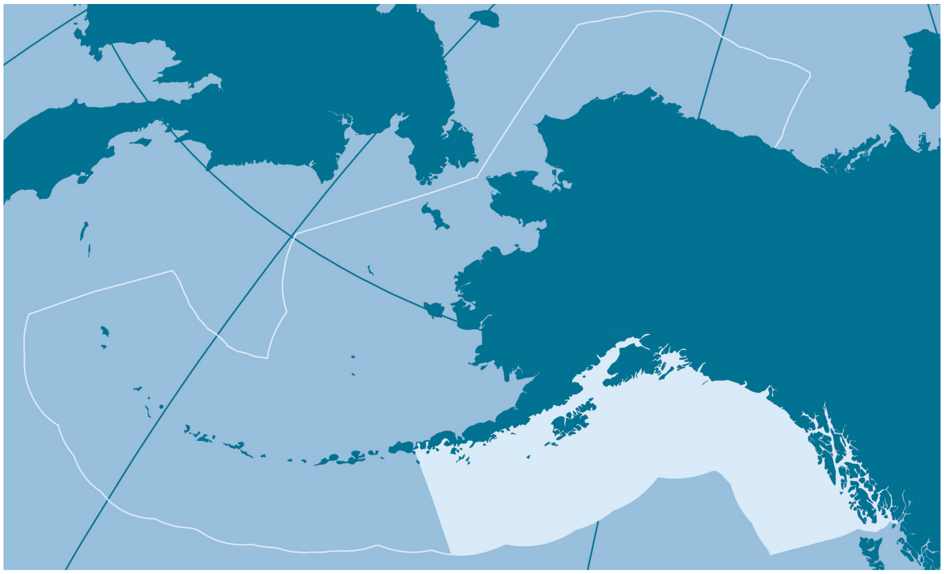
Ecosystem Status Report 2024

GULF OF ALASKA



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QR code for NOAA Alaska Fisheries Science Center's Ecosystem Status Reports webpage[1]. Time series from the report cards are also available[2].

[1] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

[2] https://alaskaesr.psmfc.org

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 (Figure 1).

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[3,4]. 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.247).

[3] https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf
[4] https://www.npfmc.org/wp-content/PDFdocuments/fmp/BSAI/BSAIfmp.pdf

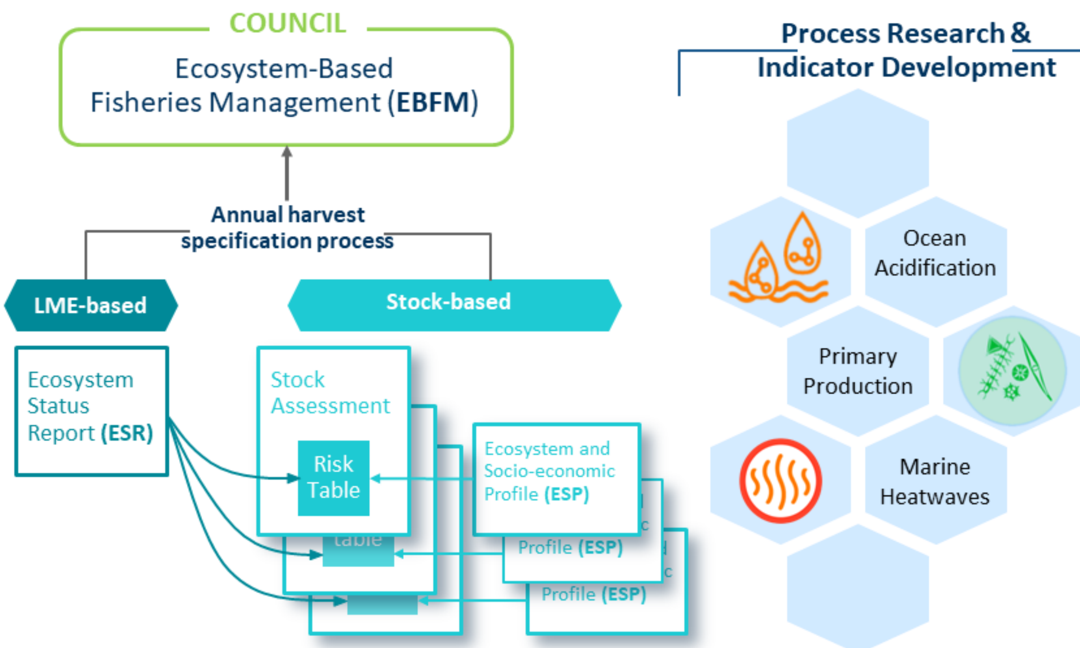

Figure 1: NOAA Fisheries' ecosystem information mapping to support ecosystem-based fisheries management through Alaska's annual harvest specification process. The 'honeycomb' on the right shows examples of ecosystem indicators that are provided to Ecosystem Status Reports (ESRs) at the large marine ecosystem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

Western Gulf of Alaska 2024 Report Card

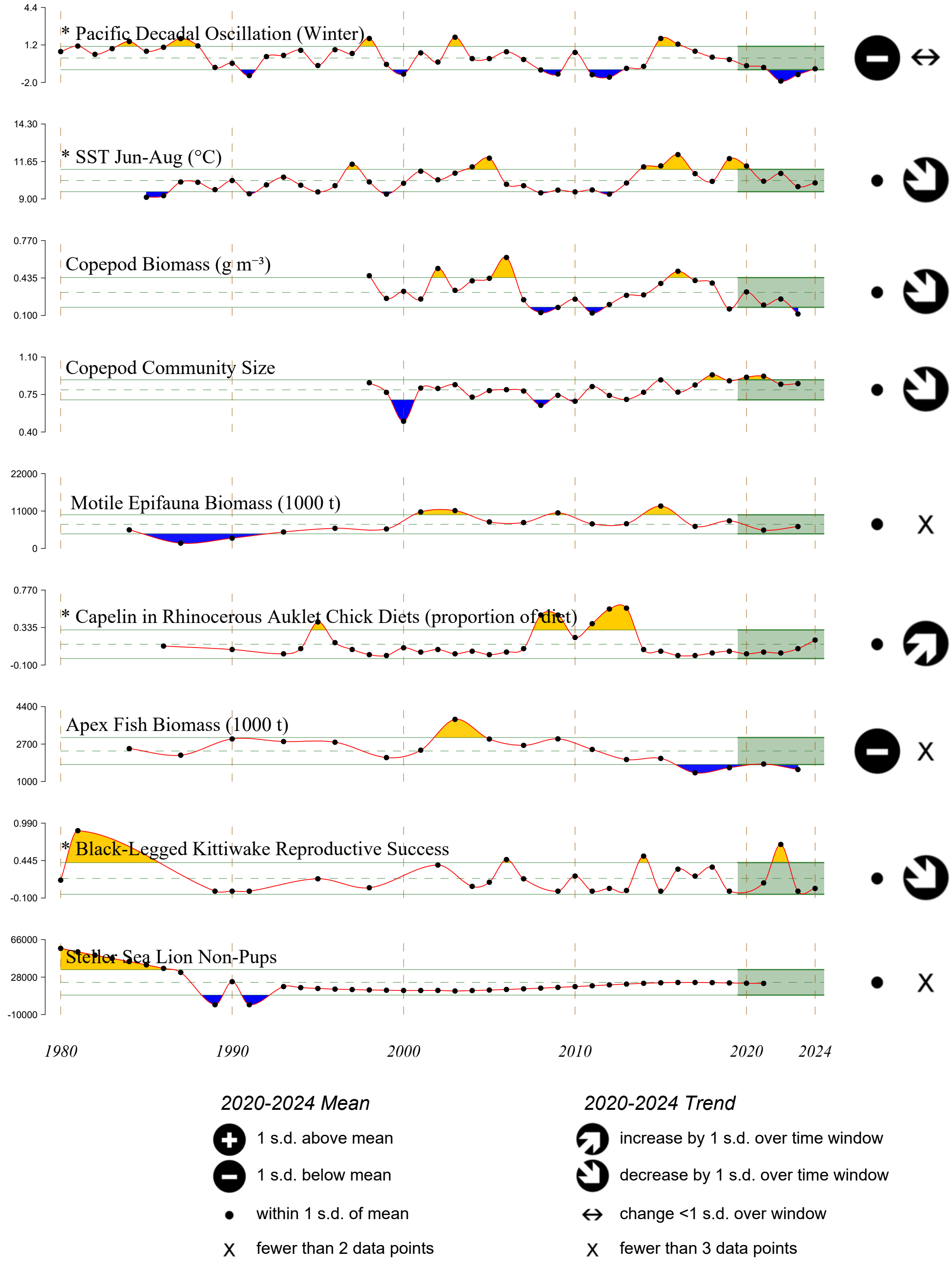

Figure 2: Western Gulf of Alaska report card indicators. For additional information on these indicators, refer to "Report Card indicator Description and Methods" in the Appendix 3 of this Report (p.256) and relevant contributions in this Report. * Indicates time series updated with 2024 data.

Eastern Gulf of Alaska 2024 Report Card

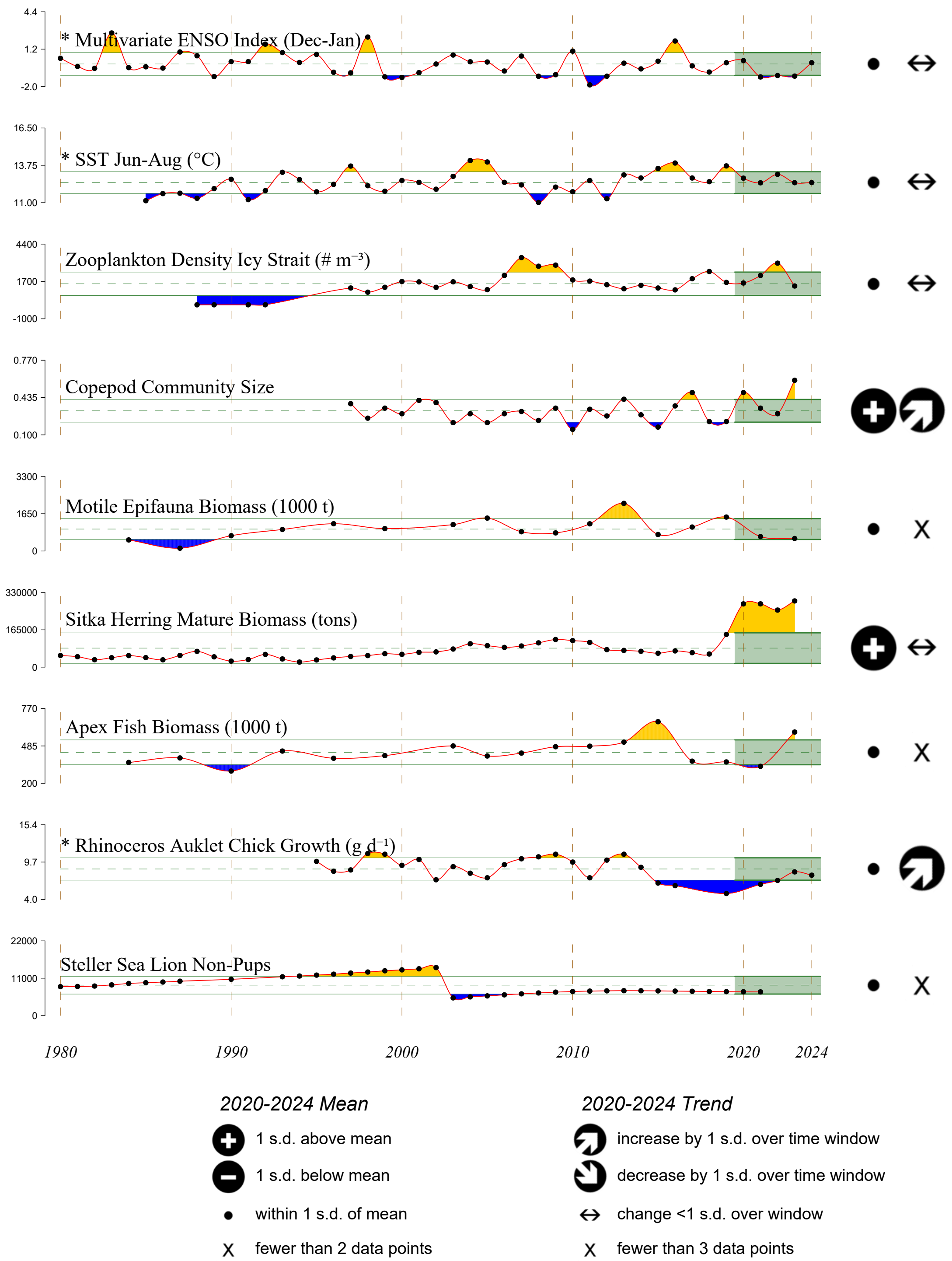

Figure 3: Eastern Gulf of Alaska report card indicators. For additional information on these indicators, refer to "Report Card indicator Description and Methods" in the Appendix 3 of this Report (p.256) and relevant contributions in this Report. * Indicates time series updated with 2024 data.

Western Gulf of Alaska 2024 Report Card

For more information on individual Report Card indicators, please see "Report Card indicator Description and Methods" in the Appendix of this Report (p.256).

- **Winter average PDO index** (Dec.-Feb., 1980 – 2024) continued its negative trend in 2024, despite a positive ENSO index (El Niño event).
- **Sea-surface temperatures in the summer (°C)** (Jun.-Aug.) in the western GOA were approximately average (baseline 1985 – 2024), slightly warmer than 2023.
- **Copepod biomass (g m^{-3})** was one standard deviation below average (1998 – 2023) in 2023, indicating below average foraging conditions for planktivorous predators. Total (large and small) calanoid copepods are surveyed south of Seward in May of each year. Euphausiid biomass was above average during the same time period. These data have not been updated since 2023.
- **Copepod community size** (ratio of large calanoid copepods to total calanoid copepods) remained elevated in 2023, close to one standard deviation above average (1998 – 2023), indicating increased large copepods in the community, relative to small copepods. Total (large and small) calanoid copepods are surveyed south of Seward in May of each year. These data have not been updated since 2023.
- **Motile epifauna biomass (1,000 t)** increased from 2021 to 2023 and is near the long-term mean (1984 – 2023). The biomass of this guild is dominated by hermit crabs, brittle stars, other echinoderms, and octopus. In 2023, brittle star biomass declined from 2021 while the biomass of hermit crabs, octopus, and other echinoderms all increased. These data have not been updated since 2023 due to biennial NOAA bottom trawl surveys.
- **Capelin abundance (proportion of diet by weight)**, as sampled by rhinoceros auklets at Middleton Island (Apr.-Aug., 1986 – 2024), continued a multi-year increase in seabird chick diets to slightly above the long-term mean, reflecting a continued rebounding capelin population in the GOA.
- **Fish apex predator biomass (1,000 t)** decreased from 2021 to 2023 and is more than one standard deviation below the long-term mean (1984 – 2023). The biomass trends for apex predators, as sampled by NOAA's bottom trawl survey, are primarily driven by arrowtooth flounder, Pacific cod, Pacific halibut, and sablefish. In 2023, arrowtooth flounder, Pacific halibut, and sablefish all declined from 2021 and are below their long-term means. Sabelfish surveyed biomass declined due to the shift of large young year classes maturing and moving to deeper slope habitat, out of the survey area. Pacific cod biomass increased from 2021 to 2023 but remain below their long-term mean. These data have not been updated since 2023 due to biennial NOAA bottom trawl surveys.
- **Black-legged kittiwakes reproductive success** in June-July, 2024 at the Semidi Islands, slightly increased from the reproductive failure of 2023 but remain well below the long-term average (1980 – 2023).
- **Western Gulf of Alaska Steller sea lion non-pup** model predicted counts continued a slightly decreasing trend from previous years, remaining within one standard deviation of the long-term mean (1980 – 2021). These data have not been updated since 2021 due to lack of GOA surveys.

