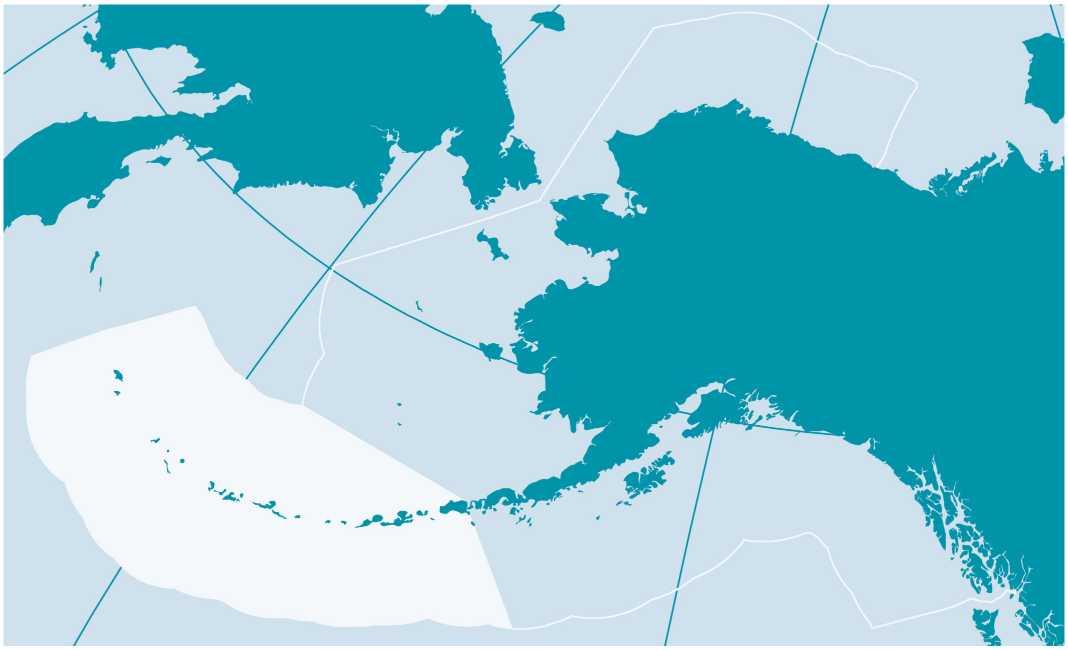
Ecosystem Status Report 2023

ALEUTIAN ISLANDS



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North Pacific Fishery Management Council

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QR code for NOAA Alaska Fisheries Science Center's Ecosystem Status Reports webpage:
`https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands`.
Time series from the report cards are available at
`https://apps-afsc.fisheries.noaa.gov/refm/reem/ecoweb/index.php`

Contributing Partners

Purpose of the Ecosystem Status Reports

This document is intended to provide the North Pacific Fishery Management Council, including its Scientific and Statistical Committee (SSC) and Advisory Panel (AP), with information on ecosystem status and trends. This information provides context for the SSC's acceptable biological catch (ABC) and overfishing limit (OFL) recommendations, as well as the Council's final total allowable catch (TAC) determination for groundfish and crab. It follows the same annual schedule and review process as groundfish stock assessments, and is made available to the Council at the annual December meeting when Alaska's federal groundfish harvest recommendations are finalized.

Ecosystem Status Reports (ESRs) include assessments based on ecosystem indicators that reflect the current status and trends of ecosystem components, which range from physical oceanography to biology and human dimensions. Many indicators are based on data collected from NOAA's Alaska Fishery Science Center surveys. All are developed by, and include contributions from, scientists and fishery managers at NOAA, other U.S. federal and state agencies, academic institutions, tribes, nonprofits, and other sources. The ecosystem information in this report will be integrated into the annual harvest recommendations through inclusion in stock assessment-specific risk tables (Dorn and Zador, 2020), presentations to the Groundfish and Crab plan teams in annual September and November meetings, presentations to the Council in their annual October and December meetings, and submission of the final report to the Council in December.

The SSC is the primary audience for this report, as the final ABCs are determined by the SSC, based on biological and environmental scientific information through the stock assessment and Tier process[1],[2]. TACs may be set lower than the ABCs due to biological and socioeconomic information. Thus, the ESRs are also presented to the AP and Council to provide ecosystem context to inform TAC as well as other Council decisions. Additional background can be found in the Appendix (p. 80).

[1] https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf

[2] https://www.npfmc.org/wp-content/PDFdocuments/fmp/BSAI/BSAIfmp.pdf

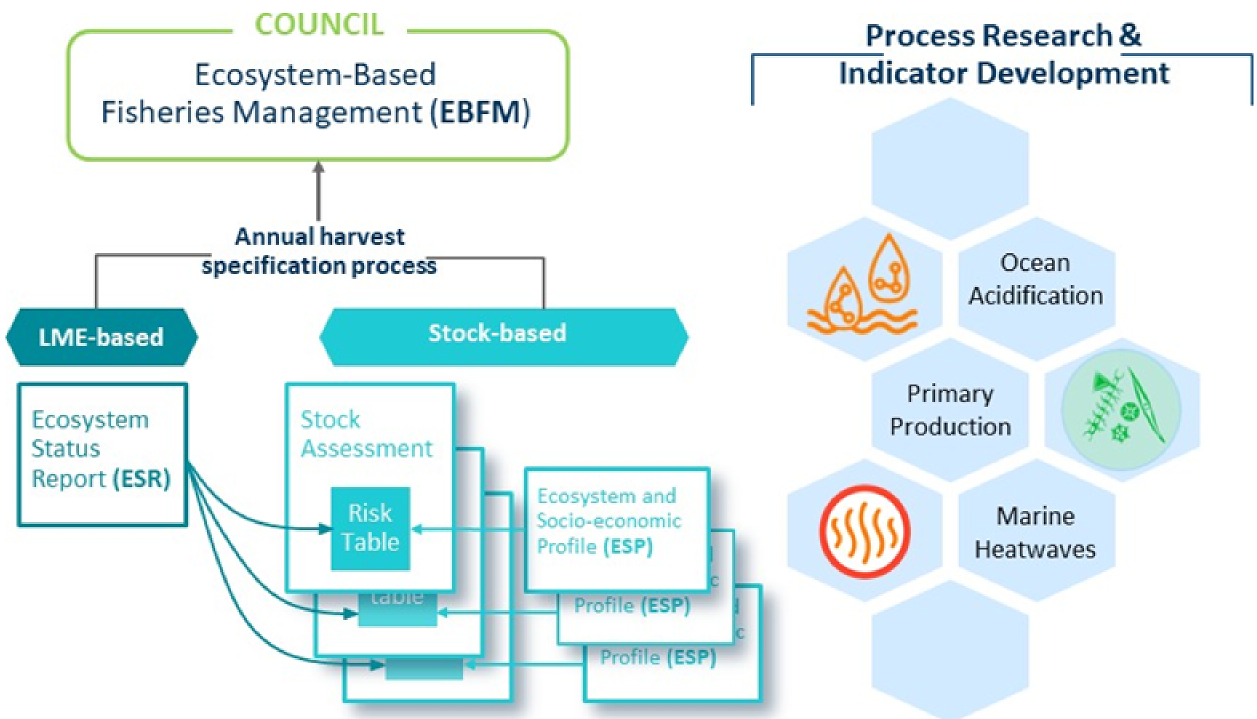

Figure 1: Ecosystem information mapping to support Ecosystem-Based Fisheries Management through Alaska's annual harvest specification process. The 'honeycomb' on the right shows examples of ecosystem indicators that are provided to Ecosystem Status Reports (ESRs) at the Large Marine Ecosystem (LME) scale and/or to Ecosystem and Socio-economic Profiles (ESPs) at the stock-based level.

Aleutian Islands 2023 Report Card

For more information on individual Report Card Indicators, please see Description of Report Card indicators (p. 87). For more information on the methods for plotting the Report Card indicators, please see "Methods Description for Report Card Indicators" (p. 92).
* indicates Report Card information updated with 2023 data

To highlight the spatial dynamics and east to west gradients characterizing the Aleutian Islands, we divide the ecosystem into three ecoregions: the Western, Central and Eastern Aleutian Islands.

Region-wide

- The **North Pacific Index (NPI)** effectively represents the state of the Aleutian Low. Above (below) average winter (November - March) NPI values imply a weak (strong) Aleutian Low and generally calmer (stormier) conditions. The NPI has been positive during 6 of the last 7 winters, with the exception being the winter of 2018-2019. The systematically positive state of the NPI (i.e., weak Aleutian Low) is consistent with the overall decline in the PDO during the interval.
- The Aleutians Islands region **was relatively stormy during the winter of 2022-23 and summer of 2023**. The cooler conditions during 2023 were accompanied by greater upper mixed layer depths than during 2022. Much of the past year included wind anomalies of the sense associated with suppressed northward flow through Unimak Pass.

Western Aleutian Islands

- The reproductive success of least, whiskered and crested auklets, planktivorous seabirds at Buldir Island was average while parakeet auklets had below the long-term average reproductive success. This indicates **overall zooplankton availability was sufficient to support seabird reproductive success in 2023 and potentially other plankton eating commercial groundfish species**, although not as good as in 2022 when reproductive success was average to above the long-term average for all seabirds.
- Forage fish trends, as indicated by their percent in the composition of tufted puffin chick meals, have varied over time, with episodic peaks lasting 1–2 years. In general, *Ammodytes* (sand lance) stayed close to the time series mean with values similar to those in 2022; age-0 gadids (pollock mostly), also stayed close to the time series average after the 2021 peak; and hexagrammids (primarily Atka mackerel) were below the time series mean, decreasing from last year. We note tufted puffins had above average reproductive success and fed mostly on squid and Pacific saury, thus signaling **potentially favorable conditions for fish foragers** though not as favorable as last year. Not shown here, squid comprised 63% (percent by weight) and Pacific saury 18% of tufted puffin chick meals. Likewise, 43% of horned puffin chick meals were Atka mackerel and 30% squid. Surface feeders eating fish and invertebrates (fork-tailed storm-petrels, kittiwakes) and diving feeders (thick billed murres and parakeet auklets feeding on fish and zooplankton respectively) had below average reproductive success. There were no seabird diets collected in 2020.

Central Aleutian Islands

- **School enrollment continued a decreasing trend in the 2022-2023 school year** driven by decreased enrollment in Adak, where school enrollment decreased from 13 to 5. Alaska schools need at least ten students to qualify for state funding. Amid rising operating costs and flat funding in general, small schools like those at Adak and Atka are at increasing risk of closure. Enrollment at Atka increased from 10 to 11. Decreasing enrollment trends impact the stability to families living in those communities. This indicator is updated annually with data from the previous year.

Eastern Aleutian Islands

- As indicated by their percent in the composition of tufted puffin chick meals **forage fish were abundant and mostly capelin**. *Ammodytes* (sand lance) and gadids were below the time-series mean, as were gadids (pollock); hexagrammids (Atka mackerel) remained close to the time series mean. Gadids were more common through the 1990s while hexagrammids are uncommon in this region. There were no seabird diets collected in 2020.
- **School enrollment fell for the third year in a row**. This is the lowest on the time series and is driven by the trend at Unalaska Elementary. Enrollemnt at the elementary school peaked in 2019-2020 at 238 students compared to the current 176 (note peak in 2018-2019 was due to the combined elementary and high school students). The small communities have either closed schools (Nikolski, in 2009) or are at risk of closure if they fall under the 10 student threshold (False Pass currently with 9 students and Akutan with 20). As in the case in the central Aleutians, decreasing enrollment trends impact the stability of families living in those communities. This indicator is updated annually with data from the previous year.

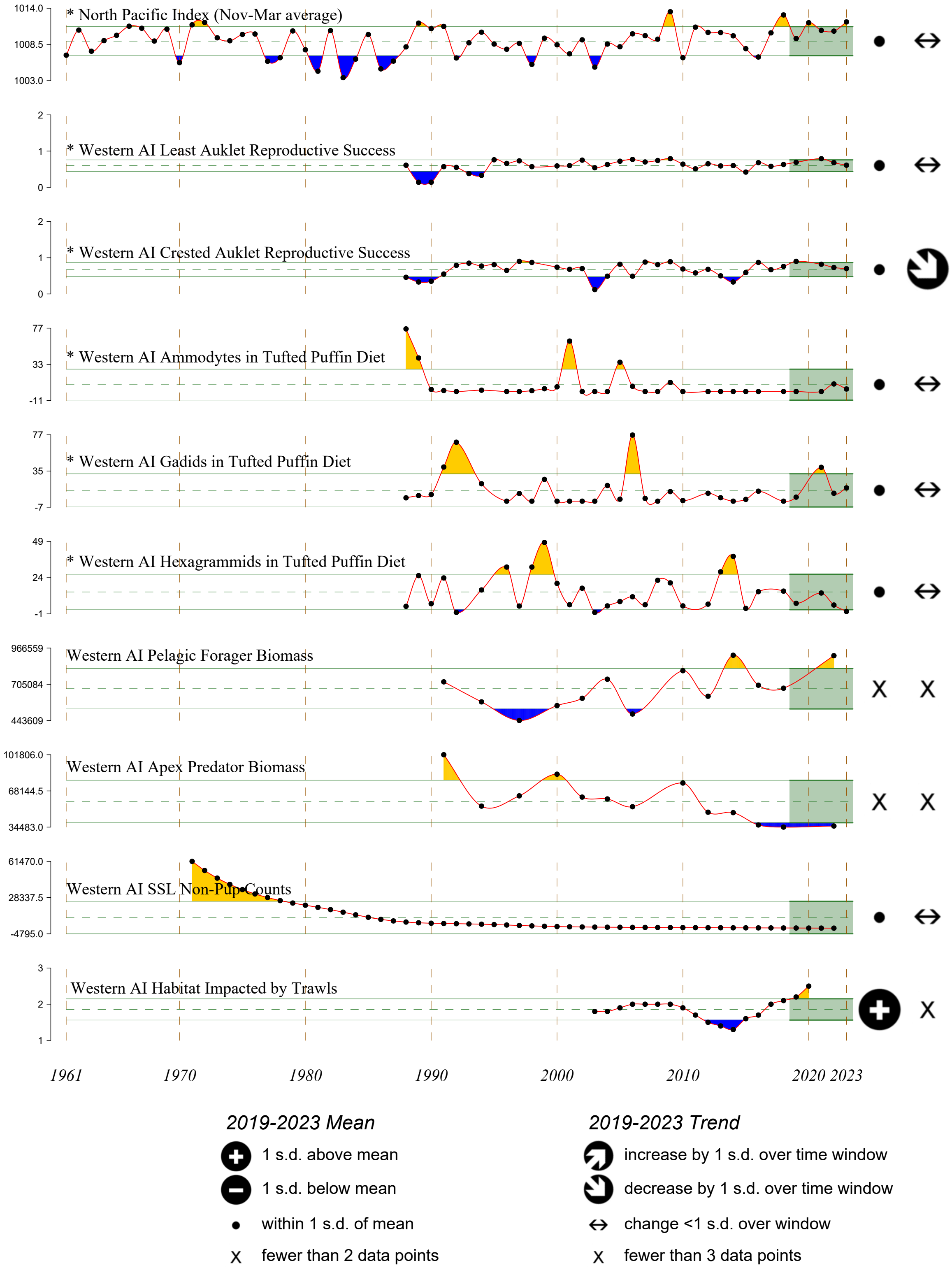

Figure 2: Region-wide and Western Aleutian Islands indicators. *indicates time series updated with 2023 data

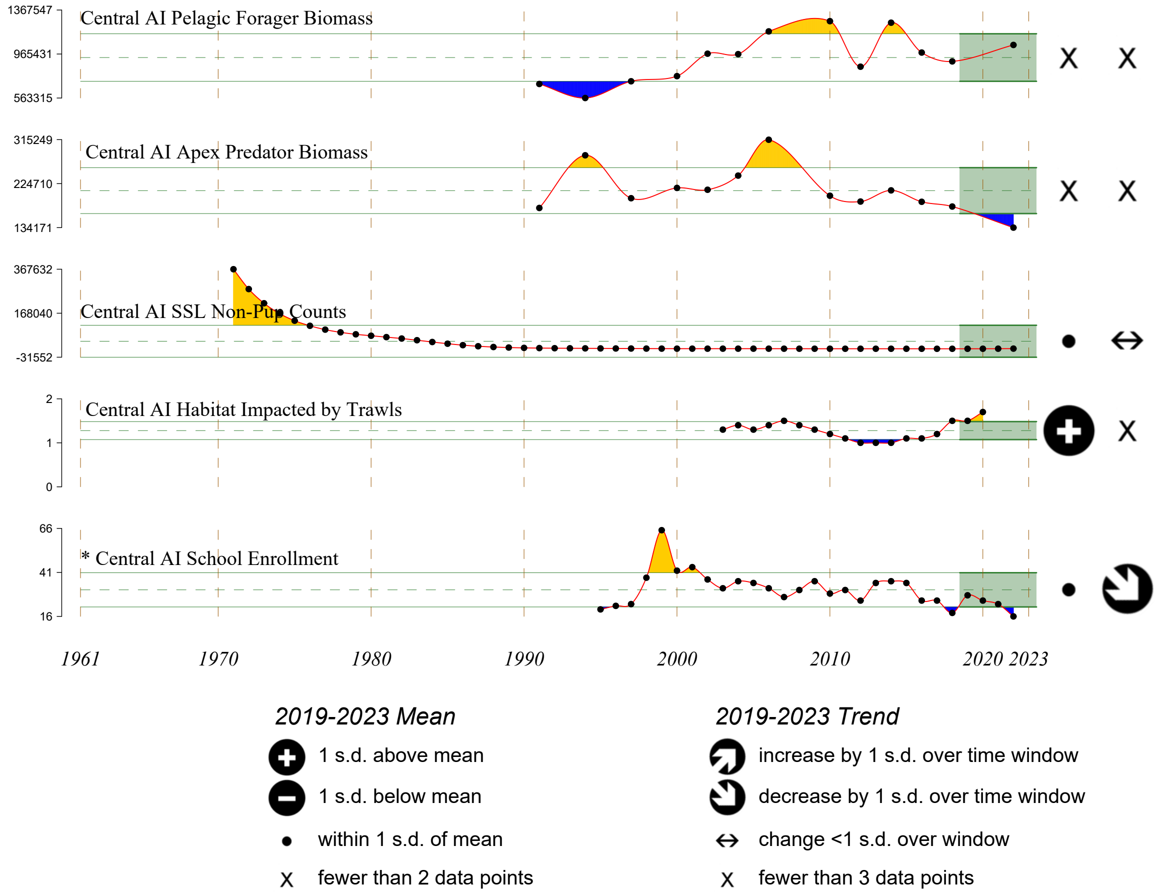

Figure 3: Central Aleutian Islands indicators. * indicates time series updated with 2023 data

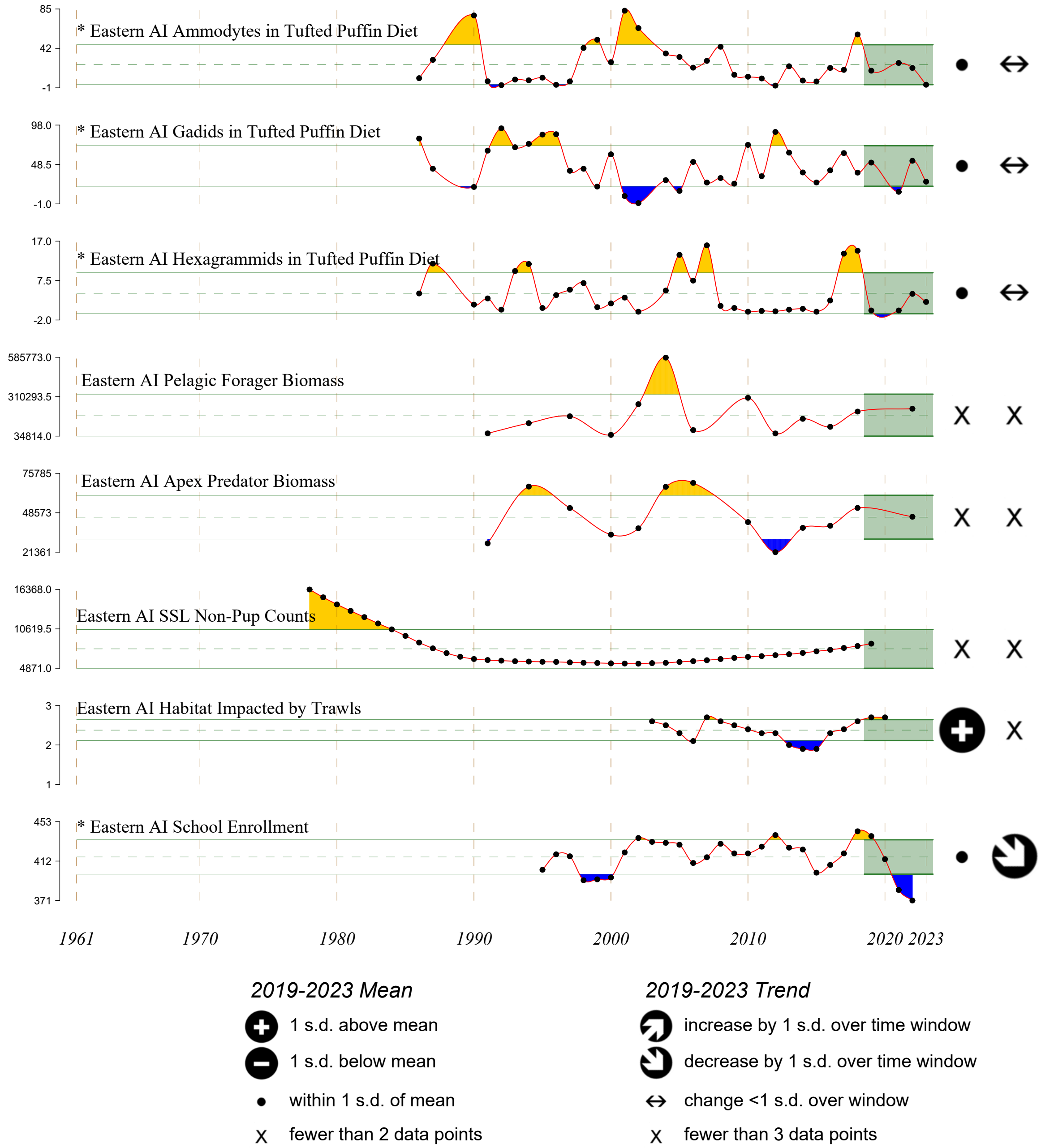

Figure 4: Eastern Aleutian Islands indicators. * indicates time series updated with 2023 data

Ecosystem Assessment

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The Aleutian Islands ecoregions

The Aleutian Islands ecosystem assessment and Report Card are presented by three ecoregions. The ecoregions were defined based upon evidence of significant ecosystem distinction from the adjacent ecoregions by a team of ecosystem experts in 2011. The team also concluded that developing an assessment of the ecosystem at this regional level would emphasize the variability inherent in this large area, which stretches 1900 km from the Alaska Peninsula in the east to the Commander Islands in the west. For the purposes of this assessment, however, the western boundary is considered the U.S.–Russia maritime boundary at 170°E.

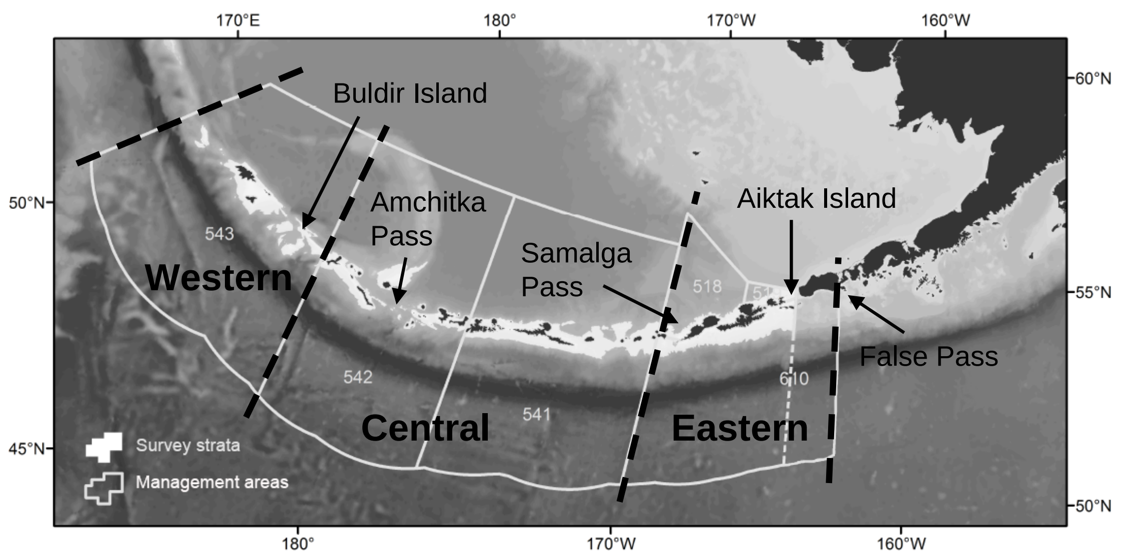

Figure 5: The three Aleutian Islands assessment ecoregions.

The three Aleutian Islands ecoregions are defined from west to east as follows (Figure 5). The western Aleutian Islands ecoregion spans $170°$ to $177°$E. These are the same boundaries as the National Marine Fisheries Service area 543. This ecoregion was considered to be distinct from the neighboring region to the east by primarily northward flow of the Alaska Stream through wide and deep passes (Ladd, pers. comm.), with fewer islands relative to the other ecoregions.

The central Aleutian Islands ecoregion spans $177°$E to $170°$W. This area encompasses the National Marine Fisheries Service areas 542 and 541. There was consensus among the team that the eastern boundary of this ecoregion occurs at Samalga Pass, which is at $169.5°$W, but for easier translation to fishery management areas, it was agreed that $170°$W was a close approximation. The geometry of the passes between islands differs to the east and west of Samalga Pass (at least until Amchitka Pass). In the central ecoregion the passes are wide, deep and short. The Alaska Stream, a shelf-break current, is the predominant source of water (Figure 6). There is

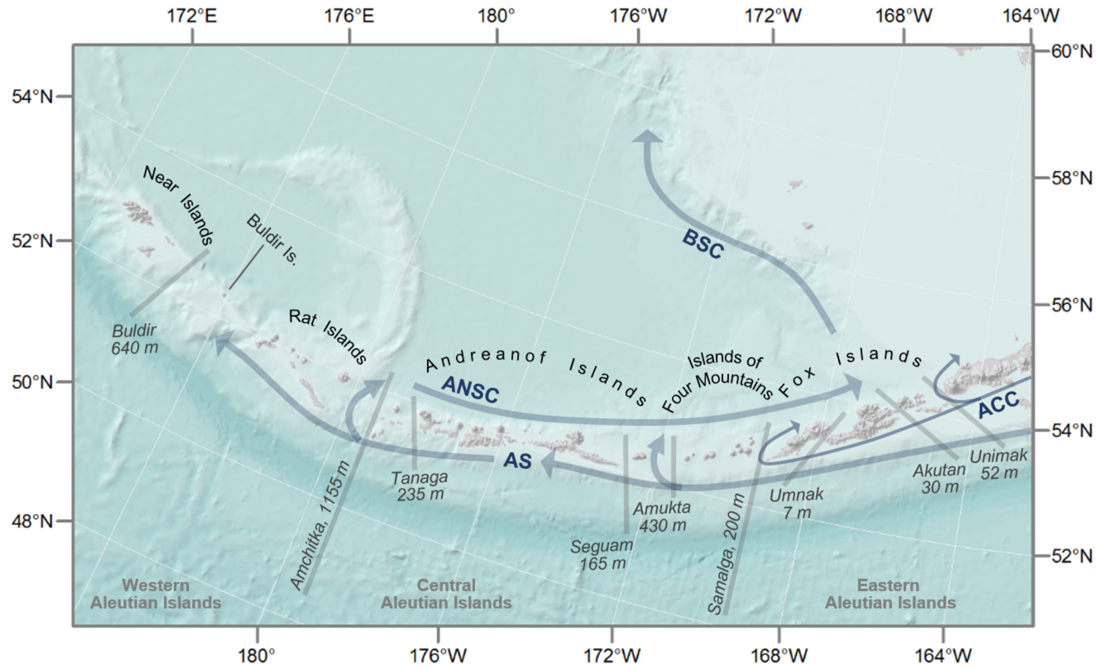

Figure 6: Ocean water circulation in the Aleutians. Currents are indicated with black lines. Currents are indicated by grey arrows. Selected passes are indicated by straight light grey lines

more vertical mixing as well as bidirectional flow in the passes. This delineation also aligns with studies suggesting there is a biological boundary at this point based on differences in chlorophyll, zooplankton, fish, seabirds, and marine mammals (Hunt and Stabeno, 2005).

The eastern Aleutian Islands ecoregion spans $170°$W to False Pass at $164°$W. The passes in this ecoregion are characteristically narrow, shallow and long, with lateral mixing of water and northward flow. The prominent source is from the Alaska Coastal Current, with a strong freshwater component. This area encompasses the NMFS areas 518, 519 (EBS) and the western half of 610 (GOA).

Aleutian Islands Ecosystem Assessment

As the Aleutian Islands are situated between the Bering Sea and the Pacific Ocean, they are influenced by different ocean currents, eddies, and geographic constraints. Given these challenges, there are large gaps in knowledge about the local physical processes. The use of technology to address these challenges can be limited. For example, persistent cloudiness can preclude obtaining comprehensive satellite-derived data, and strong currents preclude the use of various unmanned underwater vehicles. The long distances involved in surveying the island chain make comparing west–east trends in indicators difficult due to time lags during oceanographic surveys across the region. The archipelago is also influenced by different processes in the eastern than in the western Aleutian Islands. Differences in survey timing and longitudinal gradients may also affect detection of biological patterns, as gradients are seldom monotonic in any direction. Integrative biological indicators such as fish or marine mammal abundances may be responding to physical indicators such as temperature, but are less sensitive to timing of when they are surveyed compared with direct measurements of temperature. Also, the extensive nearshore component of the ecosystem is a long, narrow shelf relative to the entire ecosystem, and strong oceanographic inputs mean that some metrics commonly used as ecosystem indicators in other systems may not be as informative in the Aleutian Islands. Therefore, our synthesis of ecosystem indicators by necessity includes speculation

The Alaska Fisheries Science Center last completed its standard bottom trawl survey in 2022. While the bottom trawl survey is typically done biennially in even-numbered years, there was no survey in 2020 due to COVID-19, so the 2022 survey was the first in four years.

Current Conditions 2023

The past year in the NE Pacific, as a whole, was characterized by continuing moderate La Niña conditions and a continued negative PDO phase that followed the marine heat wave years of 2014–16. El Niño conditions developed along the equator over the summer, and El Niño is predicted to continue through the Northern Hemisphere spring (with an 62% chance during April–June 2024)[3]. Conditions in the Aleutian Islands were relatively stormy during the winter of 2022–23 and summer 2023. The year started with the warmest winter on record since 1900 based on long-term sea surface temperatures. Satellite sea surface temperatures across the Aleutian Islands show waters were in or near moderate marine heat wave status last winter. Temperatures cooled but remained above average during spring and early summer, periodically crossing the threshold to marine heatwave status. Persistent heatwave conditions returned in late summer. Both summer and winter temperature trends in the Aleutian Islands have been increasing since 2013–2014, concurring with a 2013–2014 annual mean sea surface temperature regime shift in the North Pacific recently identified by Xiao and Ren (2023). Mid-depth temperatures were above average in 2023, as they have been since 2014. Winds suppressed northward flow through Unimak Pass, and eddy kinetic energy was near or below its long-term average (1993–2022) across the chain. Together these indicators suggest that there were decreased fluxes of heat and nutrients from deeper water and through the Aleutian Island passes. The cooler conditions during late spring early summer of 2023 were accompanied by greater upper mixed layer depths than during 2022, which may have impacted the vertical distribution and availability of prey throughout the water column.

Seabirds at Buldir Island in the western Aleutians had mixed reproductive success, in contrast to the exceptionally-successful previous year. This suggests that there was not enough available prey to support successful reproduction for some seabird species in 2023. Tufted puffins that dive to capture their fish and squid prey had above average reproductive success. In contrast, fork-tailed storm petrels and kittiwakes that forage at the surface for fish and invertebrates, and thick billed murres and parakeet auklets that dive for and zooplankton respectively, had below average or complete reproductive failure. This contrasting pattern suggests that there was less available prey throughout the water column in general but perhaps more available prey below the surface and at depth. This summer continues a successful trend at Aiktak, where reproductive success has been average or above average since 2019 (there were no surveys in 2020) for most seabirds breeding at Aiktak. This indicates uniformly high prey availability for both nearshore and offshore foragers, including surface feeders and divers and across a broad spectrum of zooplankton to forage fish prey (Figure 34). However, the report of a die-off in August of over 150 shearwaters on Akutan indicates the presence of a potential stressor(s) in the region (more details below).

Eastern Kamchatka pink salmon abundance in 2023 was the third highest on record. Exceptionally high numbers of pink salmon suggest that there could be top-down pressure on their zooplankton prey and competitive impacts on species that forage on the same prey. Several papers report that the strong pink salmon biennial pattern of abundance seems to be causing trophic cascades, showing impacts on fish growth (Atka mackerel, Matta et al. 2020) and food availability for seabirds (Zador et al., 2013; Batten et al., 2018; Springer et al., 2018). High pink salmon abundance in 2023 poses a particular concern for Pacific ocean perch, Atka mackerel, and tufted puffins (Springer and van Vliet, 2014; Batten et al., 2018; Springer et al., 2018), for which some aspect of their biology has shown to be negatively correlated to pink salmon abundance. The notable steep increases in Eastern Kamchatka pink salmon abundance trends in 2009, for the more abundant odd-year classes, and in 2014 and 2016, for the less abundant even-year classes, seem to have made biennial signals potentially driven by pink salmon abundance

[3] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.pdf

more noticeable across ecosystem components.

