Ecosystem Status Report 2020

Gulf of Alaska

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Gulf of Alaska Report Cards

Western Gulf of Alaska 2020 Report Card

Report cards present a succinct summary of the state of the ecosystem based on a short list of indicators.The bullets below describe a subset of Report Card indicators updated to the current year (2020). Other Report Card indicators can only be updated to 2019 due to the nature of the data collected, sample processing, modelling efforts, or missing data, due to an off-year for biennial surveys or COVID-related survey cancellations. These, and the full suite of contributions, are described elsewhere in the Report.

- The **PDO** declined to **slightly negative** in the winter of 2020, reflecting cooling sea surface temperatures in the GOA.
- **Summer 2020 sea surface temperatures** in the western GOA were generally lower than 2019 but summer and fall temperatures were still elevated, oscillating around marine heat wave thresholds, following **average temperatures in the winter and spring**.
- 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, including 2020**. Their apparent **decline coincided with the period of warm water temperatures** in the GOA.

Eastern Gulf of Alaska 2020 Report Card

- There was a **weak-moderate El Niño in winter 2019**. Moderate **La Niña conditions are predicted for winter 2020–2021**.
- **Summer 2020 sea surface temperatures** in the eastern GOA cooled from 2019, remaining **around the long-term mean** for the winter, spring, and summer (different from the warm summer temperatures observed in the western GOA).
- Total **zooplankton density in Icy Strait in 2020 was approximately average**, similar to 2019. This suggests **average foraging conditions for planktivorous fish, seabirds, and mammals**.
- The **overall copepod community size (ratio of large calanoid copepods to total calanoid copepods) increased** in 2020 due to increased densities of large copepods and decreased densities of small copepods. This suggests above-average quality zooplankton prey, supported by measures of **average and elevated lipid content in large and small copepods respectively**.

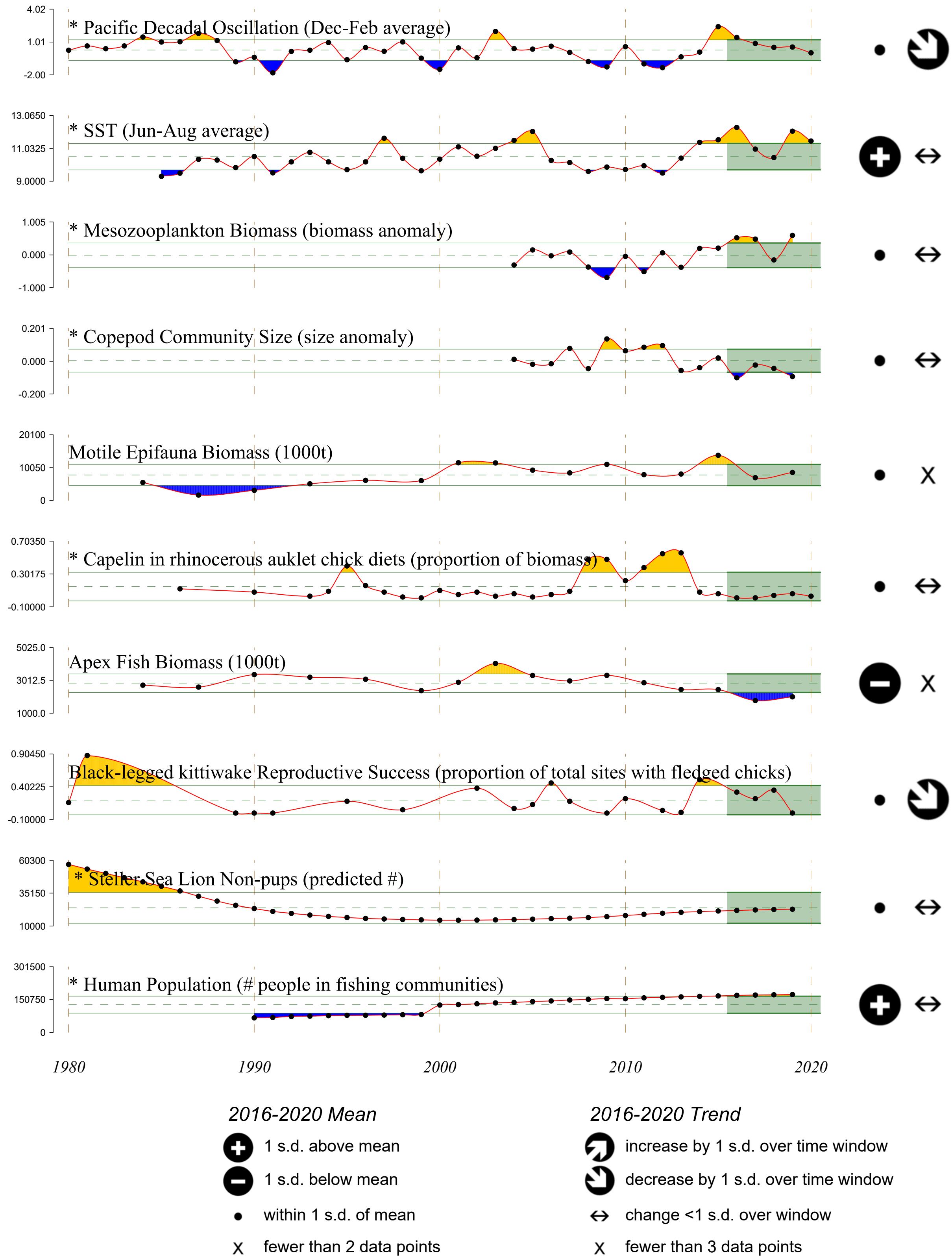

Figure 1: Western Gulf of Alaska report card indicators; see text for descriptions. * indicates time series updated in 2020

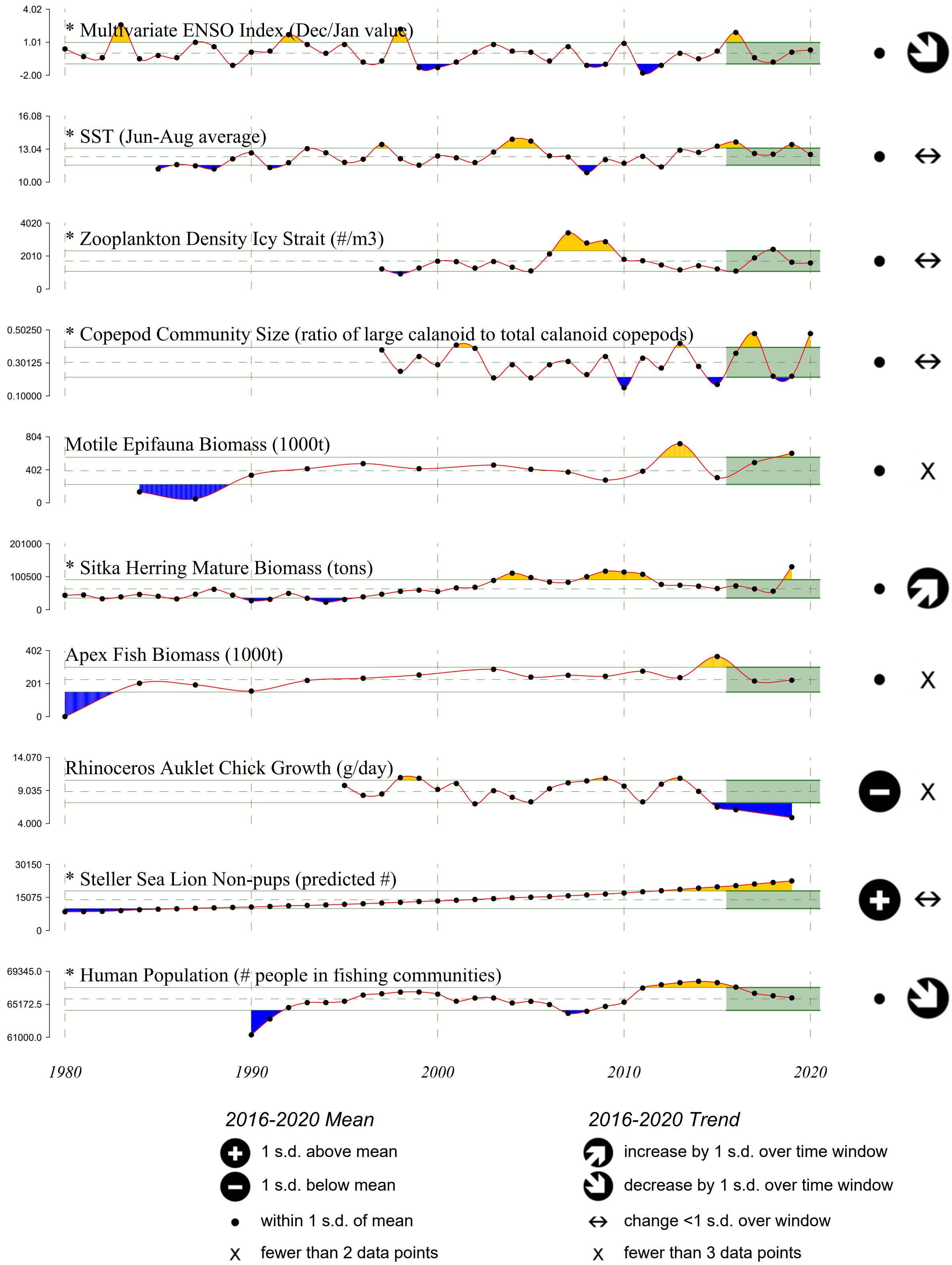

Figure 2: Eastern Gulf of Alaska report card indicators; see text for descriptions. * indicates time series updated in 2020.

Ecosystem Assessment

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Last updated: November 2020

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 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 (divided at 144°W) 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 ecosystem to be 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 2019 Ecosystem State

Some ecosystem indicators are updated to the current year (2020), while others can only be updated to the previous year, 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 2019, that includes information from both previous and current indicators. The next section (Current conditions: 2020) provides separate summaries of the 2020 ecosystem state for the western and eastern GOA (divided at 144°W) based on indicators updated this year.

The GOA returned to an extended period of heatwave conditions in western and eastern GOA (sea surface temperature above the 90% threshold over consecutive 5-day periods) starting in the fall of 2018 and continuing through December of 2019, after a 2-year (2017-2018) stretch of generally more "typical" conditions. The winter of 2018/2019 was not as warm as those of 2014/2015 and 2015/2016, potentially modulating the ecosystem impacts relative to those previous heatwave winters, which had extensive impacts on populations of piscivorous predators such as Pacific cod and murres. 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 sea surface temperatures exceeded those during the 2014–2016 heatwave. Several surveys confirmed that the warm temperatures at the surface during summer 2019 extended to depth. Bottom temperatures observed during the biennial larval fish surveys were higher in summer 2019 relative to those observed during the survey in 2015, during the previous heatwave.

Bottom-up indicators suggested a generally lower productivity overall, with some exceptions. Chlorophyll concentrations during 2019 in the WGOA indicated phytoplankton blooms were late (June) and had low early season biomass, while the blooms in the EGOA were only slightly late (May) and had approximately average biomass. WGOA zooplankton indicators suggested moderate abundance of smaller sizes were available to predators. Euphausiid biomass was below average (May 2019 Seward Line and summer acoustic survey). Large calanoid copepod abundance was below average on the Seward Line. September 2019 Seward Line results are not available due to COVID-related delays. Continuous Plankton Recorder data supported the reduction of large copepods, observing high biomass of small copepod taxa. Planktivorous parakeet auklets nesting at the Semidi 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, at the surface 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. EGOA zooplankton indicators supported decreased zooplankton biomass and lipid content in inside waters (Icy Strait), but adequate biomass in offshore waters to support high reproductive success planktivorous storm-petrels nesting on St. Lazaria Island, and positive anomalies in pollock condition in this region.

Indicators suggest that in 2019, forage fish were not abundant in WGOA but may have been more so (based on few data) in EGOA. In the WGOA, 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 Semidi Islands. Interestingly, black-legged kittiwakes, which have a mixed fish/invertebrate diet, failed reproductively at the nearby Semidi 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 confirmed that there appeared to be abundant age-1 pollock (the 2018 year class), however this year class was not observed later in the 2020 winter acoustic survey (see current conditions section below).

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. Notably, the EGOA had the largest mature spawning biomass of herring (age 3+) in Sitka Sound and Craig since at least 1971 and 1988 respectively. However, herring stocks in SEAK inside waters and Prince William Sound remained at low levels. A decreasing trend in the EGOA groundfish community mean length indicator (as sampled by the GOA bottom trawl survey) also indicated increaseng herring populations. Forage fish-eating gulls and murres nesting at St. Lazaria Island had very successful reproduction in 2019, suggesting 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. These few indicators suggest a pattern of better conditions for forage fish in outside waters versus inside waters in the EGOA.

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 (weight per unit length) 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 bias, 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 similar 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 continued to show 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 Semidi 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., 2020). 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. Steller sea lion predicted non-pup abundance continued an increasing trend in in WGOA and EGOA; however, 2019 saw the lowest non-pup counts since 2011, causing some concern. More humpback whales were observed during September 2019 in Prince William Sound than had been observed in 2017 and 2018 (none in poor body conditions); however, they remain well below 2008–2014 numbers. 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. 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 2019 ESR).

Fishing and human dimensions indicators supported a variety of trends. Landings of apex predators and salmonids increased in 2019 due to increases in sablefish and rockfish, and odd year cycle increases in pink salmon (although landings were lower than 2017 and 2015). Pollock landings (pelagic forager group) decreased. While aggregate ex-vessel revenues continued to remain fairly stable over the long-term, in 2019 they increased primarily due to increased revenues from salmon and Dungeness crab (motile epifauna functional group). Anchorage unemployment rates may be seeing benefits from increases in oil and gas activity, tourism, and military projects. The 2019 population of WGOA coastal communities continues to increase, although at a lower rate than previous years, while EGOA coastal populations remains stable.

Current Environmental State—Gulf of Alaska 2020

While COVID-19 caused disruptions to human communities, fisheries, and numerous research and monitoring programs, most data normally included in the GOA ESR were collected and analyzed as expected. Notable exceptions include missing seabird reproductive success data, due to cancelled surveys by the Alaska Maritime National Wildlife Refuge (USFWS), and delayed lab analysis of zooplankton, larvae, and ichthyofauna samples. In addition, as this was an ‘off-year’ of the biennial NOAA GOA surveys, the GOA ESR was less affected by COVID-related cancellations than in other Alaskan regions. Thanks to the great efforts of NOAA scientists and the numerous collaborators this year who provided data for this report.

Western Gulf of Alaska

The WGOA returned to near-average sea surface temperatures in the winter of 2020, after the previous marine heatwave ended in December 2019. Temperatures were close to long-term mean levels for winter and spring followed by elevated temperatures in the summer and fall. Temperatures oscillated around the heatwave threshold throughout the summer and have remained in heatwave conditions since September (as of Oct. 30$^{\text{th}}$). Residual heat from previous warm years remains at depth, as seen along the Seward Line, which remains a concern for lagged ecological recovery from previous heatwaves. Indicators of surface transport desribed upwelling-favorable westerly winds causing eastward and southward sea surface transport (described by satellite data and supported by the Papa Trajectory Index) due to anomalously high sea level pressure during winter 2019/2020 (satellite data and a strongly positive state of the Arctic Oscillation). Spring winds in Shelikof Strait were downwelling-favorable northeasterly winds, conducive to enhanced retention of larval and juvenile pollock. High eddy kinetic energy was present off the shelf west of Kodiak, potentially enhancing higher phytoplankton biomass in that region. La Niña conditions are predicted for winter 2020–2021, along with moderate to cooler sea surface temperatures across the GOA.

Chlorophyll-a data indicate early peak phytoplankton bloom timing, similar to that in 2017 and 2018, and approximately average phytoplankton biomass in WGOA. Spring biomass estimates of large copepods and euphausiids were near the long-term average along the Seward Line (May 2020), suggesting prey were not limiting. A lack of additional zooplankton data makes this trend difficult to extrapolate across the WGOA, due to an "off-year" of GOA surveys and COVID-related cancellations of planktivorous seabird surveys.

The limited forage fish data show mixed trends in WGOA. Forage fish-eating seabirds (surface-feeding and diving) at Middleton Island found sufficient prey to successfully rear chicks, although chick diets were diverse and included a notable increased proportion of greenlings. These diets suggested that the more typical forage fish, such as capelin, were not abundant. Preliminary analysis of ichthyoplankton surveys from 2019 reported relatively high abundance of larval sand lance (highest since 2007) indicating potential for elevated age-1 sand lance populations in 2020, although no surveys were conducted this year to verify. Prince William Sound herring spawning stocks increased slightly from 2019 due to a strong age 3+ recruitment, but they remain very low. Several indicators of good age-1 walleye pollock recruitment in 2020 include southwest wind trajectories in Shelikof Strait and an early spring phytoplankton bloom (similar to 2017 and 2018).

Indications of groundfish biomass trends in 2020, 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, flathead sole, Pacific cod, Pacific halibut, skates, and walleye pollock, and above the long-term mean for Tanner crab.

Paralytic shellfish toxin (saxitoxin) monitoring in phytoplankton and shellfish in SEAK, Kachemak Bay, and Kodiak Island reported a consistent presence of harmful algal blooms (HABs). Bivalve shellfish from areas that are well known for having PSP levels above the regulatory limit, including Southeast Alaska and Kodiak, continued to test above the regulatory limit in 2020, while Kachemak Bay shellfish did not exceed the limit this year.

Whales and seabirds continue to show mixed trends in the WGOA in 2020. Humpback whale counts in Prince William Sound remained lower in 2020 than pre-2014 heatwave levels. 2020 is the second year of an unusual mortality event that included 44 dead grey whales found within Alaskan waters, 24 of which were in the GOA (primarily western). 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. Overall, the status of seabirds was fair to good in the WGOA in 2020, based on an integration of qualitative and quantitative, limited data from Middleton Island, Cook Inlet, and the Kodiak Archipelago. Colony attendance remains low in some populations compared to historic levels, and some colonies were newly abandoned. However, when birds did arrive to breed, reproductive success was fair to good for both fish-eating, surface-feeding birds and fish-eating, diving birds. There was spatial variability in colony attendance and reproductive success, with Middleton Island birds performing more strongly than Kodiak Island or Cook Inlet. Middleton Island populations from both these groups experienced their strongest breeding seasons since the marine heatwave began in 2014, suggesting an increase in the availability of small schooling fish in that region of WGOA. The Alaska Maritime National Wildlife Refuge's seabird reproductive success time series were not updated in 2020, due to COVID-19 related survey cancellations, making these reported data trends difficult to compare to previous years' ESRs.

Eastern Gulf of Alaska

The EGOA returned to near-average sea surface temperatures in the winter of 2020, after the previous GOA marine heatwave ended in December 2019. Sea surface temperatures were close to long-term mean levels for winter, spring, and summer (cooler than WGOA), followed by elevated temperatures in the fall in EGOA. The EGOA is experiencing warmer sea surface temperatures than fall 2019, but has not exceeded the marine heatwave threshold (as of Oct 30^{th}). Indicators of surface transport described upwelling-favorable westerly winds causing eastward and southward sea surface transport (shown with satellite data and supported by the Papa Trajectory Index), due to anomalously high sea level pressure during winter 2019/2020 (satellite data and a strongly positive state of the Arctic Oscillation). La Niña conditions are predicted for winter 2020-2021, along with moderate sea surface temperatures in the EGOA.

Chlorophyll-a data indicate early peak phytoplankton bloom timing and approximately average phytoplankton biomass in EGOA. Total zooplankton density in SEAK inside waters (Icy Strait, summer) was near the long-term average, but included increases in large copepods, decreases in small copepods, and decreases in euphausiids. A lack of additional zooplankton data makes these trends difficult to extrapolate across the EGOA, including offshore waters, due to an off-year of GOA surveys and COVID-19 related cancellations of planktivorous seabird surveys.

Limited forage fish data show mixed trends in EGOA. Preliminary results of mature spawning herring (age 3+) show strong recruitment in 2020, continuing the 2019 high levels in Sitka Sound and Craig (ocean influenced populations). Juvenile pink and chum salmon CPUE in inside waters (Icy Strait) increased to average levels for the first time since 2016 while sockeye and coho remain lower.

Humpback whale productivity and juvenile survival in Glacier Bay and Icy Strait returned to more typical, pre-2014 heatwave levels, reflecting good feeding conditions (for females) from 2018–2020. This could include the increased herring abundance described above.

Phytoplankton and shellfish monitoring for paralytic shellfish toxins (saxitoxins) in Southeast Alaska included samples exceeding the regulatory limit in 26 out of 40 sites, slightly lower than the 30 sites observed in 2019. The lower toxicity levels may be attributed to the rainy summer and cooler temperatures in 2020.

Salmon commercial harvest was low across most of GOA, and lowest in SEAK since 1976, resulting in numerous requests for the State to declare salmon fishery disasters. The low returns in SEAK were primarily driven by low chum and sockeye. Low adult returns are tied to juvenile mortality in 2017 (and years since then for certain species) but the mechanism driving that trend (e.g., environment, predation) is still uncertain.

Marine Heatwave Update

While the persistent 2019 GOA marine heatwave conditions ended in December, 2019, residual heat remains at depth in 2020, and potential effects from the previous warm years (2014–2016 and 2019) may still be evident in the ecosystem. Species-specific changes in abundance, reproductive success, and distribution occurred in the GOA 2014–2019 period, and not all have recovered, although evidence has not been found of shifts to a new ecosystem state (Litzow et al., 2020). Among the forage fish species, there is a continued reduction in capelin since the 2014 heat wave, some evidence of moderate increases of sand lance since 2016, and increases in some herring spawning stocks (SEAK ocean influenced stocks). Southeast juvenile salmon abundance has gradually increased since a 2017 low (although juvenile sockeye and chum decreased again in 2020), a potential driver for the low adult salmon returns occuring in 2020. Of the groundfish species, the piscivorous Pacific cod and arrowtooth flounder populations experienced the greatest reduction in the 2014 heatwave, and their populations are still reduced. Sablefish populations increased during the 2014–2016 heatwave and continue to increase. The planktivorous walleye pollock persisted through the 2014 heatwave but had an uncertain response to the 2019 warm year. Specifically, the 2018 year class of age-1 pollock was not observed in the winter 2020 WGOA acoustic survey as expected, posing questions of a change in distribution or increased mortality in fall/winter of 2019/2020. Marine mammals and seabirds are partially recovering. Humpback whale productivity and juvenile survival in Glacier Bay and Icy Strait, SEAK, returned to pre-2014 levels for the first year since the that marine heatwave (although humpback whale encounter rate remained reduced in Prince William Sound). 2020 is the second year of an unsual mortality event that included 44 dead grey whales found within Alaskan waters, 24 of which were in the GOA (primarily western), linked to changes in their foraging grounds to the north. Piscivorous seabirds in the western GOA (Middelton Island, Cook Inlet, and Kodiak archipelago) experienced fair to good breeding seasons (the strongest on Middleton Island since the marine heatwave began in 2014), suggesting an increase in the availability of small schooling fish in the western GOA. While the status of pisicivorous seabirds has improved to fair conditions in general (with some abandoned colonies and limited data), common murre population counts continue to decline since the mass mortality in 2015–2016. It is important to note that these seabird data are limited in interpretation, and comparison to previous years, given the COVID-related reduced seabird data collection by USFWS in 2020.

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 2019 through summer 2020 included higher than normal sea level pressure, a strongly positive state for the Arctic Oscillation, a weak-moderate El Nino, and the Pacific Decadal Oscillation transitioned from positive to negative (p. 30).
- The climate models used for seasonal weather predictions are forecasting a mild to moderate La Nina for the winter of 2020–2021, and slightly cooler sea surface temperatures in northern GOA (p. 36).

Gulf of Alaska

- The 2019 marine heatwave ended in December (2019), and the GOA experienced sea surface temperatures near the long-term mean through to the summer (WGOA) and fall (EGOA), 2020. The WGOA oscillated around the heatwave threshold during the summer and heatwave conditions have persisted from September to present (October 30$^{\text{th}}$). The EGOA had elevated fall sea surface temperatures but has not experienced heatwave conditions in 2020, to date (p.38).
- Spring and summer thermal profiles along the Seward Line show residual heat at depth (100-200m), both nearshore and offshore, despite moderate sea surface temperatures at that time (p. 45).
- High winter sea level pressure patterns over the Gulf of Alaska resulted in upwelling-favorable westerly winds, resulting in eastward and southward surface transport (p. 32, p. 51).

Ecosystem Trends

- Chlorophyll *a* concentrations during 2020 in the WGOA and EGOA indicated early peak bloom timing, with appoximately average biomass, which could possibly affect some larval fish populations depending on their spawn timing and location (p. 59).

- Along the Seward Line, large calanoid copepod and euphausiid biomass in May 2020 was near the long-term average indicating limited effects of the early spring phytoplankton bloom and adequate prey supply for zooplankton predators, at least in this region (p. 68).
- In Icy Strait, the 2020 total density of zooplankton increased, including increases in large copepods and descreases in small copepods and euphausiids (p. 70, p. 72).
- Preliminary results of mature spawning herring (age 3+) show strong recruitment in 2020, continuing the relatively high 2019 biomass in Sitka Sound and Craig (ocean influenced) stocks. Stocks in SEAK inner waters and in Prince William Sound remain at low levels (p. 85, p. 82)
- In the nearshore waters of Icy Strait (northern southeast Alaska) during 2019, the juvenile salmon survival index continued to increase, but remained below average, for pink and chum salmon, but decreased from 2019 for coho and sockeye (p. 91).
- Diving and surface-feeding, fish-eating seabirds in Middleton Island (WGOA) had generally good reproductive success in 2020 indicating adequate abundance and availabilty of forage fish, although their diets were varied and had high proportions of greenlings, missing more common prey items including capelin. Sandlance, another common prey species was present but in moderate amounts (p. 121, p. 77).
- The status of fish-eating, surface-feeding birds and fish-eating, diving seabirds was fair to good in the WGOA in 2020, based on an integration of qualitative and quantitative, limited data from Middleton Island, Cook Inlet, and the Kodiak Archipelago. Colony attendance remains low in some populations compared to historic levels, and some colonies were newly abandoned. However, when birds did arrive to breed, reproductive success was fair to good (with highest success in Middleton Island) (p. 121).
- Humpback whale calving and juvenile return rates in Glacier Bay and Icy Strait increased to pre-2014 heatwave levels reflecting good feeding conditions (for females) from 2018–2020. (p. 130).
- During September of 2020 in Prince William Sound humpback whales remain well below 2008–2014 numbers (p. 129).
- Phytoplankton and shellfish monitoring for paralytic shellfish toxins (saxitoxins) in SEAK included samples exceeding the regulatory limit in 26 out of 40 sites in 2020, slightly lower than the 30 sites observed in 2019. The lower toxicity levels may be attributed to the rainy summer and cooler temperatures in 2020 (p. 149).
- Commercial harvest of salmon in 2020 was low across GOA and the lowest in SEAK since 1976. Low returns can be tied to low juvenile abundance in 2017, and years since then (p. 24).

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% and remain elevated in 2020 (p. 155).
- In 2019, non-target catch of scyphozoan jellyfish (caught primarily in the walleye pollock fishery) increased sharply to the 3rd highest catch since 2011, and structural epifauna (e.g., sea anemones, caught primarily in the flatfish and Pacific cod, and sablefish fisheries) decreased 43% from 2018 to 2019. Assorted invertebrates continued a decreasing trend to the lowest since 2011 (this group consists of 87% sea stars, primarily caught in Pacific cod and halibut fisheries) (p. 159).
- The numbers of seabirds estimated to be caught incidentally in western GOA fisheries in 2019 decreased from that in 2018 by 66%, and was below the 2010-2018 average of 637 birds, primarily due to decreases in black-footed albatross, northern fulmar, and gulls. Seabird incidental catch in EGOA remained similar to 2018 and previous years. (p. 161).
- No GOA groundfish stock or stock complex was subjected to overfishing, known to be overfished, or known to be approaching an overfished condition, as of June 30, 2020 (p. 166).
- Landings in the GOA remained stable through 2019. 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. Walleye pollock landings have also declined, and salmonids increased in the odd year cycle (p. 171).
- Ex-vessel revenues have remained fairly stable over time, but have been lower since 2003, as the relative share of landings has 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. Since 2018 pollock pricess have been stronger though landings have decreased. Salmon prices were down in 2019, relative to 2018 (p. 173).
- As of 2019, the unemployment rate in the western GOA was 5.5% and in the eastern GOA was 5.4%, which are both higher than the national rate of 3.7% (p. 177).
- The total population of the western GOA (excluding Anchorage) has steadily increased since 2010. Small community populations increased by 2.42% between 2010 and 2019, and larger communities increased by 4.25%. The total population of the eastern GOA has remained stable since 2000, with no significant population changes within large communities between 2010 and 2019 (p. 181).
- As of 2019, there are ten schools in the western GOA with enrollments under 30 students and 2 school closures (p. 185).
- In eastern GOA municipalities with school enrollment between 100 to 500 students, enrollment appears to be steadying since 2015. Larger districts such as Sitka and Ketchikan have the lowest graduation rates (both remaining under 60%) for the 2015–2019 cohorts, consistently placing in the lower 1/3 of school districts analyzed (p. 185).

Contents

† indicates new contribution

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Ecosystem Indicators

Noteworthy

We include information here that relevant to ecosystem considerations of fisheries managers, but does not fit our typical indicator format. Information included here is often new or a one-time event.

COVID-19 Pandemic Impacts to the Fisheries Sector in Alaska

Alaska Governor Dunleavy declared a state of emergency on March 11 and the first confirmed case occurred on March 12. Restaurants, bars, breweries, and food trucks all closed beginning on March 18, which may have limited some amount of seafood sales in some communities. However, the large scale and global nature of Alaska fisheries means that restaurant closures throughout the lower 48 and globally are more likely to impact Alaska seafood sales. The Governor announced on March 23rd that "All people arriving in Alaska, whether resident, worker or visitor, are required to self-quarantine for 14 days and monitor for illness. Arriving residents and workers in self-quarantine should work from home, unless you support critical infrastructure (see Attachment A)." Fishing and processing businesses are included in Attachment A as "essential businesses", which allowed many fishing operations to continue in 2020. This came at a substantial cost to the harvesting and processing industries in Alaska to maintain a safe working environment for their employees and minimize spread to local community residents. More information on the actions of the State of Alaska in response to this crisis can be found on the Office of Governor Mike Dunleavy's webpage on COVID-19 Health Mandates (https://covid19.alaska.gov/health-mandates/).

Industry has reported that they have spent over $50 million (McDowell September 2020) (https://www.alaskaseafood.org/covid-19-impact-reports/) to reduce the risk of COVID-19 transmission among harvesters, processors, and the local communities while still providing important seafood for the U.S. and international markets, as well as providing food security for many Alaskans. The seafood industry has been fairly successful in Alaska in limiting virus spread, but they had to deal with a substantial reduction in transportation options in many western Alaska and Aleutian Islands communities and limited ability to switch crews throughout the fishing seasons. COVID has impacted markets, shifting demand from food service to shelf stable products, which tend to have smaller margins. The NMFS Alaska Regional Office has been instrumental in devising solutions with industry to allow the continuation of fishing operations and limit the need for fisheries closures, which would otherwise lead to vessel downtime and higher crew turnover increasing the risk of COVID-19 transmission. The AFSC has developed a series of in-season, ex-vessel revenue estimates to provide the NPFMC, industry, and the public with near real-time economic information for the annual groundfish harvest specifications process for 2021. This information is titled "Groundfish and Halibut In–season Ex–Vessel Revenue Estimates for 2020", found in Section 6 of the Groundfish Economic SAFE.

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Low abundance of Gulf of Alaska salmon in 2020

The abundance and harvest of Pacific salmon (*Oncorhynchus spp.*) in the Gulf of Alaska (GOA) were low during 2020. Salmon have a significant cultural and economic importance to communities across the GOA, where they are harvested in subsistence, commercial, sport, and personal-use fisheries. Salmon have contributed to an average annual nominal ex-vessel value of $347 million dollars in GOA commercial salmon fisheries (excluding Alaska Peninsula fisheries) over the last 10 years (2010–2019) (source: ADF&G). However, recent declines in their abundance has resulted in federal fishery disaster determinations with $67 million dollars in disaster relief funds provided to GOA salmon fisheries since 2016 (NOAA, 2020), and cities/boroughs and fishery associations are requesting the state declare salmon fishery disasters throughout the GOA in 2020 (e.g., Southeast Alaska, Prince William Sound, Upper Cook Inlet, Chignik). Low harvests of salmon reflect low abundance (run size) and indicate that ocean and freshwater ecosystem conditions during 2015–2019 (species-specific life histories) have not been favorable for salmon survival. Causes for the decline in salmon abundance are unclear; however, poor survival during the early marine life-history stage is highlighted in the juvenile salmon data within Southeast Alaska. This section summarizes the commercial harvest of salmon in the GOA (other salmon harvest data are not included due to limited data availability) and provides insight into factors contributing to the poor harvest in 2020, with a focus on Southeast Alaska.

Trends: *Gulf of Alaska:* The 2020 commercial harvest (mt) of salmon in the GOA (excluding the Alaska Peninsula harvests) were at the lowest levels since 1980 (Figure 3). The decreasing trend in GOA salmon catch is masked by increased catches in other regions when aggregated across Alaska (see Whitehouse 2020, p.89). Low abundance of pink salmon (*O. gorbuscha*) in the GOA contributed to the poor harvests in 2020; however, the additional impact of low harvest of the other species of salmon (sockeye (*O. nerka*), chum (*O. keta*), coho (*O. kisutch*), and Chinook (*O. tshawytscha*) salmon) resulted in the exceptionally poor salmon harvests in 2020. Although not all commercial harvest data have been entered, the final estimates are expected to be reasonably close to the preliminary estimates shown in Figure 3.

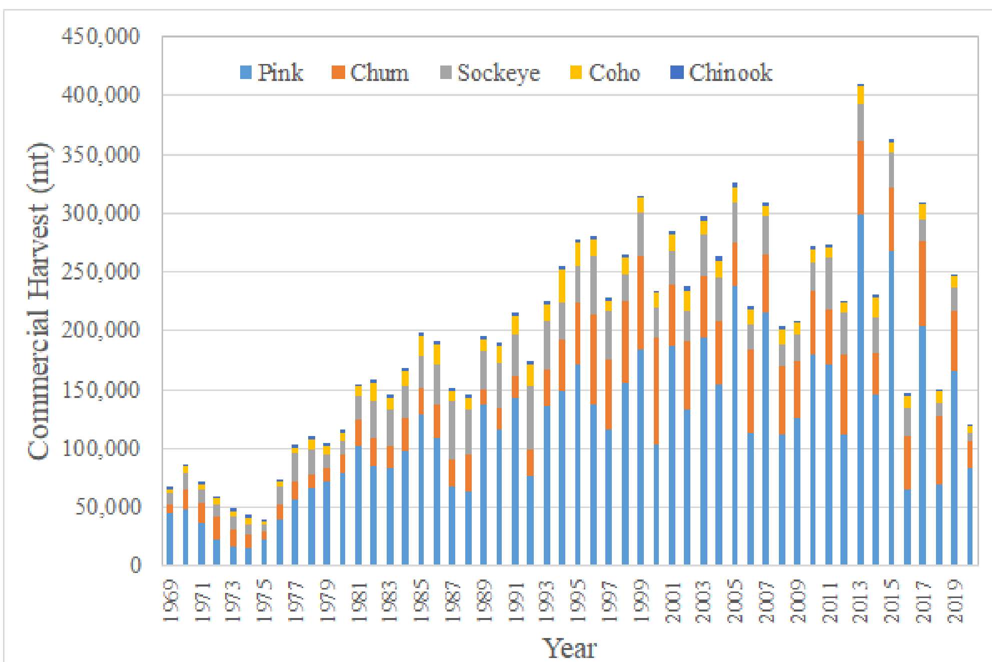

Figure 3: Commercial harvest (mt) of salmon by species in the Gulf of Alaska,1969–2020 (source: ADF&G). Data for 2020 is preliminary and subject to change (ADF&G is not responsible for errors or deficiencies in reproduction, subsequent analysis, or interpretation of harvest data).

Low salmon harvests in the GOA were somewhat expected during 2020 for some species including sockeye and Chinook salmon, and Southeast Alaska (SEAK) pink salmon (Brenner et al., 2020). For several GOA sockeye stocks in particular, sibling-based models indicated that the 2020 sockeye runs would be below average run strength. However, for chum, coho, and pink salmon outside of SEAK, lack of available data (e.g. juvenile abundances) and the life history characteristics of these species make it difficult to accurately forecast runs. Sibling models have generally not been reliable to forecast chum salmon—for which pre-season forecasts are often based on averages of run size, harvests, or marine survival—and actual GOA chum harvests in 2020 were considerably below these preseason forecasts. Chinook salmon forecasts across the GOA are based on a combination of sibling models, average run size, and average harvests; and available sibling models for Alaska Chinook stocks (mostly from SEAK) also suggested that runs would be weak during 2020. Thus, poor early ocean survival is implicated as a likely contributing factor to the weak runs of both sockeye and Chinook during 2020.

When aggregating harvest data across large regions like the GOA or the state of Alaska, harvests will often covary with climate patterns at these spatial scales, such as the Pacific Decadal Oscillation (PDO). Large-scale harvest aggregations have been used to provide insight into decadal scale patterns in salmon abundance (Hare et al., 1999); however, aggregations at this scale are limited in their ability to explain year-to-year variation, and relationships with climate are not stationary (Litzow et al., 2020). Similar to other species in the GOA, there is an overall concern that warm temperatures in the GOA could be exceeding an optimal temperature range for salmon (Mantua, 2009).

Southeast Alaska: The 2020 commercial salmon harvest (mt) in SEAK was the lowest since 1976. Abundance indices for all species of juvenile (first year at sea) salmon were at their lowest level in 2017 and have remained below average since then (see Murphy et al. 2020, p.91). Low abundance of juvenile pink salmon has contributed to reduced harvests since 2018. The low abundance of juvenile chum and sockeye salmon in 2017 is a key contributor to the overall poor harvest of salmon during 2020 as age-3 ocean fish typically dominate returns for these two species of salmon in SEAK. Juvenile abundance indices have increased after 2017, and may indicate that harvests will recover but remain below average for the next few years.

Multiple factors contribute to the change in juvenile abundance indices over time; however, poor early marine survival of salmon is likely a key factor in 2017 as all species of juvenile salmon exhibited record low abundance. The abundance of juvenile pink salmon has remained below average since 2017 and their size has ranged from below average to well above average over this time period (see Fergusson et al. 2020, p.94). It is unclear if bottom-up ecosystem processes are responsible for the low abundance of juveniles, given that 2017 sea surface temperatures were approximately average (following 2 years of marine heat wave conditions), the energetic condition of juvenile salmon was above average or average in 2017, and the size of sockeye and chum salmon were both above average in 2017 (see Fergusson et al. 2020, p.94). Although the lipid content of zooplankton was low in 2017, their density was not (see Fergusson et al. 2020, p.72). Top-down ecosystem processes, such as predation by humpback whales *Megaptera novaeangliae*, pollock (*Gadus chalcogrammus*), and squid (*Berryteuthis magister*) are a concern in SEAK; however, it is unclear if they are contributing to the low juvenile abundance. Humpback whales experienced a fifth straight year of declining abundance in Southeast Alaska in 2018 (Gabriele and Nielson, 2018), whereas GOA pollock biomass in 2017/2018 was dominated by a strong 2012 year class, posing a potentially strong predatory pressure on juvenile salmon in 2018, but not unique to that year (Dorn et al., 2018).

There are also concerns over the growth and survival of salmon after their juvenile stage. For at least the past five years, sockeye salmon scales across SEAK have exhibited little growth during their third marine year and there has been an increase in the number of fish maturing after spending four years in the marine environment (Iris Frank, personal communication), suggesting poor feeding conditions. Some stocks of sockeye salmon in the GOA (e.g., Kenai and Copper Rivers) returned later than normal in 2020, which may indicate a reduced foraging arena or that these fish required additional time to reach full maturity. Additional work is needed on survival and salmon growth after the first marine year; however, available information indicates that the low runs of adult sockeye salmon during 2020 are connected with low abundances of juveniles and, perhaps, reduced survival during their later marine stages.

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2019-2020 Gray Whale Unusual Mortality Event

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) In 2020, gray whale strandings remained elevated, but at slightly lower numbers than in 2019 (Table 1, Figure 4).

Table 1: Total number of gray whale strandings by location from January 1, 2019 to October 30, 2020

Location	2019	2020
Canada	10	5
US Total	122	77
–Alaska	48	44
–Washington	34	12
–Oregon	6	3
–California	34	18
Mexico	81	87
Total	213	169

Gray whale life history includes an annual round-trip migration of up to 20,000 km. In 2019, the mortalities started off the western coast of southern Baja California Peninsula where gray whales overwinter to mate and calve, and followed the late winter/spring migration up to Alaskan waters where foraging occurs before the fasting return journey south. This pattern was repeated in 2020. The first Alaskan gray whale stranding in 2020 occurred on April 21 in Port Heiden in the Bering Sea. Mortalities continued throughout the summer with hotspots around Kodiak Island, Bristol Bay, and coastal waters of the Bering Sea and southern Chukchi (Figure 5).

Abnormal behaviors of live whales were also reported on occasion in both years. On May 25, 2020, a yearling gray whale in poor body condition was observed approximately 1.5 miles up from the mouth of the Twenty Mile River in Turnagain Arm. The whale remained upriver until June 3, then moved downstream where it was live-stranded by a low tide near the river mouth. Once freed with the high tide, the whale moved out into Turnagain Arm. On June 12, a dead whale reported near the Theodore River mouth in upper Cook Inlet was thought to be the same whale.

The cause of the UME has not yet been determined and the investigation is continuing. Preliminary findings in several of the whales have shown evidence of emaciation; however, these findings are not consistent across all of the whales examined. Furthermore, while benthic prey, primarily ampelecid amphipods, in the Bering, Chukchi, and Beaufort Seas are considered the mainstay of gray whale foraging, there is also significant variability in foraging behavior depending on the location, season and 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

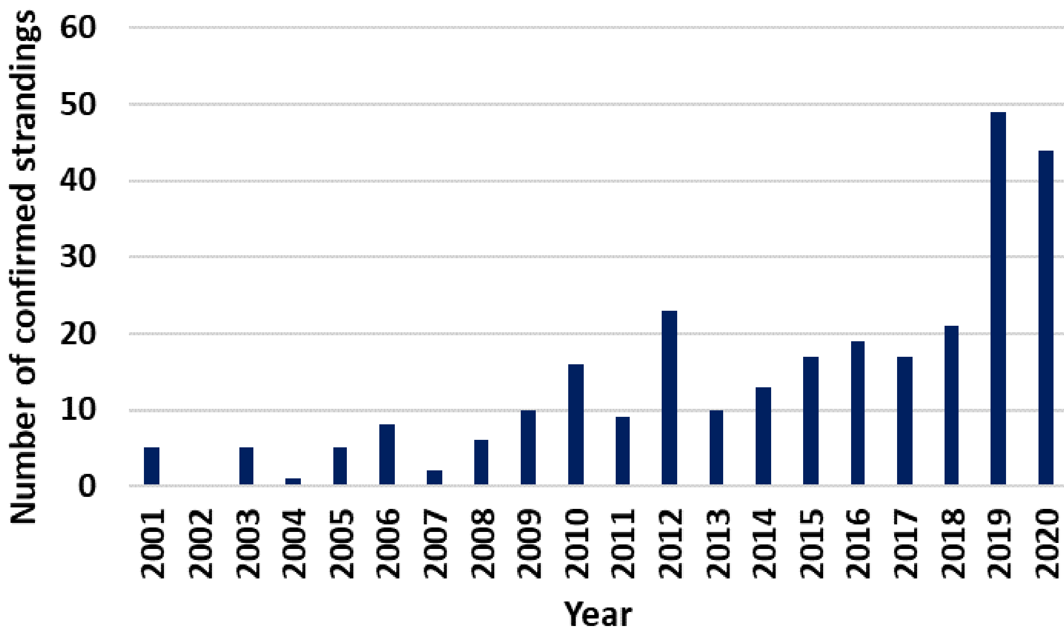

Figure 4: Number of gray whale strandings in Alaska by year, 2001–2020 (2020 numbers through 16 October).

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.

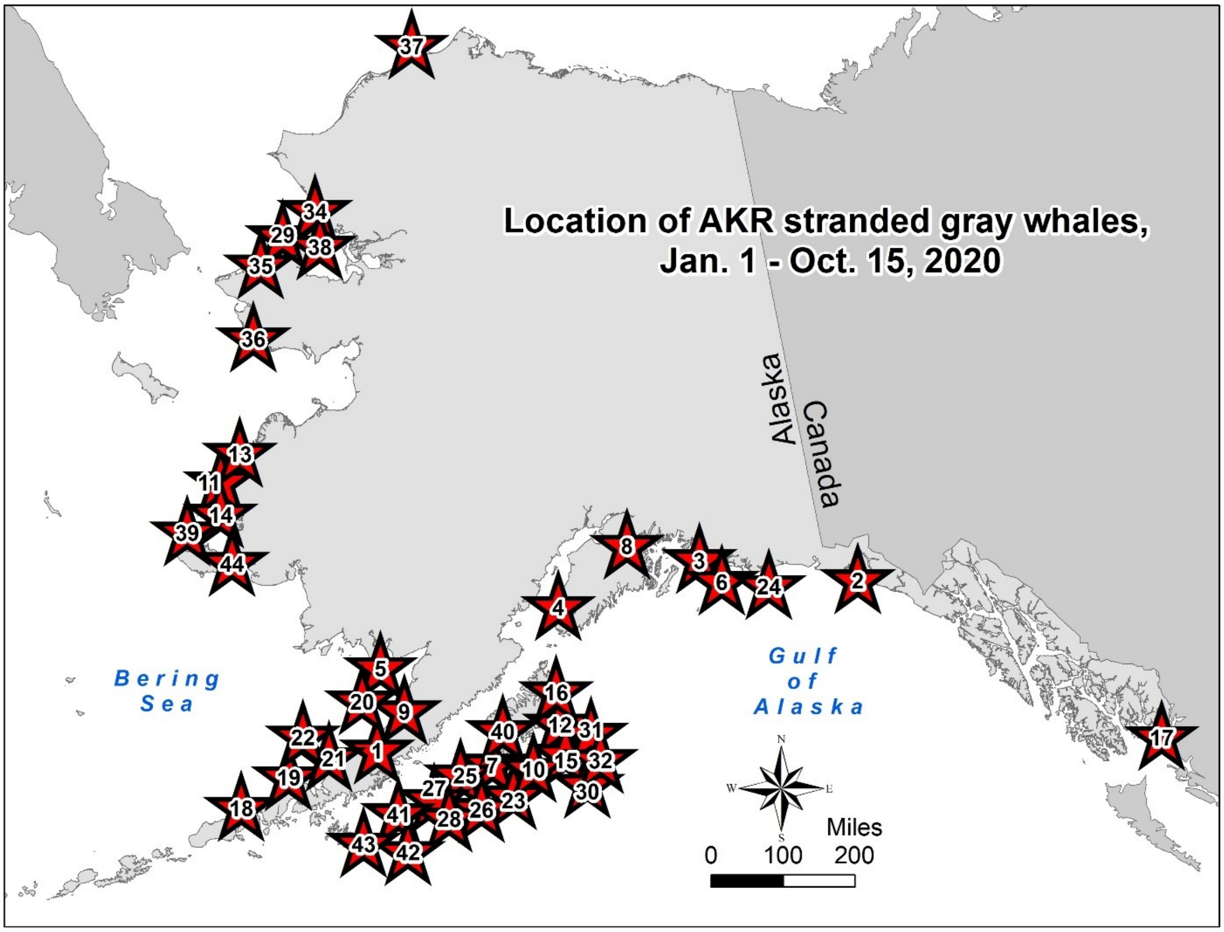

Figure 5: Locations of gray whale strandings in Alaska (NOAA/NMFS Alaska Region Marine Mammal Stranding Network unpublished data).

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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

Summary

Climate: The North Pacific atmosphere-ocean climate system during autumn 2019 through summer 2020 featured generally higher than normal sea level pressure and above-normal upper ocean temperatures south of Alaska. The anomalously high pressure was especially prominent during the winter of 2019–2020 and coincided with an intense polar vortex, as indicated by a strongly positive state for the Arctic Oscillation. This regional atmospheric circulation pattern occurred despite the co-existence of weak-moderate El Niño conditions in the tropical Pacific, with the latter usually accompanied by a strong Aleutian low, i.e., negative sea level pressure anomalies. The sea surface temperature pattern during the period considered here represented a strongly negative state of the North Pacific Gyre Oscillation, particularly during the latter portion of 2019; the Pacific Decadal Oscillation transitioned from moderately positive in summer 2019 to moderately negative during much of 2020. The climate models used for seasonal weather predictions are indicating elevated odds (∼85%) of La Niña for the winter of 2020–2021.

Temperature: Sea surface temperatures in the WGOA returned to long-term mean levels for winter and spring, after 2019 heatwave conditions, followed by elevated temperatures in the summer and fall. Temperatures oscillated around the heatwave threshold throughout the summer and have remained in heatwave conditions since September (as of Oct. 30th). Sea surface temperatures in the EGOA returned to long-term mean levels for winter, spring, and summer, after 2019 heatwave conditions, followed by elevated temperatures in the fall. The EGOA is experiencing warmer sea surface temperatures than fall 2019, but has not exceeded the marine heatwave threshold (as of Oct 30th). Residual heat remains at depth, as seen at GAK1 and along the Seward Line. Heat at depth is a concern for potential lagged ecological recovery from previous heatwaves. Sub-regional surface temperatures in Icy Strait (SEAK inside waters), Auke Creek (SEAK), and Prince William Sound all decreased from 2019 to near long-term average (Icy Strait and Auke Creek) or above average (Prince William Sound) temperatures. La Niña conditions are predicted for winter 2020–2021, along with moderate to slightly cooler sea surface temperatures in the northern GOA (National Multi-model Ensemble Model).

Transport: Westerly winds across the GOA caused eastward and southward surface transport, and upwelling conditions in the EGOA. The Papa Trajectory Index (from winter 2020) ended to the east and south, supporting the observation of eastward and southward surface transport. In the WGOA, high eddy kinetic energy off the shelf and west of Kodiak Island indicate greater transport of phytoplankton and nutrients away from the coast. Spring winds in Shelikof Strait were downwelling-favorable northeasterly winds (conducive to enhanced retention of pollock larvae and juveniles).

North Pacific Climate Overview

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Last updated: August 2020

Regional Highlights:

Aleutian Islands. The Aleutian Islands experienced relatively warm weather in the early fall of 2019 with then a transition to more normal air temperatures in winter 2020. The weather was quite variable in spring followed by a warm summer in 2020. The western portion of the Aleutian Islands tended to be relatively stormy in winter and spring 2020, with the central and eastern portions of this region on the quiet side, in large part due to an Aleutian low that was much weaker than usual. The sub-surface marine heat wave noted above for the GOA and Alaska Peninsula regions appears to have not extended farther westward along the southside of the Aleutians. According to GODAS, NOAA's operational ocean analysis, and considering temperatures in the 100 to 250 meters layer relative to historical averages, the western Aleutians have been cool and the central and eastern Aleutians have been warm since about 2016. There are relatively few direct sub-surface observations to constrain the GODAS analysis in this region so these results are tentative.

Gulf of Alaska. The coastal GOA featured slightly warmer than normal air temperatures from fall 2019 through the winter of 2019-20. There were slightly reduced wind speeds during this period, but also onshore-directed flow anomalies, resulting in greater precipitation than usual for most of the coastal watersheds of the GOA. The freshwater runoff in this region appears to have included slightly elevated flows on many rivers with a greater tendency for higher flows on the smaller streams. The GOA coastal winds anomalies were in a clockwise sense (upwelling-favorable) from late 2019 through spring 2020. The near surface ocean temperatures in the GOA were generally on the warm side, especially early in the period considered here and offshore of the shelf break. It bears mentioning that a prominent marine heat wave (MHW) occurred in the sub-surface waters (depths between roughly 100 and 250 meters) of the central and western GOA in mid-late 2019, followed by marked cooling during 2020. This warm water at depth originated off the British Columbia coast and in part represents a lingering effect of the extreme NE Pacific MHW of 2014-16. This conjecture is based on temperatures from NOAA's Global Ocean Data Assimilation System (GODAS), which uses a numerical ocean model that ingests real-time surface and sub-surface observations to monitor three-dimensional physical oceanographic conditions. The data considered here were downloaded using the application at `apdrc.soest.hawaii.edu`. Air temperatures in the vicinity of the Alaska Peninsula were mostly warmer than normal, especially during autumn 2019 and summer 2020, with more typical temperatures from late winter through much of spring 2020. Wind speeds were on the whole lower than normal. The SSTs were also on the warm side, but not to an extreme, with positive anomalies on the order of 0.5 to 1°C in coastal areas. The warmth at depth noted above for the GOA extended southwestward along the shelfbreak on the south side of the Alaska Peninsula during summer and fall of 2019, with rapid cooling beginning near the end of 2019 continuing into 2020 bringing more normal temperatures.

British Columbia Coast. This region experienced generally warm ocean temperatures (typically 0.5 to 1°C above normal) coming out of the summer of 2019. These anomalies moderated to an extent during the fall of 2019 followed by some temporary warming in the early winter. There tended to be less storminess in the fall that may account for the temporary warming. Some cooling of the upper ocean in this region during the later winter and spring of 2020 can probably be accounted to northwesterly wind anomalies and therefore enhanced coastal upwelling. Near normal temperatures continued into summer 2020; this period was relatively stormy offshore of the shelf-break, hence leading to more wind-induced mixing than usual.

Climate Indices

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Description of indices: Climate indices provide an alternative means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, PDO index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO) and Arctic Oscillation (AO). The time series of these indices from 2010 into spring/summer 2020 are plotted in Figure 6.

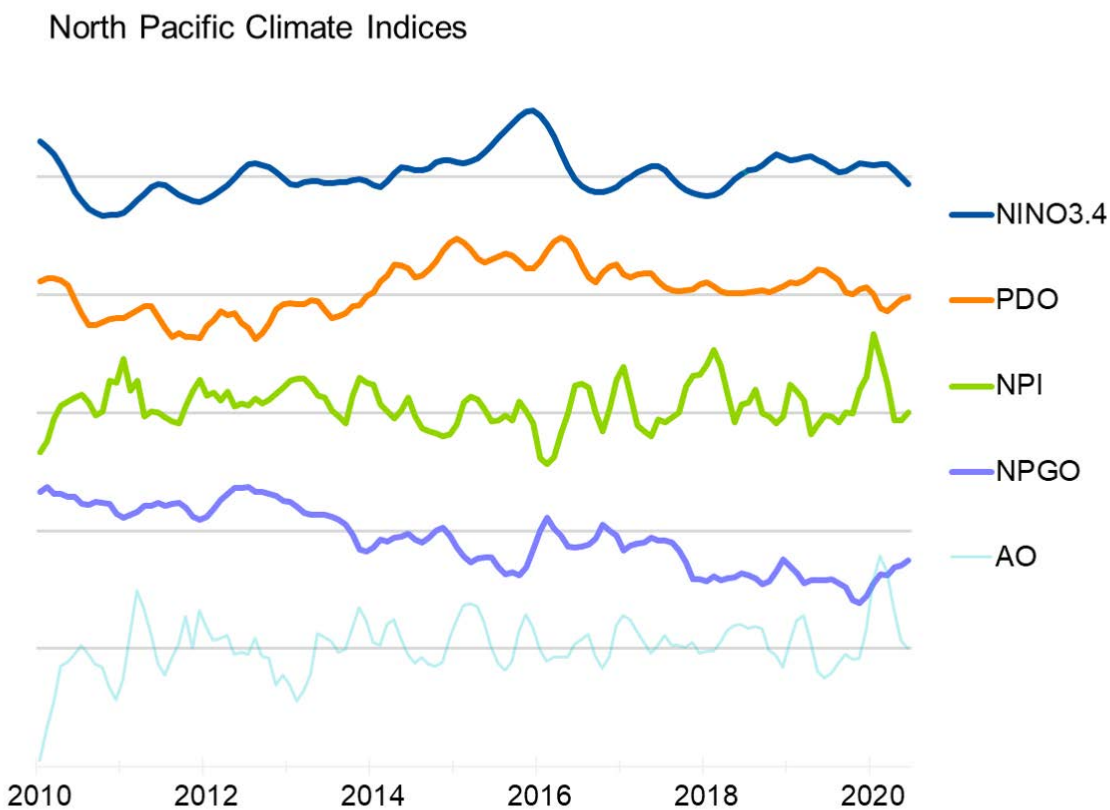

Figure 6: Time series of the NINO3.4 (blue), PDO (orange), NPI (green), NPGO (purple), and AO (turquoise) indices for 2010–2020. Bold lines (all but AO) are the most relevant of these indices for the GOA. Each time series represents monthly values that are normalized using a climatology based on the 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 was positive during 2019 through April 2020. Its magnitude was slightly above 0.5 from fall 2019 through early spring 2020, implying that equatorial Pacific ocean temperatures just reached the threshold NOAA uses to indicate El Niño conditions. It was the second boreal winter in a row meeting that threshold; it was somewhat weaker than its predecessor during the winter

2018–2019, and much weaker than the extreme event of 2015–2016. The PDO declined from a three-month average value of about +1 in summer 2019 to -0.7 in March 2020. This decline was associated with a combination of modest cooling along the west coast of North America and warming in the middle latitudes of the North Pacific west of the dateline, relative to seasonal norms. The latter region underwent cooling during the late spring and summer of 2020, resulting in an overall SST anomaly pattern that little resembles that of the PDO, and a near neutral value for that climate index. The NPI effectively represents the state of the Aleutian low, with negative (positive) values signifying relatively low (high) SLP. The NPI tended to be weakly negative during the summer of 2019 before entering a strongly positive phase during the winter of 2019–2020. This was especially the case in February 2020, during which the average SLP in the region used to specify the NPI (30–65 °N, 160 °E –140 °W) was the greatest for the month on record. The Aleutian low tends to be stronger, i.e., the NPI is negative, during El Niño. This is opposite to what occurred in the winter of 2019–2020, and to a lesser extent in the previous winter of 2018–2019. The NPI relaxed back to a near normal state in the summer of 2020.

The NPGO continued its multi-year decline from strongly positive in 2012 to strongly negative in the fall of 2019, with the extreme value of about -3 representing a record minimum for the period of record extending back to 1950. This index subsequently increased during the first half of 2020, but remained substantially negative. The negative sense of the NPGO generally includes warmer than normal upper ocean temperatures south of Alaska between 35 and 50 °N and is associated with high SLP over the GOA and low SLP in the vicinity and northeast of the Hawaiian Islands. 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. As for the NPI, early 2020 was highly unusual with a peak value of the AO approaching +4 standard deviations in terms of a seasonal (3-month) mean. This set-up helped bring about the coldest winter (Dec-Feb) for Alaska as a whole since 1998–1999, with mean temperatures on the order of 6 °C colder than those during 5 of the 6 winters immediately preceding. A marked decline in the AO occurred during the spring of 2020 to near neutral values in summer 2020.

Sea Surface Temperature and Sea Level Pressure Anomalies (North Pacific)

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Last updated: September 2020

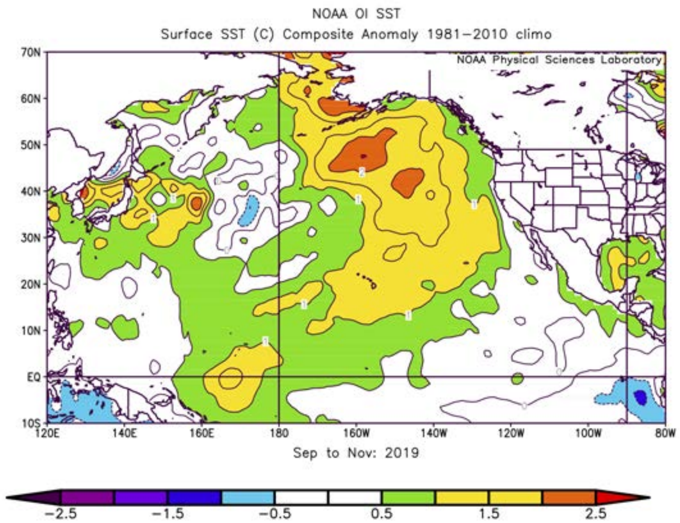
Description of indices: The state of the North Pacific climate from autumn 2019 through summer 2020 is summarized in terms of seasonal mean sea level pressure (SLP) and sea surface temperature (SST) anomaly maps. The SLP and SST anomalies are relative to mean conditions over the period of 1981–2010. The SLP data are from the NCEP/NCAR Reanalysis project; the SST data are from NOAA's Optimum Interpolation Sea Surface Temperature (OISST) analysis. Both data sets are made available by NOAA's Physical Sciences Laboratory (PSL) at `https://www.psl.noaa.gov/cgi-bin/data/composites/printpage.pl`.

Status and trends: The SST during the autumn of 2019 (Figure 7a) was warmer than normal for almost the entirety of the eastern North Pacific Ocean. Warm conditions also occurred in the western North Pacific between 30 and 45°N from the Korean Peninsula to 160°E. Especially prominent positive anomalies extended from the Chukchi Sea to a broad region between the Hawaiian Islands and the Pacific coast. The magnitude of the SST anomalies exceeded 2°C over much of the southeast Bering Sea shelf and south of the Gulf of Alaska (GOA). Warmer than normal but more moderate SSTs were present along the west coast of North America from California to the northern GOA. The lesser anomalies in this coastal strip are consistent with the upwelling-favorable wind anomalies discussed in the previous section. It is noted that temperatures at depth (roughly 100 to 250 meters) in the western GOA were considerably warmer than normal during autumn 2019 from a historical perspective (not shown). The equatorial Pacific had a patch of SST anomalies greater than 1°C just west of the dateline but otherwise near normal temperatures. The autumn 2020 SLP pattern (Figure 8a) during featured a positive anomaly center over the Gulf of Alaska (GOA), and negative anomalies from the Sea of Okhotsk to the eastern tip of Siberia. The southeasterly wind anomalies accompanying the GOA positive SLP anomaly contributed to the quite warm SST anomalies mentioned below; this SLP anomaly was also associated with upwelling-favorable wind anomalies in the northern and eastern GOA, continuing southward along the British Columbia coast.

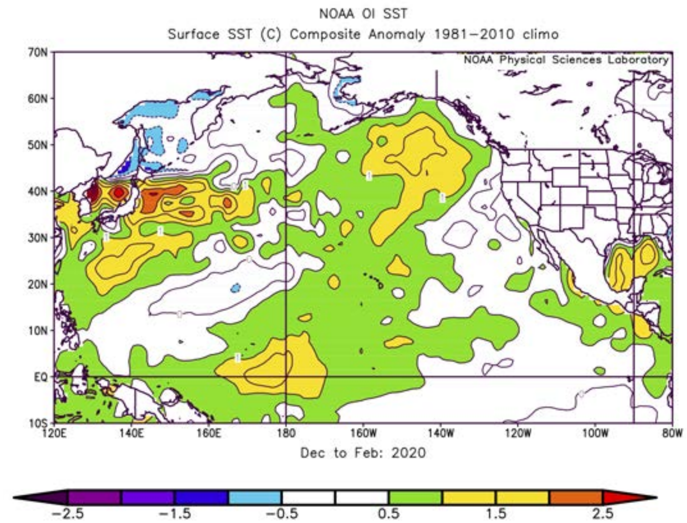
The distribution of SST anomalies during winter (Dec-Feb) of 2019-20 (Figure 7b), relative to the previous fall season, featured moderation in the magnitudes of the positive anomalies south of mainland Alaska, and considerable cooling on the southeast Bering Sea shelf. The latter conditions represent a marked contrast with the warm to extremely warm winters of that region during the 5 preceding years. The equatorial Pacific included a patch of SST anomalies slightly greater than +1°C near the dateline in association with a weak El Niño of the central Pacific or "Modoki" variety. The winter of 2020 featured a large SLP anomaly centered between the Hawaiian Islands and mainland Alaska (Figure 8b) with a peak value approaching 10 mb, which represents an anomaly of extreme magnitude. This pattern implies substantial suppression of the storminess between 30 and 50 °N across the North Pacific, especially east of the dateline. It also indicates wind anomalies from the west on the north side of the SLP anomaly center, particularly for the GOA, and hence anomalous equatorward Ekman transports for the upper ocean mixed layer in that region.

