remains. As indicated last year, the purpose of the ESR chapters is to provide the Council with information that may be relevant for adjusting the coming years' harvest specifications or biological reference points. Thus, the indices and their implications that are most valuable will be those that provide information that inform Council decisions.

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

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

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

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

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

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

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

The SSC recommends more specific methods descriptions for the report card indica-

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

We have edited the descriptions to include specific methods where possible.

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

We have included brief statements of implications in the Report Card bullets.

Gulf of Alaska Chapter

The ESR 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 GOA report card and to make progress in the development of predictive capacity, as in the EBS Ecosystem report.

This is the first year in which we have new data for almost all GOA report card indicators. The exceptions are the Steller sea lion counts, which were done this year but the data were not ready in time for this report. We replaced the oceanography indicator—fresh water input, which is not available—with the satellite-derived sea surface temperatures. This allows the same oceanography indicator to be included in the eastern GOA report card, which had previously been undefined.

The Noteworthy Observations section was buried on page 37. When these are red-flag alert issues, it would seem that they should be moved forward, perhaps to page 5, right after the report card. If the "Noteworthy Observations" is a catch-all section for information that did not fit as standard indicators, perhaps renaming would clarify that and it should stay where it is.

The Noteworthy 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. We have added relevant Noteworthy bullets to the top of the Executive Summary to highlight them when these are red-flag alert issues. We have reserved the term Hot Topics for use in our 4-page briefs (created in 2018 for the EBS and will be completed in 2019 for the EBS and GOA), in which the topics listed will be more analogous to red flags. By moving the Ecosystem Assessment closer to the front of the reports and producing briefs, we hope to draw more attention to our synthesis efforts.

In the present case, there is still considerable concern about the return of unusually warm waters. Indicators of bottom-up productivity were mixed. Positive indicators included the increase in both large and small zooplankton along the Seward Line, and the breeding success of pursuit-diving seabirds at Middleton Island and of piscivorous seabirds at the Semidi Islands was high. However, throughout both the eastern and western GOA, there were many indicators that pointed to a Gulf-wide decrease in secondary (zooplankton) productivity and a bottom-up limitation on fish stocks. This limitation will impact stocks over the next few years as the fish that were juveniles in

2017 and 2018 were of smaller size. These indicators included: (1) poor reproductive success for parakeet auklets in the Semidi Islands, (2) record low marine survival for Auke Bay coho salmon that out-migrated in 2018 and 2017, and (3) record low marine survival for pink salmon in 2018. The mix of results on zooplankton and forage fish, with some down in abundance and others up, warrants concern regarding whether the Gulf's ability to support the usually large biomasses of fish is compromised. The poor returns of salmon do not inspire confidence that all is well. Evidence from murres, humpback whales, and sea lions all suggest population-level, long-term impacts of the heat wave. There was no quick rebound in 2018, as might have been expected if individuals had moved away and returned after the heat wave.

The SSC suggests that, if similar situations occur in the future, the authors attempt to pull together in a prominent, succinct section the most relevant indicators to aid the Council in evaluating the likely impacts on fish stocks. The effort to analyze the "blob" in the 2017 ESR was an excellent example of what is needed.

We agree that with the late 2018–2019 heatwave in the GOA, recovery from the previous heatwave will be difficult to track. We have aimed to provide a synthesis in our Ecosystem Assessment this year. By moving the Ecosystem Assessment closer to the front of the report and producing a 2019 GOA ESR: In Brief (4-pager) this year, we hope to draw more attention to our synthesis efforts.

Organization and Clarity There is a need to define what is large versus small zooplankton, and to provide this information in the descriptions of the pertinent indicators (e.g., see page 35). This may resolve the confusion in indicator descriptions noted above.

Typically, zooplankton ecologists separate large and small zooplankton by those greater than or smaller that 2 mm, respectively. However, some define large and small by taxonomy. We have tried to clarify how zooplankton are classified during our editing process.

The bullets describing the report card are somewhat confusing because they appear to be a single bullet for each indicator time series, but they do not always reflect what is seen in the corresponding figure. If the report card indicator was not updated in the current year, the text could either state "no new data were available since the last report" or else clarify that background data were derived from alternate sources. Currently the text is a mix of descriptions for current years, previous years, and current years from alternate data. This may be all that is possible, but it is confusing to read. For example, bullet 2 is about freshwater input and describes conditions in the current year, but the Fresh Water Input indicator has not been updated in the last 5 years. The information that backed up this description was not presented. The SSC suggests that the text could be clarified by stating "although the FW input index was not updated recently, we learned from xx that runoff was enhanced (see Bond page...)".

We have attempted to identify information sources when they are not from the report card indicators. Updating report card bullets is challenging when we are unable to get current data.

The 3rd and 4th bullet statements (zooplankton) apparently conflict. The mesozooplankton biomass suggests plentiful but smaller zooplankton. The copepod community size statement says there were more large species available. It is not clear how these are related.

The mean size of the copepod community increased, but there were still more small copepods overall.