Eastern Gulf of Alaska 2024 Report Card

- **Multivariate ENSO Index** was positive, El Niño conditions in 2024, after three consecutive La Niña (negative ENSO index) winters. The ENSO transitioned to neutral values in the spring of 2024 and is predicted to develop a negative index value (La Niña) in the fall of 2024.
- **Sea-surface temperatures (°C)** in the summer of 2024 (Jun.-Aug.), were approximately average (1985 – 2023) in the eastern GOA.
- **Total zooplankton density (# m^{-3})** in southeastern Alaska inside waters (May-Aug.) decreased from one standard deviation above long-term mean (baseline 1988 – 2023), to average, including a decrease in calanoid copepods. Euphausiid densities remained above average. This suggests below-average foraging conditions for planktivorous fish, seabirds, and mammals. These data have not been updated since 2023.
- **Copepod community size** (ratio of large calanoid copepods to total calanoid copepods) increased to one standard deviation above average in 2023 (May-Aug., 1997 – 2023). The copepod community is sampled in Icy Strait (southeast Alaska Inside waters). This suggests above-average quality zooplankton prey in SEAK inside waters (but at lower biomass). These data have not been updated since 2023.
- **Motile epifauna biomass (1,000 t)** has decreased from 2021 to 2023 and is below the long-term mean. Eelpouts, hermit crabs, brittle stars, and other echinoderms are dominant components of this guild. Brittle stars have decreased from 2021 to 2023 and are one standard deviation below their long-term mean, while eelpouts, hermit crabs, and other echinoderms have increased from 2021 to 2023. These data have not been updated since 2023 due to biennial NOAA bottom trawl surveys.
- **Estimated total mature herring biomass (age 3+) of Sitka herring** in spring 2023 remains one standard deviation above average (1980 – 2023) continuing a 5 year trend of the largest values in the time series (since 1980) due to strong 2016 and 2020 year classes. The two populations with ocean influence (Sitka Sound and Craig) were elevated while populations in southeastern AK inner waters and Prince William Sound increased but remained low. These data have not been updated since 2023.
- **Fish apex predator biomass (1,000 t)** has increased 79% from 2021 to 2023 and is more than one standard deviation above their long-term mean. Apex predator biomass in the eastern GOA is primarily driven by arrowtooth flounder and Pacific halibut, both of which increased in survey-estimated biomass by more than 100% from 2021 to 2023. Pacific cod biomass continued to increase in 2023 from their low in 2017 and are above their long-term mean. These data have not been updated since 2023 due to biennial NOAA bottom trawl surveys.
- **Growth rates of piscivorous rhinoceros auklet chicks in June and July (g d^{-1})** decreased from 2023 and remain one standard deviation below the long-term mean in 2024 (1995 – 2023), reversing a multi-year increasing trend.
- **Eastern Gulf of Alaska Steller sea lion non-pups** model predicted counts continue a decreasing trend, but remain above one standard deviation of the long-term mean (1980 – 2021) through 2021. However, counts suggest that non-pup have been lower than predicted in 2019 and 2017. These data have not been updated since 2021 due to lack of GOA surveys.

Ecosystem Assessment: The Status of the Gulf of Alaska 2024

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Last updated: November 2024

This Assessment reflects the recognition that the western and eastern GOA ecosystems (divided at 147 °W) have substantial differences (Waite and Mueter, 2013; Mueter et al., 2016). The GOA is characterized by topographical complexity, including islands, deep sea mounts, a continental shelf interrupted by large gullies, and varied and massive coastline features such as Cook Inlet, Prince William Sound, Copper River, and Cross Sound, which bring both freshwater and nutrients into the GOA. The topographical complexity leads to ecological complexity, such that species richness and diversity differ from the western to eastern GOA. Thus, local effects of ecosystem drivers may swamp basin-wide signals. With this in mind, we highlight differences in the ecosystem state for the western and eastern GOA ecoregions in the Report Cards and Assessment.

Summary

The Gulf of Alaska's (GOA) marine ecosystem experienced a relatively productive year in 2024, generally higher and more spatially consistent than 2023. The winter El Niño conditions were more moderate than expected, although surface and deeper waters did experience some associated warming. Some highlights of the year include indicators of above average primary and secondary (zooplankton) production, suggesting a good prey base for forage fish, juvenile and plankton-eating adult groundfish, and seabirds. Capelin populations continue to rebound across the GOA, and herring populations continue to persist at relatively high levels in southeast AK. Humpback whale crude birth rates in the eastern GOA recovered to pre-2014 values for the first time since their post marine heatwave decline. Conversely, GOA commercial salmon landings were some of the lowest since 1985, driven by unexpected low returns of pink salmon in Prince William Sound. While the GOA continues to warm over the long term, 2025 is predicted to be cooler than the 1991 – 2020 average due to developing La Niña conditions.

El Niño Winter 2023/2024

The GOA experienced El Niño conditions during the winter and spring of 2023/2024, after three years dominated by La Niña, and is predicted to transition back to La Niña status in the fall of 2024. The El Niño was one of the top five strongest events since 1950, though weaker in strength than the ecologically impactful 1997/1998 and 2015/2016 events. However, the impact of El Niño in the GOA was moderated by its relatively short duration, a reduced potential for increased counterclockwise circulation and northward transport of warm surface waters due to a weak Aleutian Low, and variable/eastward winds in the winter and spring (Lemagie and Bell, p.30). The GOA also did not experience extended warm or marine heatwave conditions, as it did in 2016 when the strong El Niño coincided with additional sources of heat from the North Pacific (i.e. the "Blob").

While the GOA experienced warmer ocean temperatures in the winter and spring, a strong ecological response to warming pressure was not evident in the system. For example, the frequency and extent of harmful algal blooms remained somewhat average (they tend to increase with warm waters) (Farrugia et al., p.175). The intertidal communities retained their local, spatial variation, a pattern that becomes homogenous in the presence of overriding external environmental drivers such as marine heatwaves (Coletti et al., p.183). Seabird productivity was average to above average across the GOA (they can respond negatively to warmer conditions and related impacts on prey resources) (Drummond et al., and Whelan et al., p.152). The potential impact of a warmer first half of 2024 on groundfish recruitment, which could be expected to include strong year classes of rockfish and sablefish (favored by warm spring/summers) or weak year classes of walleye pollock, Pacific cod, and northern rock sole (favored by cool winter/springs), will become apparent when they begin to be observed in surveys, in a few years' time.

Gulf of Alaska Shelf 2024

Ocean surface temperatures were warmer than average across the GOA shelf in the winter and spring, ranging from 4 °C/5 °C (March) to 12 °C/14 °C(Aug) in western and eastern GOA respectively (Lemagie, p.43). The eastern GOA surface temperatures exceeded the marine heatwave threshold for most of Dec.-May, covering up to $\sim$75% of the eastern GOA shelf area, remaining warm through the summer. The warm late spring/early summer surface temperatures in the eastern GOA may have been favorable for feeding and survival conditions of larval sablefish and rockfish. During the western GOA winter, warm surface temperatures cooled more quickly and returned to average by March (Lemagie and Callahan, p.43). The warm late winter and early spring surface temperatures did not appear to exceed egg and larval temperature thresholds of early spring spawners (e.g., walleye pollock, Pacific cod, northern rock sole) and may have favored their growth.

The warming of deeper shelf waters in the western GOA appeared to be limited, due to decreased coastal downwelling that would transport heat to depth and the resulting potential for increased incursion of cooler, more saline, lower dissolved oxygen slope waters onto the shelf in the western and northern GOA (Pages and Hauri, p.64). Spatially limited surveys observed some moderate heat at depth in the spring (central GOA, Danielson, p.43) and summer (southeast AK inside waters, Fergusson, p.43), but not in January in Shelikof Strait (Jones et al., p.43).

Increased winter and spring counter-clockwise circulation and surface transport were reflected in numerous metrics, as expected with El Niño events. It is likely the circulation could have been even stronger if the Aleutian Low was stronger and anomalous winter/spring eastward winds were not present to moderate the westward flow. Eddies were stronger than usual along the shelf edge in the regions off Kodiak and Haida Gwaii (Cheng, p.56). The modeled northward surface transport in southeast AK, from the Papa Trajectory Index, increased from weaker (2023) to the long-term average (2024) (Stockhausen, p.61). The GAK1 mooring (near Seward) measured lower salinity in the surface waters, reflecting increased transport of freshwater from southeast AK (Danielson, p.72). The larval survival of slope spawning arrowtooth flounder, Pacific halibut, and rex sole may have increased due to transport to preferred coastal habitat.

The spring oceanographic conditions supported high energy transfer through the base of the food web. The phytoplankton community was dominated by the larger celled diatoms (Hennon p.70), similar to 2021 and 2022, and higher than 2023. Diatom production is supported by upwelling in the central GOA gyre, bringing nitrate-rich waters to the surface and onto the shelf through increased advection (Conte et al., 2024). The Northern Gulf of Alaska Oscillation index measures upwelling at the center of the Gulf gyre, which was positive (weaker upwelling) in January and February, but then negative (stronger upwelling) in the spring, supporting this theory (Pages, p.64). Strong diatom production supports larger, more energy rich zooplankton species (euphausiids and copepods), verified by an increase in observed spring euphausiid biomass in Seward Line surveys (Hopcroft, p.83). The resulting above-average spring zooplankton biomass provided good prey resources for zooplankton-eating adult groundfish (e.g., walleye pollock, Pacific Ocean perch, dusky and northern rockfish), and larval/juvenile groundfish. Planktivorous seabird reproductive success, an indicator of zooplankton availability and nutritional quality, was above average across the GOA, and increased from 2023 (Drummond et al., and Whelan et al., p.152).

The GOA forage fish populations varied across the GOA but were generally average to above average in 2024 (similar to 2023). Capelin continues to rebound from a population decline during the 2014 – 2016 marine heatwave (McGowan et al., p.101, Arimitsu et al., p.96), which is beneficial for seabirds, marine mammals, and piscivorous groundfish. Also, herring continue to have relatively elevated populations supported by the strong 2016 and 2020 year classes (Hebert and Dressel, p.105, Morella et al., p.188). Forage species that are relatively lower in abundance include eulachon, sand lance, and juvenile salmon (Arimitsu et al., p.96, Pochardt et al., p.109). The reproductive success of fish-eating seabirds was variable but generally above average across the GOA reflecting adequate prey availability for groundfish with forage fish in their diets (e.g., P. cod, sablefish, and arrowtooth flounder; Drummond et al., and Whelan et al., p.152).

The GOA 2024 commercial salmon fishery landings were within the five lowest years since 1985, largely driven by low pink salmon returns. The returns of pink salmon were unexpectedly low, primarily in Prince William Sound, while southeast AK was the exception, meeting its 2024 forecast (Whitehouse, p.113, Vulstek et al., p.124, Strasburger et al. p.116). Potential reasons driving the low returns include (a) reduced early marine survival in 2023, due to low zooplankton biomass, including evidence of smaller average length and lower body condition of juvenile pink salmon in 2023 in SEAK (Yasumiishi, 2023; Fergusson and Strasburger, 2023); and (b) poor survival of juveniles/adults in their offshore habitat due to poor ocean conditions and/or increased competition with the strong odd year class of pink salmon in this oceanic region (environmental and prey conditions are unknown) (Ferriss, p.26).

Multi-year Trends/ Community Dynamics

Oceanographic trends reveal long-term unidirectional changes in the GOA (with interannual variation), while ecological communities reflect less predictable, multi-year shifts in dynamics. The GOA shelf's long-term sea surface temperature continues to increase from 1900 through 2024, across the winter and summer months (Thoman, p.43). Temperatures at depth in the central GOA (200m – 250m) have increased since at least 1975 (GAK1 mooring, Danielson, p.72). Over the same 50 year time period, stratification has increased (reducing vertical mixing in the water column), and salinity has decreased at the surface (fresher water) while increasing at depth (more saline waters) (GAK1, Danielson, p.72). The decreased surface salinity suggests increased transport of the Alaska Coastal Current during fall, winter and spring months, coupled with potentially higher freshwater runoff (Danielson, p.72).

The GOA's marine communities continue to reflect a mixture of short- and long-term dynamics. While some species' populations respond within the same year to environmental changes (e.g., zooplankton), others have a more lagged response that manifests after a few years of consistent conditions. In the past 10 years, the GOA has experienced marine heatwave-dominated years (2014 – 2016 and 2019), followed by three consecutive La Niña years (2020 – 2023) that brought a cooling pressure, an El Niño event in 2024 with moderate warming, and a predicted return to La Niña in 2025. Explorations of shifts in ecosystem states around 2014 within Gulf of Alaska marine ecosystems have mixed results (Suryan et al., 2021; Litzow et al., 2020) but perhaps due to differences in spatial scales and species studied. Ferriss et al. (Submitted) analyzed indicators primarily used in the Gulf of Alaska Ecosystem Status Report, and concluded that a community shift occurred around 2014 in most components of the eastern and western GOA (oceanography, lower-trophic, mid-trophic, seabirds), largely persisting through 2022. At a species-level, some populations that were greatly reduced due to the 2014 – 2016 marine heatwave are still responding to that event. Pacific cod and sand lance populations remain depressed. The capelin populations were observed to continue rebounding in 2024 for a second year, and the crude birth rate of humpback whales increased to pre-2014 levels in southeast Alaska for the first time. While population dynamics of humpback whales may have contributed to their lagged recovery, the elevated herring and euphausiid populations (and reduced pink salmon predation on zooplankton) provided a good prey base for them in 2024. Other populations that experienced strong year class survival and resulting population increases from the 2014 – 2016 marine heatwave are transitioning away from that event, including the shift of large young cohorts of sablefish off the shelf as they age (Goethel and Cheng, 2024), and reduced Tanner crab biomass as the large 2016 cohort declines (Worton, p.128).

There have been longer-term (beyond 10 years) changes in relative biomass of the top groundfish species, as estimated by NOAA's bottom trawl survey (last surveyed in 2023; Callahan p.139). Pacific ocean perch biomass has been increasing, and the once-dominant arrowtooth flounder has been decreasing, since approximately 2003. Pacific ocean perch replaced arrowtooth flounder as the top groundfish biomass in 2017. Arrowtooth biomass has been slowly increasing in more recent years, along with its predation pressure on key groundfish (i.e., walleye pollock and P. cod; Adams, p.133), but remains in second place. The relatively high biomass of zooplankton predators in the GOA is supported by high biomass of P. ocean perch (highest groundfish biomass), walleye pollock (3rd highest groundfish biomass) and pink salmon in odd years (including high returns in 2021 and 2023). The impacts of this shift in prominent trophic dynamics in the GOA are uncertain.

Looking Ahead to 2025

La Niña conditions are predicted to develop in the fall of 2024 and persist through the winter of 2025. In the GOA, La Niña events are associated with cooling sea surface temperature. Despite the predicted cooling pressure, the Sitka air temperature index predicts integrated water column temperatures at GAK1 (off Seward) to be warmer than average in 2025 (Hennon and Danielson, p.40). This counter-intuitive prediction potentially reflects the delayed onset of La Niña conditions and/or the long-term warming of GAK1 temperatures, with temperatures more consistently above the long-term average (but perhaps less so in 2025). A productive spring zooplankton community and approximately average (baseline 1985 – 2014) temperatures in the fall of 2024 are conducive to potentially favorable groundfish larval growth in 2024 and survival into 2025. The predicted cooling, or slight warming, predicted in the winter and spring of 2025 are generally favorable for adult groundfish in 2025.

Contents

† indicates new contribution
* indicates contribution updated in 2024

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Noteworthy

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

Endangered Species Act and Critical Habitat Petition Updates

Contributed by Julie Scheurer and Jenna Malek, Protected Resources Division, Alaska Region NOAA Fisheries
Contact: julie.scheurer@noaa.gov (North Pacific Right Whale Critical Habitat Update) and jenna.malek@noaa.gov (Gulf of Alaska Chinook Salmon)

North Pacific Right Whale Critical Habitat Update: The Center for Biological Diversity and Save the North Pacific Right Whale submitted a petition to the Department of Commerce to review the areas designated as critical habitat for the North Pacific right whale. NOAA Fisheries, Alaska Regional Office is leading the response to the petition and published a positive 90-day finding in July 2022 that a revision to critical habitat may be warranted. In September 2023, NMFS released a 12-month finding on a petition to revise North Pacific right whale critical habitat. NOAA found that the petitioned action was warranted and have been taking the following steps to identify areas that meet the definition of critical habitat under the ESA:

1. Analyzing all available acoustic data collected in areas recommended by the petitioners and currently designated as critical habitat
2. Assessing spatial and temporal patterns of prey species (i.e., copepods and euphausiids) in conjunction with oceanographic information
3. Analyzing sightings data for evidence of feeding behavior
4. Synthesizing available acoustics data, trends in zooplankton, and sightings data to identify critical habitat areas
5. Conducting and impacts analysis

6. Developing a proposed rule for public comment

As of October 2024, NOAA is still in the analysis process and have begun the impacts analysis.