Lastly, paralytic shellfish toxins increased significantly this year compared to 2022, posing a continued seasonal concern for human health and food webs in the region. In 2023, maximum concentrations of 3,793 µg per 100 g were recorded in blue mussels. This is 47x (vs 3.4x in 2022) above the regulatory limit (80 µg per 100 g, FDA[4]). Concentrations above 1000 µg per 100 g are considered potentially fatal for humans. The level of toxins observed this year is still substantially lower than the toxins observed at 75x the limit in Unalaska during 2021. More details on this year's trends are in the regional highlights section below.

Multi-year patterns

Overall, there seem to be three major drivers of the multi-year patterns observed across the Aleutian Islands: persistent warm conditions, increasing pink salmon abundance, and increasing Pacific Ocean perch abundance. Jointly, these factors might indicate a transition of the ecosystem to a new state. The likelihood and detection of such a transition may depend on how long the current conditions prevail. As one indication of an ecosystem transition, preliminary analysis of Pacific cod stomachs in 2023 shows their diet has shifted from a majority of fish to diets dominated by invertebrates, with decreased average amount of prey consumed (as percent of predator weight). The change in diets is observed across medium (30 cm) to large (85 cm) Pacific cod (see Noteworthy, page 24). Further analysis of the food web to see if predator/prey relationships have changed over time would help to determine if these changes reflect a broader transition in the ecosystem. This would require both more diet sample collections (from fish, birds, and mammals) and analysis to inform underlying changes in the structure of the ecosystem. The data-poor nature of Aleutian Islands relative to the eastern Bering Sea or Gulf of Alaska, limits the ability to identify the extent of cascading or cumulative effects of these drivers. Additionally, as the bottom trawl surveys, from which stomach content and other data are collected, occur only in even-numbered years, potential ecosystem impacts of superabundant pink salmon in odd-numbered years is not observed in data collected during those surveys.

Persistent warm conditions since 2013: As mentioned above, Xiao and Ren (2023) identified a 2013-2014 annual mean sea surface temperature regime shift across the North Pacific. This agrees with temperature data observed in the Aleutian Islands, where surface to mid-depth and bottom waters have remained above the long term mean since 2013/14. The warm temperatures can be attributed in part to slower processes such as weaker wind/mixing, warmer air temperature, and advection of warm water from the North Pacific Ocean. However, the relative importance of each mechanism on maintaining warm temperatures is hard to assess without a detailed heat budget analysis. Other aspects of the physical environment that influence nutrient availability continue to show variability over the same time period. For example, eddy kinetic energy (EKE) averaged in regions along the Aleutian Islands with historically high long-term mean EKE was at or below average in 2023, with EKE in the eastern box reaching the historical minima (Figure 26). This suggests that there were decreased fluxes of heat and nutrients across the island chain, which has been the case in recent years except for 2021-2022. Phytoplankton biomass, as represented by satellite-derived chl-a concentration, was below average in the AI for much of spring 2023, with overall mean concentrations comparable to the previous two lowest years in the observed time series, 2016 and 2018. At present (9/12/23) there is evidence for a negative trend in spring AI chl-a across the GlobColour time series. These trends are being driven by the Alaska Stream and southeastern Aleutian Basin areas, while areas to the west of Bowers Ridge, or south of $\sim 50°$N, do not show trends (Figure 28). This coincides with the decrease in satellite-derived chl-a observed in the off-shelf region of the eastern Bering Sea (Hennon et al, EBS ESR 2023), suggesting a widespread area with little primary production. Negative zooplankton biomass anomalies and the smaller mean size of the copepod community also suggest low secondary (zooplankton) production (Figure 31). Cumulatively, these conditions suggest that there has been lower productivity across the ecosystem, concomitant with increased bioenergetic needs for fish, faster growth rates for zooplankton and larvae, and shorter incubation periods for eggs due to the warm conditions. These changes in bioenergetics and development rates can potentially lead to mismatches between egg hatching/larvae release and prey availability, which can negatively affect recruitment.

[4]https://www.fda.gov/regulatory-information/search-fda-guidance-documents/cpg-sec-540250-clams-mussels-oysters-fresh-frozen-or-canned-paralytic-shellfish-poison

Also of note is that the beginning of the period of lower fish condition as reported in the 2022 ESR and lower satellite-derived chl-a estimates seem to coincide with the notable increases of Eastern Kamchatka pink salmon in 2009 and 2014/16 for odd and even year-classes, respectively.

Eastern Kamchatka pink salmon abundance in odd years continues to increase: The biennial pattern of high pink salmon abundance in odd years and low abundance in even years continues. As mentioned above, this year was the third-highest abundance on record since 1952 (Figure 32). However, since 2009, high abundances of odd year-classes have doubled and even tripled (315 million adult fish) compared to prior levels of around 100 million fish. Low abundance [even] years reached the 100 million fish mark in 2016 and 2018 (perhaps related to higher temperatures mentioned above) but also had a notable increase in 2014 from previous years (48 million compared 24 million in 2012 and 14 million and 10 million in 2010 and 2008 respectively). In 2020, pink salmon abundance decreased to pre-2014 levels, perhaps due to low availability of prey that was suggested by anomalously low numbers of large meso-zooplankton sampled in the Continuous Plankton Recorder. The following indicators, tracked in past ESRs, also show a biennial pattern: satellite chl-a (lower in even years, Figure 28), hatch timing of tufted puffins (earlier in odd years, Figure 35), catch estimates of age-2 Atka mackerel (Lowe et al., 2022), number of age 3+ Pacific Ocean perch (Spencer et al., 2022), and the bycatch of all seabirds combined (increases in years of high pink salmon abundance and decreases during low pink salmon abundance, not available this year). That the timing of some of these biennial patterns coincides with the step changes in Eastern Kamchatka pink salmon abundance suggests that a threshold has been reached where potential ecosystem impacts increase. Interestingly, the biennial pattern seen in the age-2 Atka mackerel catch has not been observed in recruitment estimates or surveys. The biennial pattern in tufted puffin hatch timing indicates they find more favorable conditions in winter/spring when Eastern Kamchatka pink salmon abundance is low. However the abundance of pink salmon does not correlate with their reproductive success during summer. Further evaluation is needed to fully assess the influence of Eastern Kamchatka pink salmon in the system.

Rockfish have replaced Atka mackerel and pollock as the main pelagic foragers: The increase of rockfish across the Aleutian Islands has slowly changed the ratio of Atka mackerel and pollock to northern rockfish and Pacific Ocean perch, with rockfish now contributing a higher percent of the local biomass across the archipelago to pelagic foragers. Stock assessment estimates support rockfish remaining dominant, although their biomass is decreasing. An ecosystem state where sustained high biomass of Pacific Ocean perch and northern rockfish is outcompeting or displacing pollock and Atka mackerel would signal a return to conditions that existed before Pacific Ocean perch was heavily fished by the foreign fleets. The effect of rockfish dominance on the ecosystem is best captured by the mean lifespan of the groundfish community, a proxy for the mean turnover rate of species (AI ESR 2022). Mean lifespan has increased from 35 years in the 1980s to 60 years in 2018-22. Longer-lived species help to dampen the effects of environmental variability, and in ecological terms, increase the stability of the ecosystem (AI ESR 2022). The persistent poor groundfish condition suggests that Pacific Ocean perch and northern rockfish could potentially be experiencing density dependence or some other mechanism that leads to less optimal foraging conditions. Also, rockfish prefer habitats with vertical structure (Rooper 2019), particularly deep coral and sponges, and may be exerting spatial pressure on other fish in this habitat. This in turn might lower the availability of Atka mackerel and pollock to other predators such as Pacific cod, whose diet shows a general decreasing trend in the amounts of Atka mackerel consumed in NMFS areas 543 and 542. It is unclear whether this change in pelagic foragers (Figure 48) has contributed to the observed decline of harbor seals (AI ESR 2021) and/or Steller sea lions. Together with eastern Kamchatka pink salmon, Pacific ocean perch and northern rockfish consume a large portion of zooplankton previously consumed by Atka mackerel, walleye pollock and other forage fish.

Western Aleutians

Sustained high sea surface temperatures during winter resulted in a moderate marine heat wave in the western Aleutians (Figure 19). Temperatures cooled in later spring and early summer, but remained above the long-term (Dec 1985-Nov 2015) average. Heatwave conditions returned in late summer and have prevailed through early

November[5]. The heatwave could have potential negative impacts on Atka mackerel as they move to shallower areas during the spawning season, when surface temperatures were close to 11–11.5°C, which is the upper limit of the observed temperatures during Atka mackerel spawning. These higher temperatures may shorten egg development time and lead to faster growth rates in larvae. Atka mackerel nests are typically found between 32—144 m depth (Lauth et al., 2008) potentially making the shallowest nests more vulnerable to the heatwave. Bottom temperatures averaged 4.4°C in 2022, which is well below the lethal temperature of 15°C for Atka mackerel eggs (Gorbunova, 1962). Eddy kinetic energy was below average, suggesting low fluxes of nutrients, heat and salt through the passes in the Western Aleutians (Figure 26). Satellite-derived chl-a concentration was below average throughout spring, and improved somewhat in fall (Figures 28, 29).

The persistent decline in fish condition as represented by weight/length residuals from fish sampled during the bottom trawl survey may be linked to the change in prey, as suggested by a preliminary analysis of cod stomachs from the region (p. 24). Atka mackerel were almost absent from cod stomachs collected in recent years, whereas the proportion of squid and shrimp in the stomach increased over the same time period. The transition to a higher proportion of invertebrates in their diet seems to coincide with the temperature regime shift/ higher temperatures in 2013–2014, indicating that there may have been a change of the structure of the ecosystem in this region. The decline in fish condition may also be indicative of several interacting factors, including poor prey quality, low availability of prey, density dependence, and increased metabolic rate (Holsman et al., in press). Based on biomass estimates from the 2022 bottom trawl survey compared to 2018 estimates, apex predator abundance increased 3% overall. This increase was driven by Pacific cod (20%), rougheye/ blackspotted rockfish (84%) and large sculpins (2%), while all large flatfish decreased. The below average fish condition of Pacific cod and arrowtooth flounder suggests that they experienced either poor prey quality and/or low availability of prey. In contrast, the overall biomass estimate of pelagic foragers increased 35%. This increase was driven by Pacific ocean perch and Atka mackerel (33% and 58%), while pollock decreased 63%. The fish condition for all three was below average, and while this would suggest low quality and/or availability of prey, in the case of Pacific ocean perch it may also be due to density dependence, given its increasing biomass trend.

Long-term average hatch dates for fish-eating seabirds are between mid-June to late July (Dragoo et al., 2019), along with average hatching periods of 30 to 42 days. In general, hatch dates in the western Aleutians in 2023 were average or later than the 1993–2022 average. This suggests that there were poor foraging conditions during winter and early spring, which may also reflect potentially poor foraging conditions for commercial groundfish. Reproductive success was also mixed in the region, with puffins having average or above average success while all other species saw a decline in their reproductive success. Fork-tailed storm petrels and kittiwakes (both surface feeders on invertebrates and fish) had below average success or complete reproductive failure (red-legged kittiwakes). Tufted puffin chick diets at Buldir were mainly composed of squids 63% (up from 35% in 2022) and 18% Pacific saury, while horned puffin chick diets there were primarily composed of Atka mackerel (43%). The dominance of species in puffin chick diets concurs with stable or increasing biomass of these species based on bottom trawl survey data. The increase of rockfish in seabird diets observed in 2021 was not observed in 2022 or this year, as *Sebastes spp.* was only 2% of the chicks' diets. It will be interesting to see if the increase in age-0 rockfish in chick diets in 2021 lines up with future estimates of 2021 rockfish age-classes. We use reproductive success of zooplankton-eating seabirds (auklets) as indicators of zooplankton production. Their reproductive success was above average from 2019–2022, but this year declined to average. These species feed their chicks mainly euphausiids and copepods. Their average hatch dates and reproductive success this year suggest that there were sufficient foraging conditions from early spring through summer.

Central Aleutians

Similar to the Western Aleutians, the central Aleutians experienced a moderate marine heatwave in winter, warm temperatures during spring, and a return to heatwave conditions in late summer that have prevailed through early November. Mid-depth temperatures in this region have not been as warm as those in the eastern Aleutians (see 2022 ESR). Eddy kinetic energy in this region is usually lower in magnitude compared to those in the western and eastern Aleutians. Eddy events in this area are characterized either by multiyear or continuous eddies of

[5] https://shinyfin.psmfc.org/ak-sst-mhw/

low intensity. In 2023, eddy kinetic energy was generally below the 1993–2022 average, indicating potentially below-average flux of nutrients and heat across the passes. Phytoplankton biomass, as represented by chl-a concentration, was also generally below average except for an increase primarily in August of 2022 (Figures 28 and 29).

Pacific cod stomachs sampled in this region (NMFS areas 541 and 542) show a strong decrease in the proportion of fish in their diet over time and an increase in shrimp, squid, and other invertebrates. In some years, Atka mackerel are more common in diets (p. 24). Further analysis is needed to see if these periodic increases coincide with local Atka mackerel recruitment trends. Fish prey types also change along a west to east gradient in this region with Atka mackerel more common in the west and a higher proportion of shelf demersal fish to the east.

We report on school enrollment as an indication of trends in coastal, rural community populations. There are currently 2 active public schools in the Central region. School enrollment bottomed out at the state level in Alaska during 2020–2021 and decreased even further during the 2022–2023 school year. Barring renewed activity by the now-closed fish processing plant in Adak and the lost potential to be a hub for clean energy (fuel) along the great circle route, the future stability of the Adak community and school is uncertain.

Eastern Aleutians

This region encompasses the islands east of Samalga Pass to Unimak Pass. As in 2022, sea surface temperatures in the eastern Aleutians during 2023 were not as high during winter as they were in the western and central Aleutians. The marine heat wave periods were also shorter, with those in spring and early summer largely reduced, and with almost no heatwaves as of early November. However, temperatures were still above the 1985–2015 baseline in the region. Mid-water temperature profiles for 2023 show an increased warm band of water between 150–300 m with cooler temperatures above and below (Figure 24). The predominant wind pattern in 2023 suppressed flows through Unimak Pass. Eddy kinetic energy, which is typically driven by a strong pulse eddy in this area, was significantly lower this year similar to the generally low value that has largely been observed since 2012 (Figure 26) wiht the exception of 2021-2022. The spatial structure of chl-a anomalies suggest almost uniformly low chlorophyll across the region during April-June 2023, with the exception of some small positive anomalies in the Alaska Stream east of $187°$E, and in some areas further south (Figure 29).

Fish-eating seabirds, such as murres, puffins and gulls, all had above average reproductive success as in the past couple years. No auklets (primarily zooplankton-eaters) were surveyed in the region. Storm-petrels, which feed on a mix of invertebrates and zooplankton, have had average above average reproductive success since 2022. Fork-tailed storm-petrels had average hatch dates but above average reproductive success. Leach's storm-petrels had both average hatch dates and average reproductive success (Figures 36, 34). These indicators suggest good availability of forage fish to rear chicks and potentially for fish-eating groundfish. Storm petrels and murrelets, which feed on fish, invertebrates and zooplankton, had average or above average reproductive success. While it is unclear whether the conditions were as favorable for obligate zooplankton-eating seabirds as for fish-eating seabirds, the overall reproductive success suggests there was sufficient prey. Tufted puffins chick diets were fed primarily capelin (87%) followed by pollock (6%), indicating that high-quality forage fish were available to foraging seabirds.

In late August an opportunistic report of a die-off of over 150 shearwaters was reported at Akutan Island. This is particularly notable as die-offs have been rarely reported in the Aleutian Islands, likely in part due to the remote and unobserved nature of most of the coastline. Die-offs such as this one have been linked to poor food supply and/or disease. In recent years, the global spread of the Highly-Pathogenic Avian Influenza (HPIA) has been of great concern for seabirds, particularly those that nest in dense colonies where an introduction of HPIA could spread quickly due among densely-aggregated seabirds. In the past year, HPIA has been increasingly detected in seabird colonies worldwide. Six carcasses from this die-off were sent to the Alaska Department of Environmental Conservation where samples tested negative for HPAI; some carcasses are also planned to be tested for HABS toxins. It is reasonable to assume that HPIA will eventually be detected in seabirds in the Aleutian Islands, particularly as samples from the southeastern Bering Sea tested positive in August this year. Human infections with bird flu viruses are rare and most often occur after close or lengthy unprotected contact, but global efforts continue to monitor HPAI.

Pacific cod diets have been alternately dominated by fish and invertebrates in this region (the South Bering Sea bottom trawl area) (Figure 12). There does not appear to be a temporal transition from fish to invertebrates in this area as there are in the western and central Aleutians. The most common fish prey is pollock, but it is not dominant in all years. Shrimp are the most common invertebrate seen, but cod diets as a whole have a more diverse array of invertebrates relative to cod diets in the other regions.

Shellfish samples from several locations including Little Priest Rock in Summer Bay, Unalaska are collected weekly and analyzed for harmful algal blooms. Monitoring indicated that peak toxin levels occurred during June this year. Blue mussels had toxins of 47x (vs 3.4x in 2022) above the regulatory limit of 80 µg per 100 g, (FDA[6], Figure 41), which is still below the maximum of 75x documented in 2020. Public awareness efforts continue in the area to minimize impacts on human health.

Lastly, school enrollment in this region declined in 2020–21 and has not recovered. The decrease in the eastern Aleutians enrollment was driven by a large decline at Unalaska Elementary, but enrollment has also been decreasing for high school grades. All other schools (Akutan, False Pass) had similar enrollment as last year.

[6]https://www.fda.gov/regulatory-information/search-fda-guidance-documents/cpg-sec-540250-clams-mussels-oysters-fresh-frozen-or-canned-paralytic-shellfish-poison

Contents

† indicates new contribution

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Ecosystem Indicators

Noteworthy Topics

We include information here that is deemed of relevance to ecosystem considerations of fisheries managers, but does not fit our typical indicator format. Information included here is often new, a one-time event, qualitative, some other type of non-standard ecosystem indicator, or a deeper discussion on a topic of interest.

Changes in large scale sea surface temperature patterns

Recent studies have identified several large scale changes in sea surface temperature patterns and their implications for climate indices. Xiao and Ren (2023) identified a regime shift in North Pacific annual mean sea surface temperature that occurred in 2013/2014. The analysis shows that within a defined area of the northern North Pacific Ocean ($170°$E–$120°$W, $45°$–$65°$N) there were two significant and abrupt increases in annual mean temperature One occurred in 1977 and the second in 2013. This was observed in all four datasets examined: i) the fifth version of the Extended Reconstructed SST (ERSST5) (Huang et al., 2017), ii) the Hadley Centre Sea Ice and SST (HadISST) (Rayner et al., 2003), iii) the Centennial in situ Observation-Based Estimates (COBE) SST (Ishii et al., 2005), and iv) the Kaplan SSTA (Kaplan et al., 1998). The step change in 2013-2014 is also observed in the timeseries of regional satellite SST temperatures for the Aleutian Islands (Figure 18), as well as increased number of days under marine heatwave conditions (Figure 19), and coincides with increased temperatures recorded as part of the longline survey (Figure 22). Bottom temperatures have also increased, as shown by the increase in 2014 of the mean annual bottom temperature by region based on data from the Aleutian Islands bottom trawl survey (Figure 19, AI ESR 2022).

Werb and Rudnick (2023) found that the period of persistent marine heatwaves beginning in 2014 changed the first EOF (spatial mode) and PC (principal components) of SST (calculated using data from 1950 to 2021) as compared to the established PDO spatial pattern (calculated using data from 1950 to 1993). The time series for the PDO Index became negative in 2019 (Figure 14), while the first PC of the complete record remained positive until very late in 2021. In other words, the first PC of the full time series reflected the recent warm temperatures in the eastern Pacific while the PDO Index did not. Litzow et al (2020) noted positive PDO values are increasingly associated with a large area of positive winter (November to March) North Pacific SST anomalies, shifted offshore in the northern North Pacific into a more NPGO-like pattern. These changes in large-scale spatial patterns of SST mean that past indicators such as the PDO may not be as useful in the future and that their relationships with physical and ecological processes may vary as the climate continues to change.

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Key temperature ranges for commercial species in the Aleutian Islands

Published optimal temperature ranges for eggs of Pacific cod, walleye pollock and Atka mackerel are provided as indicators of threshold temperatures and vulnerability to increasing temperatures in the Aleutian Islands. The optimal temperature range for Pacific cod egg hatching success above 20% is 3-$6°$C (Laurel and Rogers, 2020). Spawning season is from January to May, and the eggs are attached to the bottom. Larvae rise to the surface waters after hatching. By July, age-0 cod are known to settle to the bottom and inhabit the demersal, shallow waters of coastal Alaska, however, in the Bering Sea they are commonly captured across the broad shelf in both demersal and pelagic trawl surveys (Farley et al., 2016). For pollock, eggs have above 20% hatching success within a temperature range of -1 to 12°C. Larvae are pelagic and spawning season extends from March to June. Atka mackerel spawn from late July to mid-October and eggs hatch October through January. Nesting in the Aleutians has been observed at temperatures between 3.9-10.7°C (Lauth et al., 2007), and temperatures below 3°C or above 15°C can be lethal to eggs or unfavorable for embryonic development depending on the exposure time (Gorbunova 1962). Gorbunova (962) describes the oceanic occurrence of Atka mackerel larvae in the Pacific Ocean and Bering Sea and suggests that they migrate out to sea after hatching in shallow water. Doyle et al. (1994) also found Atka mackerel larvae had an offshore distribution in the Gulf of Alaska, over the outer shelf and slope in the Kodiak Island region. Both Pacific ocean perch and northern rockfish are live-bearers, use internal fertilization and give birth to a large number of planktonic larvae (Conrath and Knoth, 2013). Parturition in Pacific ocean perch occurs in April and May (Conrath and Knoth, 2013) and from April through June (Chilton, 2007) in the Gulf of Alaska. Maselko et al. (2020) suggest long-lived marine species such as Pacific ocean perch may be resilient to environmental variability because cohorts have a genetic composition that is highly influenced by the environmental conditions experienced during their first year. Thus, they are able to maintain a portfolio of cohort-specific adaptive genotypes.

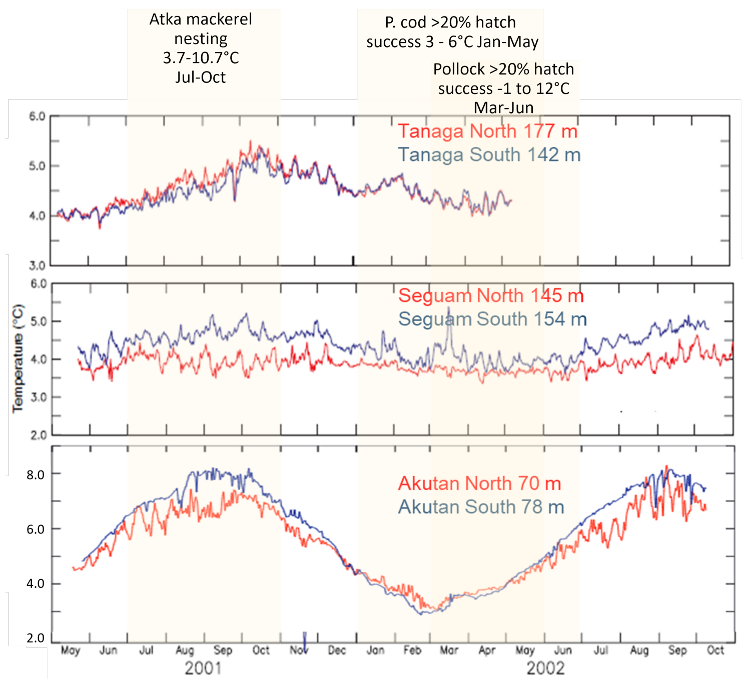

Figure 7: Bottom temperature from moorings at Tanaga, Seguam and Akutan Pass from May 2001 - October 2002 (May 2002 for Tanaga Pass) with nesting/ egg hatching period highlighted for Atka mackerel, Pacific cod (P. cod) and pollock.

The only bottom temperatures available during egg development for Pacific cod, walleye pollock and Atka mackerel. come from moorings in the Aleutian Islands and are not routinely available. However, they are useful to help interpret the data that is regularly available: 1) bottom temperature from the biennial summer bottom trawl survey, and 2) daily satellite surface temperature for the eastern, central and western Aleutians (for details on data see page 39). Based on bottom temperature time series for 2001-2002 from moorings at (west to east) Tanaga, Seguam, and Akutan Pass (Figure 7), we note three aspects: i) Seasonal variability changes with depth, longitude and differs north and south (warmer) of the islands; ii) the warmest temperatures are typically in September and October, past the summer survey, and iii) the coldest temperatures occur between February and April.

A closer look at mooring temperatures at different depths in Akutan Pass in 2002 (Figure 8) shows temperatures can differ within tens of meters, particularly towards the surface. Temperatures at 15 meters can be close to 2°C warmer than those at 65 m. When comparing the mooring-based temperatures to the corresponding satellite sea surface temperatures in the eastern Aleutians, the range of satellite-derived temperatures is bigger than that from the mooring, largely due to the difference between surface and 15 m depths, but also the large area covered by the satellite estimate as opposed to the point estimate of the mooring. Still, the satellite SST is useful in providing a proxy for the seasonal change of temperatures and offers a buffered estimate of the maximum temperatures fish may experience closer to the surface.

With this context, we now consider the temperatures collected during the biennial bottom trawl survey for 2002. The overall sea surface temperature had a mean $5.6°$C with a range of 4.1-$9.7°$C (from 06/08/2002 to 08/13/2002). From the daily sea surface temperature we can get the actual maximum in that year, not captured during the survey but it does provide a maximum (not actual) temperature for shallow areas. For bottom temperatures, the survey had a mean of $4.3°$C and a range of 3.3 to $5.2°$C, where again we should consider the maximum bottom temperature in September October, will be above the survey maximum, and warmer at depths shallower than those sampled by the survey (typically >30 m). The overall bottom temperatures in the entire survey time series reached a maximum of $6.6°$C in 2016 and a few locations in 2022, so the temperatures might have reached 7-$8°$C in October, September. Winter temperatures can be expected to be similar or below the maximum summer survey temperatures.

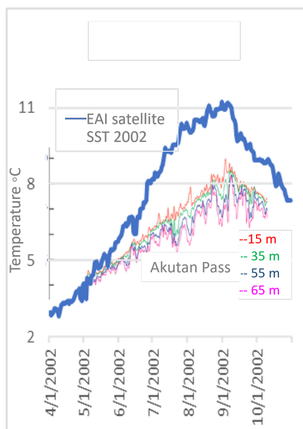

Figure 8: Bottom temperature from mooring Akutan Pass from April 2002 - October 2002 at different depths and satellite-derived daily sea surface temperature for the Aleutian Islands April 2002- October 2002

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Changes in Pacific cod diet

The Alaska Fisheries Science Center Trophic Interactions Lab routinely analyzes stomach samples collected during the biennial bottom trawl survey for the Aleutian Islands. To evaluate changes in prey availability for Pacific cod, we conducted a preliminary analysis of cod stomachs for fish between 30 and 85 cm in length that were collected from survey strata within NMFS areas 541, 542 and 543, as well as east of Samalaga Pass on north side of the eastern Aleutians in areas 518 and 519 (Figure 9). Samples were collected in years 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018 and 2022.

We found the ratio of fish to invertebrate prey in diets has changed from a majority of fish in the early portion of the time series to a majority of invertebrates in the later portion (Figure 10). Common fish prey include Atka mackerel, and shelf demersals (typically sculpins) while shrimp and squid are the most common invertebrates.We note Atka mackerel has largely not been substituted by other fish prey. The change in the ratio of fish to invertebrates is seen across the Aleutians west of Samalga Pass but is not evident east of the pass (Figure 12). The trend may be partially influenced by the decrease of Atka mackerel, however it also reflect changes in the availability of prey, as there is an overall trend to a decreased amount of prey consumed as a proportio of predator weight. Other apex groundfish predators feeding on a combination of fish and invertebrates have decreased as well, such as skates, Pacific halibut and arrowtooth flounder (Figure 48).

A large portion of zooplankton in the system is now consumed by East Kamchatka pink salmon and rockfish. East Kamchatka pink salmon has years of alternating abundance with high abundance in odd years, which had a step increase in 2009 and since then, record abundances have been recorded in 2019, 2021 and 2023. Pacific ocean perch and northern rockfish, both of which have increased in the past several years, also consume primarily zooplankton, have a long lifespan, and in general are little preyed-on by other fish, marine mammals or seabirds, thus locking a large a portion of the energy in the ecosystem. Other factors coinciding with a transition to a higher proportion of invertebrates in cod diets are the higher temperatures since 2013–2014. The also coinciding decline in fish condition since 2013–2014 may also be indicative of several interacting factors, including poor prey quality, low availability of prey, density dependence, and increased metabolic rate (Holsman et al., in press).

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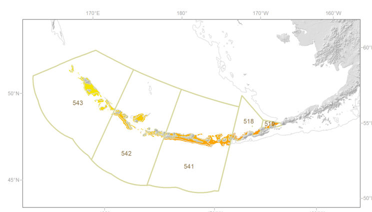

Figure 9: NMFS (green outline) and survey (yellow and orange) strata where stomach samples are collected as part of the Aleutian Islands biennial summer bottom trawl survey.

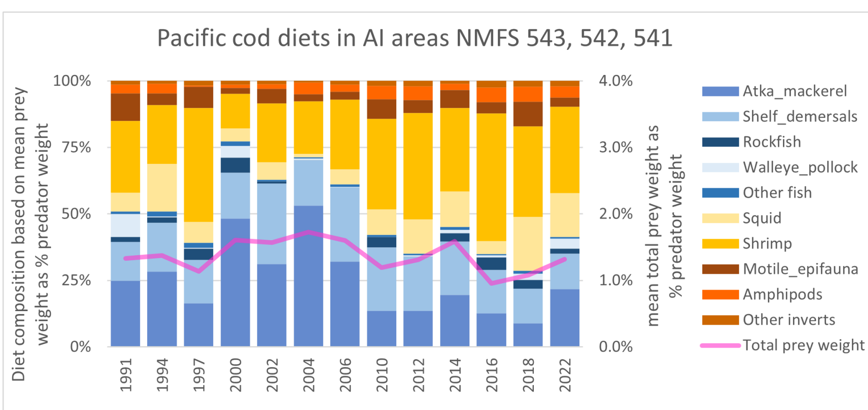

Figure 10: Pacific cod diet in the Aleutian Islands from samples collected NMFS area 541, 542 and 543 as part of the biennial summer bottom trawl survey.

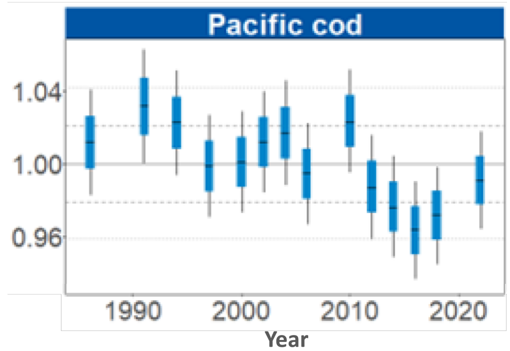

Figure 11: [Biomass-weighted residual body condition index across survey years (1984—2022) for Aleutian Islands Pacific cod collected on the National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) standard summer bottom trawl survey. Filled bars denote weighted length-weight residuals using this year's indicator calculation, error bars denote two standard errors.

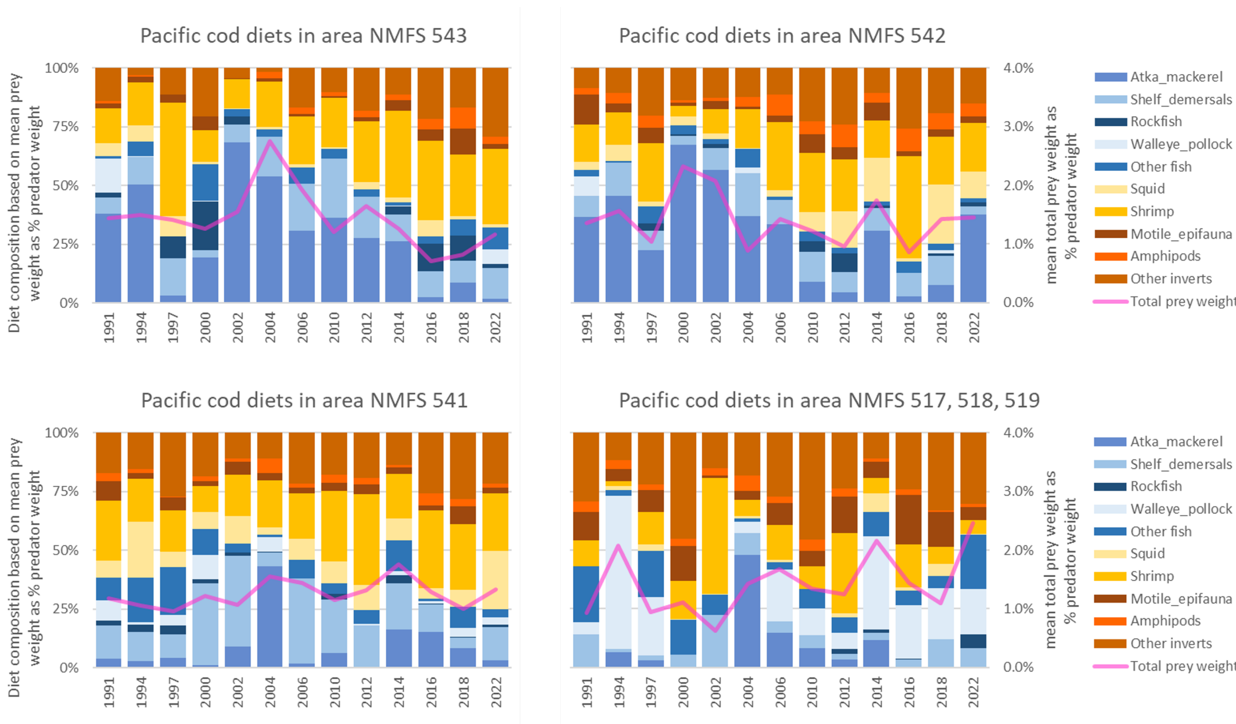

Figure 12: Pacific cod diet in the Aleutian Islands by region: NMFS area 541, 542 and 543 and east of Samalga on the northern portion of the eastern Aleutian Islands (NMFS areas 518, 519) and total mean prey weight consumed as a percent of predator's weight (pink line).