The 5th bullet (motile epifauna) was confusing because there are no data for 2018 in the graph. The bullet statement sounds current but does not specify a year, so one cannot tell if this is a statement about biomass in an earlier year or is current year data derived from a different source.

These data are current this year.

In regard to climate indicators, although all the report cards have a climate index selected (NPI or PDO), the main interest is likely sea temperature and a summary of that would be useful.

The report card indicators were selected through a process informed by a team of experts. Over time and as events occur and our scientific knowledge grows, we recognize that there are other indicators that seem to be more informative for management that those that were selected. We emphasize these indicators in our Ecosystem Assessments. Also, we have decided that our ESR: In Brief (4-pagers) will display indicators in the infographic that appear "most important" in the current year, and so by definition this group of indicators can change each year depending on what's going on in the ecosystem. Also, this year's edition of the GOA ESR includes many temperature indicators that are summarized in our assessment.

Throughout the report, there is a wide range in what "baseline" various statements are comparing to. They may be change since 2017, since the last time indicator was updated, since the heat wave period, deviations from the long term mean (taken over widely varying dates), or since a time previously thought to be significant. Although the SSC recognizes the reasons for reporting in this context, interpretation is challenging, especially since it is not always clear whether the current year is within or outside "normal" limits. The SSC encourages standardizing reporting relative to a consistent baseline when possible, and otherwise being clear on the time frame of reference.

We have tried to be consistent in our definition of baseline this year. In most cases, the long-term means are specific to the indicator time series. We have attempted to specify these years whenever possible.

There may be a problem with eliminating chicks with non-linear growth from the calculations, as this can skew the measure upwards. One should include all chicks weighed between the ages when the growth rate is linear in healthy chicks (see page 36).

The lead contributor has provided a response to this comment: Regarding the linear growth issue, we limit our analyses to chicks in which we have multiple measurements within the linear growth period (so maybe that is a better way to word it) and we calculate a mean growth rate for each chick as the slope of the linear regression line that runs through those points. When chick measurements are not remotely linear, using the slope of a linear regression is an inaccurate way of representing growth, so including those chicks wouldn't be a valid comparison of mean growth rate. While there are more complicated ways to model chick growth rate, we don't currently do that with our monitoring data. For our protocols we can't rely on chick age (and hence measure chicks within a specific time window) because we often don't have accurate hatch dates for chicks, so we have to rely on general approximations of chick size for a general linear growth window, based on the literature. Usually when chick measurements don't appear linear, it is because the beginning or end measurements are outside the bounds of linear growth, and those individual measurements are cropped from the dataset and the resultant linear measurements are still used (so the entire chick itself is not excluded, just the measurements outside of linear growth). When an entire chick needs to be excluded, it is often because the chick disappears or crews leave the island before multiple measurements can be taken. Chicks with many measurements within the linear growth period that simply don't show linear growth at all are much more uncommon; they may represent poor growth later in the nestling period, but also other issues such as inaccurate measurements, so any bias in eliminating such chicks from the sample completely may not necessarily always be upwards.

The SSC welcomes the additional computation of Annual Surplus Production with and without the inclusion of pollock.

The contributor was not able to update this contribution this year.

There should be concern about the low graduation rates of students in some schools. Is there anything that the Council or Industry could do to help bring these up by offering incentives?

This is a good and important question, but we are unable to provide suggestions at this point.

Western Gulf By late 2018, water temperatures had increased sufficiently to be considered a renewed heat wave in the western GOA, although not as severe as the heat wave of 2014-16 (the "blob"). If this new heatwave continues it may have a negative impact on fish stocks.

Earlier in 2018, there were some positive indicators, such as increases in zooplankton and increases in the abundance of large zooplankton. The 2017 shift toward larger zooplankton is likely good for groundfish, seabirds and baleen whales. However, indications that capelin abundance may be low is potentially of concern given their importance as prey of groundfish, as well as for seabirds and marine mammals. Capelin prefer cold water, and may be slow to recover as long as water temperatures remain high.

The decline in octopus catches is potentially of concern.

We appreciate these comments and have addressed some within our Ecosystem Assessment.

Eastern Gulf Although there were more zooplankton in Icy Strait, most were small, with the abundance of large species decreasing. This does not suggest improved foraging conditions for marine birds and mammals or for fish.

The continuing decrease in herring is of concern given their role as forage fish.

The failure of rhinoceros auklet breeding in 2018 points to a low abundance of forage fish, as does the decline in non-pup counts of Steller Sea Lions. The most recent diet data for Steller sea lions in the Gulf are from 1999-2009 (west) and 1997-1999 (east). The SSC suggests the authors explore if there are more recent data available on Steller sea lion diets to understand the mechanism(s) behind recent pup-declines and if the diets changed with the heatwave.

We appreciate these comments and have addressed some within our Ecosystem Assessment.

Comments Specific to the Aleutian Islands Ecosystem Status Report

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

Methods Description for the Report Card Indicators

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

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

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