Gulf of Alaska Chinook Salmon Status Review under the Endangered Species Act: On January 11, 2024, NMFS received a petition from the Wild Fish Conservancy to delineate and list one or more evolutionarily significant units (ESUs) of Chinook salmon *Oncorhynchus tshawytscha* in the Gulf of Alaska (GOA) as threatened or endangered under the Endangered Species Act, and to designate critical habitat concurrently with the listing. On May 24, 2024, NMFS announced a positive 90-day finding on the petition and commenced a status review of the species to determine whether one or more ESU warrants listing (89 FR 45815).

NMFS has convened a team of federal scientists led by the AFSC to collect and analyze the best available scientific and commercial information on the species, including its biology, ecology, abundance and population trends, and threats to the species, in order to evaluate the species' current status and extinction risk. The status review team will develop a peer-reviewed status review report to inform the agency's determination as to whether the petitioned action is warranted.

Within one year of receipt of the petition, NMFS must complete the status review and make a 12-month finding. If, after completing the status review and considering ongoing conservation efforts, NMFS determines that listing is not warranted, a negative 12-month finding will be published in the Federal Register and no further action is taken. Alternatively, if NMFS determines that a listing is warranted, we will publish a positive 12-month finding and proposed rule in the Federal Register and seek public comments on the proposed listing. The status review report, 12-month finding, and proposed rule (if applicable) for GOA Chinook salmon are expected to be completed in early 2025[5].

[5] For updates: `https://www.fisheries.noaa.gov/action/petition-list-gulf-alaska-chinook-salmon-threatened-or-endangered-under-endangered-species`

Low Returns of Pink Salmon in 2024

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Pink salmon returns in the Gulf of Alaska, in 2024, were low relative to usual lower even-year returns, and lower than forecasted (with the exception of southeast AK) (Whitehouse in this Report, p.113, Vulstek et al. in this Report, p.124, Strasburger et al. in this Report, p.116). Pink salmon survival can be influenced by freshwater conditions, early marine survival in the coastal, shelf environment, and adult survival in the oceanic environment in the GOA gyre. The salmon spend one year in the ocean environment before returning to spawn, influenced by previous year shelf and open ocean conditions (e.g., temperature and prey availability). Here we review potential explanations of the low returns in 2024.

There is some evidence that both the nearshore environment and oceanic environment may have contributed to the low pink salmon returns in 2024. Given the low returns of pink salmon affected both wild and hatchery populations, it appears freshwater conditions were not the driving reason behind the low survival. Yasumiishi (2023) summarized how the 2023 early marine environmental conditions for southeast AK juvenile pink salmon were generally less favorable for growth and survival, including lower body condition, low abundance, and shorter fish (Fergusson and Strasburger, 2023). Primary and secondary (zooplankton) production was variable but below average in parts of the GOA, indicating a reduced prey base for pink salmon, but not showing extreme reductions (Ferriss, 2023). The fact that southeast pink salmon AK forecasts were more accurate than other GOA regions, supports some evidence of early marine mortality. Southeast AK forecasts are based on juvenile salmon surveys (integrating some measures of early mortality) whereas other GOA regions' forecasts are derived from adult returns or harvest in the previous brood year (2 years prior), which doesn't integrate any components of early marine mortality for the current year adult returns.

Ruggerone (2024) describes the potential for the near record high abundance of pink salmon in 2023 may have contributed to the low returns in 2024, due to increased competition where they overlap in the GOA oceanic environment (off the shelf). There are few monitoring data to validate the potential for limited prey conditions in the GOA oceanic environment. Ostle and Batten (In this Report, p.77) report below average mesozooplankton biomass and lower biomass of large copepods, relative to smaller copepods in 2023 in the oceanic environment, similar to conditions in 2020 – 2022.

Numerous studies link variation in marine species' diets, condition, growth, and reproduction to competition with pink salmon for zooplankton, squid and forage fish (summarized in Ruggerone et al., 2023). While trophic cascades in marine systems are debated, the biennial pattern of pink salmon brood years (higher returns in odd years and lower in even years) allows for some correlative analyses. Batten et al. (2018) has suggested increased pink salmon can lead to reduced abundance of large copepods (increased grazing pressure) and increased large diatoms (reduced grazing pressure from copepods). Zooplankton-eating seabirds have shown indications of a reduced prey base in years of high pink salmon (higher competition) including reduced reproductive succeed (black-legged kittiwakes, Zador et al., 2013) and reduced condition (short-tailed shearwaters, Toge et al., 2011). Other salmon populations exhibit changes in diet and reduced condition that have been linked to pink salmon competition (Tadokoro et al., 1996; Ruggerone et al., 2003). Total pink salmon biomass (hatchery and natural origin) returning to the GOA in 2015 was approximately 403,566 mt (Ruggerone and Irvine, 2018). The odd year pink salmon abundance has been higher in 2021 and 2023. In comparison, the survey-estaimted biomass of dominant zooplankton predators in the groundfish community include Pacific ocean perch (NOAA bottom trawl survey estimate 1,595,547 mt in 2023) and walleye pollock (NOAA bottom trawl survey estimate 921,866 mt in 2023) (Callahan et al. in this Report, p.139. While pink salmon would have less of a predation impact than these groundfish populations, years of high returns of pink salmon and lower prey abundance could lead to increasde competition among these pelagic foragers. Conversely, years of low pink salmon returns (e.g., 2024) could experience reduced competition for zooplankton, squid, and forage fish prey.

Ecosystem Indicators

Physical Environment

Summary

Climate: The GOA experienced moderate El Niño conditions in the winter and spring of 2023/2024, transitioning to neutral ENSO conditions in spring, and is predicted to enter La Niña in fall 2024. The El Niño event was in the top five strongest on record, but the GOA experienced moderated oceanographic impacts due to its relative short duration, a weaker Aleutian Low, and eastward winter and spring winds that tempered the expected increased counter-clockwise flow in the GOA. This El Niño winter is a change after three winters characterized by the cooling pressures of La Niña conditions.

Through the spring, southward winds from the U.S. Arctic, along with low heat transport from the south, contributed to a maximum sea-ice extent over the Bering Sea shelf that reached near historical norms despite the warm fall conditions. Eastward wind anomalies around 45 – 50 °N in winter through early spring, associated with southward Ekman transport, may have reduced northward heat transport through the Aleutian passes and along the eastern coastal Gulf of Alaska, leading to a cooling tendency across the shelf and coastal regions. The cooling tendency over the Gulf of Alaska basin in spring may have been associated with clockwise wind anomalies driving Ekman pumping of subsurface waters towards the surface. Storminess and strong winds also contributed to vertical mixing across the regions, which is associated with cooler surface temperatures.

Ocean Temperature: Long-term surface temperatures (1900 – 2024) show a persistent warming across the GOA shelf, driven largely by increasing temperatures in the summer months (May - Oct.) (Thoman in this Report, p.43). Surface temperatures warmed across the GOA shelf in the winter and spring, associated with El Niño -related increased flow of warm surface waters from the south (Lemagie and Callahan in this Report, p.43). The eastward flowing winds in the spring and the weakening El Niño helped cool surface temperatures in the western GOA, however the eastern GOA remained above average (1985 – 2015 baseline) throughout the summer (Lemagie and Callahan in this Report, p.43). The Shelikof Strait waters in January remained slightly cooler than average at the surface and at depth, a different regional signal to the warmer satellite-derived shelf average temperatures (Jones et al. in this Report, p.43). The warming of deeper shelf waters in the western GOA appeared to be limited, due to decreased coastal downwelling that would transport heat to depth, and the resulting potential for increased incursion of cooler, more saline, lower dissolved oxygen slope waters onto the shelf in the western and northern GOA (Pages and Hauri in this Report, p.64, Danielson et al. in this Report, p.74). Spatially limited surveys observed some moderate heat at depth in the spring (central GOA) and summer (southeast AK inside waters), but not in January in Shelikof Strait (Jones et al. in this Report, p.43, Danielson in this Report, p.72). The central GOA gyre experienced increased upwelling, bringing cooler waters to the surface in this offshore region (Pages and Hauri in this Report, p.64). The eastern GOA experienced prolonged periods in marine heatwave status through the winter and spring, while the western GOA surface temperatures hovered mostly below the marine heatwave threshold (Lemagie and Bell in this Report, p.43). These warm/average temperatures are predicted to transition to cooler sea surface temperatures across the GOA shelf (National Multi-model Ensemble Model, Lemagie in this Report, p.39, and result in approximately 0.5 textsuperscriptoC warmer than the mean at GAK1 (near Seward) in the northern GOA (Sitka air temperature prediction, Hennon p.40), in alignment with a fall transition to La Niña conditions.

Ocean Transport: While the winter and spring eastward winds moderated a potentially stronger, El-Niño related, increase in counter-clockwise surface transport around the GOA, stronger winter surface transport was reflected in numerous metrics. The 2023/2024 GOA winter/spring experienced increased upwelling at the center of the GOA gyre, bringing cooler, more nutrient rich waters to the surface and onto the shelf (Pages and Hauri in this Report, p.64). Eddies were stronger along the shelf edge in the regions off Kodiak and Haida Gwaii (Cheng in this Report, p.56). The modeled northward surface transport in southeast AK, from the Papa Trajectory Index, increased from weaker (2023) to the long-term average (2024) (Stockhausen in this Report, p.61). The GAK1 mooring (near Seward) measured lower salinity in the surface waters, reflecting increased transport of freshwater from southeast AK (Danielson in this Report, p.72).

Climate

State of the North Pacific Ocean

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Last updated: September 2024

Overview:
Monthly sea surface temperature (SST) data from the NOAA High-resolution Blended Analysis of Daily SST and Ice (OI SST V2[6]), 10-m wind data from the NCEP/NCAR Reanalysis II[7], and seasonal mean sea level pressure are described from September 2023 – August 2024 across eight regions of the North Pacific Ocean and U.S. Arctic (Figure 4). The SST anomalies and SLP are relative to mean conditions over the period of 1991 – 2020.

SST were anomalously warm throughout most of the Alaskan marine waters in November 2023, but the prevailing wind anomalies and storminess in the winter through spring associated with the Aleutian low pressure system contributed to cooling the surface waters until by the summer SST was similar to or cooler than climatological mean temperatures. While the decreasing tendency of the SST anomaly was consistent across most of the geographic area (Figure 5), the mechanisms and details of this evolution varied by region.

Western Coastal Gulf of Alaska. From the coastal waters off the Kenai Peninsula to the Alaska Peninsula, SST remained near historical mean temperatures from autumn 2023 through the spring of 2024 (Figure 5). Due to large topographic features along the shoreline and the channel formed between Kodiak Island and the mainland, this region is strongly influenced by local scale winds and ageostrophic dynamics. Over the winter, a combination of wind-driven mixing, coastal upwelling, and Ekman pumping contributed to decreasing the SST anomaly to near-average temperatures. In spring, regional SST and winds remained near-normal, but in late summer 2024 wind anomalies were strongly upwelling-favorable, associated with cool SST anomalies along the coast.

Eastern Coastal Gulf of Alaska. Stronger counter-clockwise winds circulating around the Gulf of Alaska increased coastal downwelling and maintained warm SST anomalies along much of the coastal Gulf of Alaska (Figure 5). Warm SST anomalies along this coastal region are consistent with mean El Nino conditions. Along the eastern Gulf of Alaska coastal waters, wind anomalies were variable in speed and direction, but monthly mean anomalies generally remained either near or above the climatological mean and in an alongshore downwelling-favorable sense through the winter of 2023 – 2024 and into the early spring of 2024, resulting in little change to the positive coastal SST anomaly that persisted over this time period. In April and May the coastal winds shifted direction to be oriented more onshore, consistent with a southward Ekman transport in opposition to the prevailing coastal current. Over the late spring, the coastal SST anomaly decreased and by June coastal SST along the eastern Gulf of Alaska were near historic mean temperatures. However, warm temperature anomalies returned in summer.

[6]https://psl.noaa.gov/data
[7]https://psl.noaa.gov/data

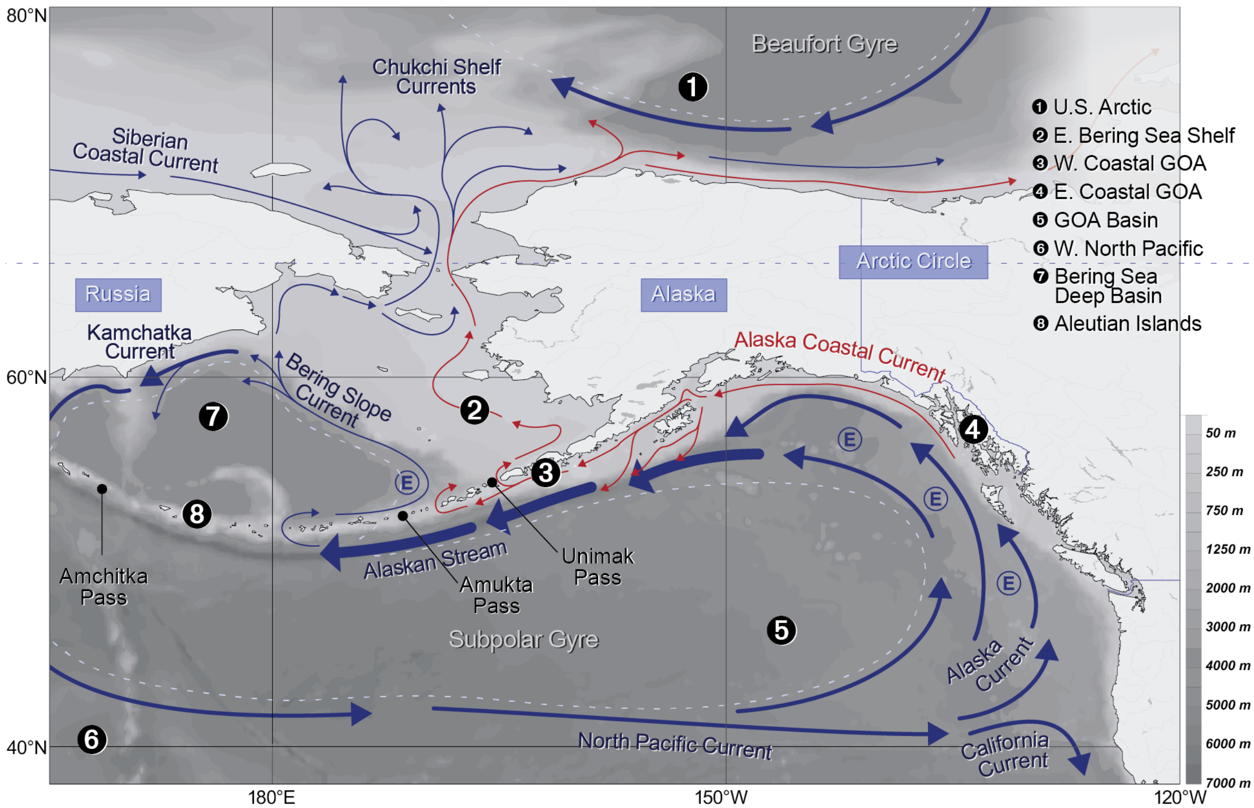

Figure 4: Geographic regions of interest, ocean bathymetry, and mean currents across the North Pacific and U.S. Arctic. Figure courtesy of Sarah Battle, PMEL.

Gulf of Alaska Basin. Positive SST anomalies over the Gulf of Alaska basin in November 2023 decreased throughout the latest winter and spring, culminating in SST anomalies as low as 1oC below the monthly mean in July 2024 (Figure 5). The prevalent winter storms increased surface ocean mixing over the Gulf of Alaska basin. The Aleutian low pressure system also drove strong winter winds towards the east and northeast over the North Pacific from 45oN to 55oN. From south to north along the eastern Gulf of Alaska, the direction of the mean wind rotates counterclockwise, which drives a divergence in the surface currents and Ekman pumping within the basin. The strong wind anomalies from winter through summer were consistent with an increase in the basin upwelling and the negative tendency of the SST anomaly, until August when positive temperature anomalies returned.