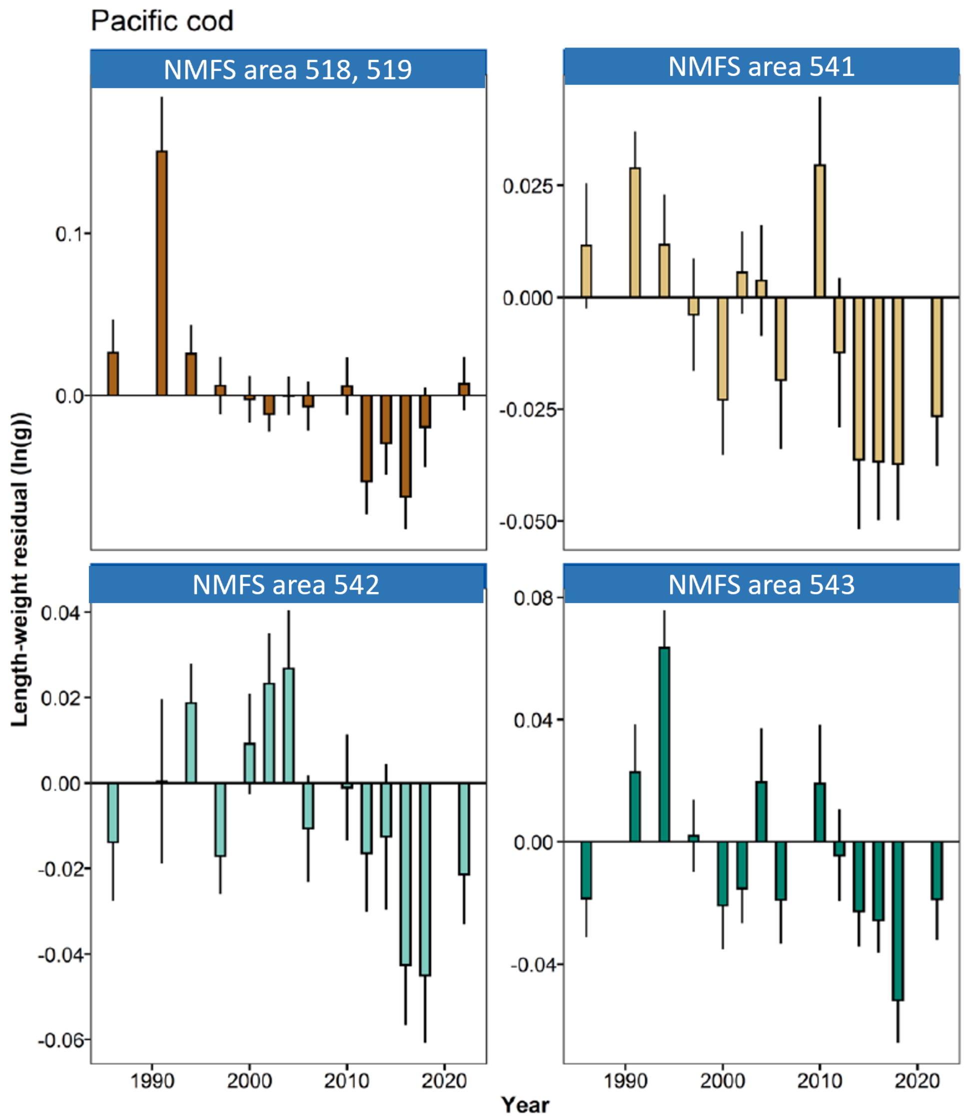

Figure 13: [Biomass-weighted residual body condition index across survey years (1984—2022) and by region for Aleutian Islands Pacific cod collected on the National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) standard summer bottom trawl survey. Filled bars denote weighted length-weight residuals using this year's indicator calculation, error bars denote two standard errors.

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`

Biophysical Synthesis

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Last updated: October 2023

Climate Summary The near-surface waters of the Aleutian Islands were generally warmer than normal from late 2022 into spring 2023 before cooling to near normal to slightly below temperatures during summer 2023. It was relatively stormy during the winter of 2022-23 and summer of 2023. The cooler conditions during 2023 were accompanied by greater upper mixed layer depths than during 2022, which may impact the vertical distribution and availability of prey. Much of the past year included wind anomalies of the sense associated with suppressed northward flow through Unimak Pass. The sea level pressure (SLP) over the mid-latitude North Pacific was generally greater than normal from autumn 2022 through summer 2023. The magnitude and position of the high pressure anomaly center varied seasonally but in general, the SLP anomaly pattern supported westerly wind anomalies for Alaskan waters. The positive SLP anomalies over the North Pacific were accompanied by warmer than normal sea surface temperatures (SSTs) between 30 and $50°$N across the western and central portion of the basin. This warmth extended eastward to near the coast of the Pacific Northwest, and moderated in its intensity in the central portion of the basin, during the summer of 2023. The relatively high SLP in an overall sense, i.e., weak Aleutian low, is consistent with co-occurring conditions in the tropical Pacific, which featured a long-lasting La Niña event ending in the late winter of 2023. The PDO was negative, in large part due to persistent positive SST anomalies in the western and central North Pacific. The climate models used for seasonal weather predictions indicate that El Niño is virtually certain to be present from late 2023 into 2024. In an ensemble sense, the models are also predicting that the first three months of 2024 will include near normal SSTs in the Bering Sea and Aleutian Island regions, and warmer than normal temperatures along the west coast of North America from northern California to the southeast GOA. The development of sea ice on the southeast Bering Sea shelf is liable to be delayed, as has been the rule over the past decade, with sea ice eventually expected to extend approximately as far south as St. Paul Island and Mooring 2.

Climate indices: The NINO3.4 index was negative from spring 2020 into early 2023, with values commensurate with La Niña of moderate intensity during the entirety of 2022, making this the third winter in a row. Conditions transitioned to El Niño in summer. The tendency for a mostly positive state to the NPI since 2020 can be ascribed, in part, to the atmospheric teleconnections associated with the extended La Niña. The systematically positive state of the NPI, i.e., weak Aleutian low, can also be linked to the overall decline in the PDO during the interval. La Niña tends to be accompanied by atmospheric circulation patterns promoting relatively warm waters in the western and central North Pacific and cool temperatures along the west coast of North America. The former feature of the PDO's characteristic SST pattern was prominent in 2022.

Ocean Temperature: Both long-term sea surface temperatures (1900-2023) and satellite sea surface temperature show the 2022-23 winter as one of the warmest on record. Satellite sea surface temperatures across the chain show waters in or near moderate MHW status beginning in winter, fewer heatwaves but temperatures still above average during spring and early summer, and a return to heatwave conditions in late summer. Both summer and winter temperatures have been increasing across the Aleutians, particularly since the 1980s during the summer. These trends show at least a $1°$C increase to date. Sea surface temperatures remained above the baseline mean (Dec 1985-Nov 2015) in all ecoregions. Subsurface water temperatures (101-300 m) from the longline survey in the eastern Aleutians in 2023 were similar in magnitude to those in 2022, continuing an extended period of warmer temperatures than those observed between 2007-2009. Of note, the warmer temperatures at mid-depth (200 m) in the eastern Aleutians, slightly deeper and cooler than the mid-depth warmer waters on the western GOA. The shift to higher temperatures coincides with the 2013-2014 North Pacific regime shift identified in sea surface temperatures by (Xiao and Ren, 2023) and a change in the dominant modes of sea surfce temperature in the North Pacific (Werb and Rudnick, 2023). The increased temperatures can increase metabolic rates, thus increasing the food required by fish. Likewise, higher temperatures have been documented to increase growth rates, and decrease incubation periods and zooplankton development, potentially impacting the phenology of various organisms and increasing the risk for mismatch between hatching/ larval periods and prey/ size spectrum availability.

Ocean transport:Currently, eddy kinetic energy (EKE) in all three regions is either near or below its respective long-term average, with values reaching their historical minima in the eastern Aleutian Islands near Unimak Pass. This concurs with winds suppressing transport to the north at Unimak Pass. The lower EKE suggests decreased heat and nutrient fluxes across all passes.

Primary Production and Zooplankton: Satellite chl-a was below average in the AI for much of spring 2023, the spatial structure of anomalies suggest almost uniformly low chlorophyll across the ecosystem during April-June 2023, with the exception of some small positive anomalies in a small portion of the ecosystem (in the Alaska Stream east of $187°$E, and some areas south of this). Overall mean concentrations are comparable to the previous two lowest years in the observed timeseries, 2016 and 2018. At present (9/12/23), there is evidence for a negative trend in spring AI chl-a across the GlobColour time series, which would indicate a lower productivity since $\sim$ 2011. These trends are being driven by the Alaska Stream and southeastern Aleutian Basin areas, while areas to the west of Bowers Ridge, or south of $\sim 50°$N, do not show trends (data not shown). Annual meso-zooplankton biomass remained negative in 2022 and the copepod community size was negative, while the diatom abundance presented a positive annual anomaly. The copepod community size anomaly has been negative in each season sampled since summer 2016 (apart from 2019 and in 2021) which suggests a real increase in the relative abundance of smaller species, potentially because of warmer than the long term average conditions.

Introduction

We provide an overview of the physical oceanographic conditions impacting the Aleutian Islands, describe conditions observed from fall 2022 through summer 2023, and place 2023 in the context of recent years. The physical environment impacts ecosystem dynamics and productivity important to fisheries within the system and their management. The information has been merged across sources, from broad-scale to local-scale, and is presented as follows:

Outline:

1. Climate Overview: Climate Indices
2. Regional Highlights
3. North Pacific Climate
4. Seasonal Projections of SST from the National Multi-Model Ensemble (NMME)
5. Long Term Sea Surface Temperatures
6. Regional Sea Surface Temperatures
7. Regional Mid Water Temperatures
8. Ocean Transport: Eddies in the Aleutian Islands
9. Primary Production: Satellite chl-a
10. Zooplankton; Continuous Plankton Recorder data

1. Climate Overview

Climate indices provide a 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, with the application of three-month running means, from 2013 into spring/summer 2023 are plotted in Figure 14. Four indices are most relevant to the AI: the NINO3.4, the PDO and the NPI and the NPGO.

The NINO3.4 index was negative from spring 2020 into early 2023, with values commensurate with La Niña of moderate intensity during the entirety of 2022. A return to more normal conditions in the tropical Pacific began in late 2022. Nevertheless, the winter of 2022-23 represented the third La Niña winter in a row; that has occurred just twice before in the last 50 years.

The PDO was negative during 2022 as part of an extended period of negative values beginning in the winter of 2019-20 following its strongly positive state during the major Northeast Pacific marine heat wave of (MHW) of 2014-16. The negative sense to the PDO over the previous 3 years is consistent with the concurrent state of ENSO; La Niña tends to be accompanied by atmospheric circulation patterns promoting relatively warm waters in the western and central North Pacific and cool temperatures along the west coast of North America. The former feature of the PDO's characteristic SST pattern was prominent in 2022.

The state of the Aleutian low can be encapsulated by the NPI, with negative (positive) values signifying relatively low (high) SLP. The NPI was positive during most of 2022 with the strongest anomalies occurring in the boreal fall. The tendency for a mostly positive state to the NPI since 2020 can be ascribed, in part, to the atmospheric teleconnections associated with the extended La Niña. The systematically positive state of the NPI, i.e., weak Aleutian low, can also be linked to the overall decline in the PDO during the interval.

The NPGO has also been relatively persistent, with a long-term but not monotonic decline beginning in late 2012 resulting in consistently negative values since 2017. The negative phase of the NPGO is generally accompanied by 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. There was some moderation in the NPGO during the late winter and spring of 2022, with the resumption of more negative values again late in the year.

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 at a latitude of roughly $45°$N. The AO transitioned from a positive state early in 2022 to a negative state by the end of the year. A negative state to the AO often is accompanied by enhanced outbreaks of arctic air to the middle latitudes of the Northern Hemisphere. That phenomenon was not prominent late in 2022, but that period did include relatively warm weather north of the Arctic circle, especially north of Alaska and the Canadian Archipelago.

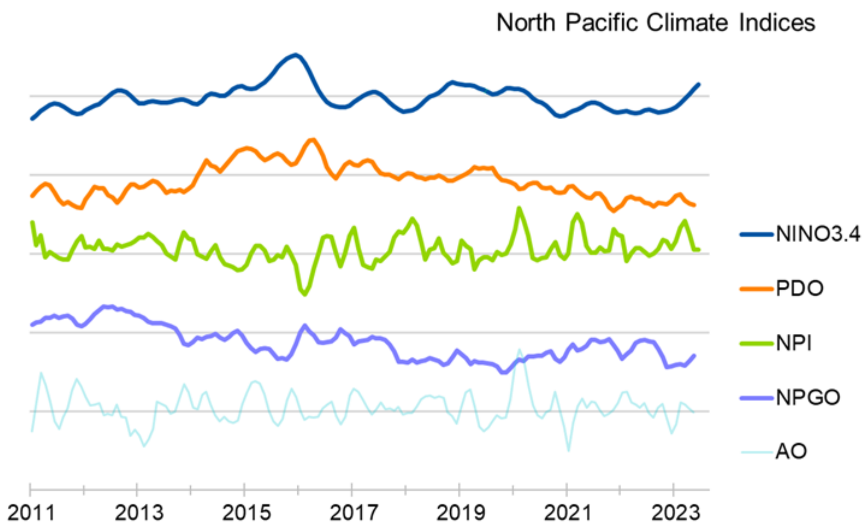

Figure 14: Time series of the NINO3.4, PDO, NPI, NPGO, and AO indices (ordered from top to bottom) for 2011–2023. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 5 standard deviations. More information on these indices is available from NOAA's Physical Sciences Laboratory at `https://psl.noaa.gov/data/climateindices/`.

2. Regional Highlights

Aleutian Islands. The near-surface waters of the Aleutian Islands were generally warmer than normal from late 2022 into spring 2023 before cooling to near normal to slightly below temperatures during summer 2023. It was relatively stormy during the winter of 2022-23 and summer of 2023. The cooler conditions during 2023 were accompanied by greater upper mixed layer depths than during 2022. Much of the past year included wind anomalies of the sense associated with suppressed northward flow through Unimak Pass..

Gulf of Alaska. The GOA underwent changes of the opposite sense from temperatures near to slightly above in autumn 2022 to 0.5-$1.0°$C below normal in summer 2023. This cooling can be attributed to relatively high SLP south of the GOA resulting in westerly wind anomalies and equatorward Ekman transports during the winter of 2022-23 through spring 2023. The summer of 2023 included somewhat stormy conditions in the western GOA. The freshwater discharges from mainstem rivers, such as the Alsek and Copper River, into the GOA were elevated during the fall of 2022 and mostly near normal during spring and summer 2023.

Alaska Peninsula. The coastal waters in the vicinity of the Alaska Peninsula were cooler than normal, based on averages for the period of 1991-2020, from autumn 2022 through summer 2023. These cool temperatures during the winter of 2022-23 were associated to the relative lack of mild maritime air masses due to a westward displacement of the stormtrack; these conditions were maintained by wind anomalies from the northwest during early spring 2023.

Bering Sea deep basin. Stormy weather prevailed for the deep basin of the Bering Sea during autumn 2022 through the following winter. After a relatively quiet spring, the summer of 2023 also featured active weather. One consequence of the autumn and winter storms was slightly less seasonal cooling than usual in that those storms generally result in periods of mild, maritime versus cold, continental air masses. The wind anomalies were from the west during spring 2023, resulting in equatorward Ekman transports and little change in the SST anomalies despite the calmer weather.

3. North Pacific Climate

North Pacific Sea Level Pressure and Sea Surface Temperature Anomalies contributed by Nick Bond

The state of the North Pacific climate from autumn 2022 through summer 2023 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 1991–2020. The SLP data are from the NCEP/NCAR Reanalysis project; the SST data are from NOAA's Extended SST V5 (ERSST) analysis. Both data sets are made available by NOAA's Physical Sciences Laboratory[7](PSL).

Status and Trends: The SLP pattern during autumn (Sep-Nov) of 2022 (Figure 15a), featured a band of strongly positive anomalies extending across the entire North Pacific north of about $35°$N, with a center of about +4 millibars (mb) located south of the Alaska Peninsula. Negative SLP anomalies were present from eastern Siberia into the Chukchi Sea. This SLP distribution resulted in wind anomalies of $\sim$ 2 m s-1 from the west across the Bering Sea, and easterly wind anomalies of 2-3 m s-1 between $35°$ and $45°$N in the central and eastern North Pacific.

During winter (Dec-Feb) of 2022-23, there were positive SLP anomalies over the central North Pacific, with an anomaly center near $40°$N, $150°$W (Figure 15b). Lower than normal SLP occurred over eastern Siberia into the western Bering Sea. The associated winds included westerly anomalies of 2 to 3.5 m s-1 from the southern Sea of Okhotsk through the eastern Aleutian Islands, and a clockwise sense of the anomalies in the GOA. These winds were accompanied by anomalous upwelling in the coastal GOA, and downwelling in the central, deep water portion of the GOA. Anomalous winds from the north were present off the coast of western North America.

Strongly positive SLP anomalies developed over the western and central North Pacific during the spring (Mar-May) of 2023 (Figure 15c), with magnitudes exceeding 7 mb south of the Aleutian Islands. This SLP distribution resulted in westerly wind anomalies of roughly 2 m s-1 across most of the Bering Sea, northwesterly wind anomalies of 2-3 m s-1 in the western and central GOA, and easterly wind anomalies of 3-4 m s-1 in the central portion of the North Pacific between $35°$ and $45°$N. Near averagw winds occurred along the west coast of North America

The summer (Jun-Aug) of 2023 reflected a transition from a prominent high SLP anomaly during the previous season to a dipole over the western North Pacific with lower than normal SLP extending from the Sea of Okhotsk to the west coast of mainland Alaska, and higher than normal SLP south of $40°$N (Figure 15d). The region between these two SLP anomaly centers experienced southwesterly wind anomalies of 2-3.5 m s-1. The positive SLP anomalies over the eastern GOA extending southward were accompanied by lower than normal precipitation for the coastal region from SE Alaska to the Pacific Northwest.

SST Status and trends: The autumn (Sep-Nov) of 2022 featured a broad band of warmer than normal SST that extended across the entire North Pacific (Figure 16a), with anomalies exceeding $2.5°$C near $40°$N and the dateline. Cooler water relative to seasonal norms was present in the Sea of Okhotsk and the eastern Bering Sea shelf. The central and eastern tropical Pacific was cooler than normal in association with moderate La Niña conditions.

[7] `https://www.psl.noaa.gov/cgi-bin/data/composites/printpage.pl`

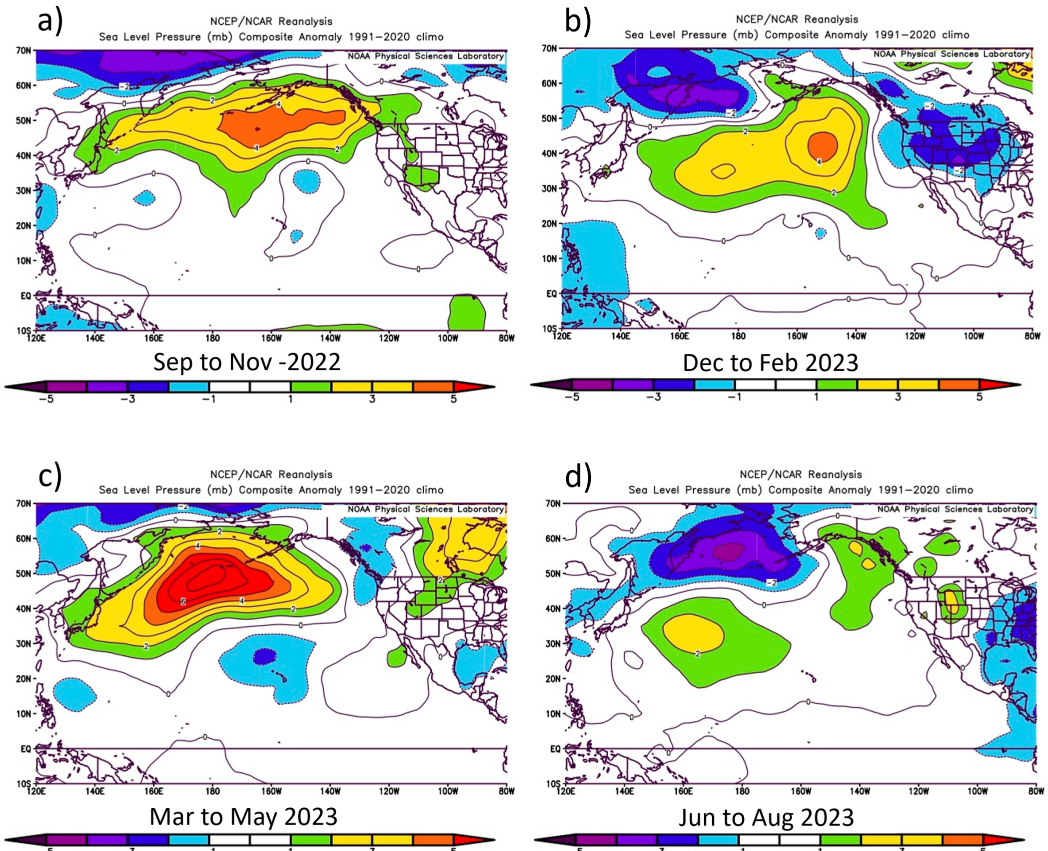

Figure 15: Left, right, top to bottom: SLP composite anomalies (hPa) 1991-2020 climo for a) autumn (September-November 2022), b) winter (December 2022-February 2023), c) spring (March-May 2023), d) summer (June-August 2023)

The positive SST anomalies in the central North Pacific persisted through the winter (Dec-Feb) of 2022-23 (Figure 16b), with moderation in the warm temperatures in the western North Pacific. During this season, Alaskan waters were mostly within $0.5°$C of normal. La Niña weakened, with only a small region of water $1°$C cooler than normal near the dateline in the equatorial Pacific.

A band of warm water centered along $40°$N across all but the far eastern portion of the North Pacific was present during spring (Mar-May) of 2023 (Figure 16c). Regions of cooler water reappeared in the Sea of Okhotsk and on the eastern Bering Sea shelf. The tropical Pacific had mostly near-normal SSTs with the exception of the immediate vicinity of the coast of South America, where positive anomalies began developing.

The summer (Jun-Aug) of 2023 brought marked moderation of the positive SST anomalies in the central North Pacific between $30°$ and $50°$N but also an eastward extension of warm anomalies to the Pacific Northwest coast. This season also included a continuation of cool conditions in the eastern Bering Sea, the development of slightly negative SST anomalies in the western GOA, and cool SSTs southwest of Baja California into the subtropical eastern North Pacific (Figure 16d)). The tropical Pacific featured strong warming east of $140°$W, with the SSTs meeting the threshold for El Niño in June 2023, according to NOAA's Climate Prediction Center (CPC).

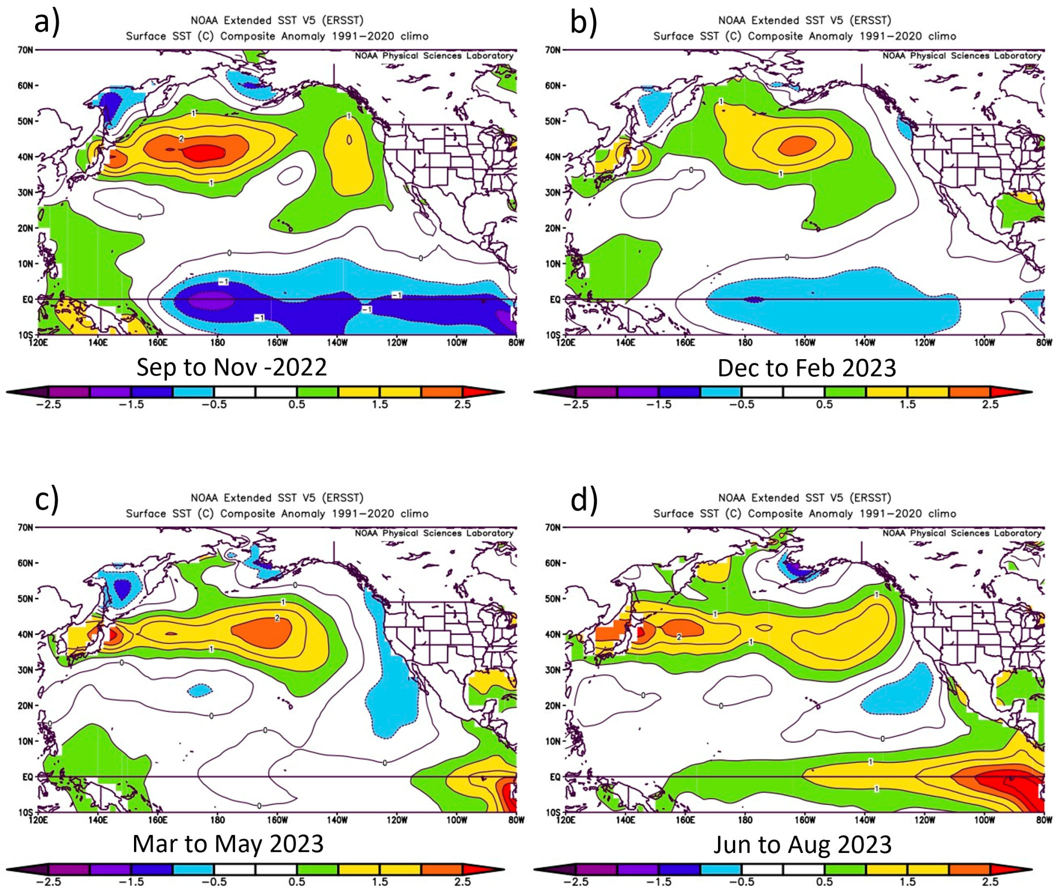

Figure 16: Left, right, top to bottom: SST composite anomalies 1991-2020 climo for a) autumn (September-November 2022), b) winter (December 2022-February 2023), c) spring (March-May 2023), d) summer (June-August 2023)

4. Seasonal Projections of SST from the National Multi-Model Ensemble (NMME)

Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 17a–c. An ensemble approach incorporating different models is 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 National Weather Service Climate Prediction Center[8].

Status and Trends: : These NMME forecasts of three-month average SST anomalies indicate a continuation of El Niño in the tropical Pacific and a large region of relatively warm water in the central and western North Pacific between 30 and $50°$N through the end of the calendar year (Nov 2023-Jan 2024; Figure 17). Positive temperature anomalies are also predicted for the western Aleutian Islands, and coastal Alaskan waters extending from the southeast Bering Sea shelf to the Beaufort Sea. The models also are indicating an atmospheric circulation pattern that would bring reduced storminess to the GOA (not shown). The ensemble of model predictions for January through March 2024 (Jan-Mar 2024; Figure 17) shows some moderation in tropical Pacific temperatures but still enough warmth to constitute El Niño. As is typical with these events; the projections show warming in the

[8] `http://www.cpc.ncep.noaa.gov/products/NMME/`

coastal zone of the eastern GOA. Moderation is indicated in the warm anomalies elsewhere in the coastal regions of Alaska. The projections for March through May of 2024 (March-May 2024; Figure 17) indicate continued decreases in tropical Pacific SST anomalies. On the other hand, substantial warming is forecast for the GOA and northern Bering Sea. It bears mentioning that the individual model predictions yield rather consistent outcomes for the GOA but range from near-normal to moderately above normal temperatures for the southeast Bering Sea shelf. Nevertheless, these solutions also indicate conditions should not be extreme relative to the past 20-30 years with the result that sea ice should extend south of $60°$N perhaps all the way to M2, and as far south as Bristol Bay along the coast. The retreat of the sea ice on the southeast Bering Sea shelf in the spring of 2024 is apt to occur earlier than usual.

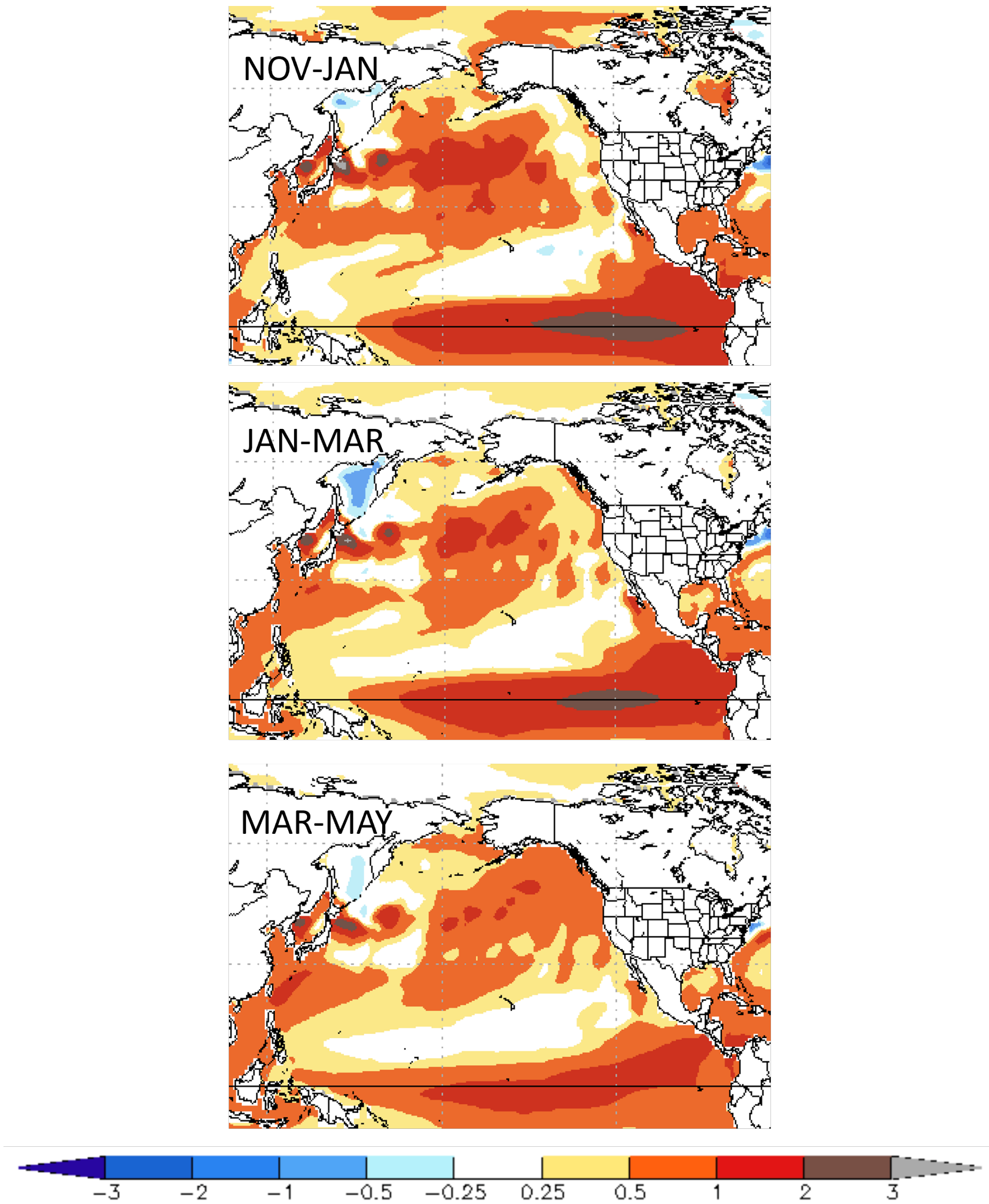

Figure 17: Predicted SST anomalies (°C) for (top to bottom): Nov-Jan 2024 (1 month lead), Jan-Mar 2024 (3 month lead), and Mar-May (5 month lead) from the National Multi-Model Ensemble (NMME) of coupled atmosphere-ocean climate models

5. Regional Long-term Sea Surface Temperature

Sea surface temperatures in the Aleutian Islands can be calculated using NOAA's Extended Reconstructed SST V5 data [9]. ERSST is a global monthly sea surface temperature dataset produced at 2 x 2 resolution starting in 1854. Statistical processes are used to to infill data sparse/missing areas and standardize the many ways that ocean surface temperatures have been collected and reported over the decades. However, known problems remain, especially pre-1900 and in the WW2 era and in general in Arctic and Southern Oceans. Constrained B-Spline regression used here is a form of nonparametric quantile regression using quadratic splines. This approach allows for conditional estimates of any quantile of interest. Initial analyses examined eastern, central nd western AI separately, but regions were combined due to reduced subregional sample sizes and similar trends across the three ecoregions.