The spring (Mar-May) of 2020 included relatively warm SSTs throughout much of the North Pacific (Figure 7c). The water that was more than 1°C warmer than usual south of Alaska increased in area from the previous season. There was also a substantial increase in temperatures in the southeastern Bering Sea, relative to seasonal norms, accompanying a rapid retreat of sea ice driven by southerly wind anomalies. The coastal waters of western North America from the GOA to Northern California had near normal temperatures. The weak El Niño of the previous winter continued to fade, with some warmth remaining along the equator west of the dateline and near normal conditions in the east. Relatively high SLP continued to dominate the central and eastern North Pacific through spring 2020 (Figure 8c), with a positive anomaly center exceeding 8 mb located just south of the Alaska Peninsula. The circulation around this high SLP center brought anomalous winds with a component from the south over the eastern and northern Bering Sea. It also implies a continuation of westerly wind anomalies for the central GOA, and upwelling-favorable northwesterly wind anomalies for the coastal regions of the eastern GOA and British Columbia. The distribution of anomalous SLP resulted in modest wind anomalies from the southwest for much of the North Pacific west of the dateline.

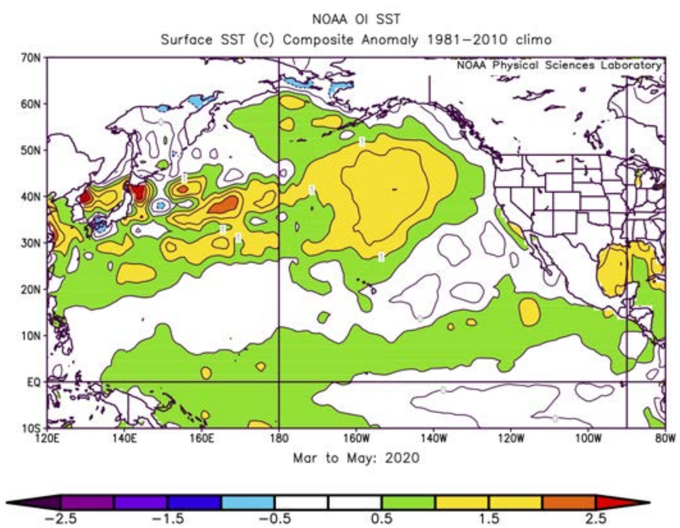
The large-scale SST anomaly pattern in the North Pacific during the summer (Jun-Aug) of 2020 (Figure 7d) featured mostly continued warmth east of the dateline between Alaska and the Hawaiian Islands. Cooling in an overall sense occurred west of the dateline, relative to the previous spring, with the development of negative anomalies from the western Aleutians to the entrance to the Sea of Okhotsk, and a diminishing of positive anomalies between about 30 and 45°N. Prominent warm anomalies on a smaller spatial scale developed on the southeast Bering Sea shelf and in the southeastern Chukchi Sea along the northwest coast of Alaska. Cold SSTs were present in the eastern equatorial Pacific, with the vestiges of the warm temperatures of the past winter and spring confined to the far western portion. The latter portion of this period featured the development of positive SST anomalies of substantial magnitude (1.5–2°C) in the central and western GOA. This warming was associated with wind anomalies from the north; this kind of flow in summer tends to bring relatively warm and dry air off of mainland Alaska over the water, resulting in enhanced warming during this time of year. The summer 2020 distribution of SLP anomalies across the North Pacific is shown in (Figure 8d). Low pressure occurred over the GOA with higher pressure to the south between Alaska and the Hawaiian Islands in a similar sense to that of the previous winter, but with much weaker magnitudes. The SLP over the western North Pacific was lower than normal north of about 35°N and higher than normal from northeast of the Philippines to east of Japan with peak anomaly magnitudes of 1–2 mb.



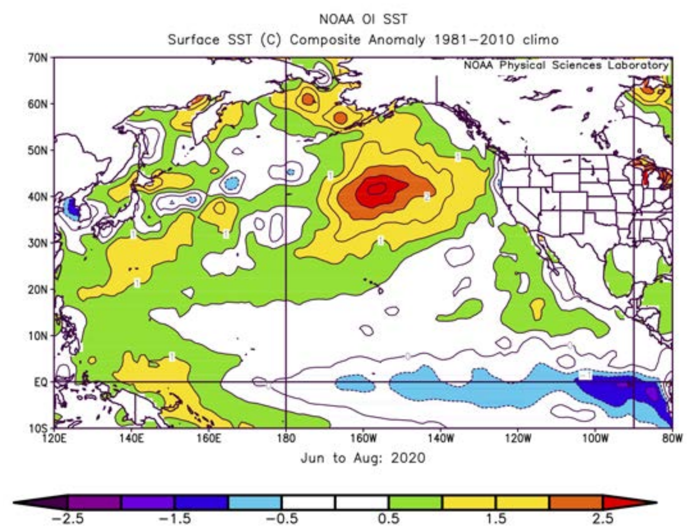
(a) Autumn



(b) Winter

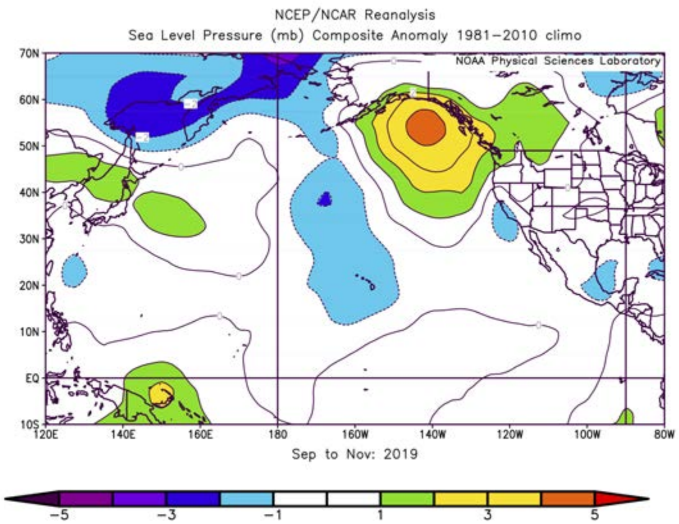


(c) Spring

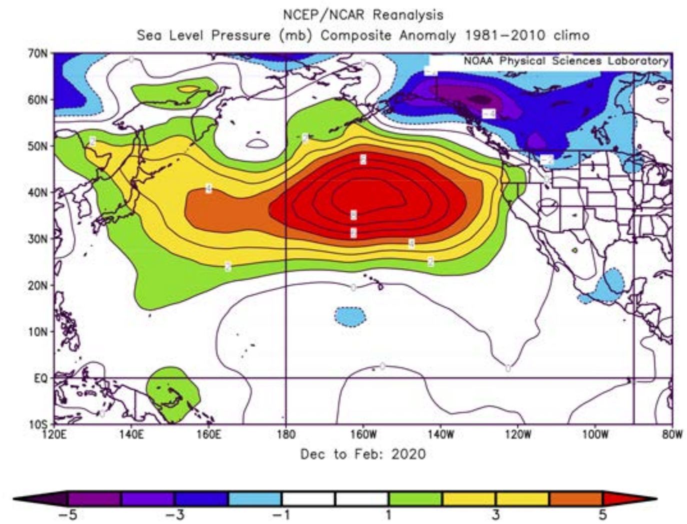


(d) Summer

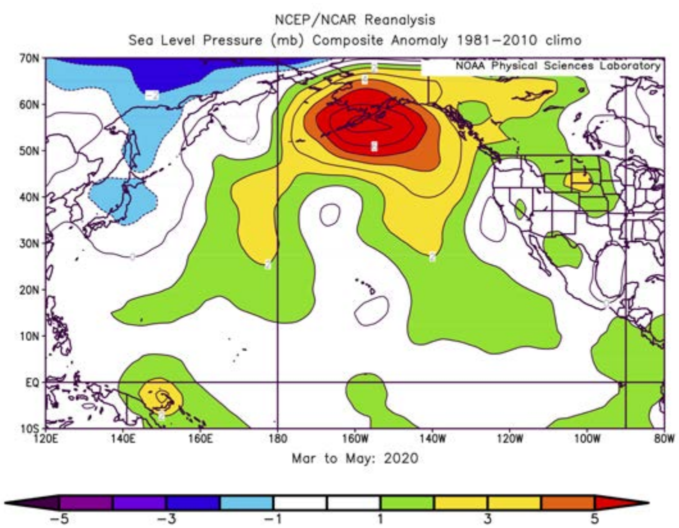
Figure 7: SST anomalies for autumn (September–November 2019), winter (December 2019–February 2020), spring (March–May 2020), and summer (June–August 2020).



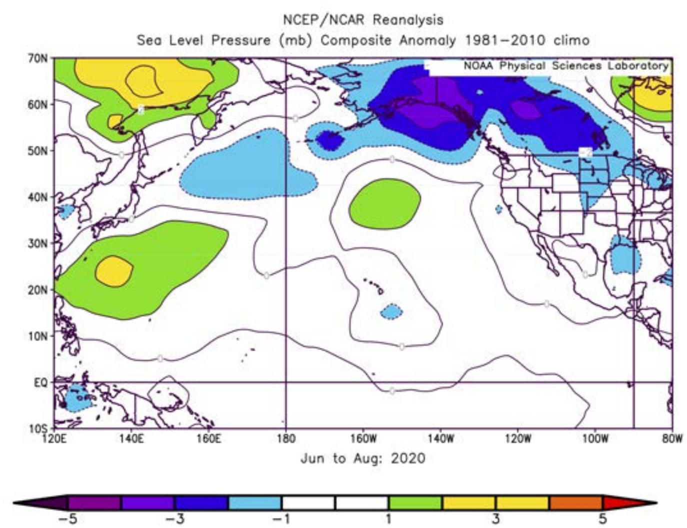
(a) Autumn



(b) Winter



(c) Spring



(d) Summer

Figure 8: SLP anomalies for autumn (September–November 2019), winter (December 2019–February 2020), spring (March–May 2020), and summer (June–August 2020).

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

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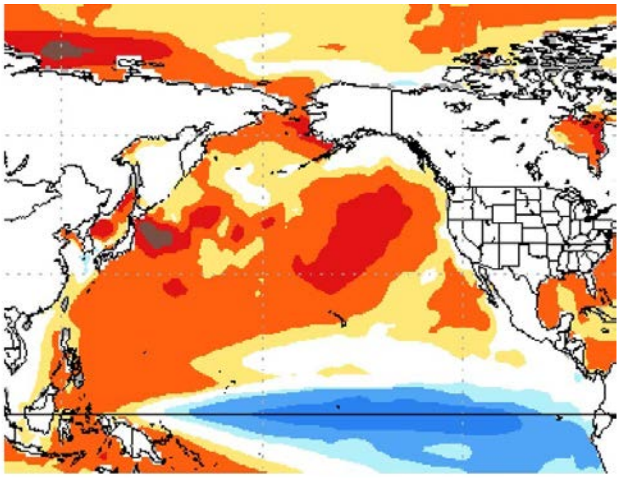
Last updated: September 2020

Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 9. 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/`.

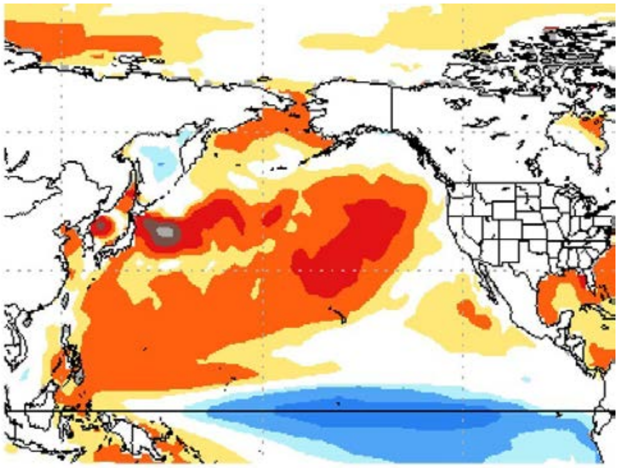
Status and trends: The projections from a year ago are first reviewed briefly. In general, the model forecasts from August 2019 for the following fall and winter indicated a continuation of positive SST anomalies south of Alaska and moderation of the initially warmer than normal conditions along the Alaska coast from the Alaska Peninsula to the SE Alaska panhandle. The sense of the evolution in the anomalies for the coastal waters of Alaska was generally correct, but for the models as a whole, the predictions indicated less cooling, relative to seasonal norms, than was actually observed. In addition, the models also predicted winter conditions that were somewhat warmer than observed for the Bering Sea shelf; the longer-term forecasts for late winter into spring were actually superior. Anomalies of weak to moderate magnitude were both forecast and the observed for the Aleutian Island region, with the model forecasts being too warm in the western portion. With regards to the tropical Pacific, the models failed to fully account for the weak central Pacific El Niño that was present in fall 2019 into early 2020, but did properly predict near neutral conditions in spring 2020. Qualitatively, this set of model projections does not appear to have quite as much overall skill as its counterparts in the previous 4 years, but again, at least the signs of the SST anomalies were forecast correctly for most locations through the period.

These NMME forecasts of three-month average SST anomalies indicate a continuation of a large region of relatively warm water between Alaska and the Hawaiian Islands through the end of the calendar year (Oct-Dec 2020; Figure 9a). Positive anomalies are also predicted for the entire Bering Sea and north of Bering Strait, with a peak value in the Chukchi Sea off the coast of northwest Alaska. The latter can probably be attributed to a predicted delay in the development of sea ice, which is highly plausible given the very low extent of sea ice in the central Arctic during the summer of 2020. The predictions also indicate warm SSTs for the Alaska Peninsula and Aleutian Islands. On the other hand, the coastal waters of the GOA are predicted to have near normal temperatures. A band of cold SST is projected in the tropical Pacific commensurate with that of a weak-moderate La Niña. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2019-February 2021 (Figure 9b) and February-April 2021 (Figure 9c) with mostly decreases in the magnitudes of the anomalies, especially on the eastern Bering Sea shelf. The near coastal waters of the GOA are forecast to become slightly cooler than normal.

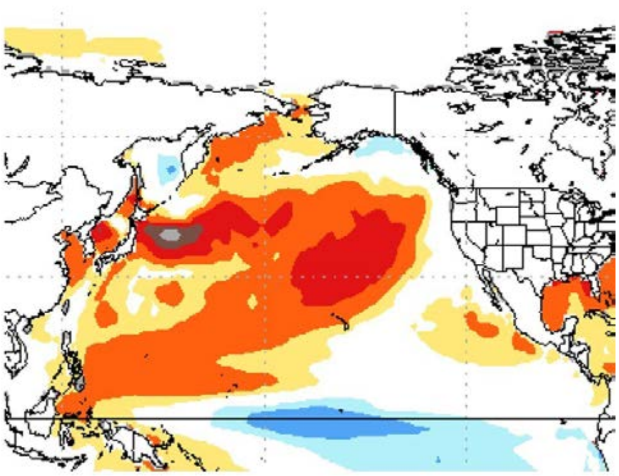
Implications: These changes are consistent with the atmospheric circulation anomalies being forecast for the North Pacific, which feature a weaker Aleutian low than usual, specifically, positive SLP anomalies south of the Alaska Peninsula. The SLP pattern being forecast is similar to that which was observed in the winter of 2019–2020 but of considerably weaker amplitude (not shown). La Niña does tend to be accompanied by atmospheric anomalies resembling those associated with the sets of predictions considered here, but it is still quite uncertain whether the perturbation in the tropical Pacific will be sufficient to yield a substantial response in the North Pacific. The model forecasts indicate a moderation in the cold conditions in the tropical Pacific by spring 2021. Coming out of the winter of 2020–2021, they suggest mostly near normal temperatures along the coast from British Columbia to the Alaska Peninsula, modestly warm conditions on the eastern Bering Sea shelf, i.e., a light but not extreme ice year, and slightly warm SSTs for the central and western Aleutian Islands.



(a) Months Oct–Nov–Dec



(b) Months Dec–Jan–Feb



(c) Months Feb–Mar–Apr

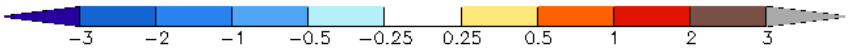


Figure 9: Predicted SST anomalies from the NMME model for Oct–Nov–Dec (1-month lead), Dec–Jan–Feb (3-month lead), and Feb–Mar–Apr (5-month lead) for the 2020–2021 season.

Satellite-derived Sea Surface Temperature and Marine Heatwaves in the Gulf of Alaska

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Last updated: September 2020

Description of indicator: Sea surface temperature is a foundational characteristic of the marine environment and temperature dynamics impact many biological processes. Changes in temperatures can influence physiological processes of fish (e.g., metabolic rates and growth rates), fish distribution (Yang et al., 2019), trophic interactions, availability of spawning habitat (Laurel and Rogers, 2020), and energetic value of prey. Extended periods of increased SST can lead to marine heat waves (Bond et al., 2015; Hobday et al., 2016). We describe trends in sea surface temperature throughout the Gulf of Alaska (GOA) ecosystem regions.

In recent years, warm water events have become so frequent in the world's oceans that a new method for describing them has been formalized. We consider marine heatwaves (MHWs) to occur when SST exceeds a particular threshold for five or more days. That threshold is the 90th percentile of temperatures for a particular day of the year based on a 30-year baseline (Hobday et al., 2016). The intensity of a MHW can be further characterized by examining the difference between the 90th percentile threshold for a given day and the baseline ("normal") temperature for that day. If the threshold is exceeded, the event is considered *moderate*, *strong* (2 times the difference between then threshold and normal), *severe* (3 times the difference between the threshold and normal), or *extreme* ($\leq$ 4 times the difference) (Hobday et al., 2018). The GOA experienced extended periods of marine heatwave conditions during the well-documented "warm lob" period (2014–2019) (Bond et al., 2015; Hu et al., 2017), and the recent 2019 marine heatwave year.

Satellite SST data from the NOAA Coral Reef Watch Program were accessed via the NOAA Coast Watch West Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html`) for April 1985 - September 2020. 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. Daily SST data were averaged within the western (144°W - 163°W) and eastern (133°W - 144°W) Gulf of Alaska (WGOA and EGOA, respectively) for depths from 10m – 200m (i.e., on the shelf). Detailed methods are online, including maps of the spatial strata and processing the data in R (`github.com/jordanwatson/EcosystemStatusReports/tree/master/SST`).

We use the earliest complete 30-year time series as the baseline period for mean and standard deviation comparisons although the guidance on such choice varies across studies (Hobday et al., 2018; Schlegel et al., 2019). Three notable differences exist between the current marine heatwave indicators and those previously presented to the North Pacific Fishery Management Council (detailed in Barbeaux et al. (2020)). First, the current indicator uses a different NOAA SST dataset, with a slightly different time period (beginning mid-1985 instead of mid-1982) and spatial resolution (the current indicator has finer spatial resolution and thus, more data points within the same region). Given the shorter time series, the 30-year baseline period is necessarily different (1986–2015 instead of the previous 1983–2012). Finally, the previous indicator was bounded spatially to target management of Pacific cod in the GOA, whereas the current indicator is bounded spatially by the ESR regions for a broader comparison.

Status and trends: In the WGOA, cooler late winter and spring temperatures in 2020 were similar to the long term average SST, departing from the warm 2019 conditions (Figure 10). However, starting in May, temperatures warmed and remained above average throughout the summer (yet generally below the 2019 summer SST). At some points during the summer, the SST was among the warmest temperatures recorded for those dates. SST cooled to approximately average or slightly greater than average values in September. In the EGOA, temperatures were consistently more similar to the long term mean SST, departing from the warm temperatures of 2019 and suggesting more of a return to average conditions.

As a whole, 2020 has been closer to average than several recent years, though some of those recent years

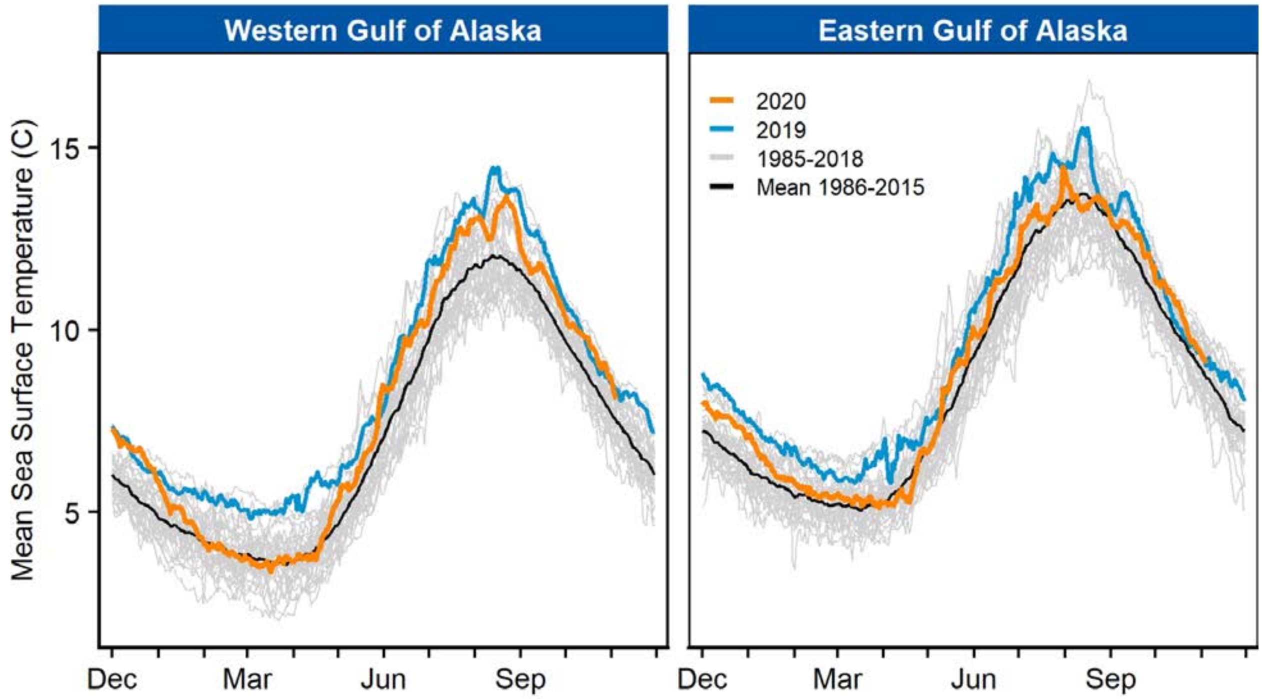

Figure 10: Seasonal sea surface temperatures (SST) for Gulf of Alaska ecosystem regions. Lines illustrate the 2020 SST through Oct. 4 (orange), 2019 SST (blue), 30-year mean SST (black), and each of the 1985–2018 SST (gray) time series.

were among the warmest on record with MHWs standing out on a global scale (Bond et al., 2015; Holbrook et al., 2019). Despite appearing more average this year (Figure 11), the western GOA still experienced more than 100 days of heatwave conditions from December 2019 - November 2020. This is a substantial reduction from the 2019 heatwave year, with persistent and intense heatwave conditions, but greater than 2017 and 2018 (Figure 12).

Factors influencing observed trends: The time period illustrated here includes recent 2019 marine heatwave year (starting in the fall of 2018), through to current conditions. In 2020 northerly winds brought relatively warm and dry air off mainland Alaska, contributing to warmer summer SST in the WGOA summer (see Bond 2020, p.30). Westerly winds drove eastward and southward surface transport in EGOA, creating upwelling conditions and contributing to moderate sea surface temperatures in that region (see Bond 2020, p.32, and Stockhausen, p.51).

Many factors can influence sea surface temperatures and the formation of MHWs, including a suite of weather, climatic, and oceanographic factors (Holbrook et al., 2019). Meanwhile, defining or contextualizing heatwaves depends upon the selection of baseline years (1986–2015). As long term climate change leads to warmer temperatures, the baseline used to define 'normal' will change as well, requiring consideration of how baseline selection affects our interpretation of deviations from normal and thus, events like MHWs (Jacox, 2019; Schlegel et al., 2019). The warm years of 2014 and 2015 have a warming influence on the definition of the climate 'normal' used here for MHWs and thus, would raise the threshold for triggering a MHW. If the baseline period had included the most recent 30-year period, then each of the warm years since 2015 would be included in the baseline as well, leading to an even higher threshold for triggering a MHW.

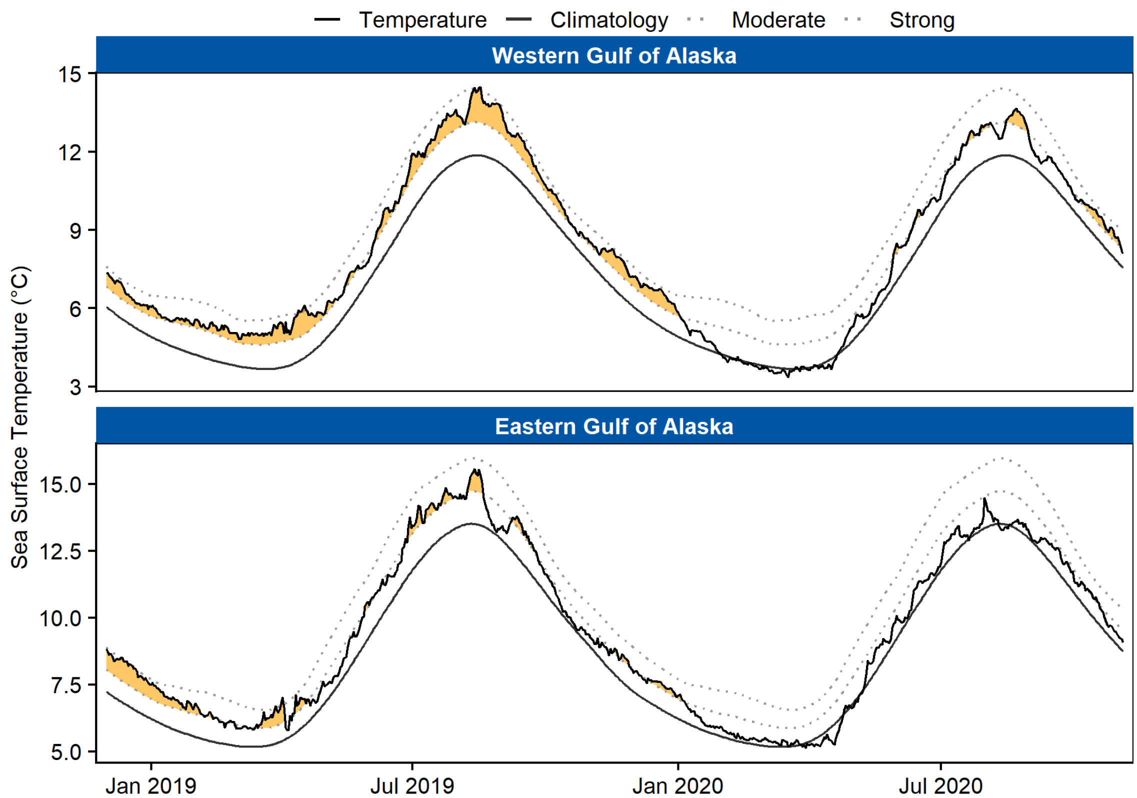

Figure 11: Marine heatwave (MHW) status from Dec. 2018 through Oct. 2020. Filled (yellow) areas depict MHW events. Black lines represent the 30-year baseline (smoothed line) and observed daily sea surface temperatures (jagged line). Faint grey dotted lines illustrate the MHW severity thresholds in increasing order (moderate and strong).

Implications: Barbeaux et al. (2020) provide tangible evidence for the potential implications of warming conditions on groundfish, in particular Pacific cod. Holsman et al. (2020) further emphasize the risk of warming conditions on gadid populations but highlight the value of an ecosystem-based management approach for buffering the impacts of projected temperature increases and more frequent marine heat waves. The approximately average 2020 winter and spring SST values across GOA, and summer SST in EGOA, provide improved conditions over 2019 for spawning, zooplankton quality and quantity, and fish metabolic demands. While the WGOA summer SST was oscillating around the heat wave threshold, the duration and intensity of warm temperatures does not equate to previous heatwave years and it is uncertain how and if the warmth in 2020 will impact the marine environment.

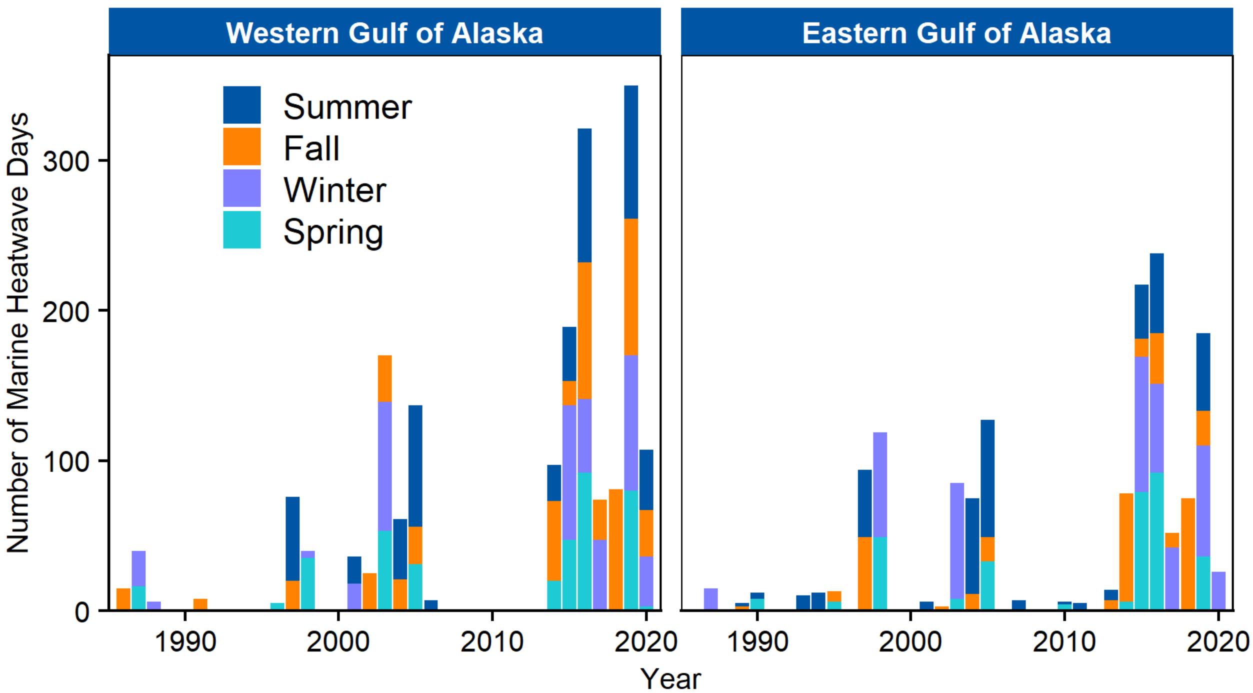

Figure 12: Number of days during which marine heatwave conditions persisted in a given year. Seasons are summer (Jun - Aug), fall (Sept – Nov), winter (Dec – Feb), spring (Mar – Jun). Years are shifted to include complete seasons so December of a calendar year is grouped with the following year to aggregate winter data (e.g., Dec 2019 occurs with winter of 2020).

Surface Temperatures in Auke Creek, Icy Strait, and Prince William Sound

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Last updated: September 2020

Description of Indicator: Ocean temperature can vary sub-regionally, due to differences in circulation, freshwater runoff, wind-driven mixing, and other oceanographic drivers (Bograd et al., 2005). Local temperatures can influence survival or condition of important species during critical life history periods, such as salmon in the inside waters of southeast Alaska. This section presents a collection of sub-regional ocean and freshwater surface temperature datasets from Auke Creek (SEAK), Prince William Sound, and Icy Strait (SEAK).

Auke Creek: 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. 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.

Icy Strait: Temperature has been collected annually in Icy Strait during monthly (May to August) fisheries oceanography surveys conducted by the Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories, AFSC. The Icy Strait Temperature Index (ISTI, °C) is the average temperature of the upper 20 m integrated water column. *Prince William Sound:* 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 (`http://gulfwatchalaska.org`) projects conducted by the PWS Science Center, UAF, and NOAA.

Status and Trends:
Auke Creek: 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 10.4°C from 1980–2019. The average temperature for 2019 was 11.7°C and 10°C for 2020 (Figure 13). 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). This lack of snowfall, and subsequent lack of snowmelt, contribute to warmer creek temperatures earlier in the year.

Icy Strait: 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 13). The ISTI in 2019 was well-above average (10.0°C), the third warmest in the 23 year time series (aftern 2005 and 2016). The ISTI in 2020 returned to just above average.

Prince William Sound: SST has been increasing in central PWS for the last four decades, at approximately 0.09°C per decade (Figure 13), although there is substantial year-to-year variability. In 2013, anomalies shifted towards strongly positive, and have for the most part stayed that way except for a brief dip in 2018, which reflects basin-scale marine heatwaves that have been noted throughout the Gulf of Alaska in 2013–2015 (Bond et al., 2015) and 2019 (Amaya et al., 2020). Temperature in PWS remained elevated for about 1 year longer than was observed offshore, which is typical. 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 2013–2014 a prolonged period of calm winter weather occurred where heat was not mixed out of the surface layer in winter as it usually is (Bond et al., 2015). In 2019 a period of calm weather allowed greater heat fluxes into the surface layer (Amaya et al., 2020). 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.,

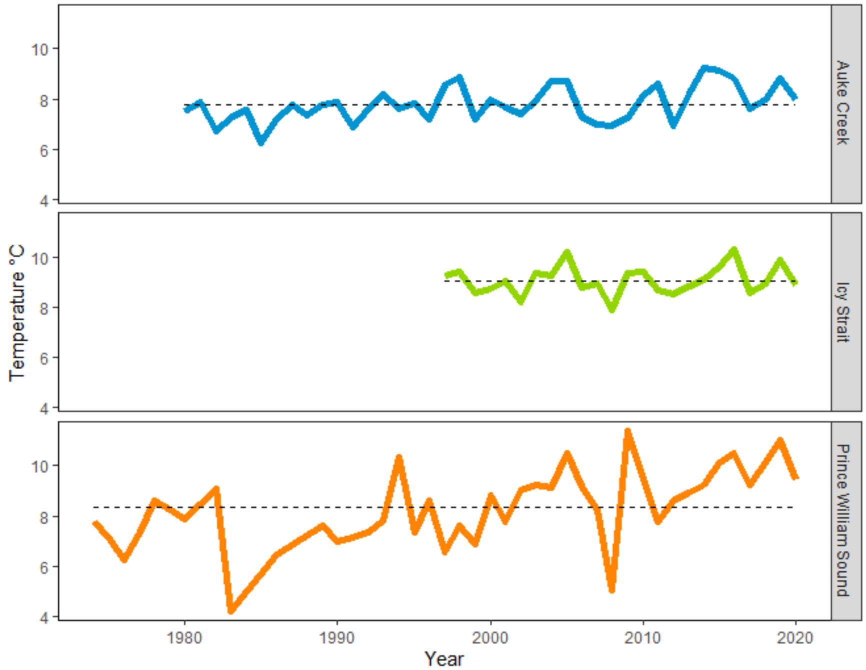

Figure 13: From top to bottom: **Auke Creek (Top):** Average temperature (°C) by months of operation for 1980–2020. Dashed line is the long-term mean. **Icy Strait (Middle):** Mean annual Icy Strait Temperature Index (ISTI, °C, 20 m integrated water column, May-August), for the northern region of SEAK from the Southeast Coastal Monitoring project time series, 1997–2020. Dashed line is the long-term mean.**Prince William Sound (Bottom):** Near surface (2 m) annual temperature (°C) in central Prince William Sound, 1974–2020. Dashed line is the long-term mean.

2010). Temperatures in 2020 decreased from the previous year to approximately 2018 and 2014 levels.

Implications:
Auke Creek: These changes in stream conditions and climate have been shown to affect 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 impact groundfish and salmon productivity, as juvenile salmon serve as an important food source (Landingham et al., 1998; Sturdevant et al., 2009, 2012). 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).

Prince William Sound & Icy Strait: Sea surface temperature in Prince William Sound and Icy Strait reflect conditions separate from the broader Gulf of Alaska shelf, although temperatures in PWS generally track those of the Gulf of Alaska with a 1 year lag. Both regions support numerous forage species (e.g., herring, juvenile salmon), groundfish, salmon, marine mammals (e.g., humback whales) and seabirds. Icy Strait is a principle migration corridor for juvenile and returning salmon and temperature can influence the species composition of the zooplankton community affecting prey quality and availability (i.e., warmer temperatures can be associated with smaller zooplankton species with lower lipid densities).

Watershed Dynamics in the Auke Creek System, Southeast Alaska

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Last updated: September 2020

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. Creek temperature is reported in the Regional Surface Temperature contribution (page 30). 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. Fifteen years of creek height data (2006–2020). This variables provide a valuable addition to the fisheries data collected at the Auke Creek Research Station.

Status and trends: From 2006–2019, average yearly creek height varied from 21.4 ft to 21.9 ft, with an overall average of 21.7 ft (Figure 14). The average gauge height for 2019 was 21.4 ft and 21.8 ft for 2020. Creek temperature is reported in the Regional Surface Temperature contribution (page 30).

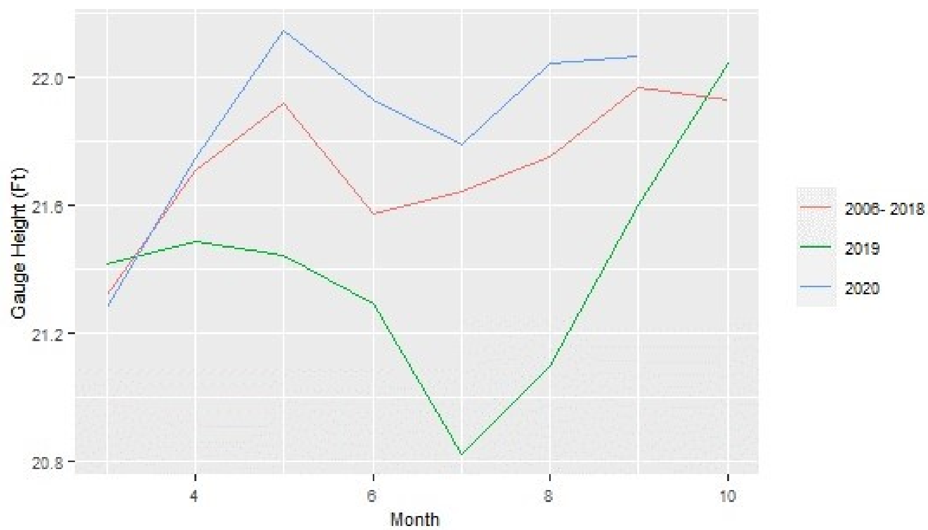

Figure 14: Auke Creek average temperature by months of operation for 1980-2018, 2019, and 2020 (top panel). Auke Creek average gauge height by months of operation for 2006-2018, 2019, and 2020 (bottom panel).

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 14).

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). 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).

Seward Line May Temperatures

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Last updated: September 2020

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. The water column profile data analyzed here have 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 northernmost station, GAK1 has been occupied for nearly 50 years, show long-term warming and surface freshening of the Gulf of Alaska Coastal Current (see Danielson, p.47, for details). The Seward Line data (Figure 15) 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). After a warm spring in 2019, May 2020 was at the long-term mean of the past 23 years, although offshore waters below 100 m were somewhat warmer than average in May, July, and September (Figure 16).

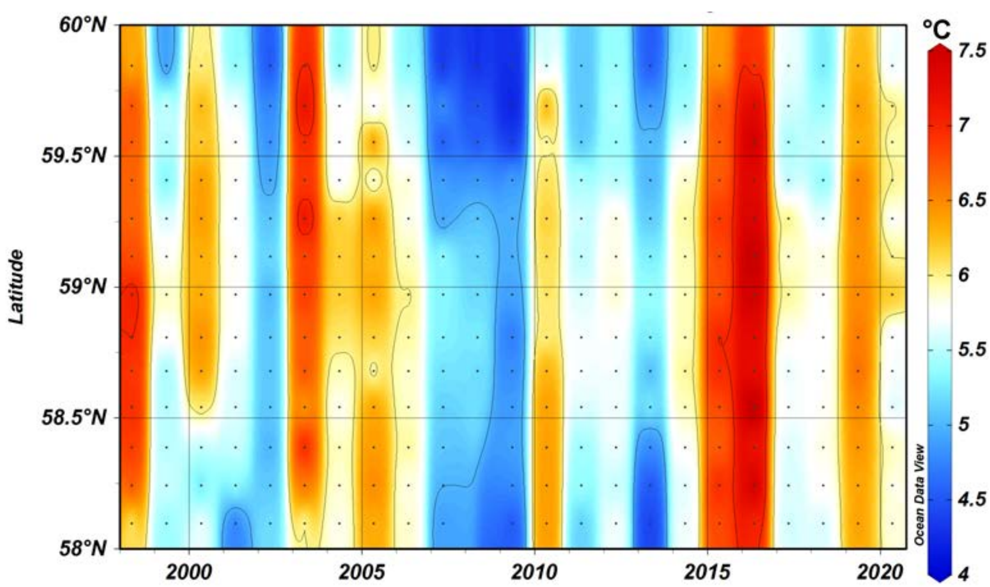

Figure 15: May sea temperatures averaged over the top 100m along the Seward Line in the northern Gulf of Alaska, 1998–2020.

Factors influencing observed trends: Warm years are often associated with El Niño events (1998, 2003, and 2016) and other marine heatwaves (2015, 2019). Cool conditions observed are often related to complex winter balances between heat loss, coastal runoff and stratification (Janout et al., 2010).

Implications: Biological observations for 2020 are still under analysis; however, they do not have appear to have been subjected to a significantly anomalous physical environment. Residual heat at depth may signify lagged responses to previous warm years in the marine ecosystem.

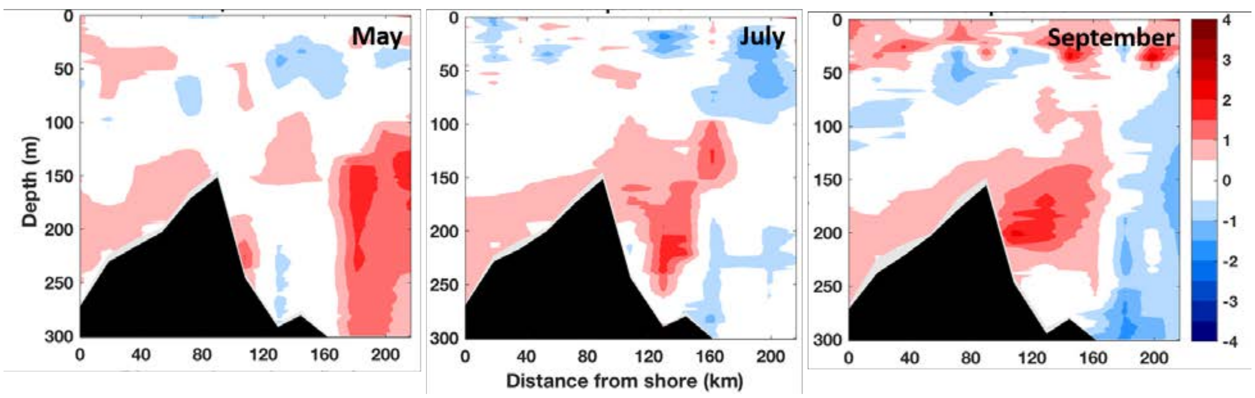

Figure 16: Temperature profiles shown as normalized anomalies (month standard deviation = 1) from surface to 300m depth along the Seward Line (northern Gulf of Alaska) in May, July, and September 2020.

Oceanographic Station GAK1 Water Column Conditions

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Last updated: September 2020

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 1970–2020 long-term mean since early 2014 (Figure 17). 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 (Table 2).

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)	1970–2020	0–50	429	0.243 +/- 0.058	0.14	1.3E-15
Temperature (°C)	1970–2020	200–250	427	0.177 +/- 0.034	0.20	7.05E-22
Salinity	1970–2020	0–50	429	-0.056 +/- 0.03	0.030	2.84E-04
Salinity	1970–2020	200–250	427	0.036 +/- 0.017	0.040	2.35E-05

Factors influencing observed trends: The long-term 1970–2020 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. Near-bottom temperatures exert strong control over northern rock sole growth, size and phenology patterns (Fedewa et al., 2015). There is a long-term decoupling of near-surface and near-bottom waters through increased stratification (Kelly, 2015) with implications for nutrient resupply to the euphotic zone and long-term changes in shelf productivity. 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, 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.

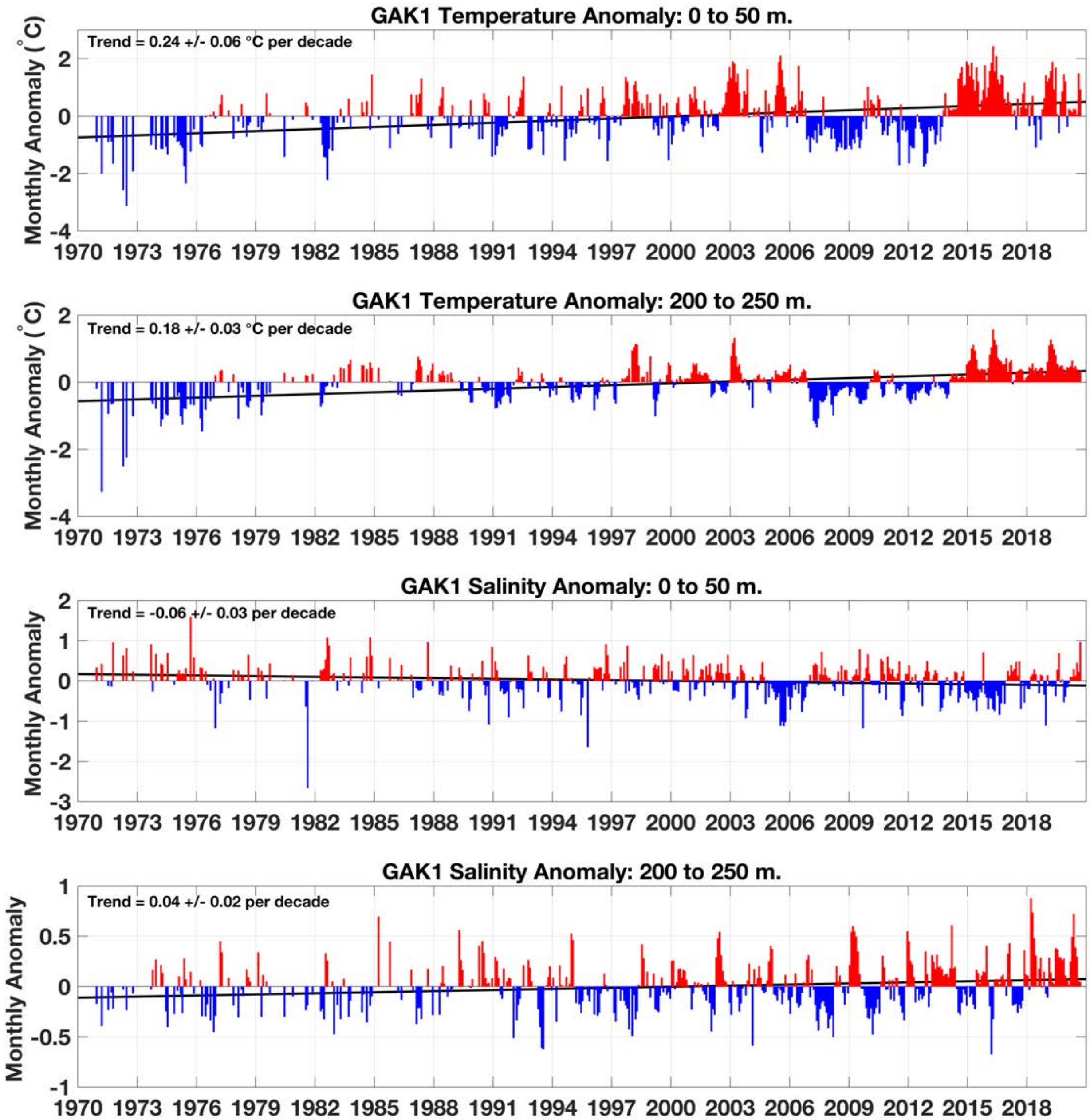

Figure 17: GAK1 monthly anomaly time series for the 1970–2020. Temperature (upper two panels) and salinity (lower two panels) anomalies represent averages over the uppermost and lowermost 50 m of the water column. The data exhibit a long-term trend in warming punctuated by signals associated with the 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.

Eddies in the Gulf of Alaska

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Last updated: August 2020

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), and ichthyoplankton (Atwood et al., 2010). In addition, the settlement success of arrowtooth flounder (Goldstein et al., 2020), the feeding environment for juvenile pink salmon (Siwicke et al., 2019), and the foraging patterns of fur seals (Ream et al., 2005) can be influenced by the presence of eddies. 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 18; 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 18). 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 19).

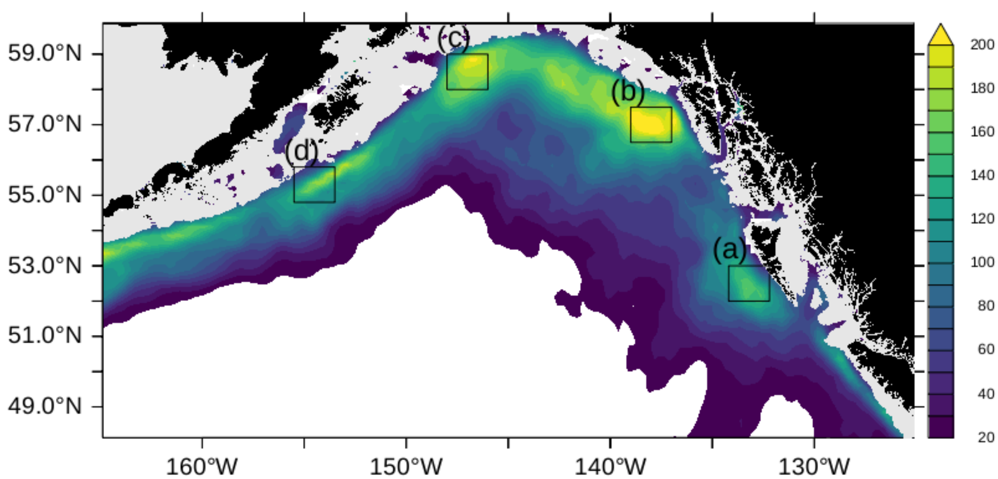

Figure 18: Eddy Kinetic Energy (cm^2 s^{-2}) averaged over January 1993–December 2019 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 19.

Status and trends: The seasonal cycle of EKE averaged over the two regions (c and d) are out

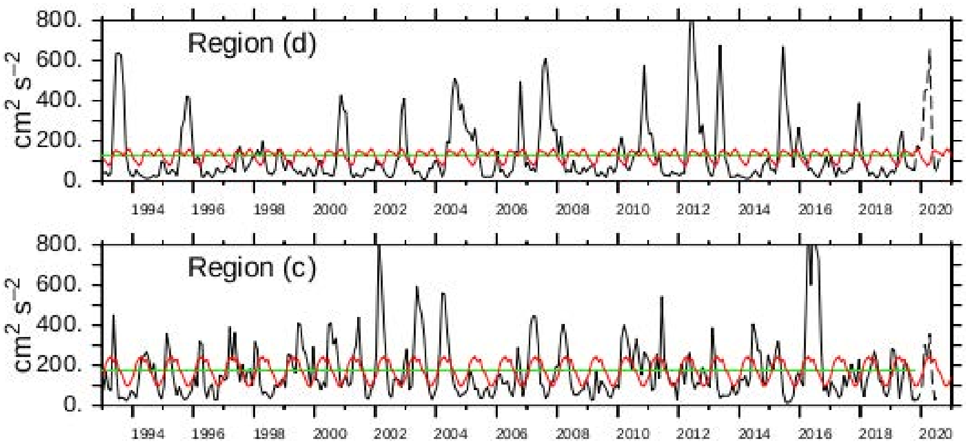

Figure 19: Eddy kinetic energy (cm^2 s^{-2}) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 18. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product), Red: seasonal cycle. Green (straight line): mean over entire time series.

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 suggest that EKE was quite high in region (d) in spring 2020 due to a strong, persistent eddy in the region. By June, the eddy had moved westward out of region (d). EKE was slightly higher than average in region (c) in spring 2020. Both regions dropped below average by summer 2020.

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: The eddy in region (d) during spring 2020 may have resulted in higher phytoplankton biomass in the off-shelf region compare to spring during years when no eddy is present. It may also have enhanced settlement success for arrowtooth flounder (Goldstein et al., 2020). Similar effects may have resulted from eddies in 2007, 2010, 2012, 2013 and 2015 (region (d)) and 2016 (region (c)). In addition, cross-shelf transport of heat, salinity, and nutrients may have been stronger in spring 2020 than in years without 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)

Ocean Surface Currents—Papa Trajectory Index

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Last updated: August 2020

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 20). 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 2019 (trajectory endpoints years 1902–2020).

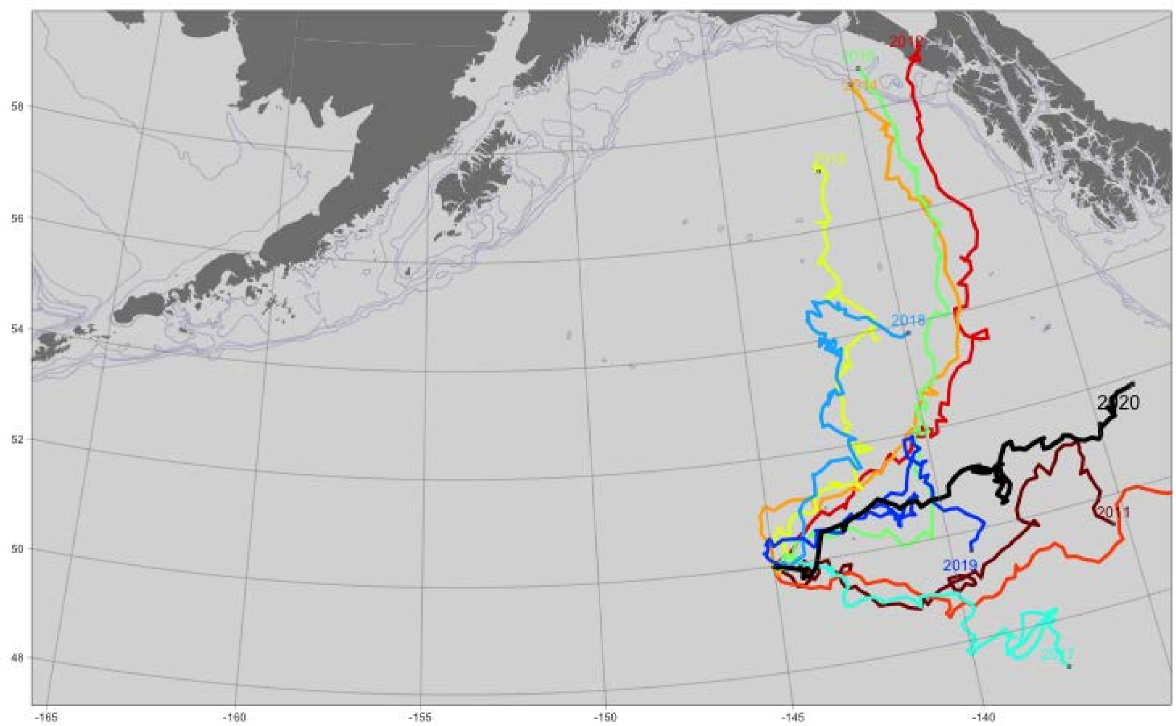

Figure 20: Simulated surface drifter trajectories for winters 2011–2020 (endpoint year). End points of 90-day trajectories for simulated surface drifters released on Dec. 1 of the previous year at Ocean Station Papa are labeled with the year of the endpoint (50°N, 145°W).Note the brown line is 2010/2011, the orange line is 2012/2013, the pale blue southernmost line is 2017/2018, and the black line is 2020.

Status and trends: The 2019/20 trajectory extended further to the east than normal (similar to that from 2012/13), driven by surface winds associated with a longitudinal ridge of high pressure centered off the west coast in February (Figure 20). This eastward and less northerly trajectory falls in a similar group of years, including 2019, 2017, 2013, and 2011.

The 2011/12 trajectory followed the general northeastward path of most drifters, but was notable because its ending latitude was the northernmost of all trajectories since 1994 (Figure 21). 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 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 a "Blob" of warm surface waters along the eastern Pacific coast and the return of the Pacfic 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 drove strong northerly winds that pushed the drifter trajectory to its most southerly latitude since the late 1930s (Figure 21). 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.

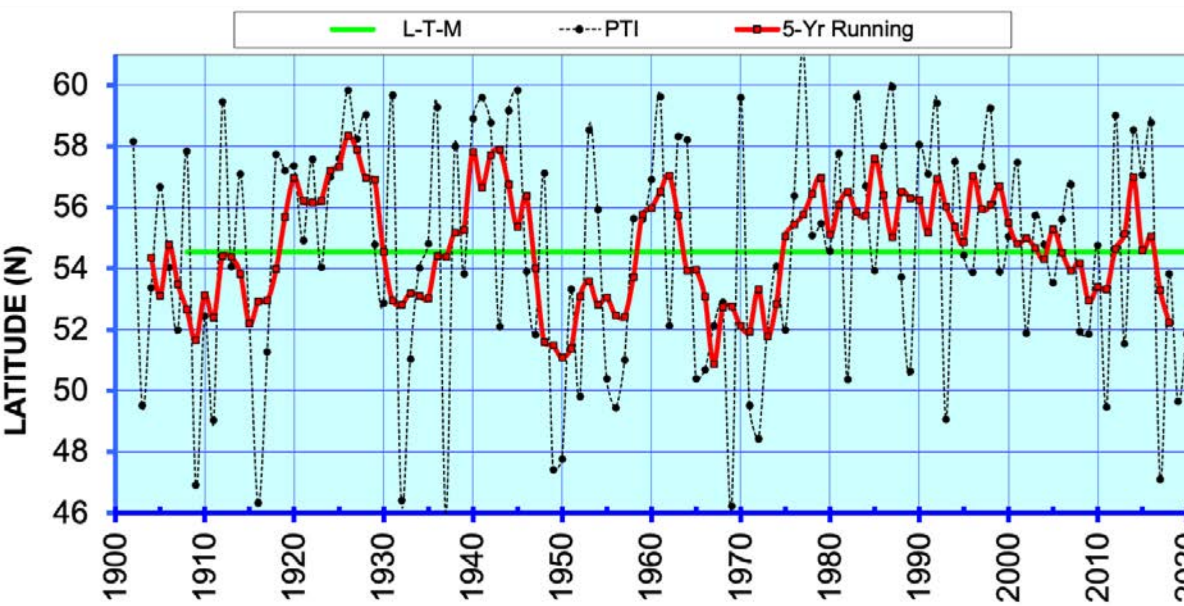

Figure 21: Annual, long-term mean (green line), and 5-year running mean (red line and squares) of the Papa Trajectory Index time series end-point latitudes (dotted black line and points) for 1902–2020 winters.

Over the past century, the filtered (5-year running average) PTI has undergone four complete oscillations with distinct crossings of the mean (one oscillation equals starting at the mean, completely crossing the mean, and returning to the mean), although the durations of the oscillations were not identical: 26 years (1904–1930), 17 years (1930–1947), 17 years (1947–1964), 41 years (1964–2005), and 10 years (2005-2015). The filtered index indicates that a shift occurred in the mid 2000s to predominantly southerly anomalous flow following a ∼25 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. A similar shift back to anomalous southerly flow appears to have occurred in 2016. Since 2005, the PTI appears to be fluctuating on a much shorter time scale (∼10 years per mean crossing) than previously.

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.

Implications: 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).

Surface Wind in the Coastal Western Gulf of Alaska during April - May

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Last updated: October 2020

Description of indicator: Surface wind is fundamental to the oceanography, hydrography, biology and ecology of the Gulf of Alaska ecosystem. As a driver of coastal circulation, surface wind affects upwelling/downwelling, turbulent mixing (e.g., mixed layer depth), and transport of planktonic organisms including zooplankton and ichthyoplankton. Its relevance to regional groundfish production in the Gulf is illustrated by studies of wind-driven turbulent mixing on walleye pollock larvae (Porter et al., 2005) and of wind-driven transport on juveniles and recruitment (Wilson and Laman, 2020).

Two complementary datasets were used here to indicate springtime (April – May) surface wind in the coastal Gulf. We focus on spring to coincide with the seasonal occurrence of many groundfish larvae. The first dataset consists of high-resolution empirical measurements recorded by the National Data Buoy Center (NDBC) at site AMAA2. We chose AMAA2 as its location might be considered a gateway of sorts where winds determine whether coastal flow either funnels into and down Shelikof Strait along the Alaska Peninsula or is diverted southward around Kodiak Island as demonstrated by Ladd and Cheng (2016). This bifurcation is a prominent feature in the circulation dynamics of the western Gulf. Springtime measurements at AMAA2 are currently available for 14 years: 2004 to present, except 2007, 2008, and 2018. Measurements were recorded hourly during 2004 and at 30 min intervals during other years (see `https://www.ndbc.noaa.gov/` for data and additional methods detail). The second dataset consists of lower-resolution, model-based data from the National Centers for Environmental Prediction (NCEP) (Kalnay et al., 1996). The NCEP data are averages by month and year from 1948–2020. We specified the geographic area to be 55 – 60°N latitude and 150 – 160°W longitude (see `https://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl` for data and additional methods detail).

For both datasets, NDBC-AMAA2 and NCEP, wind was expressed as the components u (+u is wind blowing to the east, "westerly" wind) and v (+v is northward wind, "southerly" wind). Correlation of annual means (n=13) between the two datasets was r=0.67 for the u component, and r=0.77 for the v component. The NDBC-AMAA2 data are used to construct progressive wind diagrams; conceptually, these can be thought of as a progression through time of the hypothetical displacement from AMAA2 station during any given year (Wilson and Laman, 2020).

Status and trends: The progressive wind diagram, or hypothetical displacement, at NDBC-site AMAA2 was toward the southwest during spring 2020 (Figure 22). This was similar in direction to the trajectories for 2017 and 2012, which were relatively far southwestward. Although similar to 2019, that trajectory suffered from missing two weeks of data during April (not labeled in Figure 22). In contrast, the trajectories for 2015 and 2016 were northwestward and westward, respectively, while the trajectory for 2013 was strongly southward.