Eastern Bering Sea Shelf. Despite warm SST anomalies over the Eastern Bering Sea in the autumn through winter and late winter sea-ice advance relative to historical norms, the maximum sea-ice extent was near historical norms and following sea-ice retreat. Strong off-shelf winds in October 2023, resulting in northward Ekman transport along the shelf, followed by weaker than mean westward winds from the Alaska mainland in November were accompanied by an increase in the SST anomaly over the Bering Sea shelf in the autumn (Figure 5). Historical mean winds along the southern Bering Sea shelf are westward in autumn and winter, with mean ocean currents flowing from the Gulf of Alaska northwards. Throughout the most recent winter and spring, wind anomalies over the southern Bering Sea shelf were strong and towards the east, such that the local wind-driven Ekman transport opposed the mean current and reduced heat transport of warmer waters from the south. Stormy weather also increases vertical ocean mixing that can entrain cooler water from depth into the surface layer. Spring 2024 observations from the ecosystem observatory M2 on the Eastern Bering Sea shelf reported a substantially deeper than historical mean mixed-layer depth through the summer (not shown). Surface temperature anomalies were cool in spring and summer, following seasonal sea-ice retreat, but the heat content distributed over the deeper than average surface layer was similar to the climatological mean.

Aleutian Islands. Anomalously strong and eastward winds from autumn 2023 through spring and into summer 2024 corresponded with a negative tendency in the SST anomalies and a decline from warm SST anomalies in autumn to cool SST anomalies by summer (Figure 5). Along the Aleutian Islands, winds towards the east and northeast were stronger than the historic mean conditions throughout most of the last autumn through the summer. Winds in this sense increase southward Ekman transport, which opposes the mean ocean currents over the eastern Aleutians that typically transport warmer water from the North Pacific onto the Bering Sea shelf. Strong winds also mix the water column, deepening the mixed layer and entraining colder water from below the surface. Over the western Aleutian Islands, spring surface temperatures were near normal conditions in spring, but warm anomalies returned in summer. Warm SST anomalies over the western Aleutians have been the dominant trend for the last decade, which may be due to weaker wind-driven mixing, warmer air temperature, or advection of warm water from the North Pacific Ocean.

Status and trends:

Autumn (Sep.-Nov.) 2023/Winter (Dec.-Feb.) 2024: The sea surface temperatures over the North Pacific were anomalously warm from the autumn 2023 through winter 2024 (Figure 5). The warmth was greatest between 30 °N – 45 °N, where SST anomaly peaks over the western Pacific remained above 2.5 °C into spring 2024. Warm seasonal SST anomalies extending over most of the mid-latitude Western Pacific with peak magnitudes above 2 °C have persisted since the winter of 2019 – 2020, a pattern that is represented by the negative PDO index over the last 5 years (Figure 7). Over the most recent fall and winter, strong warm anomalies were also measured along the Equator (captured by the El Niño index, Figure 7). Warm autumn SST along the eastern Pacific coast are also consistent with El Niño conditions. The autumn (Sep. – Nov. 2023) SLP was near the climatological mean, a result of shifting atmospheric conditions, and was associated with autumn storms and variable wind speed and direction throughout the season (Figure 6). Jan. – Feb. 2024 winter mean sea level pressure was also similar to the mean winter pattern. The center of the Aleutian Low was shifted to the southwest from the historical mean, and with westward wind anomalies >2 m s^{-1} along the Aleutian Islands.

Spring (Mar. - May, 2024): Equatorial temperature anomalies weakened, but remained positive, in spring 2024. North of 45 °N, and throughout much of the Alaska marine waters, the warmth abated and SST were near historical mean temperatures in spring 2024 (Figure 5). The seasonal mean SLP in spring (Mar – May 2024) resulted in a clockwise wind anomaly of $\sim$2 – 3 m s^{-1} eastward between 45 – 50 °N, westward focused between 20 – 30 °N, and southward off the U.S. west coast, enhancing coastal upwelling (Figure 6).

Summer (Jun. - Aug., 2024): In summer, near-average surface pressure and wind patterns were associated with near-normal surface temperatures over much of the region, except through the Aleutian Island passes and Eastern Bering Sea shelf where surface temperatures were below average due to the deep surface mixed layer (Figures 6 and 5).

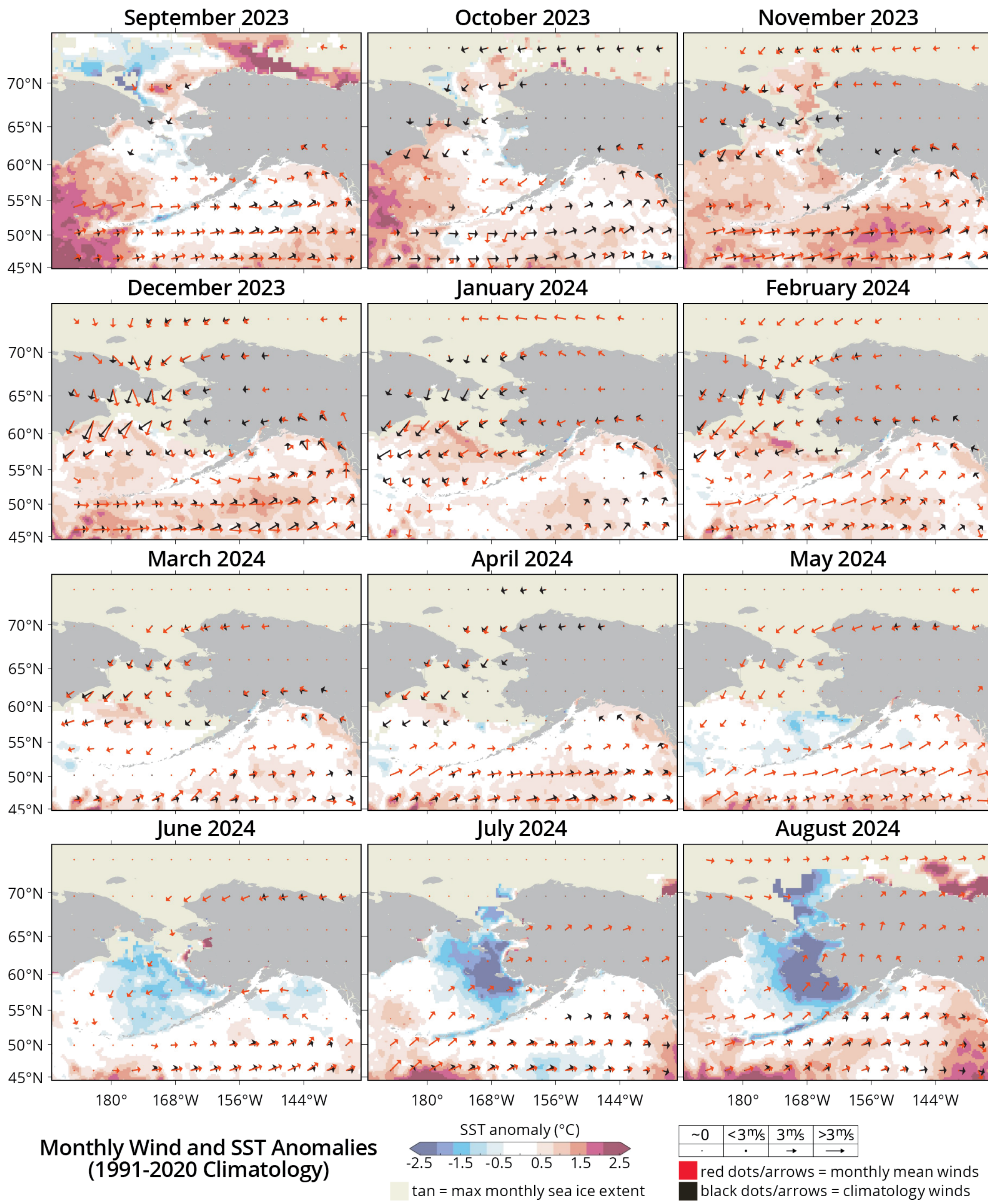

Figure 5: Monthly mean maps of sea surface temperature (SST) anomalies and surface winds. Monthly climatological winds (black) are compared to monthly mean winds (red). The climatological period is from 1991 – 2020. SST data are from the NOAA High-resolution Blended Analysis of Daily SST and Ice (OISST), and 10-m wind data are from the NCEP/NCAR Reanalysis II; both are available from NOAA's Physical Sciences Laboratory. Figure courtesy of Sarah Battle, PMEL.

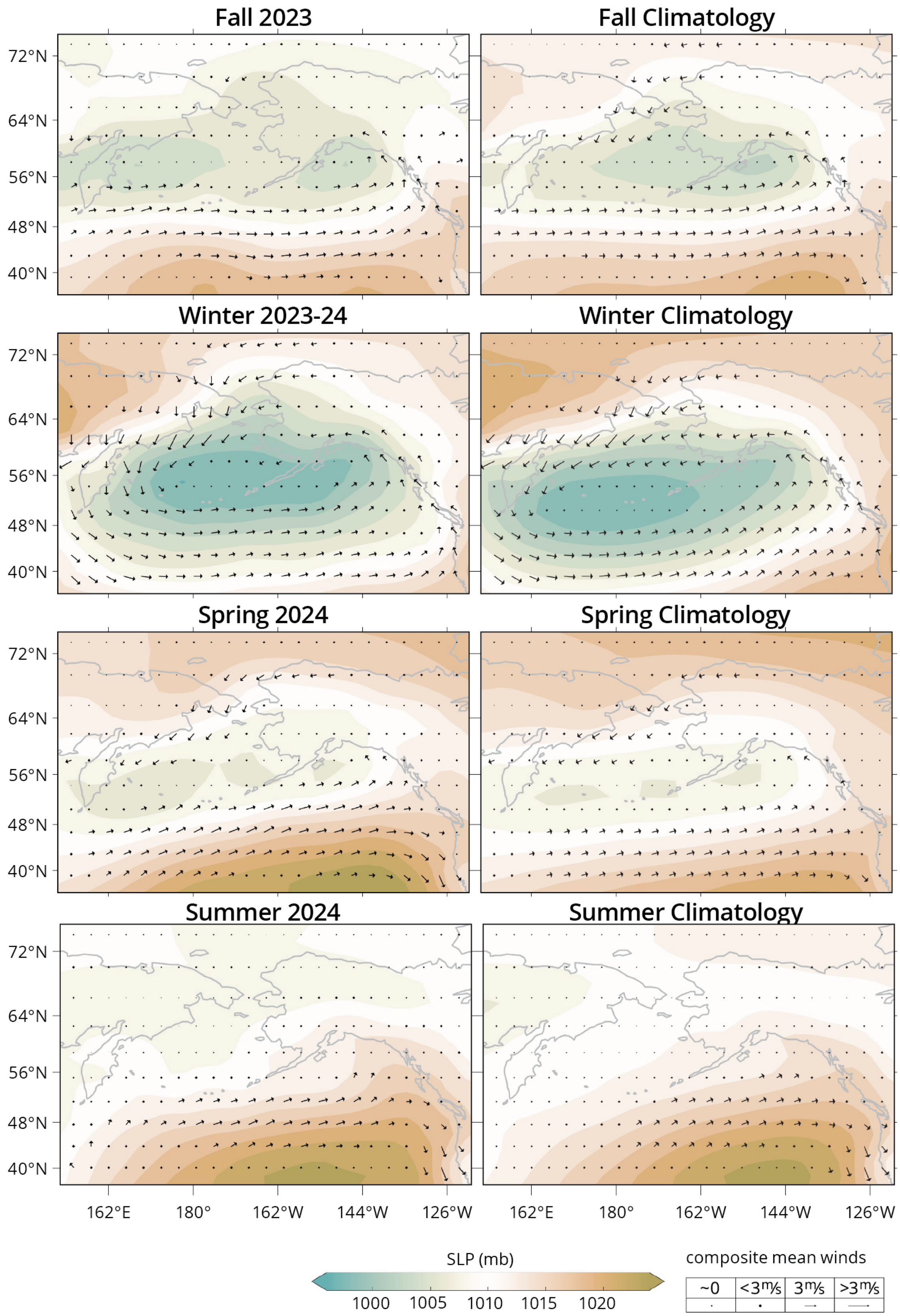

Figure 6: On the left, seasonal sea level pressure for autumn (Sep. – Nov. 2023), winter (Dec. 2023 – Feb. 2024), spring (Mar. – May 2024), and summer (Jun. – Aug. 2024), as well as seasonal mean winds. On the right, seasonal sea level pressure and wind climatologies for the same four time periods. Climatologies are calculated from 1991 – 2020.

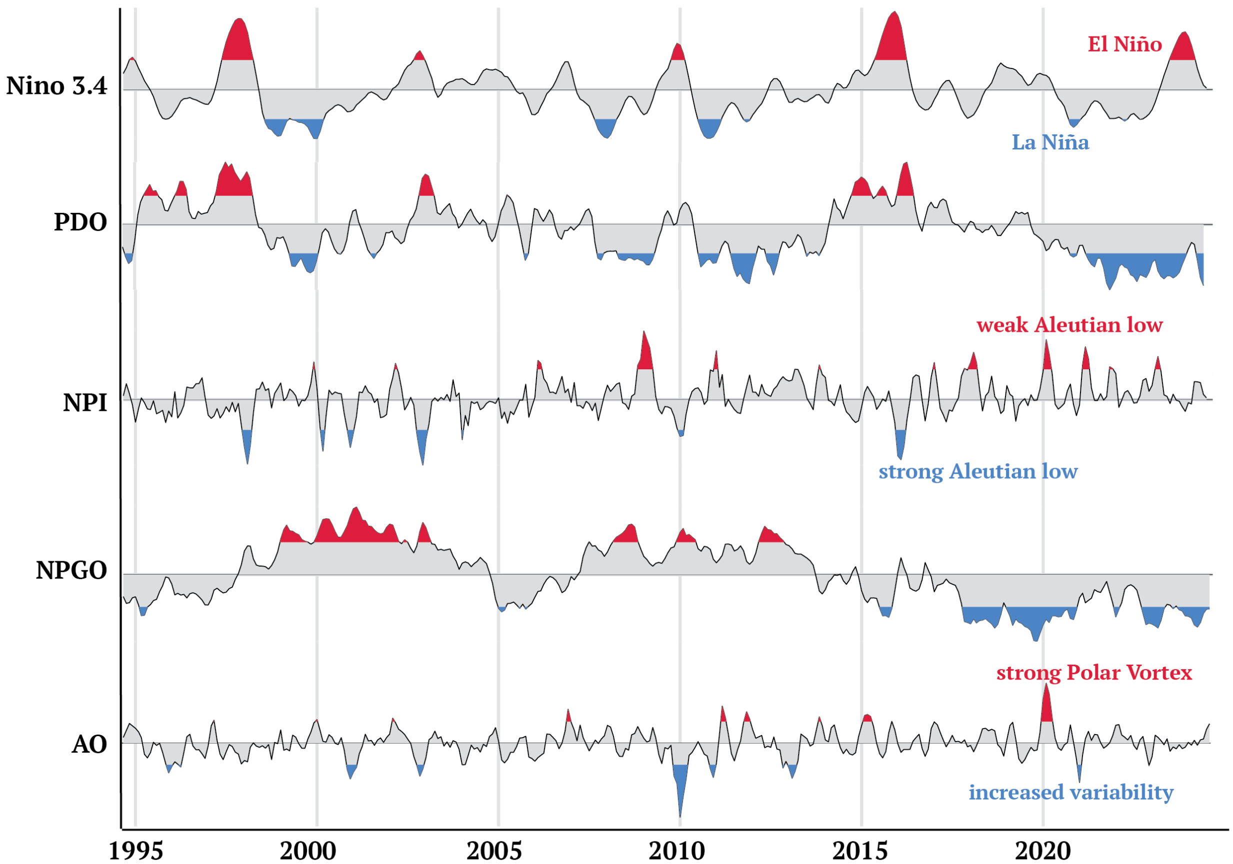

Figure 7: Time series of five commonly used indices for relating patterns across the Alaska marine ecosystem, including the NINO3.4 index for the state of the El Niño/Southern Oscillation, the Pacific Decadal Oscillation (PDO), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO), and the Arctic Oscillation (AO) indices for 2015 – 2024 (through August 31, 2024). Each monthly index is normalized using a 30-year climatology from 1991 – 2020 and smoothed using a 3-month running mean. Red and blue shading indicates positive and negative values, respectively. Lighter shaded areas are within one standard deviation of the 30-year climatology. Additional information on these indices can be found on the NOAA Physical Sciences Laboratory website[8].