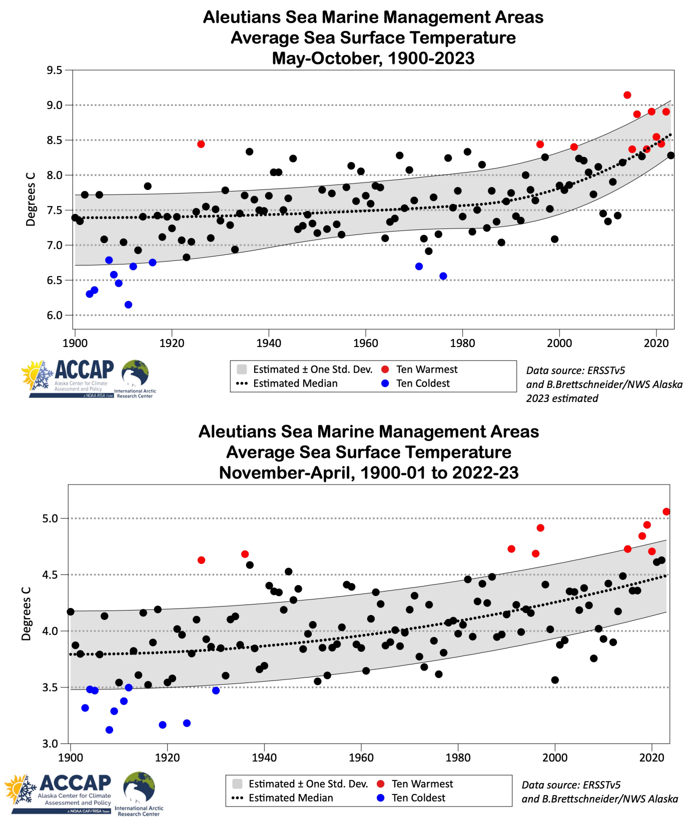

Figure 18: Sea surface temperatures for the Aleutian Islands from 1900–2023 for (a) summer (May–Oct) and (b) winter (Nov–Apr). Presented here are the quantiles representing ± 1 standard deviation of a Gaussian distribution and for completeness the median calculated using constrained B-Spline regression.

Status and Trends: Summer (May–Oct) sea surface temperatures (Figure 18 over the Aleutian Islands show a warming during the first decades of the 20th century followed by an extended period of little long-term trend, with substantial warming resuming in the late 1990s. Likewise, winter (Nov–Apr) temperatures show a significant trend over the past 123 years, with this past winter being the warmest on record.

The surface waters in the Aleutian Islands have been warming since 1900. This analysis provides context for the short-term sea surface temperature time series presented elsewhere in this report (see Sea Surface Temperature, p.39). The seasonal difference in warming trends is not determined but could be due to changes in stratification, precipitation and freshwater runoff, cloud cover, circulation or other oceanographic and atmospheric drivers.

[9] `https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html`

'Above' or 'below' average surface temperatures, as reported in shorter-term time series in this report, may have different meaning if considered relative to the longer-term time series presented here. The thermal responses of species in the Aleutian Islands marine ecosystem must be considered in terms of these longer-term shifts in temperature, to understand better their response to changing temperatures. Research on species-specific thermal ranges can also help interpret potential implications of continued warming of this marine system.

6. Regional Sea Surface Temperature and Marine Heatwaves

Sea surface temperature is a foundational characteristic of the marine environment and temperature dynamics can impact many biological processes. Changes in temperatures can influence physiological processes of fish (e.g., metabolic rates and growth rates), fish distribution (e.g., (Yang et al., 2019), trophic interactions, availability of spawning habitat (e.g., Laurel and Rogers, 2020), and energetic value of prey (von Biela V. R. et al., 2019). At shorter timescales of days-to-weeks, changes in water temperature can also influence predator-prey interactions (Sydeman et al., 2006), feeding rates (Sanford, 2002; Clements et al., 2020), and food web composition (Barth et al., 2007). Extended periods of elevated SST for greater than 5 consecutive days are defined as marine heat waves (MHWs), which can drastically influence ecosystem dynamics (Bond et al., 2015; Hobday et al., 2016). Here, trends in SST and MHWs throughout the Aleutian Islands ecosystem regions are presented (Figures 19). Note that high SST can be indicative of a shallow surface layer (high surface temperature, even if a relatively moderate or low overall heat content integrated over the full water depth), and/or high temperatures throughout the water column.

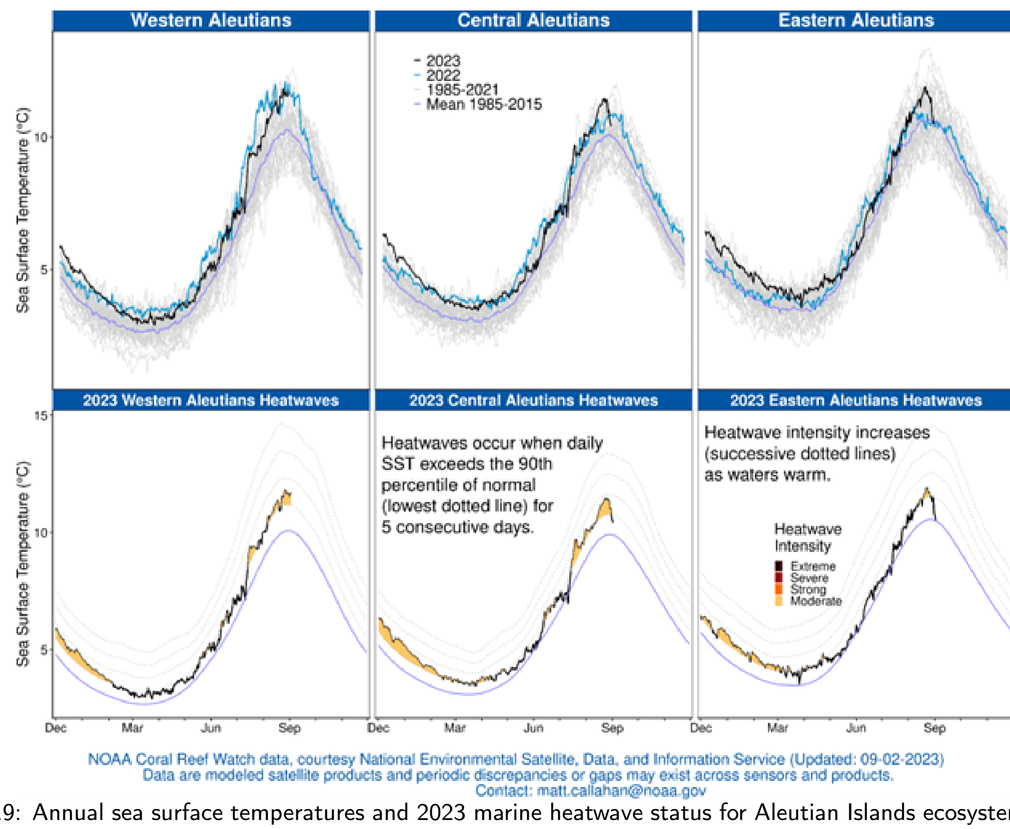

Figure 19: Annual sea surface temperatures and 2023 marine heatwave status for Aleutian Islands ecosystem regions. Data extends through September 2, 2023.

Satellite SST data (source: NOAA Coral Reef Watch Program) were accessed via Alaska Fisheries Information Network (AKFIN) database for January 1, 1985 - September 2, 2023. Daily SST data were averaged within the western (west of $177°$W), central ($170°$W–$177°$W), and eastern ($165°$W–$170°$W) Aleutian Islands. The earliest complete 30-year time series (December 1, 1985 – November 30, 2015) was used as the baseline period for mean and standard deviation comparisons (see (Hobday et al., 2018; Schlegel et al., 2019) for discussions of baseline choices). Annual SST time series are apportioned from December of the previous year through November so that the winter season (Dec–Feb) for each year can be consistently aggregated. A time series decomposition (i.e., seasonality and noise removed;(Edullantes, 2019)) is also provided to better illustrate the long-term trends in SST data (Figure 20). Detailed methods are online [10].

Warm water events have become so frequent in the world's oceans that a new method for describing them has been formalized and is widely used (Hobday et al., 2016). A MHW occurs 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. When the threshold is exceeded, the event is considered moderate, strong (2 times the difference between the threshold and normal), severe (3 times the difference), or extreme (4 times the difference; Hobday et al. 2018). MHW indices were developed using the heatwaveR package (Schlegel and Smit, 2018). New this year, we also use MHW status at a 5x5 km resolution (source:https://coralreefwatch.noaa.gov/product/marine_heatwave/, aggregated within the AKFIN database) to examine the spatial extent of heatwaves within each region throughout the year.

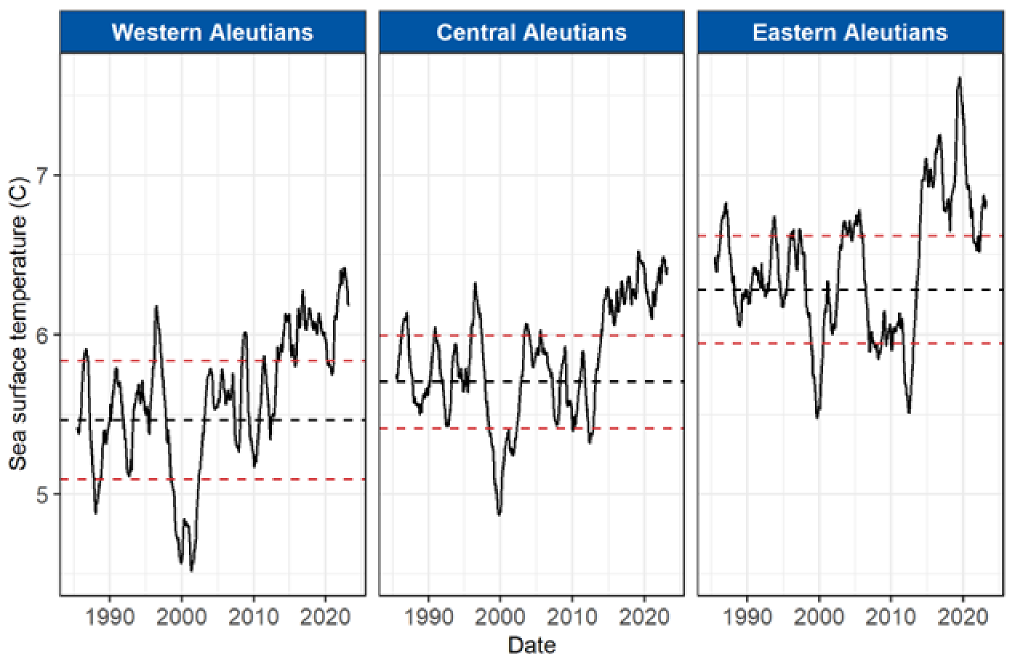

Figure 20: Time series trend (i.e., seasonality and noise removed) of sea surface temperatures. Horizontal dashed lines represent the mean (black) and standard deviation from the mean (red) during the earliest complete 30-yr baseline period (1985-2014). The trend is an annual moving average, with the latest date in March 2023, thus the current marine heatwave is not detected in this plot

Status and Trends: All three Aleutian regions experienced a warm 2023 with waters in or near moderate MHW status beginning in winter, fewer heatwaves but temperatures still above average during spring and early summer, and a return to heatwave conditions in late summer (Figure 19).

Generally, all three regions have trended towards anomalously warm (>1 standard deviation from the long term mean) conditions over the last 10 years (Figure 20).

[10] github.com/MattCallahan-NOAA/ESR-ESP/tree/main/SST/

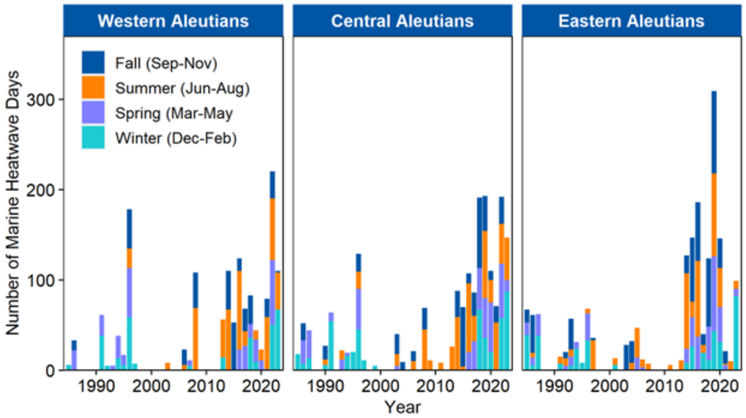

Figure 21: Number of days during which marine heatwave conditions persisted in a given year. Seasons are summer (Jun–Aug), fall (Sept – Nov), winter (Dec – Feb), spring (Mar – Jun). Years are shifted to include complete seasons so December of a calendar year is grouped with the following year to aggregate winter data (e.g., Dec 2020 occurs with winter of 2021). Data extends through Sep 2, 2023.

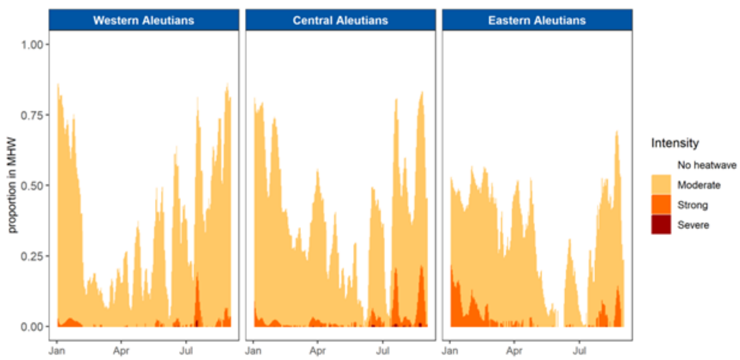

Figure 22: Proportion of region in heatwave status. Heatwave status calculations were performed on each 5 x 5 km grid cell within the Aleutian Islands. This figure shows a five day rolling average of the proportion of cells within each region that are in MHW status

MHWs have occurred periodically throughout the SST time series but with greater frequency during the last decade (Figure 21). MHWs may occur when a large portion of a region is in moderate heatwave status, or when a smaller portion of a region is in a higher MHW category. At times during winter and late summer over $\frac{3}{4}$ of the central and western Aleutians were in MHW status (Figure 22). MHWs in the eastern Aleutians tended to be triggered by warm water in a smaller portion of that region.

Factors influencing observed trends: Many factors can influence SSTs and the formation of MHWs, including a suite of weather, climatic, and oceanographic factors (Holbrook, 2019). Meanwhile, defining or contextualizing MHWs depends upon the selection of baseline years (1985–2014). As long term climate change leads to warmer temperatures, the baseline will change as well, requiring consideration of how baseline selection affects our interpretation of deviations from normal and thus, events like MHWs (Jacox et al., 2019; Schlegel, 2019). The more warm years that are included in the baseline, the warmer that baseline will appear.

Implications: Barbeaux et al. (2020) demonstrated that marine heatwaves impact Pacific cod populations and during recent warm years, the Gulf of Alaska has seen record low returns for several salmon stocks. Meanwhile, growing evidence supports the notion of temperature driven northward range shifts. While we do not connect SST to fish production here, continued warm periods are concerning for the predictability of fish populations and recruitment.

7. Mid-Water Temperatures

Contributor Kevin Siwicke

LONGLINE SURVEY

Subsurface temperature can be a useful indicator for tracking long term ecosystem trends (i.e., static, cooling, or warming). The Alaska Fisheries Science Center (AFSC) has been conducting an annual longline survey since 1987 to sample groundfish from the upper continental slope annually in the Gulf of Alaska, during odd years in the Bering Sea, and during even years in the Aleutians. More details related to this survey can be found in Siwicke (2022). Beginning in 2005, a temperature (depth) recorder (TDR SBE 39 (Seabird Electronics) has been attached directly to the middle of the longline, with a second TDR being attached deeper starting in 2019. The TDR records water temperature and depth every 10 seconds, and the downcast is processed to 1-m increments via the double parabolic method used by the World Ocean Atlas 2018 ((Reiniger and Ross, 1968; Locarnini et al., 2019).

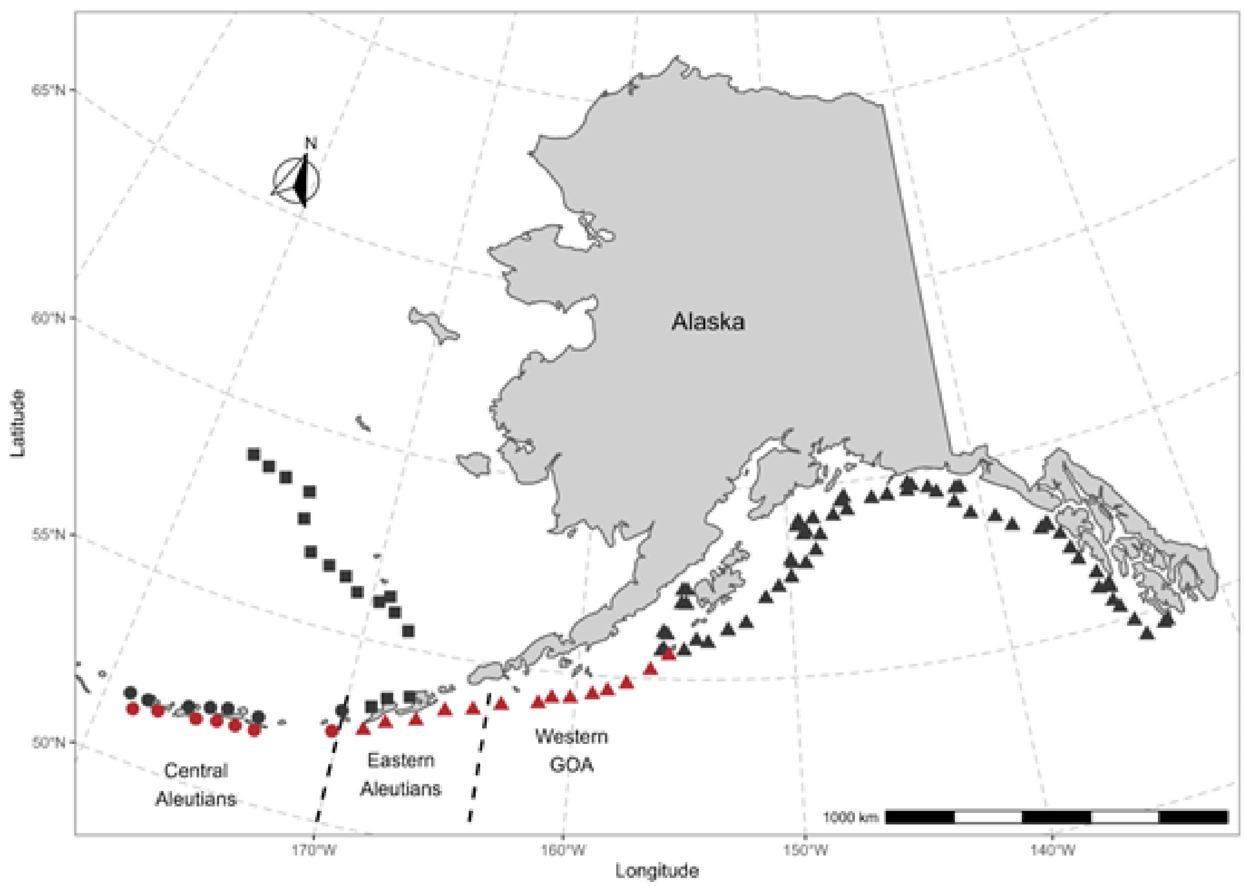

Figure 23: Longline survey in the Bering Sea (squares, odd years), the Aleutians (circles, even years) and GOA (triangles, every year). Stations shown in red are the ones used for the longitudinal comparison of mid-depth temperature from $180°$W to $154°$W

There are 22 stations sampled by the AFSC longline survey located within the Aleutians ESR region (14 in the central Aleutians and 8 in the eastern Aleutians, Figure 23). In even years, sampling begins from east to west on the north of the central Aleutian Islands, then west to east on the south of the central Aleutian Islands. Every year, four stations are sampled on the south of the eastern Aleutians Islands and continue to the Gulf of Alaska. Here we include the stations sampled south of Aleutians through the western GOA from 180°W to 154°W (Figure 23) for a longitudinal comparison of mid-water temperature along the continental slope (Figure 24).

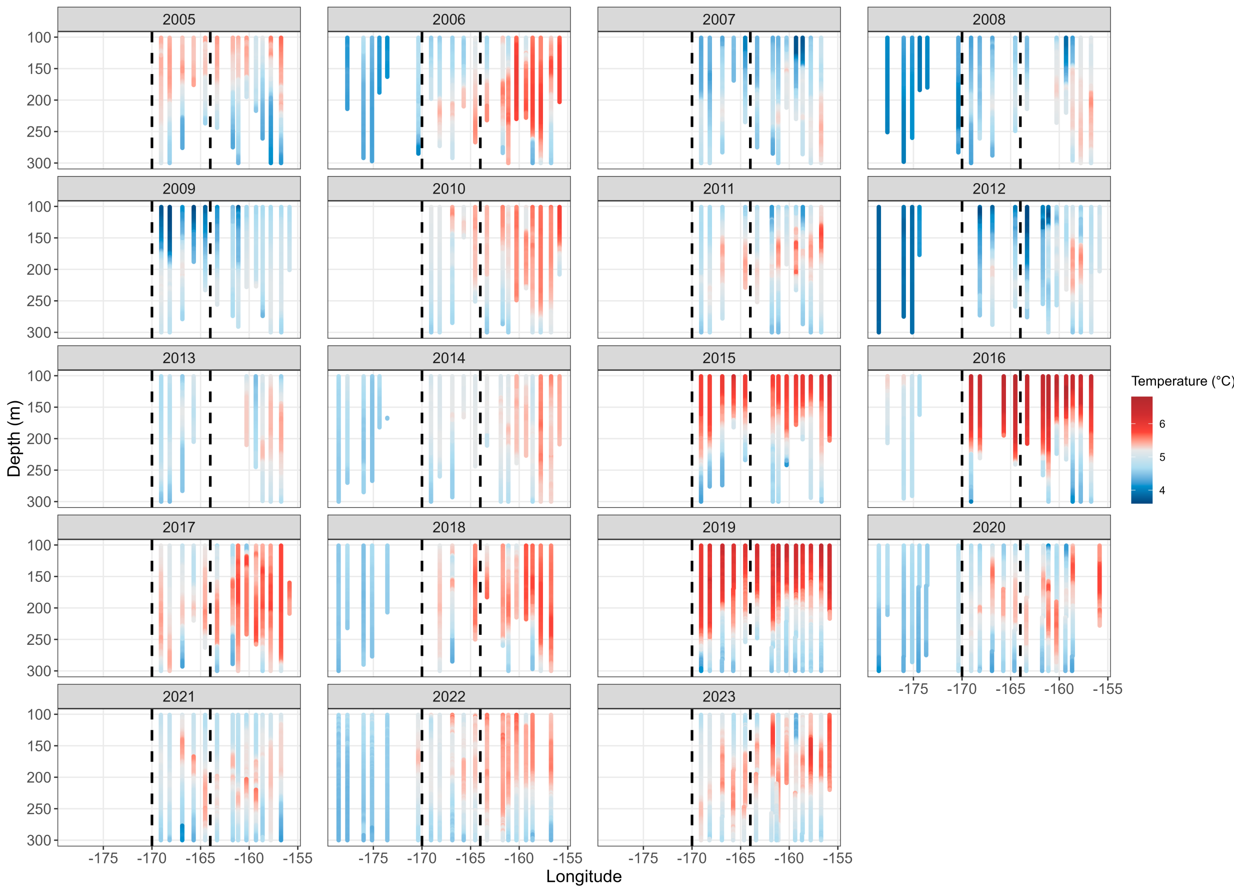

Figure 24: Temperature depth profiles (101–300 m) longitudinally along the continental slope for stations sampled during the first two legs of the longline survey and south of the Aleutian Chain. Vertical dashed lines at 170°W (-170) denote the boundary between the central and eastern Aleutians and 164°°W (-164) denotes the boundary between the eastern Aleutians and western Gulf of Alaska.

Status and trends: Longitudinal cross sections of temperature from 101-300 m depth along the continental slope south of the Aleutians show how water masses interact in this region (Figure 24). These temperature profiles are a snapshot from the month of June, and do not capture many of the dynamics of this region; however, they are representative of the thermal conditions that the survey experienced. As expected, there is a temperature gradient from east to west with colder temperatures towards the west. Although temperatures warmer than 6°C reached deeper than 100 m in the GOA during the 2014-2016 heatwave, this does not seem to be the case for water west of 170-172°W coinciding with Samalga and Amukta Passes (the easternmost deep wide pass) which are believed to be a biogeographical boundary (particularly the first one). This is most evident in 2020 when temperatures around 5°C were recorded east but not west of 172°W. However, waters west of 170-172°W seem to have remained warmer than temperatures seen in 2012 and earlier. Subsurface water temperatures in 2023 were similar in magnitude to 2022, continuing an extended period of above average temperatures. Note the warmer temperatures at mid-depth (200 m) in the eastern Aleutians, slightly deeper and cooler than the mid-depth warmer waters on the western GOA.

Factors influencing observed trends: Colder temperatures above warmer waters at 200 m were recorded through 2009 and in 2012, however this pattern changed in 2013 and seems to have remained.

Implications: Changes in vertical distribution of temperatures can affect vertical distribution of groundfish, impacting their availability as prey, but also their impact as predators. Changes in the vertical distribution of temperature can also create a mismatch between preferred seafloor habitat characteristics and preferred temperatures. The changes in temperature in general can affect primary and secondary productivity, which combined with changes in vertical distribution of groundfish can have cascading effects through the food-webs for fish, seabirds and marine mammals

8. Ocean Transport: Eddies in the Aleutian Islands

Contributed by Wei Cheng

Description of indicator: Eddy kinetic energy can be used as an index of strength and frequency of eddies. Three regions of high eddy kinetic energy are highlighted in Figure 25. Eddies in the Alaskan Stream south of the Aleutian Islands and east of $\sim 180°$ (easternmost box in map figure) have been shown to influence flow into the Bering Sea through the Aleutian Passes (Okkonen, 1996; Stabeno and Hristova, 2014). Numerical models have suggested that eddies passing near Amukta Pass may result in increased flow from the Pacific to the Bering Sea (Maslowski et al., 2008). By influencing flow through the passes, eddies can impact flow in the Aleutian North Slope Current (Stabeno et al., 2009) and Bering Slope Current (Ladd, 2014) as well as influence the transports of heat, salt and nutrients (Mordy et al., 2005; Stabeno et al., 2005) into the Bering Sea. Eddies north of the Aleutian Islands (middle box in map, Figure 25) typically form in the Bering Slope Current near Pribilof Canyon and propagate southwestward toward Amchitka Pass (Ladd et al., 2012). They are typically weaker than those in the Alaskan Stream but may play a role in modulating flow through Amchitka Pass. Eddies formed west of 180° are called Aleutian Eddies (westernmost box in Figure 25). They typically form near the Aleutian Islands and then move southwestward away from the Aleutians (Saito et al., 2016) potentially influencing the distribution of phytoplankton and zooplankton (Saito et al., 2013) during their propagation.

Since 1992, a suite of satellite altimetry system has been monitoring sea surface height. Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (Ducet et al., 2000). Average EKE in the three regions WAI, CAI, and EAI provides indices of eddy energy likely to influence flow through the passes as well as phytoplankton and zooplankton distributions. The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS)[11].

The most recent data were downloaded on September 7, 2023 so we have daily time series from 1/1/1993 to 9/07/2023 on a $0.25°$ longitude x $0.25°$ latitude grid. Original data is global but we subset it to $150°$E-$125°$W and $40°$N-$72°$N during download. Data from 1993 to 2020 is from the delayed/re-processed product whereas data from 2021 onward is from the "NRT" (near real time) products. Horizontal map (Figure 25) and monthly climatology (Figure 26) shown below are averaged over 1993-2022 (period with full year coverage).

Status and trends: In the western Aleutian Islands, (Figure 26, top panel), EKE since 2020 (2023 included) is near its long-term mean; earlier (later) months of 2023 have EKEs slightly above (below) its long-term average. Over the decadal time period (from 1993 to the present day), EKE was low from 1993 to 2006 when it abruptly increased and remained relatively high until 2012. This region experienced another period of high EKE in 2015–2016 but has been low since 2020.

[11] http://www.marine.copernicus.eu

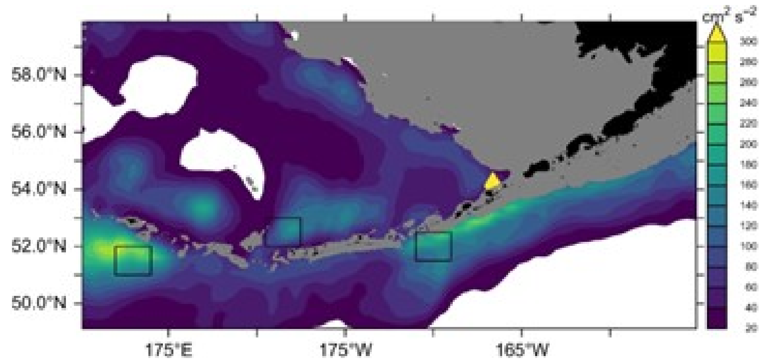

Figure 25: Eddy Kinetic Energy computed from satellite sea surface height (SSH) averaged over January 1st, 1993 – December 31st, 2022. Squares denote regions over which EKE was averaged for Figure 26.

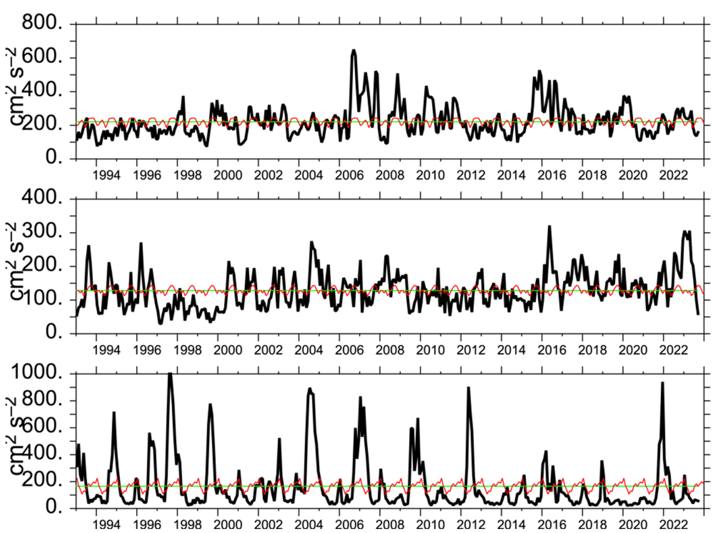

Figure 26: Eddy kinetic energy (cm^2 s^{-2}) averaged over boxes shown in Figure 25 (panels from the top to the bottom correspond to west to east boxes). Plotted are monthly EKE time series over the entire time period (black), monthly climatology of EKE (red) and the long-term mean of EKE (green straight line) averaged in year 1993-2022.

EKE north of the Aleutian Islands near Amchitka Pass in 2022 (Figure 26, middle panel), has generally been above its long-term average since 2016. The strong positive EKE anomalies in this region since late 2021 have continued until almost the present day. Note this area is north of the AI chain and generally has lower EKE than the eastern and western boxes.

Particularly strong eddies were observed south of Amukta Pass (Figure 26, bottom panel) in 1997, 1999, 2004, 2006/2007, 2009/2010, and 2021/2022. The High EKE in this box from mid-2021 to early-2022 is associated with a passing eddy. Presently, EKE in this region is below its climatological seasonal cycle and long-term average.

Factors causing trends: Eddies in the eastern AI are related to the strength of the Alaska Stream (AS) which in turn is forced by large scale atmospheric forcing and the North Pacific gyre. Local wind can push the AS against or away from the coast and change transport in Unimak Pass. Transport and eddies in the western AI passes are less studied/measured. Presumably transport in the western region is highly correlated with the AS. Causes of variability in EKE in this region are currently unclear and a subject of ongoing research. For example, it is unclear whether changes in the time series reflect a long-term trend in the large scale forcing (e.g., wind, NPGO, the latter shows a declining trend since 2011), and it is unknown whether the relationship between mean flow and eddy strength reinforce or counteract each other.

Implications: These trends indicate that higher than average volume, heat, salt, and nutrient fluxes to the Bering Sea through Amukta Pass may have occurred in 1997/1998, 1999, 2004, 2006/2007, 2009, and summer 2012, and 2021/2022. Currently, EKEs in all three boxes are either near or below their respective long-term averages, with values in the eastern Aleutians near Unimak Pass reaching their historical minima.

6. Primary Production: Satellite-derived chl-a

Contributed by Noel Pelland and Matt Calahan,

Description of Indicator: Surface chlorophyll ("chl-a"), often interpreted as a proxy of phytoplankton biomass or abundance in the surface ocean, can be an important indicator for bottom-up ecosystem processes and resources available at the base of the marine food web (e.g., Ware and Thomson (2005)). Previous ESRs for the Aleutian Islands (AI) have highlighted a need to better understand variability in surface chl-a, relationships to large-scale physical changes, and potential significance to the distribution, abundance, and reproductive success of higher trophic level organisms. This indicator focuses on the first of these needs, investigating chl-a in the AI at large spatial and temporal scales, during the spring and fall bloom.