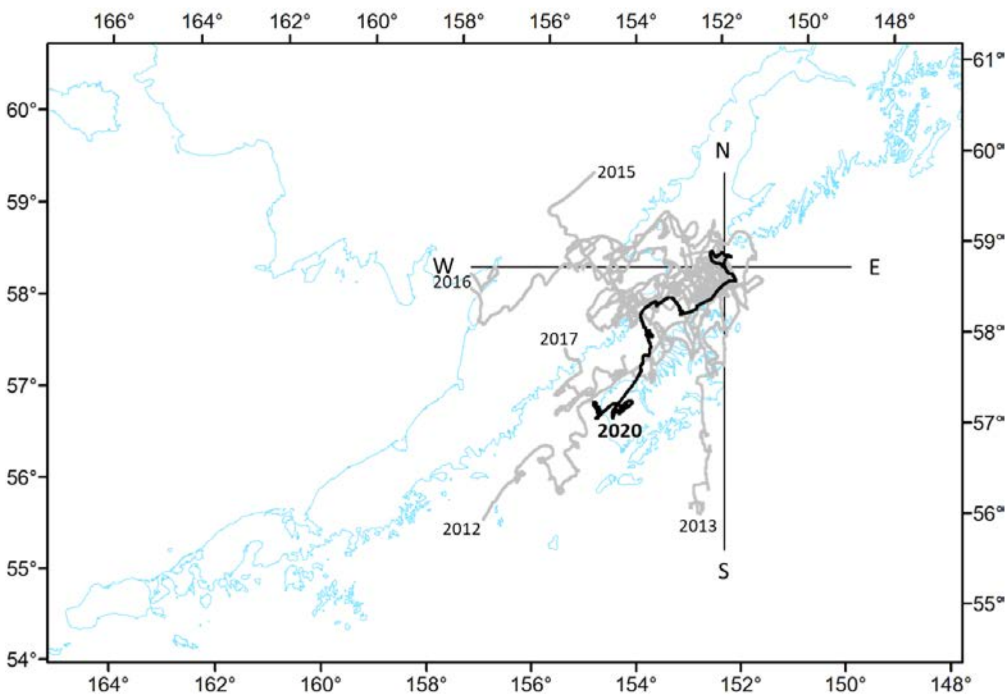

Figure 22: Progressive wind diagrams from NDBC-AMAA2 for spring (April–May) 2004–2020 (except 2007, 2008, and 2018). Select individual trajectory endpoints are labeled by year. The diagram is superimposed on the Alaska coastline with the origin centered on the location of the AMAA2 site. *Note, the scale of distance differs between the trajectories and the coastline.*

The lower-resolution NCEP winds also indicated similarity in direction and magnitude during recent years with mean wind toward the northwest (Figure 23). This contrasts with the period 2000–2014 when means indicate relatively strong southward wind.

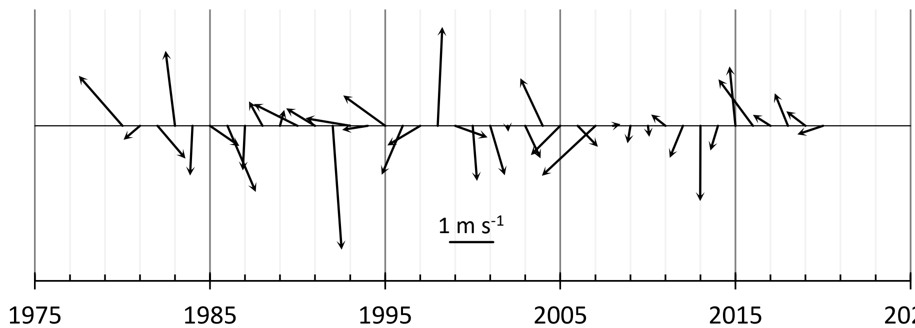

Figure 23: Mean wind from NCEP for spring (April – May) 1980–2020. Each "stick" represents the magnitude (y-axis) and direction (e.g., northward is up, eastward is to the right) toward which the wind is blowing during each year.

Factors influencing observed trends: In the Gulf, winds are dominated by cyclonic storm systems that exhibit pronounced seasonality (Stabeno et al., 2004). During spring, cyclonic winds begin to moderate and anticyclonic winds can drive intermittent upwelling. While the Aleutian Low influences wintertime conditions and the El Nino-Southern Oscillation can affect conditions in the Gulf at multi-year intervals, factors influencing the coastal environment are complicated by numerous coastal mountains. Local terrain effects can lead to "gap" winds that profoundly affect oceanographic processes. For example, the strong northerly winds during 2013 were locally intensified at AMAA2 by orographic gaps in the Alaska Peninsula (Ladd and Cheng, 2016). We specifically chose the AMAA2 site to indicate winds at a point where they are likely to affect the bifurcation of coastal flow. Interestingly, the strong northerly wind in 2013 agreed between the two datasets; however, the disparity between the datasets in other years might reflect the difference in spatial representation and location.

Implications: Wind speed and direction greatly influences coastal circulation in the Gulf at multiple scales. At small scales, wind-driven turbulence has implications for vertical stratification of the water column, and the patchiness and vertical distribution of plankton, including fish larvae. At larger scales, wind can determine the occurrence of upwelling and downwelling with consequent effects on vertical circulation and transport. At large scales, wind-driven transport influences the life history strategy of organisms, and the variation in transport has long been hypothesized to affect the replenishment of adult fish and shellfish stocks by transporting larvae to favorable or unfavorable habitat. For walleye pollock, the period April-May is particularly important because that is when the eggs and larvae are in the water column and subject to wind-driven transport. In fact, when the AMAA2 wind trajectories for this period (Apr-May) are toward the southwest (down Shelikof Strait), estimates of age-1 abundance tend to increase presumably because downwelling-favorable northeasterly winds enhance retention of larvae (Stabeno et al., 1996, 2004) and juveniles in areas that favor survival (Wilson and Laman, 2020).

Habitat

Intertidal Ecosystem Indicators in the Northern Gulf of Alaska

Contributed by Heather Coletti[1], James Bodkin, Thomas Dean, Daniel Esler, Katrin Iken, Brenda Ballachey, Kim Kloecker, Brenda Konar, Mandy Lindeberg, Daniel Monson, Brian Robinson, Robert Suryan, Ben Weitzman
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Last updated: September 2020

Description of indicator: Nearshore monitoring in the Gulf of Alaska (GOA) provides ongoing evaluation of status and trends of more than 200 species associated with intertidal and shallow subtidal habitats. The spatial extent of sampling includes 21 sites distributed across the northern GOA from western Prince William Sound (WPWS), Kenai Fjords National Park (KEFJ), Kachemak Bay (KBAY), and Katmai National Park and Preserve (KATM). Due to the COVID-19 global pandemic, field sampling was significantly reduced in 2020. Most intertidal work was completed in KBAY, however, minimal sampling was conducted in KEFJ and WPWS, while none was completed in KATM. For the past two years, we have reported one physical indicator (intertidal water temperature) and 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 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 quantitatively within mussel beds. Nearshore predator abundance is density of the most abundant sea stars, estimated along a 50 m x 4 m transect at each rocky intertidal site in the GOA. Intertidal water temperature and mussel density data, while collected at some sites, are not currently available due to laboratory restrictions constraining sample analysis. Rockweed percent cover was collected only in KBAY, while sea star densities were documented at all sites in KBAY and WPWS. Biological indicators are presented as annual anomalies compared to the long term mean of the data record by site.

Status and trends: Only metrics that were collected in 2020 and analyzed by 25 September are summarized below.

For algal cover, despite considerable variability in percent cover among sites and generally positive anomalies through 2014, KATM and KEFJ sites showed consistently negative values during the recent marine heatwave and continuing through 2019 (Figure 24). KBAY has continued to have roughly average *Fucus* cover without a noticeable response to the heatwave through 2020. Anomalies in WPWS had become slightly positive in 2019 and may indicate recovery from the heatwave effects after temperatures cooled in 2018. Percent cover in WPWS, KEFJ and KATM was not measured in 2020.

For sea star abundance, variability in density, diversity and dominance of individual sea star species varied greatly among regions through 2015. Between 2015 and 2017, abundance declined and remained strongly negative across all regions through 2018, likely due to sea star wasting disease (Konar et al., 2019). In 2019, there was some recruitment and recovery in WPWS and to a lesser degree in KATM, although anomalies were still negative. However, KBAY continues to show no

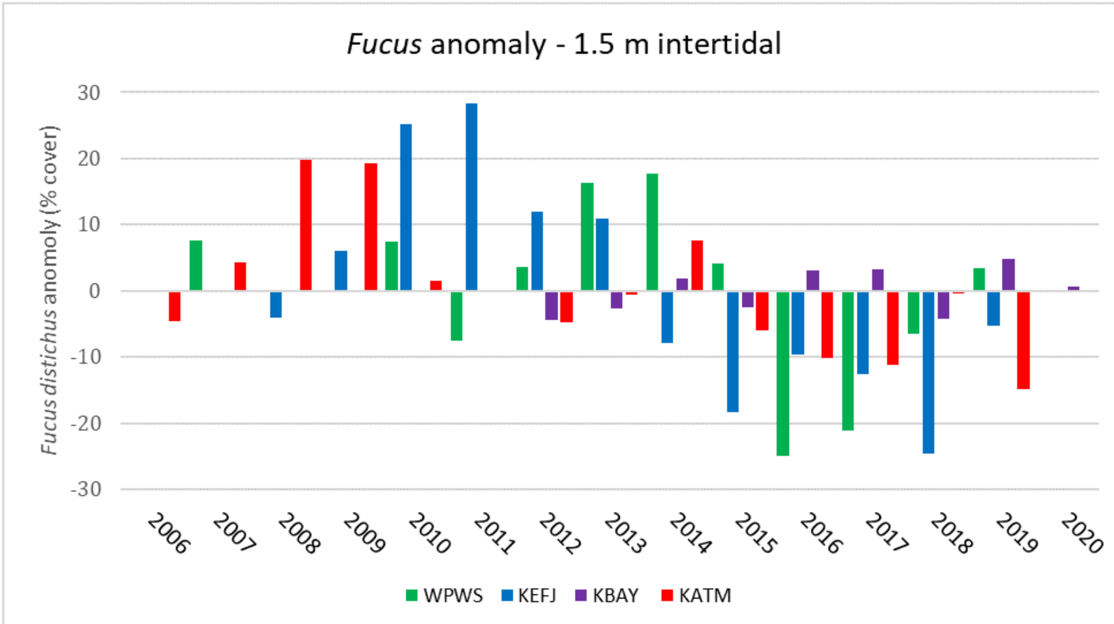

Figure 24: Percent cover anomalies for rockweed (*Fucus distichus subsp. evanescens*) in four regions of the western Gulf of Alaska, WPWS (2007, 2010–2019), KEFJ (2008–2019), KBAY (2012–2020), and KATM (2006–2010, 2012–2019).

signs of recovery through 2020 (Figure 25). There could be some lag in recovery in KBAY 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). In 2020, the sea star species thought to be unaffected by sea star wasting disease in the northern Gulf of Alaska (primarily *Henricia* and *Dermasterias*) continued to be present. The positive anomaly in WPWS during 2020 surveys was driven by high numbers of *Dermasterias* (81%; Figure 25). At the two sites sampled in KEFJ in 2020, 88% of observed sea stars were *Dermasterias.* The once more dominant sea stars (primarily *Pycnopodia*, *Evasterias*, and *Pisaster*) continue to be absent (or rare) in many of the Gulf Watch sites sampled in 2020, although one site in WPWS showed some recovery potential with many small *Pycnopodia.*

Factors influencing observed trends: The negative anomalies of rockweed in three of the four regions and sea stars across all regions were coincident with warm water temperatures in nearshore areas. The decline in sea star abundance across the Gulf was likely due to sea star wasting disease (Konar et al., 2019), first detected south of Alaska in 2014 and generally thought to be exacerbated by warm water temperature anomalies (Eisenlord et al., 2016).

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. Two of the three indicators with data from 2020 signal community level effects correlated with changing water temperatures and ecological processes of the 2014–2016 marine heatwave, with effects persisting into 2020. The decline in *Fucus distichus* may result in habitat loss for settlement of new mussel recruits but also decreased competition for space with larger mussels. *Fucus* trends also reflect a reduction in their contribution to nearshore sources of primary productivity.

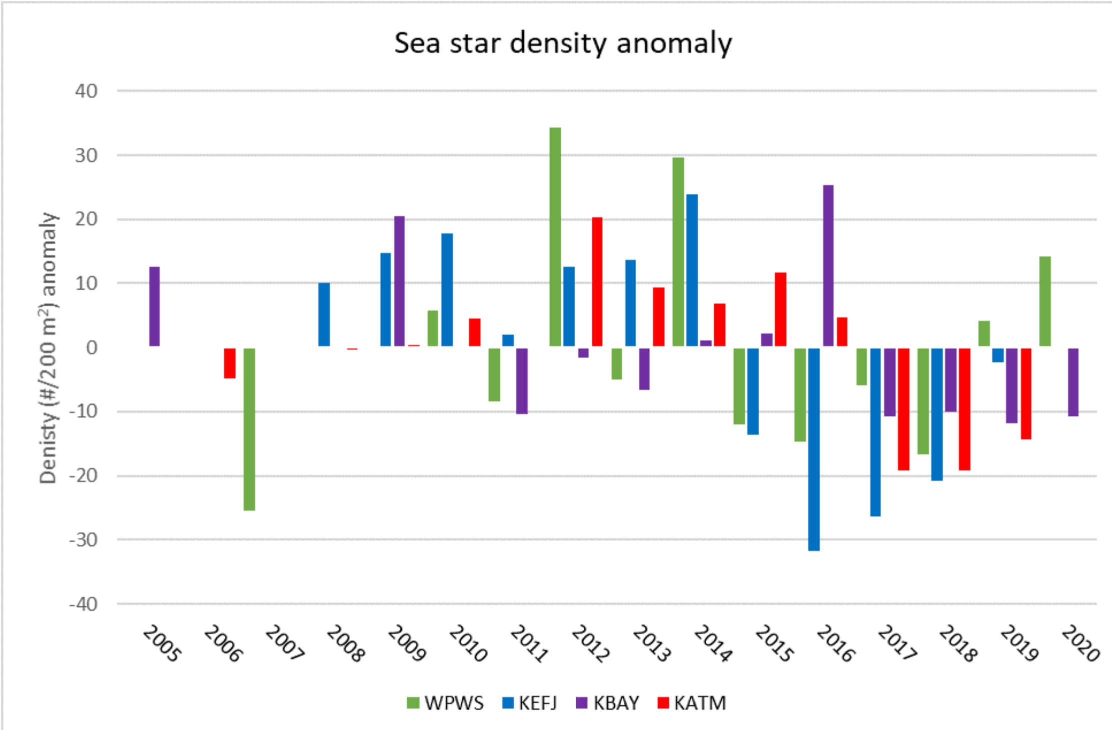

Figure 25: Density of sea stars (*Dermasterias imbricata*, *Evasterias troschelii*, *Pisaster ochraceus*, and *Pycnopodia helianthoides*) in four study areas spanning the northern Gulf of Alaska. WPWS (2007, 2010–2020), KEFJ (2008–2020), KBAY (2005, 2009, 2011–2020), and KATM (2006, 2008–2010, 2012–2019).

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 several species of rockfish. Though our sampling was spatially limited in 2020, our indicators suggest that some nearshore biological responses to the heatwave appear to continue into 2020 and could possibly affect future recruitment and survival of species whose life stages rely on nearshore habitat. Cornwall (2019) suggested that a new 'marine heat wave' forming in the Pacific will affect these coastal ecosystems, which our data support. With these perturbations, we also expect to see responses of nearshore-reliant, upper trophic level species (such as sea otters and sea ducks) to shifts in prey availability from changing ocean conditions across the Gulf of Alaska.

Primary Production

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

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Last updated: September 2020

Description of indicator: Phytoplankton provide the basal resources for secondary consumers like zooplankton and larval fish. During spring, a large bloom occurs once the upper surface of the water column stratifies, and light intensity becomes strong enough to support phytoplankton growth. This bloom takes advantage of higher nutrient stores remaining in surface waters after winter storms when phytoplankton activity is low. The spring bloom is critical for nourishing zooplankton and some fish populations and the timing and magnitude of the bloom can play an important role on the success of cohorts each year.

The timing and magnitude of spring phytoplankton blooms vary inter-annually, which not only has implications for the ecosystems, but also makes it difficult to collect *in situ* data for the annual process. Thus, satellite data provide the best opportunity to capture the large scale spatio-temporal dynamics and trends of phytoplankton. Several studies that include *in situ* data comparisons have shown that satellite chlorophyll data provide reasonable proxies for phytoplankton concentrations in surface waters (Batten et al., 2018; Waite and Mueter, 2013). We used 8 day composite chlorophyll-a data from the MODIS satellite `http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMBchla8day.html` for the eastern and western Gulf of Alaska (GOA) to examine phytoplankton dynamics from 2003–2020. We chose this protracted period for the spring bloom to ensure that we captured the variable event in each year. We summarized the magnitude of the annual spring event (Figure 26) as well as a chronology of phytoplankton concentrations throughout the season to better resolve annual phenologies. Given the primary focus of the NPFMC relative to groundfish populations, which are more shelf-driven, data were averaged spatially for depths between 10m and 200m (approximate shelf depths). Data were further filtered to include only federal waters to avoid data uncertainty of near coastal stations.

Status and trends: Average spring concentrations of chlorophyll-a in 2020 were slightly above the 2003–2020 mean in western GOA and slightly below the 2003–2020 average in eastern GOA. The timing of the spring bloom was substantially earlier in 2020 for both regions relative to their long term average. The higher values in the western GOA coincided with a spring bloom peak around day 117 (relative to the 2003–2020 mean day of 146) (Figure 27) while the eastern GOA demonstrated a peak around day 109 (2003–2020 mean day of 141). Overall, 2020 represented more of a return to normal conditions relative to 2019.

A high degree of inter-annual variability was observed for average spring chlorophyll-a values (Figure 26) and the timing of peak spring bloom (Figure 27) in both the western and the eastern GOA. In the western GOA, chlorophyll-a concentrations were particularly low in 2016 and 2019 (Figure 26), years that also appear to have had a late spring bloom peak (Figure 27). Meanwhile, during 2011, 2016, 2017, and 2019 spring chlorophyll-a concentrations were particularly low in the eastern GOA (Figure 26), but peak spring bloom was closer to average timing (Figure 27). Interestingly, the two highest values in the western GOA were complemented by the two lowest values in the eastern GOA during 2006 and 2011. The eastern GOA had persistently low chlorophyll throughout the spring and summer in 2006 and 2011, and thus the low value was not simply the result of a delayed bloom. Note 2014 had the third lowest values in the western GOA and the highest values in the eastern GOA (reversing the trend described above), reflecting an early bloom in the eastern GOA. Inter-annual variability is a persistent feature of chlorophyll-a concentrations and while still variable, average spring chlorophyll-a concentrations have been below the long-term average in the eastern GOA since 2016 and four of the past six years in the western GOA.

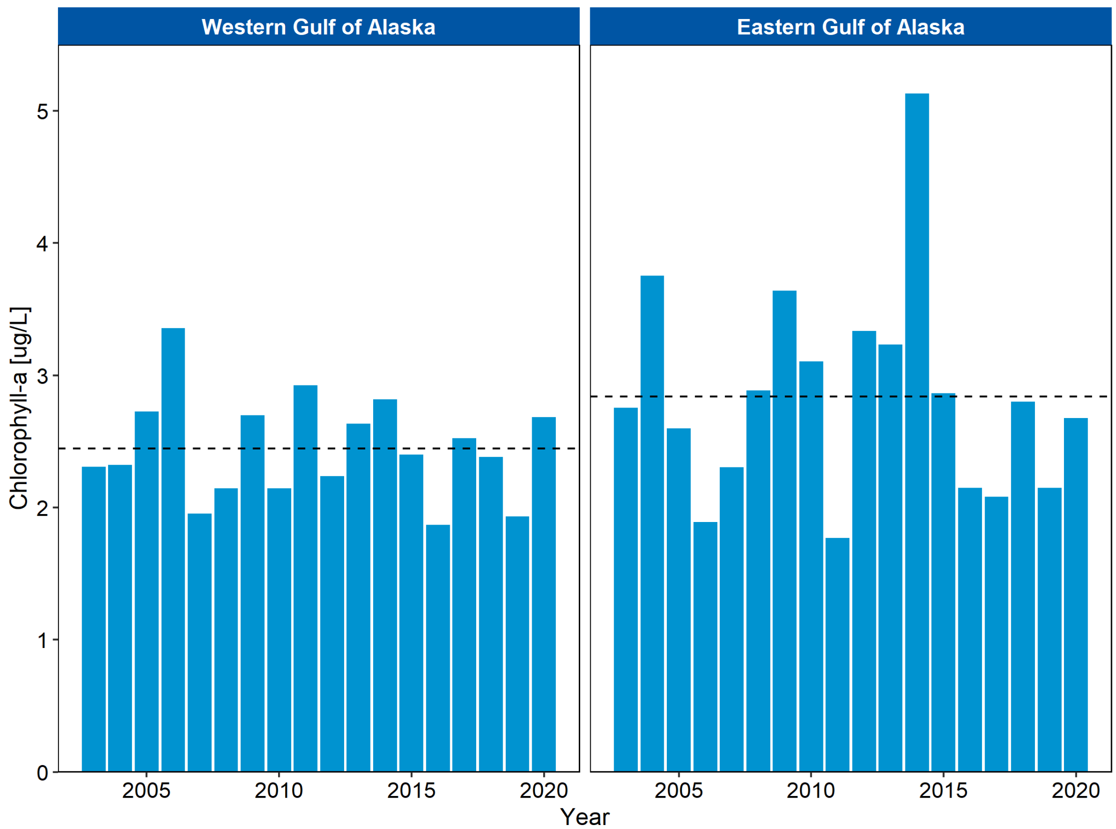

Figure 26: Average spring (April-June) chlorophyll-a concentrations based on MODIS satellite 8 day composites for the western and eastern Gulf of Alaska. The horizontal dashed line is the long-term mean (2003–2020).

Factors influencing observed trends: There were no significant relationships with average spring chlorophyll-a concentrations and sea surface temperatures (SST) in either the western or the eastern GOA at the spatial scales presented here. However, additional explorations of chlorophyll-a concentrations and SST across finer spatial areas and including off-shelf areas suggested weak negative relationships between SST and chlorophyll-a concentrations. Given that the temperature relationship with phytoplankton was negative, it is possible that recent marine heatwaves in the GOA may have negatively impacted spring phytoplankton concentrations. It is unclear whether such relationship would be the function of increased zooplankton grazing at higher temperatures or decreased primary production. We only examined simple linear relationships here but it is likely that nonlinear relationships with temperature exist, and recent warm events may have exceeded certain threshold conditions that diminish the linear relationships observed here. Furthermore,

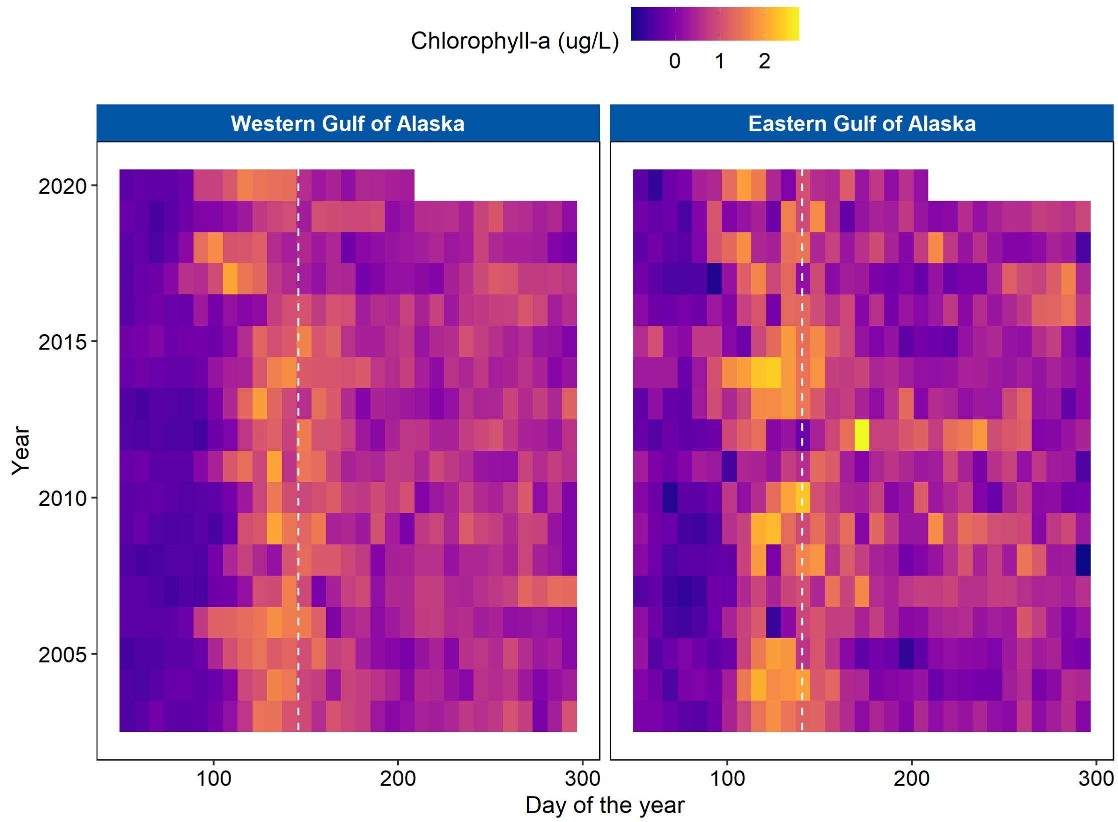

Figure 27: Average 8-day composite chlorophyll concentrations (log-transformed) for the western and eastern Gulf of Alaska. The brightest (yellow) color within each year will represent the peak bloom. Vertical dashed lines illustrate the mean day of the year of spring bloom timing for the western (day 146; approximately May 25) and the eastern (day 141; approximately May 20) Gulf of Alaska. For reference, days of year 100 and 200 fall around April 9 and July 19, depending on leap years.

temperatures alone are unlikely to drive phytoplankton concentrations. It is known that mesoscale eddies play a large role in the GOA and the patchy nature of phytoplankton 'hot spots' over the shelf. Researchers are further examining the impacts of winds and other potential oceanographic drivers, which also play a role. A persistent consideration with satellite-based chlorophyll data is the effects of cloud cover, which precludes quality data collection. On average, about 25% of data were missing during the spring periods examined for each year and further research is necessary to fully resolve the impacts of these missing data on inference.

Implications: Chlorophyll concentrations are a proxy for food availability for zooplankton and many of the planktivores that rely on zooplankton. The chlorophyll-a indicator is relatively new and more work will be required to resolve any connections between groundfish recruitment and chlorophyll concentrations. Meanwhile, we explored some relationships between chlorophyll-a and pink salmon, which rely on zooplankton prey during their critical one year at sea. With the limited on-shelf chlorophyll-a concentrations that were the focus of this indicator, we did not find any notable correlations between pink salmon and the zooplankton grazers of phytoplankton. However, preliminary explorations that included broader spatial extents within the GOA (off-shelf) indicated relatively strong positive relationships between chlorophyll-a concentrations and pink salmon harvests (not shown). Thus, declines of off-shelf spring chlorophyll concentrations, especially in the eastern GOA, may be consistent with some of the lowest pink salmon returns on record observed in recent years.

Finally, we observed inter- and intra-regional differences in chlorophyll-a concentrations and trends in the eastern and western GOA. This highlights the sensitivity of results and implications to spatial scales and emphasizes the need for future nuanced analyses.

Zooplankton

Continuous Plankton Recorder Data from the Northeast Pacific, 2000–2019

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Description of indicator: Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. Two transects are sampled seasonally, both originating in the Strait of Juan de Fuca, one sampled monthly (∼Apr–Sept) which terminates in Cook Inlet, the second sampled 3 times per year (in spring, summer and autumn) which follows a great circle route across the Pacific terminating in Asia. Several indicators are now routinely derived from the CPR data and updated annually. In this report we update three indices for three regions (Figure 28); 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 (2002–2019 for the GOA). Each sampled month's mean is then compared to the long-term geometric 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 eastern GOA, oceanic western GOA, and the Alaskan shelf southeast of Cook Inlet (Figure 28). The oceanic GOA regions have better sampling resolution than the Alaska shelf as both transects intersect here. This region has been sampled up to 8 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 at an average level for 2019, whereas it was positive in 2017 and 2018 (Figure 29). On the eastern side of the oceanic GOA the diatom anomaly was also at an average level, whereas it had been negative for 2017 and 2018. On the western side of the oceanic GOA the diatom abundance anomaly was negative for the last two years. The copepod community size anomaly was strongly negative in both the Alaskan shelf and eastern GOA regions, but it was almost average in the western GOA. Zooplankton biomass anomalies were positive in both the shelf and western GOA regions (strongly so in the shelf), while the anomaly was negative for two years running in the eastern side of the GOA.

Factors influencing observed trends: The Pacific Decadal Oscillation (PDO) monthly values were often negative in 2017 causing a lower annual mean value compared to the preceding years of 2014–2016, which had experienced a marine heat wave (Di Lorenzo and Mantua, 2016). 2019 is another warm year. In warm conditions smaller species tend to be more abundant and the copepod

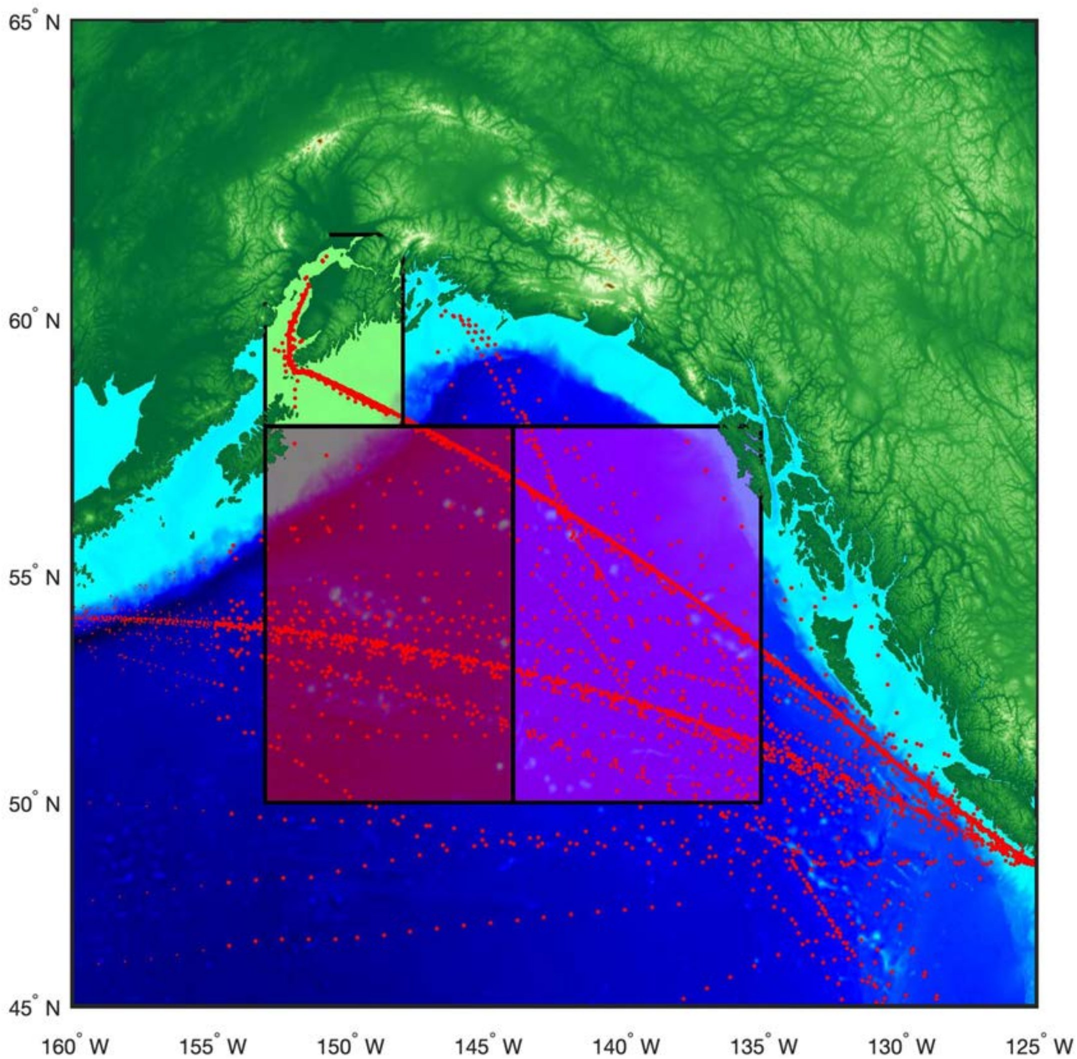

Figure 28: Location of the data used in this report, highlighted as Alaskan shelf (yellow rectangle), eastern Gulf of Alaska (magenta rectangle), and western Gulf of Alaska (red rectangle). Red dots indicate actual sample positions (note that for the shelf region the multiple transects overlay each other almost entirely).

community size index was mostly negative throughout the marine heat wave periods of 2014–2016, and 2018–2019. The decline in zooplankton biomass seen in 2018 is reversed in 2019, particularly in the shelf region, which had their most positive anomaly of the time series in 2019. The large diatom abundance was close to the average of the sampling period in all three GOA regions in 2019, with only the western GOA region showing a lower than average diatom abundance. This decrease in diatom abundance could potentially be linked to the increase in mesozooplankton abundance increasing predation on diatoms in the area.

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 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

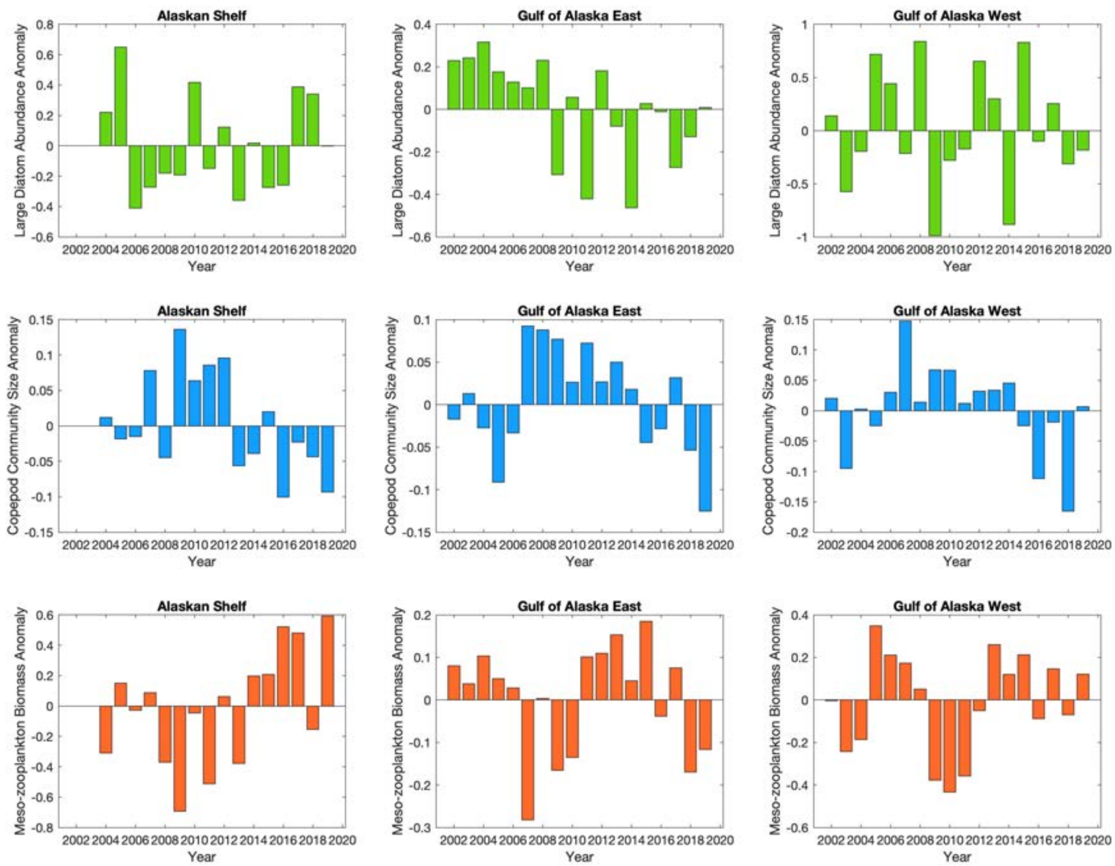

Figure 29: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for all three regions shown in Figure 28. Note that sampling of the shelf region did not begin until 2004.

to their predators. Changes in abundance or biomass, together with size, influences availability of prey to predators. It is likely that the high temperatures of 2019 have led to high mesozoopankton biomass and a decrease in diatom abundance due to increased predation, in both the shelf and western oceanic GOA regions.

Current and Historical Trends for Zooplankton in the Western Gulf of Alaska

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Last updated: September 2020

Description of indicator: In 2015, AFSC implemented a method for an at-sea Rapid Zooplankton Assessment (RZA) for biennial (off-year) surveys, 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., 2000). The categories are small copepods (< 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp. and *Oithona* spp.), large copepods (> 2 mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids (< 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 μm mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 μm mesh, 60 cm bongo net. Other, more rare zooplankton taxa were present but were not sampled effectively with the on-board sampling method. RZA abundance estimates may not closely match historical estimates of abundance as methods differ between laboratory processing and ship-board RZA, particularly for euphausiids which are difficult to quantify accurately (Hunt et al., 2016). Rather, RZA abundances should be considered estimates of relative abundance trends overall. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1 year post survey).

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: Large copepods showed variability over time during spring (Figure 30). Most notable was the rise in abundance of large copepods seen in spring from 2003–2006 and the decline in large copepods observed in 2015 and 2019. In the summer, large copepod abundances have remained low since 2008. Small copepods showed very little variability over time in either spring or summer (Figure 30). Euphausiid abundances showed considerable variability over time and were low during 2003-2006 and during 2015 and 2019 (Figure 30).

Factors influencing observed trends: Large zooplankton abundances appear to respond to different environmental conditions most strongly in spring, notably temperature (Sousa et al., 2016; Kimmel and Duffy-Anderson, 2020). Specifically, warmer temperatures likely accelerated the entry into diapause for the larger copepods *Neocalanus cristatus* and *N. plumchrus/flemingeri* lowering overall large copepods numbers. This was most pronounced during the recent marine heatwaves in 2015 and 2019. During less extreme warm conditions as in 2003–2005, large copepod numbers increase and this is likely due to the increased abundances of *Calanus marshallae* (Kimmel and Duffy-Anderson, 2020) that are developing to later stages more quickly. Large copepod numbers have remained low in the summer recently as *C. marshallae* may either enter into diapause earlier due to more rapid development times or is subject to increased mortality. The exact mechanism is not known and increased temperatures may lead to a second cohort of *C. marshallae*, whose earlier stages would not be considered large copepods (Banas et al., 2016; Kimmel and Duffy-Anderson, 2020). Small copepod abundances appear to be less impacted by warming as opposed to the larger copepods and showed little variability in either spring or summer. This makes sense with respect to life history characteristics of small copepods, e.g. multiple generations per year, faster turnover times, and metabolic rates that scale less dramatically with temperature (Kiörboe and Sabatini, 1995). The large error bars occurring from 1999 to 2011 represent the fact that these samples only came from Line 8. The error for small copepods dramatically reduces when the sampling area increased in 2013 (Figure 30. In spring, there is a possibility that earlier stages of the large

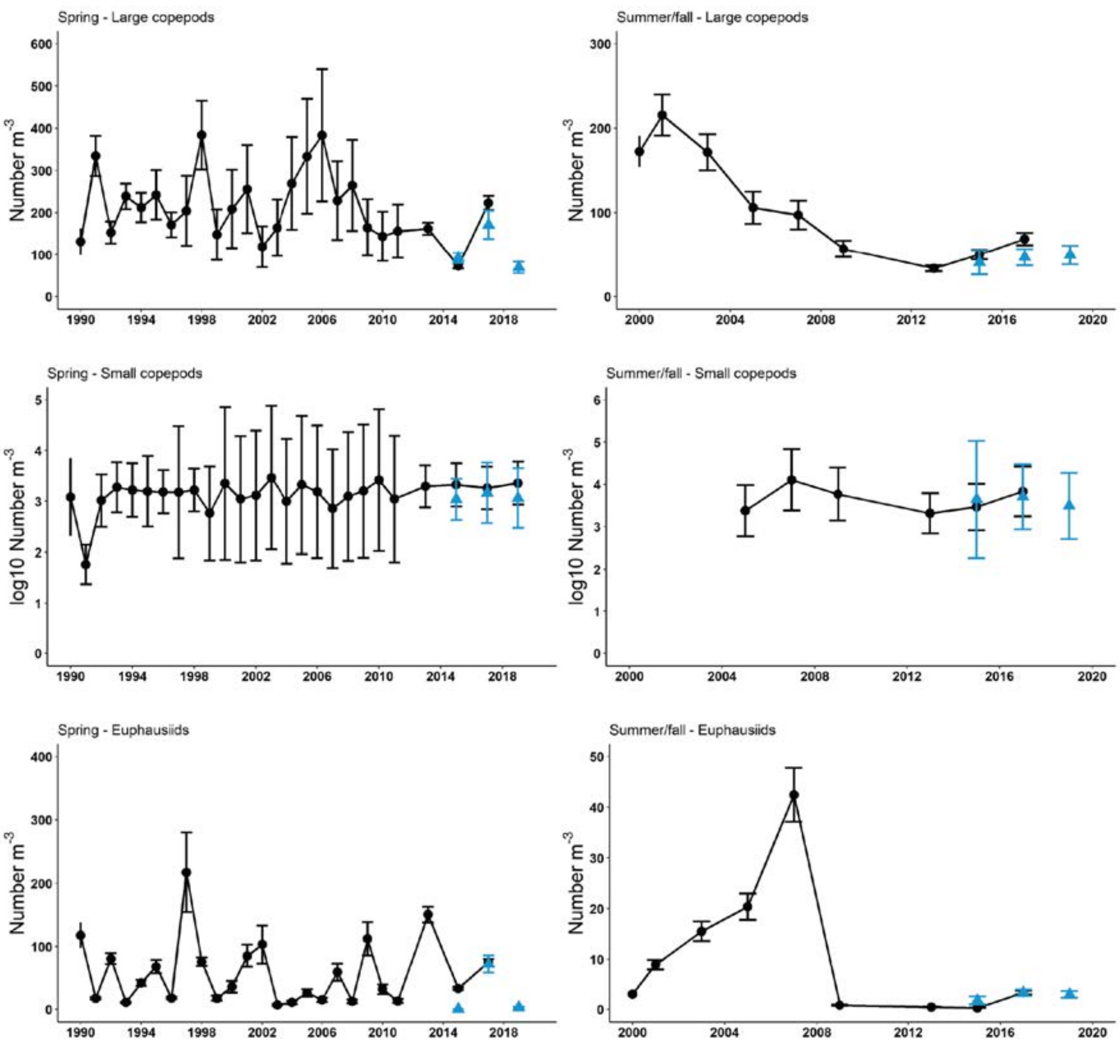

Figure 30: Spring (left) and summer (right), annual, mean abundance of large copepods (>2 mm), small copepods (<2 mm), and euphausiids (<15 mm) in the Gulf of Alaska, FOCI sampling region. Black points and lines represent FOCI archived data from the Line 8 region, blue points represent RZA data from spring sampling across the Gulf of Alaska in 2015, 2017, and 2019. Error bars represent standard error of the mean.

copepods may be counted as small copepods, as some life-history stages may be < 2 mm. A 2 ml Stempel pipet is used to estimate small copepods, as opposed to the larger 10 ml pipet used to subsample for large copepods. Therefore, we are much more likely to be counting smaller species such as *Oithona spp.* and *Pseudocalanus* spp. as opposed to members of the annual cohort of the large species, such as *Calanus* spp. The significant decline in euphausiid numbers during the spring (Figure 30 can be partially explained by the development of euphausiids resulting in larger sized individuals that can effectively avoid the 60 cm bongo net. This reflects the inability of the bongo nets to adequately capture older euphausiids. Furthermore, it should be noted that the RZA and processed estimates of abundances often differ (Figure 30. This is expected due to the patchy nature of euphausiid distribution and the difficulty in accurately estimating euphausiid abundances (Hunt et al., 2016).

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. Note the small copepod proportion does not include nauplii (the primary prey for early larval fish) and recent work has suggested a decline in nauplii did occurring during the recent marine heatwave (Rogers et al., 2020). 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 (Kimmel and Duffy-Anderson, 2020). The recent, low large copepod abundances in summer suggest the standing stock of *C. marshallae* is lower during warming events. A lack of large copepods leads to diet shifts (Lamb and Kimmel, unpub. data) where less energetically dense prey items are consumed. 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. 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.

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

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Last updated: September 2020

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: While large copepod biomass in May 2019 was at or slightly-below average, preliminary data for May 2020 suggests average or slightly above average calanoid biomass (Figure 31). Euphausiid biomass in May 2019 appears to be well above average, while May 2020 may be only slightly-above average (note large confidence intervals are due to low sample size as not all samples have been analyzed). September 2019 and September 2020 data are not yet available due to COVID-19 related delays (2019) and time for analysis (2020) (Figure 32).

Factors influencing observed trends: May of 2020 was at the 23-year thermal mean along the Seward Line and surface temperatures remained relatively average through the remainder of the season (see p.45). 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.

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. May 2019 biomass appears to be well above average, while May 2020 is may be only

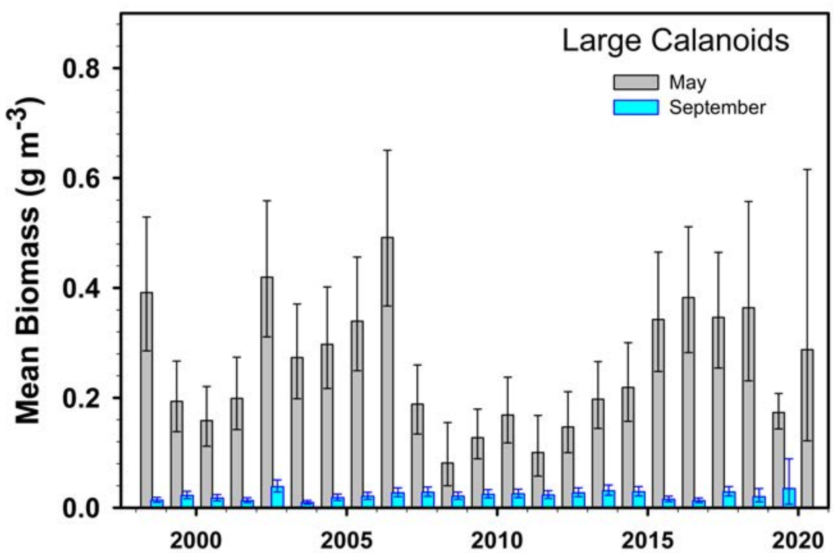

Figure 31: Biomass of calanoid copepods along the Seward Line sampled using a 0.5 mm mesh at night. Transect means and 95% confidence intervals are calculated on power-transformed data.

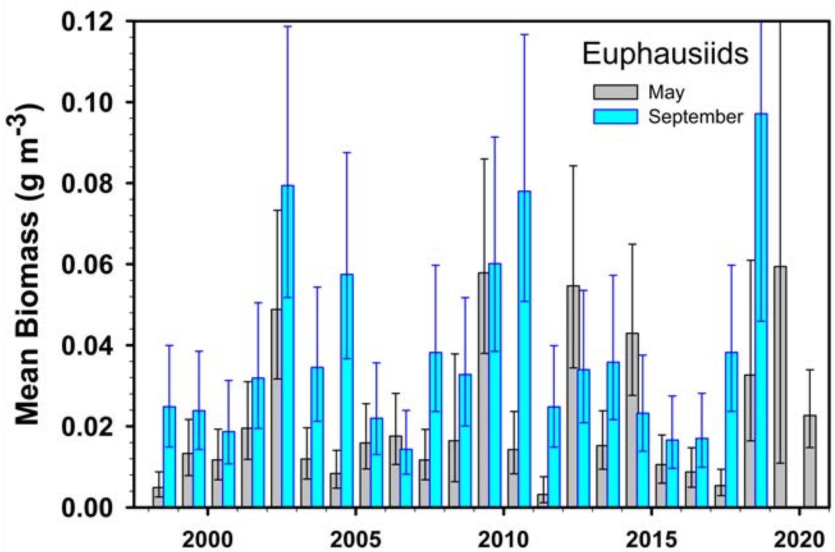

Figure 32: Biomass of euphausiids along the Seward Line sampled using a 0.5 mm mesh at night. Transect means and 95 confidence intervals are calculated on power-transformed data.

slightly-above average.

Implications: While high biomass of larger zooplankton does not guarantee success of species dependent upon them (due to 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 only average during May 2020, relatively normal prey resources can be expected throughout 2020.

Zooplankton Trends in Icy Strait, Southeast Alaska

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Last updated: September 2020

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). Zooplankton data have been collected annually in Icy Strait during monthly (May to July) fisheries oceanography surveys.

This report presents 2020 annual values of zooplankton data in relation to the long-term trends in Icy Strait. 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). Zooplankton density anomalies were computed as deviations from the long-term annual mean values for small copepods (species whose adults are $\leq$ 2.5mm), and large copepods (species whose adults are $>$ 2.5 mm).

Status and trends: Zooplankton density trends over time represent prey availability to higher trophic levels and the zooplanktons response to climate and ocean conditions. Total zooplankton density ranged from 922 to 3,420 organisms per m^3 from 1997 to 2020 (Figure 33). Recent trends in total zooplankton indicated little change from 2019 anomalies which were close to zero, which reflect average density values. The consistent average density indicates stability in the prey field utilized by larval and juvenile fish in Icy Strait.

For 2020, small calanoid copepods ($\leq$2.5 mm length), euphausiid larvae, and gastropods decreased from 2019 densities and all were below average. Large calanoid copepods ($>$2.5 mm) and hyperiid amphipods increased from 2019 densities. The large calanoid copepods increased from below to above average, to the 4^{th} highest density in the time series. A similar increase in large copepod densities was observed in 2017 when water temperatures were decreasing from the anomalously high temperatures measures during the marine heat wave of 2014–2016.

Factors influencing observed trends: Subarctic zooplankton typically follow seasonal cycles of abundance, however, responses to climate change vary by species. Additionally, changes in abundance are influenced by seasonal timing cues, phenology, physiology, and environmental parameters including temperature and phytoplankton bloom intensity (Mackas et al., 2012), and these responses also depend on the monthly timing, magnitude, and duration of temperature anomalies in warm or cold years.

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

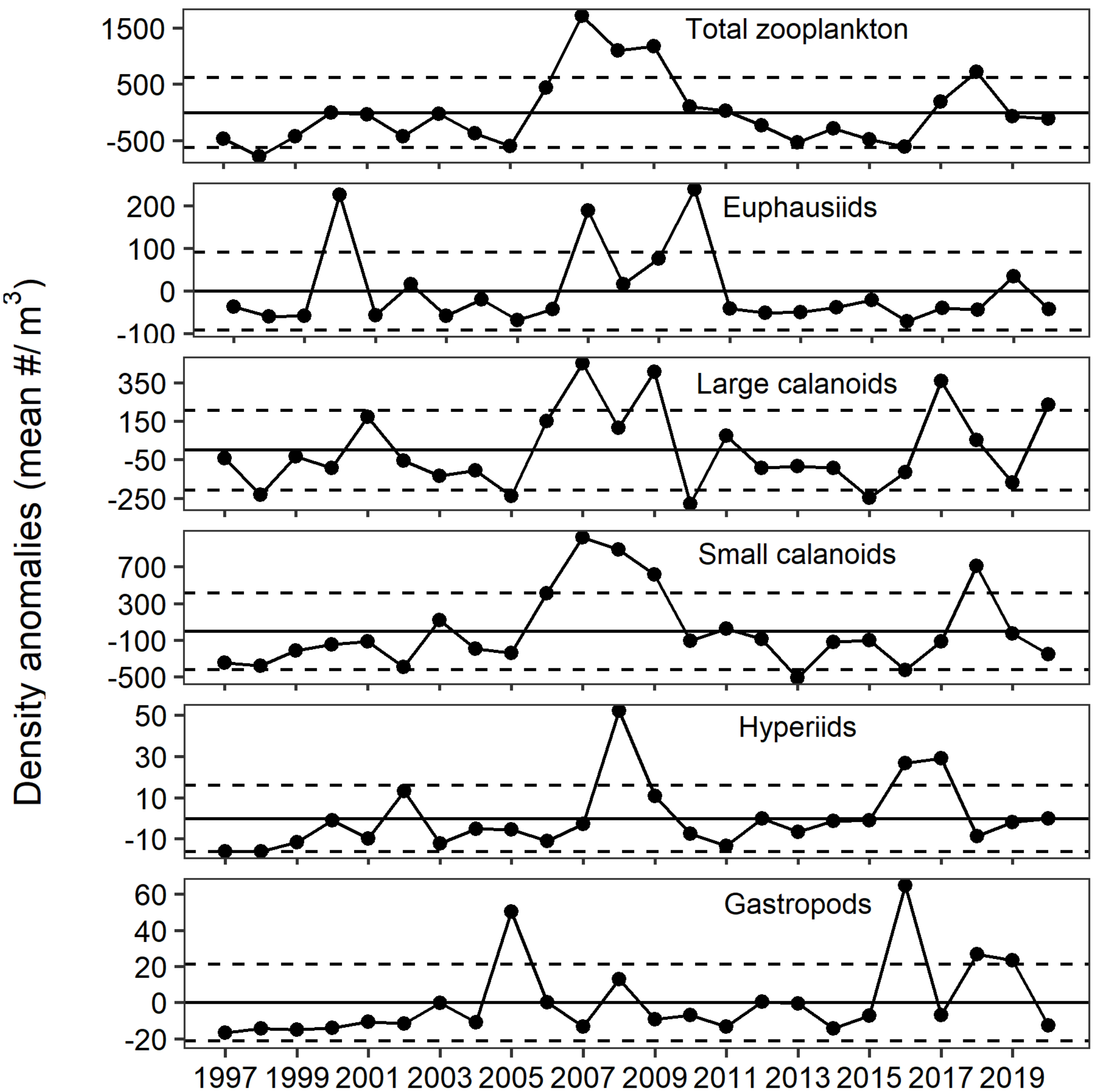

Figure 33: Average annual total zooplankton and taxa specific density anomalies for the northern region of SEAK (Icy Strait) from the Southeast Coastal Monitoring project time series, 1997–2020. One standard deviation above and below the mean is indicated by the dashed lines. Annual densities are composed of zooplankton samples collected monthly from May to July 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 2020

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., 2020; Murphy et al., 2020). Since 2013, zooplankton lipid content data have been collected annually in Icy Strait during monthly (May to August) fisheries oceanography surveys.

This report presents 2020 annual values of zooplankton lipid content for specific taxa in relation to the past 7 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., 2020; 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: Trends from 2013 to 2020 for all taxa showed mean percent lipids ranging from >0.01% to 21% (Figure 34). In 2020, percent lipids for all zooplankton taxa increased from 2019 values, lipids of three taxa increased from below to above average (with the exception of *C. marshallae*). This increase in lipid content indicates an increase in the nutritional quality of the prey field utilized by larval and juvenile fish in Icy Strait.

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 community and abundance (zooplankton food), and predator abundance (top-down control). Changes in the zooplankton community influence the food web and trophic relationships, which 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 cold years relative to warm years, when lower lipid copepods dominate the prey field (Coyle et al., 2011). The abundance of high-lipid copepods trophically link 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 can drive recruitment success of age-1 pollock relative to recruitment during warm years.

Implications: The increase in nutritional quality of zooplankton indicates favorable feeding conditions for larval and juvenile stages of many commercially and ecologically important species of fish (e.g., pollock, salmon, and herring) that reside in Icy Strait, which may directly or indirectly affect fish growth and recruitment.

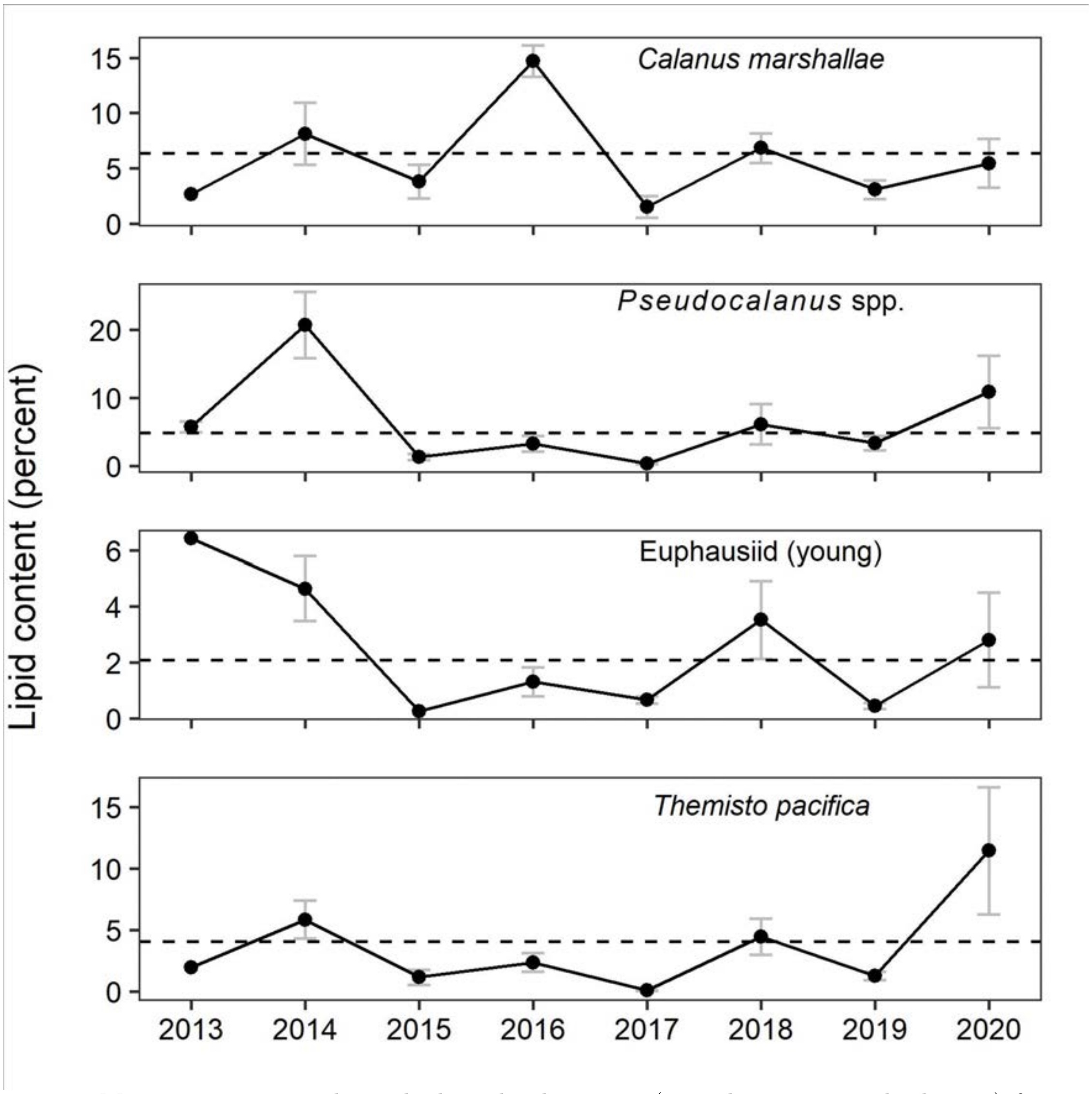

Figure 34: Mean percent annual zooplankton lipid content (error bars are standard error) from zooplankton collections in Icy Strait, AK by the Southeast Coastal Monitoring project, 2013–2020. Time series average is indicated by the dashed line.

Ichthyoplankton

Larval Fish Abundance in the Gulf of Alaska 1981–2019

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Last updated: September 2020

Description of indicator: The Alaska Fisheries Science Center's (AFSC) Ecosystems and Fisheries Oceanography Coordinated Investigations Program (EcoFOCI) has been sampling ichthyoplankton in the Gulf of Alaska (GOA) from 1972 to the present, with annual sampling from 1981–2011 and biennial sampling during odd-numbered years thereafter. The primary sampling gear used is a 60-cm bongo sampler fitted with 333 or 505 μm mesh nets. Oblique tows are carried out mostly from 100 m depth to the surface or from 10 m off bottom in shallower water (Matarese et al., 2003, Ichthyoplankton Information System `http://access.afsc.noaa.gov/ichthyo`). Historical sampling has been most intense in the vicinity of Shelikof Strait and Sea Valley during mid-May through early June Figure 35). From this area and time, a subset of data has been developed into time series of ichthyoplankton abundance (after Doyle et al., 2009)) for the 12 most abundant larval taxa in the GOA, including commercially and ecologically important species (Figure 36). Time series are updated in even years, one year after collection, due to processing time required for quantitative data. On-board counts of a limited number of taxa give rapid assessments of abundance, which are presented in the year of collection. Due to the COVID–19 pandemic and the closure of the Western Regional Center, the 2019 ichthyoplankton data have not followed the same quality assurance steps established by EcoFOCI as the data prior to 2019 and are, therefore, preliminary. Quantitative data for 6 of 12 taxa are provided, with the remaining 6 pending laboratory verification. The 2019 data will be updated and are subject to change once full quality assurance steps can be completed.

Status and trends: In 2019, abundances for many species were below average, similar to the low larval abundance noted in 2015 during the extended marine heatwave in the Gulf of Alaska. Species with low abundance in 2019 included arrowtooth flounder, walleye pollock, Pacific cod, Pacific halibut, northern rock sole, and southern rock sole. Rockfish abundance remained elevated in 2019 relative to the first two decades of observations, but declined from the high abundances of the most recent decade. Flathead sole were more abundant than average, similar to 2017. Pacific sand lance continued an upward trend and were highly abundant, similar to the high catches last observed in 2006–2007. For three taxa (ronquils, starry flounder, northern lampfish) we had neither Rapid Larval Assessment not quantitative data to assess abundance trends for 2019. For the three taxa with both quantitative and rapid data, we found close agreement in estimates, confirming the utility of our onboard rapid assessments.

Factors influencing observed trends: In 2019, warm conditions returned to the Gulf of Alaska, including at depth, eliciting many of the same ecological responses as observed during the 2015-16 heatwave. During the heatwave, overall larval abundance and species richness were low in the Gulf of Alaska (Nielsen et al., 2020), notably impacting commercially-important gadids (Pacific cod and walleye pollock). However, a few differences were noted in 2019 that made it distinct from 2015:

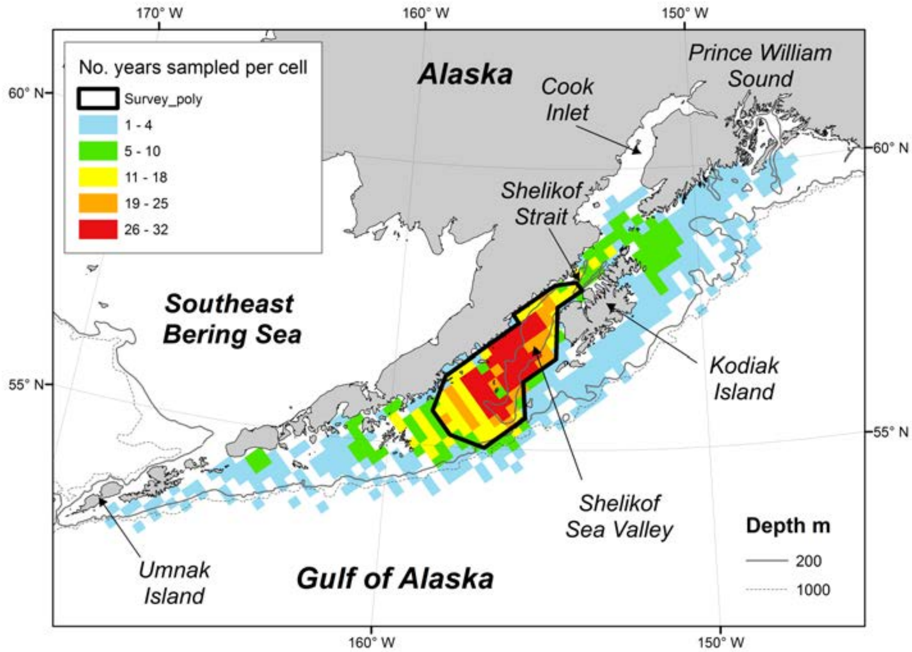

Figure 35: Distribution of historical ichthyoplankton sampling in the Gulf of Alaska by NOAA's Alaska Fisheries Science Center using a 60 cm frame bongo net. Sampling effort is illustrated by the number of years where sampling occurred in each 20 km^2 grid cell during late spring. A time series has been developed for the years 1981–2019 from collections in the polygonal area outlined in black where sampling has been most consistent during mid-May through early June. Note that this polygon was updated in 2018 to reflect sampling intensity through the most recent years.