Wintertime Aleutian Low Index

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Last updated: September 2024

Description of indicator: The Aleutian low is the dominant feature of the atmospheric pressure system in the Northern North Pacific during winter (December to March), which develops and strengthens seasonally between the Beaufort high and North Pacific high pressure regions. Variability in strength and the position of the low is important to the Alaska marine ecosystem through its impact on circulation, surface heat fluxes, mixed layer depth, and the extent of sea ice cover over the Bering Sea, all of which influence the rich biological resources of the sea (Rodionov and Overland, 2005; Wooster and Hollowed, 1995). In general, the intensity and position of the Aleutian Low can significantly influence storm tracks, ocean circulation, and weather patterns across the North Pacific, impacting North America. Motivated by work from Rodionov and Overland (2005), we defined the Aleutian Low Index (ALI) as the areas where sea level pressure (SLP) is less than or equals to 1000hPa in the North Pacific region (40 – 60 °N, and 160E – 160 °W). Aleutian Low is a statistical low, which exists in winter only. We computed the monthly Aleutian Low Index, and then averaged for the winter mean (January and February). A 30-yr climatology (1991 – 2020) mean is removed from the index.

The strength and location of the Aleutian low in January-February 2024 were similar to historical means (Figure 8. The Aleutian low is a key driver of the Pacific storm track and cyclones that form in the North Pacific tend to follow the path of the Aleutian low. The position and strength of the low determine whether these cyclones move northward into the Bering Sea or remain in the mid-latitudes. A strong Aleutian low brings more storms - stronger winds - to the Bering Sea, leading to increased precipitation. This is not the case for 2024. It can also be seen from Figure 8.

When there is a strong Aleutian low pressure system present, the ALI is positive, meaning the low center occupies a larger area. However, the other factors that matter are how strong the Aleutian low center is and where the low center is located, with the latter playing a more important role. The east-west position of the Aleutian low center is captured relative to longitude 180: When the Aleutian low center is located to the west of 180, it is associated with warm ocean temperatures and low winter sea-ice extents over the Bering Sea shelf. Following Rodionov and Overland (2005), cases with the Aleutian central pressure south of 51 °N are removed, and these years are left blank in Figure 10, as those tend to have a more zonal pattern. Based on Figures 9 and 10 together, we can see that the Aleutian low in 2024 is relatively weak (negative anomaly in 9), and the center is more toward the eastern part of the Bering Sea (near 170 °W in Figure 10). Both the strength and location of the Aleutian Low resembles its climatological condition, i.e., it is an average year. This may partially explain the near average sea ice extent observed in winter 2024 in the Bering Sea as a weaker low allows for colder conditions and potentially greater sea ice coverage. Figure 9 shows the anomalies of the ALI, from the 30-yr mean for each winter since 1980.

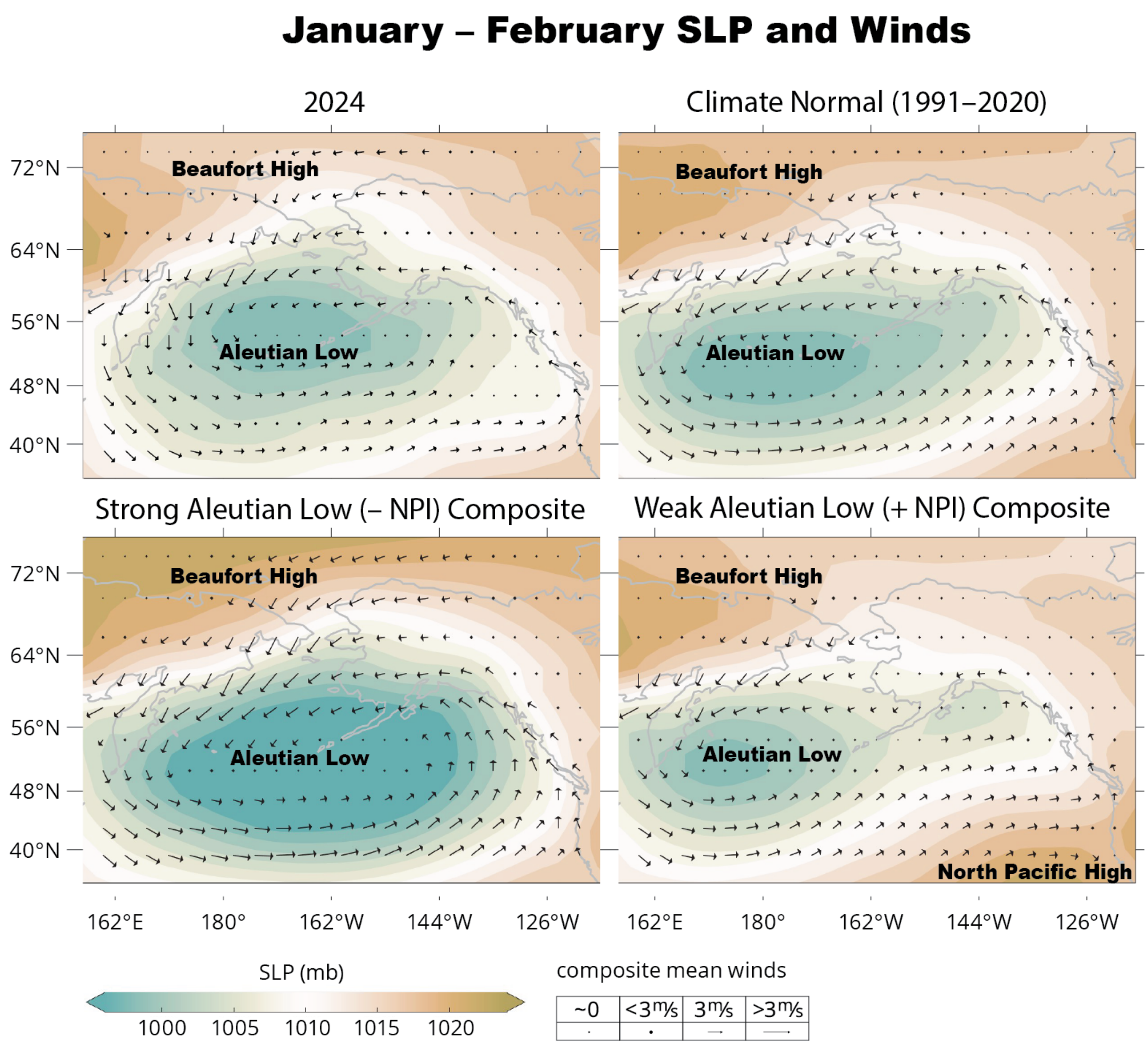

Figure 8: Top row: Mean January–February SLP and surface wind patterns in 2024, from the climatological mean (1991 – 2020). For reference, January–February SLP composite mean patterns for negative (strong Aleutian low) and positive NPI (weak Aleutian low) conditions are also shown.

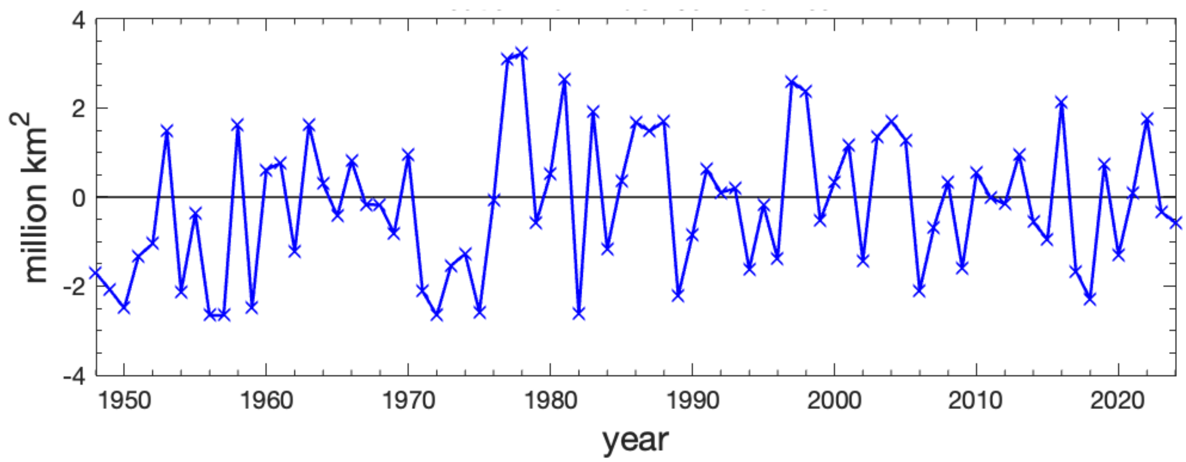

Figure 9: Winter (Jan and Feb) Aleutian Low Index which is defined as the area occupied by sea level pressure less than or equal to 1000hPa in the North Pacific region (40 – 60 °N, and 160E – 160 °W). Time series shows the anomalies relative to 1991 – 2020 period mean.

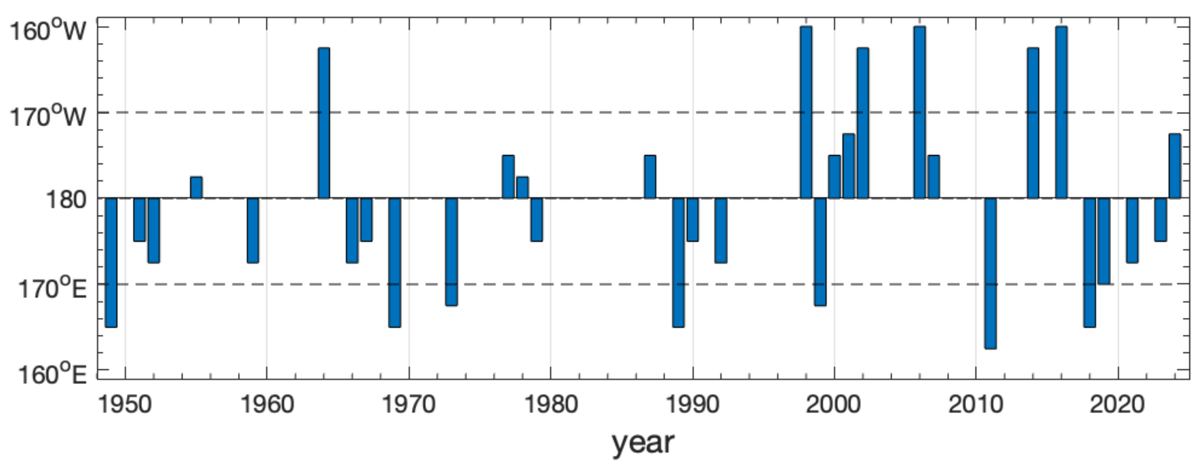

Figure 10: Longitude of the January-February Aleutian low central pressure location when the center is located north of 51 °N for 1948 – 2024. Dashed line indicates 170 °W/E. For center locations south of 51 °N, or the low center above 1000hPa the plot has a blank year. SLP data are based on NCEP/NCAR Reanalysis.

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

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Last updated: August 2024

Description of indicator: Seasonal predictions of SST anomalies from the National Multi-Model Ensemble (NMME) are shown in Figure 11. An ensemble approach incorporating different models is particularly appropriate for seasonal and interannual predictions. 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 predictions of other variables, are available at the NCEP website[9].

Status and trends: The NMME SST forecast projects warm anomalies in the approaching winter and spring over the western North Pacific between 30 °N and 50 °N, with a decreasing anomaly towards the Eastern Pacific, where temperatures along the U.S. West Coast are forecast to be near the historical mean (Figure 11). Further north, in the Gulf of Alaska, SST anomalies are forecast to drop to cool anomalies 0.25 – 0.5 °C below the historical mean by spring 2024. Cool ocean temperature anomalies along the U.S. and Canadian west coasts and eastern Gulf of Alaska are consistent with the La Niña conditions that are predicted by the NOAA Climate Prediction Center. While SST over the eastern Bering Sea shelf are forecast to remain near the historical mean for each time period, and warm anomalies of 0.25 – 0.5 °C magnitude are forecast in the Arctic Ocean, cool anomalies as low as -2 °C are forecast in the vicinity of the Bering Strait in winter. Cool SST anomalies over the Chukchi Sea and near the Bering Strait may be positive indicators of seasonal sea ice advance.

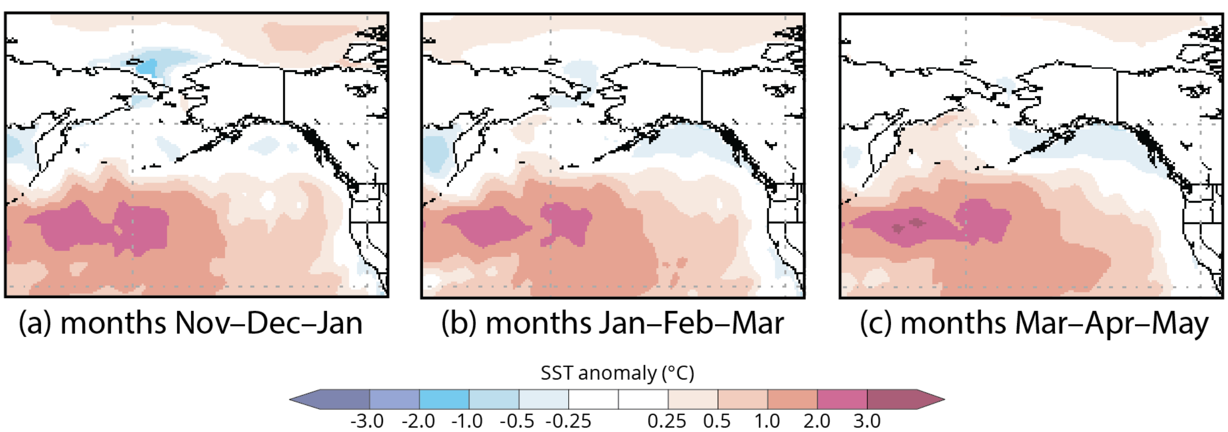

Figure 11: Predicted sea surface temperature anomalies from the NMME model for Nov–Dec–Jan (1-month lead) for the 2024 – 2025 season, Jan–Feb–Mar (3-month lead), and Mar–Apr–May (5-month lead) 2025.

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

Predicted Ocean Temperatures in Northern Gulf of Alaska

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Last updated: October 2024

Description of indicator: Air temperatures in Sitka, AK are dominated by the marine climate. Danielson et al. (2022) found Sitka air temperatures had a weak but significant predictive power for integral coastal water column temperatures in the following year at the nearshore station (GAK1) of the Seward Line Transect, in northern GOA ($r^2 = 0.37$, $p < 0.05$). This predictive power can be explained by Sitka's 'upstream' location of GAK1 along the Alaska Coastal Current. Records of Sitka air temperatures exist since 1850 and GAK1 has recorded ocean temperatures since 1970. The temperature anomalies for both GAK1 and Sitka air temp are seasonally adjusted, and relative to the long-term average (1970-present for GAK1).

Status and Trends: The 2025 integrated water column temperatures for the nearshore GAK1 station of the Seward Line transect are predicted to be warmer than average based on 2024 Sitka air temperatures. The average Sitka Air temperature through Sept 8th, 2024 was ∼0.9 °C warmer than average (Figure 12). Based on these temperatures, GAK1 integrated ocean temperatures (± 1SD) are predicted to range from 6.3 to 7.3 °C (centered on 6.8 °C) (Figure 13). The GAK1 long-term full water column depth averaged temperature is 6.24 °C for the period of record, and there is a range of about -0.5 to 1.6 between ± 2 standard deviations (∼ 95% CI) of our anomaly trend line. If the anomalies, so far in 2024, persist (i.e., Sitka air temperatures in Sep. to Dec. remain ∼0.9 °C above seasonal average), we could expect whole water column GAK1 temperatures in 2025 to be ∼ 0.5 °C above average (compared to the seasonal average). The long-term trend in temperature is for more than a 1-degree change in the mean over the 50 years.