Specifically, we show spatial averages of chl-a in non-coastal areas of the AI, along with spatial patterns of monthly chl-a deviations from climatology. These estimates are constructed from 8-day composite GlobColour [12] 4km chl-a images in April–June (spring) and August-October (late summer/fall), obtained from the NOAA CoastWatch West Coast Regional Node [13] from 1998 to 2023.

Data from each composite image are averaged within Alaska Department of Fish and Game Groundfish Statistical Areas [14] ("SAs"). SAs of area >2500 km2 only are retained for data availability. This excludes data in some shelf areas in the central and eastern Aleutians. Averages within SAs are then used to compute spatial averages across the AI in each 8-day image, along with a composite seasonal cycle of chl-a across years. Confidence bounds for 8-day averages within SAs, monthly anomalies within SAs, and average chl-a across the ecosystem overall, are based on bootstrap sampling of 8-day images that are fully resolved or nearly so.

Status and trends: At present (9/12/23) there is evidence for a negative trend in spring AI chl-a across the GlobColour time series (Figure 27. Using data from 1998 -spring 2023, spring maximum spatial-average AI chl-a has a linear trend of -0.030 mg m^{-3} yr^{-1} (r^2 = 0.22, p = 0.0153, two-sided t-test, 24 DOF), 1998-2023, while spring average chl-a has a trend of -0.016 mg m^{-3} yr^{-1} (r^2= 0.38, p = 0.0013). The p-value for the spring average chl-a takes into account the additional uncertainty in the observations themselves (i.e., confidence intervals around each year's mean spatial-average chl-a). These trends are being driven by the Alaska Stream and southeastern Aleutian Basin areas, while areas to the west of Bowers Ridge, or south of $\sim 50°$N, do not show trends (data not shown).

The available data indicate that chl-a was below average in the AI for much of spring 2023, with overall mean concentrations comparable to the previous two lowest years in the observed time series, 2016 and 2018 (Figure 28a, b). The spatial structure of anomalies suggest almost uniformly low chlorophyll across the ecosystem April-June 2023, with the exception of some small positive anomalies in a small portion of the ecosystem (in the Alaska Stream east of 187oE, and some areas south of this (Figure 28a). Monthly anomalies are mostly significant, reflecting the increased data coverage in the multi-satellite GlobColour composites. In contrast, chl-a was slightly above average, trending towards average in late summer/fall of 2022, similar to concentrations observed in fall of 2021 (Figure 28c, d). Above average chl-a was largely driven by positive chlorophyll anomalies in the western and central AI in August (Figure 28d). In September/October, there were moderate negative anomalies in the center of the ecosystem, and positive anomalies near the periphery (Figure 28e, f).

Factors causing observed trends: Light and nutrient availability, temperature, grazing pressure (Batten et al., 2018), turbulence intensity, and stratification are all significant factors that may affect phytoplankton growth, biomass, and chlorophyll concentrations. There is a significant (p<0.05) positive correlation between NPGO and spring-average AI chlorophyll at lead times 0-12 months (NPGO leading chl), but peaking at 4-6 months (r^2 = 0.36 to 0.39). Therefore, internal climate variability acting through consistent low NPGO values since $\sim$ 2013 (Figure 14) likely has played some role in low chlorophyll values in the AI. The NPGO is associated with salinity

[12] https://www.globcolour.info/
[13] https://coastwatch.pfeg.noaa.gov/data.html
[14] https://www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByFishery.statmaps

and nitrate variability throughout the northeast Pacific, and negative NPGO values strongly correlate with lower nitrate availability in the southeastern AI in multi-decade numerical simulations (Di Lorenzo et al. 2009, their Fig. 3b). Mixing in the Aleutian passes (Mordy et al., 2005) is another mechanism influencing chl-a in the southeast Aleutian Basin, but the observed trends are negative both north and south of the Aleutian chain, suggesting a decrease in nutrient injection at the passes is not the main driver. There is also significant negative correlation between mixed layer depth and chl concentrations in May, within the more limited subset of years with Argo data (not shown), consistent with stormier springs reducing phytoplankton biomass. However, this correlation is also associated more with areas north of the chain. Notably, low chl-a has also been observed in the adjacent off-shelf areas of the Eastern Bering Sea, and shelf areas in the Gulf of Alaska in recent years (see 2023 ESRs). This opens the possibility that there may be recent systematic drivers across the subarctic North Pacific gyre leading to low chlorophyll which have yet to be elucidated.

The contrast between conditions observed in late summer/fall 2022, and spring 2023, is consistent with the lack of interannual correlation in chl-a between these two seasons noted in the 2021 AI ESR. This implies differing factors influencing interannual variability in these two time periods in the AI.

Implications: The continued negative to neutral chl-a anomalies at large scales in the AI spring bloom warrant further monitoring and investigation, especially in regards to potential links with adjacent ecosystems. A strongly above-average spring bloom has not been observed since 2009; mostly negative anomalies are evident since 2016. Elevated SSTs, regional climate-driven changes in nutrient availability, spring weather conditions, and links to higher trophic levels are possible factors that could be investigated.

It should be emphasized that at present, there is very limited understanding as to the bottom-up consequences of lower chl-a for zooplankton, forage fish, seabirds, and marine mammals in the AI. There is a suggestion in neighboring shelf ecosystems that fall chl-a can be important to overwinter survival of young-of-the-year forage fish (Ladd and Stabeno, 2012) but it is unknown if similar relationships occur in the AI.

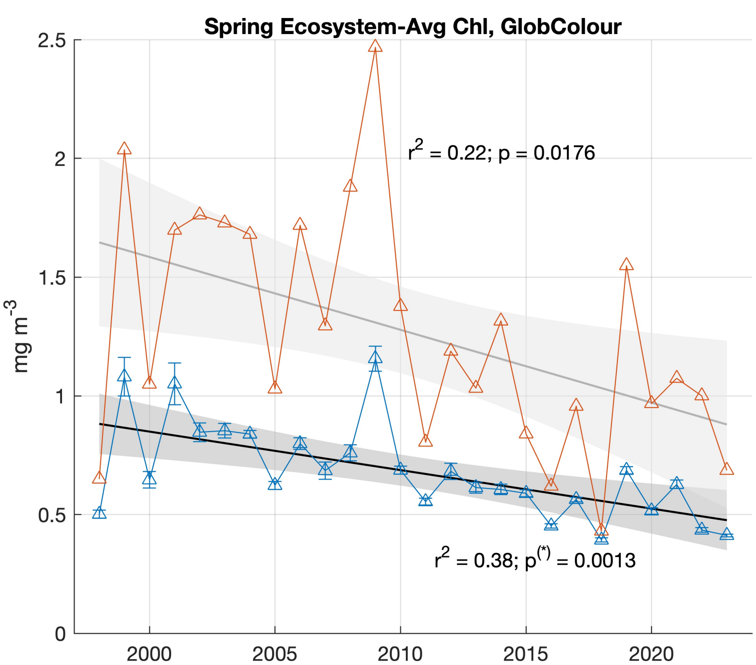

Figure 27: Trends in spring satellite chla-a 1998 to 2023 GlobColour, showing trend for spring maximum spatial-average AI chl-a and for spring average chl-a in the Aleutian Islands

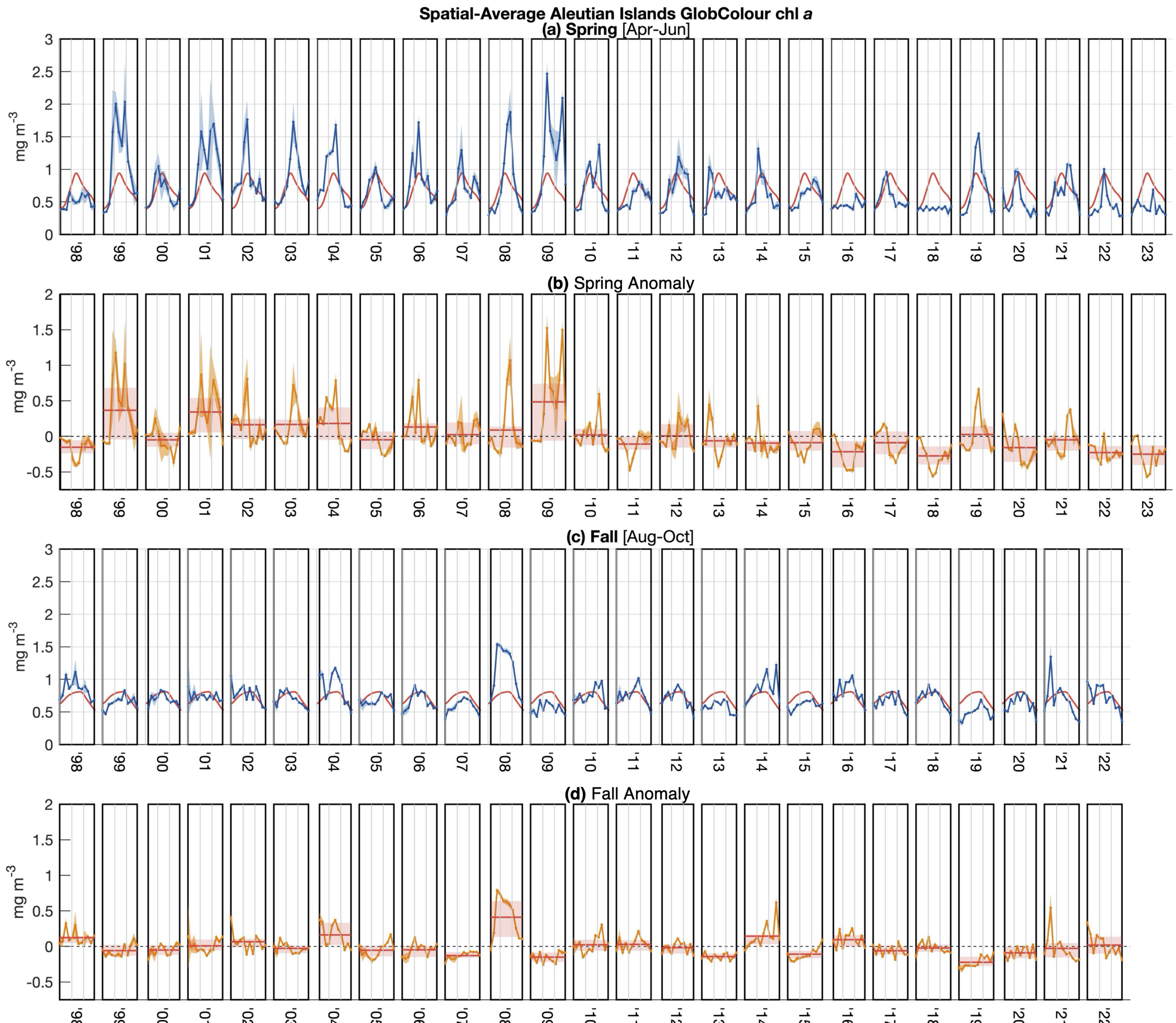

Figure 28: Time series of spatial-average Aleutian Islands chlorophyll a in GlobColour 8-day composites, for the months of (a)-(b) April to June, and (c)-(d) August to October. Panels (a) and (c) show the full time series, while (b) and (d) show anomalies from a composite seasonal cycle (red line in (a)/(c)). In (b) and (d), red line and shading respectively indicate the mean and interquartile range of anomalies in each year. Gray shading indicates (preliminary) 95% confidence bounds. Light gray lines delineate monthly boundaries.

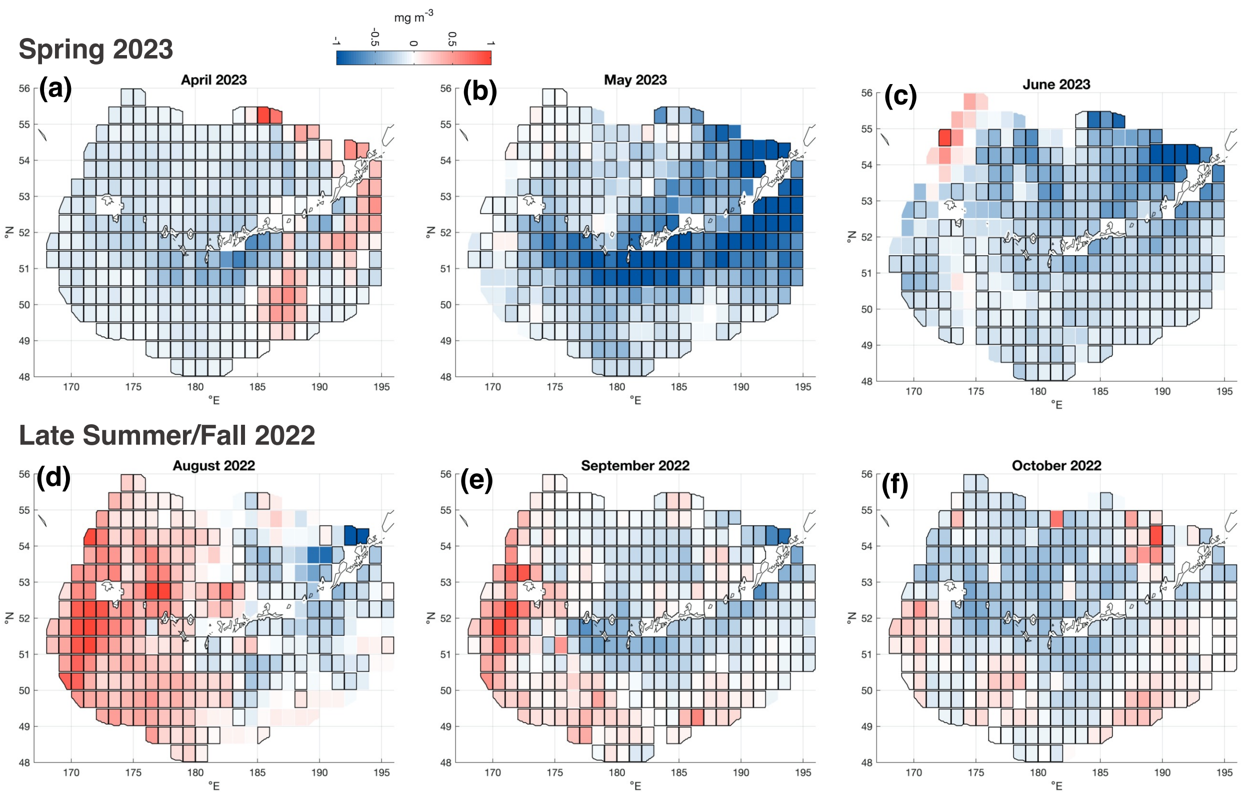

Figure 29: Spatial patterns in monthly-average anomalies from the seasonal cycle, April–June 2023 (top row) and August-October 2022 (bottom row). Anomalies are composed from data averaged with Alaska Department of Fish and Game Statistical Areas, restricted to areas of size >2500 square kilometers. Areas with a black boundary have a monthly anomaly exceeding the 95% confidence bounds. Gray shading indicates areas not sampled within a given month.

7. Zooplankton: Continuous Plankton Recorder Data from the Aleutian Islands and southern Bering Sea

Contributed by Clare Ostle and Sonia Batten

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 the region around the Aleutian islands, including deep waters of the southern Bering Sea (Figure 30): 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 (geometric mean) is first calculated. Each sampled month is then compared to the mean of that month (calculated using the geometric mean) and an anomaly calculated (Log_{10}). The mean anomaly of all sampled months in each year is calculated to give an annual anomaly.

The Aleutian Island region, including the southern Bering Sea is sampled at most 4 times per year by the east-west transect. Note that in 2001, 2015, 2017 the region was only sampled in June, October and May respectively owing to variability in the ship's transect.

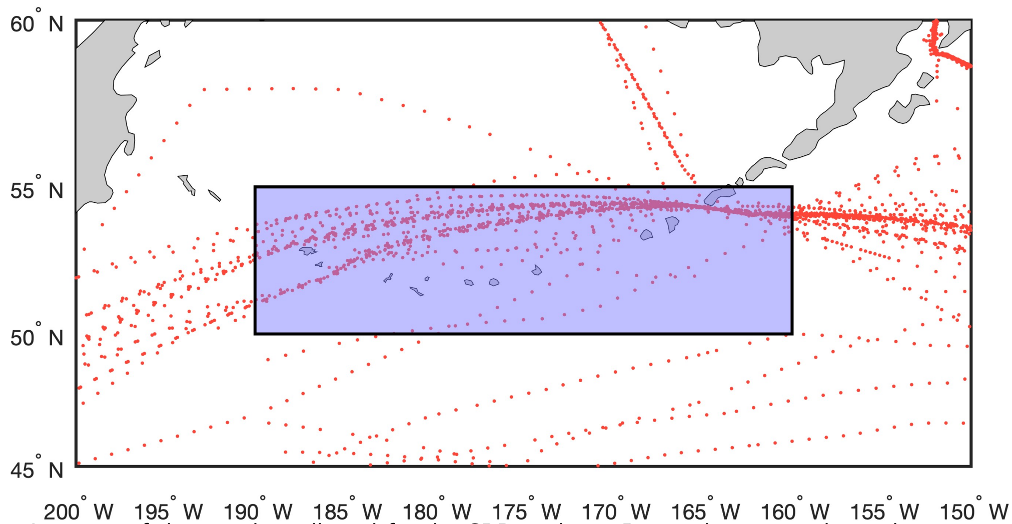

Figure 30: Location of the samples collected for the CPR analysis. Dots indicate actual sample positions and may overlay each other.

Status and trends: Figure 31 shows that the annual meso-zooplankton biomass remained negative in 2022 and that the copepod community size was negative, while the diatom abundance presented a positive annual anomaly.

Factors influencing observed trends: Analysis of summer CPR data in this region has revealed a general alternating (and opposing) pattern of high and low abundance of diatoms and large copepods between 2000 and 2012, believed to be the result of a trophic cascade caused by maturing Pink Salmon present in the region (Batten et al., 2018). Although the upper panel (diatoms) in Figure 31 contains data from spring and autumn, as well as summer, the alternating pattern is clear up until 2014. The zooplankton data in Figure 31 consist of more taxa than just large copepods but it is likely that there is some top-down influence of the Pink Salmon also present in these data. In 2013 the east Kamchatka Pink Salmon run was much lower than expected and in 2014 it was much higher. CPR data were not collected in this region in the summers of 2015 to 2017 so we are not certain if their influence on the plankton continues, nor how to tease out the simultaneous influence of ocean climate. However, the copepod community size anomaly has been negative in each season sampled since summer 2014 (apart from 2019 and in 2021) which suggests a real increase in the relative abundance of smaller species, potentially because of warmer than normal conditions.

Implications: This region appears to be subjected to top down influence by Pink Salmon as well as bottom up forcing by ocean climate, which is particularly challenging to interpret. Changes in community (e.g. abundance and composition of large diatoms, prey size as indexed by mean copepod community size) may reflect changes in the nutritional quality of the organism to their predators. Changes in abundance or biomass, together with size, influences availability of prey to predators.

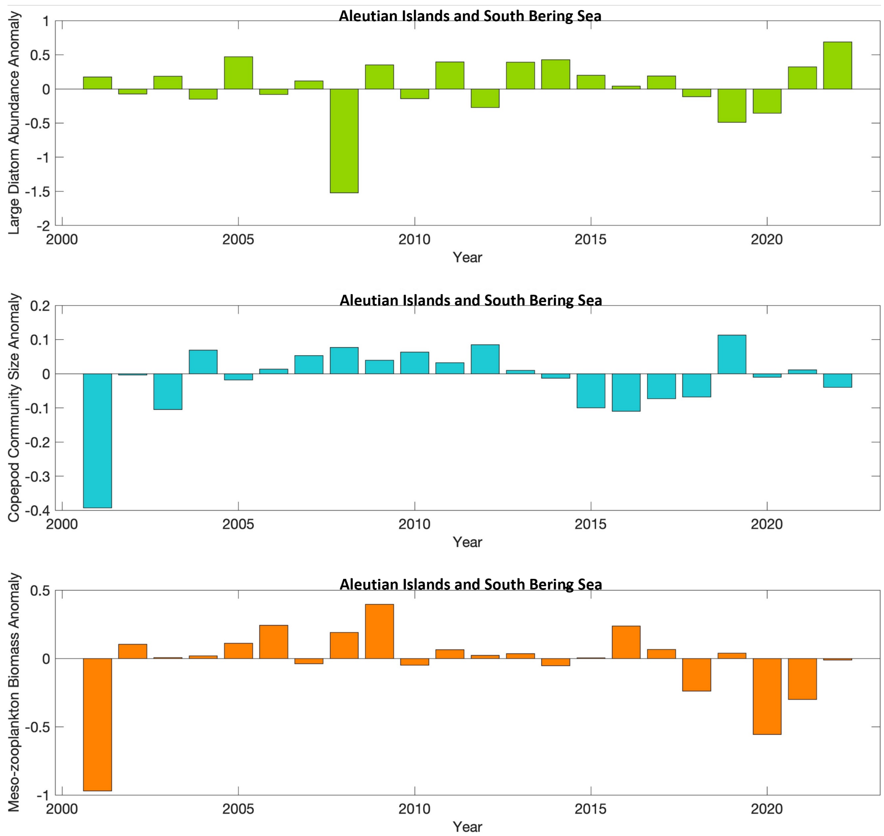

Figure 31: Annual anomalies of three indices of lower trophic levels from CPR data (from top to bottom): Large diatom abundance, copepod community size and meso-zooplankton biomass (see text for description and derivation) for region shown in Figure 30.

Acknowledgments: The North Pacific CPR survey is supported by a consortium comprising the North Pacific Research Board, the Exxon Valdez Oil Spill Trustee Council through Gulf Watch Alaska, Fisheries and Oceans Canada, the North Pacific Marine Science Organisation and the Marine Biological Association, UK.

Habitat

There are no updates in this year's report. See the contribution archive for previous indicators at: https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands.

Jellyfish

There are no updates in this year's report. See the contribution archive for previous indicators at: https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands.

Salmon

The Increasing Abundance and Expanding Role of Eastern Kamchatka Pink Salmon in the Aleutian Islands Ecosystem

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Last updated: 21 September 2023

Description of indicator: Eastern Kamchatka pink salmon (Russia) are the primary pink salmon population occupying the Aleutian Islands Ecosystem and adjacent areas, based on historical tag and recovery studies (Takagi et al., 1981). Other pink salmon populations from Russia, Japan, and Alaska may occur here to a lesser extent. However, stock-specific analyses of pink salmon in this region have not been conducted in several decades and it is unknown whether the increasing abundances of all pink salmon populations has led to a broader distribution at sea. Eastern Kamchatka pink salmon emerge from spawning grounds in coastal rivers during early spring, migrate to sea with little rearing in freshwater, then migrate southward in epipelagic waters of the East Kamchatka Current and eastward with the Subarctic Current along the southern side of the Aleutian Islands up to about 150°W. Little sampling of age-0 pink salmon has occurred in the Aleutian Islands Ecosystem owing to their small size, but some have been captured in this region during August and September. Pink salmon spend only one winter at sea and are typically distributed farther south below the Aleutian Islands during winter compared with sockeye salmon (Ruggerone et al., 2005). During spring (primarily June and July), maturing pink salmon migrate north and west through the Aleutian Island passages (including the eastern area) and into the Bering Sea where they are exceptionally abundant in spring and summer of odd-numbered years prior to migrating back to their natal rivers in summer. Sampling at sea indicates abundance of pink salmon in odd years is approximately 40 times greater than that in even years (Batten et al., 2018), owing to their fixed two-year life history.

Status and trends: The eastern Kamchatka pink salmon is an exceptionally abundant population of wild pink salmon, especially in odd-numbered years (Figure 32). No hatchery production of pink salmon occurs in this region. Pink salmon abundance was relatively stable over time from 1952 through the mid-1970s, then odd year runs began to increase over time. Even year abundances began to increase in 2014, corresponding with the unexpected decline in the 2013 return (only ∼33 million adults). From 2011 to 2023, abundance averaged 210 million salmon in odd-numbered years and 64 million salmon in even-numbered years. The largest run on record occurred in 2019 (∼315 million adults), followed by the small run in 2020 (∼28 million adult fish), a very large run in 2021 (273 million), and a small run in 2022 (53 million adult fish). In 2023, preliminary harvest data through September 5 indicate another very large run (260 million adults; catch plus escapement). During odd years (2015, 2017, 2019, 2021), Eastern Kamchatka pink salmon represented ∼38% of total pink salmon returning from the North Pacific compared with 18% during even years (2016, 2018, 2020 and 2022).

As a species, pink salmon represent nearly 70% of all Pacific salmon (Ruggerone and Irvine, 2018). In 2018 and 2019, record numbers of Pacific salmon returned from the North Pacific (950 and 854 million, respectively, excluding Chinook and coho salmon that represent less than 4% of the total), of which approximately 75% were pink salmon (Ruggerone et al., 2021). In 2021, record high total abundances of Pacific salmon continued (988 million adults) with pink salmon representing approximately 81% of the total (∼797 million fish; Ruggerone et al. 2023). Furthermore, abundance of non-native pink salmon in the Atlantic Ocean continues to increase every odd-numbered year, raising concerns for native species (Lennox et al., 2023)

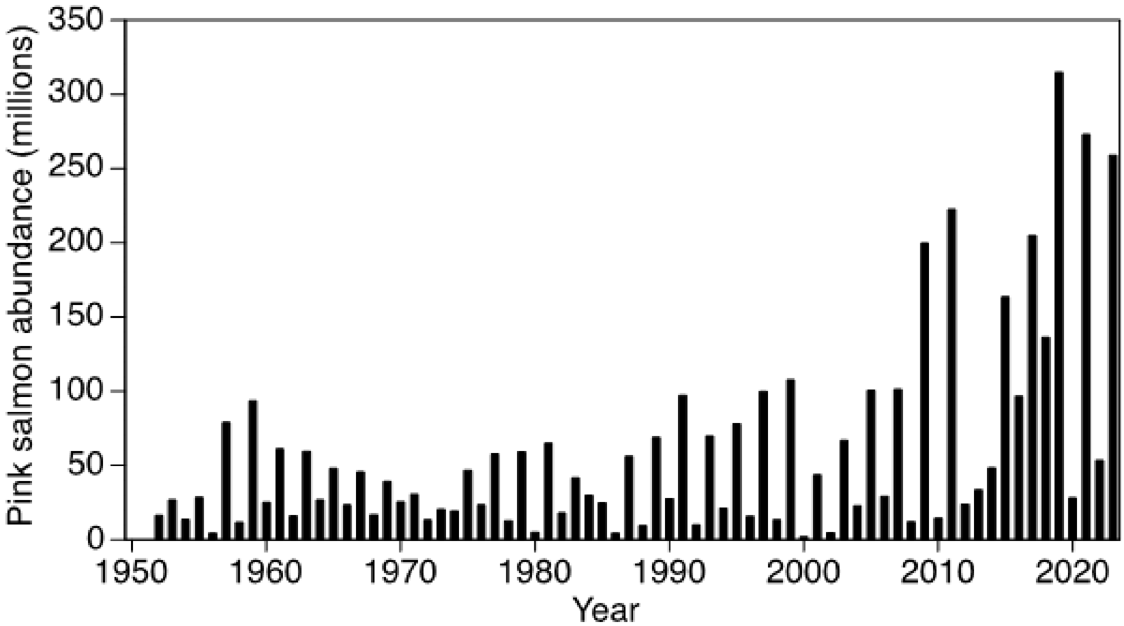

Figure 32: Time series of Eastern Kamchatka pink salmon abundance, 1952–2023. Values include catch and spawner abundances. Sources: (Ruggerone and Irvine, 2018; Ruggerone et al., 2021, 2023). The 2023 value is based on preliminary harvest data (Fish Information & Service `www.seafodd.media`).

Factors influencing observed trends: Abundances of pink salmon in Eastern Kamchatka and other regions increased after the 1977 ocean regime shift that was generally associated with warmer sea surface temperatures and greater zooplankton production (e.g., Brodeur and Ware 1992). Ocean heat content of the North Pacific Ocean explained 51% of the annual variability in pink salmon numbers returning from the North Pacific Ocean, 1952-2021, suggesting that climate change is benefiting pink salmon abundance and thus indirectly contributing to increased competition at sea for prey. In 2013 the abundance of Eastern Kamchatka pink salmon declined sharply for unknown reasons, potentially supporting an increase in even-year abundances of pink salmon in 2014, 2016 and 2018, exceptionally low abundance in 2020, then high abundance for an even-year in 2022 (Figure 32). Odd-year abundances quickly recovered after 2013 to record numbers in 2019 and near record numbers in 2021 and 2023.

Implications: Pink salmon is the smallest (and youngest) species of Pacific salmon (as mature adults), but they grow exceptionally fast, consume a large amount of various prey, and potentially affect growth and survival of other species in the North Pacific Ocean and Bering Sea, including all species of Pacific salmon and steelhead trout, 11 seabird species, four forage fish species, and southern resident killer whales (Ruggerone et al., 2023). The unique biennial pattern of pink salmon in this region facilitates detection and evaluation of pink salmon competition with other species because physical oceanography studies have not been able to explain the biennial patterns. In the Aleutian Islands region, pink salmon give rise to a trophic cascade in which zooplankton declines and phytoplankton increases as pink salmon abundance increases (Batten et al., 2018). In 2013, when pink salmon abundance abruptly declined, the abundance of zooplankton rebounded to a high level, providing additional support for the trophic cascade hypothesis. The effects of this trophic cascade in the Aleutian Island region have been documented in the growth, survival, and abundance of Bristol Bay sockeye salmon (Ruggerone et al., 2003; Connors et al., 2020), Yukon/Kuskokwim/Nushagak Chinook salmon (Ruggerone et al., 2016*b*), otolith growth of Atka mackerel (Matta et al., 2020), and reproduction of seabirds (Zador et al., 2013; Springer and van Vliet, 2014) that occupy the Aleutian Islands Ecosystem.

In 2020, the commercial harvest of all five salmon species, including salmon populations from most regions of the North Pacific, declined more than ever since comprehensive record keeping began in 1925 (Ruggerone et al., 2021). Chinook salmon experienced the greatest decline relative to the previous 10 years (54% decline). Investigators hypothesized that frequent marine heatwaves and unprecedented abundances of pink salmon in 2018 and 2019 contributed to the harvest decline.

Bristol Bay sockeye salmon, which inhabit the Aleutian Islands Ecosystem, was a primary exception to the unprecedented decline of all salmon species in 2020. Abundances of Bristol Bay sockeye salmon set record highs in 2021 (66 million adults) and 2022 (78 million; www.adfg.alaska.gov). The exceptional abundance of both Eastern Kamchatka pink salmon and Bristol Bay sockeye salmon in recent years might seem counterintuitive because evidence indicates Kamchatka pink salmon adversely affect the growth, survival and abundance of Bristol Bay sockeye salmon (e.g., (Ruggerone et al., 2003, 2016*a*). However, competition for prey between these salmon populations does not begin until the second growing season at sea, based on scale growth analysis. Furthermore, studies of seasonal and annual growth of Bristol Bay sockeye salmon reported that the large increase in survival and abundance of Bristol Bay sockeye salmon after the 1976/1977 ocean regime shift was associated with greater growth during early marine life (Ruggerone et al., 2005, 2007). The recent consistently high abundance of Bristol Bay sockeye salmon is likely associated with greater early marine growth and survival in the warming Bering Sea, a benefit that overwhelms the adverse effect of pink salmon during later marine life (Ruggerone et al., 2023).

Groundfish

There are no updates in this year's report. See the contribution archive for previous indicators at: `https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands`.

Benthic Communities and Non-target Fish Species

There are no updates in this year's report. See the contribution archive for previous indicators at: `https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands`.

Seabirds

Integrated Seabird Information

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Last updated: November 2023

Synthesis: *Most seabirds in the Aleutians feed offshore, so population and reproductive trends at breeding colonies can reflect conditions in the pelagic ocean environment. In 2023, the timing of breeding was average or earlier for all fish-eating seabird species monitored at Aiktak Island in the eastern Aleutians, but average for storm-petrels which have mixed diets. This contrasts with seabirds monitored at Buldir Island in the western Aleutians, where hatch dates for fish-eating seabirds were either average or later than average. Both mixed diet (fish and invertebrates) and fish-eating species had an exceptionally successful reproductive season at Aiktak in 2023, presumably indicating uniformly high prey availability for both nearshore and offshore foragers, including surface feeders and divers. Capelin was particularly abundant in tufted puffin diets at Aiktak, followed by age-0 pollock, in much smaller quantities. This summer continues a successful trend at Aiktak, where reproductive success has been average or above average since 2019 (there were no surveys in 2020) for most seabirds breeding at Aiktak. Reproductive success at Buldir in 2023 was mixed. Reproductive success of thick-billed murres (that prey on fish) and kittiwakes and fork-tailed storm-petrels (that prey on fish and invertebrates) was below average, while Leach's storm-petrels (that prey on fish and invertebrates) were above average, and most of the auklets (that prey on plankton) were average. The generally average to above-average reproductive success for puffins (diving fish- and squid eaters) at Buldir suggests that there were favorable foraging conditions for them, with tufted puffins feeding chicks predominately squids and Pacific saury, and horned puffins feeding chicks mostly Atka mackerel, squid, and Pacific saury.*

Jointly, the negative NPGO and PDO as well as positive NPI in recent years seem to have created favorable foraging conditions for seabirds via conditions that support increased zooplankton production and less stormy winters, both of which benefit seabird foraging. However, with the moderating NPGO and El Niño conditions starting this summer and expected to continue through spring next year, foraging conditions have not been as favorable this year and may remain unfavorable into next year. Also, a stormier early winter in 2022-2023 may have contributed to less favorable winter foraging conditions compared to the year before.