Pacific sand lance were relatively abundant, whereas rockfishes (a group that is typically dominated by Pacific ocean perch) were not.

Previous work has explored trends in abundance of these species in relation to atmospheric and oceanographic conditions (Doyle et al., 2009; Doyle and Mier, 2012). Similarities in response to environmental forcing were apparent among species that display similarities in patterns of early life history exposure to the environment (Doyle et al., 2009). For instance, years of high abundance for the late winter to early spring shelf spawners Pacific cod, walleye pollock, and northern rock sole were associated with cooler winters and enhanced alongshore winds during spring. Pacific sand lance recruitment and abundance is notably higher at warmer temperatures, however, this is likely only true for a certain thermal range with expected declines in recruitment once this thermal window is exceeded, especially in the spring (Hedd et al., 2006; Sydeman et al., 1998). 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, 2020). Warmer temperatures could also result in a higher potential of match-mismatch dynamics for larval fishes depending on the thermal

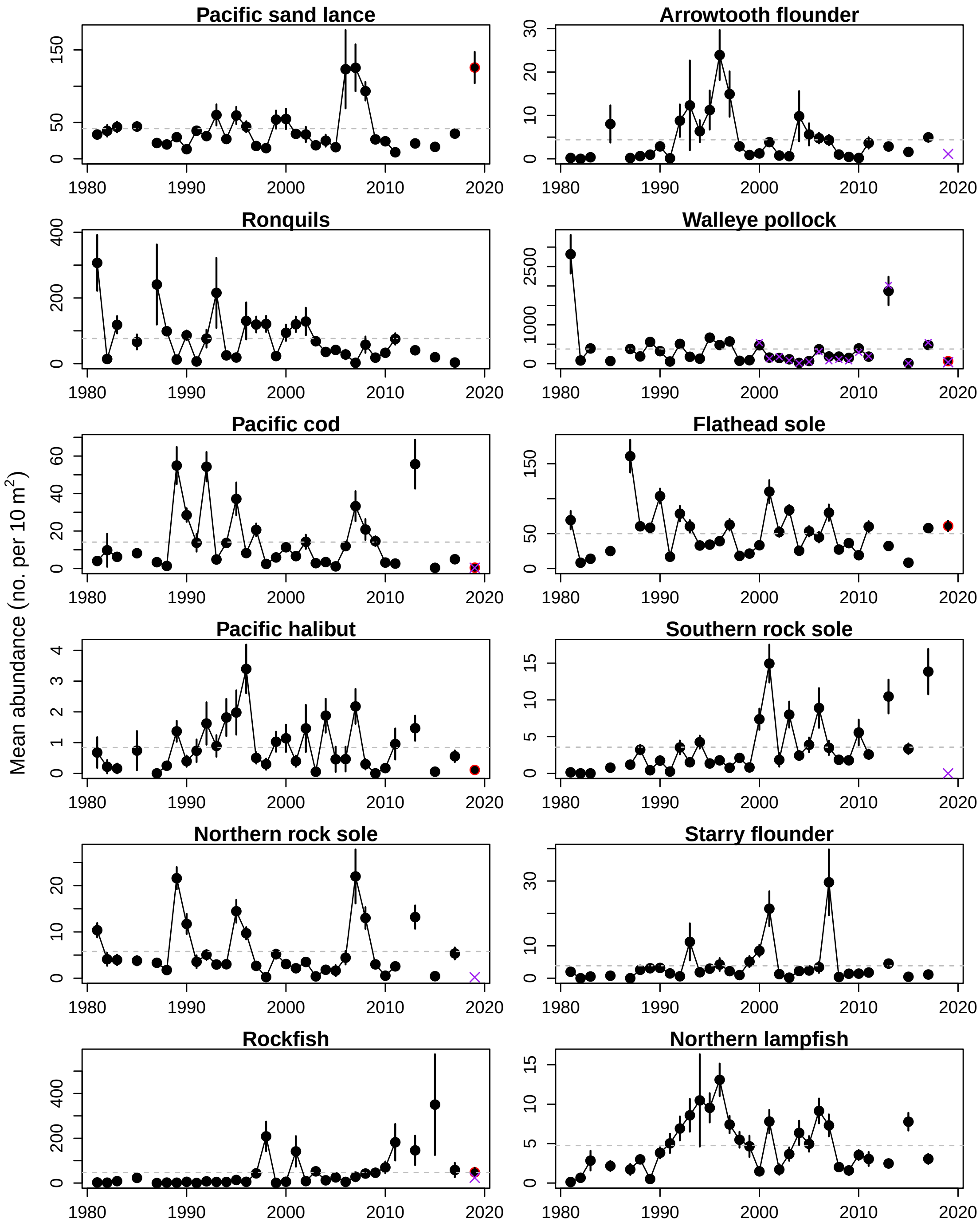

Figure 36: Interannual variation in late spring larval fish abundance in the Gulf of Alaska 1981–2019. The larval abundance index is expressed as the mean abundance (no. 10 m^{-2}), and the long-term mean is indicated by the dashed line. Error bars show +/- 1 SE. No data are available for 1984, 1986, 2012, 2014, 2016, 2018 or 2020. Purple x's denote estimates from onboard Rapid Larval Assessments. Points with red outlines indicate preliminary quantitative data for 2019. Due to laboratory restrictions in 2019, data were not available for select species.

sensitivity of spawning, development, and zooplankton prey availability and production (Kimmel and Duffy-Anderson, 2020).

Implications: Ichthyoplankton surveys can provide early-warning indicators for ecosystem conditions and recruitment patterns in marine fishes. In both 2015 and 2019, low abundances of walleye pollock and Pacific cod larvae were the first indicators of failed year-classes for those species. Arrowtooth flounder, a notable fish predator of walleye pollock, was also low in 2019, suggesting reduced future predation pressure from this species. While mortality during later life stages is clearly important, poor conditions during the first few weeks and months of life can already determine the potential for a large year class, emphasizing the importance of studying processes affecting mortality and abundance of early life history stages. In addition, a paucity of small fishes indicates reduced prey availability for piscivorous predators, including seabirds and fishes; however, the increase in Pacific sand lance, an important forage fish in the GOA, may have helped to buffer these impacts in 2019.

Forage Fish and Squid

Seabird-Derived Forage Fish Indicators from Middleton Island

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Last updated: September 2020

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 (59.4375°N, 146.3277°W), 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 those 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 (> 6,000 samples to date). From an evaluation of alternative methods of analyzing and reporting diet results, the preferred metric for kittiwakes is prey relative occurrence (Hatch, 2013), for which the relevant sample unit (denominator for calculations of frequency) is total occurrences of identified prey types in a given collection of samples. 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. Samples consist of whole prey specimens, thus the reported data are simple calculations of percentage biomass per species. Since 1978, more than 140 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 37) 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 were prevalent (e.g., 2014–2017), the diets of surface-feeding kittiwakes and diving auklets diverged in respect to prey-switching behavior to alternate species such as myctophids, salmon, and greenlings.

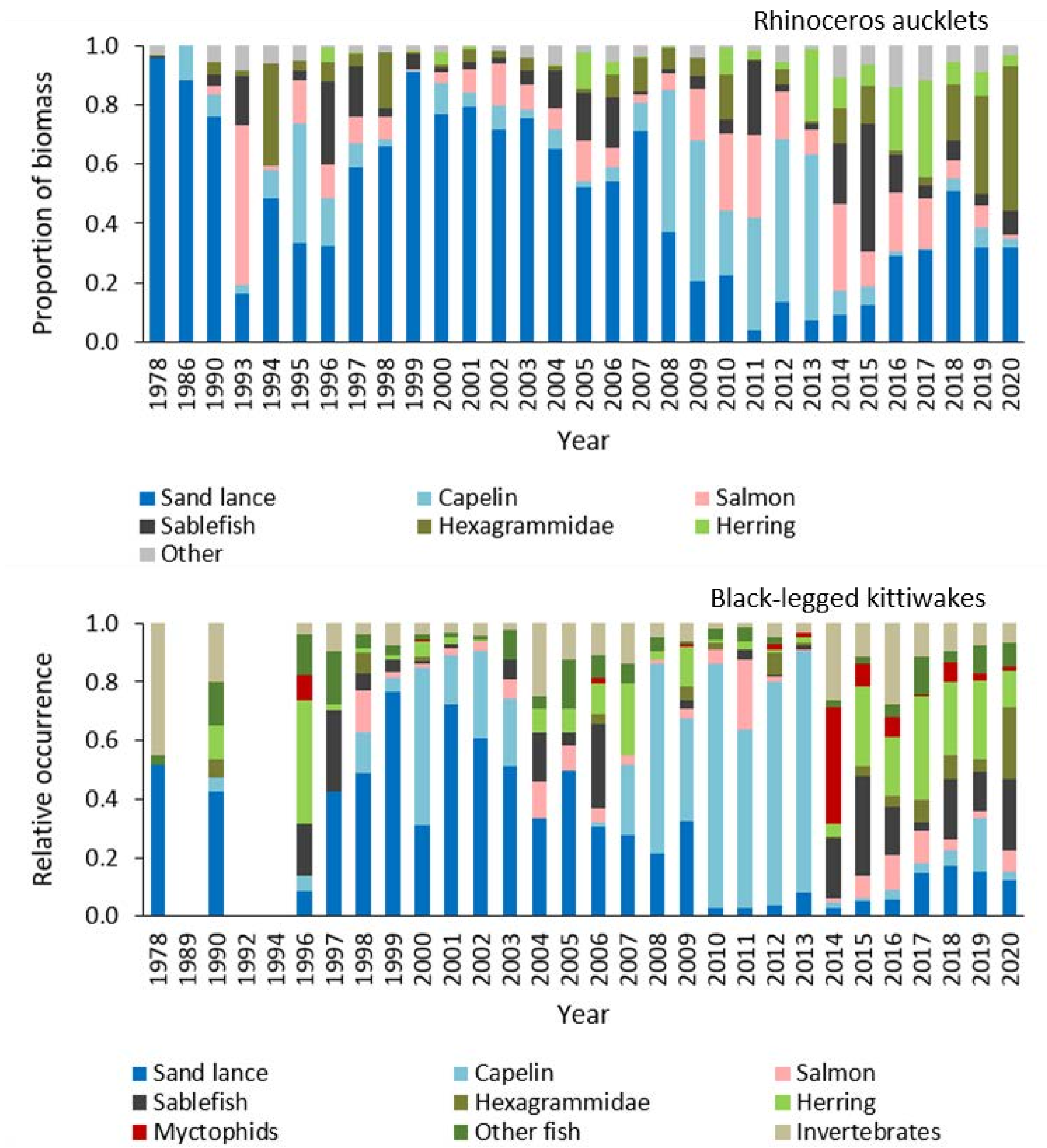

Figure 37: Interannual variation in diet composition of chick-rearing rhinoceros auklets (upper panel) and black-legged kittiwakes (lower panel) on Middleton Island, June-August 1978–2020.

Auklet data plotted separately by prey type highlight the interannual dynamics of individual species (Figure 38). 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 38).

In 2019, sand lance declined slightly as compared with the previous year, the difference being offset by a modest increase in capelin—seemingly a more or less direct and predictable tradeoff that is evident throughout our datasets. Greenlings were prominent in the auklet (but not kittiwake) diet during 2019, to a degree not seen since 1994 (Figure 37). The occurrence of herring and other coastal species in seabird diets from Middleton possibly reflects greater use of nearshore/inner shelf habitats because of reduced availability offshore of key 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, especially at the southern end of Montague Island.

Totals of 609 kittiwake diet samples and 322 rhinoceros auklet samples were obtained in 2020. As in two the prior years (2018 and 2019), but to an even greater degree in 2020, greenlings were a substantial part of the diet in both seabird species (Figure 37 and Figure 38). While our analysis focuses on hexagrammid species as a group (greenlings, lingcod, and Atka mackerel), it is noteworthy that in addition to kelp and rock greenlings (similar fish not identified to species in the field or lab), Atka mackerel (large-bodied fish relative to other hexagrammids collected) have seen a marked increase, especially this year. For reference, the breakdown of Hexagrammidae in 2020 was as follows: 1% lingcod, 4% Atka mackerel, 95% greenlings (biomass) in rhinoceros auklets, and 10% lingcod, 21% Atka mackerel, 69% greenlings (relative occurrence) in kittiwakes. Collectively, hexagrammids constituted in 2020 about 50% of the auklet diet (biomass) and 25% of kittiwake prey (relative occurrence), numbers not seen in any prior year on Middleton (Figure 37 and Figure 38).

A species new to the list of seabird prey at Middleton—chub mackerel (*Scomber japonicus*)—was first encountered in 2019 (4 occurrences), increasing to 15 occurrences in 2020. To date the species appears only in late-season samples obtained from black-legged kittiwakes (earliest occurrences 6 August 2019 and 6 August 2020). Co-occurrence in samples with myctophids, squid, and pelagic crustaceans suggests chub mackerel are coming from the pelagic zone south of Middleton, where kittiwakes alone are known to forage with some regularity.

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 for several years beginning late winter 2013 (Bond et al., 2015). A salient finding during the anomaly was the virtual disappearance of capelin from the seabird diets on Middleton, following 6 prior years when capelin were predominant (Figure 37). 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.

The PDO turned negative in early 2020 and remained so during most subsequent months to the present time (September 2020), a development discussed elsewhere as it pertains to seabird responses on Middleton (see 'Seabird breeding performance on Middleton Island' in this report). Unlike previous intervals with cool-water conditions, capelin have not made any appreciable comeback in seabird diets as yet. Rather the salient response to date has been the ascendance of greenlings and other hexagrammids, as described above.

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.

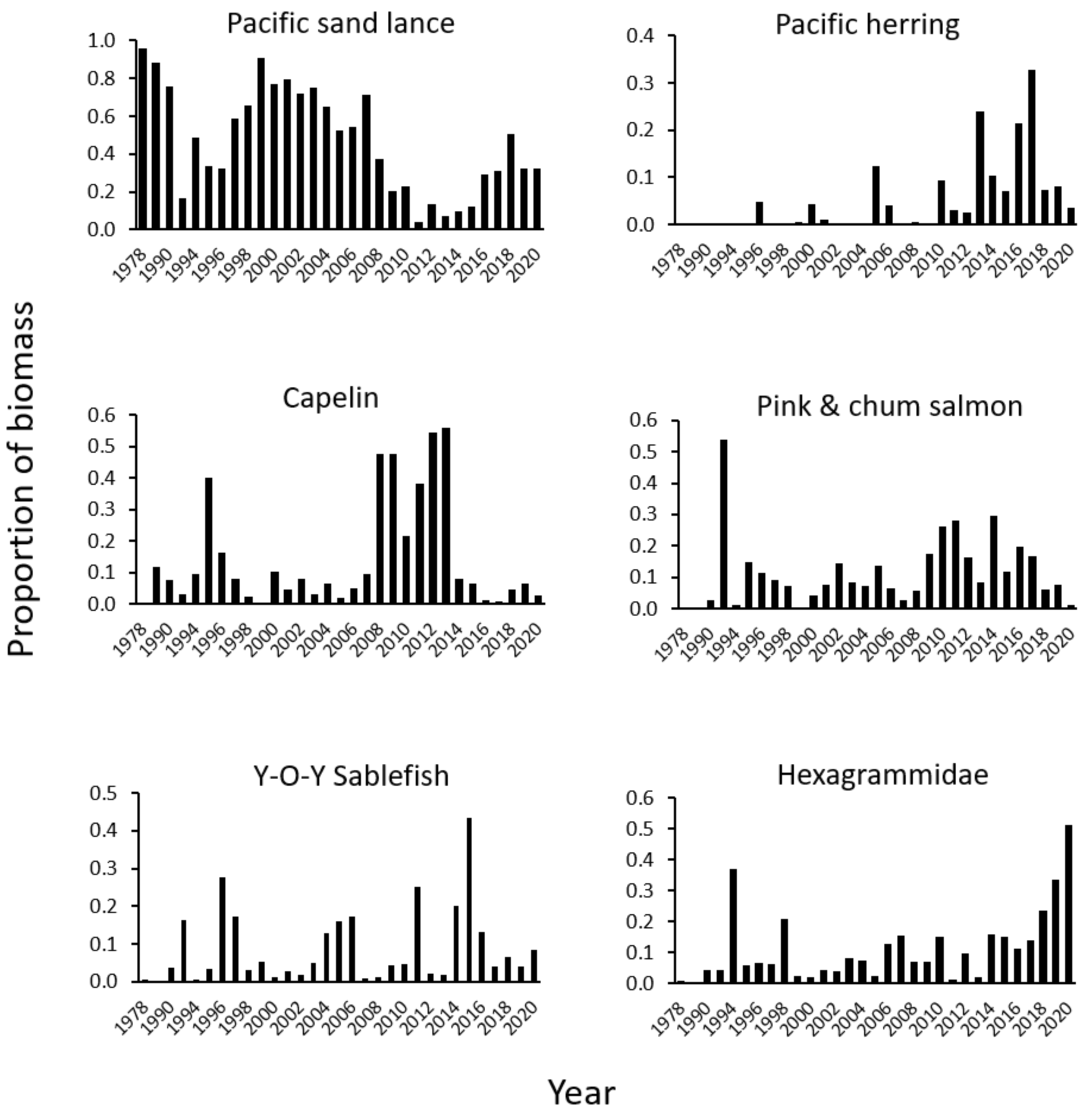

Figure 38: Prey species occurrence in the nestling diet of rhinoceros auklets on Middleton Island from 1978–2020.

Herring

Prince William Sound Herring

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Last updated: September 2020

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 used became more consistent beginning 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 39). There is not complete agreement about the cause of the decline in the early 1990s, but an outbreak of viral hemorrhagic septicemia (VHS) is one mechanism thought to be possibly responsible for the decline. After that decline, the population remained fairly steady. In recent years the BASA model estimated a declining trend in herring biomass, with a rapid increase beginning in 2019 (Figure 39). The decline in the observed mile-days of milt is more rapid than the model decline (Figure 40) but also shows a rapid increase starting in 2019. The rapid increase is associated with the recruitment of the large 2016 year class to the spawning biomass. The observed mile-days of milt in 2020 continued to increase as the 2016 year class continued to recruit into the spawning biomass.

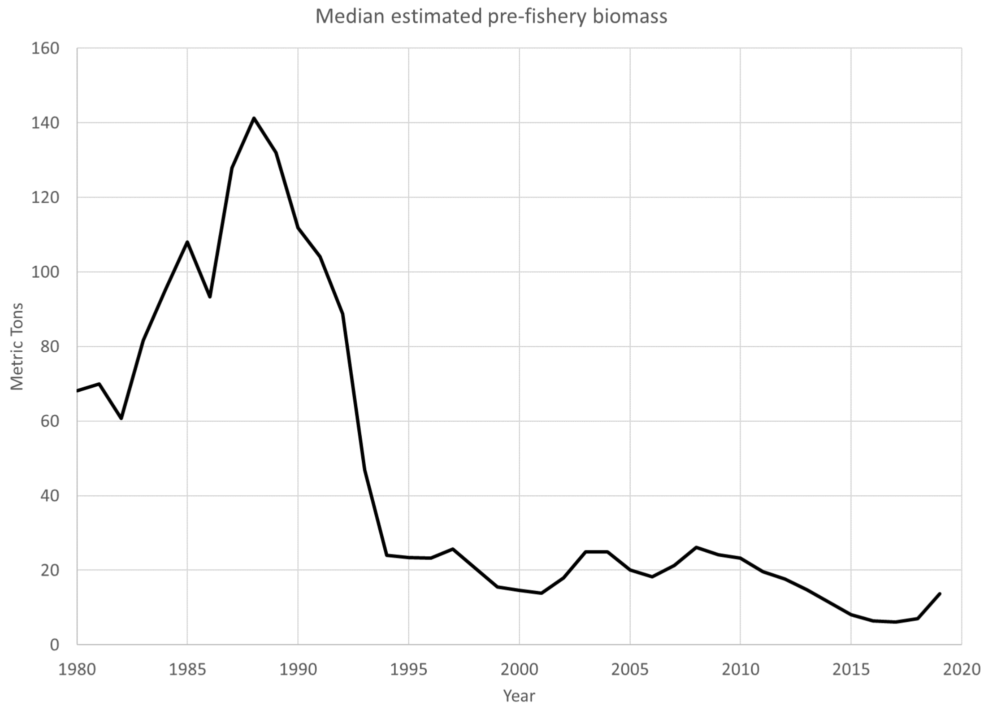

Figure 39: The Bayesian age-structured assessment model median estimate of the pre-fishery biomass.

Factors influencing observed trends: There was a peak in antibodies to the VHS virus observed in 2015 that is consistent with an outbreak of that pathogen between 2014 and 2015. The 2016 year class may have been a successful year class for herring throughout the Gulf of Alaska with recruit to spawner metrics across the region being nearly four times greater than the next most successful year class since 1980.

Implications: The herring population is beginning to increase but will need additional large year classes to join the spawning biomass to reach the levels observed as recently as 2014. It is possible that lower abundance of herring may have negative impacts on predators that rely on them.

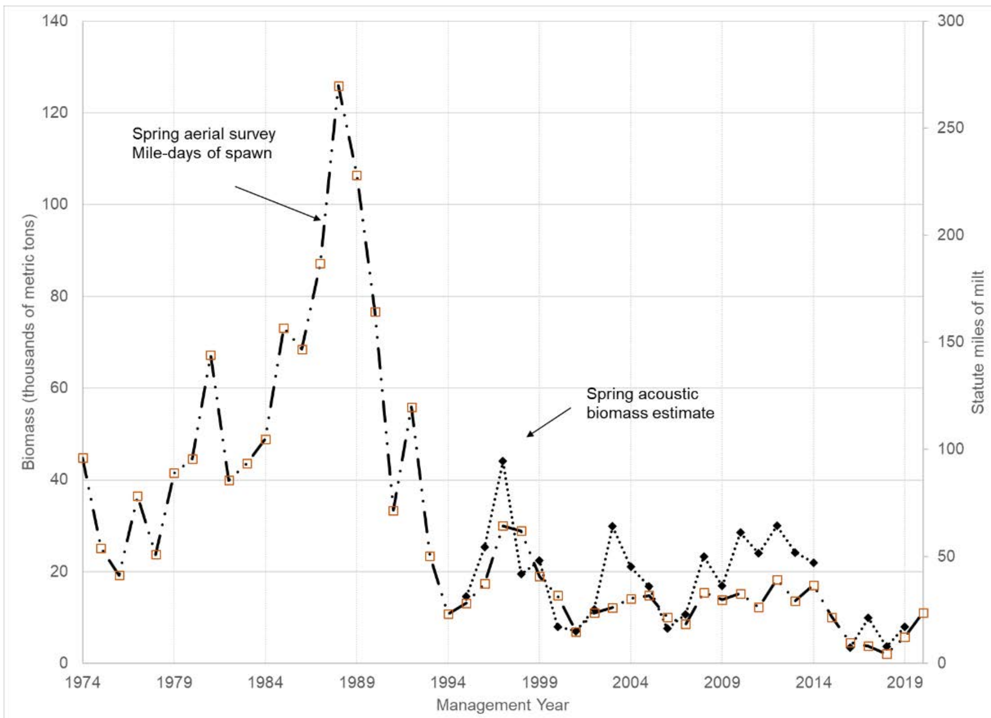

Figure 40: Mile-days of milt in Prince William Sound based on aerial surveys and biomass estimates from acoustic surveys. Includes preliminary results of the 2020 survey from Alaska Department of Fish and Game.

Southeastern Alaska Herring

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Last updated: September 2020

Description of indicator: Pacific herring (*Clupea pallasi*) stocks that reside in Southeast 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 in terms of 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 41). Monitoring of spawning stock size has been conducted at some of these areas for most years since at least the 1980s by the Alaska Department of Fish and Game, primarily by combining estimates of egg abundance with herring age and size information (Hebert, 2017). Starting in 2016, surveys and stock assessments were eliminated for many stocks in southeastern Alaska due to budget cuts. Although spawning at these nine areas accounts for a large proportion of the spawning biomass in southeastern Alaska in any given year, other areas typically of more limited spawning also exist throughout southeastern Alaska. However, little or no stock assessment activity occurs at these minor locations other than occassional and opportunistic aerial surveys to document the miles of milt along shoreline. The herring that spawn in all areas of Southeast Alaska are believed to be affected by the broad-scale 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 beginning in the early 1900s, with catch peaking in 1935, the most reliable estimates of biomass exist from those data collected since 1980, which are discussed here. In aggregate (all nine consistently monitored spawning areas combined), the biomass of Southeast Alaska herring has generally increased since 1980 (Figure 42). The combined biomass level remained relatively consistent until the late 1990s, at which time it began to increase. Age-structured assessment (ASA) 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 change in ocean temperature, 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 decreased substantially until 2015–2018. ASA modeling indicates that this may be attributed at least in part to lower survival rates for several years after the peak.

Following a period of generally low biomass during the 1980s through the mid-1990s, most Southeast Alaska stocks increased to their peaks between 2008–2011. Although the two largest and most consistently abundant stocks, Sitka Sound and Craig, declined substantially from their peaks of 2009 and 2011, respectively, they continued to be at moderate levels and well above the thresholds established to allow commercial fisheries. They then increased dramatically in 2019 following the highest recruitment of age-3 herring documented for these areas. Based on limited aerial surveys, other Southeast Alaska stocks appear to have declined to low levels over the past several years and in some cases to small fractions of their historical abundance (e.g. Hoonah Sound, Seymour Canal, Ernest Sound). Current biomass levels for these areas are unknown because stock assessment

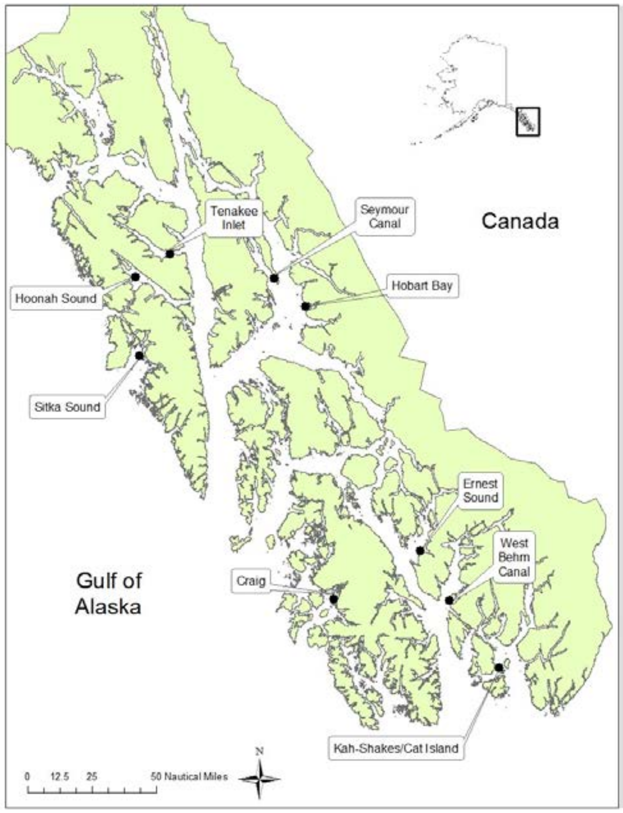

Figure 41: Location of nine Pacific herring spawning locations, historically surveyed in Southeast Alaska. Sitka Sound, Craig, and Kah-Shakes/Cat Island are considered "outside stocks" with greater ocean exposure, while all others are considered "inside stocks", less exposed to open ocean influence.

surveys were suspended starting in 2016, due to budget reductions.

Currently mature biomass for Sitka Sound and Craig herring is at a high level due to an extremely large recruitment event of age-3 herring observed in 2019. The 2019 recruitment event was by far the largest recruit class in the Sitka Sound and Craig model time series (since 1980 for Sitka Sound and since 1988 for Craig). Although survey estimates (egg deposition and age composition) for 2020 were not available at the time of publication, preliminary results indicate that egg deposition and the proportion of age-4 herring for Sitka and Craig stocks were very high, corroborating survey and model results from 2019 that the recruitment event in 2019 was indeed exceptional. A large percent of 2019 age-3 recruits was also observed in other southeast Alaska stocks (Kah Shakes-Cat Island, Seymour Canal, and Ernest Sound) and in other Gulf of Alaska stocks (Prince William Sound and Kodiak Island). Of the twelve surveys conducted for Gulf of Alaska herring stocks in 2018 and 2019, nine showed large increases in relative abundance indices in 2019 corresponding to the large recruitment. Although biomass has not recently been estimated for most Southeast Alaska stocks other than Sitka Sound and Craig, limited aerial surveys of spawn events suggest that although there were increases due to the 2019 recruitment, they are still at relatively low levels compared to spawn mileage in 1990–2010.

Factors influencing observed trends: Herring population abundance is known to fluctuate dramatically, and is susceptible to environmental influences (Toresen, 2001). The exact underly-

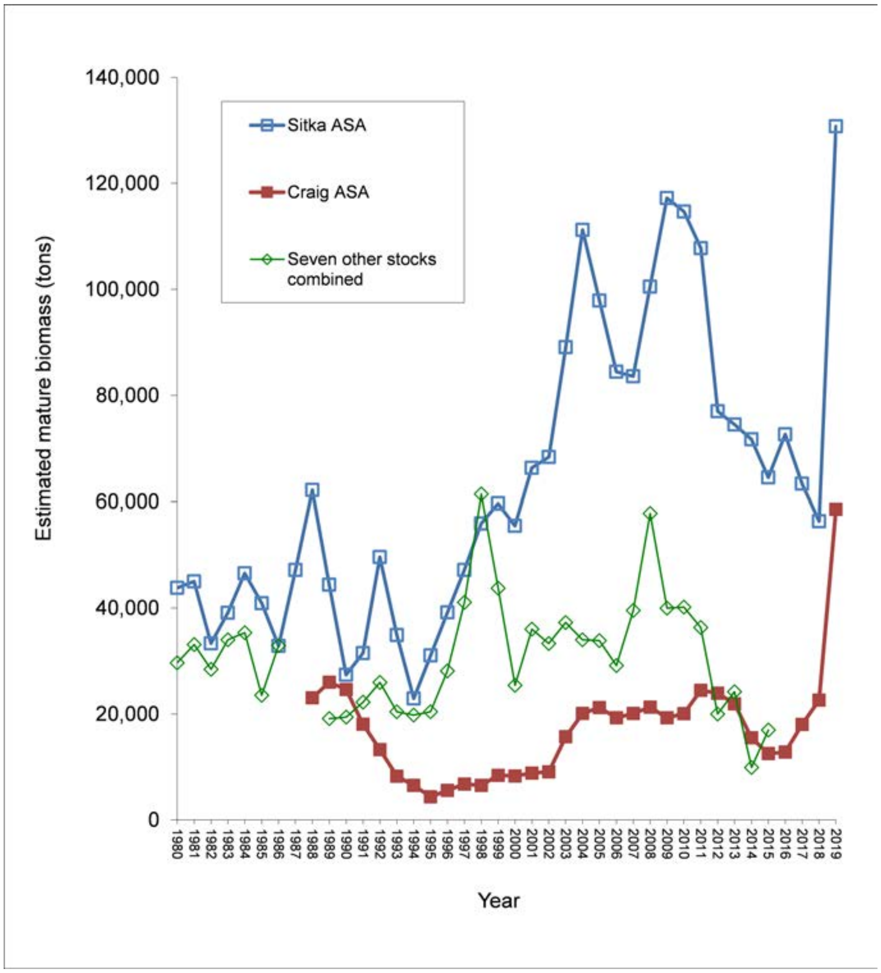

Figure 42: Estimated mature herring biomass (i.e. prefishery biomass) for nine important southeastern Alaska (SEAK) spawning areas, 1980–2019. Biomass estimates for Sitka and Craig are based on age-structured assessment (ASA) models and those for all other stocks, where ASA model estimates are not available, 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.

ing causes for the increase in the 1990's, decrease during about 2010-2018, and the exceptional recruitment in 2019 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), varying levels of predatory fish, or recent shifts in sea surface temperatures as reflected in the PDO, which could affect herring food sources, life history, spawn timing, and metabolism. While commercial fishing has occurred during some years for some stocks, the similar decline of inside stocks, which for some occurred in the absense of fishing, suggests that the decline may have been environmentally influenced.

The very high recruitment event of 2019 is unprecendented in recent times, since standardized stock assessments have been conducted, and it is unclear what caused it. Extremely high percentages of age-3 fish were also observed for other stocks in 2019 across the Gulf of Alaska, including Prince William Sound and Kodiak, indicating that the cause was of large scale. One possibility is that the unusually warm water mass that circulated through the northern Pacific Ocean during 2014—2016 (Gentemann et al., 2017), known commonly as "the Blob", contributed to increased survival of larval and/or juvenile stages of the 2016 brood year. Ocean temperature has been positively correlated with recruitment in Atlantic herring *Clupea harengus* (Toresen, 2001), and Pacific herring (Zebdi and Collie, 1995).

Implications: There appears to be a gradient between patterns of herring biomass observed for Southeast Alaska spawning stocks exposed directely to Gulf of Alaska waters (outside stocks) and those found in inside waters. While all spawning stocks exhibited a decline from about 2010, spawning stocks along the outer coast declined to moderate levels, while those of inside waters declined to low levels. The 2019 recruitment event has made the gradient appear more pronouced. While all Southeast Alaska spawning stocks sampled exhibited high percent of age-3 fish in 2019, the outer stocks increased from moderate to high biomass, whereas smaller inside stocks continued to remain low. The high herring biomass along the outer coast is expected to be available to support marine predators and fisheries for the next two to three years as the strong 2016 year class ages. Lower abundance of herring in inside waters may not support predators that rely on herring to the same extent as the 2010s, although there is not adequate information about populations of alternative forage species to understand the broader net impact on predators. The relatively short life-span of herring and the natural volatility of stock levels make it difficult to speculate on long-term implications to the ecosystem.

Salmon

Historical and Current Alaska Salmon Trends—Gulf of Alaska

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Last updated: September 2020

Description of indicator: This contribution provides historic and current commercial 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 (e.g., (Brenner et al., 2020) and on their website (`https://www.adfg.alaska.gov/`) .

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 commercial fisheries in Alaska; they are sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*).

Status and trends: *Statewide*—Catches from directed fisheries on the five salmon species have fluctuated over recent decades but in total have been generally strong (Figure 43). According to ADF&G, total salmon commercial harvests from 2019 totaled 207.9 million fish, which was about 5.3 million less than the preseason forecast of 213.2 million. The total statewide salmon harvest increased more than 92 million from 2018 to 2019, and was bolstered in 2019 by the catch of 128.6 million pink salmon. In 2020 ADF&G is projecting a decrease in the total commercial salmon catch down to 132.7 million fish, due to expected decreases in the number of pink and sockeye salmon. While all of the 2020 commercial salmon harvest data are not yet final, preliminary data from ADF&G for 2020 indicates that statewide total commercial salmon harvests are about 113.4 million (as of 22 September), which is below the preseason forecast but nearing the 2018 total harvest of 115.7 million fish.

Gulf of Alaska—In the Southeast region, 2019 salmon harvests totaled 33.5 million, which was 65% of the recent 10-year average harvest and 82% of the long-term average harvest. Pink salmon represented 63% of the total number of salmon harvested in 2019. Since 2006, pink salmon returns have followed a cycle of strong odd years and weak even years, and that pattern continued in 2019 with a commercial catch of 21.2 million fish. Preliminary data for 2020 indicate a much lower catch of 7.8 million pink salmon, which is slightly less than the last even-year pink salmon harvest of 7.9 million in 2018.

The 2019 harvest of Chinook, sockeye, and coho salmon in the Southeast region were all below their respective long-term average harvests and recent 10-year average harvests. The Chinook salmon harvest of 188,000 was the third lowest since 1962. Preliminary 2020 data indicate an increase in Chinook salmon harvest to 208,000 fish and a decrease in sockeye salmon harvest to 371,000 fish.

In the Kodiak management area, the 2019 total salmon harvest of 36.1 million fish was above the recent 10-year average harvest of 21.2 million fish. The 2019 sockeye salmon commercial harvest of 2.2 million was near the recent 10-year average and preseason forecast of 2.3 million. The 2019 pink salmon harvest of 33.0 million was above the recent 10-year average harvest of 17.8 million. Preliminary 2020 data indicates the total harvest will decrease to about 23.6 million but remain above the recent 10-year average of 21.8 million.

In the Prince William Sound Area of the Central region, the 2019 total commercial salmon harvest was 57.2 million fish, of which 48.7 million were pink salmon. The 2019 pink salmon harvest was 18% below the recent 5-year odd-year average. Preliminary harvest numbers for 2020 show the total harvest to be about 24.9 million, including 21.7 million pink salmon.

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 43). 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). 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.

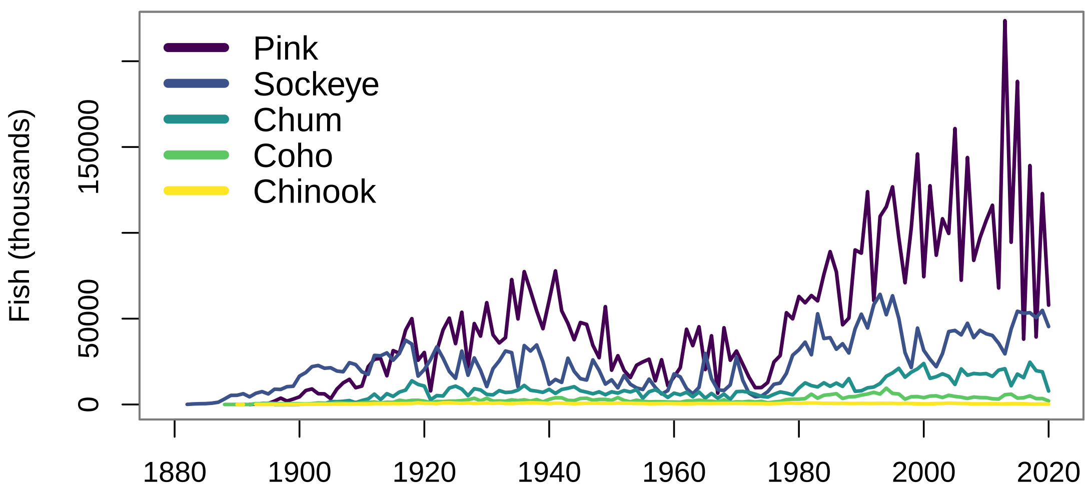

Figure 43: Alaska historical commercial salmon catches, 2020 values are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.)

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. However, preliminary data for 2020 indicates the total salmon catch in Southeast Alaska will be well below the recent 10-year and long-term means.

Juvenile Salmon Abundance in Icy Strait, Southeast Alaska

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Last updated: September 2020

Description of indicator: Information on fish, zooplankton, and oceanographic conditions in Southeast Alaska (SEAK) are collected during the Southeast Alaska Coastal Monitoring (SECM) surveys (Fergusson et al., 2020; Murphy et al., 2020). SECM data are used in a variety of research applications, however the information on juvenile salmon *(Oncorhynchus spp.)* abundance is a key data product due to its use in harvest and run forecast models (Murphy et al., 2019). SECM surveys and salmon forecast models (`http://www.adfg.alaska.gov/static/applications/dcfnewsrelease/1126221367.pdf`) are part of a cooperative research effort by the Alaska Fisheries Science Center (AFSC) and the Alaska Department of Fish and Game (ADF&G) in support of salmon stocks and fisheries in SEAK.

Juvenile salmon abundance indices are constructed from surface (0–20m) rope trawl catches in Icy Strait, the northern migratory corridor between the inside waters of SEAK and the Gulf of Alaska. Abundance indices are the peak monthly average log-transformed catch-per-unit-effort (CPUE) data in Icy Strait during the months of June and July, and are adjusted for fishing power differences between the survey vessels that have conducted SECM surveys over time (Wertheimer et al., 2010). CPUE data for juvenile pink *(O. gorbuscha)*, chum *(O keta)*, sockeye *(O. nerka)*, and coho *(O. kisutch)* salmon are included in (Figure 44).

Status and trends: Juvenile salmon abundance (CPUE) has been below average for the last four years, and juvenile abundance in 2017 was the lowest recorded for pink, chum, and sockeye salmon in the history of the SECM project (Figure 44). Juvenile catch rates of pink and chum salmon were both higher in 2020 than 2019; however, catch rates of sockeye and coho salmon were down slightly from 2019.

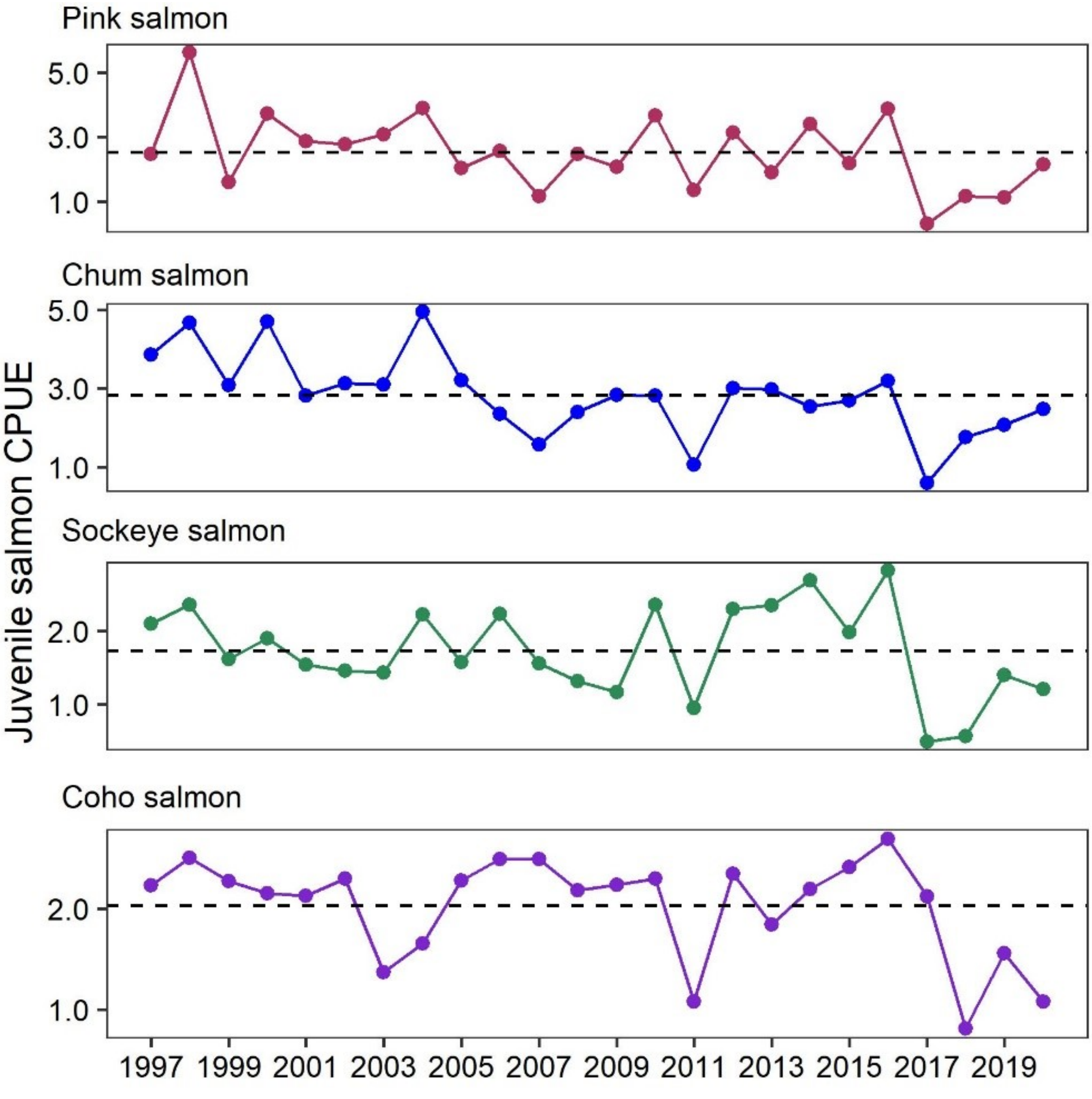

Figure 44: Time series of juvenile salmon catch rates (number of fish per hour) during southeast Coastal Monitoring (SECM) surveys from 1997–2020.

Factors influencing observed trends: Multiple factors contribute to the variation in juvenile salmon catch rates over time and the relative importance of these factors differ by species. However, the dominant factor is believed to be the early life-history survival of salmon. There are a couple of important exceptions to survival with pink salmon. Escapement goals have not been met in recent even-year runs of pink salmon within the northern inside region of SEAK, and this is likely an important contributor to the odd-even year pattern present in juvenile pink salmon abundance. Catch rates of juvenile pink salmon are corrected for temperature in harvest forecast models, and this correction is believed to reflect the effect of temperature on juvenile migration and survey capture rates (Murphy et al., 2019). The pink salmon index therefore reflects a combination of survival, escapement, and migration; however, the most important factor is believed to be survival. Hatcheries accounted for approximately 87% of the chum salmon harvested in SEAK from 2010 to 2019, therefore the dominate factor influencing the juvenile chum salmon index is expected to be early marine survival. Freshwater and early marine survival are both important factors in the abundance indices for sockeye and coho salmon as these species typically spend at least one full year in freshwater before migrating to sea.

Implications: Juvenile pink and chum salmon catch rates are significantly related to adult returns to SEAK. Although juvenile models have not yet been developed for sockeye and coho salmon, it is likely that comparable relationships exist for these species. Salmon harvests were at extreme low levels in 2020 (Figure 45). The low abundance of juvenile chum and sockeye in 2017 is likely the key contributor to the poor harvest in 2020 as these two species spend 2–4 years in the ocean before returning as adults to spawn and age-3 ocean fish typically dominate returns for many stocks. The increase in juvenile abundance after 2017 should indicate that harvests will recover over the next few years. However, we expect harvests to remain below average with below average juvenile abundance.

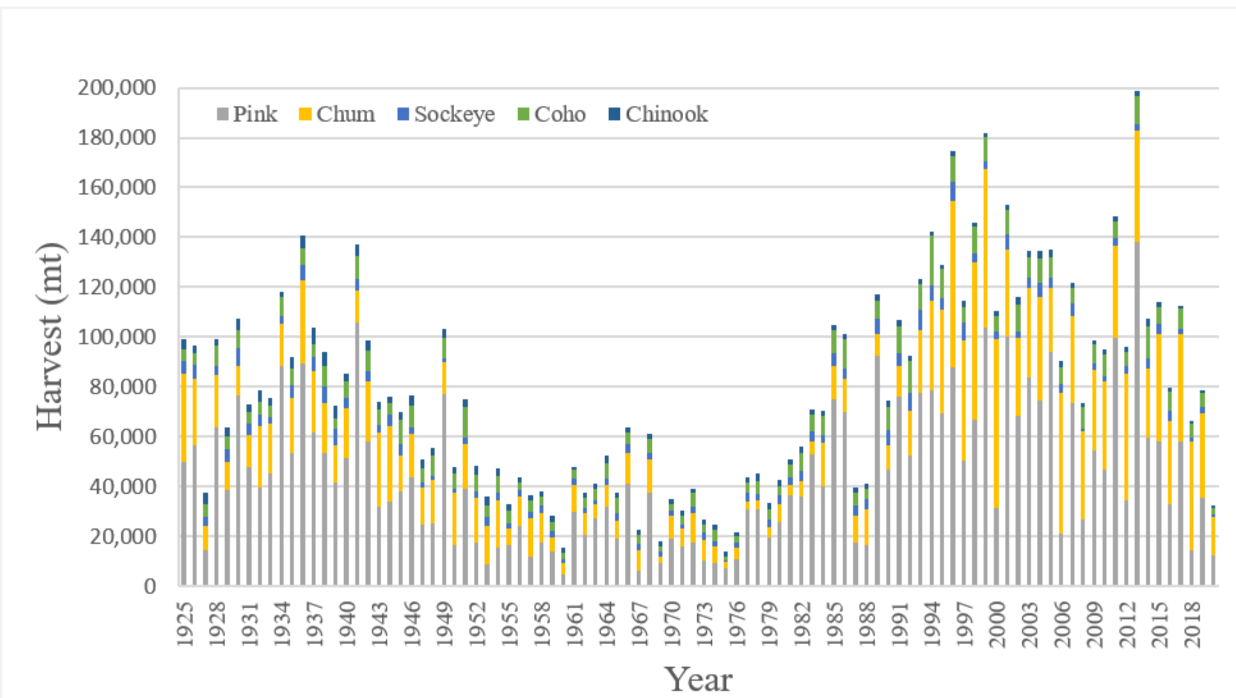

Figure 45: Commercial harvest (mt) of salmon in Southeast Alaska, 1925–2020. The 1925–2019 harvest data are provided by ADF&G and available at `www.npafc.org`. The 2020 harvest data are preliminary data up to Sep 22, 2020 and provided by Rich Brenner, ADF&G.

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

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Last updated: September 2020

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., 2020; Murphy et al., 2020). 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 (fork length) through 2020 and energy density data through 2019 for juvenile salmon in Icy Strait.

Status and trends: IIn 2020, juvenile salmon lengths decreased from 2019 values except for coho salmon. For juvenile pink, chum, and sockeye salmon, length values decreased from above average to close to the 24 year average (Figure 46). Juvenile coho salmon length values increased to average values, continuing the trend observed over the previous two years.

In 2019, juvenile pink and sockeye salmon energy densities (ED, kJ/g dry weight) were above average and increased from the 2018 values (Figure 47). Chum salmon energy density decreased from above to below average. Coho salmon energy density remained at average levels, similar to the previous two years.

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 outmigrating juvenile pink and coho salmon in 2017 and 2018 may have resulted from low escapement in 2015 and 2016 and/or low freshwater survival (Murphy et al., 2020).

Implications: The average size values observed for the juvenile salmon reflect the colder water temperatures experienced by the fish during the early marine residency in Icy Strait. Larger fish generally have increased foraging success and decreased predation risk resulting in higher survival. These fish entered the Gulf of Alaska in 2020 with average size so further growth and survival will be dependent on favorable resources being available over winter in the Gulf of Alaska. The pink and sockeye salmon above average energy densities indicates that these fish entered the Gulf of Alaska in 2019 with above average energy stores which may contribute to higher survival. The decrease in chum salmon energy density indicates that these fish entered the Gulf of Alaska in 2019 with below average energy stores which may contribute to lower survival.

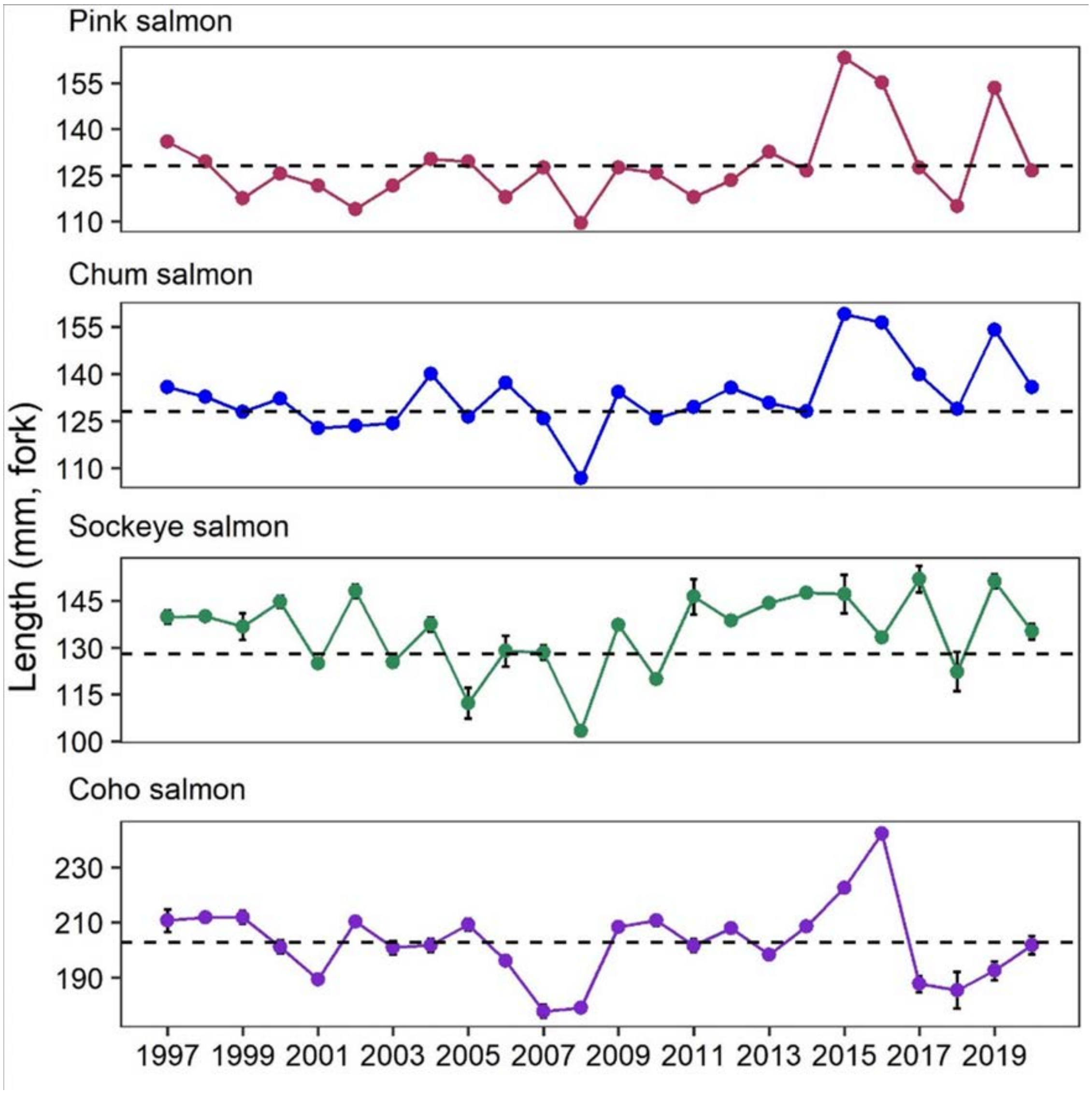

Figure 46: Average fork length (mm; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2020. Time series average is indicated by the dashed line.

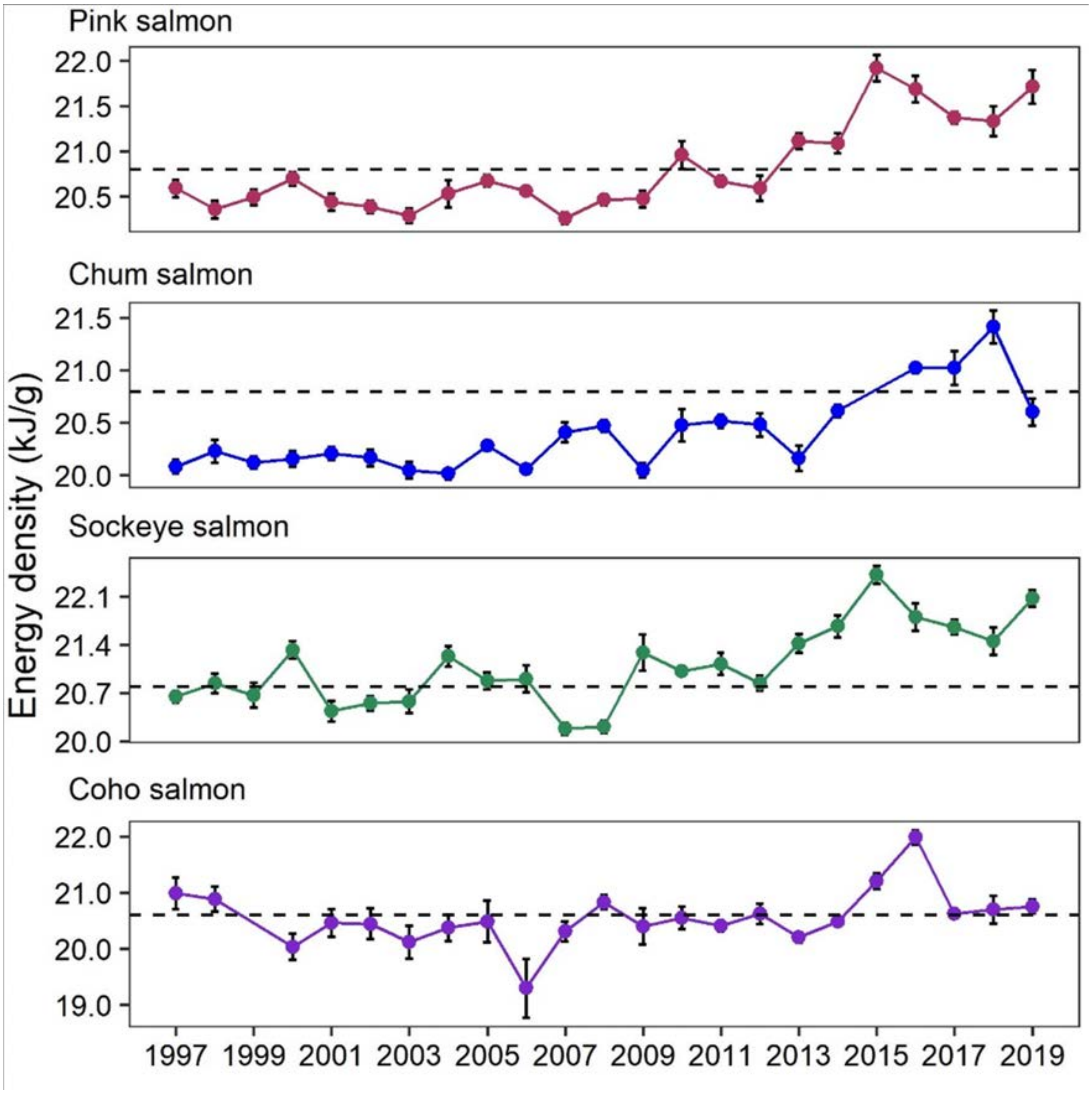

Figure 47: Average energy density (kJ/g, dry weight; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2019. Time series average is indicated by the dashed line.

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

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Last updated: September 2020

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 the series is an excellent choice for 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 1.1% to 53.3%, with an average survival of 11.2% from ocean entry years 1980–2019 (Figure 48). Marine survival for the 2019 ocean entry year was 20.7% and overall survival averaged 8.9% over the last 5 years and 15.5% over the last 10 years. 2020 saw the 4th lowest return of pink salmon to Auke Creek with 1304 returning adults (Figure 49).

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

During juvenile development, the local conditions of stream discharge and temperature are strong determinants of egg and fry survival. 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). 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 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

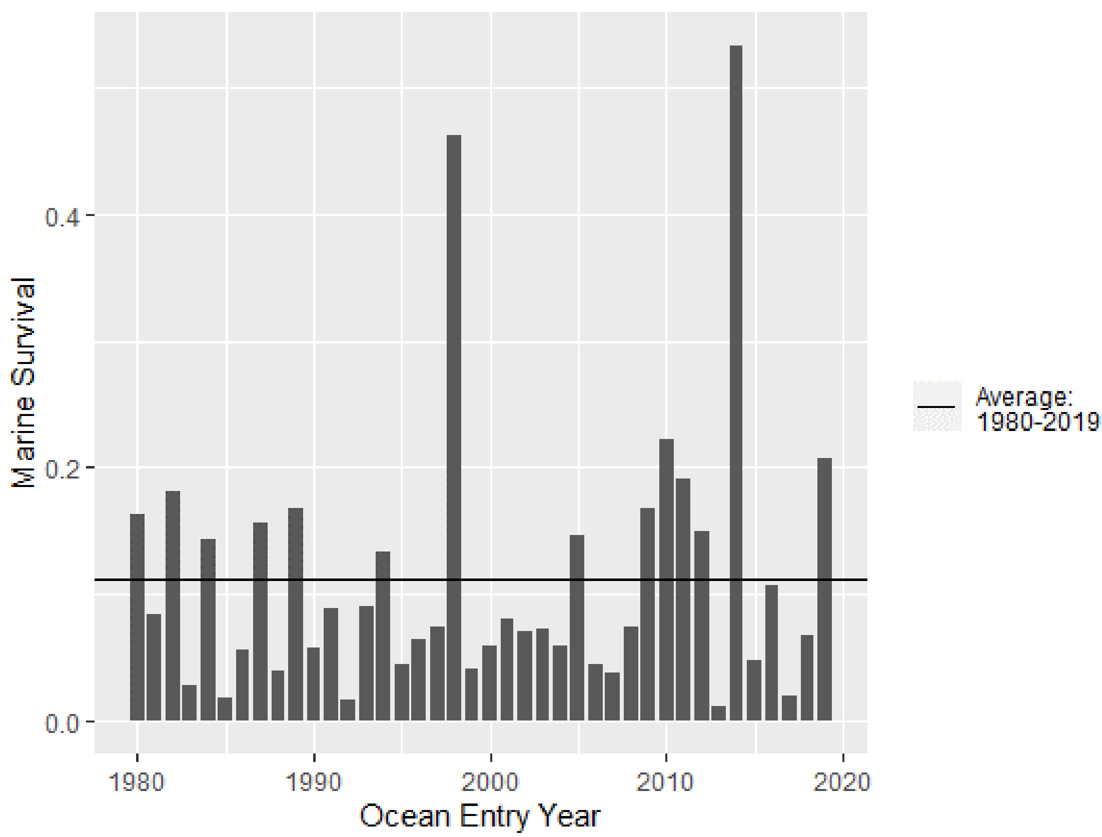

Figure 48: Auke Creek pink salmon marine survival index by ocean entry year.

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 an abundant 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.

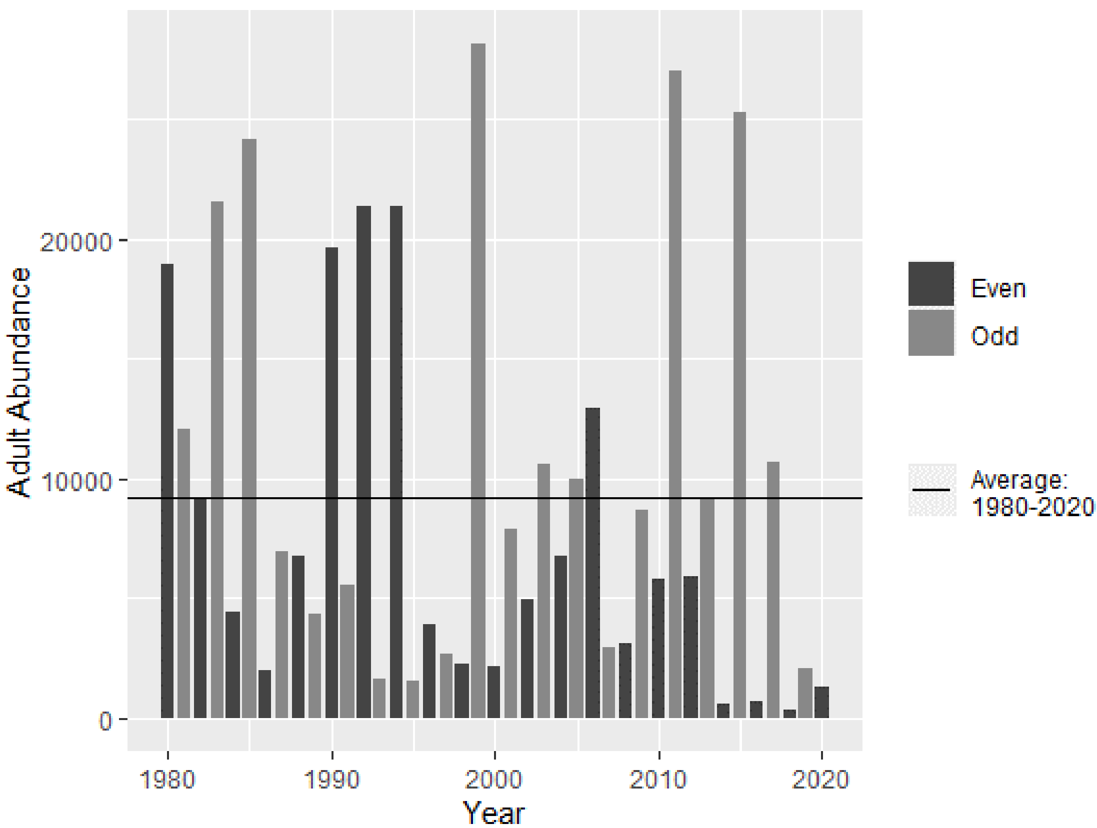

Figure 49: Auke Creek pink salmon adult returns by year.