Factors influencing observed trends: The north Pacific transitioned from to El Niño conditions to ENSO neutral in the spring of 2024, and is expected to enter La Niña conditions in the fall of 2024. Surface waters move into the GOA in a counterclockwise direction, via the Alaska Current and Coastal Current, passing Sitka to reach GAK1 and the Seward area in northern GOA. Ocean surface warming associated with an El Niño occurend in the winter/spring of 2024 (Lemagie and Callahan in this report, p.43). GAK1 is predicted to have warm waters in 2025, but less warmer than the previous year. The slow development of La Niña in the fall of 2024. The long-term trend is for more than a 1-degree change in the mean over the 50 years in the fall of 2024 may result in a mild cooling signal in GAK1 2025 temperature predictions. driving the cooling temperatures The mild cooling may be discrepancy may be due to the slow development of La Niña in the fall of 2024. The long-term trend is for more than a 1-degree change in the mean over the 50 years

Implications: Warm surface waters in the GOA are generally associated with earlier peak spring phytoplankton blooms, earlier Pacific cod hatch timing (Laurel et al., 2023), and a change in the zooplankton community. The duration and intensity of warming can determing how the effects of warming permeates through the marine ecosystem.

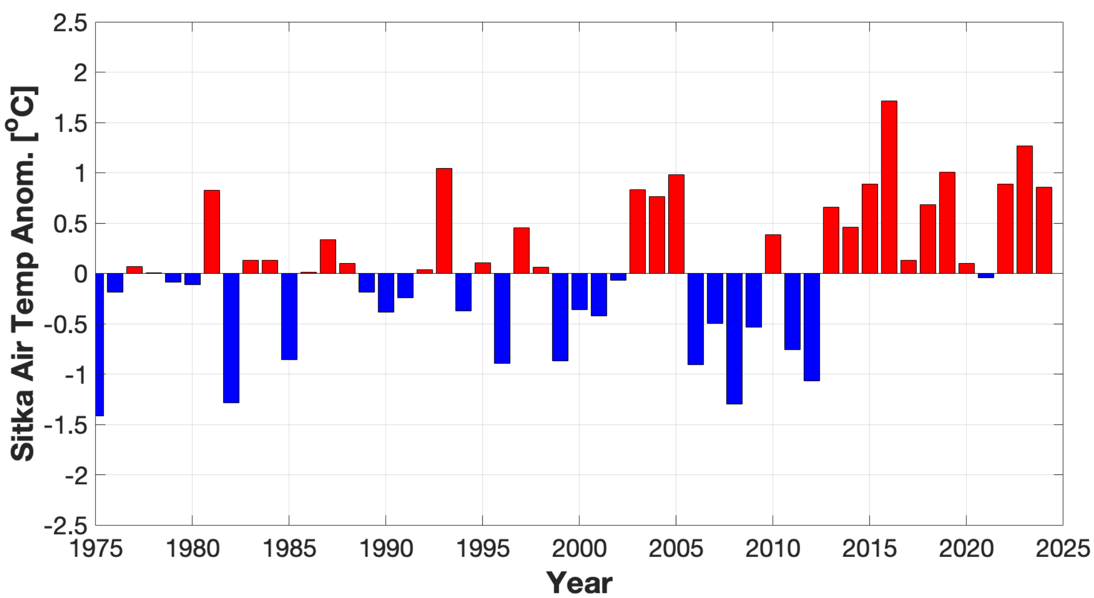

Figure 12: Annual averages of monthly temperature anomalies (seasonal climatology removed) Sitka, Alaska air temperature (entire record is 1828 – 2024; figure shows 1975 to present). Records are shown relative to a 50-year baseline computed over 1970 – 2024, updated from Danielson et al. (2022).

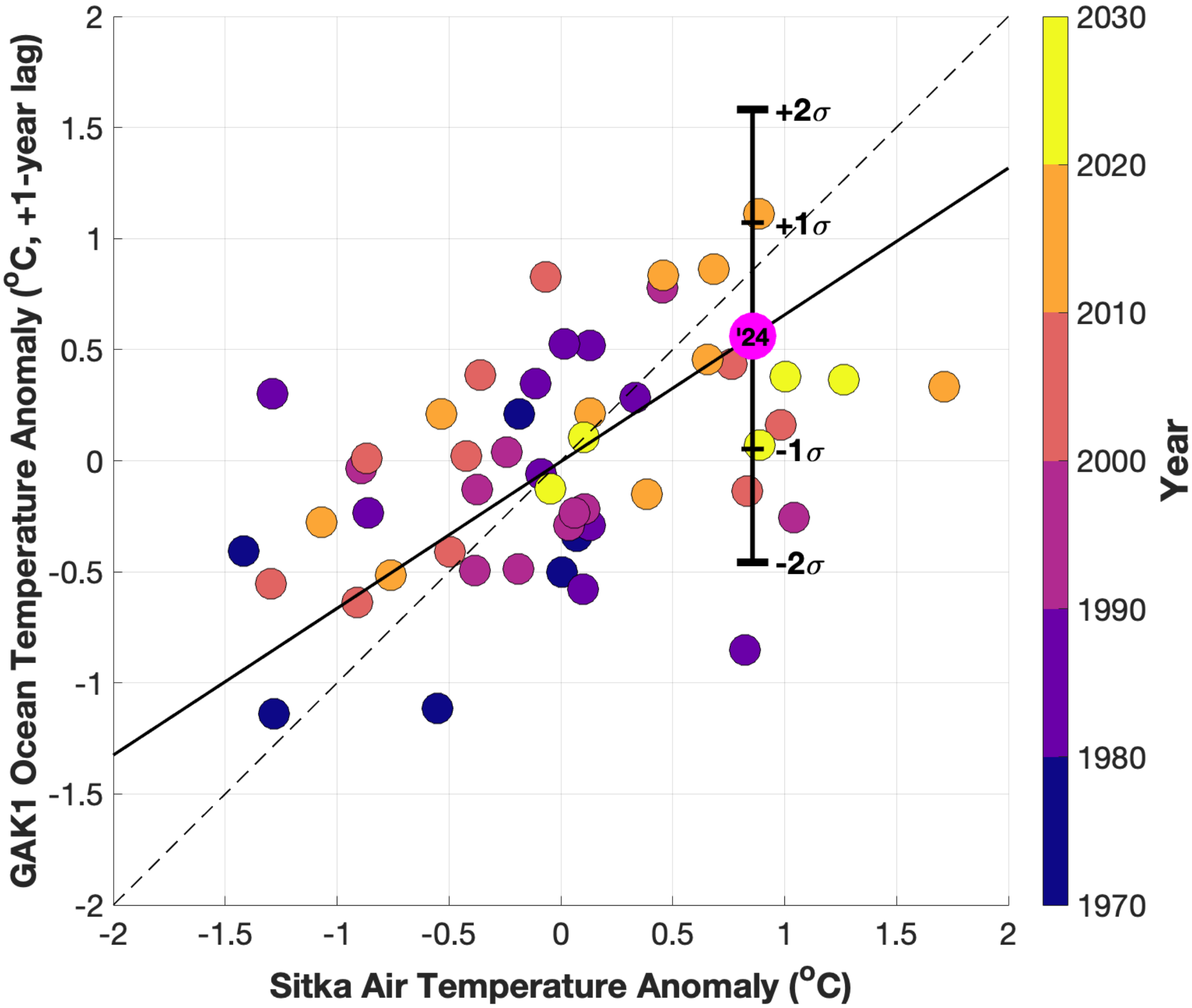

Figure 13: Relationship between the detrended annual Sitka air temperature anomaly (x axis) and the following-year whole water column ocean average temperature anomaly measured at station GAK1 (y axis), with a +1 year lag compared to Sitka. Dashed black line shows a 1:1 slope and the solid black line is the least squares best fit line between the two records. Both anomalies are referenced to the average temperature from the early 1970s to present (1971 for GAK1, 1973 for Sitka air). The blue to yellow dots show each yearly comparison between Sitka air anomaly and the next year's GAK1 anomaly. The pink dot shows the 2024 air temperature anomaly (through Sept 9, 2024). The error bars show one and two standard deviations of variability from the trend line (which is the solid black line, the dashed line is 1:1).

Ocean Temperature: *Synthesis

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Long-term SST: Rick Thoman, International Arctic Research Center,University of Alaska Fairbanks; Contact:rthoman@alaska.edu and
Brian Brettschneider, NOAA National Weather Service Alaska Region Headquarters
NOAA EcoFOCI Spring Larval Survey: Kelia Axler and Lauren Rogers, EcoFOCI, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, NOAA Fisheries; Contact: kelia.axler@noaa.gov
ADF&G Large Mesh Trawl Survey: Carrie Worton, Alaska Department of Fish and Game, Kodiak; Contact: carrie.worton@alaska.gov
NOAA Acoustic-Trawl Survey: Darin Jones, Mike Levine, and Patrick Ressler, Midwater Assessment and Conservation Engineering Program (MACE), Alaska Fisheries Science Center (AFSC), NOAA Fisheries; Contact: darin.jones@noaa.gov

Last updated: October 2024

Description of indicator: Ocean temperature can vary sub-regionally, due to differences in circulation, freshwater runoff, wind-driven mixing, and other oceanographic drivers (Bograd et al., 2005). Local temperatures can influence survival or condition of critical life history periods of certain species, such as salmon in the inside waters of southeast Alaska. Year-to-year changes in temperatures can influence physiological processes of fish (e.g., metabolic rates and growth rates), fish distribution (Yang et al., 2019), trophic interactions, availability of spawning habitat (Laurel and Rogers, 2020), and energetic value of prey (Von Biela et al., 2019). 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). Sea surface temperature (SST) is a foundational characteristic of the marine environment and temperature dynamics impact many biological processes. Extended periods of increased SST can drastically influence ecosystem dynamics (Bond et al., 2015; Hobday et al., 2016).

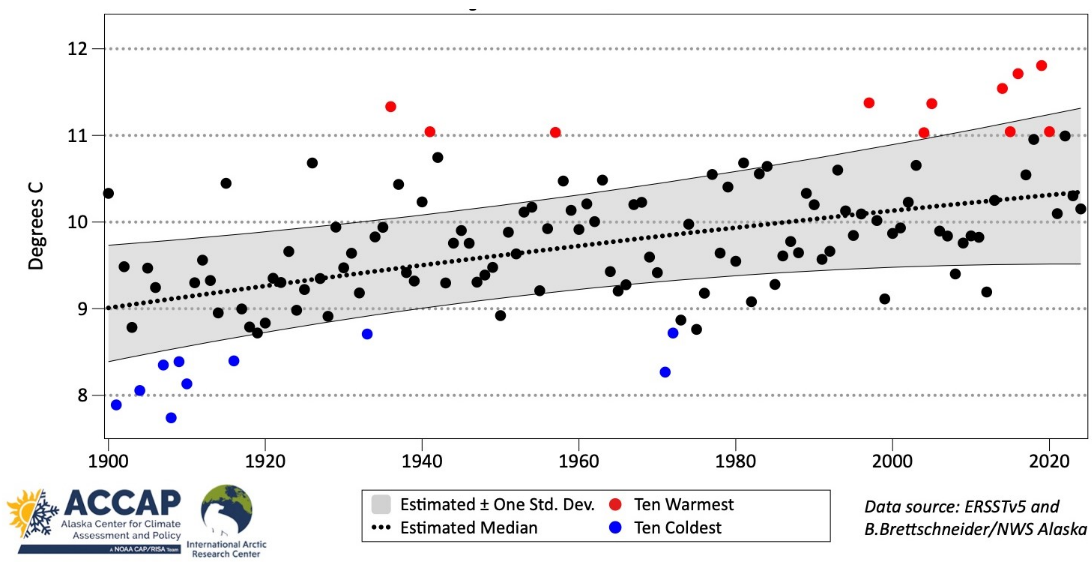
In recent years, warm water events have become so frequent in the world's oceans that a new method for describing them has been formalized. We consider marine heatwaves (MHWs) to occur when SST exceeds a particular threshold for five or more days. That threshold is the 90 th percentile of temperatures 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 90 th percentile threshold for a given day and the baseline temperature for that day. If the threshold is exceeded, the event is considered *moderate*, *strong* (2 times the difference between then threshold and normal), *severe* (3 times the difference between the threshold and normal), or *extreme* ($\leq$ 4 times the difference) (Hobday et al., 2018).This section presents a collection of empirically collected temperature measurements from 2021 spring and summer surveys.

In this section we describe trends in ocean temperature at surface and at depth throughout the GOA. We first show 2024 GOA sea surface temperatures (averaged across the shelf) in context of long-term trends (1900-present) using NOAA's Extended Reconstructed SST V5 data[10]. We then present satellite-derived sea surface temperatures for 2024, averaged across the western GOA and eastern GOA shelf. This is followed by a description of trends observed across multiple GOA sub-regional surveys conducted in the winter, spring, and summer of 2024. We then show observations related to marine heatwave conditions. Detailed methods are listed at the end of the contribution.

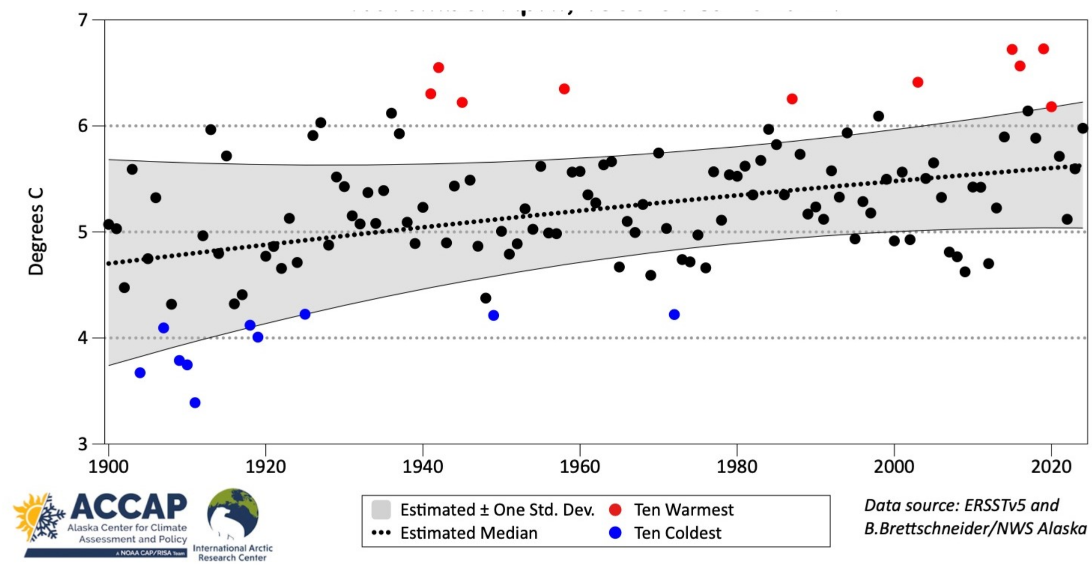
Status and trends:

Long-term sea surface temperatures (1900 – 2024): Summer (May - Oct.) sea surface temperatures (Figure 14) over the GOA shelf (10 m - 200 m) were cooler than most years in the past decade, though still above the pre-2000 median. It should be noted the May-Oct 2024 mean SST was estimated by using the observed May-August temps and then assuming Sept. and Oct. sea surface temperatures will be at the 1991–2020 mean. If Sept. and Oct. sea surface temperatures differ significantly from that 30-year mean, this result would change. The overall trend in summer temperatures show a warming during the first decades of the 20 th century followed by an extended period of little long-term trend, with substantial warming resuming in the late 1990s. In contrast, Winter (Nov.- April) temperatures show much less warming over the past 123 years.

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



(a) Summer (May - Oct.)



(b) Winter (Nov. - April)

Figure 14: Sea surface temperatures for the Gulf of Alaska from 1900 – 2024 for (a) summer (May-Oct.) and (b) winter (Nov.-April). Presented here are the quantiles representing $\pm$ 1 standard deviation of a Gaussian distribution and for completeness the median calculated using constrained B-Spline regression.

Winter 2024: In the western and eastern GOA, satellite-derived surface water temperatures were warmer than winter 2023, and above average (baseline: 1985 – 2014) from December through March (western) and December through May (eastern) (Figure 15). At a smaller regional scale, observed temperatures were cooler than survey-specific average including at the surface (3.21 °C; baseline 1980 – 2023) and aroud 100m (4.00 °C; baseline 2001 – 2023) temperatures were slightly below the long-term means of these time series (3.71 °C and 4.38 °C, respectively) for the acoustic-trawl survey of Shelikof Strait (Figure 16). The absolute difference between surface and deep temperatures measured in this survey have increased in recent years (since 2016).