No large or unusual seabird die-offs were documented via standardized beach-based surveys. Opportunistic reports of beached birds included low numbers of seabirds that have nesting colonies in the Aleutians. An opportunistic report in mid-September of a die-off of over 150 shearwaters was reported at Akutan Island. Six carcasses from this die-off were sent to the Alaska Department of Environmental Conservation where samples tested negative for Highly Pathogenic Avian Influenza (HPAI). Some carcasses are also planned to be tested for HABs There was no bycatch estimate this year for seabirds in groundfish fisheries.

The influence of pink salmon abundance on seabirds that breed in Alaska can be observed in the reproductive *timing of some species and potentially bycatch trends, but they do not seem to drive die-offs. This contrasts with seasonally resident shearwaters that breed in Australia during the austral summer/northern winter. High pink salmon abundance has been found to correlate to occasional mortality events and low abundance of short-tailed shearwaters.*

Description of indicator: Seabirds are considered to be useful ecosystem indicators, as their breeding performance and diet composition reflect conditions in the marine environment. Here we provide an overview of environmental impacts to seabirds and what those may indicate for ecosystem productivity as it pertains to fisheries management. We synthesize data and field observations collected by government, university and non-profit partners to assess the status of seabirds in the Aleutian Islands during 2023.

We present information in three main sections as indicators of processes at different spatio-temporal scales:

1. i) timing of breeding, which reflects ecosystem conditions prior to breeding,
2. ii) reproductive success, which reflects feeding conditions during the breeding season and/or system phenology, and
3. iii) population information, including mortality, which encompasses environmental and ecosystem effects during spring/summer.

Each type of information is presented for seabirds based on their feeding strategy and main prey: surface or diving seabirds feeding on fish or plankton (see Figure 33). Seabirds discussed here feed offshore, as well as nearshore (∼3 km from land, Byrd et al. 2005), regardless of their feeding strategy or prey. However, because nearshore feeders generally forage in shallow water, their prey is less likely to be affected by currents and fronts (Byrd et al., 2005). The western Aleutians are dominated numerically by planktivorous seabirds, while the eastern Aleutians are dominated by piscivorous seabirds.

strategy	prey	habitat	common name
surface 	plankton	offshore	fork-tailed and Leach's storm-petrels
	fish	nearshore	glaucous-winged gull
	fish	offshore	red/black-legged kittiwakes and northern fulmars
diving 	plankton	nearshore	parakeet auklets, whiskered auklet
	plankton	offshore	ancient murrelets, least auklets, crested auklet
	fish	nearshore	red-faced cormorant, horned puffin
	fish	offshore	common murre, thick-billed murre, tufted puffin

Figure 33: Feeding strategy, prey and habitat of the main seabird species monitored annually by AMNWR in the Aleutian Islands, based on Byrd et al. (2005)

TIMING OF BREEDING AND REPRODUCTIVE SUCCESS (BULDIR AND AIKTAK)

Seabirds at Buldir Island, in the western Aleutians, and Aiktak Island, in the eastern Aleutians, were monitored by the Alaska Maritime National Wildlife Refuge (AMNWR). The long-term average hatch dates for seabirds at Buldir fall between mid-June to early August (Dragoo et al., 2019), along with average hatching periods of 30 to 42 days. In 2023, at Aiktak, in the eastern Aleutians, hatch dates were mostly earlier than average for most seabirds, including puffins and murres, which suggests favorable foraging conditions for fish foragers. None of the monitored species were later than average. At Buldir, in the western Aleutians, only puffins were later than average, while other fish- eaters such as murres and kittiwakes, as well as planktivorous auklets, had average hatch timing. Storm-petrels hatched chicks earlier than average (Figure 34).

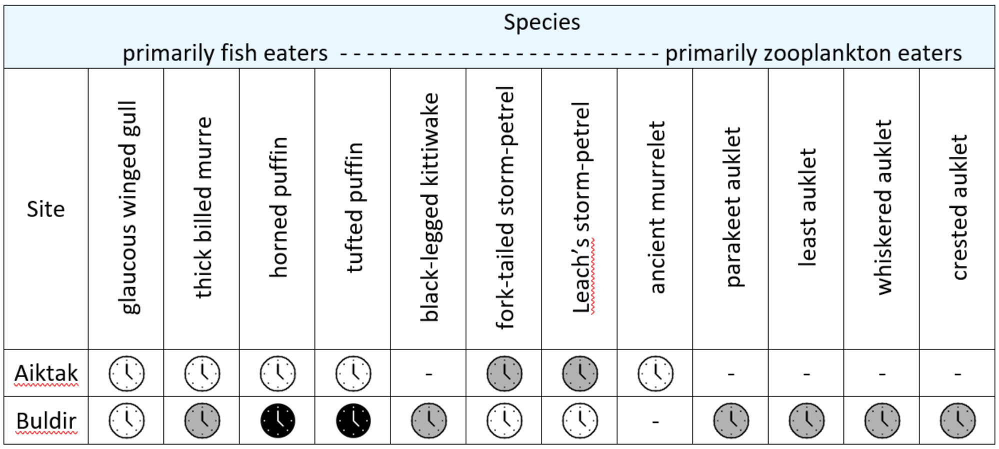

Figure 34: Seabird relative breeding chronology in 2023 compared to long-term averages for past years at Aiktak and Buldir islands. White clock indicates hatching chronology was >3 days earlier than average. Gray clock within 3 days of average. Black clock <3 days later than average. Dashes indicate species not monitored at a site or for which sample size too small for comparison.

The breeding timing of tufted puffins nesting at Buldir has been shown to vary between odd and even years, matching the pattern of high/low biennial runs of Kamchatka pink salmon (Springer and van Vliet, 2014) where high pink salmon numbers (odd years) correlated with later tufted puffin hatch dates. The pattern could not be discerned in some of the recent years, 2017-2018, which were two consecutive years of poor reproductive success, with little or no hatch data; in 2020 no fieldwork was conducted thus no data collected. The biennial pattern that correlates with pink salmon is observed again in 2021-2023 (Figure 35). In 2023, tufted puffin mean hatch date was four days later than the long-term mean, concurring with a high abundance (odd) for pink salmon.

Seabird reproductive success in 2023 was average to above average of the long-term mean for all species monitored at Aiktak in the eastern Aleutians. This is the fourth year since 2019 (not including 2020 when no data was collected) that breeding by most seabirds at Aiktak was average or above average. This includes diving, fish-eating seabirds (common and thick-billed murres, tufted and horned puffins), mixed foragers (storm-petrels, consume mix of fish and invertebrate), and predominately planktivores (ancient murrelets). Reproductive success

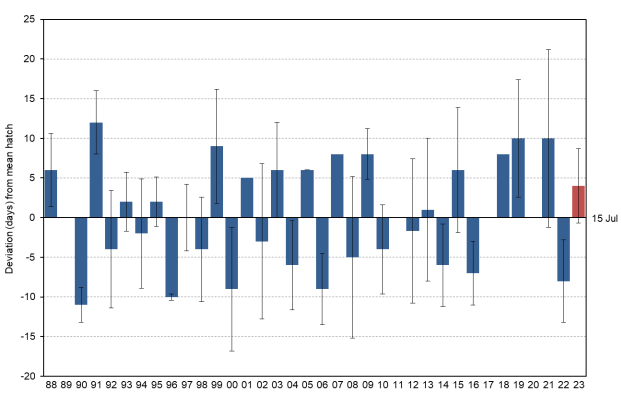

Figure 35: Yearly hatch date deviation (from the 1988–2023 average of 15 July) for tufted puffins at Buldir Island, Alaska. Negative values indicate earlier than mean hatch date, positive values indicate later than mean hatch date. Error bars represent standard deviation around each year's mean hatch date (years without error bars have sample size of one); red highlights the current year. No data were collected in 2020; no hatch dates were recorded with the appropriate egg to chick interval (≤7 days) in 1989 or 2017 and no eggs hatched in plots in 2011.

at Buldir was more mixed. Tufted puffins had above average reproductive success; least, crested, and whiskered auklets were average (with average or above average success in the past three years); Leach's storm petrels had the fourth highest reproductive success for this species on Buldir. Thick-billed murres, black-legged kittiwakes, parakeet auklets, and fork-tailed storm-petrels were below average; red-legged kittiwakes had complete reproductive failure (Figure 37).

Species Primarily fish eaters - Primarily zooplankton eaters														
Site	glaucous winged gull	common murre	thick billed murre	horned puffin	tufted puffin	red-legged kittiwake	black-legged kittiwake	fork-tailed storm-petrel	Leach's storm-petrel	ancient murrelet	parakeet auklet	least auklet	whiskered auklet	crested auklet
Aiktak						-	-				-	-	-	-
Buldir		-								-				

Figure 36: Seabird reproductive success in 2023 compared to long-term means for past years at Aiktak and Buldir islands. Big smiley face indicates reproductive success >1 SD above the long term mean, smiley indicates within 1 SD of long term mean, frowny face indicates >1 SD below long term mean, and broken faces indicate failure, which is considered values at or near zero. Dashes indicate species not present or monitored at a site or for which sample size too small for comparison.

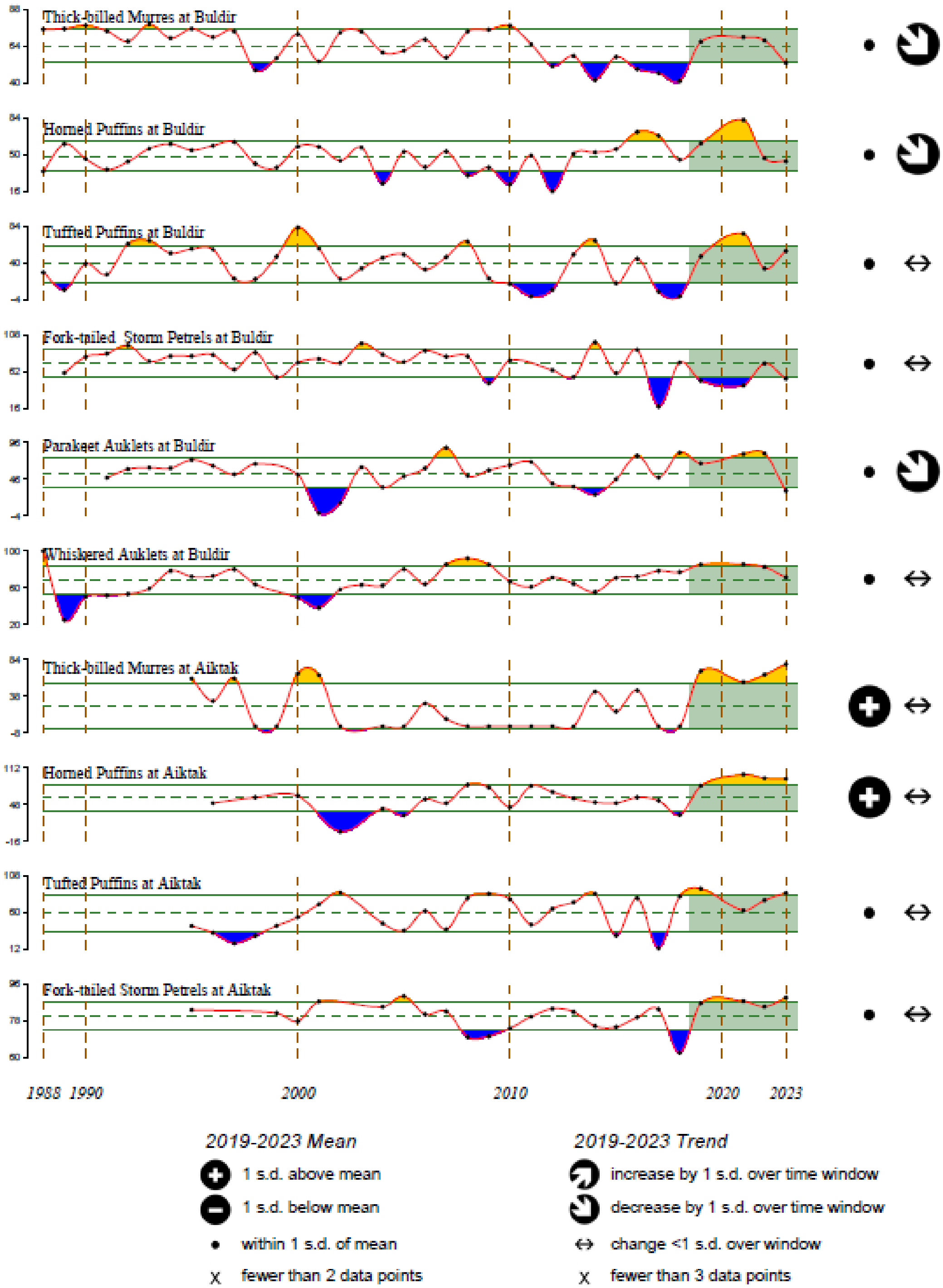

Figure 37: Time series of seabird reproductive success through 2023 at Buldir and Aiktak Islands

DIET

Tufted puffins and horned puffins medium-sized seabirds that nest in varying densities throughout the Aleutians. AMNWR samples puffin chick diets annually at Buldir and Aiktak Islands, and less frequently at puffin colonies on other Aleutian Islands. Puffins carry multiple prey items in their bills when they return to their colonies to feed their chicks. Forage fish and squid comprise most of puffin chick diets. In the absence of direct measures of forage fish abundance, the diet composition by percent biomass in puffin chick meals can be used as indicators of forage fish recruitment and system-wide productivity.

In 2023, Tufted puffin chick diets by biomass at Buldir were largely composed of squids (63%), followed by Pacific saury (18%), and gadiids (10% pollock). Horned puffins also fed chicks squid (30%) and Pacific saury (16%), but their primary prey was Atka mackerel (43%). In contrast, diets of tufted puffin chicks on Aiktak were primarily composed of capelin (86%), followed by pollock (6%) (Figure 38).

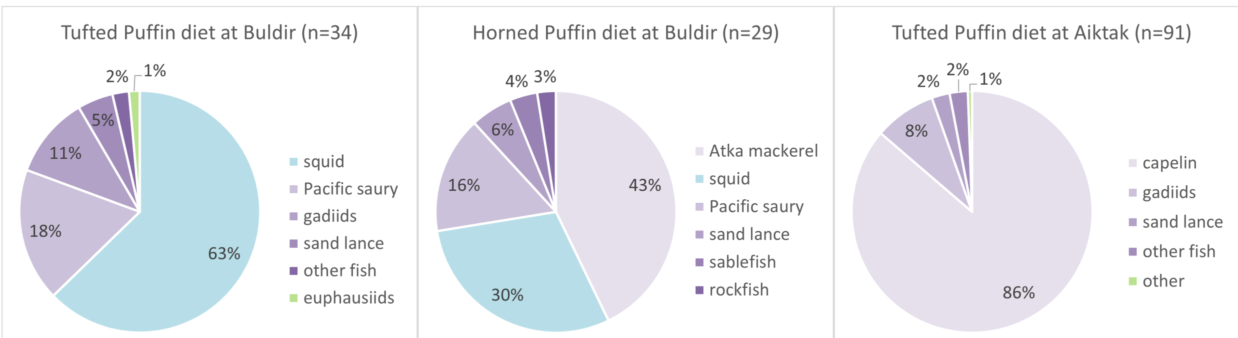

Figure 38: Diet composition by percent weight, based on samples collected in 2023 for tufted puffin and horned puffin at Buldir (wester Aleutians) and tufted puffin at Aiktak, (eastern Aleutians)

POPULATION INFORMATION—MORTALITY

Historically, seabird die-offs are not uncommon in Alaska (Bailey and Davenport 1972), but are seldom reported from the Aleutian Islands, likely due to its remoteness, where die-offs may go unobserved (Alaska Report 2006). Opportunistic reports of beached birds were submitted to COASST and regional partners during the summer of 2023. These reports combine contributions by community members in remote coastal locations with reports by citizen scientists. Documentation of species (if known), count, and location is required for each report, but standardized survey effort (outside of COASST and NPS surveys) is rarely available.

In late July to early August, during an AMNWR seabird survey in the Near Islands, in the western Aleutians, a seabird die-off was noted, along with small algal blooms observed nearshore, particularly at Agattu and Attu islands. The main species found dead or dying on shorelines and in kelp birds were common murres and glaucous-winged gulls; specimens were collected for testing. Algal bio toxins are suspected to be the cause of death, but lab results are on-going, with initial testing of some of the specimens being negative for HPAI. Between May and September 2023, most reports of carcasses in the Aleutian Islands were from AMNWR seasonal surveys (using COASST protocols) at Buldir, Adak, and Aiktak Islands. The number of carcasses reported in 2023 is not indicative of a major die-off event in this region. .

Monitoring by the Coastal Observation and Seabird Survey Team (COASST) and regional partners provides a standardized measure of relative beached bird abundance. Surveys began in the Aleutian Islands in 2006, and since that time over 670 surveys have taken place across 18 beaches. In 2023, 38 surveys took place across 7 beaches located mainly in the Eastern Aleutians. Detailed methods for beached bird surveys can be found in (Jones et al., 2019).

In 2023, surveyors reported slightly higher than average numbers of carcasses across beaches in the Aleutian Islands, despite normal survey effort. However, encounter rates were not indicative of a die-off event, which is generally defined as 5x the baseline encounter rate for mass mortality events. Beach-cast seabird species composition was primarily small alcids (e.g., auklets, murrelets), storm-petrels, and gulls, as shown in Figure 39. The observed composition of species is not unusual given the abundance of these species that breed on the islands where monitoring primarily took place.

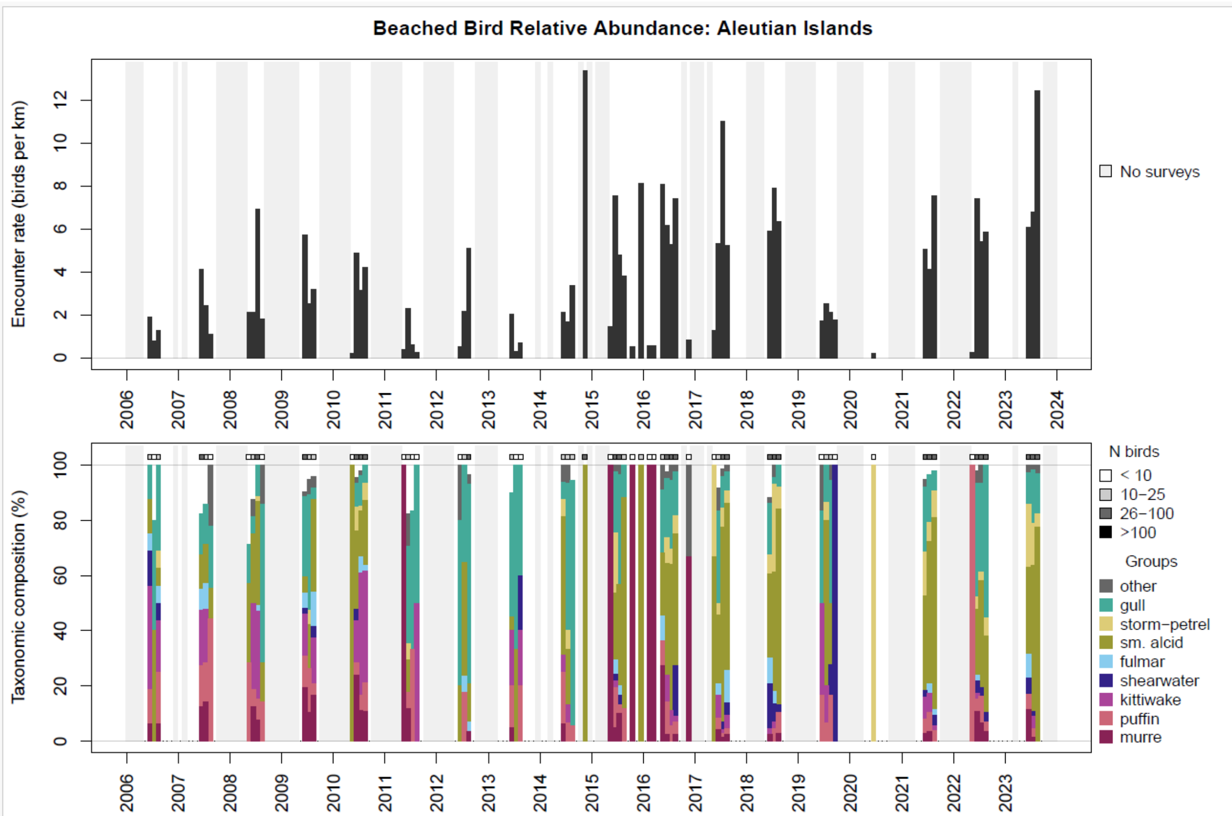

Figure 39: Encounter rate (top panel) and month-averaged beached bird abundance (bottom), standardized per km of survey effort, for the Aleutian Islands. Species groups (gull, storm-petrel, small alcid, fulmar, shearwater, kittiwake, puffin, murre) are depicted with different colors within each bar, with gray bars indicating months where no survey was conducted. Credit: COASST

In mid-September an opportunistic report of a die-off of over 150 shearwaters was reported at Akutan Island. A total of 115 carcasses were recovered with still 25-30 in the water when recovery efforts were discontinued due to choppy water conditions. The carcasses were located between docks and boats and appeared to be in relatively good health. This is particularly notable as die-offs have been rarely reported in the Aleutian Islands, likely in part due to the remote and unobserved nature of most of the coastline. Die-offs such as this one have been linked to poor food supply and/or disease. In recent years, the global spread of the Highly-Pathogenic Avian Influenza (HPIA) has been of great concern for seabirds, particularly those that nest in dense colonies where an introduction of HPIA could spread quickly due among densely aggregated seabirds. In the past year, HPIA has been increasingly detected in seabird colonies worldwide. Six carcasses from this die-off were sent to the Alaska Department of Environmental Conservation where samples tested negative for Highly Pathogenic Avian Influenza (HPAI); some carcasses are planned to be tested for HABs toxins.

Avian influenza Type A virus does not normally infect people. Human infections with bird flu viruses are rare and most often occur after close or lengthy unprotected contact. There were several other opportunistic reports of beached birds found in the southeastern Bering Sea. One described $\sim$ 150 beached birds in early August at the Salmon River/Platinum Village on the southern side of Goodnews Bay. In mid-August approximately 250 beached murres were reported from the Nushagak Peninsula south of Togiak Bay in the southeastern Bering Sea. Biologists at Togiak National Wildlife Refuge revisited both the Platinum Village area and the Nushagak area and collected samples from five murres at Platinum Village and 15 murres at Nushagak Peninsula. Fourteen of the 15 samples tested positive for Highly Pathogenic Avian Influenza (HPAI; Avian influenza Type A, bird flu virus, or H5N1) at Platinum Village, and four of five samples tested positive at the Nushagak Peninsula site.

Seabird bycatch rates have been shown to be related to environmental conditions and bird abundance (Bi et al., 2020). In the Aleutians, the total estimated seabird bycatch in groundfish and halibut fisheries for all gear types appears to follow a biennial pattern starting in 2014 (ESR, 2022) with higher bycatch coinciding with years of high Eastern Kamchatka pink salmon. This biennial pattern is not evident in the relative abundance of beached birds. Also, the species composition of seabird bycatch estimates differs from that of beached birds. One possible explanation could be that the competitive effects of pink salmon abundance on seabird prey might increase how aggressively seabirds go after bait, but not enough to drive mortality or beached bird numbers. Pink salmon abundance has been linked to kittiwake reproductive success on the Pribilof Islands, with lower reproductive success in odd-numbered years (Zador et al., 2013). Similarly, short-tailed shearwater reproductive success at breeding colonies in Southeastern Australia is negatively correlated with high runs (odd years) of Eastern Kamchatka pink salmon in the preceding austral winter (Springer et al., 2018). Estimated shearwater bycatch has increased since 2017, with higher estimates in odd years, again coinciding with high abundance of pink salmon (ESR 2022).

Factors influencing observed trends: In 2023, all seabirds monitored at sites in the western and eastern Aleutians had a mixed breeding season with contrasting levels of reproductive success between Buldir and Aiktak. At Aiktak most seabirds had above average reproductive success and early or average hatch dates, which suggests widespread zooplankton and small fish abundance during spring and summer throughout the eastern Aleutians. At Buldir, only puffins had later than the long-term average hatch dates, with the rest being either average or earlier than average. While puffins and most auklets had average or above the long-term average reproductive success, several seabirds feeding from fish to plankton had below the long-term average reproductive success. This would suggest that there was a mixed availability of prey. In 2023 the deeper mixed layer may have adversely impacted the availability of prey for both surface feeders and diving seabirds. While we may have expected plankton feeders to have been negatively impacted in their breeding efforts by the high abundance of pink salmon this year (which was the third highest on record), most planktivorous seabirds at Buldir did well.

In terms of oceanographic conditions, Bond et al. (2011) (2011) suggested a correlation exists between a strong Aleutian Low and decreased seabird productivity in the Aleutian Islands, which may be due to decreased prey (zooplankton) availability; additionally, they found a higher NPGO index corresponded with lower seabird reproductive success. The NPGO index has remained negative since late 2013 with some moderation during the late winter and spring of 2023, with the resumption of more negative values again late in the year. The PDO changed to a negative phase in 2020 and the NPI has been positive (i.e. weak Aleutian Low) five out the last 7 winters (except winter 2018-2019). Jointly, these indices suggest increased zooplankton availability and favorable conditions for seabird productivity. However, with conditions transitioning to an El Niño year, decreased flows through the passes, and smaller sized zooplankton, conditions are currently not as favorable as they were in past years (see Figures 14, 26, and 31). affects the timing and size of available prey.

Implications: Reproductive activity of central-place foraging seabirds can reflect ecosystem conditions at multiple spatial and temporal scales. This year all monitored species in Aiktak had average to above average breeding success compared to the long-term means. This suggests that foraging conditions for both plankton and fish-eating commercial groundfish may have been favorable in 2023 in the eastern Aleutians. The reappearance of capelin, considered a high-quality forage fish, supports this assessment. In the western Aleutians at Buldir, the fact that seabirds had from above to below the long-term average reproductive success across feeding strategies and prey types suggest a mixed availability of prey. The low numbers of beach carcasses found on surveyed beaches provide additional evidence that conditions did not suggest extreme concern. Finally, the influence of pink salmon abundance on resident seabirds in Alaska can be observed in the reproductive timing of a few species, but they do not seem to drive die-offs. This implies that the same might be true for groundfish, where pink salmon might influence some processes but as of yet not present extreme concerns.

Methods

1. 1. AMNWR: The Alaska Maritime National Wildlife Refuge (AMNWR) has monitored seabirds at colonies around Alaska in most years since the early- to mid-1970's. Monitored colonies in the Aleutians include Buldir Island in the western Aleutians and Aiktak Island in the eastern Aleutians. The Refuge monitors breeding chronology, productivity and/or population parameters for indicator species representing four major feeding guilds: 1) diving fish-feeders (e.g., common and thick-billed murres, horned and tufted puffins), 2) surface fish- feeders (e.g., black and red-legged kittiwakes), 3) diving plankton feeders (e.g., parakeet and least auklets), and 4) surface plankton feeders (e.g., Leach's and fork-tailed storm-petrels).

   The timing of breeding is based on mean hatch date at a site. The deviation of the current year mean hatch dates from the mean of all prior years is used to determine whether the timing in the current season is earlier, average, or later than the long-term mean. For this summary, early hatch is defined as >3 days earlier than mean hatch, average as within 3 days of the mean, and late as >3 days later than the mean. Reproductive success is defined as the proportion of nest sites with eggs (or just eggs for murres, which do not build nests) that fledged a chick. For the summary presented in Figure 36 of seabird productivity at these sites, success categories (depicted with egg icons) were determined using parametric SD estimates for most species, and nonparametric bootstrap SD estimates (based on 1000 resamples) for those species with the possibility of more than one egg/chick. For each species and location, using all previous years' data, success was delineated as follows:

   (a) Way above average: current year's values above the quantity (mean + 1 SD) received big smiley faces;
   (b) current year's values between (mean - 1 SD) and (mean + 1 SD) received smiley faces; III.
   (c) Below average: current year's values below (mean - 1 SD) received frowny faces;
   (d) Complete failure: current year's values at or near zero received cracked frowny faces.

2. Seabird Reproductive time series: Based on data from AMNWR above, shown with respect to the average of the entire time series. (AMNWR uses the mean of previous years only; the current year is not included).

3. COASST: The Coastal Observation and Seabird Survey Team (COASST) provided a stan- dardized measure of relative beached bird abundance collected by citizen scientists for the Aleutian Islands from 2006 to present. Time-series of month-averaged beached bird abundance show several of the recent mortality events that have affected the Bering Sea. Time- series of month-averaged beached bird abundance for the Aleutian Islands show several of the recent mortality events that have affected this area.

Marine Mammals

There are no updates in this year's report. See the contribution archive for previous indicators at: `https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands`.

Ecosystem or Community Indicators

There are no updates in this year's report. See the contribution archive for previous indicators at: `https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands`.

Disease Ecology Indicators

Harmful Algal Blooms in the Aleutian Islands

Contributed by Thomas Farrugia[1], Natalie Rouse[2],Kathleen Easley[3], Louisa Castrodale[3], Bruce Wright[4]

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[2] Alaska Veterinary Pathology Services, AK 99577)
[3]USGS Alaska Science Center, Anchorage, AK
[4]Knik Tribe of Alaska, 1744 North Prospect Palmer, AK 99645

Contact: farrugia@aoos.org
Last updated: October 2023

Sampling Partners:

Alaska Ocean Observing System	UAF Alaska Sea Grant
Alaska Veterinary Pathologists	Aleutian Pribilof Island Association
Aleut Community of St. Paul	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	Norton Sound Health Corporation
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	Sunaq Tribe of Kodiak*
University of Alaska Fairbanks	USGS Alaska Science Center
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 [15] since (Ostasz, 2001). Analyses of paralytic shellfish toxins are commonly reported as µg of toxin/100 g of tissue, where the US Food and Drug Administration (FDA) limit for paralytic shellfish poinsoning is 80µg/100g. Toxin levels between 80µg–1000µg/100 g are considered to potentially cause non-fatal symptoms in humans, 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. *Pseudo-nitzschia* has been detected in 13 marine mammal species and has the potential to impact the health of marine mammals and birds in Alaska. No human health impacts of domoic acid have been reported in Alaska, although both acute and chronic amnesic shellfish poisoning has been reported in several states, including Washington and Oregon.

[15]see DHSS fatality report: https://aoos.org/wp-content/uploads/2019/06/DHSS_PressRelease_PSPFatality_20200715.pdf)

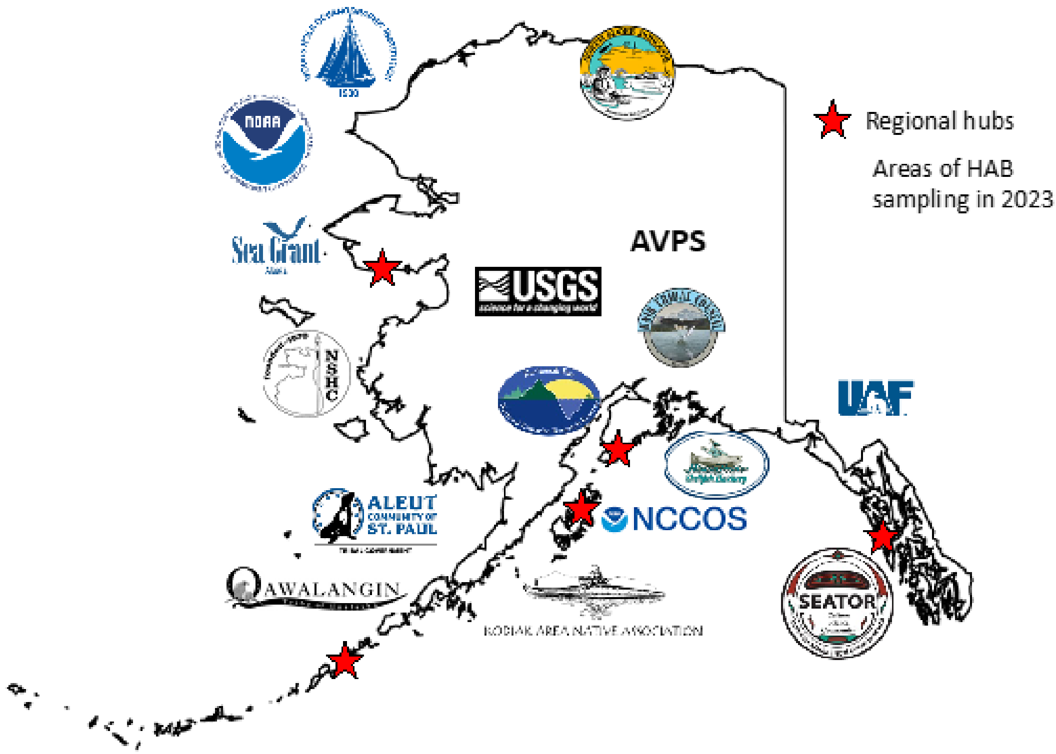

Figure 40: Map of sampling areas and sampling partners in 2023

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 harvesters and researchers, and to reduce human health risk (top map, Figure 40). 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[16] or through the sampling partners listed above.

Status and trends: Alaska Region:: Results from shellfish and phytoplankton monitoring showed a slight uptick in the presence of harmful algal blooms (HABs) and toxins throughout all regions of Alaska in 2023 compared to 2022, although the overall levels were still lower than in 2019-2021. Bivalve shellfish from areas that are well known for having PSP levels above the regulatory limit, including Southeast Alaska and the Aleutians, continued to have samples that tested above the regulatory limit, albeit less frequently than since 2019 and 2020. Overall, 2023 seems to have been slightly less active for blooms and toxin levels than 2021, 2020 and 2019, but areas continue to have HAB organisms in the water, and shellfish testing well above the regulatory limit, especially between March and September. Over the last few years, the dinoflagellate *Dinophysis* (which may cause Diarrhetic Shellfish Poisoning, DSP) has become more common and abundant in water samples, and 2023 continued that trend.