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

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Last updated: September 2020

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 Laboratory 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 41 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 high 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 wild, CWT coho salmon as ocean age-0 and age-1 classes.

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% from smolt years 1980–2019 (Figure 50; top panel). Marine survival for 2019 was the nineth lowest on record at 14.5%, and overall survival averaged 8.8% over the last 5 years and 14% over the last 10 years. The survival index for ocean age-1 coho varies from 3.9% to 36.6% from smolt years 1980–2019 (Figure 50; middle panel) and for ocean age-0 coho varies from 0.2% to 11.2% from smolt years 1980–2019 (Figure 50; bottom panel). Return data for 2020 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 among the lowest on record at ∼11% (marine survival was at 11% as of 25 September 2020, with recent fishery and escapement counts still ongoing).

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 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.

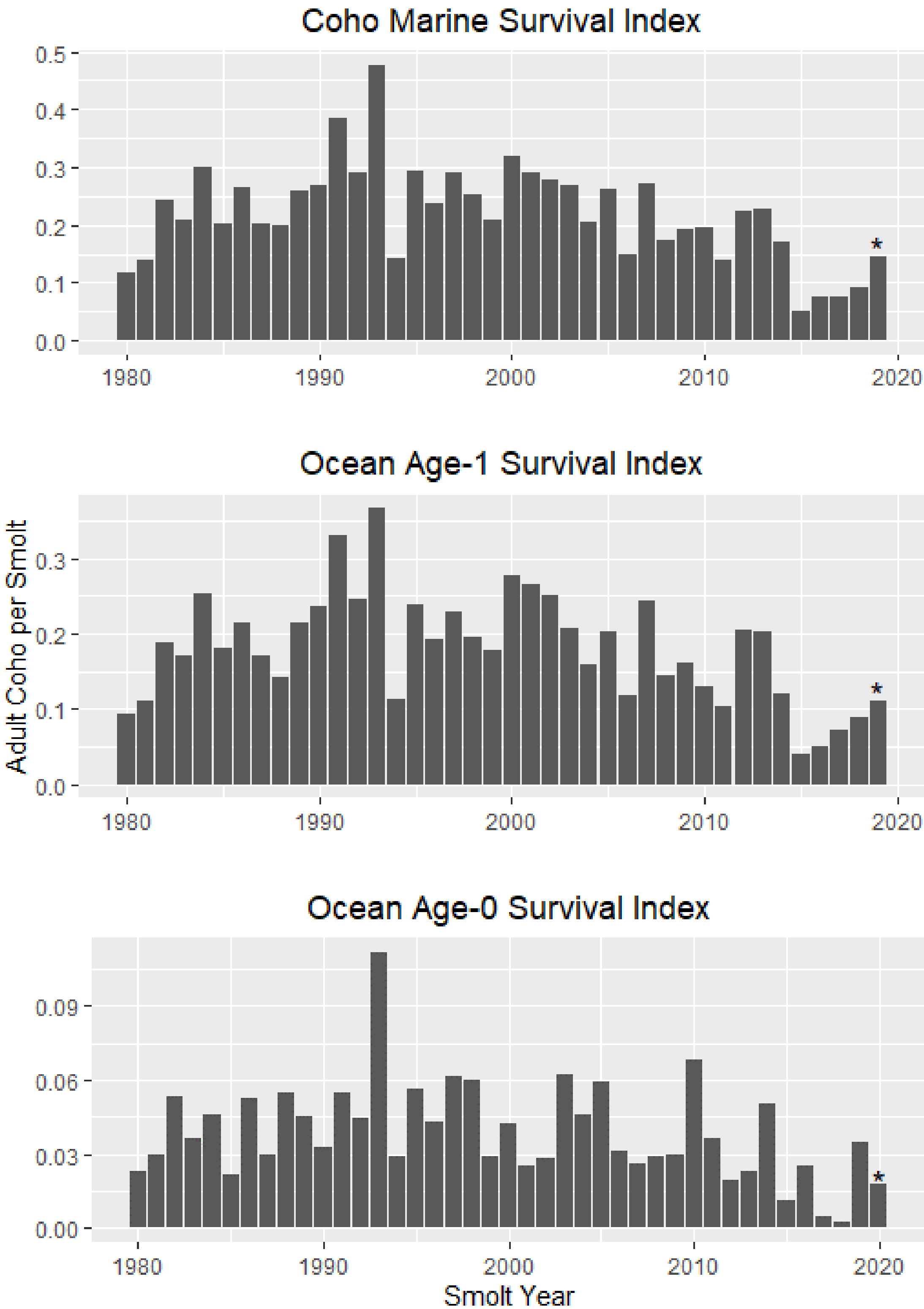

Figure 50: Auke Creek coho salmon marine survival indices showing total marine survival (ocean age-0 and age-1 harvest plus escapement; top panel), percentage of ocean age-1 coho per smolt (harvest plus escapement; middle panel), and percentage of ocean age-0 coho per smolt (escapement only; bottom panel) by smolt year. Return year 2020 data are denoted with an asterisk as these may change by the end of the coho return.

Wild Productivity and Escapement of Sockeye Salmon from Auke Creek, Southeast Alaska

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Last updated: September 2020

Description of indicator: The time series of wild productivity and escapement for sockeye salmon from the Auke Creek Research Station in Southeast Alaska is the longest-running continuous series available in the North Pacific, spanning 41 years. The Auke Creek weir structure facilitates near-complete capture of all migrating sockeye smolt and returning adults, and is the only weir capable of such precision on a wild system in the North Pacific. While no stock-specific harvest information is available for Auke Creek sockeye salmon for a direct estimation of marine survival, the precision of this long-term dataset is still unmatched and the series is an excellent choice for model input relating to nearshore and gulf-wide productivity.

Status and trends: The historical trend shows productivity of wild sockeye salmon smolts from Auke Creek varies from 1619 to 33616, with an average productivity of 16343 from ocean entry years 1980–2020. Productivity for the 2020 saw 7347 outmigrant smolts, the fifth lowest on record (Figure 51). Escapement of wild sockeye salmon smolts from Auke Creek has varied from 325 to 6123, with an average escapement of 2641 from return years 1980–2020. The 2020 season saw the second lowest escapement of sockeye salmon to Auke Creek with 705 returning adults (Figure 52).

Factors influencing observed trends: Factors influencing observed trends include: smolt age, smolt size, migration timing, predation, and marine environmental conditions. Age and size at saltwater entry, along with regional sea surface temperate have been shown to influence juvenile mortality at ocean entry (Yasumiishi et al., 2016). Within the Auke Creek watershed, a system undergoing rapid climatic change, climate-induced phenological shifts have been shown to influence a trend of later migration of sockeye adults and age-1 smolts, while age-2 smolts are trending earlier (Kovach et al., 2013; Shanley et al., 2015). Additionally, positive effects of temperature have been observed on sockeye biomass and length of age-2 smolts in the Auke Creek system (Kovach et al., 2014). In Southeast Alaska, sablefish have been observed to prey upon juvenile sockeye in early summer before more abundant food resources become available (Sturdevant et al., 2009).

Implications: The productivity and escapement of Auke Creek sockeye salmon is related to large-scale ocean productivity indices and to important rearing habitats of many southeast Alaska groundfish species.The productivity and escapement indices of Auke Creek sockeye salmon provide an opportunity for the examination of annual variation in habitat quality of rearing areas and general ocean conditions and productivity. Within Southeast Alaska, sockeye salmon productivity and escapement are of great interest to the Pacific Salmon Commission with relation to the Transboundary and Northern Boundary areas and indices such as Auke Creek help in assessment. As a result of these implications, the productivity and escapement of Auke Creek sockeye salmon provide valuable proxies for Gulf of Alaska and Southeast Alaska productivity, and may provide insight to the overwintering survival and recruitment of sablefish and other groundfish species.

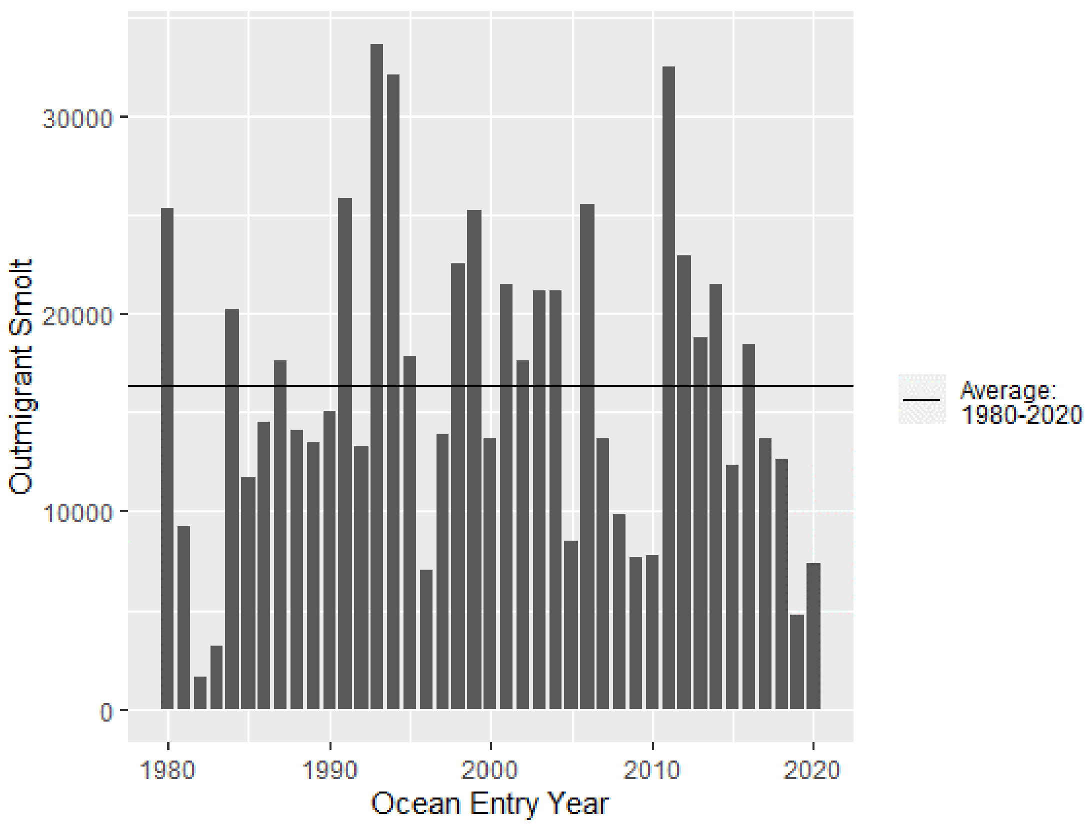

Figure 51: Auke Creek sockeye salmon smolt productivity by ocean entry year

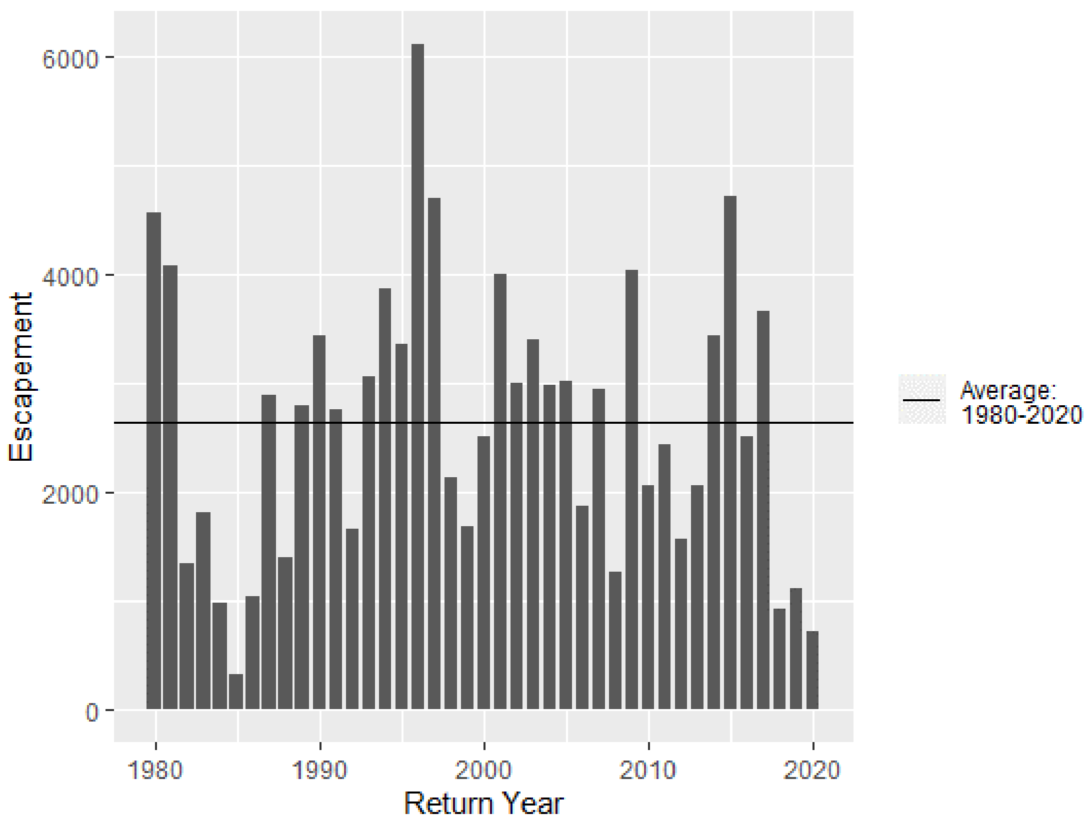

Figure 52: Auke Creek sockeye salmon adult returns by year.

Groundfish

Gulf of Alaska Groundfish Condition

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Last updated: September 2020

Description of indicator: Residual body condition computed from a long-term average of length-weight-based body condition is an indicator of variability in somatic growth (Brodeur et al., 2004) and represents how heavy a fish is per unit body length. As such, it can be considered an indicator of ecosystem productivity. Positive residual body condition is interpreted to indicate fish in better condition (heavier per unit length) than those with negative residual body condition indicating poorer condition (lighter per unit length). Overall body condition of fishes likely reflects fish growth which can have implications for their subsequent survival (Paul and Paul, 1999; Boldt and Haldorson, 2004).

Paired lengths and weights of individual fishes were examined from the Alaska Fisheries Science Center biennial Resource Assessment and Conservation Engineering (AFSC/RACE) - Groundfish Assessment Program's (GAP) bottom trawl survey of the Gulf of Alaska (GOA). Analyses focused on walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), arrowtooth flounder (*Atheresthes stomias*), southern rock sole (*Lepidopsetta bilineata*), northern rockfish (*Sebastes polyspinis*), Pacific ocean perch (*Sebastes alutus*), and dusky rockfish (*Sebastes variabilis*) collected in trawls with satisfactory performance at standard survey stations. Data were combined in the International North Pacific Fisheries Commission (INPFC) strata; Shumagin, Chirikof, Kodiak, Yakutat and Southeast (Figure 53).

Length-weight relationships for each of the seven species were estimated within each stratum across all years where data were available (1984–2019) from a linear regression of log-transformed exponential growth, W = aLb, where W is weight (g) and L is fork length (mm). A different slope was estimated for each stratum to account for spatial-temporal variation in growth and bottom trawl survey sampling. Length-weight relationships for 100–250 mm fork length (1–2 year old) walleye pollock were established independent of the adult life history stages caught. Bias-corrected weights-at-length (log scale) were estimated from the model and subtracted from observed weights to compute individual residuals per fish. Length-weight residuals were averaged for each stratum and weighted in proportion to INPFC stratum biomass based on stratified area-swept expansion of summer bottom trawl survey catch per unit effort (CPUE). Average length-weight residuals were compared by stratum and year to evaluate spatial variation in fish condition. Combinations of stratum and year with <10 samples were used for length-weight relationships but excluded from indicator calculations.

Methodological Changes: The method used to calculate groundfish condition this year (2020) differs from previous years in that: 1) different regression slopes were estimated for each stratum, 2) a bias-correction was applied when predicting weights prior to calculating residuals, 3) stratum mean residuals were weighted in proportion to stratum biomass, and 4) stratum-year combinations with sample size <10 were not used in indicator calculations. As in previous years, confidence intervals for the condition indicator reflect uncertainty based on length-weight residuals, but are larger due to differences in sample sizes and stratum biomasses among years. Confidence intervals do not account for uncertainty in stratum biomass estimates.

Status and trends: Residual body condition varied amongst survey years for all species considered (Figure 54). The updated computational methods used to calculate this year's residual body condition indexes returned different values than those reported last year (Laman, 2019). The patterns of above or below average residual condition observed in 2019 largely match those generated here from the updated computations, but with a notable reduction in magnitude for most years. The lower magnitude results come from using stratum-specific regression coefficients and samples weighted in proportion to biomass which reduces the influence of spatio-temporal variation in sampling intensity on the residuals. Some exceptions are 2009 southern rock sole, reported to have above average condition in 2019, shifted to neutral or slightly negative here and, for 2003 northern rockfish, residual condition calculated with the updated method here was higher above the long-term condition average than was reported in 2019. Based on these new methods, body condition is still below average for most species since 2015 (e.g., large walleye pollock, arrowtooth flounder, dusky rockfish) with some species trending downward over that time period (e.g., northern rockfish and possibly Pacific ocean perch). Residual body condition of Pacific cod and southern rock sole is trending upward over the same time, although southern rock sole remain below average. Prior to 2011, residual body condition indexes of these GOA species vary from survey to survey, cycling between negative and positive residuals with no clear temporal trends. Residual body condition of 100–250 mm walleye pollock in the GOA is strikingly positive during early years in the time series, but has remained mostly neutral or slightly negative since the early 1990s.

The general patterns of above and below average residual body condition index across recent survey years for the Gulf of Alaska as described above was also apparent in the spatial condition indicators across INPFC strata (Figure 55). The relative contribution of stratum-specific residual body condition to the overall trends (indicated by the height of each colored bar segment) does not demonstrate a clear pattern. Although, for many species, the direction of residual body condition (positive or negative) was synchronous amongst strata within years. Patterns of fish distribution are also apparent in the stratum condition indexes. For example, Northern rockfish have primarily been collected from the Shumagin and Chirikof strata in recent surveys. The trend of increasingly positive Pacific cod residuals appears to be largely driven by a shift in residual body condition in the Kodiak and Shumagin strata.

Factors influencing observed trends: Factors that could affect residual fish body condition presented here include temperature, trawl survey timing, stomach fullness, movement in or out of the survey area, or variable somatic growth. Since the Warm Blob in 2014 (Bond et al., 2015; Yang et al., 2019), there has been a general trend of warming ocean temperatures in the survey area through 2018 that could be affecting fish growth conditions there. Changing ocean conditions along with normal patterns of movement can cause the proportion of the population resident in the sampling area during the annual bottom trawl survey to vary. The date that the first length-weight data are collected is generally in late May and the bottom trawl survey is conducted throughout the summer months moving from west to east so that spatial and temporal trends in fish growth over the season become confounded with survey progress. In addition, spatial variability in residual condition may also reflect local environmental features which can influence growth and prey availability in the areas surveyed (e.g., warm core eddies in the central Gulf of Alaska; (Atwood et al., 2010). The updated condition analyses presented here begin to, but do not wholly account for spatio-temporal

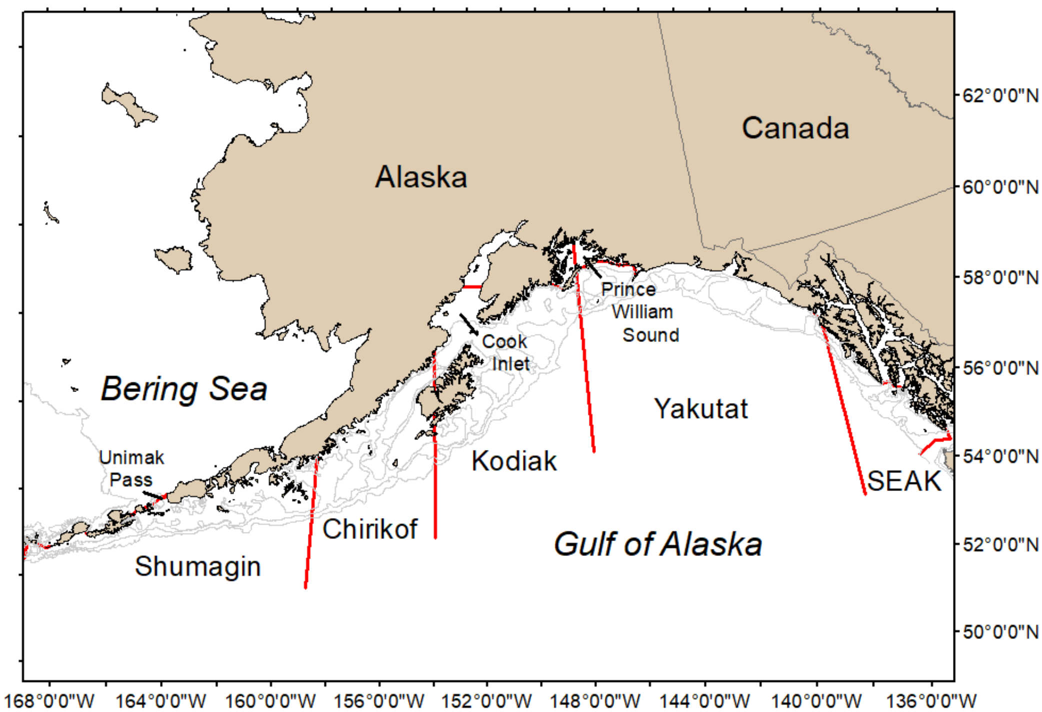

Figure 53: AFSC/RACE Groundfish Assessment Program summer bottom trawl survey area in the Gulf of Alaska; red lines demarcate International North Pacific Fisheries Commission statistical fishing Areas.

variability in the underlying populations sampled.

Implications: Variations in body condition likely have implications for fish survival. In Prince William Sound, the condition of herring prior to the winter may influence their survival (Paul and Paul, 1999). The condition of Gulf of Alaska groundfish may similarly contribute to survival and recruitment. As future years are added to the time series, the relationship between length-weight residuals and subsequent survival will be examined further. It is important to consider that residual body condition for most species in these analyses was computed for all sizes and sexes combined. Requirements for growth and survivorship differ for different fish life stages and some species have sexually dimorphic growth patterns. It may be more informative to examine life-stage (e.g., early juvenile, subadult, and adult phases) and sex-specific body condition in the future.

The trend toward lowered body condition for many Gulf of Alaska species over the last 3–4 RACE/AFSC GAP 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 Warm Blob (Bond et al., 2015; Yang et al., 2019) has been followed by subsequent years with elevated water temperatures (e.g. Barbeaux et al., 2020; Laman, 2018) 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

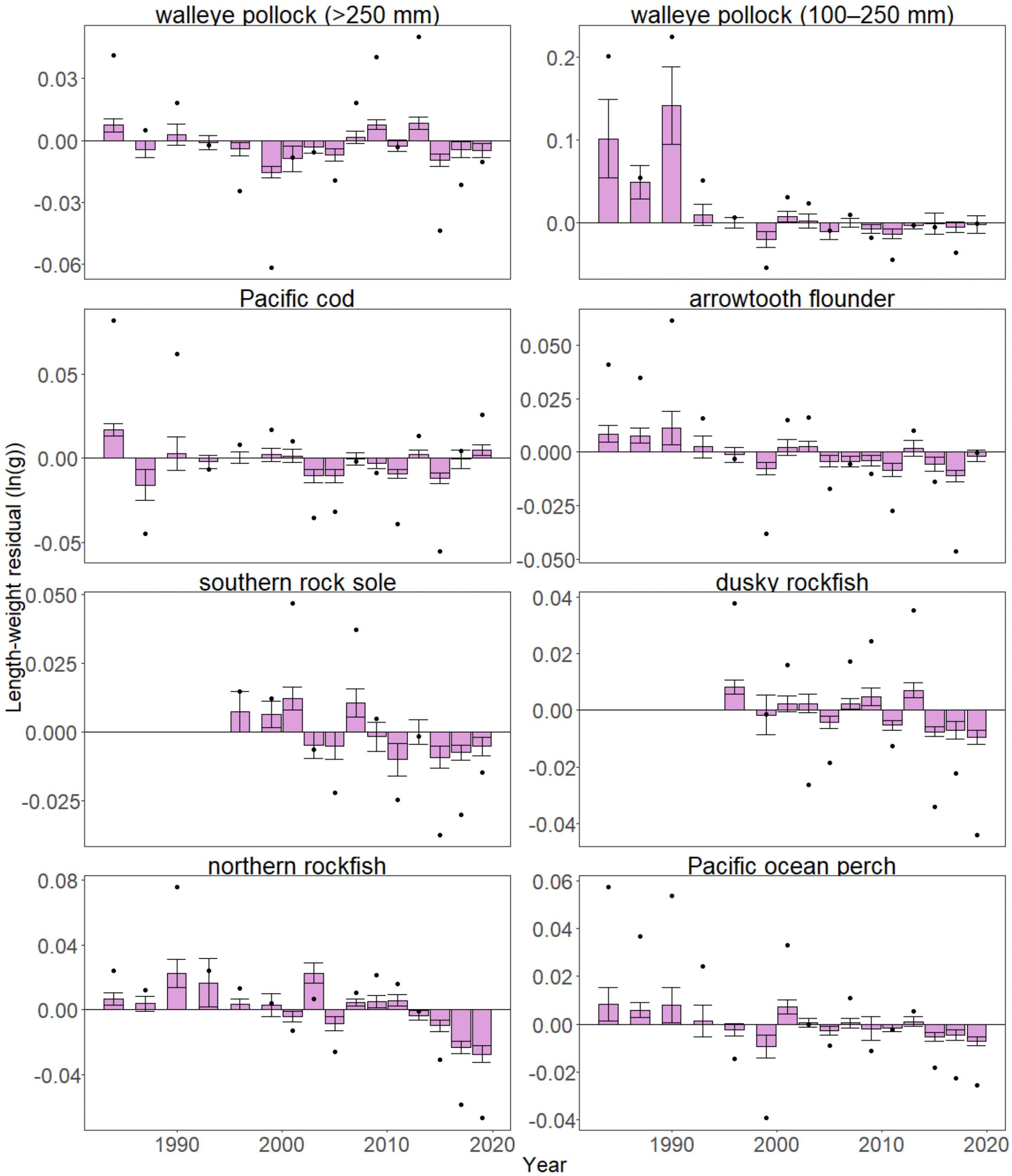

Figure 54: Biomass-weighted, length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985–2019. Filled bars denote weighted length-weight residuals using this year's indicator calculation, error bars denote two standard errors, points denote the mean of the unweighted length-weight residual from the previous year's (2019) ESR

our knowledge of the relationships between condition, growth, production, and survival, we hope to gain more insight into the overall health of fish populations in the Gulf of Alaska.

Research priorities: Efforts are underway to redevelop the groundfish condition indicator for next year's (2021) ESR, using a spatio-temporal model with spatial random effects (VAST). The change is expected to allow more precise biomass expansion, improve estimates of uncertainty, and better

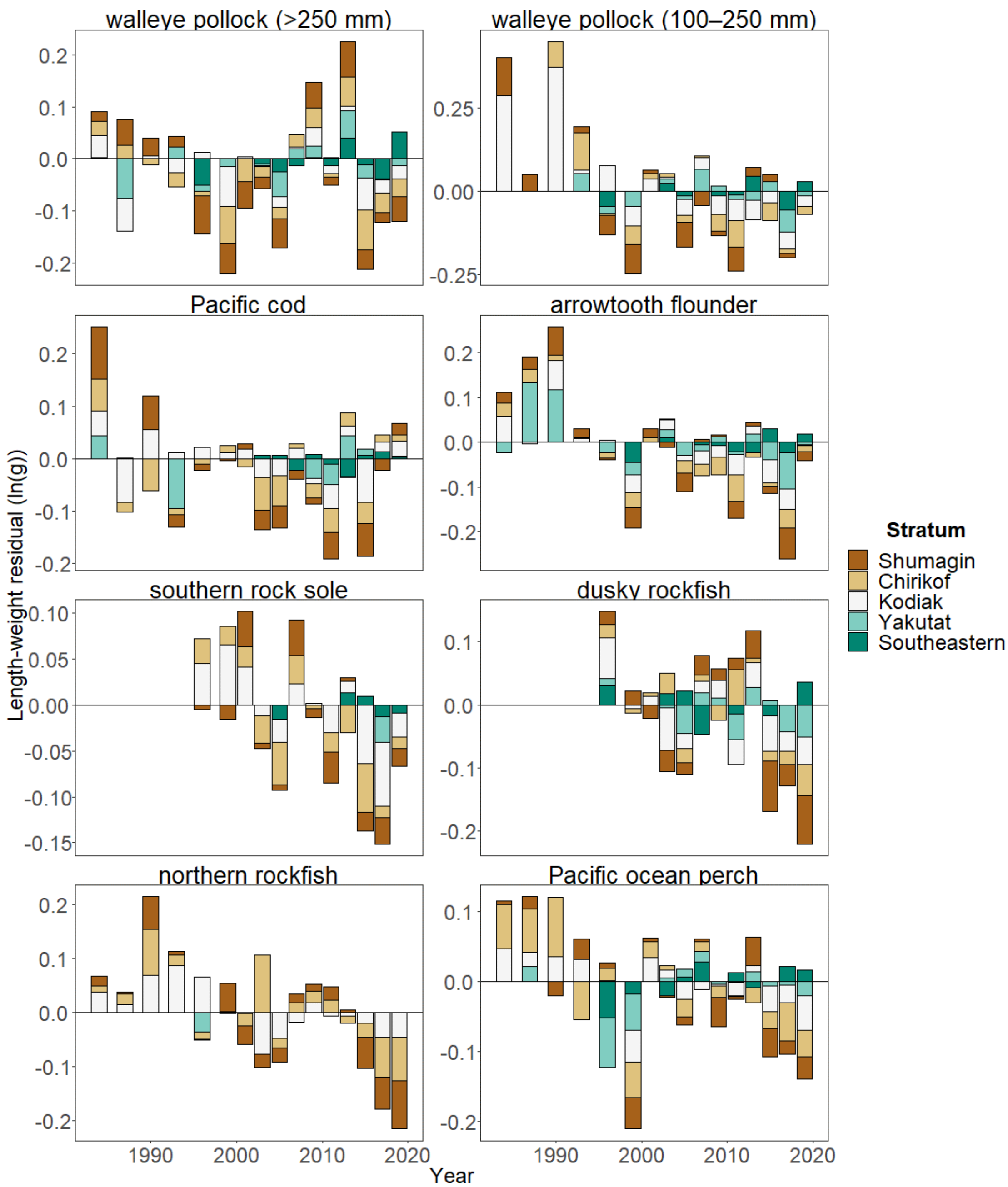

Figure 55: Length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985–2019, grouped by International North Pacific Fisheries Commission statistical sampling strata.

account for spatial-temporal variation in length-weight samples from bottom trawl surveys due to methodological changes in sampling (e.g. transition from sex-and-length stratified sampling to random sampling). For 2021, revised indicators will be presented alongside a retrospective analysis that compares the historical and revised condition indicator. Currently, research is being planned across multiple AFSC programs to explore standardization of statistical methods for calculating condition indicators, and to examine relationships among morphometric condition indicators, bioenergetic indicators, and physiological measures of fish condition.

ADF&G Gulf of Alaska Trawl Survey

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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 2020, a total of 222 stations were sampled from June 14 through July 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 56). 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 57). 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 58). Temperature anomalies were calculated using average bottom temperatures recorded for each haul from 1990 to present (Figure 59).

Status and trends: 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 57). Although still at relatively low levels, 2020 survey data showed a slight increase in overall biomass in the offshore stations. Arrowtooth flounder and Tanner crab have been the predominant species in the ADF&G trawl survey catches in the last two years. Flatfish slightly increased in 2020, from historically low catches in recent years. Starfish catches have significantly decreased in the inshore areas since 2017 and remain low in 2020.

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 11% of catch and walleye pollock 88% in 2020.

Below average anomaly values for arrowtooth flounder and flathead sole were recorded again in 2020 for both inshore and offshore areas; along with Pacific cod, Pacific halibut, skates, and walleye

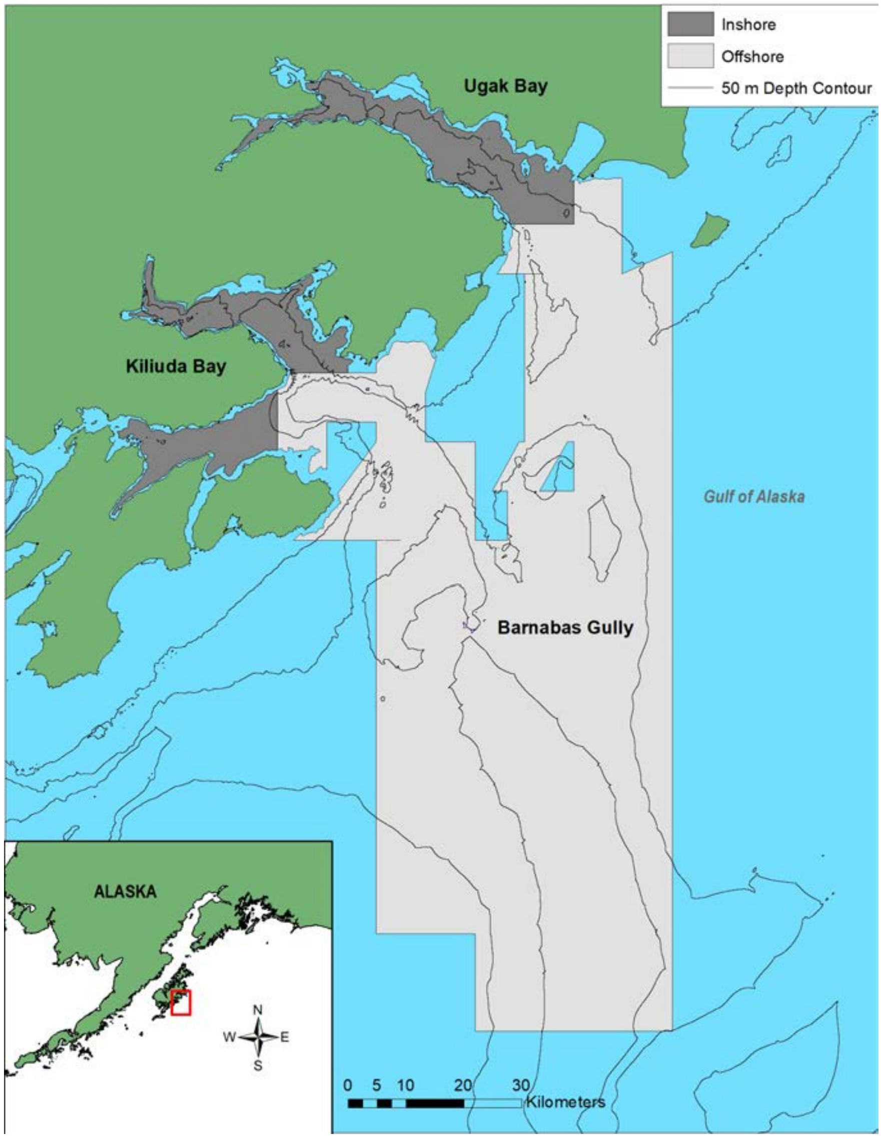

Figure 56: Kiliuda Bay, Ugak Bay, and Barnabas Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

pollock (Figure 58). The above average anomaly values for Tanner crab continued in 2020, due to a large recruitment event occurring in both inshore and offshore areas (Spalinger, 2020).

Temperature anomalies for both inshore and offshore stations were below average in 2020, contrast to previous years (Figure 59). The higher than average temperature is past years frequently occur during moderate and strong El Niño years, except for 2019 (`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 1993 to 1999 (Figure 57) may reflect the greater frequency of El Niño events on overall production,

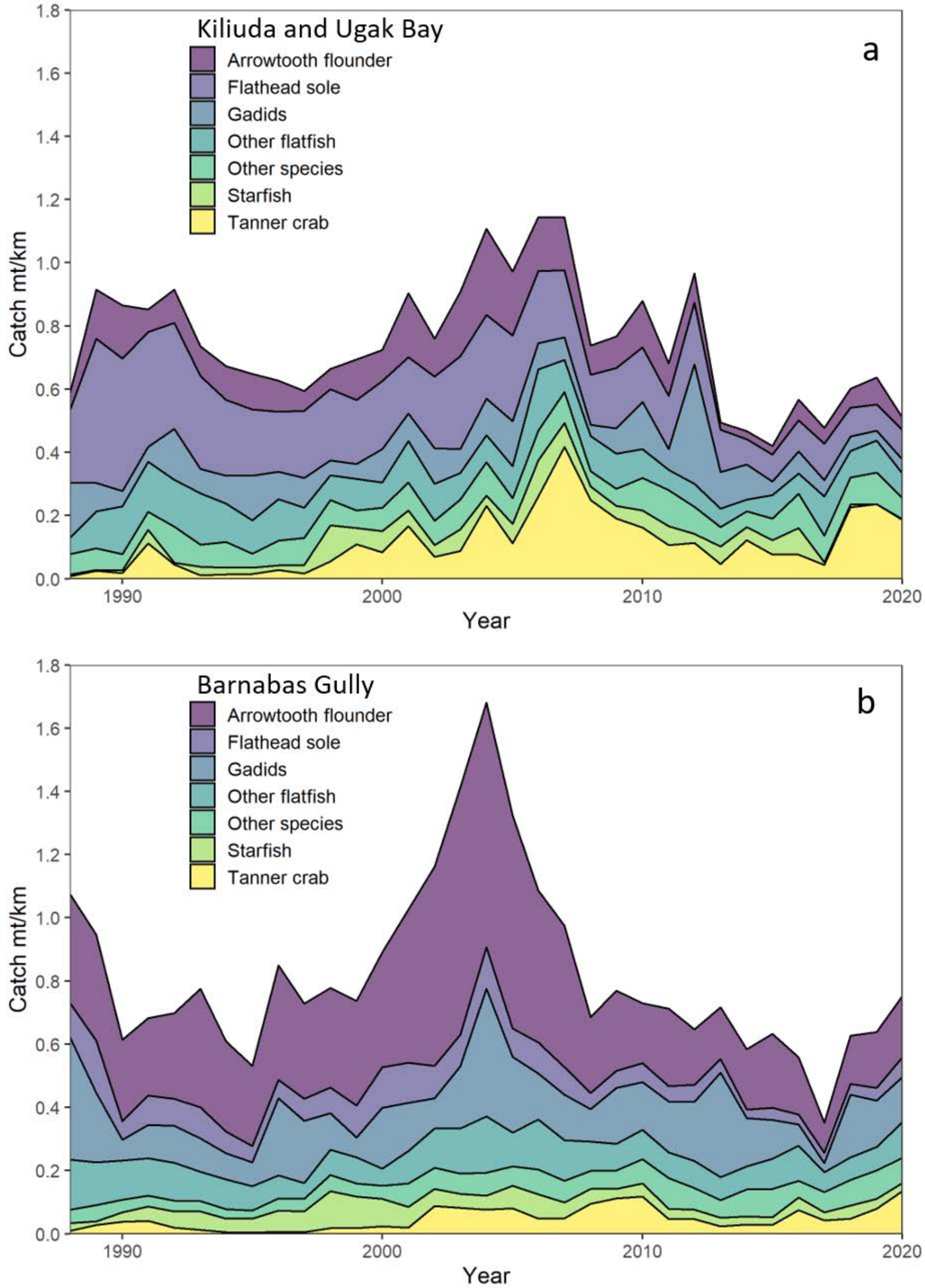

Figure 57: Total catch per km towed (mt/km) of selected species from Kiliuda and Ugak Bay (a) and Barnabas Gully (b) survey areas off the east side of Kodiak Island, 1987–2020.

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.

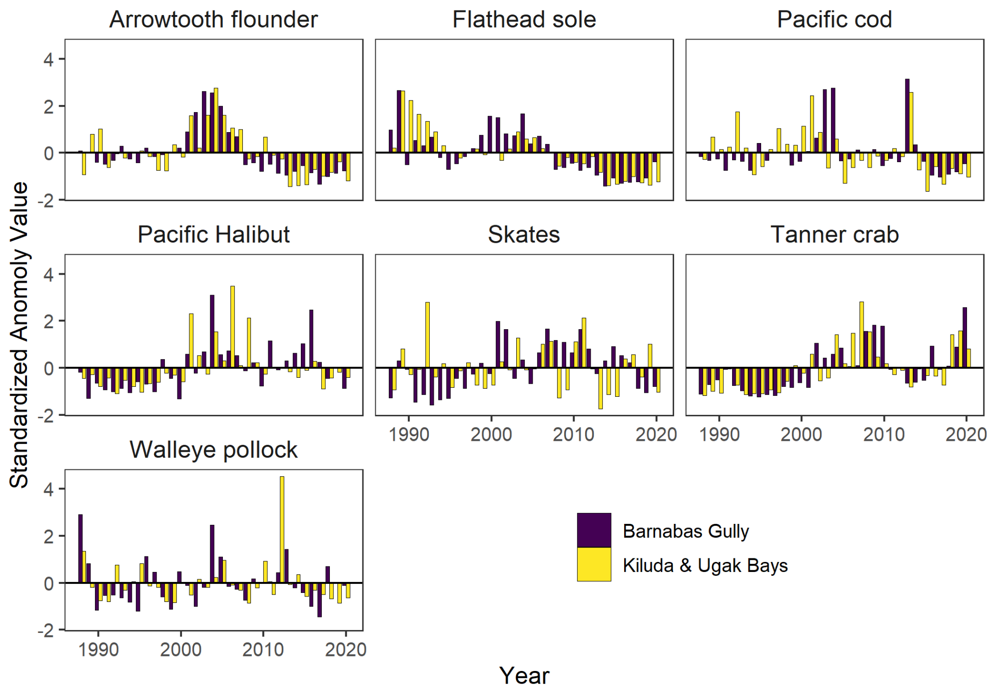

Figure 58: A comparison of standardized anomaly values, based on catch (kg) per distance towed (km) for selected species caught from 1988 to 2020 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

Implications: Although trends in abundance in the trawl survey appear to be influenced by major 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. This survey data is 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.

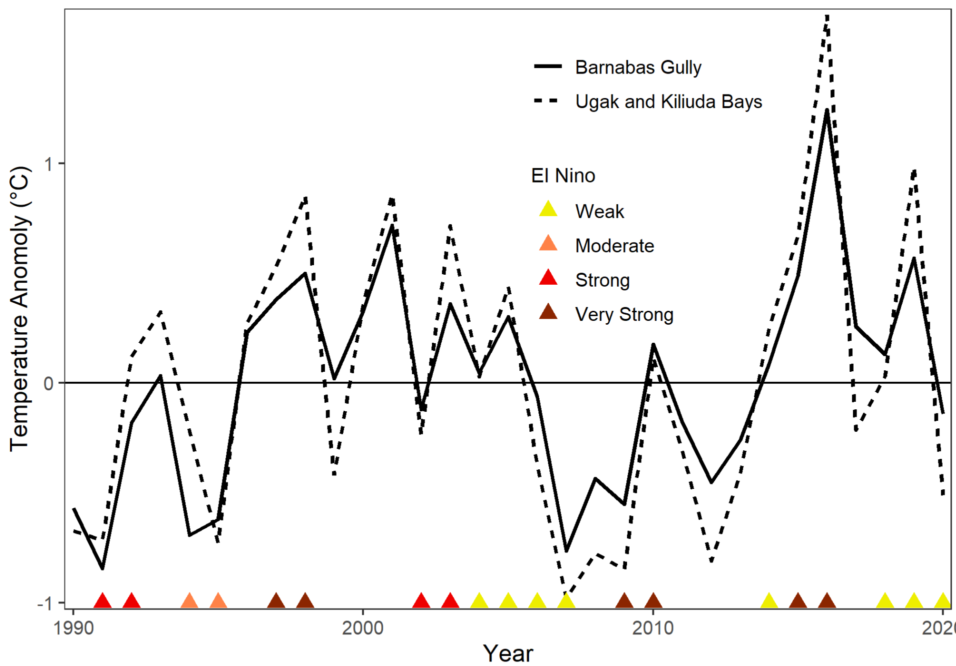

Figure 59: Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2020, with corresponding El Niño years represented.

Recruitment Predictions for Sablefish in Southeast Alaska

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Description of indicator: Biophysical indices from surveys in 2018 and 2019, and salmon returns in 2020, were used to explore predicting the recruitment of sablefish to age-2 in 2020 and 2021 (Hanselman et al., 2019; Yasumiishi et al., 2015*a*,*b*). Biophysical indices were collected during the southeast coastal monitoring (SECM) survey. The SECM survey has an annual survey of oceanography and fish in inside and outside waters of northern southeast Alaska since 1997 (Orsi et al. 2012). Oceanographic sampling included, but was not limited to, sea temperature and chlorophyll-a. These data are available from documents published through the North Pacific Anadromous Fish Commission website from 1999 to 2012 (`www.npafc.org`) and from Emily Fergusson at the Alaska Fisheries Science Center in Juneau, Alaska. An index for pink salmon survival was based on adult returns of pink salmon to southeast Alaska (Piston and Heinl, 2014). These oceanographic metrics may index sablefish recruitment, because sablefish use these waters as rearing habitat early in life (late age-0 to age-2). Chlorophyll-a is an indicator for primary production, or phytoplankton, prey from small copeods that are fed on by euphausiids that are consumed by age-0 sablefish.

Status and trends: We modeled age-2 sablefish recruitment estimates from 2001 to 2019 (Hanselman et al., 2016) as a function of sea temperatures during 1999–2017, chlorophyll-a during 1999–2017, and adult pink salmon returns in 2000–2018. The regression model indicated a significant positive coefficient for the predictor variables chlorophyll-a, but not significant for sea temperature, and pink salmon returns were positively in the sablefish model ($R^2 = 0.79$, Adjusted $R^2 = 0.75$, F-statistic: 59.8 on 1 and 17 DF, p-value: < 0.001).

Trends in the scaled chlorophyll-a indicate high values in 2000, 2014, and 2016 that relate to strong year classes of sablefish (Figure 60). Based on the recent low values of chlorophyll-a in 2018 and 2019, 1.70 and 1.49 respectively, we predict below average abundance of age-2 sablefish for the 2018 and 2019 year classes (Figure 61).

Factors influencing observed trends: Warmer sea temperatures were associated with high recruitment events in sablefish (Sigler and Zenger Jr., 1989). Higher chlorophyll-a content in sea water during late summer indicate higher primary productivity and a possible late summer phytoplankton bloom. Higher pink salmon productivity, a co-occurring species in near-shore waters, was a positive predictor for sablefish recruitment to age-2. These conditions are assumed more favorable for age-0 sablefish, overwintering survival from age-0 to age-1, and overall survival to age-2. Other factors that often correlate with higher recruitment of age-2 sablefish include temperature during the age-0 life stage of sablefish (higher temperatures relate to increased feeding and growth) and increased abundance of juvenile pink salmon (an indicator for good feeding and growing nearshore conditions), as juvenile pink salmon and age-0 sablefish have similar growth rates.

Implications: Our 2020 model indicates that we should expect weak 2018 and 2019 year classes of sablefish.

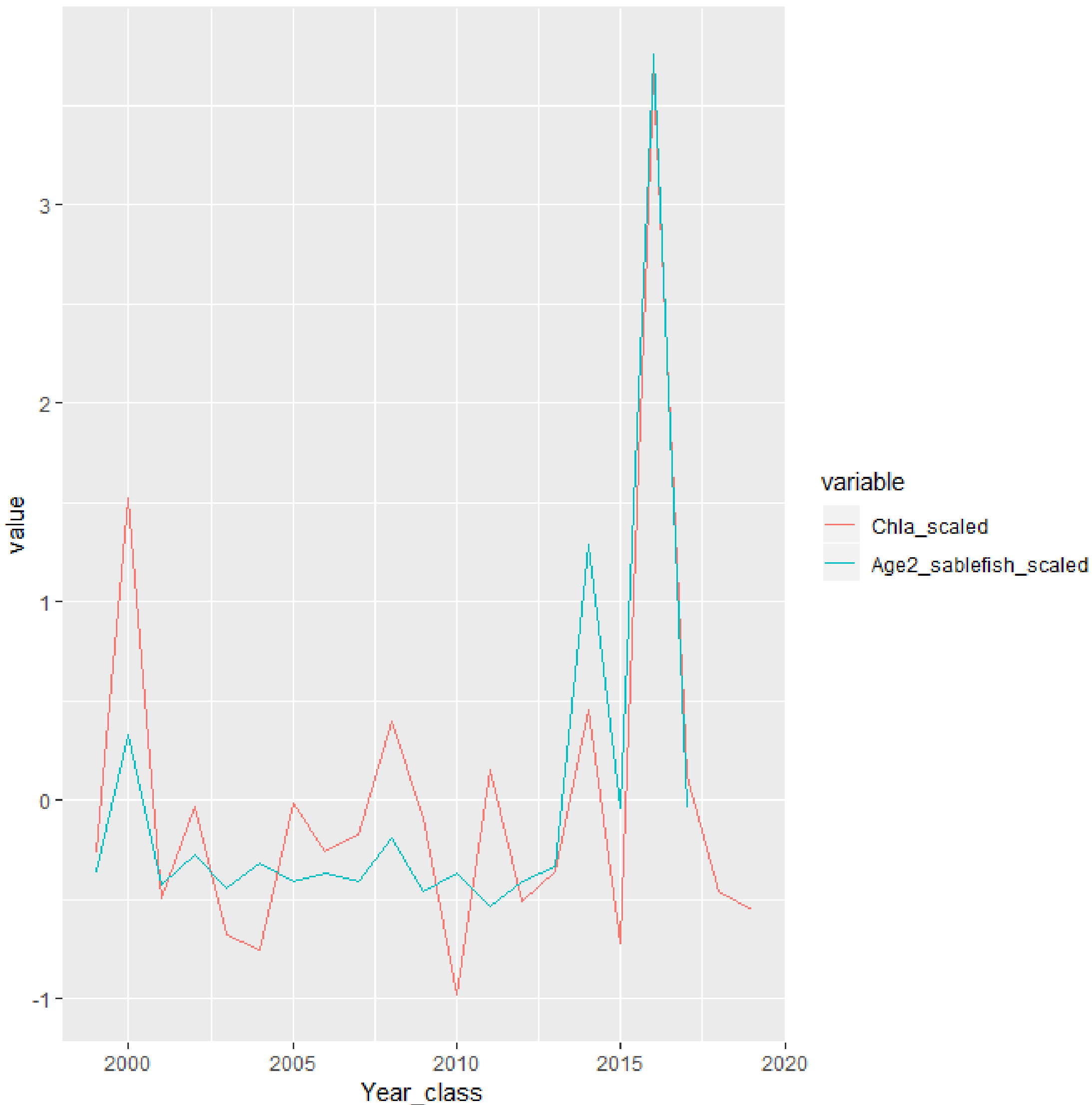

Figure 60: Scaled time series of age-2 sablefish lagged to year class 1999 to 2017 (Age2_sablefish_scaled) and scaled data for chlorophyll-a sampled in Icy Straits during the Southeast Coastal Monitoring survey from 1999–2019 (Chlorophyll-a_scaled) during the age-0 life stage of sablefish.

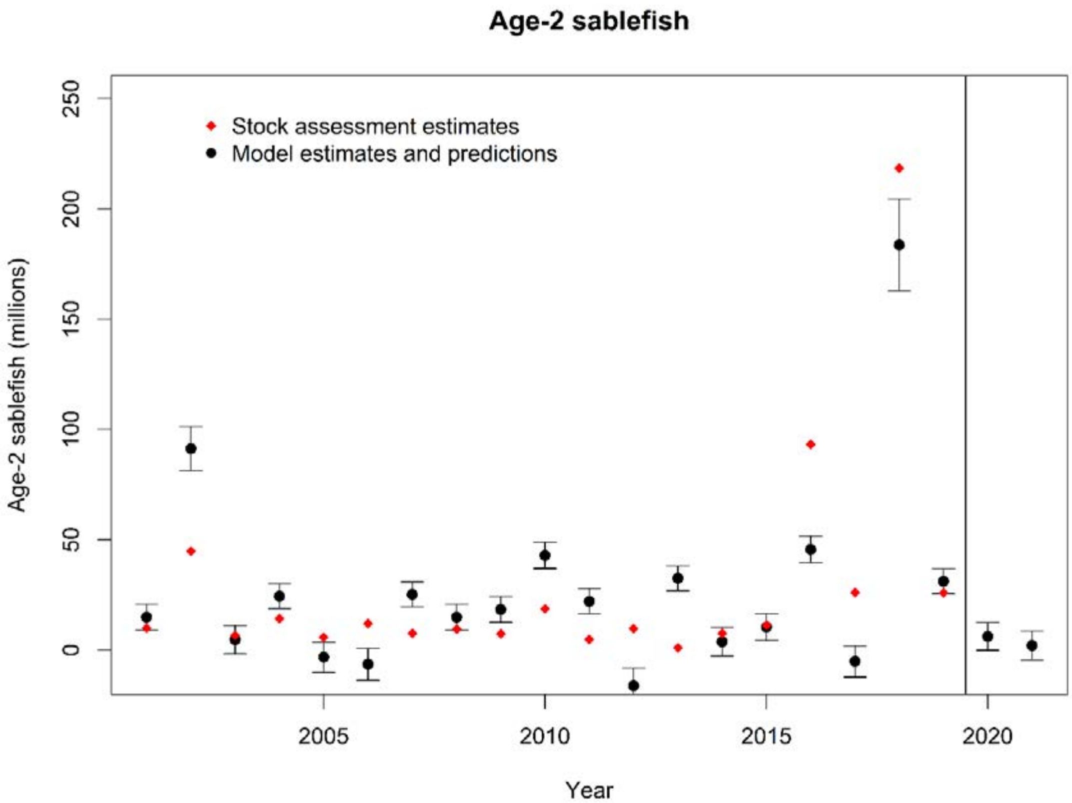

Figure 61: Stock assessment estimates (2001–2019), model estimates (2001–2019), and the 2020 and 2021 predictions for age-2 Alaska sablefish (to the right of th vertical line). Stock assessment estimates of age-2 sablefish were modeled as a function of late August chlorophyll-a levels in the waters of Icy Strait in northern southeast Alaska during the age-0 stage (t-2). This predictor is an indicators for the conditions experiences by age-0 sablefish, conditions include. Stock assessment estimates of age-2 sablefish abundances are from Hanselman (personal communications).

Distribution of Rockfish Species in Gulf of Alaska Trawl Surveys

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Description of indicator: In a previous analysis of rockfish from 14 bottom trawl surveys in the Gulf of Alaska and Aleutian Islands (Rooper, 2008), five species assemblages were defined based on similarities in their distributions along geographical position, depth, and temperature gradients. The 180 m and 275 m depth contours were major divisions between assemblages inhabiting the shelf, shelf break, and lower continental slope. Another noticeable division was between species centered in southeastern Alaska and those found in the northern Gulf of Alaska and Aleutian Islands.

In this time series, the mean-weighted distributions of six rockfish (five *Sebastes* spp. and *Sebastolobus alascanus*) species along the three environmental gradients (depth, temperature, and position) were calculated for the Gulf of Alaska and Aleutian Islands. A weighted mean value for each environmental variable was computed for each survey as:

$$Mean = \frac{\sum (f_i x_i)}{\sum f_i},$$

where f_i is the CPUE of each rockfish species group in tow i and x_i is the value of the environmental variable at tow i. The weighted standard error (SE) was then computed as:

$$SE = \frac{\sqrt{\frac{(\sum (f_i x_i^2)) - ((\sum f_i) * mean^2)}{(\sum f_i) - 1}}}{\sqrt{n}},$$

where n is the number of tows with positive catches. Details of the calculations and analyses can be found in Rooper (2008). These indices monitor the distributions of major components of the rockfish fisheries along these environmental gradients to detect changes or trends in rockfish distribution.

Status and trends: In the Gulf of Alaska, there are no significant trends in the distribution of rockfish with position and temperature (Figure 62), and these results are similar to those observed in the 2017 analysis for the Gulf of Alaska. However, there was a slight and significant decrease in depth (shallowing) for northern rockfish and shortspine thornyhead. While the statistical analysis of temperature found no significant changes in temperatures experienced by rockfish, most ambient temperatures experienced by rockfishes were higher for rockfish in 2015 and 2017 than during earlier surveys.

Factors causing observed trends: In the Gulf of Alaska, the stability of rockfish distributions indicate that each of the species occupy a fairly specific geographical distribution and generally the same depth distribution. This is seen in the flat line time series of distribution across areas and depths despite the variability in temperature, especially recently. As temperatures rise and fall around the mean, the depth distribution does not change, indicating that most rockfishes are not changing their habitat or distribution to maintain a constant temperature. The slight decrease in depth over time for northern rockfish and shortspine thornyhead warrants further investigation or additional surveys to determine if this is a consistent long-term trend.

Implications: The trends in the mean-weighted distributions of rockfish should continue to be monitored, with special attention to potential causes of the shift in depth and position distributions of rockfish, especially as they relate to changing temperatures.

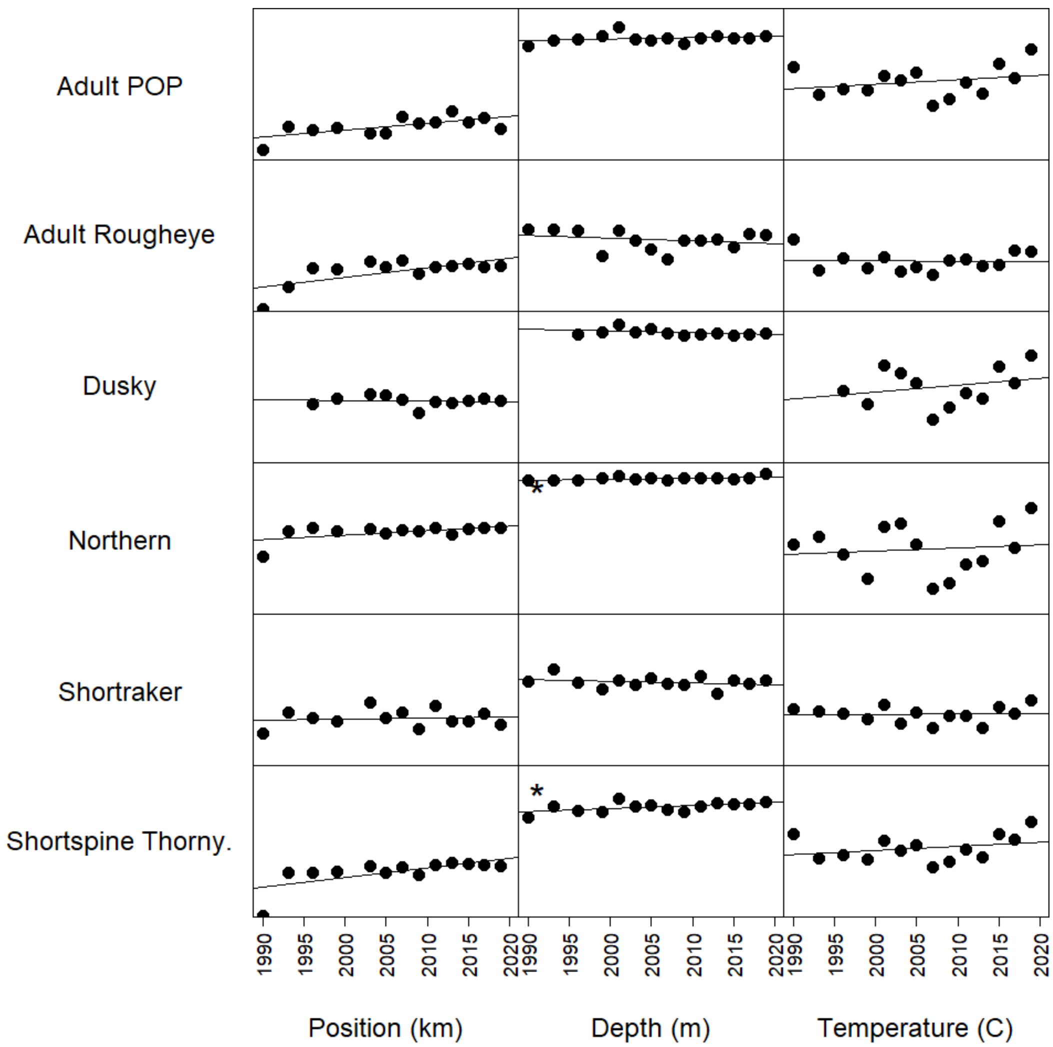

Figure 62: Plots of mean weighted (by catch per unit effort) distributions of six rockfish species-groups along three environmental variables in the Gulf of Alaska. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance from Hinchinbrook Island, Alaska, with positive values west of this central point in the trawl surveys and negative values in southeastward. Asterisk indicates significant trend over the time series.

Seabirds

Seabird Synthesis

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Summary Statement: Overall, the status of seabirds was fair to good in the WGOA in 2020, with limited data available from Middleton Island, Cook Inlet, and the Kodiak Archipelago (Figure 63). Colony attendance remains low in some populations compared to historic levels, and some colonies were newly abandoned. However, when birds did arrive to breed, reproductive success generally appeared fair to good for fish-eating, surface-feeding birds and fish-eating, diving birds. There was spatial variability in colony attendance and reproductive success, with Middleton Island birds performing more strongly than Kodiak Island or Cook Inlet. Middleton Island populations from both these groups experienced their strongest breeding seasons since the marine heatwave began in 2014, suggesting an increase in the availability of small schooling fish in that region of WGOA. No large-scale mortality event was recorded based on monthly beach surveys in the WGOA. This year's integrated approach to reporting seabird status is less comparable to previous Ecosystem Status Reports, as the Alaska Maritime National Wildlife Refuge's seabird reproductive success time series were not updated, due to COVID-19 related survey cancellations.

Description of indicator: Seabirds are sensitive indicators of changes in the productivity of marine ecosystems, and their populations can signal processes affecting the availability of prey for commercial fish stocks. In this section we synthesize data and field observations collected by government, university and non-profit partners to provide an assessment of the status of seabirds in the Gulf of Alaska in 2020. We present this information with an emphasis on describing environmental impacts on seabirds, and interpreting changes in seabird status in light of their implications for understanding ecosystem productivity.

In this synthesis we divide seabirds into groups according to whether they feed on **fish** or **plankton**, and whether they exhibit **diving** or **surface** feeding behavior. Each of these groups responds to a different part of the ocean ecosystem. To describe the status of seabird groups, we use three types of information that represent different spatial and temporal scales of seabird responses:

1. *Colony attendance and breeding timing*, which can represent conditions prior to breeding and/or phenological variation in the environment. Birds arriving to breed in lower numbers or at a later date can reflect poor winter foraging conditions or later peaks in ocean productivity.