Spring 2024: Satellite-derived surface spring temperatures were near-average in the western GOA and and above-average in the eastern GOA shelf (baseline: 1985 – 2014; Figure 15). The eastern GOA briefly cooled to average temperatures in the end of May. The Seward Line survey (averaged across shelf stations) observed an increase in spring surface temperatures from 2023 to 6.4 °, approximately the mean value of the time series (1998 – 2024) and cooled at depth (176m - 226m) to 5 ° (Figure 17). The cooler temperatures at depth integrate stations across the shelf transect and mask some warmer temperatures measured at the nearshore GAK1 mooring (Danielson in this Report, p.72).

Summer 2024: The western GOA remained at near-average surface temperatures in the summer (baseline: 1985 – 2014). The summer surface waters in eastern GOA warmed again to generally above-average temperatures in July and August, 2024, reaching a maximum of 12 °C in the wastern GOA and 14 °C in the eastern GOA (Figure 15). Summer surface temperatures in Southeast Alaska inside waters were also warmer than the survey average (9.34 °C in the top 20m; Icy Strait Survey; baseline 1997 – 2023; Figure 18). The satellite-derived data and the eastern GOA Southeast AlaskaCoastal Monitoring Survey were the only summer time series updated in 2024.

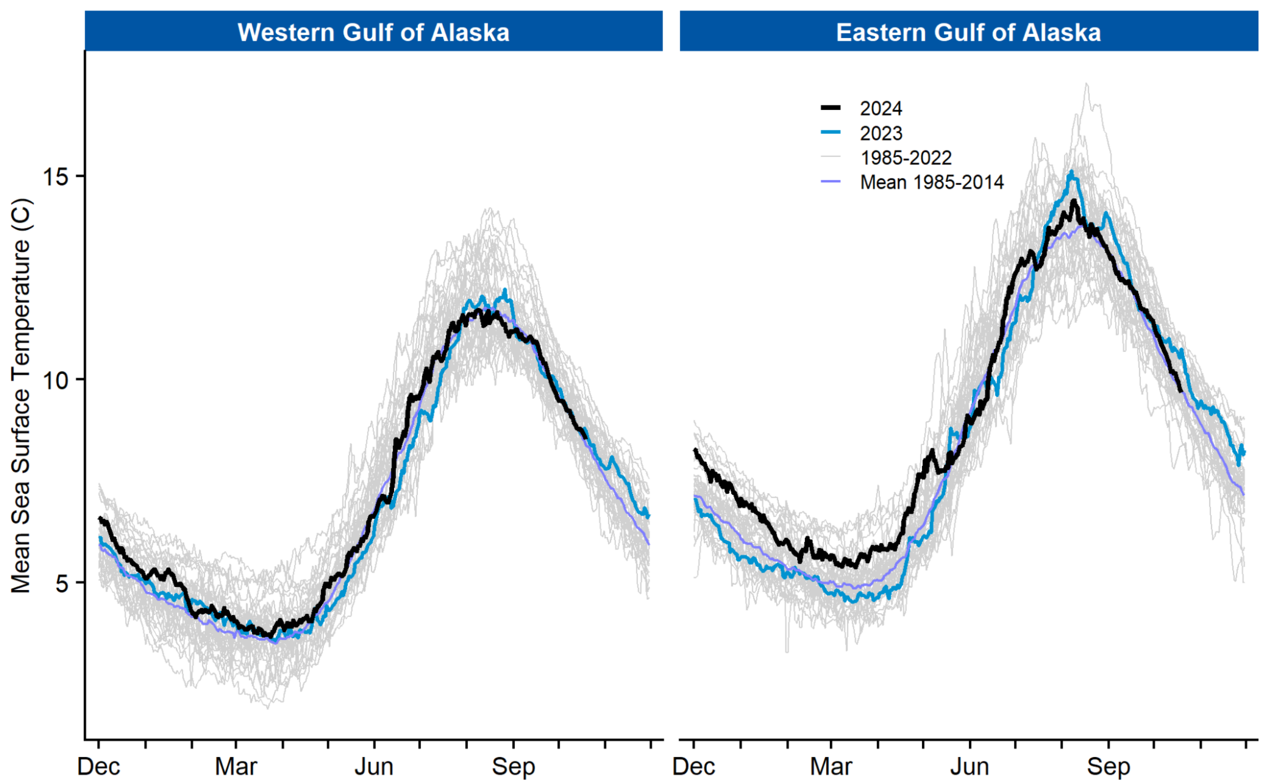


Figure 15: Daily sea surface temperatures (SST) for the western GOA and eastern GOA. Lines illustrate the daily SST for 2024 through October 31 (black), the daily SST for 2023 (blue), the 30-year (1985 – 2014) mean SST for each day (purple), and daily SST for each year of the time series (1985 – 2022; gray). Details are in the "Methods" section at the end of this contribution.

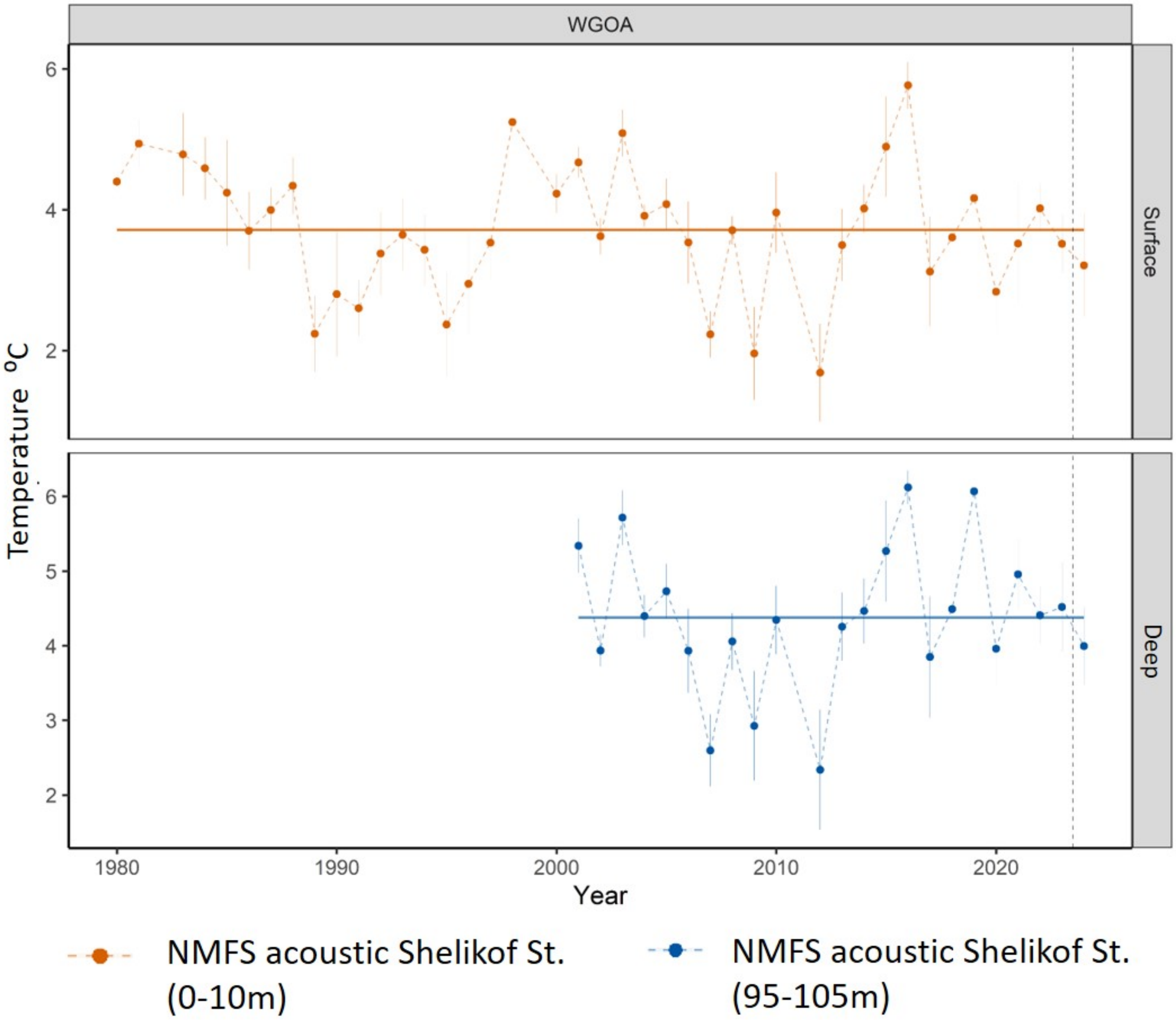


Figure 16: Average 'surface' (1 – 10 m) and 'deep' (95 – 105 m; blue) temperature (°C) at trawl locations during acoustic-trawl surveys of Shelikof Strait from 1980 (surface) and 2001 (depth) to 2024. Error bars indicate 1 standard deviation. Points to the right of the dashed vertical line are current year measurements. Details are in the "Methods" section at the end of this contribution.

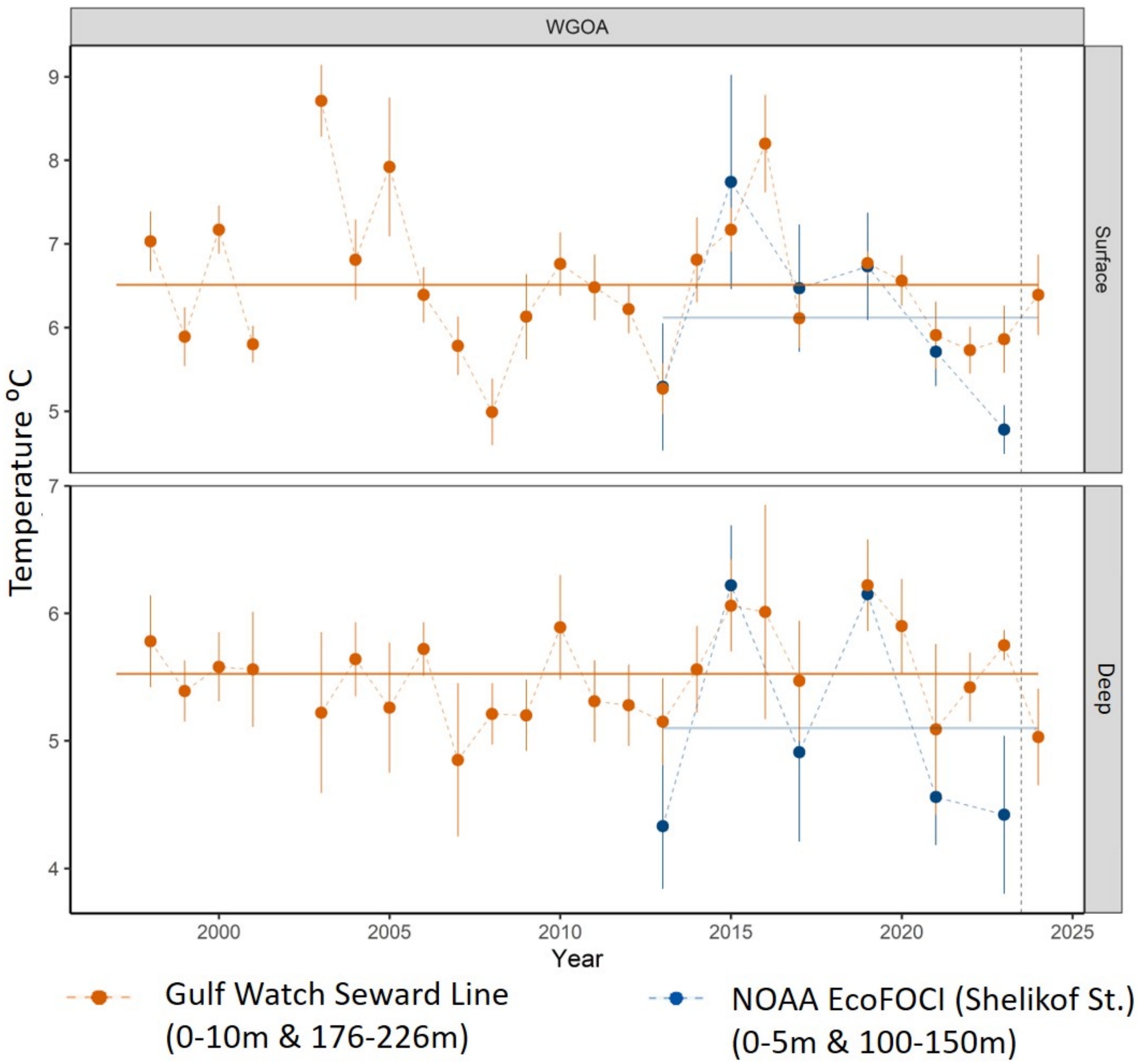


Figure 17: Observed temperatures at surface and depth from the AFSC EcoFOCI spring (May-June, alternating years) larval survey and the Gulfwatch Alaska spring (May) Seward Line survey. Data to the right of the vertical dashed line were collected in 2024. Multiple surveys are shown to reflect commonalities or differences in trends, primarily due to temporal and spatial coverage. Survey details are in the "Methods" section at the end of this contribution.

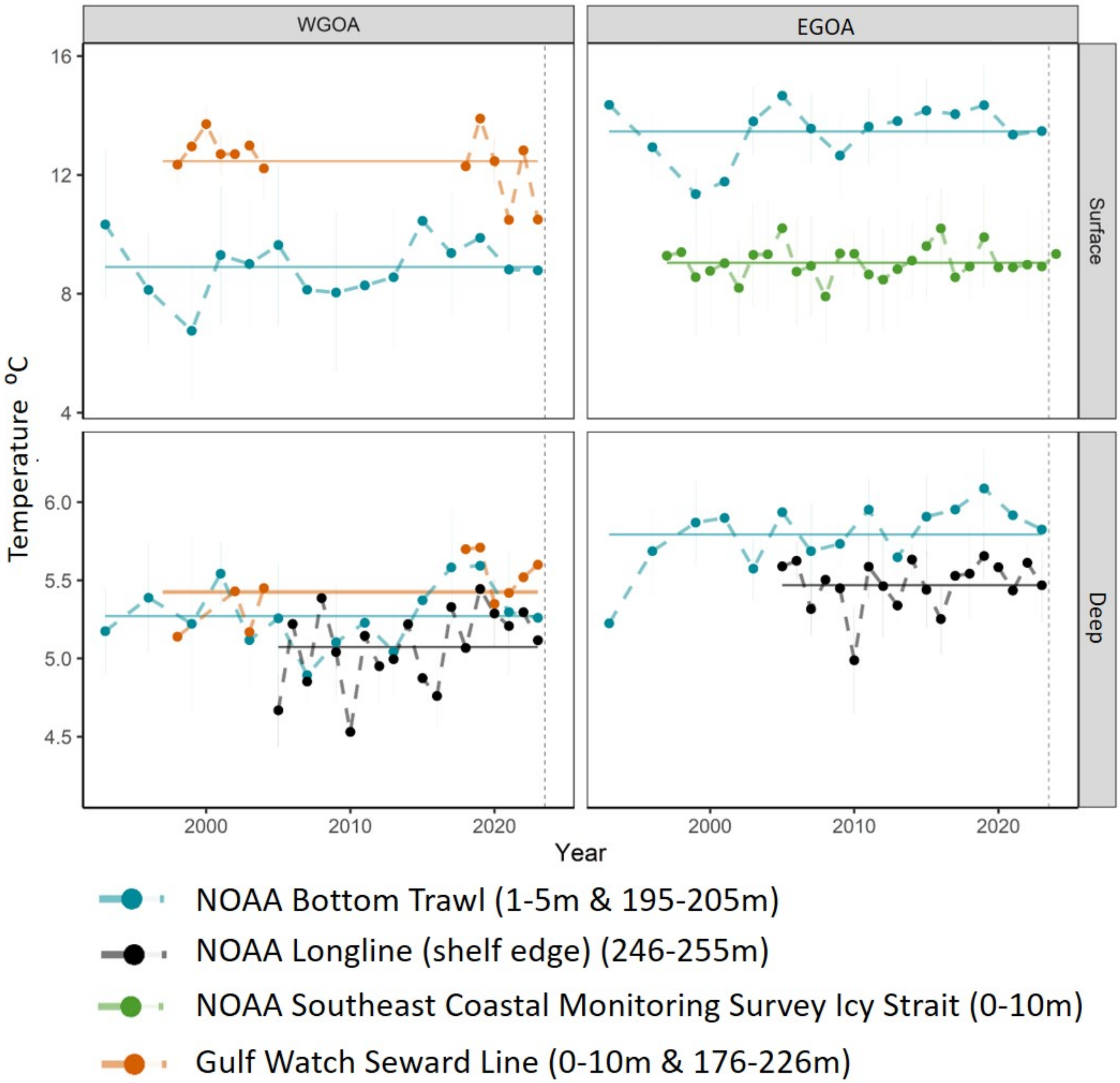


Figure 18: Observed temperatures at surface and depth from the AFSC Bottom Trawl Survey (alternating years, May - Sep.), AFSC Longline Survey (western GOA: June, eastern GOA: August), AFSC Southeast Alaska Coastal Monitoring (SECM Survey; May - Aug.), ADF&G Large Mesh Trawl Survey (Jun./Jul.), and the Gulfwatch Alaska summer(July) Seward Line survey. Multiple surveys are shown to reflect commonalities or differences in trends, primarily due to temporal and spatial coverage. Data points to the right of the vertical dashed line are current year. Survey details are in the "Methods" section at the end of this contribution.