We are also seeing a geographic expansion of areas that are sampling for phytoplankton species, so the decrease in the number of HABs detected may be more related to generally cooler water temperatures, especially in the Gulf of Alaska. In the Bering Sea, HABs were being monitored through the opportunistic placement of Imaging Flow Cytobots on the R/V Sikuliaq as it transited the Bering and Chukchi Seas on research cruises.

[16] https://aoos.org/alaska-hab-network/

Alaska Veterinary Pathology Services (AVPS) and University of Alaska Anchorage spearheaded a behavioral log as part of the ECOHAB project where any unusual (and potentially HABs exposure-related) wildlife behaviors could be recorded. They also collected 27 samples for saxitoxin and domoic acid testing at WARRN West, pending shipment this fall (Natalie Rouse, AVPS).

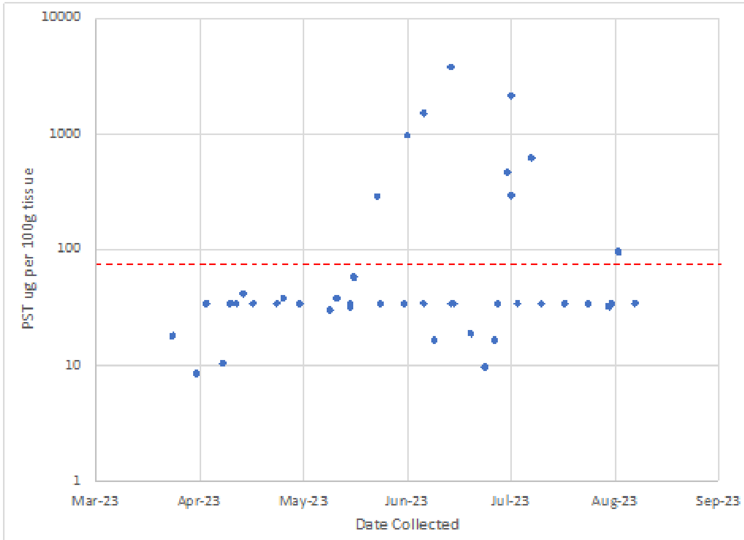

Figure 41: Paralytic shellfish toxins detected in blue mussels samples collected at three locations in Unalaska during 2023. Data and figure from Qawalangin Tribe of Unalaska

Aleutian Islands: In Unalaska, the Qawalangin Tribe has been conducting phytoplankton tows to monitor the presence of HAB species. Staff have collected 19 samples so far in 2023, and have detected the presence of both *Alexandrium* sp. and *Pseudo-nitzschia* sp. *Pseudo-nitzschia* was found in samples starting in February, with elevated concentrations found in April and June. *Alexandrium* was first detected in April and was consistently present in samples through July.

The Knik Tribe has been sampling for PSTs in the Aleutian Islands for several years, and 42 blue mussel samples were tested from the Aleutian Islands in 2023. Samples came from three locations in Sand Point, three locations on Unalaska, one location in False Pass and one location in Akutan. The results of the sampling show a notable increase in PSTs in blue mussels between the end of May and early August 2023, with the highest value (3,793 µg per 100 g) found on June 15, 2023 (Figure 41).

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). A multi-disciplinary statewide study funded by NOAA's ECOHAB program is underway and encompasses ship-based sediment samples, water samples, zooplankton samples which include krill and copepods, multiple species of fish, bivalves, and the continuation of sampling subsistence-harvested and dead stranded marine mammals.

Fishing and Human Dimensions Indicators

Discards and Non-Target Catch

Time Trends in Groundfish Discards

Contributed by Anna Abelman, Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA; and Alaska Fisheries Information Network, Pacific States Marine Fisheries Commission

Contact: anna.abelman@noaa.gov

Last updated: September 2023

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 42 below are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area-gear-target sector. Where rates are described below for species or species groups, they represent the total discarded weight of the species/species group divided by the total catch weight of the species/species group for the relevant area-gear-target sector. These estimates include only catch of FMP-managed groundfish species within the FMP groundfish fisheries. Discards of groundfish in the halibut fishery and discards of forage fish and species managed under prohibited species catch limits, such as halibut, are not included.

Status and trends: Since 1993 discards and discard rates of groundfish in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock and non-pollock trawl sectors in the Aleutian Islands (AI), (see Figure 43). Discard biomass in the trawl pollock sector was highest from 1995 to 1997, averaging 2,330 mT annually during this period, before falling in 1998 to 215 mT and averaging 320 mT annually from 1998 to 2020. The 2020 discard biomass in this sector (1265 mT) was the highest since 2007, but decreased once again to 223 mT this year. The non-pollock trawl sector has seen the steepest declines in discard biomass and rates since 1993. Discards in this sector peaked at 32500mT in 1996 (21% discard rate); annual discard biomass and rates averaged 15,300 mT and 15% annually from 1997 to 2007 and 4,315 mT and 4% annually from 2008 to 2022.

In the fixed-gear sector, the discard volume and discard rate have also declined across the AI area in general since 1993. Over the most recent 5-year period (2018–2022), the annual discard biomass and discard rate in the AI fixed gear sector have averaged 1,055 mT and 9%, respectively, compared to 2,173 mT and 10% averaged over the longer 1993–2022 period. When disaggregated by subarea, fixed gear discard rates in the Western (WAI) and Central AI (CAI) subareas show large interannual variation over the 10 most recent years. Discard rates in the non-pollock trawl sector have generally declined across all three subareas since 2010. To date in 2023, discard biomass through week 37 is higher in the trawl non-pollock relative to the preceding 5-year (2018–2022) period, whereas discards in the pollock trawl gear and fixed gear sectors are lower (Figure 43).

Factors influencing observed trends: Improved-retention regulations implemented in 1998 prohibiting discards of pollock and Pacific cod help account for the sharp declines in discard rates in the GOA and BSAI trawl pollock fisheries after 1997. Discard rates in the BSAI non-pollock trawl sector had a similar decline in 2008 following implementation of a groundfish retention standard for the trawl head-and-gut fleet. Improved observer coverage on vessels less than 60' long and on vessels targeting IFQ halibut may account for the apparent increase in the volume of discards in the GOA fixed gear sector in 2013.

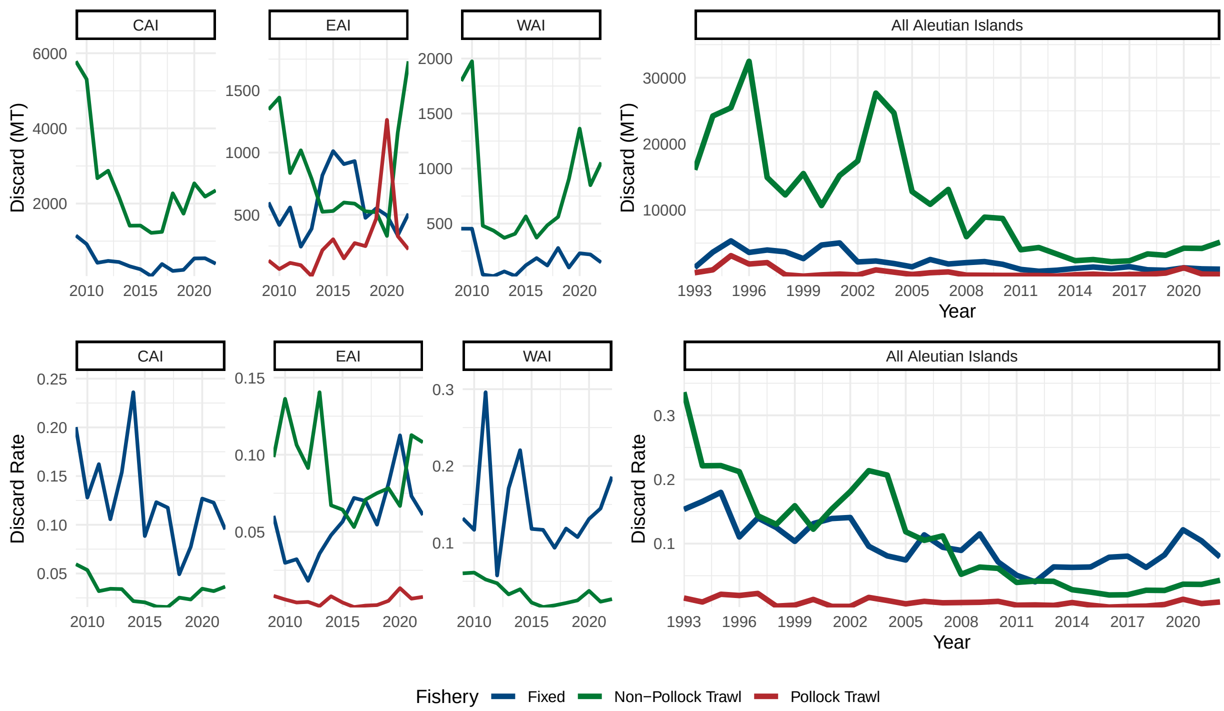

Figure 42: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear, pollock trawl, and non-pollock trawl sectors for the Aleutian Islands region, 1993-2022; and for central (CAI), eastern (EAI), and western (WAI) subregions, 2009-2022. Discard rates are calculated 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)

.

Additionally, the regulations 50 CFR 679.20(j) and 50 CFR 679.7(a)(5) primarily require operators of catcher vessels using hook-and-line, pot, for jig gear (fixed gear) to fully retain rockfish landings in the BSAI or GOA. These regulations, which also restricts the amount of rockfish that can enter into the market, were implemented back in March 2020 with the overall purpose of limiting total catch of rockfish.

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, NMFS2011, 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 1995, Alverson 1994, Catchpole 2006, Zador et al. 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.

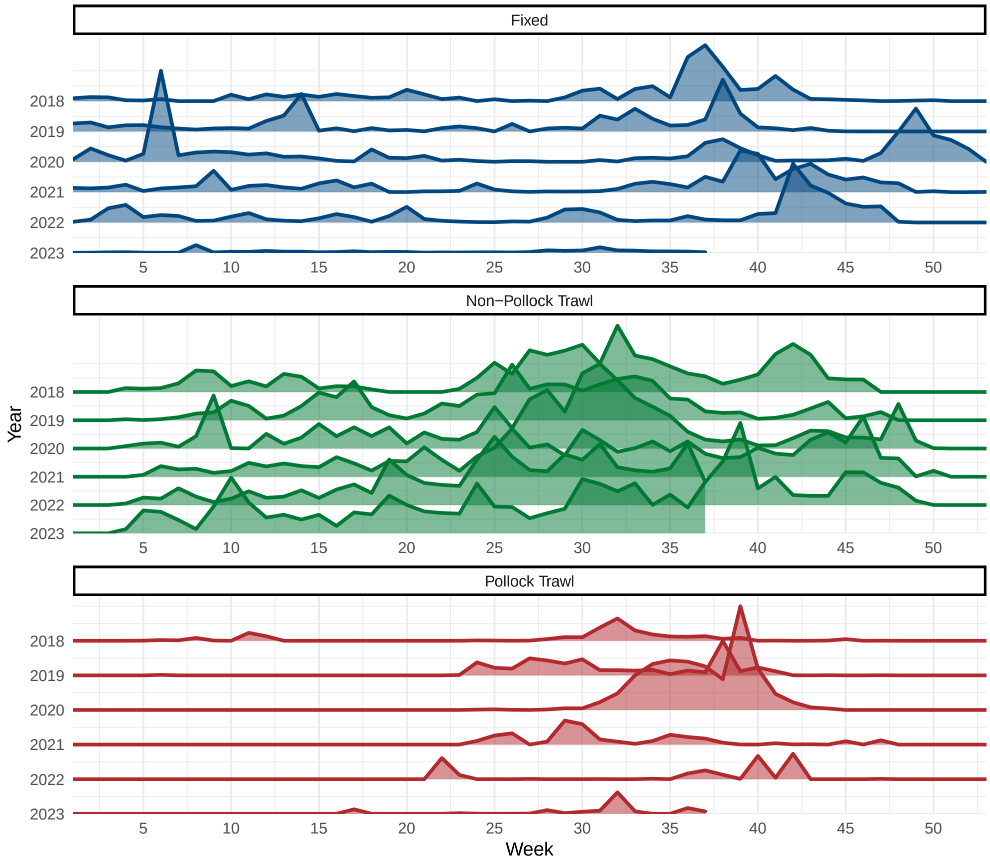

Figure 43: Total biomass (MT) of FMP groundfish discarded in the Aleutian Islands region by sector and week, 2018 - 2023 (data for 2023 is shown through week 37). Plotted heights are not comparable across sectors.

Time Trends in Non-Target Species Catch

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Last updated: August 2023

Description of indicator: This indicator reports the catch of non-target species in groundfish fisheries in the Aleutian Islands (AI). 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. Since 2013, the three categories of non-target species tracked 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).

The catch of non-target species/groups from the AI includes the reporting areas 518, 519, 541, 542, 543, and 610 [17]. Within reporting area 610, the GOA and Aleutian Islands (AI) Large Marine Ecosystems (LMEs) 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 AI increased from 2015 to 2020, with peaks in 2017 and 2020, and has since declined to its second lowest value over this time series in 2022 (Figure 44). Scyphozoan jellies are primarily caught in the pollock fishery. The catch of structural epifauna in the AI has been variable from 2011-2021, with a peak catch in 2015 and a low catch in 2022. Sponge comprise the majority of the structural epifauna catch, followed by corals and bryozoans. These species are primarily caught in the Atka mackerel and rockfish fisheries. The catch of assorted invertebrates in the AI has been variable from 2011 to 2022, with a peak in 2013 and lows in 2011, 2014, and 2020. Sea stars dominate the catch of assorted invertebrates and are primarily caught in the Pacific cod and halibut fisheries.

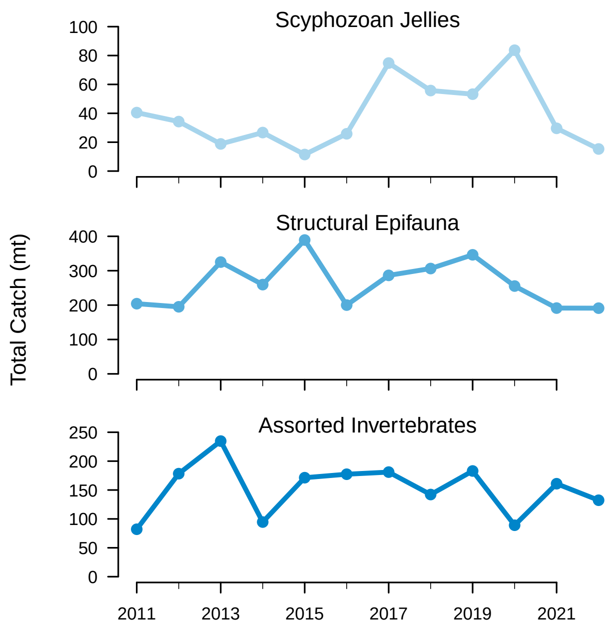

Figure 44: Total catch of non-target species (tons) in AI groundfish fisheries (2011–2022). Please note the different y-axis scales.

Factors causing 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. Alternatively, changes in allowable catch for target species, external market forces, fishing effort, or fishing gear restrictions can affect the catch of non-target species. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, wind-mixing, ocean currents, and prey abundance (Purcell, 2005; Brodeur et al., 2008).

Implications: The catches of structural epifauna species and assorted invertebrates are very low compared with the catches of target species. The higher catches of scyphozoan jellies in 2017–2020 may reflect interannual

[17] https://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones

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).

Maintaining and Restoring Fish Habitats

There are no updates in this year's report. See the contribution archive for previous indicators at: `https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands`.

Sustainability (for consumptive and non-consumptive uses)

Fish Stock Sustainability Index – Bering Sea/ Aleutian Islands

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Last updated:August 2023

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[18]. 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%).

Additionally, there are 26 non-FSSI stocks in Alaska, three ecosystem component species complexes, and Pacific halibut which are managed under an international agreement. Two of the non-FSSI crab stocks are overfished but are not subject to overfishing. The Pribilof Islands blue king crab stock is in year nine of a rebuilding plan, and the Saint Matthews Island blue king crab stock is in year three of a 26-year rebuilding plan. 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 [19].

Status and trends: The overall Alaska FSSI generally trended upwards from 80% in 2006 to a high of 94% in 2018 (Figure 45)) and has since trended downward to 88.9% in 2023.

As of June 30, 2023, no BSAI groundfish stock or stock complex was subject to overfishing, or known to be approaching an overfished condition (Table 1). One was known to be overfished. The BSAI groundfish FSSI score is 59 out of a maximum possible 64. The AI Pacific cod stock and the walleye pollock Bogoslof stock both have FSSI scores of 1.5 due to not having known overfished status or known biomass relative to their overfished levels or to B_{MSY}. All other BSAI groundfish FSSI stocks received the maximum possible score of four points

The BSAI king and Tanner crab FSSI is 17 of a possible 20. One point was deducted for the Bristol Bay red king crab stock's biomass decreasing to below the B/BMSY threshold and two points were deducted for Bering Sea snow crab becoming overfished and their biomass dropping to 23% of B_{MSY}.

[18]https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates
[19]https://www.fisheries.noaa.gov/national/population-assessments/status-us-fisheries

Table 1: Summary of status for the 21 FSSI stocks in the BSAI updated through June 2022.

BSAI FSSI (21 stocks)	Yes	No	*Unknown*	*Undefined*	N/A
Overfishing	0	21	0	0	0
Overfished	1	18	2	0	0
Approaching Overfished Condition	0	18	2	0	1

The overall BSAI FSSI score is 76 out of a maximum possible score of 84 (Table 2). The overall FSSI has generally trended upward from 74% in 2006 to a peak of 95.5% in 2019 but has since declined to 90.5% (Figure 46).

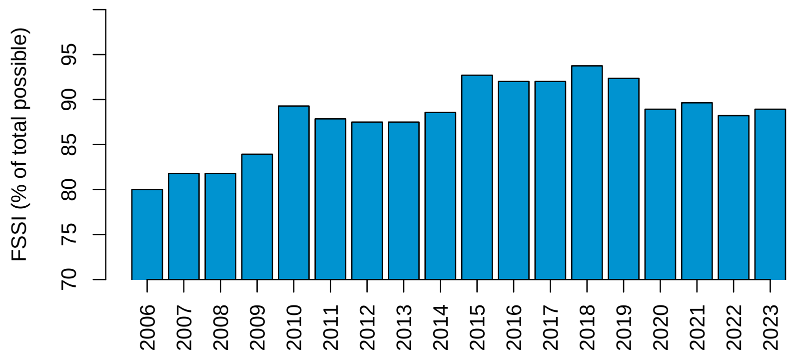

Figure 45: The trend in overall Alaska FSSI from 2006 to 2023 as a percentage of the maximum possible FSSI. The maximum possible FSSI was 140 from 2006 to 2014, 144 from 2015 to 2019, and 140 since 2020. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website[20]

Factors causing trends: The overall trend in Alaska FSSI has been positive over much of the duration examined here (2006–2023).The recent decline in the Alaska total FSSI and in BSAI from 2021 to 2022 reflects the points lost for Bering Sea snow crab becoming overfished and their low biomass relative to B_{MSY}.

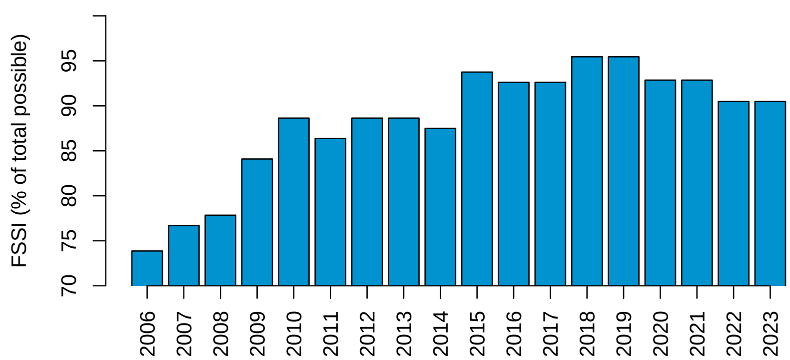

Figure 46: The trend in BSAI FSSI from 2006 to 2023 as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website.

Implications: The majority of Alaska groundfish and crab fisheries appear to be sustainably managed. None of the FSSI groundfish stocks in the BSAI are subject to overfishing or known to be overfished. Only snow crab is currently overfished.

Table 2: Table 2. BSAI FSSI stocks under NPFMC jurisdiction updated through June 2023 adapted from the NOAA Fishery Stock Status Updates webpage `www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.
*See FSSI and Non-FSSI Stock Status Table on the Fishery Stock Status Updates webpage for definition of stocks and stock complexes.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B_{MSY}	FSSI Score
Golden king crab - Aleutian Islands[a]	No	No	No	N/A	N/A	1.115/0.894	4
Red king crab - Bristol Bay	No	No	No	N/A	N/A	0.58	3
Red king crab - Norton Sound	No	No	No	N/A	N/A	1.27	4
Snow crab - Bering Sea	No	No	No	N/A	N/A	0.23	2
Southern Tanner crab - Bering Sea	No	No	No	N/A	N/A	1.18	4
BSAI Alaska plaice	No	No	No	N/A	N/A	1.58	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.16	4
BSAI arrowtooth Flounder	No	No	No	N/A	N/A	2.58	4
BSAI Kamchatka flounder	No	No	No	N/A	N/A	1.5	4
BSAI flathead Sole Complex[b]	No	No	No	N/A	N/A	2.08	4
BSAI rock sole complex[c]	No	No	No	N/A	N/A	1.61	4
BSAI skate complex[d]	No	No	No	N/A	N/A	2.28	4
BSAI Greenland halibut	No	No	No	N/A	N/A	1.49	4
BSAI Northern rockfish	No	No	No	N/A	N/A	2.1	4
BS Pacific cod	No	No	No	N/A	N/A	1.07	4
AI Pacific cod	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.60	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	1.31	4
Walleye pollock - Bogoslof	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.477	4
BSAI yellowfin sole	No	No	No	N/A	N/A	1.94	4

References

Barbeaux, S. J., K. Holsman, and S. Zador. 2020. Marine Heatwave Stress Test of Ecosystem-Based Fisheries Management in the Gulf of Alaska Pacific Cod Fishery. Frontiers in Marine Science **7**:703.

Barth, J. A., B. A. Menge, J. Lubchenco, F. Chan, J. M. Bane, A. R. Kirincich, M. A. McManus, K. J. Nielsen, S. D. Pierce, and L. Washburn. 2007. Delayed upwelling alters nearshore coastal ocean ecosystems in the northern California current. Proceedings of the National Academy of Sciences **104**:3719–3724.

Batten, S. D., G. T. Ruggerone, and I. Ortiz. 2018. Pink Salmon induce a trophic cascade in plankton populations in the southern Bering Sea and around the Aleutian Islands. Fisheries Oceanography **27**:548–559.

Bi, R., Y. Jiao, H. Bakka, and J. A. Browder. 2020. Long-term climate ocean oscillations inform seabird bycatch from pelagic longline fishery. ICES Journal of Marine Science **77**:668–679.

Bond, A. L., I. L. Jones, W. J. Sydeman, H. L. Major, S. Minobe, J. C. Williams, and G. V. Byrd. 2011. Reproductive success of planktivorous seabirds in the North Pacific is related to ocean climate on decadal scales. Marine Ecology Progress Series **424**:205–218.

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

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

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

Byrd, G., V, H. Renner, and M. Renner. 2005. Distribution patterns and population trends of breeding seabirds in the Aleutian Islands. Fisheries Oceanography **14**:139–159.

Cahalan, J., J. Gasper, and J. Mondragon. 2014. Catch sampling and estimation in the Federal groundfish fisheries off Alaska 15 Edition.

Clements, J. C., L. A. Poirier, F. F. Pérez, L. A. Comeau, and J. M. Babarro. 2020. Behavioural responses to predators in Mediterranean mussels (Mytilus galloprovincialis) are unaffected by elevated pCO2. Marine Environmental Research **161**:105148.

Connors, B., M. J. Malick, G. T. Ruggerone, P. Rand, M. Adkison, J. R. Irvine, R. Campbell, and K. Gorman. 2020. Climate and competition influence sockeye salmon population dynamics across the Northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences **77**:943–949.

Di Lorenzo, E., J. Fiechter, N. Schneider, A. Bracco, A. J. Miller, P. J. S. Franks, S. J. Bograd, A. M. Moore, A. C. Thomas, W. Crawford, A. PeÃ±a, and A. J. Hermann. 2009. Nutrient and salinity decadal variations in the central and eastern North Pacific. Geophysical Research Letters **36**:L14601.

Dorn, M. W., and S. G. Zador. 2020. A risk table to address concerns external to stock assessments when developing fisheries harvest recommendations. Ecosystem Health and Sustainability **6**:1813634.

Dragoo, D., H. Renner, and K. R.S.A. 2019. Breeding Status and Population Trends of Seabirds in Alaska, 2018. U.S. Department of the Interior, U.S. Fish and Wildlife Service, AMNWR, Homer, Alaska. page 64 pp .

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

Edullantes, B. 2019. Visualisation of decomposed time series with ggplot. GitHub. `https://github.com/brisneve/ggplottimeseries`

Fritz, L. W., and C. Stinchcomb. 2005. Aerial, ship, and land-based surveys of Steller sea lions (*Eumetopias jubatus*) in the western stock in Alaska, June and July 2003 and 2004.

Harley, J. R., K. Lanphier, E. Kennedy, T. Leigheld, A. Bidlack, M. Gribble, and C. Whitehead. 2020. The Southeast Alaska Tribal Ocean Research (SEATOR) Partnership: Addressing Data Gaps in Harmful Algal Bloom Monitoring and Shellfish Safety in Southeast Alaska. Toxins **12**:407.

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

Hobday, A. J., A. S. Gupta, M. T. Burrows, P. J. Moore, M. S. Thomsen, T. Wernberg, and D. A. Smale. 2018. Categorizing and naming marine heatwaves. Oceanography **31**:162–173.

Holsman, K. K., J. N. Ianelli, K. Y. Aydin, A. E. Punt, and E. Moffitt. in press. Comparative biological reference points estimated from temperature-specific multispecies and single species stock assessment models. Deep Sea Res II .

Hunt, G. L., and P. J. Stabeno. 2005. Oceanography and ecology of the Aleutian Archipelago: spatial and temporal variation. Fisheries Oceanography **14**:292–306.

Jones, T., L. M. Divine, H. Renner, S. Knowles, K. A. Lefebvre, H. K. Burgess, C. Wright, and J. K. Parrish. 2019. Unusual mortality of Tufted puffins (Fratercula cirrhata) in the eastern Bering Sea. PLOS ONE **14**:1–23.

Keyes, M. C. 1968. The Nutrition of Pinnipeds. Appleton-Century-Crofts, New York, NY.

Ladd, C. 2014. Seasonal and interannual variability of the Bering Slope Current. Deep Sea Research Part II: Topical Studies in Oceanography **109**:5–13.

Ladd, C., and P. J. Stabeno. 2012. Stratification on the Eastern Bering Sea shelf revisited. Deep Sea Research Part II: Topical Studies in Oceanography **65**-**70**:72–83.

Ladd, C., P. J. Stabeno, and J. E. O'Hern. 2012. Observations of a Pribilof eddy. Deep Sea Research Part I: Oceanographic Research Papers **66**:67–76.

Laurel, B. J., and L. A. Rogers. 2020. Loss of spawning habitat and prerecruits of Pacific cod during a Gulf of Alaska heatwave. Canadian Journal of Fisheries and Aquatic Sciences **77**:644–650.

Lauth, R. R., S. W. McEntire, and H. H. Zenger. 2008. Geographic Distribution , Depth Range , and Description of Atka Mackerel Pleurogrammus monopterygius Nesting Habitat in Alaska.

Lefebvre, K. A., L. Quakenbush, E. Frame, K. B. Huntington, G. Sheffield, R. Stimmelmayr, A. Bryan, P. Kendrick, H. Ziel, T. Goldstein, J. A. Snyder, T. Gelatt, F. Gulland, B. Dickerson, and V. Gill. 2016. Prevalence of algal toxins in Alaskan marine mammals foraging in a changing arctic and subarctic environment. Harmful Algae **55**:13–24.

Lennox, R. J., H. H. Berntsen, H. Garseth, S. G. Hinch, K. Hindar, O. Ugedal, K. R. Utne, K. W. Vollset, F. G. Whoriskey, and E. B. Thorstad. 2023. Prospects for the future of pink salmon in three oceans: From the native Pacific to the novel Arctic and Atlantic. Fish and Fisheries **24**:759–776.

Locarnini, R., A. Mishonov, O. Baranova, T. Boyer, M. Zweng, H. Garcia, J. Reagan, D. Seidov, K. Weathers, C. Paver, and I. Smolyar. 2019. World Ocean Atlas 2018, Volume 1: Temperature. Fishing News Books Ltd, A. Mishonov, Technical Editor. NOAA Atlas NESDIS 81. https://www.ncei.noaa.gov/sites/default/files/2020-04/woa18_vol1.pdf

Maslowski, W., R. Roman, and J. C. Kinney. 2008. Effects of mesoscale eddies on the flow of the Alaskan Stream. Journal of Geophysical Research-Oceans **113**.

Matta, M. E., K. M. Rand, M. B. Arrington, and B. A. Black. 2020. Competition-driven growth of Atka mackerel in the Aleutian Islands ecosystem revealed by an otolith biochronology. Estuarine, Coastal and Shelf Science **240**:106775.

McKenzie, J., and K. M. Wynne. 2008. Spatial and Temporal Variation in the Diet of Steller Sea Lions in the Kodiak Archipelago, 1999-2005. Marine Ecology Progress Series **360**:265–283.

Mordy, C. W., P. J. Stabeno, C. Ladd, S. Zeeman, D. P. Wisegarver, S. A. Salo, and G. L. Hunt. 2005. Nutrients and primary production along the eastern Aleutian Island Archipelago. Fisheries Oceanography **14**:55–76.

NMFS. 2010. Endangered Species Act Section 7 Consultation, Biological Opinion. Authorization of groundfish fisheries under the fishery management plans for groundfish of the Bering Sea and Aleutian Islands management area and the Gulf of Alaska. NMFS Alaska Region, Juneau AK page 472 pp .

Okkonen, S. R. 1996. The influence of an Alaskan Stream eddy on flow through Amchitka Pass. Journal of Geophysical Research-Oceans **101**:8839–8851.

Ostasz, M. 2001. PST toxin concentrations in Alaska, page 51 . Fairbanks, AK: University of Alaska Sea Grant.

Pitcher, K. W., and F. H. Fay. 1982. Feeding by Steller Sea Lions on Harbor Seals. Murrelet **63**:70–71.

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

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

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

Reiniger, R., and C. Ross. 1968. A method of interpolation with application to oceanographic data. Deep Sea Research and Oceanographic Abstracts **15**:185–193.

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

Riemer, S. D., and R. F. Brown. 1997. Prey of Pinnipeds at Selected Sites in Oregon Identified by Scat (Fecal) Analysis, 1983-1996. Oregon Department of Fish and Wildlife, Technical Report No.97-6-02. .

Robinson, K. L., J. J. Ruzicka, and M. B. Decker. 2014. Jellyfish, Forage Fish, and the World's Major Fisheries. Oceanography **27**:104–115.

Ruggerone, G., B. Agler, B. Connors, J. E.V. Farley, J. Irvine, L. Wilson, and E. Yasumiishi. 2016*a*. Pink and sockeye salmon interactions at sea and their influence on forecast error of Bristol Bay sockeye salmon. North Pacific Anadromous Fish Commission Bulletin pages 349–361 .

Ruggerone, G., Connors, B.M., B. Agler, L. Wilson, and D. Gwinn. 2016*b*. Growth, age at maturation, and survival of Yukon, Kuskokwim, and Nushagak Chinook salmon. Final report to Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative, Anchorage, Alaska.

Ruggerone, G., E. Farley, J. Nielsen, and P. Hagen. 2005. Seasonal marine growth of Bristol Bay sockeye salmon (*Oncorhynchus nerka*) in relation to competition with Asian pink salmon (*O. gorbuscha*) and the 1977 ocean regime shift. Fishery Bulletin **103**:355–370.

Ruggerone, G., J. Irvine, and B. Connors. 2021. Did Recent Marine Heatwaves and Record High Pink Salmon Abundance Lead to a Tipping Point that Caused Record Declines in North Pacific Salmon Abundance and Harvest in 2020? North Pacific Anadromous Fish Commission Technical Report pages xx–xx .

Ruggerone, G., J. Nielsen, and J. Bumgarner. 2007. Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955–2002. Deep Sea Research Part II: Topical Studies in Oceanography **54**:2776–2793.

Ruggerone, G., A. Springer, G. van Vliet, B. Connors, J. Irvine, L. Shaul, M. Sloat, and W. Atlas. 2023. From diatoms to killer whales: impacts of pink salmon on North Pacific ecosystems. Marine Ecology Progress Series **719**:1–40.

Ruggerone, G. T., and J. R. Irvine. 2018. Numbers and biomass of natural- and hatchery-origin pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean, 1925–2015. Marine and Coastal Fisheries **10**:152–168.

Ruggerone, G. T., M. Zimmermann, K. W. Myers, J. L. Nielsen, and D. E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O-nerka*) in the North Pacific Ocean. Fisheries Oceanography **12**:209–219.