2. *Reproductive success*, which can represent food availability around the colony during the

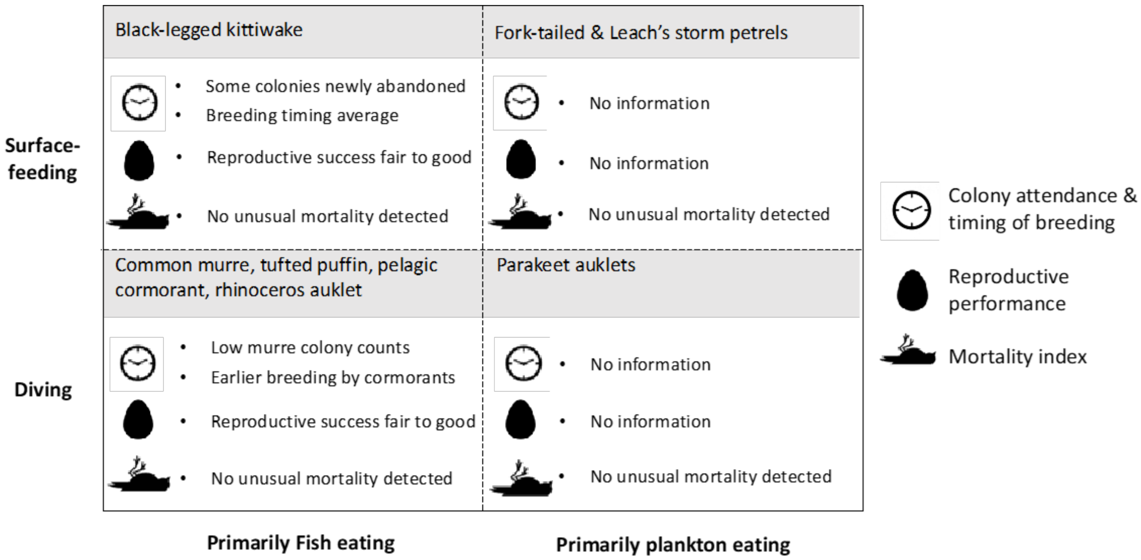

Figure 63: Summary of 2020 seabird status for surface-feeding and diving, fish and plankton eating seabirds in the Gulf of Alaska

breeding season, with a lower number of fledged chicks generally reflecting a decrease in the local abundance of high-quality prey.

3. *Mortality*, which gives insight into environmental and ecosystem impacts beyond breeding colonies and the breeding season. Unusual mortality events in the Gulf of Alaska have been linked to declines in prey abundance and quality during recent marine heatwaves.

Status and trends:

Fish-eating, surface feeding seabirds: Fish-eating, surface feeding seabirds in the Gulf of Alaska include black-legged kittiwakes (*Rissa tridactyla*) and glaucous-winged gulls (*Larus glaucescens*). These species feed on small schooling fish that are available at the surface (e.g., sand lance, sablefish, capelin and herring), making them potential indicators of processes affecting juvenile groundfish that migrate to the surface to feed.

Colony attendance and breeding timing: Some fish-eating, surface feeding seabird colonies were newly abandoned in 2020, while breeding timing appeared average across all colonies. There was a continued trend of abandonment of colonies on the Kodiak Archipelago by black-legged kittiwakes, with two additional colonies abandoned this year that have previously seen consistent breeding attempts over at least the past 11 years. The timing of breeding by black-legged kittiwakes was average at Middleton Island, and did not appear unusual on the Kodiak Archipelago.

Reproductive success: Reproductive success of fish-eating, surface-feeding seabirds appeared fair to good in 2020. Black-legged kittiwakes showed strong reproductive success on Middleton Island, following a period of poor breeding success beginning in 2014 (Figure 64). Kittiwakes appeared to have variable reproductive performance on the Kodiak Archipelago, with one colony having higher than average numbers of chicks per nest and another colony having no chicks at the time the island was visited.

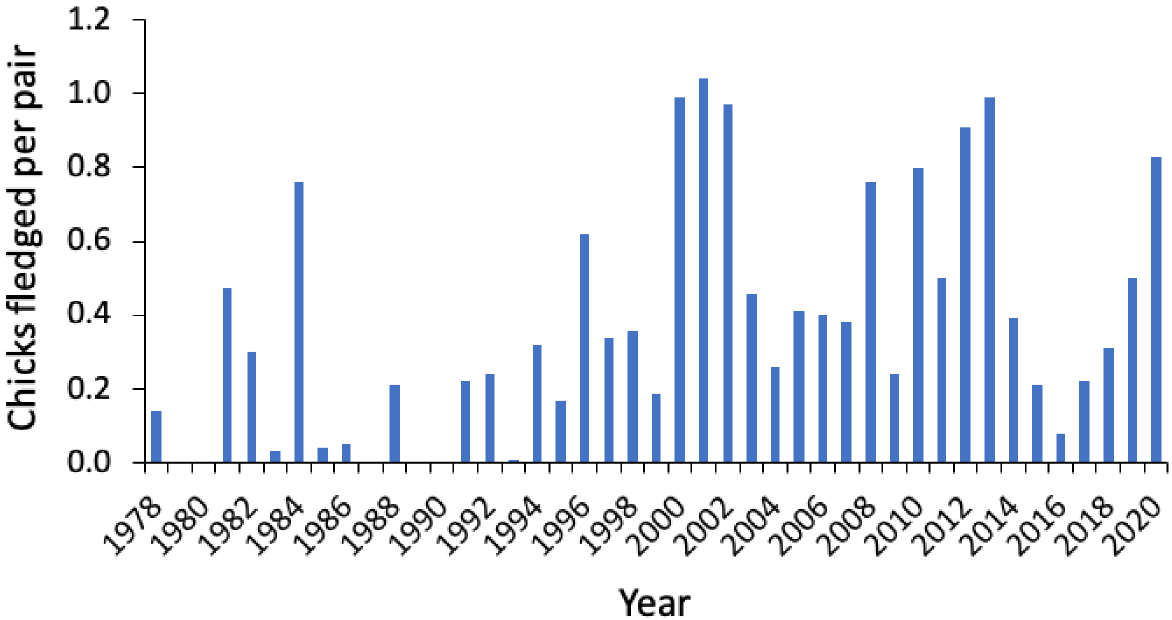

Figure 64: Reproductive performance indicators for black-legged kittiwakes, a species of fish-eating, surface feeding seabird breeding on Middleton Island. Figure provided by the Institute for Seabird Research and Conservation, October 2020.

Mortality: No large-scale mortality event was recorded for fish-eating, surface-feeding seabirds in 2020 based on beach surveys in the Western Gulf of Alaska (Figure 65).

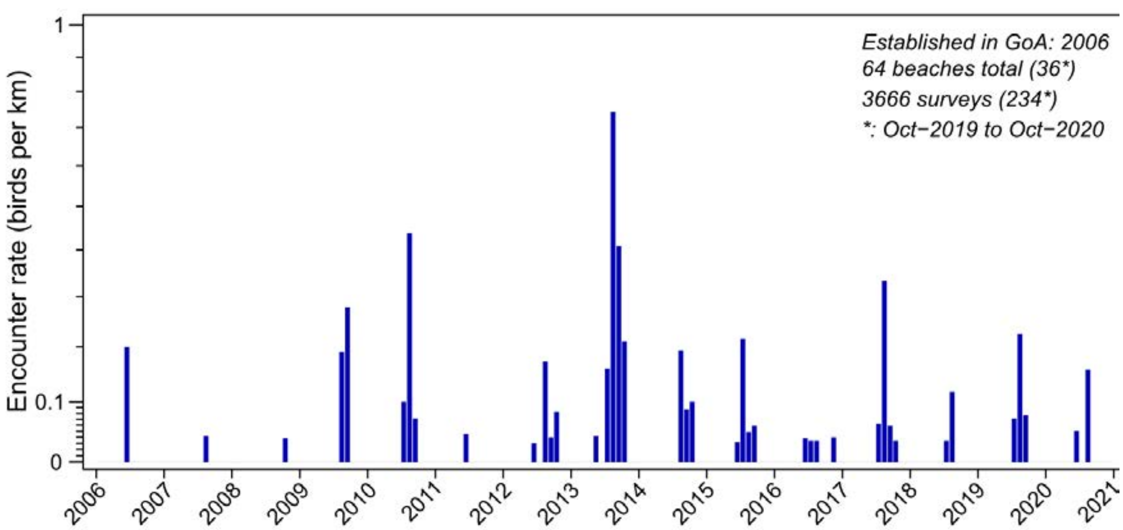

Figure 65: The number of dead black-legged kittiwakes encountered per km of beach surveyed by citizen scientists in the Gulf of Alaska. Data are aggregated across 64 beaches (42 in 2020) in the Western Gulf of Alaska (see Figure 7) to show regional trends, but are biased toward more accessible beaches in areas of higher population density. Figure provided by the Coastal Observation and Seabird Survey Team (COASST), October 2020.

Fish-eating, diving seabirds: Fish eating, diving seabirds in the Gulf of Alaska include common murres (*Uria aalge*), rhinoceros auklets (*Cerorhinca monocerata*), tufted puffins (*Fratercula cirrhata*) and pelagic cormorants (*Phalacrocorax pelagicus*). The status of this group is impacted by changes in the availability of small, schooling fish up to $\sim$ 90 m (300 feet) below the surface, making them potential indicators of feeding conditions that may affect fish-eating groundfish species.

Colony attendance and breeding timing: Colony attendance was low (common murres) and breeding timing was average (tufted puffins) to early (pelagic cormorants) in 2020. The total number of common murres counted across two colonies in the lower Cook Inlet (Gull and Chisik Islands) in 2020 was approximately 20% lower than 2019 and slightly lower than 2018. This continues a declining trend in counts since 2016 when monitoring of these colonies was resumed in response to the 2014–2016 marine heatwave. Numbers in 2020 are less than half the numbers observed at the same colonies in the late 1990s (Figure 66). The timing of breeding by pelagic cormorants on Middleton Island was earlier than recent years, continuing a 6-year trend of gradual advancement of breeding in this population. Field observations suggest that the timing of tufted puffin breeding on the Kodiak Archipelago did not appear unusual.

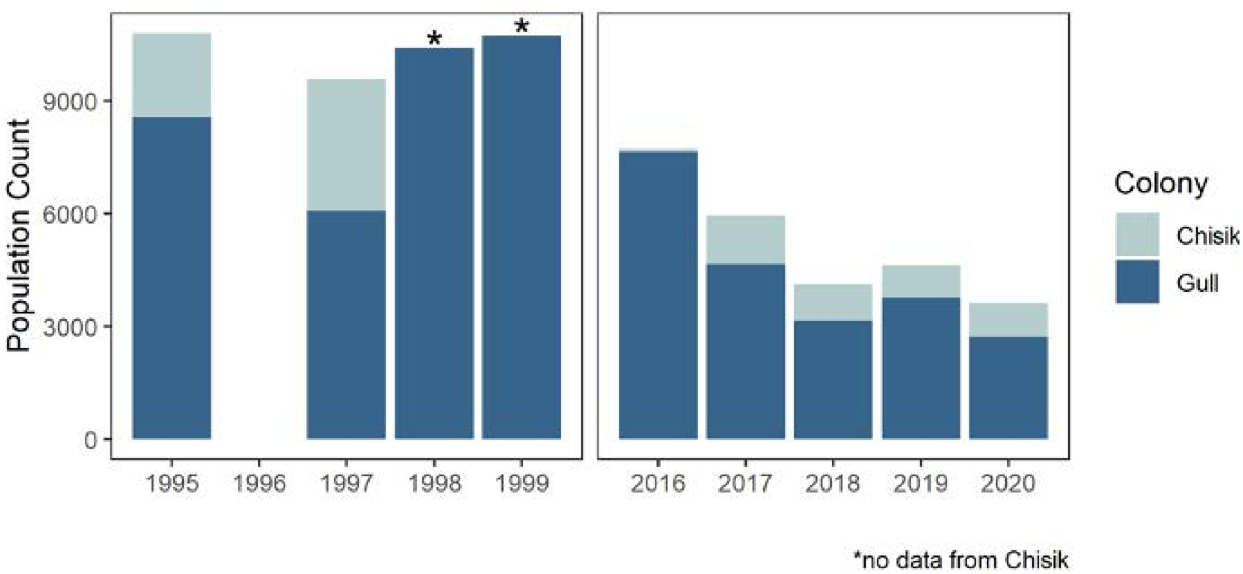

Figure 66: Common murre population counts at nesting colonies on Chisik Island (western Cook Inlet) and Gull Island (Kachemak Bay). Figure provided by U.S. Geological Survey, October 2020.

Reproductive success: Reproductive success appeared fair to good for fish-eating, diving seabirds in 2020. Rhinoceros auklets and pelagic cormorants breeding on Middleton island exhibited their best breeding performance since 2008 and since at least 2002, respectively (Figure 67). Tufted puffins breeding on the Kodiak Archipelago appeared to have fair to good breeding performance, with nests hatching and many birds sighted flying around the colony with bills full of fish to feed chicks. Common murres produced chicks in the lower Cook Inlet for the first time (Chisik Island) and second time (Gull Island) following a period of total breeding failure related to the marine heatwave in 2014–2016. However, observations of murres rafting around colonies instead of attending to nests suggest that breeding production is likely to remain low at these colonies relative to numbers recorded in the late 1990s.

Mortality index: No large-scale mortality event was recorded for fish-eating, diving seabirds based

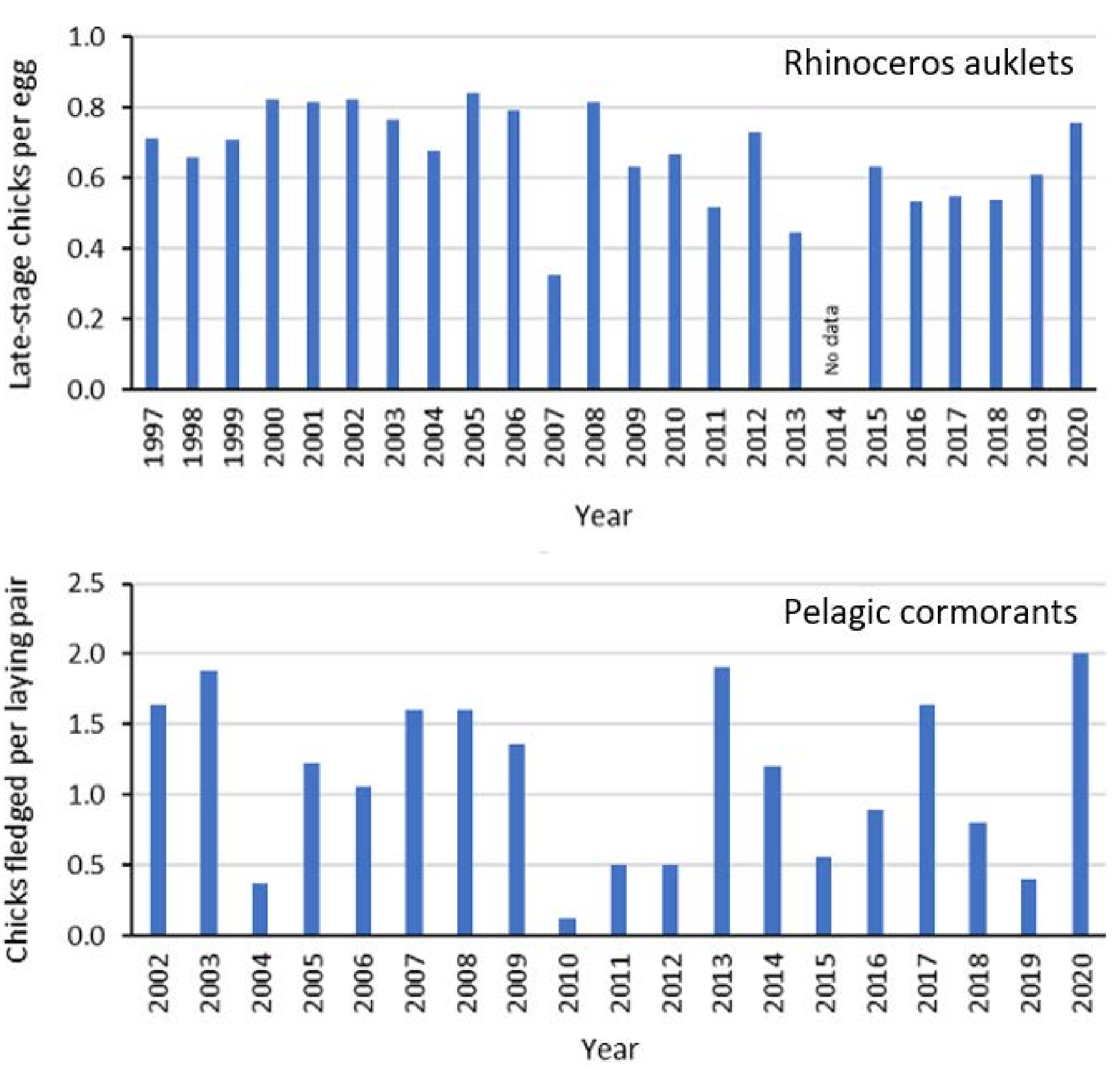

Figure 67: Reproductive performance indicators for rhinoceros auklets (top) and pelagic cormorants (bottom), two species of fish-eating, diving seabirds breeding on Middleton Island. Figure provided by the Institute for Seabird Research and Conservation, October 2020.

on beach surveys in the Western Gulf of Alaska in 2020, marking four years since the unusual mortality of common murres that was linked to the 2014–2016 marine heatwave (Figure 68). However, a noteworthy number of juvenile tufted puffins were seen close to shore around the Kodiak Archipelago post-fledging in 2020, with several reports of dead fledglings, which were apparently emaciated.

Plankton-eating seabirds: Plankton-eating seabirds in the Gulf of Alaska include surface-feeding species such as Leach's and fork-tailed storm petrels, and diving species such as least auklets (*Aethia pusilla*) and crested auklets (*Aethia cristatella*). The status of these groups are impacted by changes in plankton production, making them potential indicators of feeding conditions that may affect planktivorous groundfish species, including the larvae and juveniles of fish-eating species. No

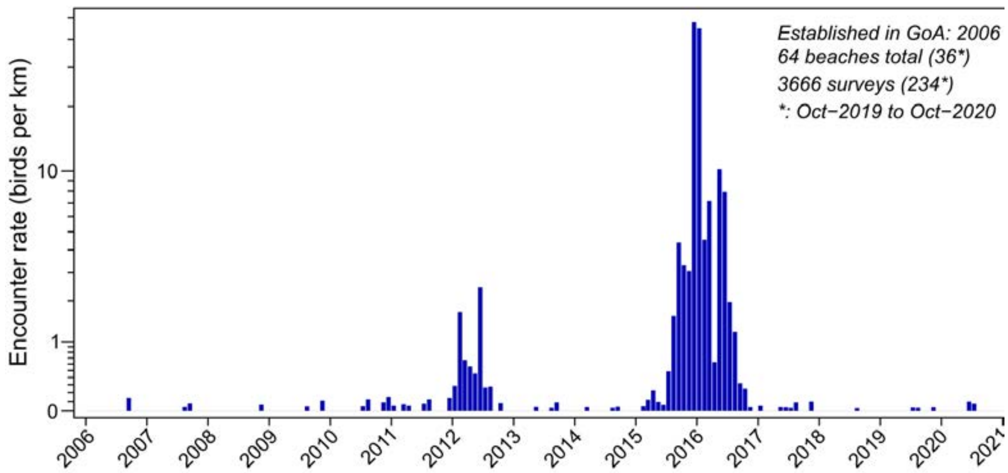

Figure 68: The number of dead common murres encountered per km of beach surveyed by citizen scientists in the Gulf of Alaska. Data are aggregated across 64 beaches (42 in 2020) in the Western Gulf of Alaska (see Figure 69) to show regional trends, but are biased toward more accessible beaches in areas of higher population density. Figure provided by the Coastal Observation and Seabird Survey Team (COASST), October 2020.

data or observations were available on colony attendance or reproductive performance of plankton-eating seabirds in the Gulf of Alaska in 2020. Beach surveys did not identify any unusual mortality events for species in this group.

Factors influencing trends and implications for ecosystem productivity: The strong breeding performance that was observed in many of the fish-eating seabird populations in the Western Gulf of Alaska likely reflects an increase in the availability of small schooling fish in the region. The clearest evidence for this is an ongoing experiment on Middleton Island, where black-legged kittiwakes are randomly assigned to a group receiving supplemental feeding, or a group that relies only on natural foraging. Stronger relative performance of naturally foraging kittiwakes compared to supplementally fed birds has previously been related to cool ocean conditions, a negative Pacific decadal oscillation (PDO), and more capelin in their diet.

In 2020, breeding performance by naturally foraging kittiwakes was much better relative to supplementally fed birds than in any year since 2013, indicating a substantial increase in the abundance of surface-shoaling fish near the colony (Figure 69). The PDO was weakly negative in 2020, in line with previous observations that negative PDO and cool sea surface temperatures are linked to higher food availability. However, the proportion of capelin in kittiwake diets in 2020 was lower than in other strong breeding years, with the birds feeding mostly on sablefish, sand lance, hexagrammids (greenlings), and herring, indicating that these species were more available to foraging birds this year (see contribution by Hatch in the forage fish section of this report).

Strong breeding performances by most diving, fish-eating birds suggest that small schooling fish were also relatively abundant at depth near the colonies. Diet information for rhinoceros auklets suggests that their diet in 2020 was dominated by sand lance and an unusually high proportion of hexagrammids (e.g., greenlings; see contribution by Hatch in the forage fish section of this report). Decreasing colony attendance and low breeding effort by common murres may indicate lingering effects from the 2014–2016 heatwave which saw a mass mortality of this species. Abandonment of colonies by kittiwakes may reflect a reduction in population size following a series of years with low reproductive output, or poor over-winter conditions.

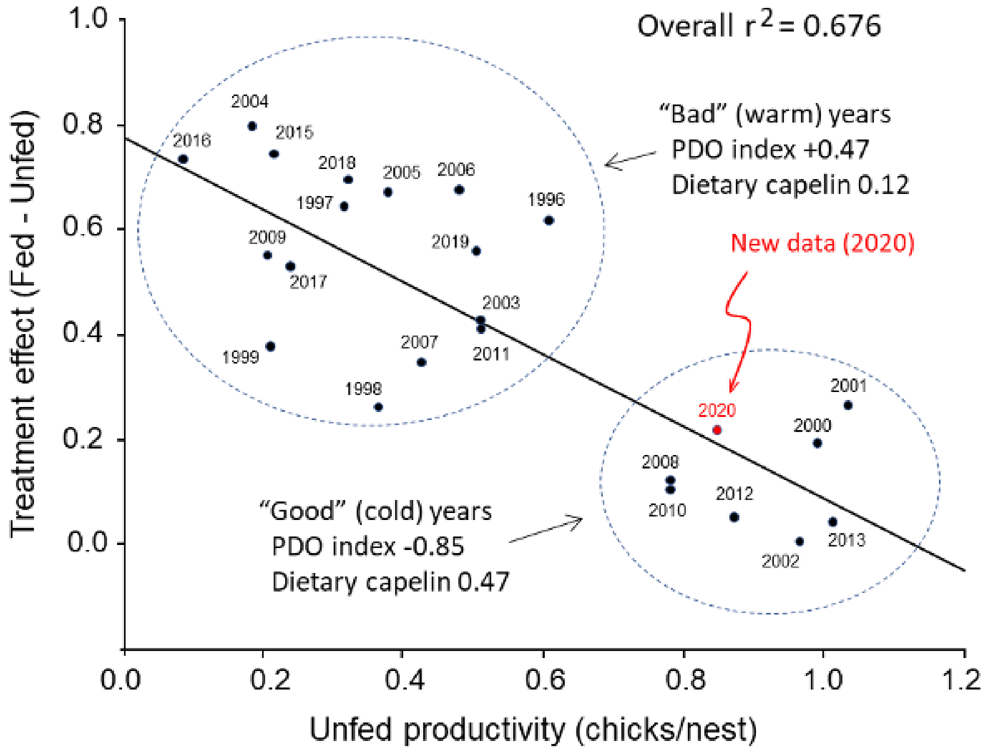

Figure 69: Effect of supplemental food treatment on black-legged kittiwake breeding performance on Middleton Island. Productivity of naturally foraging pairs can be considered a proxy for quality of the foraging environment, and treatment effect is the difference in productivity between supplementally fed and naturally foraging pairs. "Bad" years are characterized by warm ocean conditions (mean June-August PDO index of +0.47), a low proportion of capelin in the diet (mean relative occurrence of 12%), and a marked effect of food treatment on kittiwake production. "Good" years have cool ocean conditions (mean June-August PDO index of -0.85), a higher proportion of dietary capelin (mean relative occurrence of 47%), and reduced or no difference in breeding performance of supplementally fed and naturally foraging pairs.

Methods:

- The Coastal Observation and Seabird Survey Team (COASST) and regional partners provided a standardized measure of relative beached bird abundance collected by citizen scientists. Information for the two most data-rich species are included in this report: common murres and black-legged kittiwakes, representatives of the diving, fish eating group and the surface feeding, fish eating group respectively. Note that data collection is biased toward accessible beaches close to population centers.
- The Institute for Seabird Research and Conservation (ISRC) provided data on breeding timing and/or reproductive performance of pelagic cormorants, rhinoceros auklets and black-legged kittiwakes on Middleton Island. These data have been collected since the mid-1990s, including an experiment involving feeding a group of kittiwakes to highlight the effect of food availability on the reproductive performance of wild-foraging birds.

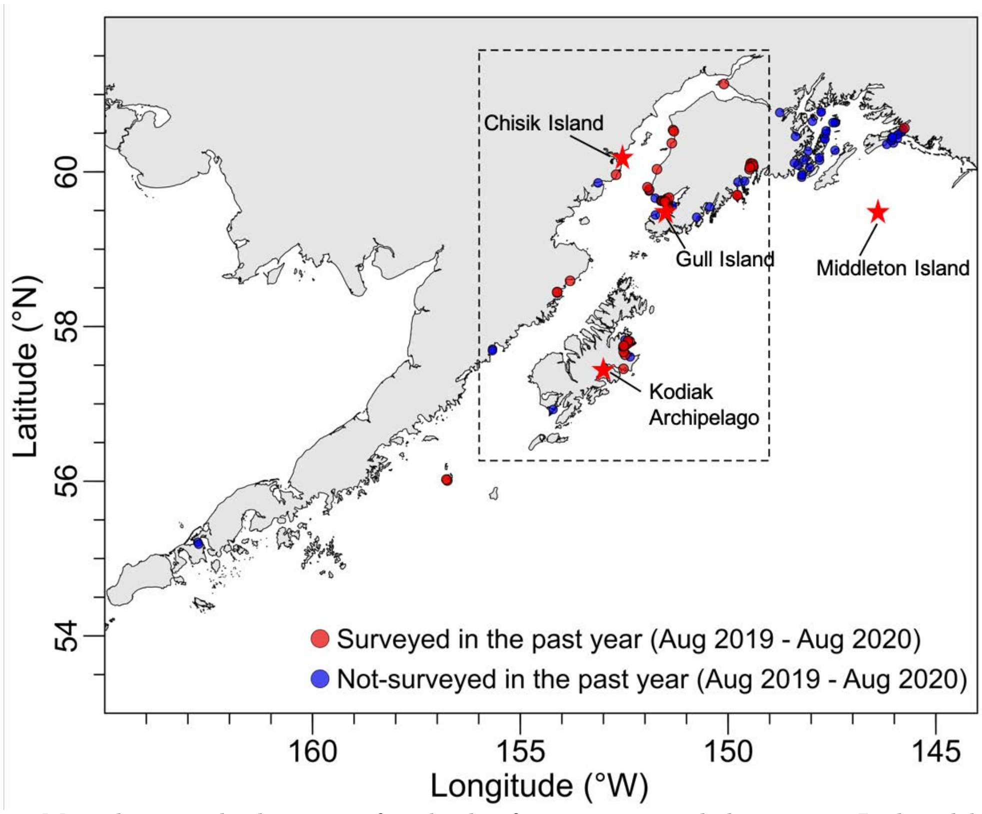

Figure 70: Map showing the location of seabird information provided in 2020. Red and blue circles represent beaches surveyed for dead birds by citizen scientists as part of the COASST program in 2020 (red), and in all previous years (blue). The bounding box indicates the extent of beaches included in the COASST beached bird time series plots presented in Figures 65 and 68. Red stars indicate the locations of seabird colonies where information was collected on colony attendance and/or reproductive performance in 2020 by other partners (ISRC: Middleton Island; USGS: Gull and Chisik Islands; USFWS: Kodiak Archipelago).

- USGS provided data on colony counts of common murres at Gull and Chisik Islands in the lower Cook Inlet. Data collection spans the 1990s and was resumed in 2016 after a hiatus. Qualitative field observations of reproductive activity were provided for 2020.
- USFWS provided qualitative field observations of kittiwakes and tufted puffins made during 12 days of surveying seabird colonies around the Kodiak Archipelago.

Marine Mammals

Fall Surveys of Humpback Whales in Prince William Sound

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Last updated: October 2020

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, in Prince William Sound, 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 the herring population to its former abundance. Humpback whale abundance and calf production within Prince William Sound often tracks herring abundance and indicates the ability of the ecosystem to support populations of large vertebrate predators.

Status and trends: Our annual September survey in Prince William Sound occurred in 2020, but effort was reduced due to COVID-19 travel restrictions. In 2020, counts of whales remained low within the Sound relative to the years prior to the 2014-2016 marine heatwave. The encounter rate for humpback whales (number of whales/nm traveled) also remains low (Table 3). The 2020 survey saw an increase in calf production, however, calf numbers continue to remain below pre-heatwave levels. We did not conduct acoustic surveys for prey in 2020 and, therefore, have limited information on prey selection by humpback whales this year.

Factors influencing observed trends: The biomass of herring in Prince William Sound has yet to return to pre-2014 levels. The primary prey of humpbacks switched from adult herring (prior to the heatwave) to euphausiids in 2019. Although 2020 spawn surveys and modeling indicated an increase in herring biomass, it does not appear that whale numbers followed suit. It is possible that the whales which typically forage in Prince William Sound have moved to better feeding grounds. We have identified a higher than expected number of whales seen in multiple feeding areas and are currently investigating the movements of whales between Prince William Sound and Southeast

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
Sep-20	14	2	331	0.04

Alaska.

Implications: The trend in whale numbers and calf production within Prince William Sound contrasted sharply with observations from Southeast Alaska and Hawaii where both the sightings of adults and calves were near pre-heatwave levels during 2020. The majority of the Hawaiian humpback whale population feed in the Gulf of Alaska. The increase in calves seen in Hawaii implies that conditions were favorable in 2019 for females to carry their fetuses to term. Whale numbers from the inside waters of Southeast Alaska have also rebounded and calf survival appears to be good, again implying that the prey base for whales in Southeast Alaska and possibly the Gulf of Alaska was adequate for nursing through the summer of 2020.

Given the limited survey effort in 2020 and the differing trends between Prince William Sound and Southeast Alaska, it is difficult to determine the implications of these trends across the Gulf of Alaska. Increase sightings of calves in Hawaii and Southeast Alaska suggest that euphausiid and forage fish abundance is improving, however the continued low abundance of whales in Prince William Sound requires further investigation.

Trends in Humpback Whale Calving in Glacier Bay and Icy Strait

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Last updated: September 2020

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 1985–2020, 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 Nielson, 2018, 2019) 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; Piatt et al., 2020). In 2020, humpback whale calving and juvenile return rates returned to more typical levels as compared to 1985–2013 (Table 4).

We observed 12 cow/calf pairs in June-August 2020, plus an additional four pairs if we included May and September when our survey effort is not standardized. The total whale count in 2020 is not yet available, therefore we cannot compute a CBR. The CBR over the past five years (2014–2019 mean = 2. 5%) is significantly lower than typical CBRs prior to 2014 (1985–2013 mean = 9.3%; Table 4). When available, we expect the 2020 CBR to be higher than during the period of reduced

Table 4: Humpback whale calf production and survival observations in Glacier Bay and Icy Strait, 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. #One was resighted in late fall in British Columbia. The total number of whales is not yet available for 2020**. ***Overall calf mortality rate for 2014–2020 is 7 out of 37 (18.9%).

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	1.3	0
2020	12	8**	0

reproductive success in 2014-2019 (Figure 71). We estimate that the total number of whales will be higher in 2020 than 2019, thus the estimated CBR would fall between 6% and 8% (Figure 71). A CBR in this range represents a positive trend compared to recent years, yet reproductive success remains below average compared to 1985-2013.

Calves in 2020 appeared to be in relatively good physical condition when last sighted with their mothers which bodes well, but is no guarantee, of their continued survival. We saw no evidence of apparent mid-season calf mortality this year, unlike recent years (Table 4) (Neilson et al., 2015; Gabriele and Nielson, 2018). Most mothers, in 2020, appeared to be in sub-optimal body condition based on their rough skin, an overall "angular" appearance, the presence of a post-cranial depression, and/or visible scapulae (Figure 72). In the 1990s and 2000s, it was typical to see a few mothers that looked moderately emaciated in the spring, but by mid to late summer their body condition would improve. In 2019 and 2020, most of the mothers still looked emaciated at the end of summer (Figure 72).

We documented one yearling in 2020 (# 2652, calf of # 219) but none of the other 24 Glacier Bay/Icy Strait calves born in 2014–2019 have been documented as juveniles in Southeast Alaska or elsewhere. With the geographically expanded matching effort made possible by HappyWhale, we determined that a calf we documented in June 2017 in upper Glacier Bay (# 2024_calf_2017) was sighted several times with its mother in British Columbia in fall 2017 (J. Hildering, pers. comm. September 2020). This animal has not been sighted in subsequent years, so its fate post-weaning is unknown. To date, HappyWhale has not revealed any additional juvenile survivals in the 2014–2019 period, although it has documented the previously undetected survival of at least 18 Glacier Bay/Icy Strait calves born prior to 2014 as juveniles and adults outside our study area.

Factors influencing observed trends: Improved feeding conditions in 2018–2020 are the main factor in the observed positive trend. The increase in calf production indicates sufficiently good feeding conditions for females prior to conception and during pregnancy. Improved (apparent) calf survival suggests sufficiently good conditions this summer to keep the mothers well-fed. Other indications of improved feeding conditions in Glacier Bay in 2020 include: an apparent increase in whale abundance (data analysis in progress), an increase in whale group sizes, visual assessment of prey patches observed on our depth-sounder during whale surveys, and visual observations of forage fish schooling near the surface. In the 2014–2018 period, pairs, trios and larger group sizes

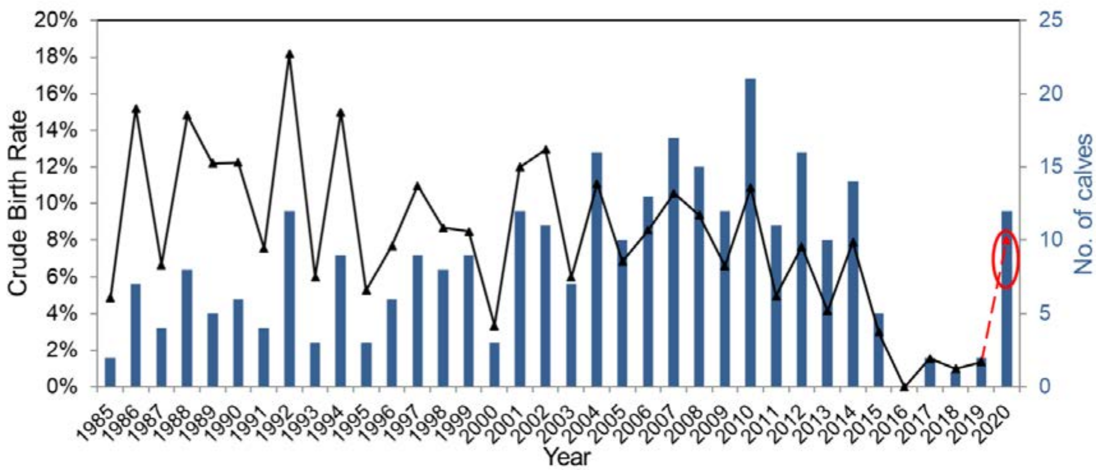

Figure 71: Crude birth rate (black line) (1985–2020) and annual number of calves (blue bars) (1985–2020) in Glacier Bay-Icy Strait. Red circle for 2020 indicates that the CBR is unknown but expected to be less than 2% (see text).

Figure 72: Health assessment photograph of mother #1657 on August 29, 2020 showing rough skin, post-cranial depression behind the blowholes, visible scapula, and general "angular" appearance that characterize poor body condition.

were conspicuously absent, whereas in 2019 and 2020, we began to see whales feeding together again, sometimes in large and stable groups, which suggests an improvement in feeding conditions. The absence of large vessel traffic in Glacier Bay and Icy Strait this summer due to the COVID-19 pandemic may also have influenced whale behavior and group size.

Probably the biggest factor in the relatively high number of calves in 2020 was that very few females had calves in the past four years or so. Since adult female humpback whales tend to have a calf every 2–3 years in Southeast Alaska (Gabriele et al., 2017) and gestation lasts approximately 11 months (Chittleborough, 1958), more than half of females are unavailable for mating in a given year. The sharp decline in calving since 2015 meant an unusually high number of available females in the winter 2018–2019 breeding season, resulting in the 2020 bumper-crop of calves. Five of the 2020 mothers were sighted in the study area every year since 2016. Three of the 2020 mothers were apparently absent from the study area in one year since 2016, four were apparently absent in two or more years. Thus, the return of reproductive females to the study area was also a factor in the observed trend.

Implications: The observed improvement in humpback whale productivity and calf survival and apparent improvement in feeding conditions in comparison to recent years may indicate that groundfish have also experienced better feeding conditions. In the absence of standardized forage species monitoring, we rely on data from elsewhere to infer what may be happening in Glacier Bay and Icy Strait. Pairing this long-term whale population monitoring with sustained, quantitative monitoring for forage species in Glacier Bay and Icy Strait would enable a deeper understanding of the root causes of observed changes in whale population parameters and the marine ecosystem in general.

Reproduction and recruitment from within, as opposed to immigration from outside the population, have been key drivers of humpback whale population growth in Glacier Bay and Icy Strait over the past 30 years (Pierszalowski et al., 2016), thus the resumption of calf production and survival will be an important factor in the long-term trend for this population. This year's observation of a more typical rate of calf production and survival are encouraging and seem likely to persist if oceanographic conditions support a prey base that promotes whale health and reproduction.

Steller Sea Lions in the Gulf of Alaska

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Last updated: August 2020

Description of indicator: Counts of adult and juvenile Steller sea lions *Eumetopias jubatus* are used in the Aleutian Island ecosystem assessment to represent the status of a large, K-apex piscivorous predator whose diet consists primarily of commercially-fished species. During the summer breeding season, sea lions aggregate on land, usually their natal rookery site, to breed and birth pups (Fritz et al., 2016). During the non-breeding season, sea lions disperse and can range widely throughout the North Pacific Ocean, especially juveniles and males. The Marine Mammal lab (MML) conducts annual population surveys during the peak of the breeding season to collect counts throughout their range in Alaska (Fritz et al., 2016) (Figure 73). Challenging survey conditions usually means there are data gaps for sites that cannot be surveyed. MML uses agTrend (Johnson and Fritz, 2014) to fill in the missing data to model counts we would expect if we surveyed all sites and also used in estimated annual rates of change (i.e., trend). MML does not report abundance estimates but rather count estimates of animals hauled out on land and therefore, non-pup counts do not account for animals at-sea during the survey. Pup counts do not account for those animals born (or that died) before (or after) the survey; however, since pups do not take to the water until they are older (∼1 month), this count is considered a census.

The Gulf of Alaska geographic area is comprised of four Steller sea lion regions: eastern, central and western Gulf of Alaska regions (western DPS), and southeast Alaska region (eastern DPS) (Figure 73). The range of eastern DPS Steller sea lions extends along the west coastline of Canada and the U. S. (Fritz et al., 2016; Sweeney et al., 2018, 2019).

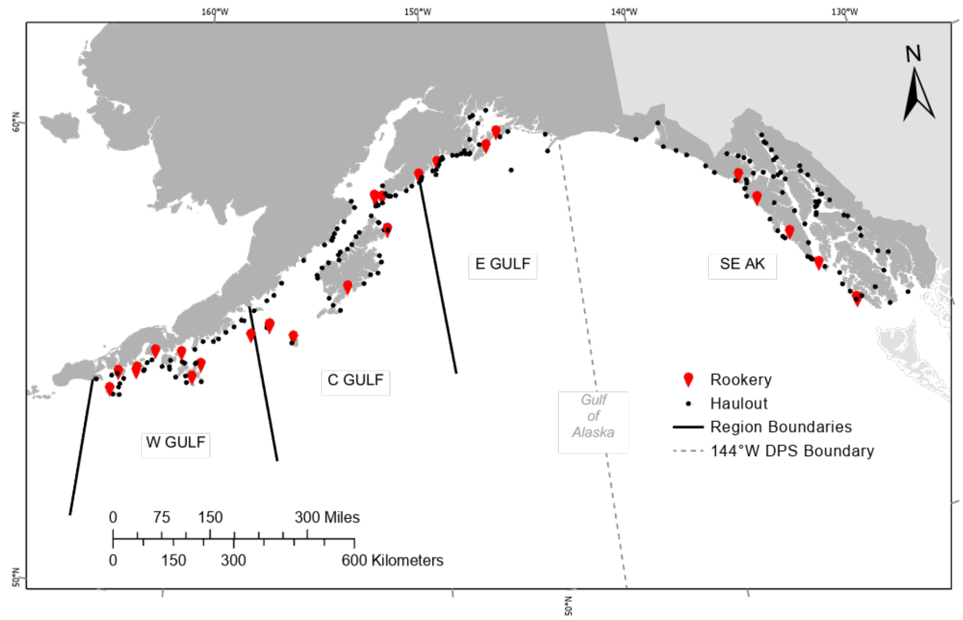

Figure 73: Steller sea lion regions in the Gulf of Alaska.

A note about agTrend & SSL outputs—MML uses the R package agTrend to model raw Steller sea lion (SSL) non-pup (NP) and pup counts to model count estimates (an index of population abundance) and trends in Alaska (Johnson and Fritz, 2014). This package produces two types of count estimates:

1. *Realized counts*—Uses the standardized variance of raw counts at each site throughout the time series to estimate survey counts we could expect to collect if we had completely surveyed all sites. Therefore, the more complete the survey, the more similar raw counts are to realized counts. When available, MML uses realized counts that have not been "smoothed" (i.e., predicted counts) to report on changes over time.
2. *Predicted counts*—Uses the model fit to estimate count values that would be predicted at a site in a given year if it were resurveyed. For trend analyses, predicted counts are more appropriate because they account for both measurement and process error.

Status and trends: Declines in Steller sea lion populations were first observed in the 1970s, with the steepest declines occurring in the mid-1980s. In the western DPS in Alaska between 2002 and 2019, non-pup and pup counts for increased at a rate of 1.82% y^{-1} (95% CI 1.29–2.38% y^{-1}) and 1.63% y^{-1} (95% CI 1.12–2.16% y^{-1}), respectively (Figure 74). In the combined eastern, central, and western GOA regions, non-pup and pup sea lion counts increased 3.12 and 3.13% y^{-1} (respectively) between 2002 and 2019. However, in looking more closely at realized counts, the 2019 non-pup count for this area has not been this low since 2011 (Sweeney et al., 2019). This portion of the western DPS showed fairly steady and consistent increases in counts until recent years, when concerning and anomalous trends have appeared. In 2017, MML observed that the eastern GOA non-pup realized count had declined by ∼1,000 sea lions with an increase in the central GOA, since the 2015 survey (combined region counts remained stable between 2015 and 2017). This indicated atypical westward movement of mostly adult females and juveniles to the central GOA (and not into the western GOA). Despite this movement of adult females (and stability in non-pup counts), pup counts declined 33 and 18% in the eastern and central GOA (respectively).

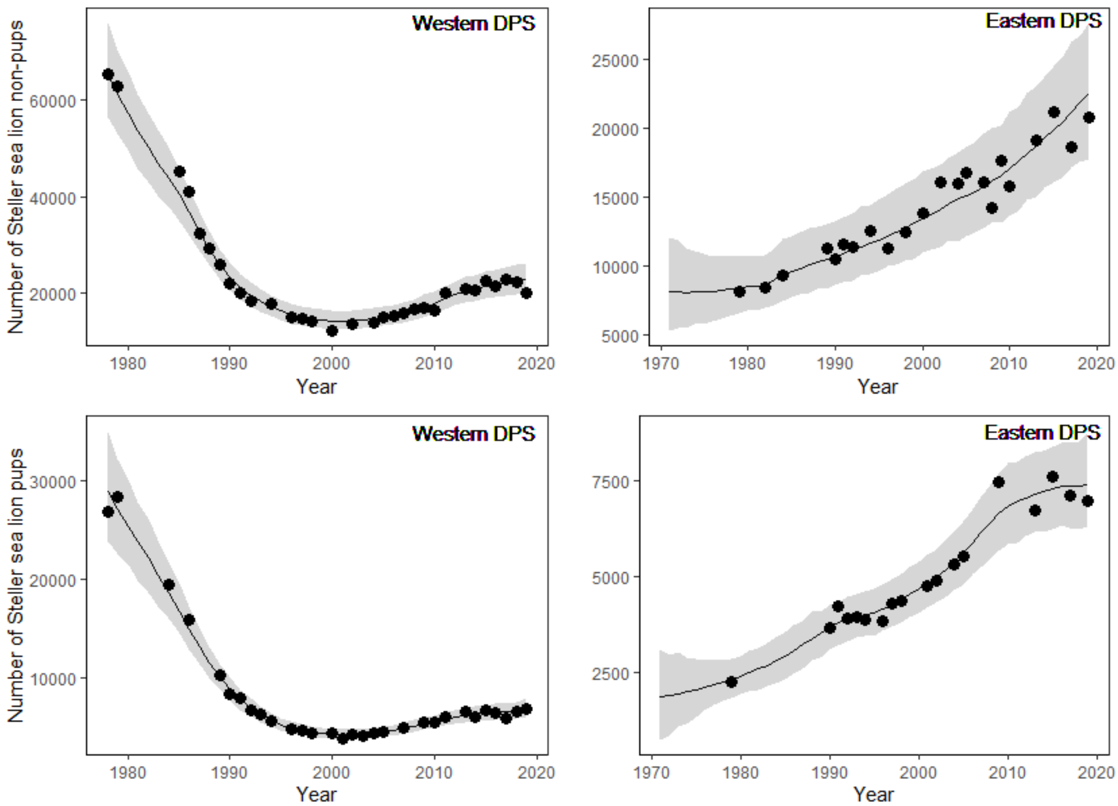

Figure 74: Predicted (line with 95% confidence intervals shaded) and realized (points) counts of Steller sea lion non-pups (top) and pups (bottom) in the western designated population segments (WGOA; left) and eastern designated population segments (SEAK; right).

In 2019, pup counts in the eastern and central GOA regions rebounded to about what we had observed in 2015 (Sweeney et al., 2019). In contrast, eastern and central GOA non-pups had declined by 2,628 since the 2017 survey. In southeast Alaska, between 1989 and 2019, non-pup and pup counts increased 2.53 and 2.85% y^{-1}, respectively (Sweeney et al., 2019). Since around 2013, this region seems to be oscillating around carrying capacity however, more data are necessary to distinguish this as a pattern. After 5 years of relative stability in non-pup counts in southeast Alaska, non-pups increased (2,168) between 2017 and 2019.

As 2020 Aleutian Islands (AI) surveys were cancelled because of COVID-19, 2021 survey effort will be focused in the AI and not the GOA.

Factors influencing observed trends: Part of the decline in western DPS pup counts could be attributed to a reduction in juvenile recruitment due to the 2017 decline in pup production and potential declines that occurred in non-survey years (Fritz et al., 2016). However, it does not appear that this lack of recruitment accounts for all of the decline. Other likely explanations could be reduced juvenile survival caused by a reduction in foraging success due to reduced prey, and (or) potential eastward movement to southeast Alaska.

The increase in eastern DPS non-pup counts in 2019 could be explained by movement of non-pups from the west. Alternatively, this reduction in non-pups could be an artifact of only surveying rookery and some major haulout sites (and not a majority of haulout sites where these animals could have potentially moved to). Despite this non-pup increase, pup counts remained relatively stable (and have been since 2009).

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

Ecosystem or Community Indicators

Stability of Groundfish Biomass in the Gulf of Alaska

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Last updated: August 2020

Description of indicator: The stability of the groundfish community total biomass is measured with the inverse biomass coefficient of variation (1 divided by the coefficient of variation of total groundfish biomass (1/CV[B])). This indicator provides a measure of the stability of the ecosystem and its resistance to perturbations. The variability of total community biomass is thought to be sensitive to fishing and is expected to increase with increasing fishing pressure (Blanchard and Boucher, 2001). This metric is calculated following the methods of Shin et al. (2010). The CV is calculated as the standard deviation of the groundfish biomass index over the previous 10 years divided by the mean 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 (1984–2019). This metric is presented as an inverse, so as the CV increases the value of this indicator decreases, and if the CV decreases the value of this indicator increases.

Several species of pelagic forage fishes are abundant in the GOA and their populations may vary substantially which could drive the value of this indicator. While many species of pelagic forage fish are occasionally encountered during the survey, most are not consistently sampled well enough to be included in the survey biomass index, including sandlance, capelin, and other pelagic smelts. Herring and eulachon are included in the survey index, so we have recalculated this indicator with and without herring and eulachon to examine their influence on this indicator.

Status and trends: The stability of groundfish biomass in the western Gulf of Alaska has been relatively constant over (Figure 75). There was a slight increase in stability from 2007 (4.5) to 2019 (4.7), with a series low in 2017 (4.0). When herring and eulachon are removed, this indicator has slightly higher values from 2007–2015 (Figure 75), and follows the same overall trends of the indicator with herring and eulachon. In the eastern Gulf of Alaska, this indicator has been stable over the time series with only minor fluctuations between survey years (Figure 75). When herring and eulachon are excluded from the indicator, the values are much higher indicating less variability in total groundfish biomass (Figure 75). The indicator values in the eastern GOA are approximately equivalent to values in the western GOA (about 4) when herring and eulachon are excluded.

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 ad-

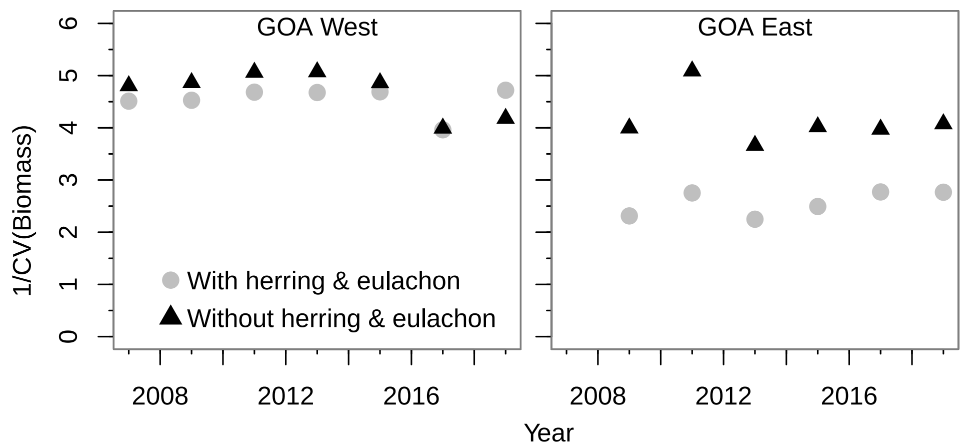

Figure 75: The stability of groundfish in the western and eastern GOA represented with the inverse biomass coefficient of variation (1/CV[B]). Ten years of data are required to calculate this metric, so this time series begins in 2007 for the western GOA and in 2009 for the eastern GOA (no survey in 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).

vantage 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 with herring and eulachon included, reached its highest level in 2019, reflecting the relative stability of the groundfish biomass index in the most recent ten survey years. 2017 was 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 survey-year average, reducing the CV, and increasing the indicator value.

In the eastern GOA, this indicator in 2019 is unchanged from 2017. Overall, this indicator with herring and eulachon included has lower values in 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.

The 10-year average dampens the effect of the survey index of any given year (e.g., marine heatwave years of 2014–2016). While the 2014 heatwave contributed to the low 2017 value, given documented decreases in some species including Pacific cod and arrowtooth flounder (Barbeaux et al., 2020), other factors contribute to that value as well. In 2017, the survey biomass index was the second lowest over the time series (1999 was the lowest), the 10-year mean was the lowest over the time series, and the SD was the highest over the time series. It is important to note that the 10 [survey] year window contributing to the 2017 value includes the two lowest survey index values (1999 and 2017) and the four highest index values, over the survey index time series. This led to the high SD in 2017 and thus the low indicator value.

Implications: The stability of groundfish biomass in the eastern and western GOA appears constant over the time period examined and there is no indication of a directional change. However, there is greater biomass variabiliy in the eastern GOA due to the relatively higher proportion of pelagic fish in the survey index in this region.

Mean Length of the Fish Community in the Gulf of Alaska

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Last updated: August 2020

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.

Several species of pelagic forage fishes are abundant in the GOA and their populations may vary substantially, which could drive the value of this indicator. While many species of pelagic forage fish are occasionally encountered during the survey, most are not consistently sampled well enough to be included in the survey biomass index, including sandlance, capelin, and other pelagic smelts. Herring and eulachon are included in the survey index, so we have recalculated this indicator with and without herring and eulachon, to examine their influence on the indicator state and trends.

Status and trends: *With herring and eulachon*—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 (Figure 76, left panel, gray circles). 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 (Figure 76). Despite declines in this indicator in both regions from 2015 to 2019, this indicator has generally been stable over the years examined and the recent decreases are still within the range of historical indicator values (except 2019 in eastern GOA, which is the series minimum value).

Without herring and eulachon—The status and trends in the mean length of the groundfish community with herring and eulachon excluded, are qualitatively similar to the status and trends when they are included, but are shifted slightly higher in value (Figure 76). In the western GOA, there is relatively little difference in the indicator values between the two series. While in the eastern GOA there is a larger difference between the status of the two series, particularly since 2005.

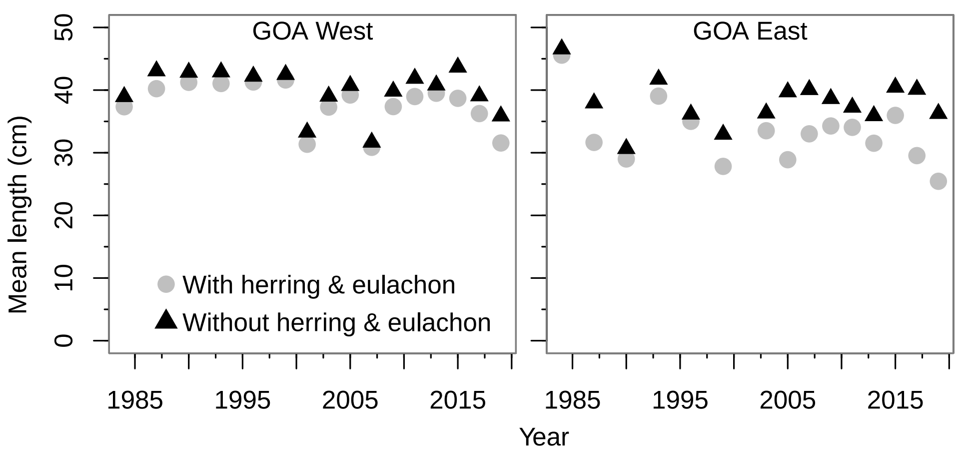

Figure 76: Mean length of the groundfish community sampled during the NMFS/AFSC summer bottom-trawl survey of the western Gulf of Alaska (1984–2019). The groundfish community mean length is weighted by the relative biomass of the sampled species. The gray dots represent the indicator series with herring and eulachon included and the black triangles are the indicator series with herring and eulachon excluded.

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 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 efficiently caught by the bottom-trawl. In the eastern GOA, herring have mean lengths shorter than much of the groundfish community, are a dominant component of the biomass index and can have large fluctuations in abundance from year to year. Years with low mean groundfish length in the eastern GOA typically coincide with years of higher than average herring biomass. This is particularly visible in eastern GOA for the years 1987, 1999, 2005, 2017, and 2019 (Figure 76). When herring is removed from this indicator, the indicator value in these years is much higher. The decline in this indicator from 2015 to 2019 when herring and eulachon were included was initially concerning as it coincided in time with the 2014-2016 marine heatwave. However, after removing herring and eulachon, this indicator jumped back up to values closer to the series mean for the eastern GOA.

In the western GOA, herring and eulachon are not as dominant a component of the groundfish biomass index, so removing them from the indicator did not result in as large a difference in indicator values in most years. In the most recent three years (2015, 2017, and 2019) when herring and eulachon were removed from the indicator, the values did visibly increase (Figure 76) and are much closer to the long-term indicator mean. The low indicator value in the western GOA in 2019 is in part due to relatively high biomass indices for smaller forage species but also partly attributable to lower than average biomass indices for some larger commercial species (e.g., walleye pollock, arrowtooth flounder). Additionally, the 2019 mean lengths for arrowtooth flounder, Pacific cod, Pacific halibut, and walleye pollock were all below their long-term means.

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: August 2020

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`). The GOA bottom trawl survey was conducted triennially from 1984 to 1999, and then switched to a biennial schedule beginning in 2001. The groundfish community mean lifespan is weighted by the relative biomass of each 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.

Several species of pelagic forage fishes are abundant in the GOA and their populations may vary substantially which could drive the value of this indicator. While many species of pelagic forage fish are occasionally encountered during the survey, most are not consistently sampled well enough to be included in the survey biomass index, including sandlance, capelin, and other pelagic smelts. Herring and eulachon are included in the survey index, so we have recalculated this indicator with and without herring and eulachon, to examine their influence on the indicator.

Status and trends: The mean lifespan of the western GOA demersal fish community with herring and eulachon included is 20.3, which is down from 22.6 in 2017, and is the second lowest from 1984–2019 (Figure 77). When herring and eulachon are excluded from the series, the indicator follows the same general pattern but with the values shifted slightly higher. In the eastern GOA, the mean lifespan in 2019 with herring and eulachon included dropped to its second lowest value (18.4) over the time series (Figure 77). When herring and eulachon are removed from the series, the indicator values are shifted higher but follow similar overall trends.

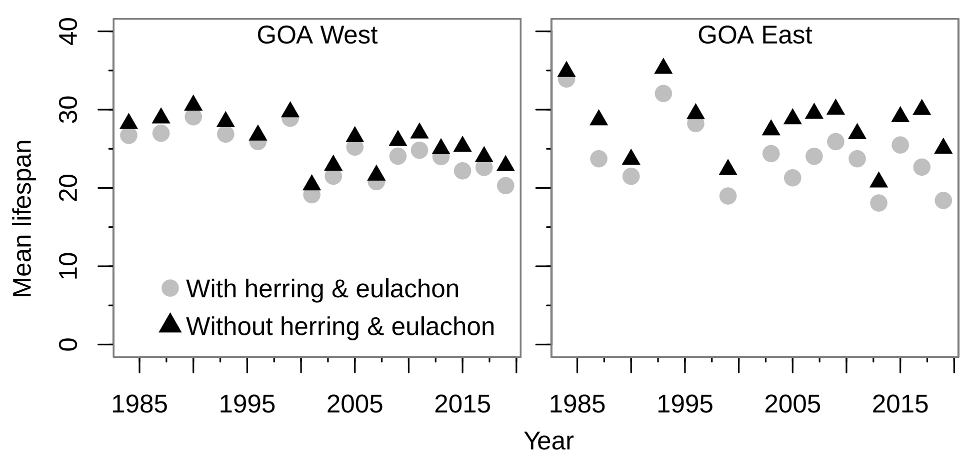

Figure 77: The mean lifespan of the eastern and western Gulf of Alaska demersal fish communities, weighted by relative biomass calculated from the NMFS/AFSC summer bottom-trawl survey. The gray dots represent the indicator series with herring and eulachon included and the black triangles are the indicator series with herring and eulachon excluded.

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 weak recruitment could also influence the mean community lifespan by altering the relative abundance of age classes and species. For example, in the western GOA in 2001, 2007, and 2019 biomass indices for the relatively shorter-lived Pacific herring and other managed forage species were high, which 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, reflecting impacts of the 2014-2016 and 2019 marine heatwaves (Barbeaux et al., 2020; Rogers et al., 2020).

In the eastern GOA, low indicator values in 1987, 1999, 2005, 2013, 2017, and 2019 corresponded to years with high biomass indices for Pacific herring (Figure 77). When herring and eulachon are excluded from the indicator series, the values are much higher in these years (Figure 77). The series without herring and eulachon generally follows the same trends as the original series, however, the values are shifted higher without herring and eulachon included.

Implications: The groundfish mean lifespan in the western and eastern GOA has shown interannual variability over the time series, with years of low indicator values corresponding to years with high biomass indices for shorter-lived forage species, such as herring. Species that are short-lived are generally smaller and more sensitive to environmental variation than larger, longer-lived species (Winemiller, 2005). Longer-lived species help to dampen the effects of environmental variability, allowing populations to persist through periods of unfavorable conditions and to take advantage when favorable conditions return (Berkeley et al., 2004; Hsieh et al., 2006). Since 2011, this indicator has been trending negative in the western GOA. The low values in 2017 and 2019 in the western GOA are in part due to lower biomass indices for some commercial groundfish species. The delcline might be, in part, due to marine heatwave-related decreases Pacific cod and arrowtooth flounder, but the indicator reflects a community-wide, directional response and may be driven by other forces or species as well. 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.

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys in the Gulf of Alaska, 1993–2019

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Last updated: October 2020

Description of indicator: This index provides a measure of the overall biomass of benthic, demersal, and semi-demersal fish and invertebrate species. We obtained catch-per-unit-effort (CPUE in kg ha^{-1}) of fish and major invertebrate taxa for each successful haul completed during standardized bottom trawl surveys on the Gulf of Alaska shelf (GOA), 1993–2019. Total CPUE for each haul was computed as the sum of the CPUEs of all fish and invertebrate taxa. To obtain an index of average CPUE by year, we modeled log-transformed total CPUE (N = 7160 and 1789 hauls in the western (west of 147°W) and eastern GOA, respectively) as smooth functions of depth, alongshore distance and sampling stratum with year-specific intercepts using Generalized Additive Models following Mueter and Norcross (2002). Hauls were weighted based on the area represented by each stratum. To avoid biases due to gear and vessel issues, data prior to the 1993 survey was not included in the analysis.

Status and trends: Total log(CPUE) in both the eastern and western GOA decreased from recent high values to their lowest (west) or second lowest value (east) in 2017 and increased somewhat from 2017 to 2019 in both areas (Figure 78). There was no significant long-term trend over time from 1993 to 2019 in either region (Generalized least squares regression with first-order autoregressive residual autocorrelation, $p > 0.2$), but total CPUE decreased significantly by 30–40% from 2009 to 2017 in the western GOA and from 2013 to 2017 in the eastern GOA. Total log(CPUE) in both regions increased slightly from 2017 to 2019 due to increases in walleye pollock, Pacific Ocean perch, rex sole and sablefish, among others.