Saito, R., A. Yamaguchi, I. Yasuda, H. Ueno, H. Ishiyama, H. Onishi, and I. Imai. 2013. Influences of mesoscale anticyclonic eddies on the zooplankton community south of the western Aleutian Islands during the summer of 2010. Journal of Plankton Research **36**:117–128.

Saito, R., I. Yasuda, K. Komatsu, H. Ishiyama, H. Ueno, H. Onishi, T. Setou, and M. Shimizu. 2016. Subsurface hydrographic structures and the temporal variations of Aleutian eddies. Ocean Dyn. **66**:605–621.

Sanford, E. 2002. Water Temperature, Predation, and the Neglected Role of Physiological Rate Effects in Rocky Intertidal Communities1. Integrative and Comparative Biology **42**:881–891.

Schlegel, R., and A. J. Smit. 2018. heatwaveR: Detect heatwaves and cold-spells. R package version 0.3.0. R package. `https://CRAN.R-project.org/package=heatwaveR`

Schlegel, R. W., E. C. J. Oliver, A. J. Hobday, and A. J. Smit. 2019. Detecting Marine Heatwaves With Sub-Optimal Data. Frontiers in Marine Science **6**:737.

Sease, J. L., and A. E. York. 2003. Seasonal distribution of Steller's sea lions at rookeries and haul-out sites in Alaska. Marine Mammal Science **19**:745–763.

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

Sinclair, E. H., and T. K. Zeppelin. 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopia jubatus*). Journal of Mammalogy **83**:973–990.

Spencer, P. D., A. B. Hollowed, M. F. Sigler, A. J. Hermann, and M. W. Nelson. 2019. Trait-based climate vulnerability assessments in data-rich systems: An application to eastern Bering Sea fish and invertebrate stocks. Global Change Biology **25**:3954–3971.

Springer, A. M., and G. B. van Vliet. 2014. Climate change, pink salmon, and the nexus between bottom-up and top-down forcing in the subarctic Pacific Ocean and Bering Sea. Proceedings of the National Academy of Sciences pages E1800–E1888 .

Springer, A. M., G. B. van Vliet, N. Bool, M. Crowley, P. Fullagar, M.-A. Lea, R. Monash, C. Price, C. Vertigan, and E. J. Woehler. 2018. Transhemispheric ecosystem disservices of pink salmon in a Pacific Ocean macrosystem. Proceedings of the National Academy of Sciences **115**:E5038–E5045.

Stabeno, P. J., and H. G. Hristova. 2014. Observations of the Alaskan Stream near Samalga Pass and its connection to the Bering Sea: 2001–2004. Deep Sea Research Part I: Oceanographic Research Papers **88**:30 – 46.

Stabeno, P. J., D. G. Kachel, N. B. Kachel, and M. E. Sullivan. 2005. Observations from moorings in the Aleutian Passes: temperature, salinity and transport. Fisheries Oceanography **14**:39–54.

Stabeno, P. J., C. Ladd, and R. K. Reed. 2009. Observations of the Aleutian North Slope Current, Bering Sea, 1996–2001. Journal of Geophysical Research: Oceans **114**.

Sydeman, W. J., R. W. Bradley, P. Warzybok, C. L. Abraham, J. Jahncke, K. D. Hyrenbach, V. Kousky, J. M. Hipfner, and M. D. Ohman. 2006. Planktivorous auklet Ptychoramphus aleuticus responses to ocean climate, 2005: Unusual atmospheric blocking? Geophysical Research Letters **33**.

Takagi, K. K., A.G.Hartt, and M.B.Dell. 1981. Distribution and origin of pink salmon (Oncorhynchus gorbuscha) in offshore waters of the North Pacific Ocean. Int. North Pac. Fish. Comm. Bull. pages 40–195 .

Tobin, E. D., C. L. Wallace, C. Crumpton, G. Johnson, and G. L. Eckert. 2019. Environmental drivers of paralytic shellfish toxin producing Alexandrium catenella blooms in a fjord system of northern Southeast Alaska. Harmful Algae **88**:101659.

Trenberth, K., and J. W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics **9**:303–319.

Trites, A. W., D. Calkins, and A. J. Winship. 2007. Diets of Steller Sea Lions (*Eumetopias jubatus*) in Southeast Alaska, 1993-1999. Fishery Bulletin **105**:234–248.

Vandersea, M. W., S. R. Kibler, P. A. Tester, K. Holderied, D. E. Hondolero, K. Powell, S. Baird, A. Doroff, D. Dugan, and R. W. Litaker. 2018. Environmental factors influencing the distribution and abundance of Alexandrium catenella in Kachemak bay and lower cook inlet, Alaska. Harmful Algae **77**:81 – 92.

von Biela V. R., A. M. L. P. J. F., H. B., S. K. Schoen, T. J. L., and C. M. Clawson. 2019. Extreme reduction in nutritional value of a key forage fish during the Pacific marine heatwave of 2014-2016. Marine Ecology Progress Series **613**:a71–182.

Waite, J. N., and V. N. Burkanov. 2006. Steller Sea Lion Feeding Habits in the Russian Far East, 2000-2003. University of Alaska, Fairbanks.

Ware, D. M., and R. E. Thomson. 2005. Bottom-Up Ecosystem Trophic Dynamics Determine Fish Production in the Northeast Pacific. Science **308**:1280–1284.

Werb, B. E., and D. L. Rudnick. 2023. Remarkable Changes in the Dominant Modes of North Pacific Sea Surface Temperature. Geophysical Research Letters **50**:e2022GL101078.

Williams, T. M. 2005. Reproductive energetic of sea lions: implications for the size of protected areas around Steller sea lion rookeries. in T. R. Loughlin, D. Calkins, and S. K. Atkinson, editors. Synopsis of Research on Steller sea lions: 2001-2005. Alaska Sealife Center., pages 83–89 . Alaska Sealife Center, Alaska Sealife Center, Seward, AK.

Winship, A. J., A. W. Trites, and D. A. S. Rosen. 2002. A Bioenergetic Model for Estimating the Food Requirements of Steller Sea Lions (*Eumetopias jubatus*) in Alaska, USA. Marine Ecology Progress Series **229**:291–312.

Xiao, D., and H.-L. Ren. 2023. A regime shift in North Pacific annual mean sea surface temperature in 2013/14. Frontiers in Earth Science **10**.

Yang, Q., E. D. Cokelet, P. J. Stabeno, L. Li, A. B. Hollowed, W. A. Palsson, N. A. Bond, and S. J. Barbeaux. 2019. How "The Blob" affected groundfish distributions in the Gulf of Alaska. Fisheries Oceanography **28**:434–453.

Zador, S., G. L. Hunt, T. TenBrink, and K. Aydin. 2013. Combined seabird indices show lagged relationships between environmental conditions and breeding activity. Marine ecology Progress series **485**:245–258.

Zador, S. G., A. E. Punt, and J. K. Parrish. 2008. Population impacts of endangered short-tailed albatross bycatch in the Alaskan trawl fishery. Biological Conservation **141**:872–882.

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[21].

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 for the current year. These concerns could be categorized as those reflecting the assessment model, the population dynamics of the stock, and environmental and ecosystem concerns—including those based on information from Ecosystem Status Reports. In the past, concerns used to justify an ABC below the maximum estimated by the assessment model were documented in an ad-hoc manner in the stock assessment report or in the minutes of the Groundfish Plan Teams or Scientific and Statistical Committee (SSC) 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 as specified by the stock assessment model or a lower value. The recommended ABC (whether at maximum or lower) from the lead stock assessment author is subsequently reviewed and adjusted or accepted by the Groundfish Plan Team and the Scientific and Statistical Committee. Five risk tables were completed in 2018 as a test case. After review, the Council requested risk tables to be included in all full stock assessments in 2019. The SSC also requested a fourth category of concern to be added to the risk tables. The fishery performance category serves to represent any concerns related to the recommended ABC that can be inferred from commercial fisheries performance. Importantly, these concerns refer to indications of stock status, not economic performance.

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. Some ecosystem information can also be used to inform concerns related to the population dynamics of the stock. Initially, there were 4 levels of concern from no concern to extreme. In 2023, based on a recommendation from the SSC, the levels of risk were reduced to 3, from low (no concern) to high (major/extreme). For stock assessments which include and Ecosystem and Socioeconomic Profile (ESP), the ESP is also used to inform the ecosystem risk column as well as the population dynamics and fisheries performance columns.

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.

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,

[21] The Arctic report is under development

and assessing the ecosystems (Figure 47). 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.

/vspace15 points It was requested that contributors to the Ecosystem Status Reports provide actual time se-

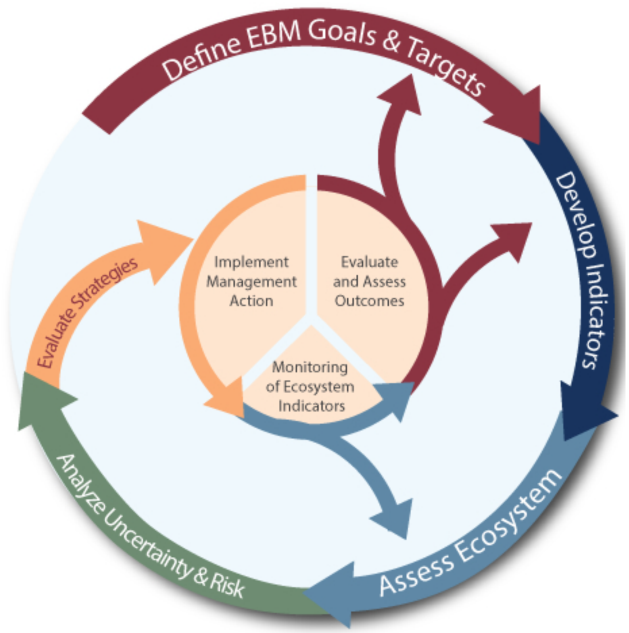

Figure 47: The IEA (integrated ecosystem assessment) process.

ries 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 2022 and October 2023 meetings

December 2022 SSC Final Report to the NPFMC

C-3 and C-4 GOA Ecosystem Status Reports

The SSC received presentations from Elizabeth Siddon (NOAA-AFSC), Ivonne Ortiz (University of Washington), and Bridget Ferriss (NOAA-AFSC). Lauren Divine (Aleut Community of St. Paul Island) provided public testimony on the eastern Bering Sea (EBS) Ecosystem Status Report (ESR); there was no public testimony for the Aleutian Islands (AI) or Gulf of Alaska (GOA) ESRs. The SSC thanks the presenters for their efforts in providing excellent, clear, and well-focused summaries of information on the status of the marine ecosystems that support federally managed fisheries off Alaska. The SSC appreciated the structure of the reports and the In-Briefs and noted that the various ways of communicating the information in the reports was valuable in reaching different audiences and informing different purposes. The SSC welcomed the addition of graphics in each report demonstrating how this information is incorporated into Council processes and was pleased to hear from communities and stakeholders that they value seeing their contributions in the report and the "In Brief" products

Thank you. We want to acknowledge the effort and thank all those involved in collecting, analyzing, interpreting, and communicating the observations included in these reports.

General comments applicable to all three ESRs

*The SSC was pleased to see several instances where authors provided very long time series, which provided a context for present observations. The SSC notes that there is a need for some authors to define what is "normal" and when some aspect of the environment is considered an anomaly that is above or below "normal." When there is a reference to "long-term-mean",**the SSC requests that authors for each section be encouraged to state the period over which "normal" (the mean, or median) is calculated, and the degree of departure from the mean or median needed to identify something as an anomaly.** It would also be helpful if authors would state the source(s) of their data and the website/url where the data can be found, if applicable.*

Response: ESR authors and contributors paid close attention to defining time series length, defining the average or median (authors are trying to move away from using "normal"), and articulating what constitutes an anomaly. Data sources are provided, where appropriate.

*The SSC recognizes that considerable thought has gone into developing a statistically sound definition of marine heat waves based on excursions above the mean temperature for a given time of the year at a given place. **The SSC suggests that it would be useful to consider that different species may react differently to a given temperature**regardless of location and time of year. Is there a need, and a way, to present marine heat waves in relation to the temperature sensitivities of the species of concern?*

ESR authors believe the role of the ESR is to provide whole-ecosystem context. We work closely with ESP teams as those documents are developed and produced and believe ESPs are a more appropriate report for documenting species-specific thresholds.

For stock assessments that do not have ESPs, the ESR authors will continue review species-specific reference temperatures and/or phenology (spawning, egg development, hatching timing, location, growth curves) for discussion with the stock assessment authors for risk table determinations..

The SSC understands the challenges of reporting zooplankton to species in the Rapid Assessments. That said,

the SSC suggests that additional information indicating the abundance of key copepod species that are large and lipid-rich at later stages (C4 or C5) would be valuable

ESR Editors communicated this recommendation to AFSC zooplankton expert, David Kimmel. Below is Dr. Kimmel's response:
"We agree with the SSC that additional information on key copepod species that are lipid rich and in the C4/C5 stage would be useful. We Will determine if our large copepod time-series correlates with key species, such as Calanus glacialis, later in the year. Identifying copepods at sea is simply not possible given the time and expertise necessary to carry out such a task across multiple ecosystem surveys."

For indicators that do not have any updated data in 2022 (e.g., groundfish surveys, Steller sea lion surveys), ***the SSC recommends that the authors are consistent in providing headers but omit repetition of data****that was presented in the prior year without any additional updates*

The ESR editors will be consistent in not including contributions that have not been updated since the previous year's ESR. Where appropriate, we will provide headers identifying contribution that were not updated but are expected to return when new data are available. While the ESR has been largely successful in working with our collaborators to include present year data, there are still some contributions that are 1 year lagged due to data analysis requirements or the delayed availability of survey data.

BSAI Ecosystem Status Reports

Aleutian Islands

Most climate indices were within their expected ranges and did not present issues of concern to fisheries management. However, sea surface temperatures (SST) remained high in 2022 throughout the AI, with temperatures above the 1985-2014 mean. As in the past, marine heat waves were recorded throughout the Aleutian passes, with especially strong heat waves in the central and western Aleutians. ***This was the warmest year on record for SSTs in the western Aleutians****; mid-water and bottom temperatures were above average, as they have been since 2014. The heatwave in the western Aleutians raised surface-water temperatures close to 11-11.5° C, the upper limits observed during and after Atka mackerel spawning.*

We will continue to track maximum temperatures across all temperature sources as we ll as identify (when possible) their location and timing within the ecosystem to compare them to important biological areas/ periods. This year we are also reporting on two recent papers large scale changes in sea surface temperature, the information is included in this year's Noteworthy.

The AI region was surveyed in 2022 by bottom trawl for the first time since 2018. In 2022, as in recent past surveys, several groundfish species had low weights-at-length ***Since 1985, there appears to be a downward trend in this condition index for Pacific cod, Pacific ocean perch, northern rockfish, and arrowtooth flounder, though the statistical significance of these apparent trends has not been tested.*** *The authors suggest two possible sources of increasing competition for prey: East Kamchatka pink salmon and Pacific ocean perch (POP), both of which have been increasing in recent years. Increased competition is supported by the apparent negative impacts on timing of nesting and reproductive success of seabirds at Buldir Island associated with high densities of East Kamchatka pink salmon in odd-numbered years.* ***NOAA bottom-trawl surveys in the Aleutians are only conducted in even-numbered years, so it has not been possible to determine if fish condition shows an alternating year pattern, which would also support the possibility of Russian pink salmon as a significant source of competition.*** *The SSC suggested that additional information from odd years would allow for better understanding of the impacts of high densities of pink salmon on the AI ecosystem. One example would be to conduct additional AI trawl surveys in odd years (even if for a limited period of time) in addition to conducting trawl surveys in the AI in even years. Recognizing the limitations of funding for surveys (the SSC did not discuss this suggestion in the context of survey prioritization), other research could also be* *informative. For example, archived otoliths from groundfish in the AI may be available to examine annual growth patterns*

The authors have included a preliminary analysis of Pacific cod stomachs and commented on the timing of changes in prey in relation to east Kamchatka pink salmon, changes in rockfish abundance and changes in temperature. While there is no diet or fish condition information in odd and even years, east Kamchatka pink salmon had a step increase in abundance in 2009 for high abundance years and had peak abundances for low abundance years in 2016 and 2018 that can be compared to trends in the diets. This information is included in this year's Noteworthy.

The marine ecosystems of the western and central Aleutian Islands (e.g., the Delarof, Rat, and Near Islands) have been changing. To the west of Samalga Pass, Steller sea lion counts continue to show little or no sign of recovery. In addition to declining condition indices, there have been major declines in the abundances of cormorants and other breeding seabirds, harbor seals, Steller sea lions, and sea otters. The cause(s) of these declines are not known. The species involved are not commercially harvested, and the implications for the continued productivity and management of commercial fisheries are unclear. ***The SSC encourages efforts to explore mechanistic and food-web links for these observed trends, prioritizing diet data when samples are available.***

We conducted a preliminary analysis of Pacific cod diets which may offer some insights. Preliminary results show a transition in the ratio of fish to invertebrates in the diet composition with fish contributing a higher proportion of the diet at the beginning of the time series, and invertebrates contributing a higher proportion towards the end of the timeseries.

Other trends to note are continued harmful algal blooms in the Unalaska area, with toxin levels above those which are toxic to humans (3x the legal limit). The level of toxins in shellfish in other areas of the Aleutians is not known. Also, in the eastern and central AI, school enrollments are dropping, which may affect the stability of these AI communities and could be of concern to the Council, as the fishing industry is dependent on these communities for processing and logistic support.

Some samples have been taken in the central Aleutians where no HABs were found, however neither the central nor the Western Aleutians are regularly sampled.

We continue to monitor and report on school enrollment as part of the report cards for the central and western Aleutians.

Weather predictions for 2022–2023 indicate that there is a 76% chance of La Niña conditions during December–February 2022–23, with a transition to ENSO-neutral favored in February–April 2023 (57% chance). It is expected that the PDO will continue to be negative and that warm conditions in the western Aleutians will persist.

We provide an update on the conditions and predictions for this year. Conditions met the criteria for El Niño in June of this year according to the Climate Prediction Center, National Centers for Environmental Prediction, National Weather Service.

October 2023 SSC Draft Report to the NPFMC
C-1 BSAI Crab
Ecosystem Status Report Preview

The SSC received presentations by Elizabeth Siddon (NOAA-AFSC), Bridget Ferriss (NOAA-AFSC), and Ivonne Ortiz (U. Washington) previewing the Ecosystem Status Reports (ESR) for the Eastern Bering Sea (EBS), the Gulf of Alaska (GOA) and the Aleutian Islands (AI), with specific attention to indicators that may be influential to consider for crab stock assessments. ***The SSC appreciates the effort to provide this information at the October meeting as data are still incoming and being incorporated.*** *The SSC looks forward to the full ESR in December.*

Thank you. We appreciate the opportunity to participate in your October meeting

Generalized summaries were provided for the GOA and AI ESRs. No ecosystem concerns were identified for the GOA, and the author noted ocean temperatures remain near the long-term average with mixed pelagic feeding conditions for adult groundfish.

For the AI, warming conditions persisted, characterized by high sea surface temperatures, with the winter of 2022/23 representing one of the warmest on record since 2013. The strongest effects of this warming were present in the western and central AI. ***The SSC suggested information on which species are most vulnerable to these persistent conditions would be helpful for understanding ecosystem impacts.***

There has not been a formal vulnerability assessment for the AI, and there are no ESPs for stocks in the Aleutian Islands. Instead, we review the trends of environmental conditions changing the most, review literature (or new ongoing studies) for temperature/ habitat or other environmental species-specific information and evaluate the risk in the ecosystem. We address some of the current vulnerabilities in this year's Noteworthy. Also, the visual summaries for each risk table review in detail all species-specific relevant information (environment, prey, predator and competitors) and a written documentation on these conditions and relevance to the species is provided to the stock assessment authors. While we also consider the trait-based climate vulnerability assessment by (Spencer et al., 2019), we use current and other contextual information to update their findings, e.g. the sensitivity and vulnerability of Pacific cod was assessed as low, however (Laurel and Rogers, 2020) found the optimal thermal envelope for Pacific cod egg hatching is between 3-$6°$C

Report Card Indicator Descriptions

The suite of indicators that form the basis for the Aleutian Islands Report Cards was selected to provide a comprehensive view of the Aleutian Island ecosystem reflecting across trophic levels from the physical environment to top predators and humans, as well as both the nearshore and offshore environments. Ideally, they would be regularly updated across all ecoregions (Western, Central and Eastern), thereby characterizing a global attribute with local conditions. Although a single suite of indicators was chosen for the entire ecosystem, not all are available or applicable in each of the three ecoregions. The final selection reflected the limitations of available data sets for the Aleutian Islands ecosystem.

1. North Pacific Index Nov-Mar mean
2. Reproductive anomalies of planktivorous least auklet and crested auklets as indicators of zooplankton productivity
3. Proportions of Ammodytes, gadids, and hexagrammids in tufted puffin chick diets
4. Apex predator and pelagic forager fish biomass indices
5. Steller sea lion non pup counts (juveniles and adults)
6. Percent of shelf <500m deep trawled
7. K-12 enrollment in Aleutian Islands schools

North Pacific Index (NPI) winter average (Nov-Mar):

The North Pacific Index (Trenberth and Hurrell, 1994), the area weighted mean sea level pressure over the region was selected as the single most appropriate index for characterizing the climate forcing of the Bering Sea. The NPI is a measure of the strength of the Aleutian Low, specifically the area-weighted sea level pressure (SLP) for the region of 30° - 65°N, 160°E - 140°W. Above (below) average winter (November - March) NPI values imply a weak (strong) Aleutian Low and generally calmer (stormier) conditions.

The advantage of the NPI include its systematic relationship to the primary causes of climate variability in the Northern Hemisphere, especially the El Ni no-Southern Oscillation (ENSO) phenomenon, and to a lesser extent the Arctic Oscillation (AO). It may also respond to North Pacific SST and high-latitude snow and ice cover anomalies, but it is difficult to separate cause and effect.

The NPI also has some drawbacks: (1) it is relevant mostly to the atmospheric forcing in winter, (2) it relates mainly to the strength of the Aleutian Low rather than its position, which has also been shown to be important to the seasonal weather of the Bering Sea (Rodionov et al., 2007), and (3) it is more appropriate for the North Pacific basin as a whole than for a specific region (i.e., Bering Sea shelf).

Implications: For the Bering Sea, the strength of the Aleutian Low relates to wintertime temperatures, with a deeper low (negative SLP anomalies) associated with a greater preponderance of maritime air masses and hence warmer conditions. It has been suggested that correlations between a strong Aleutian Low and decreased seabird productivity in the Aleutian Islands may be due to decreased prey (zooplankton) availability (Bond et al., 2011). Also, stormier conditions may make seabird foraging more difficult for both surface-feeding and pursuit-diving seabird species. The winter index is the average NPI from November through March (year of January), and the anomalies are normalized by the mean (8.65) and standard deviation (2.23) for 1961-2000. Data is updated every month, indicator is updated annually.

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Reproductive anomalies of planktivorous least auklet and crested auklets

Least auklets (*Aethia pusilla*) and crested auklets (*A. cristatella*) are small, abundant seabirds that nest in the Aleutian Islands. The USFWS stations field biologists to monitor auklet chick diets and reproductive success annually at Buldir Island and less frequently at other islands on which they occur. Both species are planktivorous and dive to capture their prey. Least auklet chick diets are mainly composed of *Neocalanus cristatus*, *N. plumchrus*, and *N. flemingeri*. Crested auklet chick diets consist of mainly Euphausiacea and *N. cristatus*. Due to the lack of time series of direct measurements of zooplankton in the Aleutian Islands, the team selected reproductive anomalies of least and crested auklets as indicators of copepod and euphausiid abundance, respectively. Reproductive anomalies were selected as the metric of interest instead of chick diets because reproductive success is an integrative indicator of ecosystem productivity and forage for planktivorous commercially-fished species. Surveys are conducted on an annual basis.

Reproductive success is defined as the ratio of number of nest sites with a fledged chick to the number of nest sites with eggs. In the Western ecoregion, reproductive success of least and crested auklets have been recorded annually at Buldir Island with the exception of 1989, 1999 and 2020. In the Central ecoregion, reproductive success was monitored annually at Kasatochi Island from 1996-2007. In 2008 a volcanic eruption covered the monitored colony in ash, disrupting breeding. This indicator was dropped in 2020 as it is unknown when auklets will nest there again and if so, whether observations will continue. Data were provided by the Alaska Maritime National Wildlife Refuge.

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Proportions of hexagrammids, gadids, and Ammodytes *in tufted puffin chick diets*

Tufted puffins (*Fratercula cirrhata*) are medium-sized seabirds that nest in varying densities throughout the Aleutians. The USFWS stations field biologists to monitor puffin chick diets annually at Buldir and Aiktak Islands (Figure 5) and less frequently at other Aleutian islands on which they occur. Puffins carry multiple prey items in their bills when they return to their colonies to feed their chicks. Forage fish and squid comprise most of puffin chick diets. In the absence of direct measures of forage fish abundance, time series of percent biomass of hexagrammids, gadids, and *Ammodytes* in puffin chick meals were selected as indicators of forage fish recruitment and system-wide productivity. Surveys are conducted on an annual basis.

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Apex predator and pelagic forager fish biomass indices

We present two foraging guilds to indicate the status and trends for fish in the Aleutian Islands: apex predators and pelagic foragers. Each is described in detail below. This guild analysis was based on the time series available as part of the NOAA summer bottom trawl survey for the Aleutian Islands (Western and Central ecoregions) and the Aleutian Islands and Gulf of Alaska combined (Eastern ecoregion). These two guilds are based on the aggregation of Aleutian species by trophic role, habitat and physiological status. The species included in each guild are listed in Table 3.

Time series for the Western and Central ecoregions are based on data collected from the AI bottom trawl survey, which is conducted every other year during even years. The Eastern ecoregion time series is a composite of the Aleutian Islands survey, which samples the northern portion of the islands, and the Gulf of Alaska survey, which samples the southern portion. Since surveys in these two areas are conducted in different years, the biomass estimates represent the closest pair of years pooled together to get a total biomass estimate for the shelf region

Table 3: Species included in foraging guild-based fish biomass indices for the Aleutian Islands

Fish Apex Predators	Pelagic Fish Foragers
Pacfic cod	Atka mackerel
Pacific halibut	Northern Rockfish
Arrowtooth flounder	Pacific ocean perch
Kamchatka flounder	Walleye pollock
Rougheye rockfish	
Blackspotted rockfish	
Large sculpins	
Skates	

(0-500m). This time series excludes deep-water species such as sablefish and grenadiers, as most are found deeper than the trawl survey samples. The Team acknowledges that these would be good to include, but that the trawl survey does not sample them well.

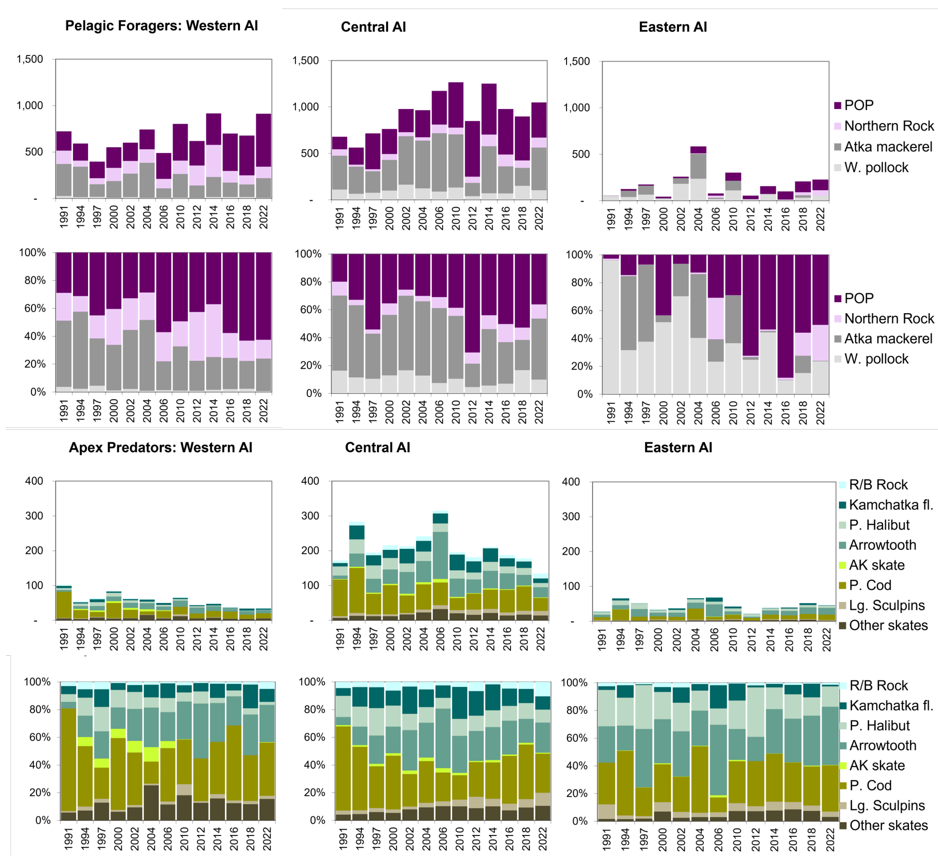

Figure 48: NOAA Alaska Fisheries Science Center's human dimensions indicators mapping

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Steller sea lion non pup counts

Counts of adult and juvenile Steller sea lions (*Eumetopias jubatus*) are used in the Aleutian Island ecosystem assessment to represent the status of an apex piscivorous predator whose diet consists primarily of commercially-fished species. The Steller sea lion inhabits coastal regions of the North Pacific Ocean, breeding in summer on terrestrial rookeries located from California north throughout the Gulf of Alaska, the eastern Bering Sea, the Aleutian Islands, Kamchatka Peninsula, Sea of Okhotsk, and the Kuril Islands (NMFS, 2010). The Steller sea lion is the world's largest member of the Otariidae family of pinnipeds. On average, Steller sea lions consume 6-10% of their body weight per day, but during lactation, energy intake by adult females may increase by as much as 3-fold (Keyes, 1968; Winship et al., 2002; Williams, 2005). Steller sea lions are generalist predators and consume a wide variety of fish and cephalopods in habitats ranging from nearshore demersal to offshore epi-pelagic, with local diets reflecting the species composition of the local fish community (Pitcher and Fay, 1982; Riemer and Brown, 1997; Sinclair and Zeppelin, 2002; Waite and Burkanov, 2006; Trites et al., 2007; McKenzie and Wynne, 2008; Fritz and Stinchcomb, 2005). In the Aleutian Islands, the diet consists largely of Atka mackerel, followed by salmon, cephalopods, Pacific cod, sculpins and walleye pollock (Sinclair and Zeppelin, 2002). Unlike phocid pinnipeds, otariids do not have large blubber (energy) stores, and as a consequence, require reliable access to predictable, local prey aggregations to thrive (Williams, 2005; Sigler et al., 2009).

Status and trend of Steller sea lion populations in Alaska are assessed using aerial photographic surveys of a series of 'trend' terrestrial haul-outs and rookeries that have been consistently surveyed each summer breeding season, when the proportion of animals hauled out is the highest during the year (Sease and York, 2003). Since 2004, NMFS has used high-resolution vertical photography (computer-controlled camera mounted in the belly of the plane) in its sea lion surveys in Alaska. This replaced the oblique, hand-held photographic techniques used from the first surveys in the 1960s and 1970s through 2002. Counts from vertical high resolution photographs were found to be 3.6% higher than those from oblique photos, necessitating the use of a correction factor to correctly compare recent counts with the rest of the time series (Fritz and Stinchcomb, 2005). Trend sites include the vast majority (>90%) of animals observed in each survey. Adults and juvenile (non-pup) numbers used for population trend assessment are sums of counts at trend sites within sub-areas or across the range of the western DPS in Alaska (NMFS, 2010). Replicate surveys conducted in the summers of 1992 and 1994 indicated that sub-area trend site counts of non-pups are stable within each breeding season (coefficients of variation of ∼5%; NMFS, unpublished data).

In our Aleutian Island ecosystem assessment, estimated counts of adult and juvenile Steller sea lions at trend sites are used to indicate of the 'health' of apex piscivores whose diet consists primarily of commercially-fished species. The estimated counts are updated annualy. The survey sites used in the assessment are:

- Western (172-177°E; 10 sites in the Near Island group and Buldir west of Kiska),
- Central (177°E to ∼170°W; 62 sites in the Rat, Delarof, and Andreanof Island groups, plus the Islands of Four Mountains), and
- Eastern ecoregions (163-170°W; 30 sites in the Fox and Krenitzin Islands, on Unimak Island, and on and near Amak Island in the southeastern Bering Sea)

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Habitat disturbance from trawls

This indicator uses output from the Fishing Effects (FE) model to estimate the habitat reduction of geological and biological features over the Bering Sea domain, utilizing spatially-explicit VMS data. The effects are cumulative, incorporating both estimated recovery time and disturbance. The time series for this indicator is available since 2003, when widespread VMS data became available. The monthly value in December is used as an annual indicator, which is updated anually.

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K-12 enrollment in Aleutian Islands schools

The number of children enrolled in schools was selected as an indicator of vibrant, sustainable communities in the Aleutian Islands ecosystem. Community residents are closely tied to the ecosystem through sense of place and daily experience and activity. Enrollment statistics for kindergarten through twelfth (K-12) grades by school and region were compiled for the years 1996 through 2014 (`http://www.eed.state.ak.us/stats/`). School enrollment numbers fluctuate widely and serve to highlight the difficulties in maintaining sustainable communities within the Aleutian Islands ecosystem. Enrollment statistics are updated annually.

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Methods for the Report Card Indicators

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

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

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