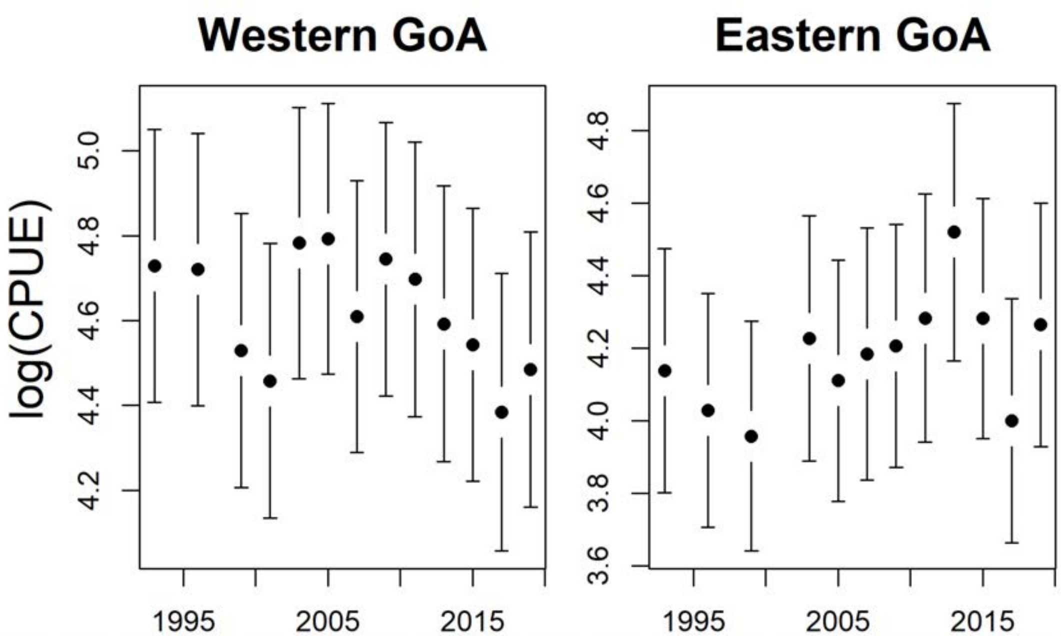

Figure 78: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from in the western (west of 147°W) and eastern Gulf of Alaska by survey year with approximate 95% confidence intervals. Estimates were adjusted for differences in depth and sampling locations (alongshore distance) among years. No sampling in the eastern Gulf of Alaska in 2001.

Factors influencing observed trends: Commercially harvested species account for over 70% of total survey catches. Fishing is expected to be a major factor determining trends in survey CPUE, but environmental variability is likely to account for a substantial proportion of the observed variability in CPUE through variations in recruitment, growth, and distribution. Substantial declines in many species in recent years may be associated with the unusual warm conditions in the GOA in 2014–2015, which appeared to affect prey availability and were associated with unusual mortality events in seabirds and marine mammals. The subsequent increase in CPUE from 2017 to 2019 suggests improved conditions for growth and recruitment.

Implications: This indicator can help address concerns about maintaining adequate prey for upper trophic level species and other ecosystem components. A sharp drop in total biomass of demersal fish and invertebrates affecting commercial and non-commercial species, suggests poor availability of zooplankton prey for these species and a reduced prey base for upper trophic level species following the 2014/15 warm event.

Average Local Species Richness and Diversity of the Gulf of Alaska Groundfish Community

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Description of indicator: Indices of local species richness and diversity are based on standard bottom trawl surveys in the western (WGOA; west of 147°W) and eastern Gulf of Alaska (EGOA). We computed the average number of fish and major invertebrate taxa per haul (richness) and the average Shannon index of diversity (Magurran, 1988) by haul based on CPUE (by weight) of each taxon. Indices for the Gulf of Alaska were based on 76 fish and common invertebrate taxa that have been consistently identified since the early 1990s. Indices were computed following (Mueter and Norcross, 2002). Briefly, annual average indices of local richness and diversity were estimated by first computing each index on a per-haul basis, then estimating annual averages with confidence intervals across the survey area using a Generalized Additive Model that accounted for the effects of variability in geographic location (latitude/longitude) and depth with year-specific intercepts. In addition to trends in the indices over time, we mapped average spatial patterns for each index across the survey region.

Status and trends: Richness and diversity were generally higher in the EGOA than in the WGOA with, on average, 2–3 additional species per haul in the east (Figure 79). Richness and diversity have been relatively stable in the western Gulf with slightly higher local richness in the 2015–2019 surveys compared to the 2011/13 surveys. Local species richness in the eastern Gulf increased substantially in 2013, declined by more than 2 species per haul in 2015 and increased in 2017 and 2019. Diversity in the EGOA declined from 2007 to 2015, but increased in 2017 and 2019 associated with the increase in local richness (Figure 79). Species diversity in both areas in 2019 was at or near the maximum observed values. Both richness and diversity tend to be highest along the shelf break and slope (Figure 80), with richness peaking at or just below the shelf break (200–300m), and diversity peaking deeper on the slope (300m +), as well as in some shallow water regions (< 100m). Notably, both richness and diversity are high off the Kenai Peninsula.

Factors influencing observed trends: Local richness and diversity reflect changes in the spatial distribution, abundance and species composition that may be caused by fishing, environmental variability, or climate change. If species are, on average, more widely distributed in the sampling area the number of species per haul increases. Local species diversity is a function both of how many species are caught in a haul, and how evenly CPUE is distributed among these species, hence time trends (Figure 79) and spatial patterns (Figure 80) in species diversity differ from those in species richness. Diversity typically increases with species richness and decreases when the abundance of dominant species increases. For example, the decreasing trend in diversity in the EGOA since 2007 appears to be due to an increase in the abundance and dominance of a few species, including arrowtooth flounder, walleye pollock and Pacific ocean perch. The unusual increase in local species richness in the EGOA in 2013 appears to have resulted from increased catches of a number of fish and invertebrate species, including walleye pollock, several *Sebastes* species, skates, grenadiers, sea stars and others. The increase in richness and diversity in 2017 and 2019 reflects reduced dominance of many of these species and possibly a more even distribution across space.

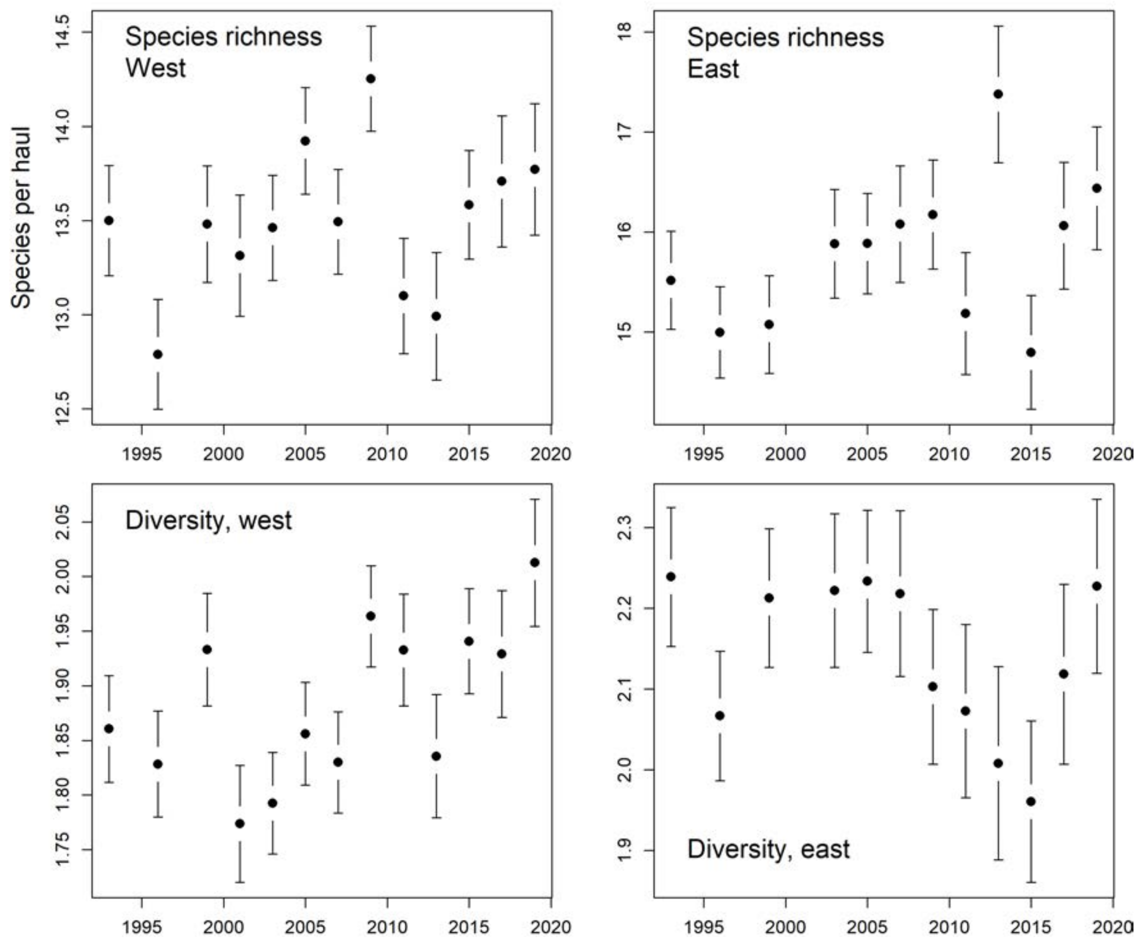

Figure 79: Model-based annual averages of species richness (average number of species per haul, top panels) and species diversity (Shannon index, bottom panels), 1993–2019, for the Western (left) and Eastern (right) Gulf of Alaska based on, respectively, 74 and 73 fish and invertebrate taxa collected by standard bottom trawl surveys with 95% pointwise confidence intervals. Model means were adjusted for differences in depth, date of sampling, and geographic location.

Implications: There is evidence from many systems that diversity is associated with ecosystem stability, which depends on differential responses to environmental variability by different species or functional groups (McCann, 2000). To our knowledge, such a link has not been established for marine fish communities.

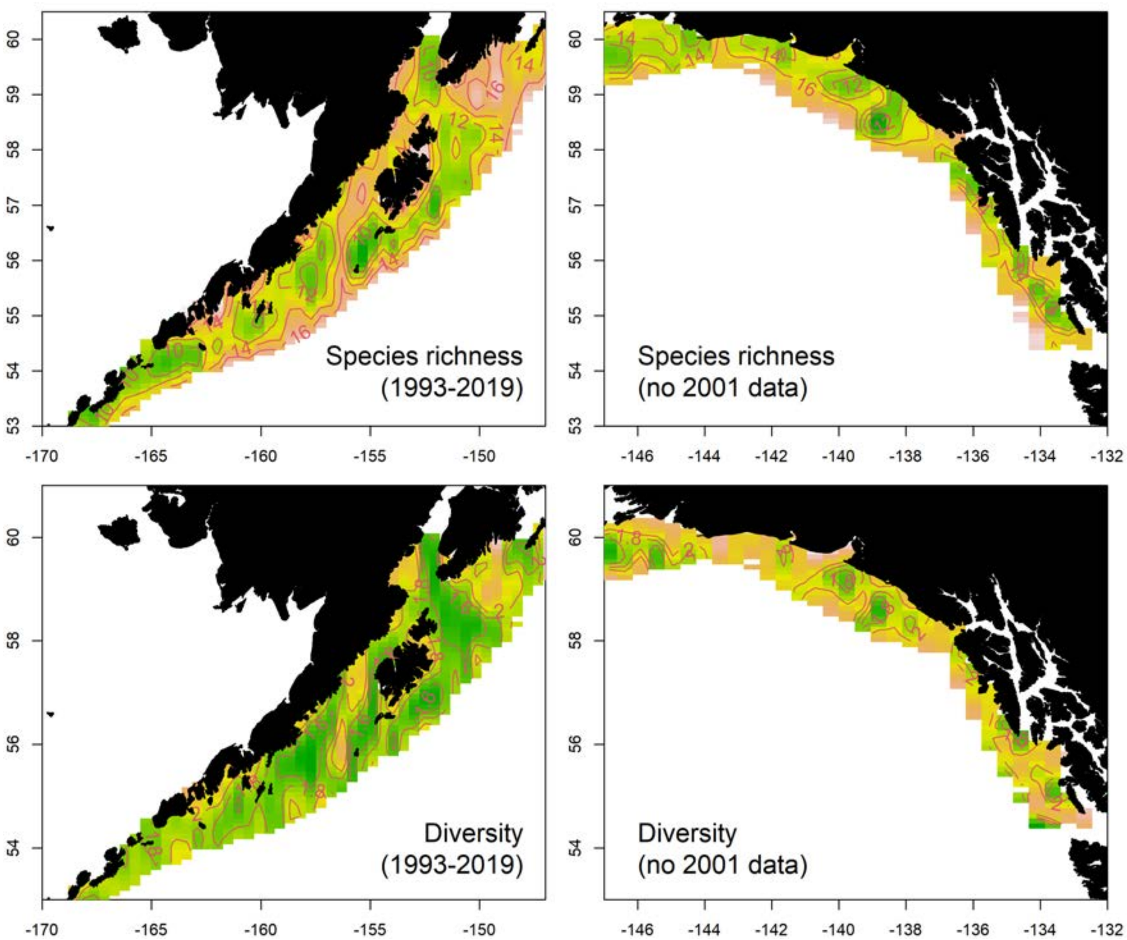

Figure 80: Average spatial patterns in local species richness (species per haul, top panels) and Shannon diversity (bottom panels) for the Western (left) and Eastern (right) Gulf of Alaska. Green colors are lower values and warmer colors are higher values for both plots).

Disease & Toxins Indicators

Harmful Algal Blooms in the Gulf of Alaska

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[8] NOAA Northwest Fisheries Science Center, 2725 Montlake Blvd E, Seattle, WA 98112
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Contact: dugan@aoos.org
Last updated: September 2020

Sampling Partners:

Alaska Ocean Observing System
UAF - Alaska Sea Grant
Alaska Veterinary Pathologists
Aleutian Pribilof Island Association
Central Council of Tlingit and Haida*
Chilkoot Indian Association*
Craig Tribal Association*
Hoonah Indian Association*
Hydaburg Cooperative Association*
Kachemak Bay NERR
Ketchikan Indian Association*
Klawock Cooperative Association*
Knik Tribe of Alaska
Kodiak Area Native Association
Metlakatla Indian Community*
NOAA Kasitsna Bay Lab
NOAA WRRN-West
North Slope Borough
Organized Village of Kake*
Organized Village of Kasaan*
Petersburg Indian Association*
Qawalangin Tribe of Unalaska
Sitka Tribe of Alaska*
Skagway Traditional Council*
Southeast Alaska Tribal Ocean Research
Sun'aq Tribe of Kodiak*
Woods Hole Oceanographic Institution
Wrangell Cooperative Association*
Yakutat Tlingit Tribe*

**Partners of Southeast Alaska Tribal Ocean Research (SEATOR)*

Description of indicator: Alaska's most well-known and toxic harmful algal blooms (HABs) are caused by *Alexandrium spp.* and *Pseudo-nitzschia spp.* *Alexandrium* produces saxitoxin which can cause paralytic shellfish poisoning (PSP) and has been responsible for five deaths and over 100 cases of PSP in Alaska since 1993 (see DHSS fatality report: `http://www.dhss.alaska.gov/News/Documents/press/2020/DHSS_PressRelease_PSPFatality_20200715.pdf`). Analyses of paralytic shellfish toxins are commonly reported as µg of toxin/100 g of tissue, where the FDA regulatory limit is 80µg/100g. Toxin levels between 80µg - 1000µg/100 g are considered to potentially cause non-fatal symptoms, whereas levels above 1000µg/100g ($\sim$ 12x) are considered potentially fatal.

Pseudo-nitzschia produces domoic acid which can cause amnesic shellfish poisoning and inflict permanent brain damage. Domoic acid has been detected in 13 marine mammal species and has the potential to impact the health of marine mammals and birds in Alaska.

The State of Alaska tests all commercial shellfish harvest, however there is no state-run shellfish testing program for recreational and subsistence shellfish harvest. Regional programs, run by Tribal, agency and university entities, have expanded over the past five years to provide test results to inform harvests and researchers, and to reduce human health risk (Figure 81). All of these entities are partners in the Alaska Harmful Algal Bloom Network which was formed in 2017 to provide a statewide approach to HAB awareness, research, monitoring, and response in Alaska. More information on methods can be found on the Alaska HAB Network website `https://aoos.org/alaska-hab-network/` or through the sampling partners listed above.

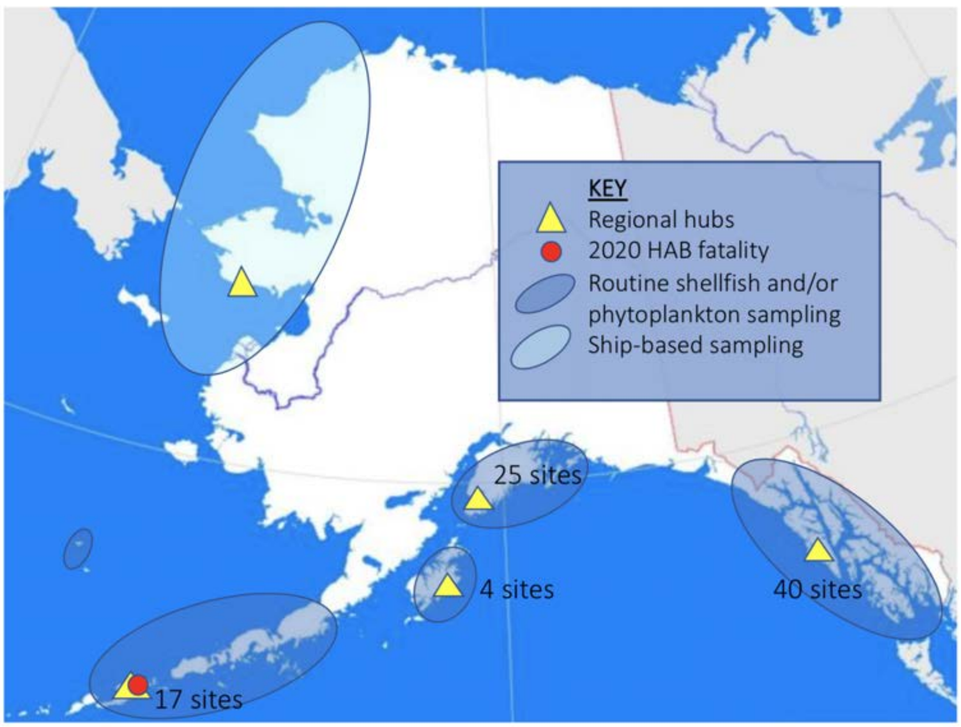

Figure 81: Map of 2020 sampling efforts conducted by partners of the Alaska Harmful Algal Bloom Network (AHAB). Opportunistic sampling of marine mammal tissue and other marine species occurs statewide and is not shown here. A more detailed view of ship-based sampling will be available after the 2020 fall field season.

Status and trends:

Alaska Region: Results from shellfish and phytoplankton monitoring showed a consistent presence of harmful algal blooms (HABs) throughout all regions of Alaska in 2020. Bivalve shellfish from areas that are well known for having PSP levels above the regulatory limit, including Southeast Alaska and Kodiak, continued to test above the regulatory limit, while shellfish in other areas, which have not traditionally seen high levels, had unprecedented levels, including in the Aleutian region.

East GOA: Southeast Alaska Tribal Ocean Research (SEATOR) partners sample shellfish and phytoplankton in 16 communities in Southeast Alaska along with sites in Kodiak. As of early September 2020, the observed paralytic shellfish toxin peak concentrations and the number of toxic samples were lower than observed in 2019. Shellfish and phytoplankton samples exceeded the regulatory limit for paralytic shellfish toxins (80µg/100g) in 26 out of 40 sites, compared to 30 sites in 2019 (Figure 82). In 2020, 160 samples exceeded the regulatory limit compared to over 200 in 2019. The lower levels in 2020 compared to 2019 were likely influenced by a particularly rainy summer which resulted in cooler water temperatures.

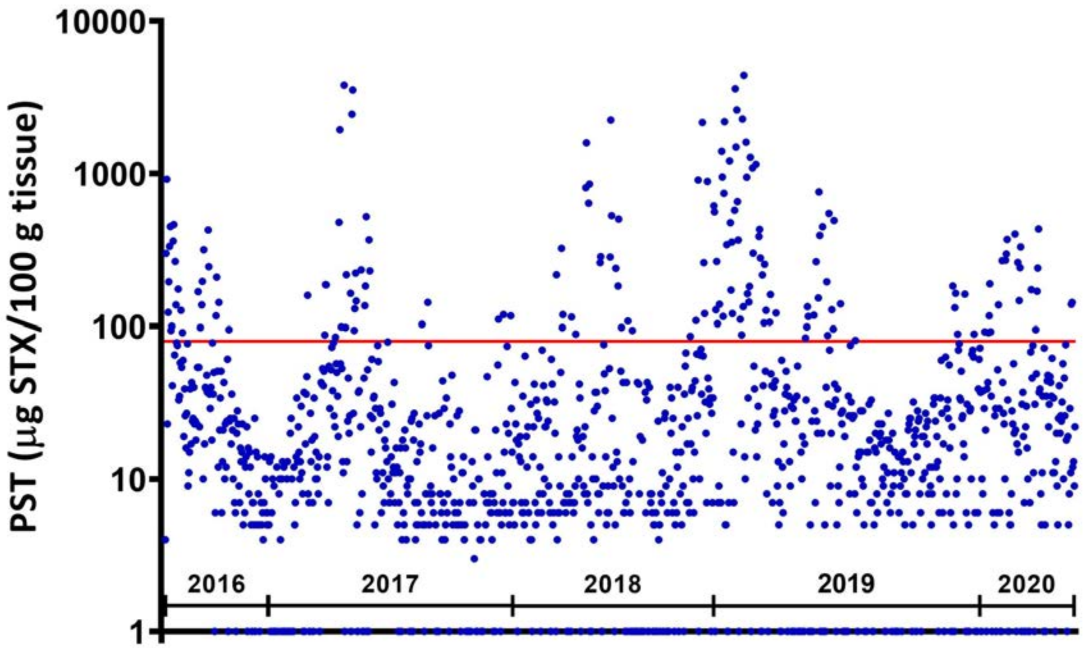

Figure 82: Paralytic shellfish toxicity (PST) results from blue mussel samples collected from 2016 through September 2020 in Southeast Alaska and Kodiak communities. The red line is the regulatory limit (80 µg of toxin/100 g of tissue. Data provided by SEATOR.

West GOA: Phytoplankton and shellfish monitoring in Kachemak Bay showed levels of paralytic shellfish poisoning toxins (saxitoxins) in 2020 that approached, but stayed under the regulatory limit for human consumption (Figure 83). These levels were consistent with those observed in 2018 and 2019 and below those observed in 2016 and 2017. Higher than average water temperatures were recorded in Kachemak Bay in July-August, similar to what was observed in summer 2016 during the marine heat wave. Unlike 2016, when higher saxitoxin levels were persistently observed with the higher water temperatures, factors other than temperature played a role in the below-limit values this year. Kachemak Bay National Estuarine Research Reserve's (NERR) Community Monitoring Program collected over 200 phytoplankton samples in 2020 from over 25 sites throughout South-central Alaska and had 14 shellfish samples analyzed for paralytic shellfish toxins. Additionally in this region, NOAA Kasitsna Bay Laboratory (KBL) researchers collected over 30 shore-based phytoplankton samples in 2020. Through the Gulf Watch Alaska long-term monitoring program, KBL also contributed 90 shipboard phytoplankton and zooplankton samples for HAB species and saxitoxin analyses, as well as 45 samples of salmon and halibut for measuring saxitoxin transfer in the food web.

Figure 83: Saxitoxin concentrations (log scale) in shellfish sampled from locations in Kachemak Bay from 2016 through August 2020. The red dashed line shows the regulatory limit of saxitoxins for safe human consumption at 80µg/100g of shellfish tissue. As shown in the plot, samples in Kachemak Bay in 2020 were below the regulatory limit as of September. Data above was collected by Kachemak Bay National Estuarine Research Reserve and NOAA Kasitsna Bay Lab.

On Kodiak Island, shellfish and phytoplankton toxicity monitoring occurs at four locations on the road system (Northeast and Southwest Mission Beach, North and South Trident Basin). Overall, paralytic shellfish toxins values in 2020 have been lower than 2019, which was the first year of routine sampling. Of the 54 blue mussel samples, 17 (31%) were above the regulatory limit. Of the 52 butter clam samples, 32 (62%) were above the regulatory limit. Several high toxicity samples were collected including blue mussel with toxins 5 times the regulatory limit in July, and butter clams close to 6 times the regulatory limit in February.

Factors influencing observed trends: HABs are likely to increase in intensity and geographic distribution in Alaska waters with warming water temperatures. Observations in Southeast and Southcentral Alaska suggest *Alexandrium* blooms occur at temperatures above 10°C and salinities above 20 (Vandersea et al., 2018; Tobin et al., 2019; Harley et al., 2020). As waters warm throughout Alaska, blooms may increase in frequency and geographic extent.

Implications: HABs pose a risk to human health when present in wildlife species that people consume, including shellfish, birds and marine mammals. Research across the state is attempting to better understand the presence and circulation of HABs in the food web. HAB toxins have been detected in stranded and harvested marine mammals from all regions of Alaska in past years (Lefebvre et al., 2016) (Figure 84). A multi-disciplinary statewide study funded by NOAA's ECOHAB program is underway and encompasses ship-based sediments samples, water samples, zooplankton samples, krill samples, copepod samples, multiple species of fish, bivalves, and the continuation of sampling subsistence-harvested and dead stranded marine mammals.

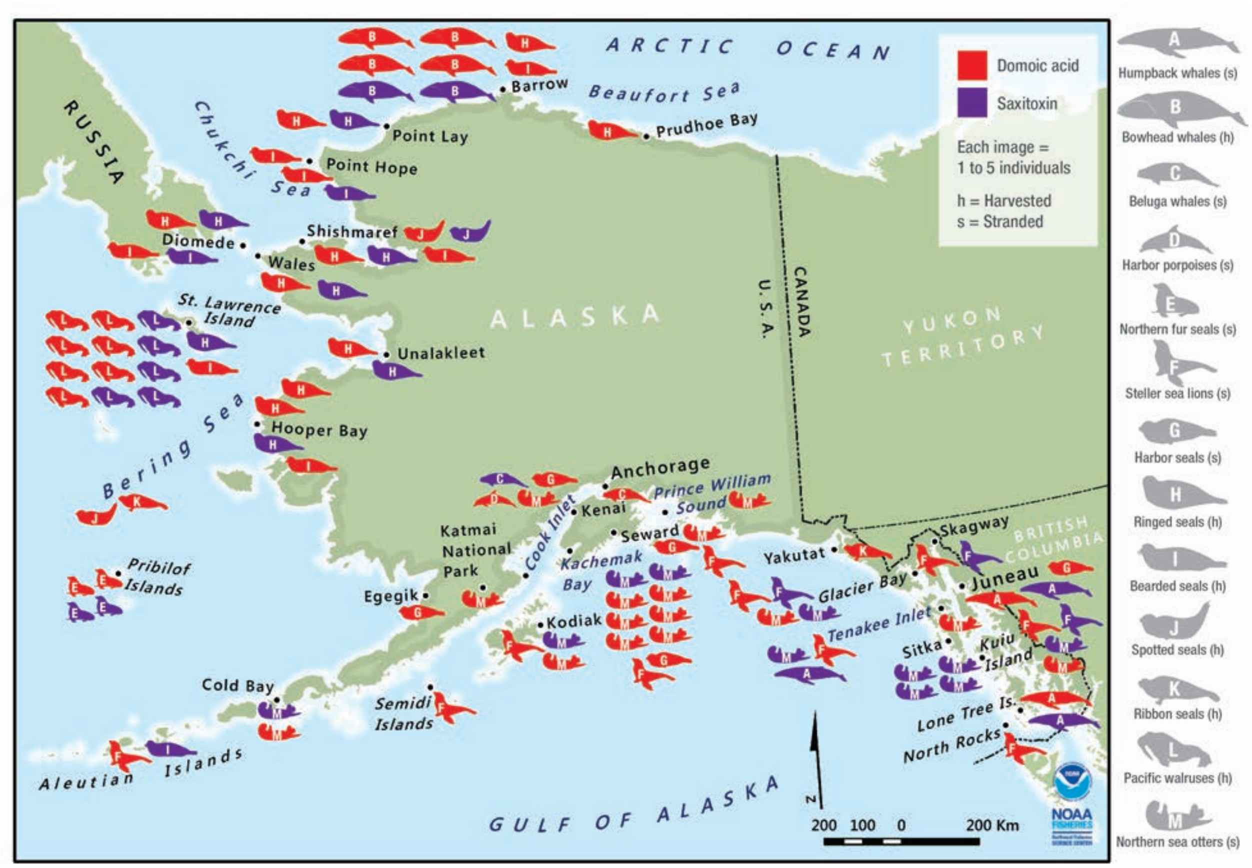

Figure 84: Algal toxins detected in stranded and harvested marine mammals suggest widespread prevalence of HABs throughout the food web in all regions of Alaska (Lefebvre et al., 2016). Updates to HAB toxin levels in Arctic/subarctic marine mammals are currently in progress.

"Mushy" Halibut Syndrome Occurrence

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Last updated: October 2020

Description of indicator: The condition was first detected in Gulf of Alaska halibut in 1998. Increased prevalence occurred in 2005, 2011, 2012, 2015, and 2016. It was apparently absent in 2013 and 2014, and there were relatively few occurrences in 2018. It is most often observed in smaller halibut of 15–20 lbs in the Cook Inlet area, but has also been noted in Kodiak, Seward, and Yakutat. Alaska Department of Fish and Game (ADF&G) describes the typical condition consisting of fish having large areas of body muscle that are abnormally opaque and flaccid or jelly-like. The overall body condition of these fish is usually poor, and often they are released because of the potential inferior meat quality. Data are collected through searches of ADF&G fishing reports and queries to IPHC staff. Incidence of mushy halibut is reported opportunistically in recreational fishing reports, and may not represent true trends. In particular, for these types of qualitative indicators, absence of reporting does not prove absence in the environment.

Status and trends: There were no reports of "mushy" halibut during the 2019 or 2020 sport fishing seasons in central Alaska (`http://www.adfg.alaska.gov/sf/fishingreports/`). However there was one anecdotal report of "mushy" halibut in a tribal fishery off Washington in 2020 (pers. comm. Josep Planas, IPHC).

Factors influencing observed trends: The condition is considered a result of nutritional myopathy/deficiency, and thus may be indicative of poor prey conditions for halibut. According to ADF&G, the Cook Inlet and Homer/Seward areas are nursery grounds for large numbers of young halibut that feed primarily on forage fish that have recently declined in numbers. Stomach contents of smaller halibut now contain mostly small crab species. Whether this forage is deficient, either in quantity or in essential nutrients is not known. However, mushy halibut syndrome is similar to that described for other animals with nutritional deficiencies in vitamin E and selenium. This muscle atrophy would further limit the ability of halibut to capture prey possibly leading to further malnutrition and increased severity of the primary nutritional deficiency.

Implications: The relatively few reports of "mushy" halibut, particularly relative to its recent prevalence in 2015 and 2016, may indicate that foraging conditions for young halibut have been more favorable in recent years. However, reporting is opportunistic and may not reflect true prevalence.

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 2020

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 85 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 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 85). 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 for fixed gear across the GOA as a whole increased to over 17% in 2018 and 2019 after remaining at 11% or lower from 2013 to 2017. Discard rates for fixed gear in the Eastern GOA have trended upward since 2010, surpassing 20% in 2016, 2018, and 2019. For 2020, discard biomass in all sectors is tracking lower relative to the previous 5 years through week 36 (Figure 86). Fixed gear discard rates for 2020 in the Eastern and Western GOA are trending in line with 2018-2019, while discard rates in both the pollock and non-pollock trawl sectors are trending lower.

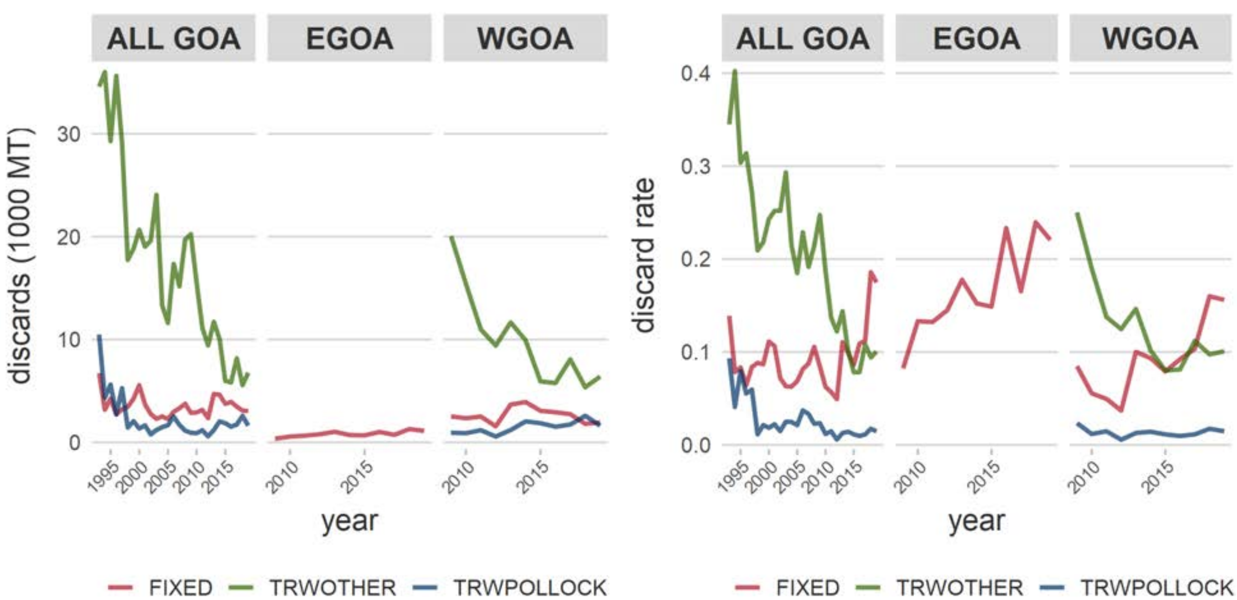

Figure 85: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear (FIXED), pollock trawl (TRWPOLLOCK), and non-pollock trawl sectors (TRWOTHER) for the Gulf of Alaska (ALL GOA) region, 1993–2019; and for and eastern (EGOA) and western (WGOA) subregions, 2009–2019. 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

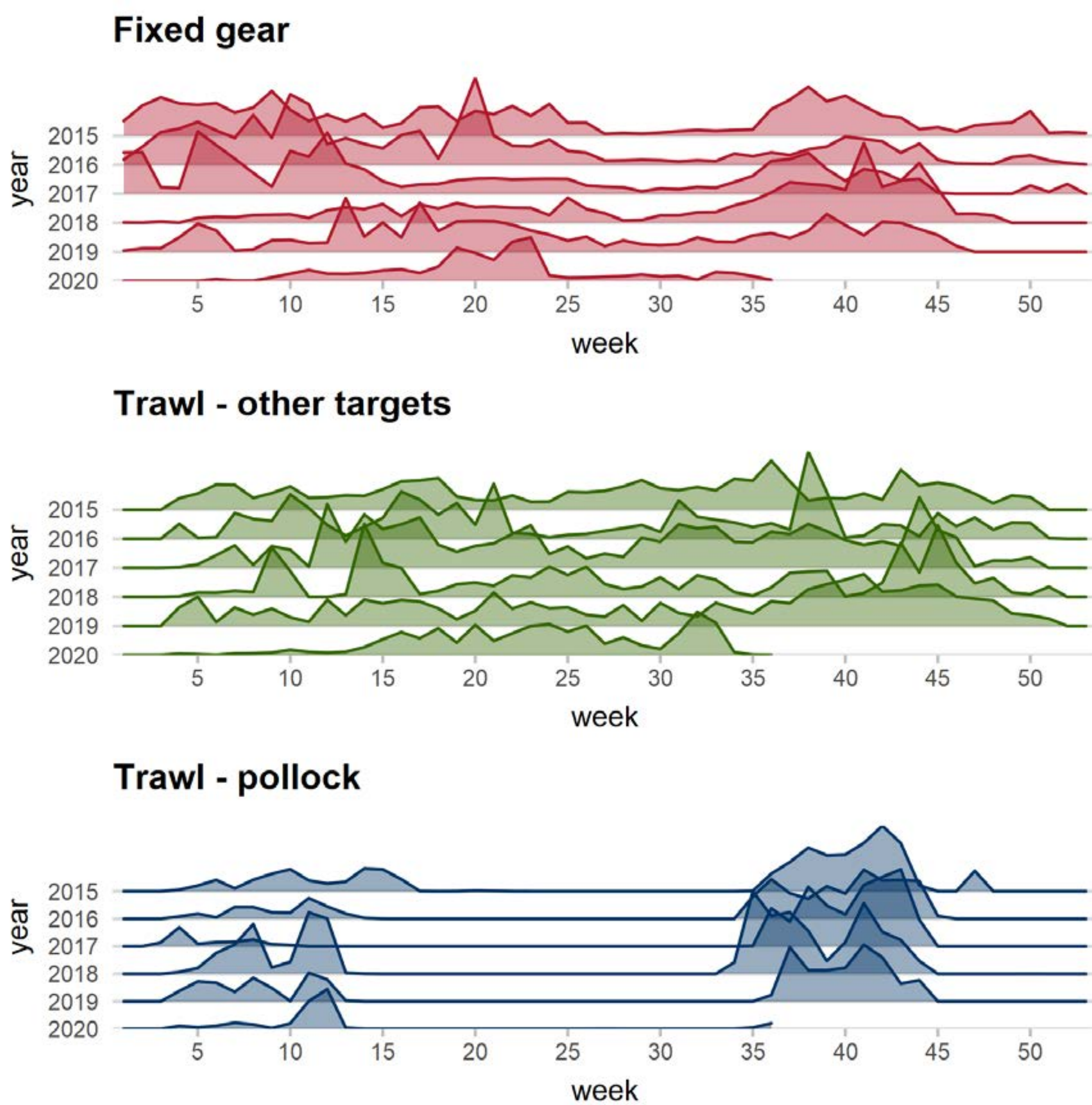

Figure 86: Total biomass of FMP groundfish discarded in the Gulf of Alaska by sector and week of the fishing season, 2014–2020 (data for 2020 is shown through week 36). Plotted heights are not comparable across fisheries.

various multilateral initiatives and in National Standard 9 of the Magnuson-Stevens Fishery Conservation and Management Act (Alverson, 1994; FAO, 1995; National Marine Fisheries Service, 2011). In the North Pacific groundfish fisheries, mechanisms to reduce discards include limited access privilege programs (LAPPs), which allocate catch quotas and may reduce economic discards by slowing down the pace of fishing; in-season closure of fisheries once target or bycatch species quotas are attained; minimum retention and utilization standards for certain fisheries; 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, and 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 2013 to 2015, and, in 2016, a reduction in the MRA for GOA skates from 20% to 5% (Ormseth, 2017).

Implications: Fishery discards 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). Discards 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; National Marine Fisheries Service, 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

Contributed by George A. Whitehouse[1] and Sarah Gaichas[2]
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Last updated: August 2020

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/north-pacific-groundfish-stock-assessments-and-fishery-evaluation`). 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 (Cahalan et al. 2014). 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://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones`). Within reporting area 610, the GOA and Aleutian Islands (AI) Large Marine Ecosystems (LME) are divided at 164°W. Non-target species caught east of 164°W are 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 2011–2019, with peaks in 2012, 2015, 2016, and 2019 (Figure 87). The catch of jellies in 2018 and 2017 were the second and third lowest over this time period, respectively. The catch increased sharply in 2019 to the third highest catch since 2011. 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. The catch of structural epifauna decreased 43% from 2018 to 2019. 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 2019. Sea stars dominate the assorted invertebrate catch, accounting for more than 87% of the total assorted invertebrate catch in each year. Sea stars are caught primarily in the Pacific cod and halibut fisheries.

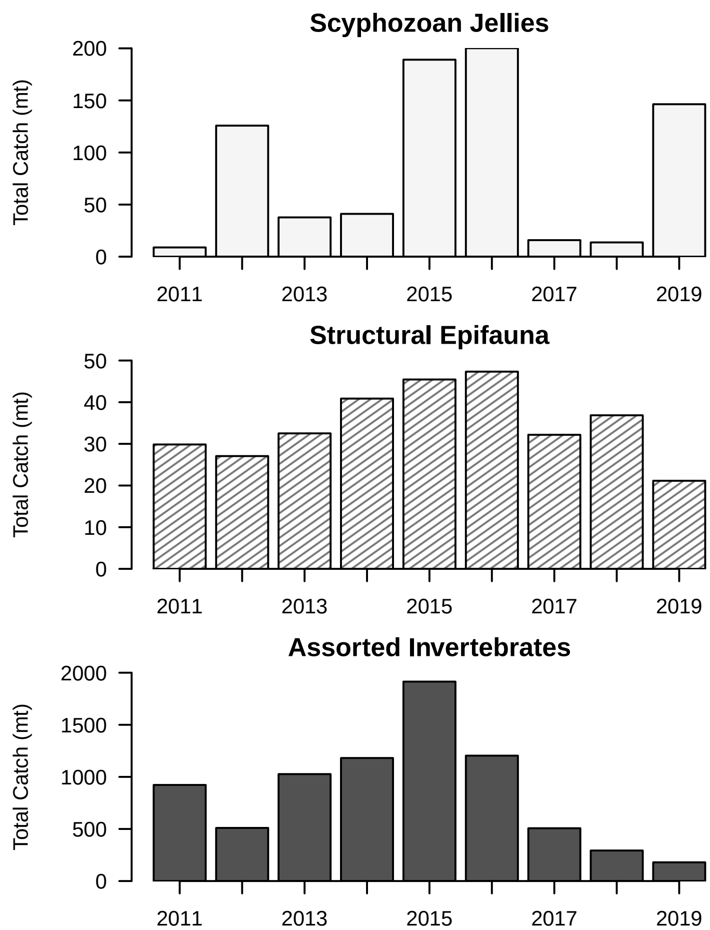

Figure 87: Total catch of non-target species (tons) in the GOA groundfish fisheries (2011–2019). Note the different y-axis scales between species groups.

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).

Seabird Bycatch Estimates for Groundfish Fisheries in the Gulf of Alaska

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Last updated: August 2020

Description of indicator: This report provides estimates of the numbers of seabirds caught as bycatch in commercial groundfish fisheries operating in federal waters of the U.S. Exclusive Economic Zone of the Gulf of Alaska for the years 2010 through 2019. 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.

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 (Alaska Fisheries Science Center (AFSC), 2011), and (2) industry reports of catch and production. Observer deployment plans are reviewed and updated annually in the Annual Deployment Plan (National Marine Fisheries Service, 2019). The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2014, 2010). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. 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.

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 eastern Gulf of Alaska fisheries in 2019 (196 birds) was similar to that in 2018 (192 birds), and was below the

2010–2018 average of 234 birds by 16% (Table 5), (Figure 88).

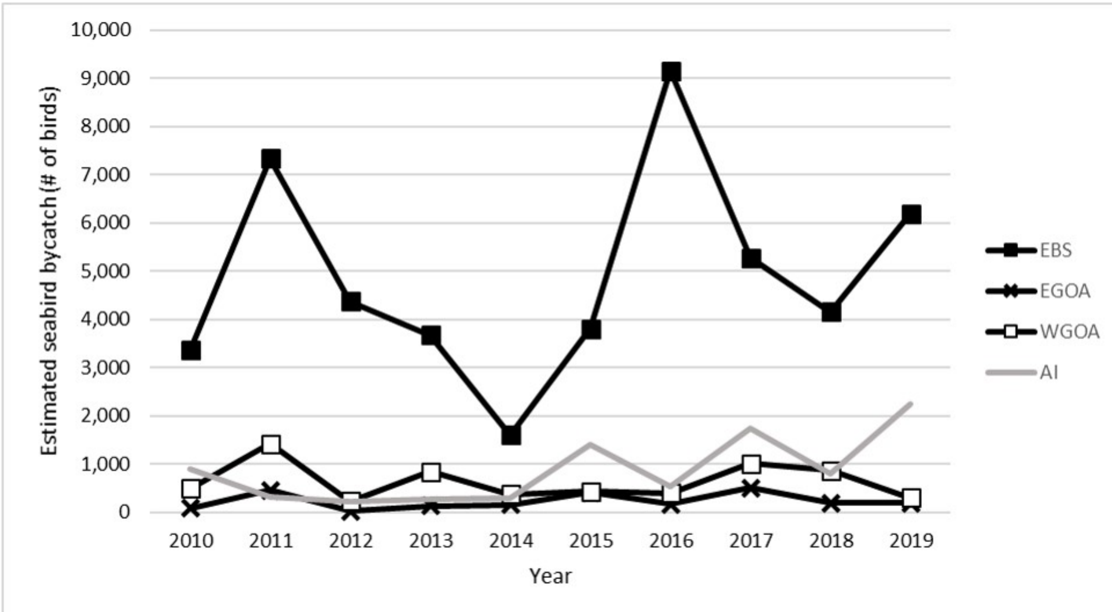

Figure 88: Total estimated seabird bycatch in eastern Bering Sea (EBS), Eastern Gulf of Alaska (EGOA), Western Gulf of Alaska (WGOA), and Aleutian Islands (AI), groundfish fisheries, all gear types combined, 2010 through 2019.

Black-footed albatross, northern fulmar, and Laysan albatross were the most common species caught incidentally. In 2019, the number of black-footed albatross (99 birds) was similar to that in 2018 (96 birds), and slightly above the 2010–2018 average of 95 birds by 5%. In 2019, the number of northern fulmar was more than 2 times higher than in of 2018 and was above the 2010–2018 average of 27 birds by 53%. The estimated number of Laysan albatross in 2019 (37 birds) was the second highest reported in this time series for the eastern Gulf of Alaska. The only year with more Laysan albatross takes was 2013.

The number of seabirds estimated to be caught incidentally in western Gulf of Alaska fisheries in 2019 decreased from that in 2018 by 66%, and was below the 2010–2018 average of 637 birds by 53% (Table 6), (Figure 88). Black-footed albatross, northern fulmars, and gulls were the most common species or species group caught incidentally. In 2019, the number of black-footed albatross decreased by 51% compared to 2018, and was below the 2010–2018 average of 190 birds by 40%. In 2019, the number of gulls decreased by 81% compared to 2018 and was below the 2010–2018 average of 155 birds by 74%. The estimated number of northern fulmars also decreased from 2018 to 2019 by 49% and was below the 2010–2018 average of 202 birds by 53%.

Focusing solely on the bycatch of albatross (unidentified, short-tailed, Laysan, and black-footed) in the sablefish IFQ fishery, vessels fishing with hook and line gear in the Gulf of Alaska averaged 297 albatross per year from 2010 through 2019 (Krieger and Eich) (Figure 89).

The sablefish IFQ fishery using demersal longline is responsible for the majority of seabird bycatch in the Gulf of Alaska—the average annual seabird bycatch for 2010 through 2019 is 574 birds per year (Table 13 in Krieger and Eich). In 2019, the estimated seabird bycatch was similar to the 2010-

Table 5: Estimated seabird bycatch in the eastern Gulf of Alaska groundfish fisheries for all gear types, 2009 through 2019. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Unidentified Albatross	0	0	0	26	0	0	0	0	42	1
Laysan Albatross	20	39	4	9	3	6	4	2	3	37
Black-footed Albatross	17	62	19	39	76	221	93	225	96	99
Northern Fulmars	5	131	0	13	4	19	6	31	18	41
Shearwaters	0	16	0	0	0	1	2	23	2	2
Gulls	43	208	5	47	77	116	66	220	31	16
Auklets	0	0	0	0	0	1	0	0	0	0
Cormorants	0	0	0	0	0	24	0	0	0	0
Unidentified Birds	0	3	1	0	0	17	2	1	0	0
Grand Total	85	459	29	134	160	405	174	501	192	196

Table 6: Estimated seabird bycatch in the western Gulf of Alaska groundfish fisheries for all gear types, 2009 through 2019. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Unidentified Albatross	0	9	0	3	0	0	0	0	10	18
Laysan Albatross	60	99	6	57	25	30	39	23	21	2
Black-footed Albatross	45	152	120	389	186	119	82	471	221	113
Northern Fulmars	168	748	18	239	47	64	175	238	231	95
Shearwaters	0	29	0	51	0	4	17	13	39	30
Gulls	218	375	46	91	77	156	74	258	212	41
Auklets	0	0	0	0	2	45	0	0	0	0
Other Alcids	0	0	0	0	37	0	0	0	0	
Cormorants	0	0	0	0	0	3	0	0	0	0
Unidentified Birds	0	6	32	7	0	17	16	13	140	0
Grand Total	491	1418	223	838	375	438	403	1016	872	300

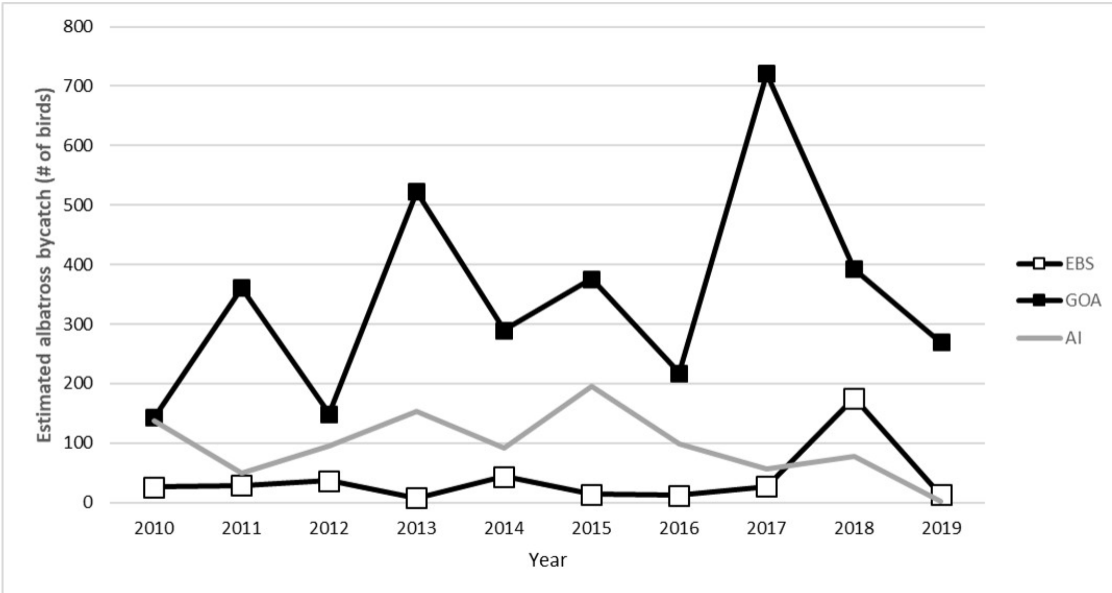

Figure 89: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2010 through 2019.

2018 average (589 birds; Table 13 in (Krieger and Eich)). Figure 90 shows the spatial distribution of observed seabird bycatch from 2014–2019 from the sablefish IFQ fishery from vessels fishing with hook and line overlaid onto heat maps depicting fishing effort for the fishery.

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.

Vessels fishing with hook-and-line gear have traditionally been responsible for about 90% of the overall seabird bycatch in Alaska, as determined from the data sources noted above. However, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates may be downward biased.

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. Thus, while annual seabird bycatch estimates number in the 1,000's, given the vast size of the fishery, actual takes of seabird remains relatively uncommon (Krieger and Eich).

Implications: Estimated seabird bycatch in the eastern Gulf of Alaska in 2019 remained relatively unchanged from 2018, while seabird bycatch in the western Gulf of Alaska decreased by 66% from 2018 to 2019. This was primarily due to reduced takes of northern fulmars, black-footed albatross, and gulls. Estimated seabird bycatch increased from 2018 to 2019 in the eastern Bering Sea and Aleutian Islands, but this is largely attributed to the shearwater mortality event that occurred throughout Alaska in 2019. These differences indicate localized changes in the Bering Sea, Gulf of Alaska, and Aleutian Islands regarding seabird distribution, fishing effort, and/or seabird prey

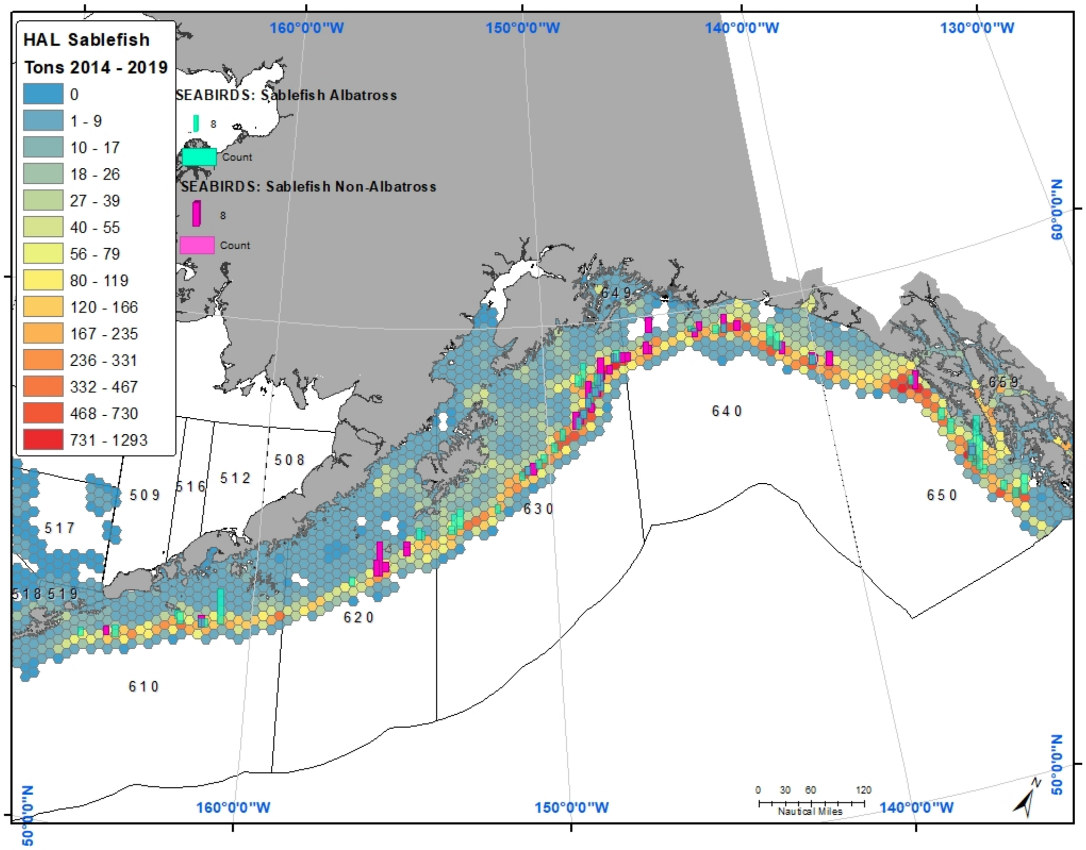

Figure 90: Spatial distribution of observed seabird bycatch from 2014 – 2019 from the sablefish IFQ fishery from vessels using hook and line gear. Colored vertical bars indicate the sum of incidental takes at a location grouped within 1/10 of a degree of latitude and longitude. Incidental takes are separated between takes of albatross and takes of non-albatross seabirds. Images on the left include locations of incidental takes of seabirds overlaid on to heat maps depicting fishing effort for each relevant fishery. Note the difference of scale of observed takes of seabirds.

supply, all of which could impact bycatch.

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

There are no updated or new indicators in this section this year.

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 2020

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-updates`). 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 35 FSSI stocks and an overall FSSI of 140 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). 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.

The list of stocks included in the FSSI was revised in 2020 to focus on stocks of heightened commercial and recreational importance (`https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`). In the GOA, this meant that the deepwater flatfish complex was removed from the FSSI and Shortraker rockfish were added. In the GOA region there are 14 FSSI stocks including sablefish (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 28 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement. Two of the non–FSSI crab stocks in the BSAI region are overfished but are not subject to overfishing. None of the other non–FSSI stocks are known to be subject to overfishing, are overfished, or are approaching an overfished condition. 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, 2020, none of the GOA groundfish stock or stock complex is subject to overfishing, are known to be over fished, or known to be approaching an overfished conditions (Table 7). The overall Alaska FSSI is down from 92% in 2019 to 89% in 2020 (Figure 91). Until 2019, the overall Alaska FSSI had generally trended upwards from 80% in 2006 to a high of 94% in 2018.

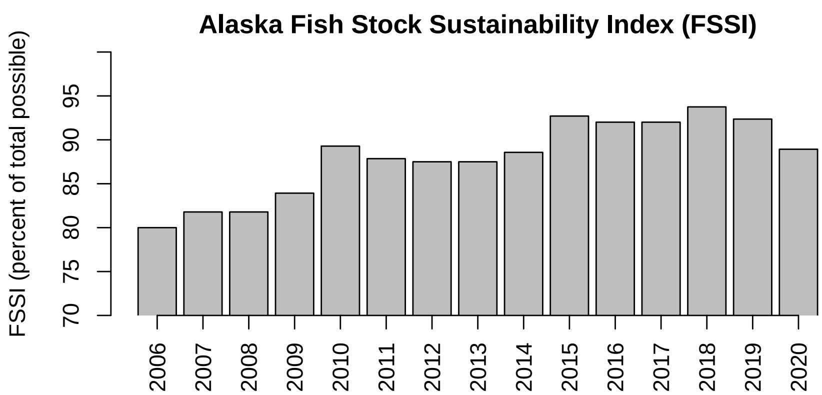

Figure 91: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2020. The maximum possible FSSI is 140 for 2006 to 2014, 144 from 2015 to 2019, and 140 in 2020. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

The GOA FSSI is down two points from last year at 49 out of a maximum possible 56, or 87.5% (Figure 92). GOA Pacific cod and GOA/BSAI sablefish each lost a point this year for having biomass drop below 80% of B_{MSY} (Table 8). 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 92). There were minor drops in the FSSI in 2008–2009 and again in 2012–2013. In 2008 and 2009 a point was lost each year for B/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

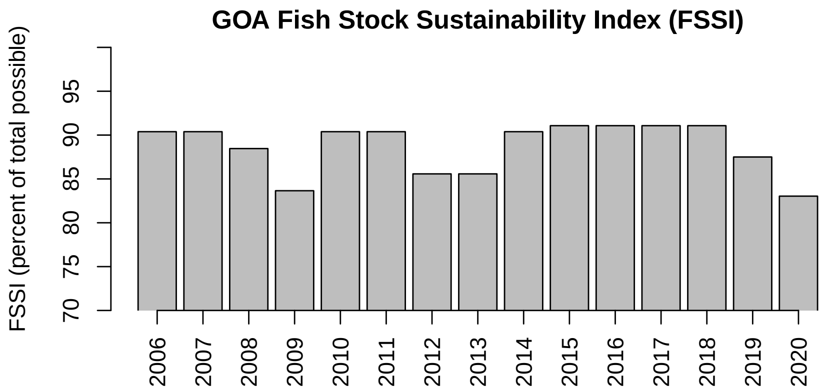

Figure 92: The trend in FSSI from 2006 through 2020 for the GOA region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

Table 7: Status summary for GOA FSSI stocks managed under federal fishery management plans, updated through June 2020.

GOA FSSI (14 stocks)	Yes	No	Unk	Undef	N/A
Overfishing	0	14	0	0	0
Overfished	0	11	3	0	0
Approaching Overfished Condition	0	11	3	0	0

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 8: GOA FSSI stocks under NPFMC jurisdiction updated June 2020 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	2.60	4
GOA Shallow Water Flatfish Complex[a]	No	No	No	N/A	N/A	2.32	4
GOA Rex sole	No	No	No	N/A	N/A	2.36	4
GOA Blackspotted and Rougheye Rockfish complex[b]	No	No	No	N/A	N/A	1.96	4
GOA Shortraker rockfish	No	Unknown	Unknown	N/A	N/A	Not estimated	1.5
GOA Demersal Shelf Rockfish Complex[c]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
GOA Dusky Rockfish	No	No	No	N/A	N/A	1.35	4
GOA Thornyhead Rockfish Complex[d]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Northern rockfish-Western / Central GOA	No	No	No	N/A	N/A	1.75	4
GOA Pacific Ocean perch	No	No	No	N/A	N/A	1.75	4
GOA Pacific cod	No	No	No	N/A	N/A	0.77	3
Walleye pollock-Western / Central GOA	No	No	No	N/A	N/A	1.23	4
GOA BSAI Sablefish[e]	No	No	No	N/A	N/A	0.77	3

FSSI Endnotes and stock complex definitions for FSSI stocks listed in Table 8, adapted from the Status of U.S. Fisheries website: `www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

(a) 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.

(b) 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.

(c) 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.

(d) 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.

(e) 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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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 93). Landings are plotted by functional group. While many species comprise a functional group, it is the handful of species that fishermen target that dominate the economic metrics in each group. The primary target species in the apex predators' functional group are Pacific cod, Pacific halibut, sablefish, and arrowtooth flounder. The primary target species in the pelagic foragers' functional group are walleye pollock, Pacific ocean perch, northern rockfish and dusky rockfish. The primary species caught in the benthic foragers' functional group are flathead sole, and rex sole. The primary target species in the salmonid functional group are Chinook, sockeye, and pink salmon. The primary species caught in the motile epifauna functional group are tanner and Dungeness crab. Because of significant differences in the relative scale of landings across functional group landings are plotted in logs.

Status and trends: Landings in the Gulf of Alaska are primarily comprised of catch from three functional groups salmon, pelagic foragers, and apex predators. Salmon landings display a stable cycle driven by large returning year classes of pink salmon 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 in a drop in the pelagic forager landings index. 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.

Apex predator landings increased in 2019 with increased landings of sablefish and rockfish. Relative to the preceding three functional groups, benthic forager and motile epifauna are caught in significantly smaller quantities. Motile epifauna landings increased in 2019 with increased landings of Dungeness crab. Rex sole and flathead sole have target fisheries and total landings are well below the annual TACs for these species. Benthic forager landings were stable in 2019.

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 infor-

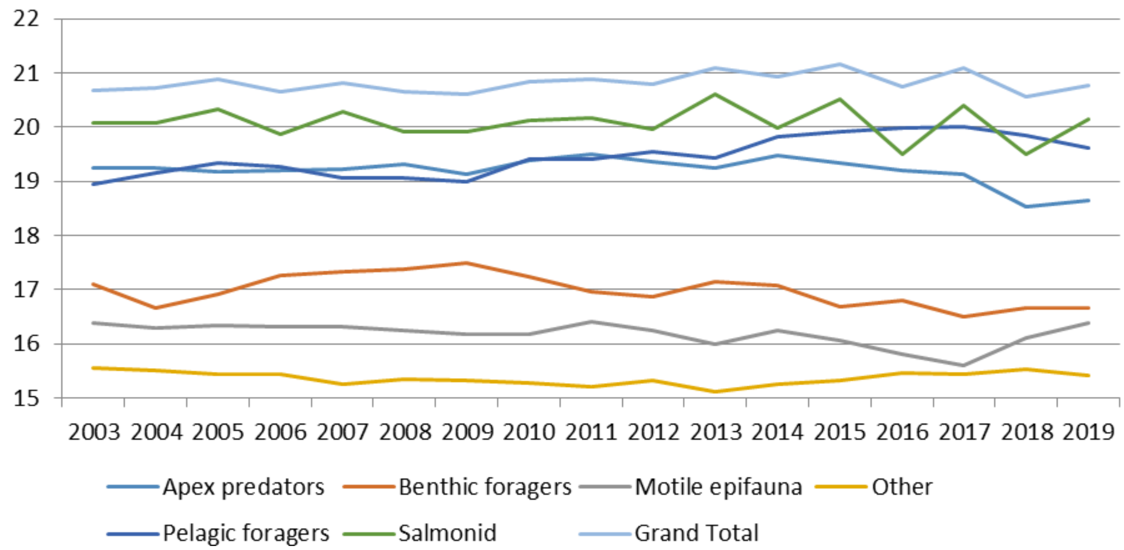

Figure 93: Gulf of Alaska landings by functional group (pounds in log scale).

mation 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 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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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 the 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, and 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 94). Aggregate ex-vessel value increased in 2019, primarily as a result of increased revenues from salmon and motile epifauna. 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. Since 2018, cod value has been substantially diminished as a result of conservation-based reduction in the TAC. Since 2018 sablefish catches have improved but an abundance of small fish has resulted in lower prices. Year-over-year salmon value was up in 2019 as it was an odd year in the pink salmon cycle, however revenues were lower than 2017 and 2015. Sockeye salmon revenues were also up with landings. In general, salmon prices were down in 2019 relative to 2018. Pollock accounts for roughly 60% of the pelagic forager revenue with herring and rockfish splitting the majority of the balance. Despite large catch volumes pollock prices are comparatively lower than apex predators or salmon. Since 2013, depressed pollock prices have resulted in flat or decreasing revenue despite increased landings. Since 2018 pollock prices been stronger though landings have decreased. 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 increased in 2018 and 2019 with increased revenues of Dungeness crab.

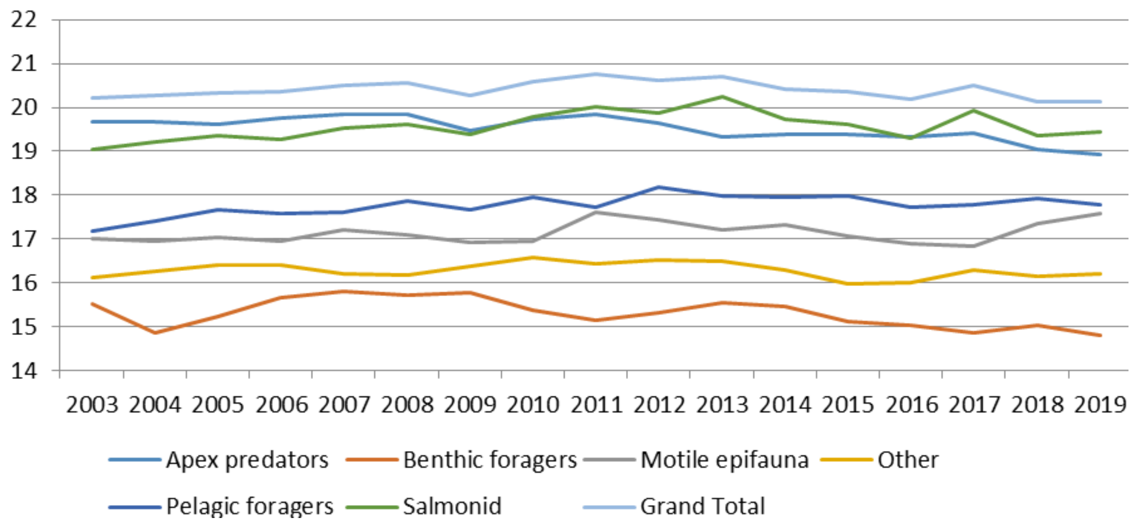

Figure 94: Gulf of Alaska real ex-vessel value by functional group (2019 dollars logged).

First-wholesale value is the revenue from the sale of processed fish (Figure 95). 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. Revenue for the salmonid group increased in 2019 which is an up 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 and 2019 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 landings decreased in 2019 which contributed to a decrease in the pelagic forager value index. Benthic forager first-wholesale value was down in 2019 with a decrease in prices. First-wholesale value in the motile epifauna group largely mirrors the changes in ex-vessel revenue.

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 96). 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 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

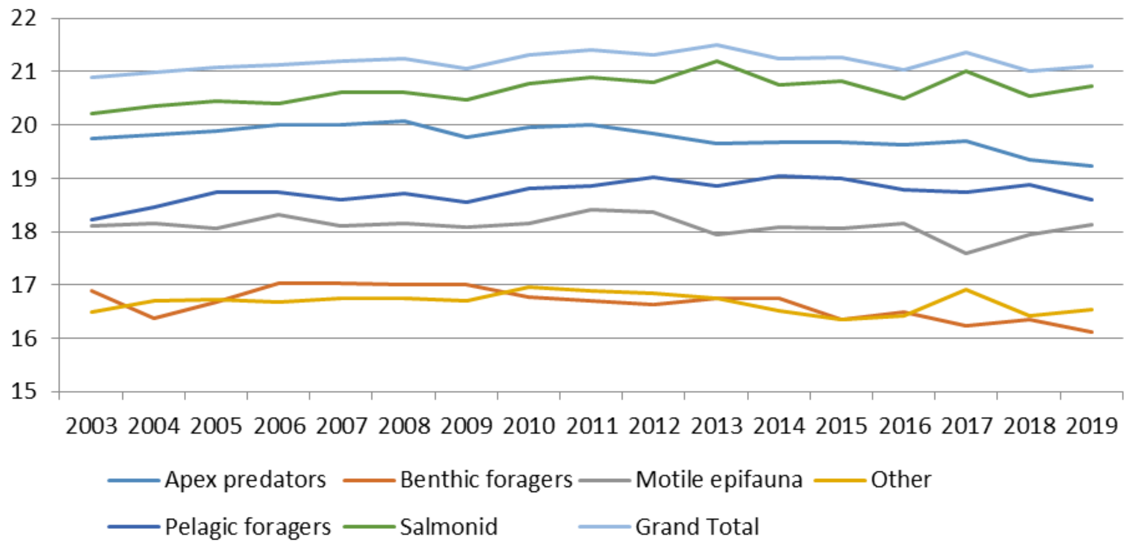

Figure 95: Gulf of Alaska real first-wholesale value by functional group (2019 dollars logged).

for the decreasing unit value trend from 2012–2015. Since 2018 unit values have been increasing and decreased global whitefish supply put upward pressure on prices of cod and pollock. The total catch unit value decreased in 2019 largely as a result of lower salmon prices and decreasing prices for sablefish.

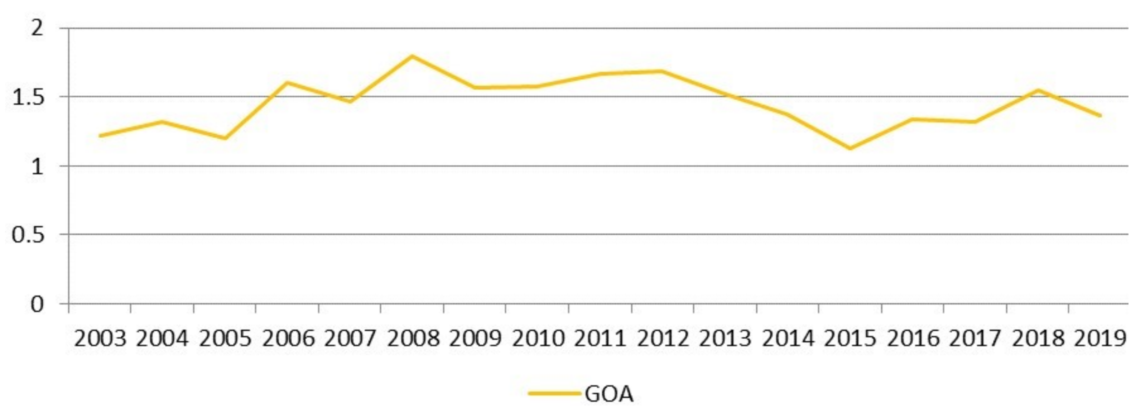

Figure 96: Real first-wholesale to total catch unit value in the Gulf of Alaska (2019 dollars).

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 95 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.

Implications: The economic metrics displayed here provide perspective on how the human component of the ecosystem feeds off, and receives value from, the Gulf of Alaska and the species within that ecosystem. Ex-vessel and first-wholesale value metrics are measures 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: September 2020

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 western (between 164°W and 144°W) and eastern (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 1990–2019 (ADLWD, 2018).

Status and trends: In the eastern GOA, unemployment rates from 2010 to 2019 were lower than statewide rates and moved from below to above the national rates in 2014 (Figures 97 and 98). As of 2019, the unemployment rate in the eastern GOA was 5.4% which was slightly higher than the national rate of 3.7%. Eastern GOA unemployment rates reflect State trends overall with unemployment gradually decreasing from 2010 to 2019.

In the western GOA, unemployment rates were slightly lower than state rates from 2000 to 2019 and moved from below to above the national rate in 2014 (Figures 97 and 98). As of 2019, the unemployment rate was 5.5% which was higher than the national rate of 3.7%. With Anchorage rates excluded, western GOA had a rate lower than state, national and eastern GOA rates at 2.4%.

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, 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

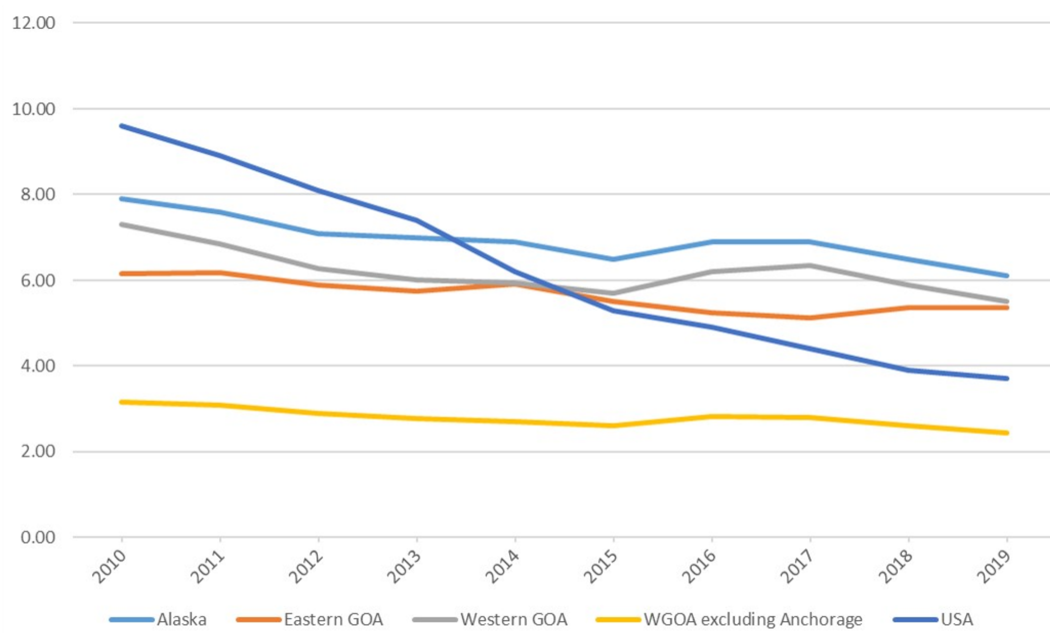

Figure 97: Unemployment rates for the eastern and western Gulf of Alaska (GOA), Alaska and USA, 2010–2019.

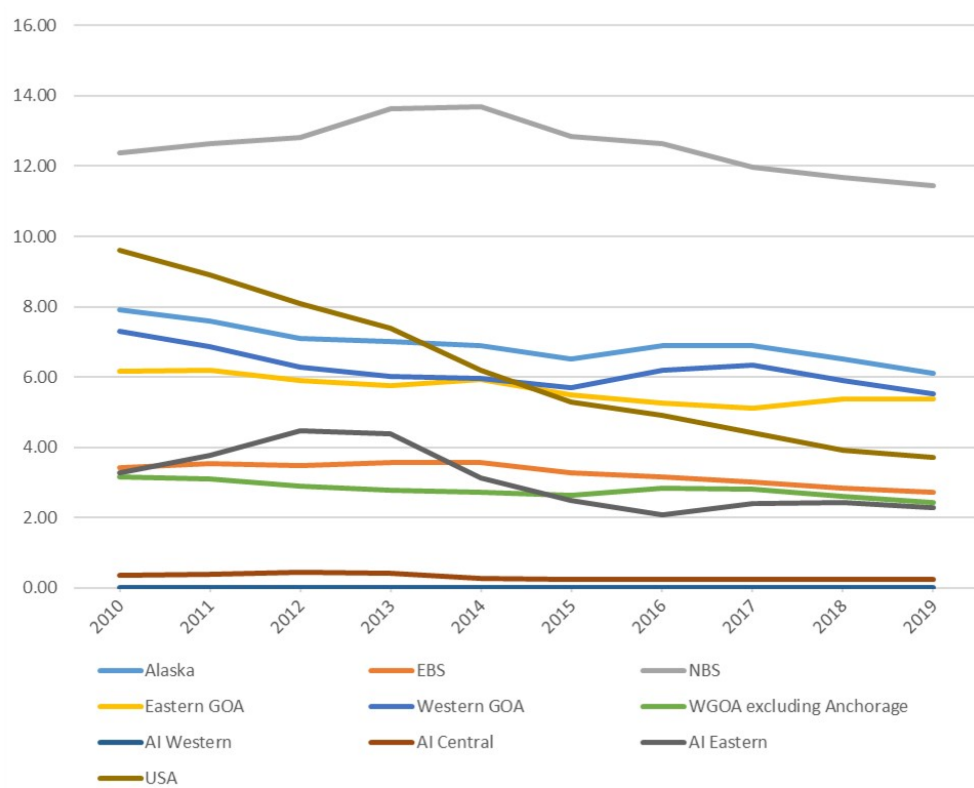

Figure 98: Unemployment rates for all regions(E is east, W is west, BS is Bering Sea, GOA is Gulf of Alaska, AI is Aleutian Islands), Alaska and USA, 2010–2019.

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 98.

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 97 is worth considering in terms of how the economic conditions are changing differentially between Anchorage and the rest of the western GOA region.

Socio-Cultural Dimensions

Defining Fishing Communities

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

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

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

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

Contributed by Sarah P. Wise

Trends in Human Population in the Gulf of Alaska

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Last updated: September 2020

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 western (between 164°W and 144°W) and eastern (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 $\geq$1,500). Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2019 (ADLWD, 2018).

Table 9: Gulf of Alaska (GOA) population 1880–2019. Percent change rates are decadal until 2019.

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
2019	731,007	2.9	65,985	0.82	465,462	4.28	173,617

Status and trends: The western GOA (WGOA) is composed of 87 coastal communities with a total population of 465,462 as of 2019. The total population excluding Anchorage was 173,617. The total population of small communities (population less than 1,500) was 19,580, and large communities 154,037 (excluding Anchorage). The total population of the WGOA (excluding Anchorage) has steadily increased since 2000 (Table 9 and Figure 99). Small community populations increased by 2.42% between 2010 and 2019, and larger communities increased 4.25%. This increase in population is consistent with State trends as the population of Alaska increased from 2010 to 2015 before beginning to gradually decrease from 2016 to 2019.

The eastern GOA (EGOA) is composed of 41 coastal communities with a total population of 65,985 as of 2019. There are 35 small communities with a combined total population of 10,217, and six large communities with a combined total population of 55,768. The total population of EGOA has remained stable since 2000, with minimal decadal changes (Table 9). There were no significant population changes within large communities between 2010 and 2019 (Figure 100).

Factors influencing observed trends[1]: The main factors that affect population growth are natural increase (births minus deaths) and migration, with the latter being the most unpredictable aspect of population change (Williams, 2004; ADLWD, 2016*a*). Between 2012–2016, 59% of Alaska's population was born outside of State (US Census Bureau, 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).

Population trends in Alaska and the GOA region have been largely attributed to changes in resource extraction and military activity (Williams, 2004). Historically, the Gold Rush of the late 19th century doubled the State's population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD, 2016*b*). However, certain areas have experienced population shifts at various periods, particularly those with military bases. For example, the population of Kodiak

[1] See the Alaska Department of Labor and Workforce Development "Alaska Economic Trends" magazine that is published monthly for detailed information on factors influencing observed trends in the state (https://labor.alaska.gov/trends/)

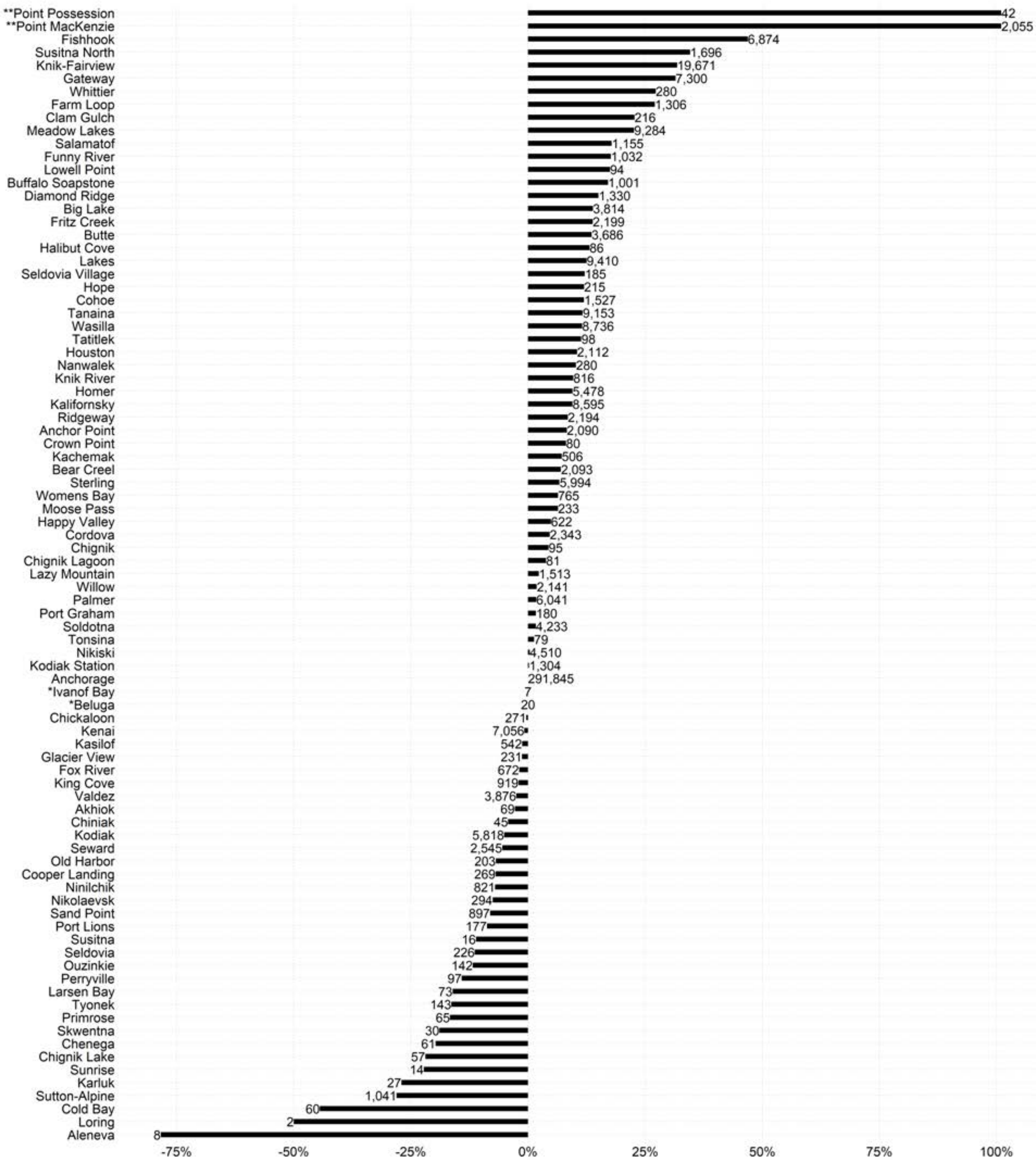

Figure 99: Population and population change of WGOA communities 2010–2019. Bars represent the percentage change and the number represents the 2019 population.

declined in the 1990s because of Coast Guard cut-backs (Willliams, 2004c). The fishing industry also influences community population. Kodiak and the Aleutian Islands have the most transient populations because of the seafood processing industry (Williams, 2004). Some GOA communities that experienced fishery permit loss subsequently experienced population decline (Donkersloot and Carothers, 2016). Also, reduction of jobs in the lumber industry have caused population decrease.

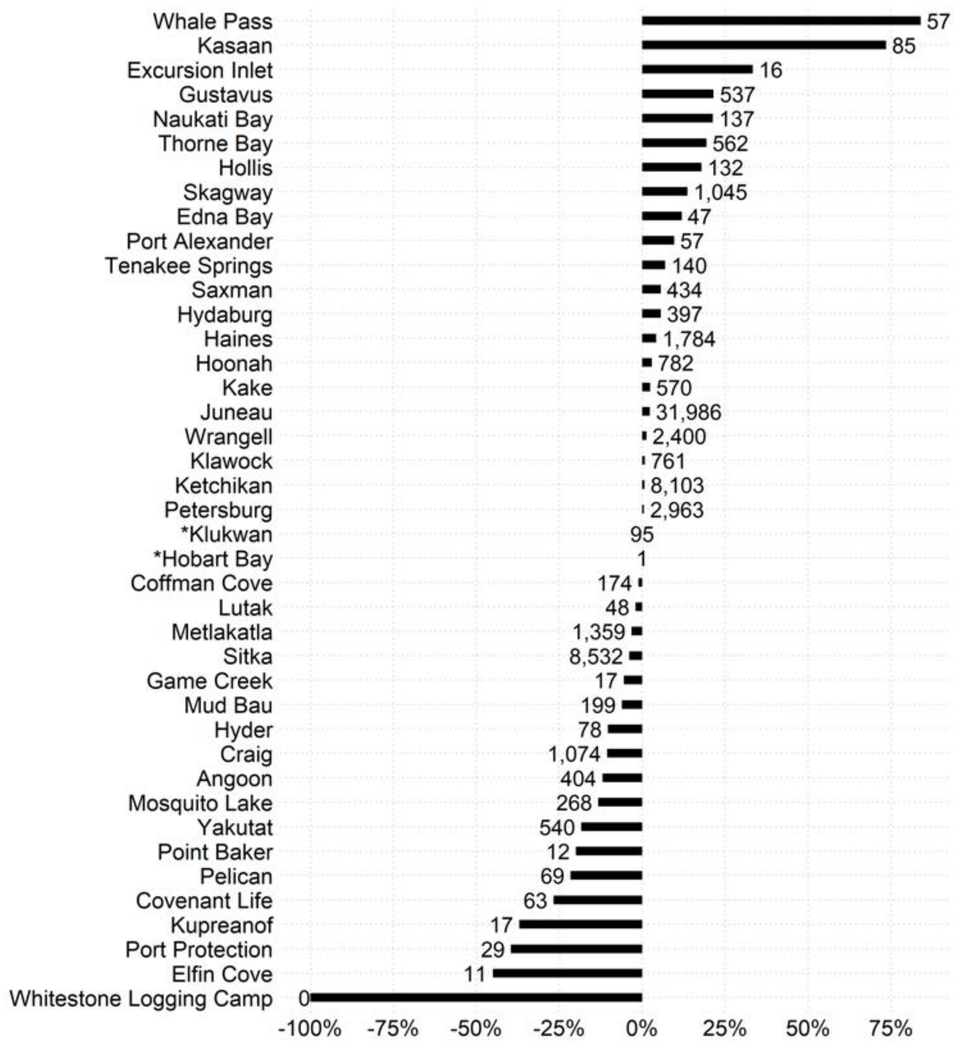

Figure 100: Population and population change of EGOA communities 2010–2019. Bars represent the percentage change and the number represents the 2019 population.

For example, the Whitestone Logging Camp population fluctuated from 164 to 0 between 1990 and 2006, increased to 17 in 2010 and was zero in subsequent years (ADLWD, 2017).

Implications: Population shifts 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

Contributed by Sarah P. Wise[1] and Kim Sparks[1,2]
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Last updated: September 2020

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, and can influence outmigration and level of public services.

Public school enrollment rates were analyzed at the community level, and then aggregated to school district enrollment rates. All data originate from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`). In an effort to examine trends over time, data from all years available were included in the analysis. Enrollment statistics for K-12 grades by school and region were compiled for 1995–2019 (from the Alaska Department of Education and Early Development - `http://www.eed.state.ak.us/stats/`). Previous data naming errors were corrected this year; school data were classified according to the year the data were collected (aka the beginning of the school year). Thus, the most recent data reflects the 2019/2020 school year, but is named as 2019 data. School graduation rates are based off of the four year adjusted cohort graduation rate, which was implemented in Alaska starting in 2011. Graduation rates are reported for the 2015–2019 cohorts, based upon school district. Dropout rates are reported by school district from 1990–2019. All current school locations and names were verified using the EPA EJ mapping tool (`https://ejscreen.epa.gov/mapper/`) and Alaska Department of Education website (`https://education.alaska.gov/`).

Status and trends: In the WGOA, school enrollment patterns vary considerably depending on whether in rural or urban areas and the population of the municipality. Within municipalities where school enrollment is over 500 students, school enrollment has decreased since 1995, including Homer (-47%), Seward (-36%), Cordova (-37%), and Nikiski (-19%). The exception to this decline was Soldotna where enrollment increased by 10.8% since 1995, peaking in 2009 with 3,684 students. (Figure 101).

In smaller municipalities with enrollment between 100 and 500 students, there is an overall downward trend with many schools declining by at least 50% since 1995. One exception would be the Chugach school district, which increased from 154 students in 1995 to 478 in 2019 (an increase of 210%). Both King Cove School (-44%) and Sand Point School (-27%) in the Aleutians East district have experienced enrollment declines since 1995. All of the Lake and Peninsula district schools

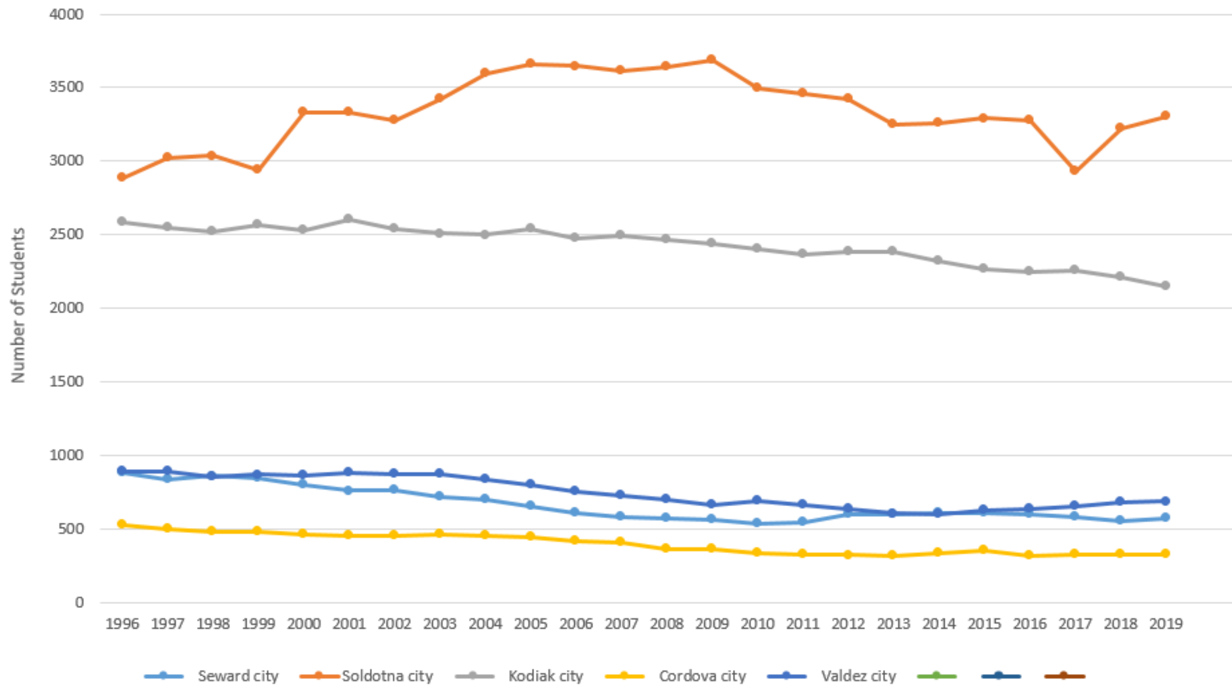

Figure 101: WGOA fishing community schools with enrollment over 500 students.

within the WGOA ecoregion have enrollment under 30 students (Table 10).

There is an overall downward trend for Kodiak Island Borough schools (excluding Kodiak City), which have collectively experienced a 69.5% decrease in enrollment since 1995. Larsen Bay School closed in 2018, and Karluk School closed in 2019. The remaining school enrollment ranges from 12 to 23 students (Figure 102).

School enrollment in the urban municipality of Anchorage has been relatively stable, with a slight decrease in enrollment (-3.6%) starting in 2010. The Mat-Su Borough school district has grown 56% since 1995 from 12,231 students in 1995 to 19,114 students in 2019. Graduation rates vary among WGOA school districts, with Anchorage and Chugach districts generally having lower graduation rates (Figure 103). Dropout rates vary from 0–11.6% for WGOA, and are generally lower than

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

Enrollment	Number of Schools	Schools
Now closed	2	Larsen Bay, Karluk
<15 students	7	Cooper Landing Marathon School (Kenai), Port Lions, Chignik Bay, Chignik Lagoon, Chignik Lake, Chenega
16–30 students	10	Hope, Homer Flex School, Moose Pass, Tebughna School (Tyonek), Akhiok, Chiniak, Old Harbor, Ouzinkie, Perryville, Tatitlek

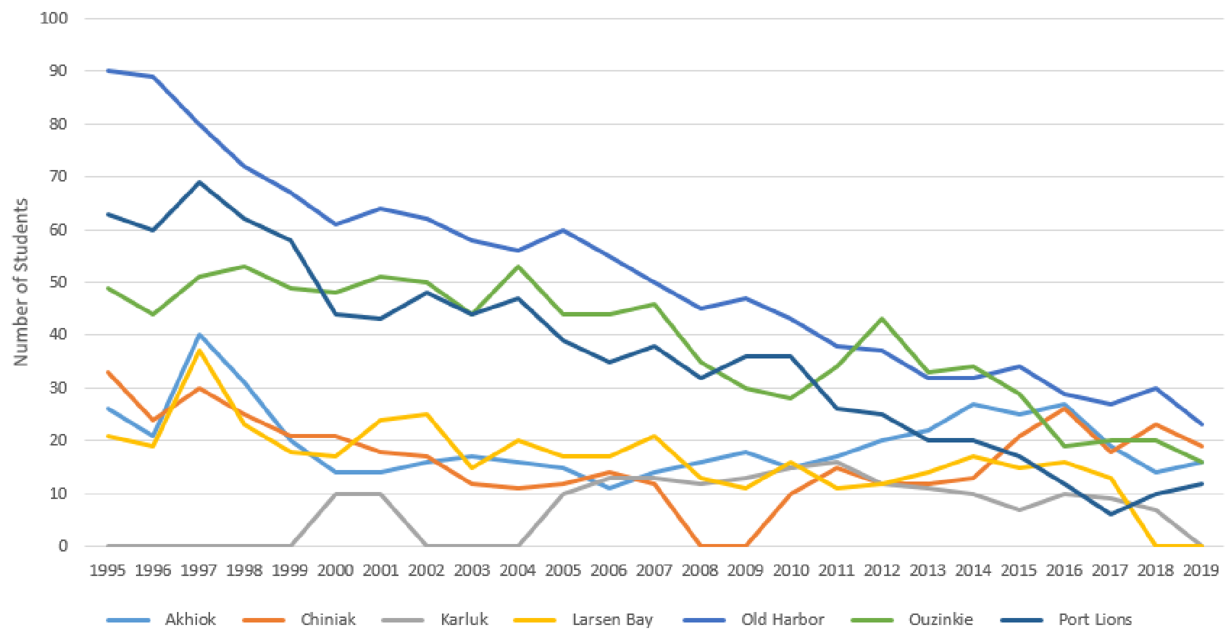

Figure 102: School enrollment in the Kodiak Island Borough.

other ecoregions. The greatest outlier is Chugach school district, with an 18.5% dropout rate in 2000.

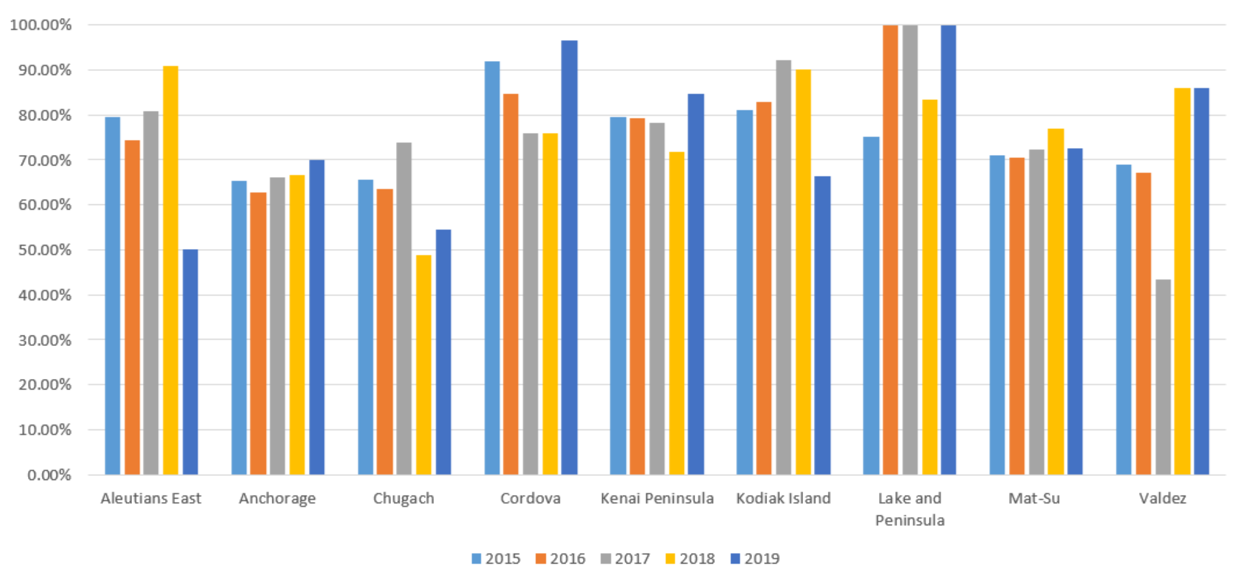

Figure 103: Graduation rates for western GOA school districts, 2015–2019.

Factors influencing observed trends: The WGOA ecoregion varies substantially in population and community structure and vitality. The region holds several larger municipalities, with larger school enrollment, compared to other parts of Alaska. As people migrate to other areas, populations increase in adjacent communities. Enrollment may shift to the larger communities; however other factors should be considered including economic opportunity and infrastructure (such as functional ports, airports, or medical facilities) which provide needed services for a viable community. Those schools with enrollment under 30 students experience the greatest uncertainty in terms of educational stability. Two schools have closed recently (Larsen Bay and Karluk on Kodiak Island), 10 schools have enrollment under 30, and 7 schools have enrollments under 15 students (Table 10). 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 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 Kim Sparks[1,2] and Sarah P. Wise[1]
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[2] Alaska Fisheries Information Network, Pacific States Marine Fisheries Commission
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Last updated: September 2020

Description of indicator: Ensuring the productivity and sustainability of fishing communities is a core mandate of Federal fisheries management. One indicator to evaluate community vitality is K-12 public school enrollment. Enrollment trends are of particular relevance due to the value of schools to community cohesion and identity, and can influence outmigration and level of public services.

Public school enrollment rates were analyzed in the Eastern Gulf of Alaska (EGOA) at the community level, and then aggregated to school district enrollment rates. All data originate from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`). In an effort to examine trends over time, data from all years available were included in the analysis. Enrollment statistics for K-12 grades by school and region were compiled for 1995–2019 (from the Alaska Department of Education and Early Development - `http://www.eed.state.ak.us/stats/`). Previous data naming errors were corrected this year; school data were classified according to the year the data were collected (aka the beginning of the school year). Thus, the most recent data reflects the 2019/2020 school year, but is named as 2019 data. School graduation rates are based off of the four year adjusted cohort graduation rate, which was implemented in Alaska starting in 2011. Graduation rates are reported for the 2015–2019 cohorts, based upon school district. Dropout rates are reported by school district from 1990–2019. All current school locations and names were verified using the EPA EJ mapping tool (`https://ejscreen.epa.gov/mapper/`) and Alaska Department of Education website (`https://education.alaska.gov/`).

Status and trends: School enrollment patterns vary considerably in the EGOA depending on whether the area rural or urban areas and the population of the municipality. Within municipalities where student membership is over 500, school enrollment decreased since 1995, with the exception of Craig School District, which grew 32%. Since 1995, the Ketchikan School District decreased by 22.8%, Sitka by 24.5%, Petersburg by 37.7%, Wrangell by 44% and Juneau by 17% (Figure 104). Since 2015, some of these trends shifted upwards, with Petersburg enrollment increasing 2% and Wrangell 12.4% (2015-2019). However, Ketchikan (-1.8%), Sitka (-9.5%), and Juneau (-2.1%) continued to see declines since 2015.

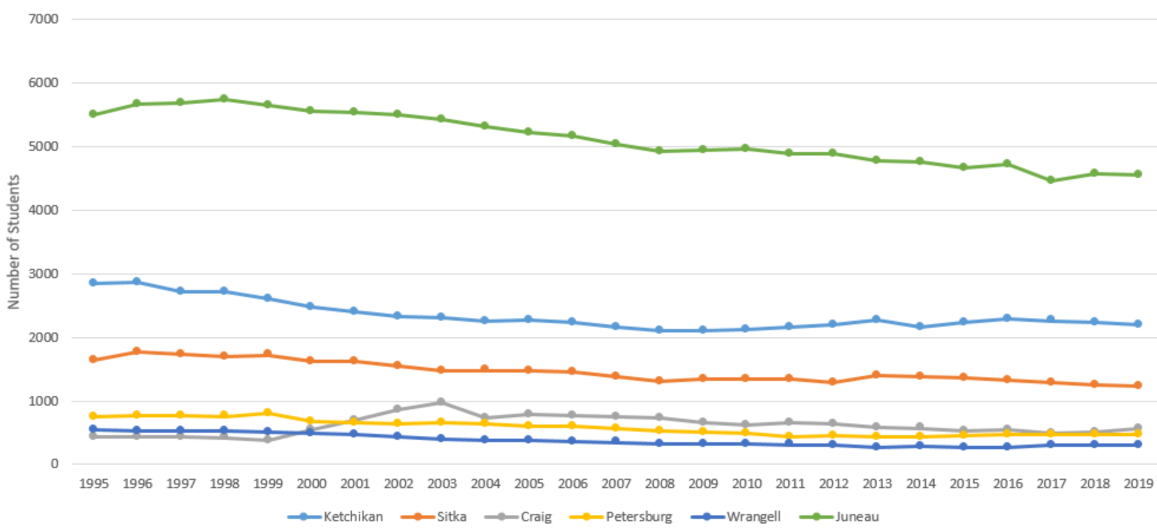

Figure 104: EGOA fishing community schools with enrollment over 500 students.

In municipalities with school enrollment between 100 to 500 students, enrollment has declined in all school districts since 1995, with the most dramatic decreases in Chatham (-52%), Hoonah (-54.6%), Kake (-47.7%), Kalwock (-40.6%), and Pelican (-54.3%) school districts. Enrollment appears to be steadying a bit since 2015, with modest increases in some areas (Skagway (15.5%), Klawock 10.5%), Pelican (14.3%), and Yakutat (11%), while other schools continued to decline, such as Chatham (-9.5%), Annette Island (-6.5%), and Kake (-6.5%) (Figure 105).

There is a large variation in the graduation rates of EGOA school districts. For the 2015–2019 cohorts, Sitka and Ketchikan have the lowest graduation rates (both remaining under 60%) (Figure 106), and consistently place in the lower 1/3 of school districts analyzed and well below the State graduation average rate (75.6% in 2015, 76.1% in 2016, 78.2% in 2017). Dropout rates vary for EGOA school districts, but typically average 1.41% - 4.49%.

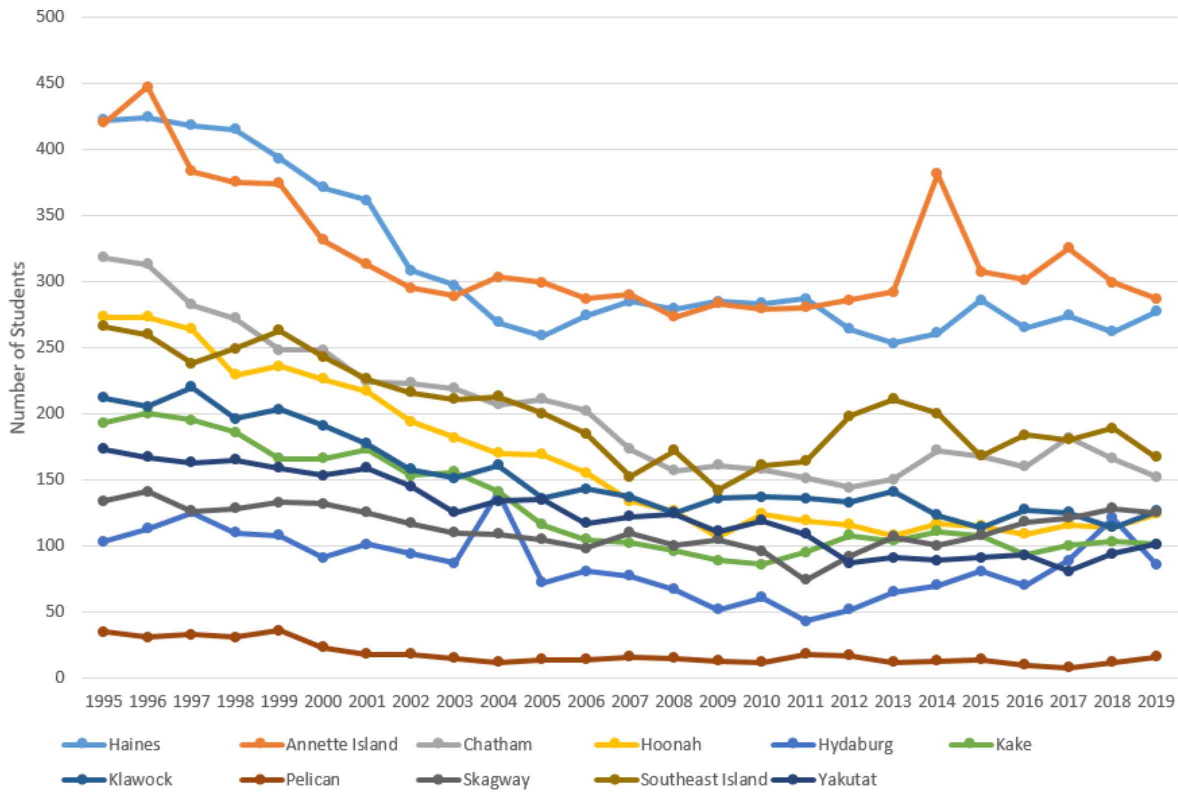

Figure 105: EGOA school districts with enrollment between 100 and 500 students.

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

Enrollment	Number of Schools	Schools
Now closed	2	Port Protection, Tenakee Springs
<15 students	5	Hyder, Kasaan, Hydaburg City, Klukwan (Angoon), Port Alexander
16–30 students	6	Hollis, Naukati Bay, Whale Pass, Angoon, Pelican, Coffman Cove

Factors influencing observed trends: The EGOA ecoregion varies substantially in population, community structure, and vitality. The region holds several larger municipalities, with generally larger school enrollment than other parts 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 access to stable education. As of 2019, six schools in the EGOA have enrollment under 30, and five schools have enrollments under 15 (Table 11). Juneau and Sitka are considered two of the larger school districts in Alaska, and thus the decline in enrollment in these districts warrants further monitoring.

With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and social disruption. The reasons for decreasing enrollment likely involve complex social

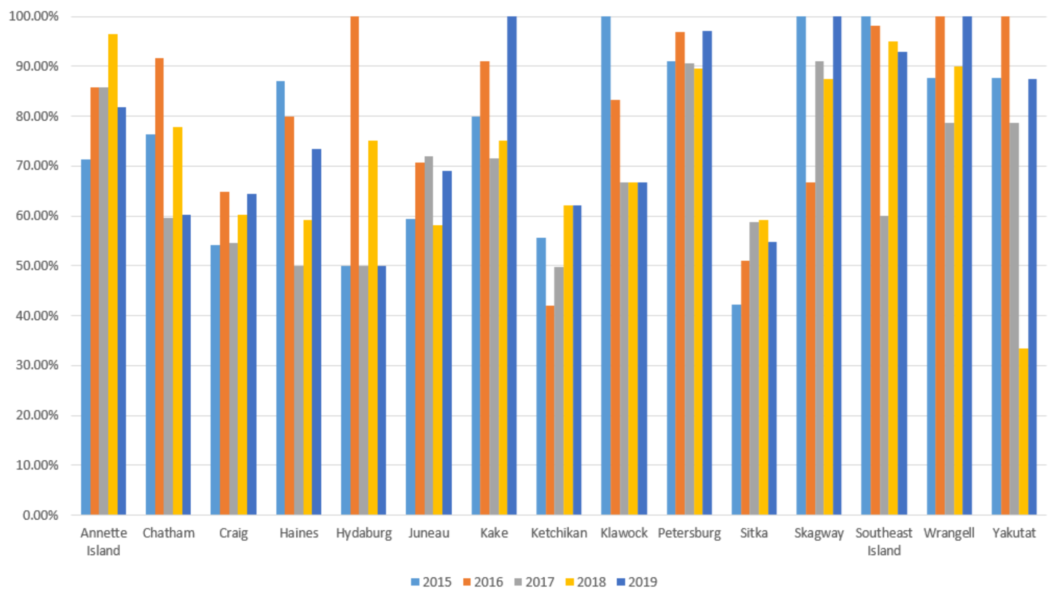

Figure 106: Graduation rates for Eastern GOA school districts, 2015–2019.

and economic drivers including migratory patterns, resource availability, and shifting employment opportunities. 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: 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, economic opportunity, and overall decline in reported quality of life scores, as well as fragmented community systems, lost in business, and cultural cohesion, 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. Because many of these small communities are highly reliant on fisheries, school enrollment can be a strong indication of the linkage between sustainable fisheries and community well-being.

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`. (See Bond, p.31)

Contact: nicholas.bond@noaa.gov

Summer Sea Surface Temperature The NOAA Coral Reef Watch Program provides a gap-free daily SST dataset (`https://coralreefwatch.noaa.gov/product/5km/`) that was accessed via the NOAA Coast WatchWest Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html`). Daily summer temperatures (June-August) were averaged for the western GOA (144°W–163°W). (See Watson, p.38)

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. (See Ostle and Batten, p.63)

Contact: claost@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. (See Ostle and Batten, p.63)

Contact: claost@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. In 2019, data were not available in time for this indicator to be updated and 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). This alternative metric was used again in 2020 as the full suite of data were not available in 2020 due to COVID-19 related seabird survey cancellations. (See Hatch et al., p.77)

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. These data were not updated in 2020 due to COVID-19 related survey cancellations.

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). (See Sweeney and Gelatt, p.133)

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. The human population data from 2010 to 2020 has been validated by the author. Data prior to 2010 requires further quality assurance by the author but was included in the report card to provide a general estimate of the long-term mean and standard deviation (data validation to be completed in 2021). (See Rhodes-Reese, p.181)

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`. (See Bond, p.31)

Contact: nicholas.bond@noaa.gov

Summer Sea Surface Temperature The NOAA Coral Reef Watch Program provides a gap-free daily SST dataset (`https://coralreefwatch.noaa.gov/product/5km/`) that was accessed via the NOAA Coast WatchWest Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html`). Daily summer temperatures (June-August) were averaged for the eastern GOA (133°W–144°W). (See Watson, p.38)

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. (See Fergusson, p.70)

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. (See Fergusson, p.70)

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. (See Hebert and Dressel, p.85)

Contact: kyle.hebert@alaska.gov

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. 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. These data were not updated in 2020 due to COVID-19 related seabird survey cancellations.

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. (See Sweeney and Gelatt, p.133)

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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. The human population data from 2010 to 2020 has been validate by the author. Data prior to 2010 requires further quality assurance by the author but was included in the report card to provide a general estimate of the long-term mean and standard deviation (data validation to be completed in 2021). (See Rhodes-Reese, p.181)

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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 reports, 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 Briefs' were started in 2018 for EBS, 2019 for GOA, and 2020 for AI. These more public-friendly, succinct versions of the full ESRs are now planned to be produced in tandem with the ESRs.

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.

Ecosystem and Socioeconomic Profiles (ESPs) were initiated in 2017 (sablefish) and ESR editors began working closely with ESP teams in 2019 (starting with GOA walleye pollock); these complimentary annual status reports inform groundfish management and alignment in research that feeds these reports increases efficiency and collaboration between ecosystem and stock assessment scientists.

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 107). 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.

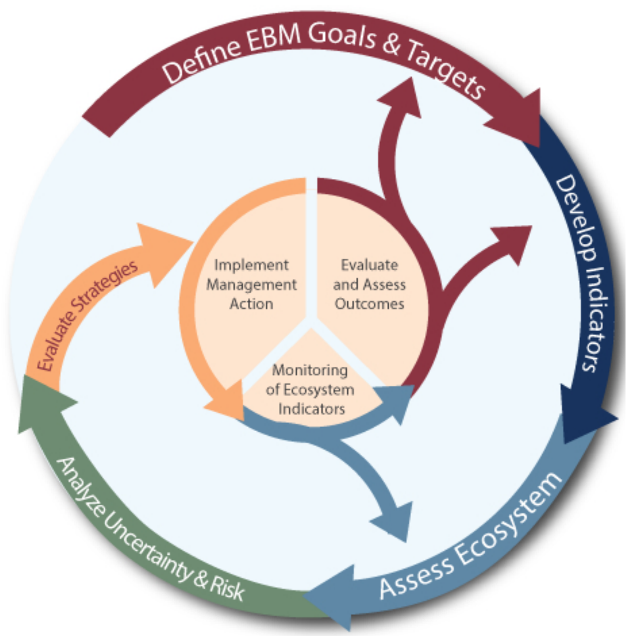

Figure 107: The IEA (integrated ecosystem assessment) process.

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-evaluation

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

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

December 2019 SSC Comments

General comments for all Ecosystem Status Report sections.

This year, as in the past, the ESRs were insightful, well-written, and well-edited. Both chapters were helpful in providing a context within which to assess the stocks of commercially harvested fish in the Federal waters off Alaska. The editors and authors have been very responsive to the comments and suggestions provided by the SSC in 2018, with many improvements evident. The SSC appreciates the positive impacts of the additional resources devoted to the ESRs. These additional resources allowed for a more in-depth analysis of recent environmental changes, such as the examination of the reappearance of the heatwave in 2019 in the Gulf of Alaska, and the extraordinary conditions in the northern Bering Sea in both 2018 and 2019.

Thank you. This year we provide updates to the Eastern Bering Sea (Siddon), Gulf of Alaska (Ferriss & Zador, with Rob Suryan providing coordination with Gulf Watch Alaska), and Aleutian Islands (Ortiz & Zador) Ecosystem Status Reports (ESRs). We anticipate updating the Eastern Bering Sea and Gulf of Alaska ESRs in 2021 as NOAA continues to support and provide resources to these Reports.

Given the rapidly changing conditions in the EBS, there is increased need for information about the effects of climate on the carrying capacity of the EBS and GOA marine ecosystems. This need is great in both the southeastern Bering Sea and the northern Bering Sea. Likewise, there is cause for concern because the western Gulf of Alaska has remained in heatwave conditions for most of 2019, and summer sea surface temperatures were similar to the warmest temperatures during the 2014 - 2016 marine heatwave. ***The SSC strongly recommends the conduct of annual surveys of not only groundfish, but also zooplankton across the entire eastern Bering Sea and the GOA.*** *This additional coverage should not be at the expense of biennial surveys of the Aleutians and Bering Sea slope.*

The AFSC has engaged in extensive survey planning and prioritization in 2020, in collaboration with the North Pacific Fisheries Management Council, in the context of responding to COVID-19 and balancing research and monitoring needs.

These are very long reports and it is likely that few readers will read them in their entirety. Their greatest value is in the syntheses and in the sections that focus attention on emerging ecosystem-wide problems and key messages. Presently, there are a number of areas in the ESRs where there are several overlapping contributions on the same subject. It would shorten the ESRs and make the information more comprehensible if the authors could collaborate to produce a single contribution on a given subject that summarizes the current situation. As an example, ***the SSC recommends that there be a single, short, but comprehensive (integrated) contribution on sea temperatures in each region*** *(presently, 17 Figures in the GOA ESR). The integrated section on seabirds might provide a good example. Synthesis products, presentations, discussions with assessment authors, and collaboration among contributors are among the high value outcomes of the ESR reports.*

The GOA ESR is taking an iterative approach to creating a single, comprehensive contribution on sea temperatures. In the 2020 ESR, we have combined all the sea temperature data into one section (Physical Environment) and we have combined three sub-regional temperature datasets into a single figure, to reduce the number of figures. We also provide a short summary of temperature data at the beginning of the Physical Environment section. The 2020 ESR has 9 figures related to sea temperature. The 2021 ESR will include a further revised synthesis of temperature data when we receive the biennial survey updates and have a full suite of data to work with.

In both the EBS and GOA, there are several Ecosystem or Community Indicators that could be much more informative if split up into different species groups. Mean Community Life Span, Mean Community Length, Mean Community Weight, Mean Community Trophic level (not in this year's reports) are often indices that are driven by the abundance of one or two species. In the EBS, pollock dominate the statistics, and in the GOA, forage fish may drive the averages. ***The SSC suggests calculating these indices with and without the dominant species,*** *or in several species groups that make some ecological sense.*

In the GOA there are many species of pelagic forage fishes (e.g., herring, capelin, etc.) that collectively could drive the value of fish community indicators. The indicators Mean Lifespan of the Fish Community, Mean Length of the Fish Community, and Stability of Groundfish Biomass are specific to the portion of the groundfish community that are efficiently sampled with bottom-trawling gear used by the AFSC during their biennial summer survey of the GOA. While many species of pelagic forage fish are occasionally encountered during the survey, most are not consistently sampled well enough to be included in the biomass index, including sandlance, capelin, and other pelagic smelts. Herring and eulachon are included in the survey index, so we have recalculated the 2019 GOA contributions for Mean Lifespan of the Fish Community, Mean Length of the Fish Community, and the Stability of Groundfish Biomass, with and without herring and eulachon to examine their influence on these community indicators.

The SSC strongly supports the production of the 'In Brief' versions of the ESRs *aimed at conveying a summary of ecosystem information to the public. The 'In Brief' report on the EBS from 2018 was well-received by communities, and the 2019 versions for both the EBS and GOA look excellent. The SSC continues to encourage these efforts, as well as further attempts to provide information back to the communities that have provided information for the ESR.*

Thank you we agree! We will be producing 2020 'In Brief' versions of the EBS, GOA, and AI ESRs this year. In addition, in collaboration with AFSC communications team, we are producing story maps and short educational outreach videos to further describe the 2020 ESRs to a broader audience.

In the human dimensions section of the ESRs, the utility of a number of the indicators would be improved with the addition of a spatial dimension. Seafood production, value, and unit value indicators are presented at the EBS-level only, and unemployment is presented at the EBS and NBS levels only, which does not allow for discernment of changing patterns over time at a sub-regional or community scale. Trends in population are presented at a community level but, like observed trends of unemployment, there is no apparent nexus of changes in ecosystem- or fishery-specific variables to changes in human dimension indicators (e.g., no community level time series data on federally managed fisheries engagement are presented that would provide a perspective on potential relationships between these data and observed population trends).

Eco-regional maps with identified communities are in development and will be included in next year's ESRs. The level of analysis (e.g., GOA-level) is consistent with the ESR scope. For sub regional and community scale, these data are available in the Ecosystem and Socioeconomic Profiles (ESP; stock specific); Annual Community Engagement and Participation Overview (ACEPO; Groundfish and crab FMPs); and the Economic SAFE (economic information).

Overall, the human dimensions section would benefit from a series of maps that show the relationships between the various geographic units discussed and the location of communities within those geographies (and the larger ecosystem geographies). It would also be beneficial to clarify the relationship between the type of human dimensions data that are contained in ESRs, ESPs, SAFEs, the Economic SAFE, and the apparently new and to-be-defined documents that will contain the fishing community information that was removed from the current version of the Economic SAFE. This would provide clarity and consistency in meeting the data needs to address social and community focused management obligations under National Standard 2 and National Standard 8 while avoiding redundancy of effort.

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Gulf of Alaska Chapter

As in the EBS, GOA SST in the summer of 2019 was similar to the warmest temperatures during the 2014- 2016 marine heatwave. However, some components of the GOA differed in 2019 compared to 2014-2016 (e.g., mesozooplankton biomass). The comparisons of these two heatwave events provides a nice addition that will eventually help tease apart the differences between heatwaves and their impacts on the GOA ecosystem.

Thank you. We continue to consider impacts of the 2014–2016 and 2019 heatwaves throughout the GOA ESR, including in the initial 2020 Ecosystem Assessment (Marine Heatwave Update).

The spatial analysis showed that not all areas of the GOA were affected in the same way (e.g., variability in the responses of euphausiids and age-0 pollock). Thus, the SSC appreciates the continued efforts to present GOA data specific to western and eastern regions, recognizing that a number of indicators are only available for one region (e.g. several zooplankton indicators are available for the western GOA, while the only comparable indicator is available for the eastern GOA). Where possible the SSC encourages continued exploration of new data sources that can address these gaps.

We continue to explore new data sources and collaborations across the GOA, including EGOA. This year we added a new harmful algal bloom indicator that includes monitoring data from Southeast Alaska.

In the eastern GOA, several indicators suggest that forage availability may be limited: 1) below average zooplankton counts in Icy Strait, 2) the overall size of zooplankton being small, and 3) low *growth rates for rhinoceros auklets. This lack of forage is of concern.*

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

Ecosystem Status Indicators section:

- *Figure 39: There is a need to integrate what we know about bloom timing and zooplankton biomass and growth. Will temperature alone cause them to be mis-matched in time?*

  We agree there is a need to integrate the information on bloom timing and its effects on zooplankton biomass and growth in the GOA. Due to the complicated nature of phytoplankton community dynamics coupled with zooplankton life cycles, it is not known how much of an effect temperature will have on the timing of the phytoplankton bloom in the GOA and in turn, on zooplankton biomass and growth. Investigations on this topic within the GOA are scarce and may not mirror the same dynamics we see in the Bering Sea. Therefore, we are currently making headway (to continue in 2021) on aligning spatial presentation of temperature, chlorophyll a, zooplankton, and ichthyoplankton data to better address this question.

- *Middleton Island seabirds: How can one tell whether the changes reflect the relative abundance of prey, the accessibility of prey, or actual preferences of the birds. Are there any independent data that might help?*

  That is a good question that applies to many observational time series where there are limited sampling methods that each have their own catchability or selection biases. For seabird diets, comparing diets of species with different foraging methods (e.g., surface vs diving) may provide support that trends common to both types of foragers may better reflect abundance. Currently that is the best comparison that can be made with the Middleton diets as there are no time series of net- or acoustic-based small pelagics surveys in that area that we are aware of. Without independently-determined abundance trends, we can only infer the influence of the birds' selection biases on the data.

Marine mammal section: *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. The overall body condition of humpback whales in PWS was good. However, adult herring are still missing from whale diets in PWS. These observations contrast with those from Glacier Bay where mothers were in sub-optimal condition and low birth rates persisted. The SSC welcomed the development of the integrated data sharing system "HappyWhale.com" that enables assessment of trends in abundance/sightings to be differentiated from shifts in distributions.*

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

The SSC notes that data on non-pup counts of Steller Sea Lions (SSL) were received too late for the ESR report, but they were available for the presentation to the SSC. There was a pattern of decreasing non-pup numbers from west to east in the western GOA, but then increasing numbers in the eastern GOA. The SSC suggests an exploration of whether this pattern reflected emigration. Numbers of SSL pups in the western GOA continued increasing following the 2014-2016 heatwave. This suggests there was a lagged effect and that conditions for SSLs may be improving after two seasons of 'normal' conditions. ***The SSC recommends continued efforts to make this indicator dataset available in time to be included in the ESR.***

Given all we have to assess the movement of animals as evidenced by modeled counts, it's too strong to state whether this is emigration or atypical movement during a breeding season when prey scarcity is an issue (i.e., 'warm' years) is occurring. Looking at other movement indicators (movement of marked animals, satellite tagged animals, etc.) is also needed to assess what we observed from modeled counts alone. It is one of MML's leading priorities to annually survey the endangered SSLs in all areas we are seeing concerning trends (Aleutian Islands and the Gulf of Alaska). The 2020 Aleutian survey effort was cancelled due to COVID and 2021 plans are to complete that survey and continue with Gulf survey effort in 2022. The suggestion of a lagged effect could be true however, more information is needed. With warm water anomalies occurring more frequently, it's most important to keep in mind this population is still extremely sensitive and depleted from abundance levels prior to declines that began in the 1970s. While we value including current SSL data in the ESRs, analysis of the data after summer surveys usually extends beyond the ESR deadlines. However, we are developing an artificial intelligence automated count program that would expedite these analyses so future timelines might be expedited.

This year (2019) was the first among recent 4-5 years that Aleutian terns have had any nesting success at all in the GOA. After many years of complete reproductive failure, they successfully hatched and raised chicks in many colonies in the GOA. This suggests improved foraging conditions for this nearshore obligate piscivore.

While we usually don't cover Aleutian terns in the ESR, we agreed that this was notable for 2019 as an indicator of improvements in ecosystem condition for some components.

- *Page 120/121: The observation of low ocean survival for salmon may be related to the heat-waves, zooplankton abundance or forage fish abundance. Analysis of the causes of low ocean survival would be useful in developing an understanding of how the warmer temperatures are impacting the GOA marine ecosystem, including groundfish.*

  We appreciate these comments and have addressed some of the question around low ocean survival of salmon in our noteworthy section on low salmon abundance in the GOA in 2020.

- *Page 132/33: The increase in shrimp around Kodiak is interesting. Is there any indication of why this may be happening?*

  The reasons for increased abundance of shrimp around Kodiak are not known; however, contributing factors could include favorable environmental conditions and decreased predator abundance, including walleye pollock, Pacific cod, and Pacific halibut.

- *Figures 20 and 21: These are from two different authors, and both use the same colors of blue for WGOA, EGOA and SEA, but assign them differently. Consistency in legends would be helpful.*

  Figures 20 and 21 (2019 GOA ESR) are not in the 2020 GOA ESR but we appreciate your comment and continue to make efforts to standardize color schemes and figures within the report.

The SSC recommends continued efforts to add information about Harmful Algal Blooms in the GOA. *Many new research efforts are ongoing in this field. An Arctic tern mortality event in June in Southeast Alaska received press coverage because saxitoxin was found in the carcasses of Arctic tern chicks at the same time as it was found in shellfish in a local, non-commercial harvest.*

Saxitoxin is clearly of high interest to local residents for food safety reasons and has been implicated in the deaths of nearshore-foraging terns in other instances.

We have collaborated with the Alaska Ocean Observing System's (AOOS) Alaska Harmful Algal Bloom program (AHAB) to create a new Harmful Algal Bloom contribution in the 2020 ESR.

Human Dimensions Section: *Specific to fishing and human dimensions aspects of the GOA ESR, the term "urban" is contrasted with both "remote" and "rural" in different places in the text; it is unclear when the term is being used in a technical/subsistence regulatory sense versus in a common use sense. This should be clarified.*

We appreciate these comments and the have reviewed the usage of terms "remote" and "rural" in the ESR 2020. We worked to clarify whether used in a technical regulatory sense or common usage.

- *Figure 109 should be clarified by removal of extraneous BSAI data and Figure 116 should be clarified with the addition of a key.*

  The editors, in consultation with the lead author, decided to keep Figure 109 (unemployment rates for all regions in Alaska; Figure 94 in 2020 ESR) to show unemployment rates in the Gulf of Alaska relative to other Alaskan regions. The figure before that (Figure 108 in the same contribution; Figure 93 in 2020 ESR) only shows Gulf of Alaska data to clearly highlight the relevant trends as requested by the SSC.

- *Employment Trends: 3rd paragraph, "The unemployment rate increased by 90.24% between 1990 and 2018." Why? Was this change related to fisheries?*

- *Figure 121: Do we have any ideas as to why Yakutat graduation rates dropped so much in 2018? Is this fishing-related?*

  It is extremely difficult to point to causal linkages with available data. These are great questions and warrant additional research. In the meantime, we explored the available data to identify possible linkages to present in the ESR 2020 text.

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 "2016–2020 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 "2016–2020 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.