Marine Heat Waves: No marine heatwaves occurred in the western Gulf of Alaska in 2024, while there were periods of moderate marine heatwaves in the eastern Gulf of Alaska in summer and autumn 2024 (Figures 19 and 20). Despite a warm summer in the eastern GOA, this year along with 2021 stands out from the previous half decade as having remarkably few days in marine heatwave status (Figure 20). An important ecological consideration with marine heatwaves is the extent of a particular area that experiences the warm conditions, and whether there may be thermal refugia for species within that domain. From winter through spring, there were multiple periods when $>$ 50% of the satellite pixels (5 km grid) in the eastern GOA experienced a marine heatwave. This contrasts with the western GOA, where only a small fraction of the region was simultaneously in MHW status at a given time (Figure 21).

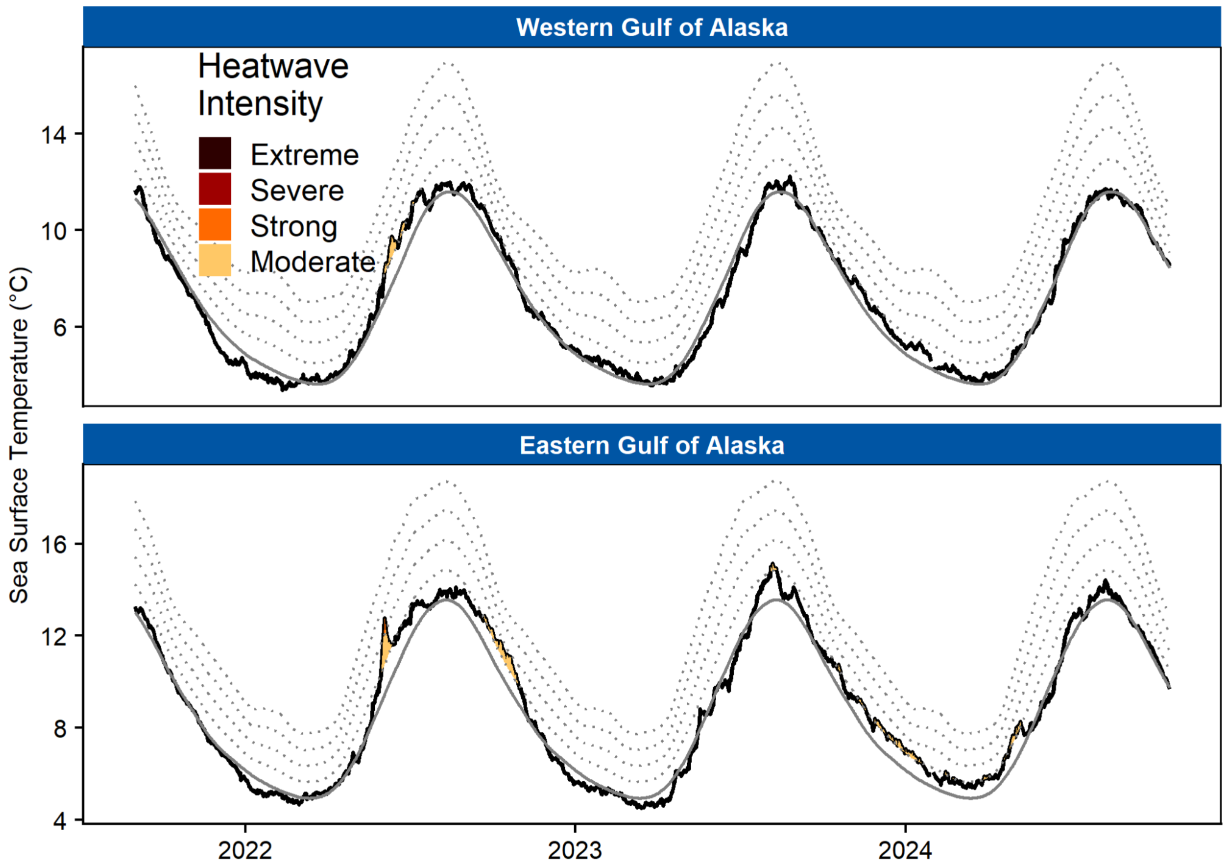


Figure 19: Marine heatwave (MHW) status from Sep. 2020 through Oct. 2024. Filled (yellow) areas depict MHW events. Black lines represent the 30-year baseline (smoothed line; 1985 – 2014.) and observed daily sea surface temperatures (jagged line). Faint gray dotted lines illustrate the MHW severity thresholds in increasing order: if the threshold is exceeded, the event is considered *moderate*, *strong* (2 times the difference between then threshold and normal), *severe* (3 times the difference between the threshold and normal), or *extreme* ($\leq$ 4 times the difference) (Hobday et al., 2018).

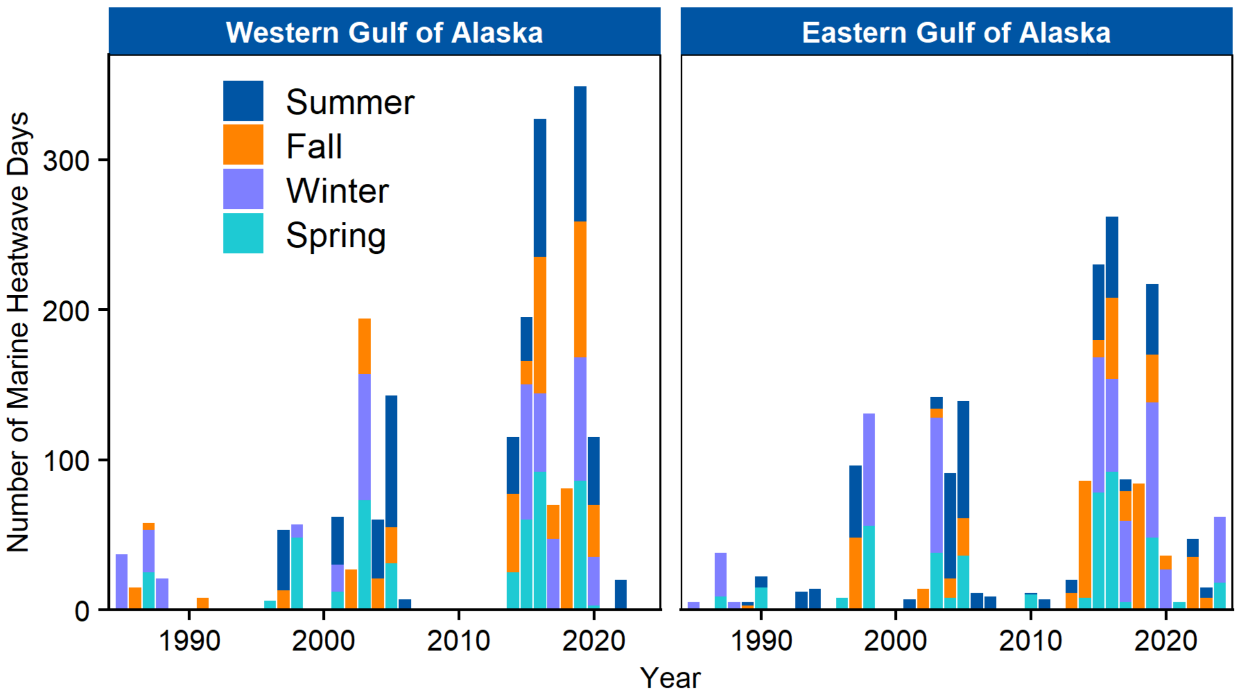


Figure 20: Number of days during which marine heatwave conditions persisted in a given year, through Oct. 31, 2024. Seasons are summer (Jun. - Aug.), fall (Sept. - Nov.), winter (Dec. - Feb.), spring (Mar. - Jun.). Years are shifted to include complete seasons so December of a calendar year is grouped with the following year to aggregate winter data (e.g., Dec. 2021 occurs with winter of 2022).

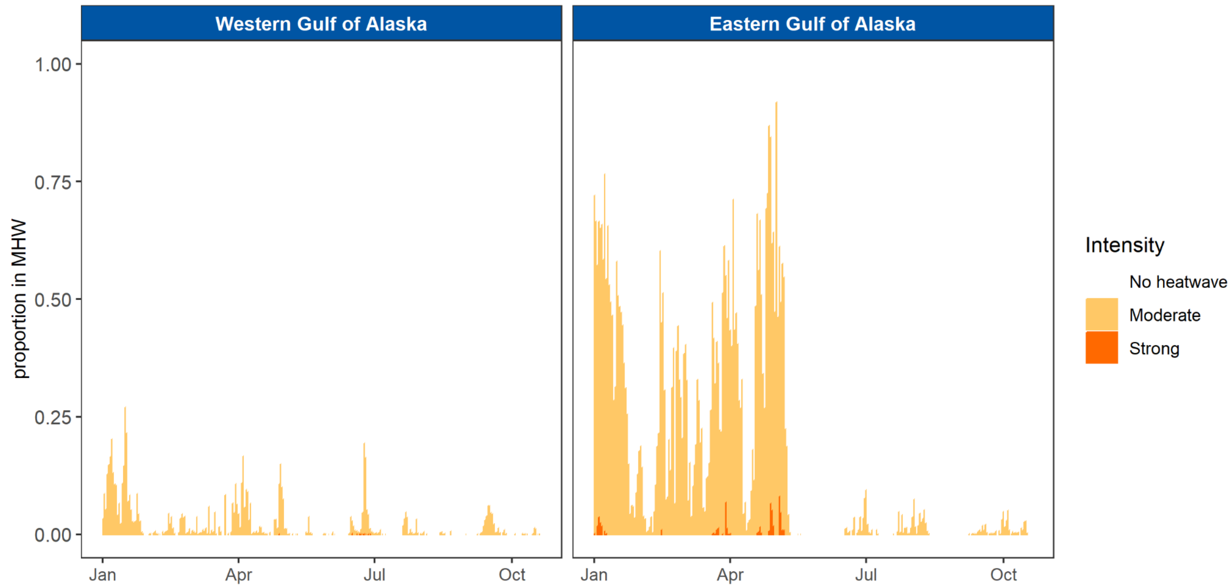


Figure 21: Proportion of region in heatwave status, through Oct. 31, 2024. Heatwave status calculations were performed on each 5 x 5 km grid cell within the Gulf of Alaska. This figure shows a five day rolling average of the proportion of cells within each region that are in heatwave status.

Factors influencing observed trends: The Gulf of Alaska was moderately influenced by El Niño in 2024, after 3 consecutive La Niña winters, causing an influx of warmer surface waters from the south that increased surface water temperatures across the GOA in the winter of 2024. The marine heatwave conditions in the eastern GOA dominated winter and spring, however the ocean temperatures in 2024 reflect a fifth consecutive year of no year-long persistent marine heatwave conditions across the GOA since 2019 (and 2014 – 2016 prior to that) (Bond et al., 2015; Hu et al., 2017; Barbeaux et al., 2020*b*). Icy Strait differs from the other shelf-oriented temperature datasets, reflecting conditions in the inside waters in southeastern Alaska.

Many factors can influence sea surface temperatures and the formation of MHWs, including a suite of weather, climatic, and oceanographic factors (Holbrook et al., 2019). Meanwhile, defining or contextualizing heatwaves depends upon the selection of baseline years (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, 2019; Schlegel et al., 2019). The more warm years that are included in the baseline, the warmer that baseline will appear.

Implications: The GOA shelf surface waters have been warming since 1900. Summer temperatures are primarily driving this warming trend. The seasonal difference in warming trends are not determined but could be due to changes in stratification, precipitation and freshwater runoff, cloud cover, circulation or other oceanographic and atmospheric drivers. '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 GOA marine ecosystem must be considered in terms of these longer-term shifts in temperature, to understand better their response to changing temperatures. As of this report, surface temperatures are predicted to cool in the winter/spring 2025 (Lemagie and Callahan in this report, p.43).

These observations suggest that temperature conditions in the Shelikof Strait survey area in winter 2024 were close to the long-term mean. Despite the warmer than surface waters across the GOA shelf, temperatures in Shelikof St. at surface and depth did not exceed known thresholds for groundfish spawning and larval survival. Extremely warm conditions in the Gulf of Alaska have been associated with poor recruitment, reduced prey availability, and increased mortality for some species (Barbeaux et al. 2020, Arimitsu et al. 2021, Litzow et al. 2021).

Methods:

Long-term Sea Surface Temperature: Sea surface temperatures in the Gulf of Alaska can be calculated using NOAA's Extended Reconstructed SST V5 data[11]. ERSST is a global monthly sea surface temperature dataset produced at 2 ° x 2 ° resolution starting in 1854. Statistical processes are used 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 and western GOA separately (divided 147 °W) but the regions were combined due to reduced subregional sample sizes and similar trends across the western and eastern shelf.

AFSC EcoFOCI Spring Larval Survey: EcoFOCI conducts biennial surveys in spring (May-June) and summer (August-September) in the Western Gulf of Alaska, targeting early life stages of fishes and their prey. At each sampling station, a bongo net array is towed obliquely from surface to 100 m (spring) or 200 m (late summer), or to 10 m off bottom in shallower waters. Attached to the wire above the bongo frame is a Seabird FastCAT profiler which measures temperature, salinity, and depth. Up casts were processed and used to generate maps and time-series of temperatures at the surface and at 100–150 m depth using the custom R package FastrCAT[12]. While surveys have been ongoing for multiple decades, time-series are provided here for the most recent 6 surveys with similar survey extent. In 2023, the spring survey dates were May 16–21, 2023 and the summer survey dates were September 4–12, 2023. Due to crew staffing shortages and reduced ship time, the Shelikof Strait was not able to be sampled in 2023 and no summer survey was conducted in 2021.

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

Spatial and temporal coverage of the GOA RACE-GAP summer bottom trawl surveys has varied from year to year. Starting dates have ranged from the middle of May to the first week in June, and survey end dates ranged from the third week in July to the first week in September. The number of vessels employed, the areal extent, and the maximum depth of the GOA survey have all varied among survey years (e.g., water temperatures were not collected from the eastern GOA in 1993 and 2001, stations in the deepest GOA stratum [700–1000 m] have been sampled in just 5 of the last 13 surveys). Since the GOA survey sweeps from west to east over the late spring and summer, the expectation is a trend toward warmer water temperatures collected late in the summer in southeast Alaska compared with those collected in the western GOA in late spring; this anticipated trend is expected to be particularly pronounced in the upper layers of the water column. 2023 temperatures were not standardized to account for the effect of collection date as in past years.

Gulfwatch Alaska Seward Line Survey: Since 1998, hydrographic transects have been completed in May

[11] `https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html`
[12] `https://github.com/Copepoda/FastrCAT`

(typically during the first 10 days of the month) along a sampling line that extends from the mouth of Resurrection Bay near Seward to the outer continental slope of the northern GOA. Data analyzed here are water column profile data that have been averaged over the top 100m of the water column to provide an index of upper water column heat content on the northern GOA shelf.

AFSC Southeast Coastal Monitoring Survey (Icy Strait): Temperature has been collected annually in Icy Strait during monthly (May to August) fisheries oceanography surveys conducted by the Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories, AFSC. The Icy Strait Temperature Index (ISTI, °C) is the average temperature of the upper 20 m integrated water column.

Satellite Data: Satellite SST data and 5 km grid mhw status from the NOAA Coral Reef Watch Program were accessed via the Alaska Fisheries Information Network (AKFIN) for January 1985 - September 2023. Daily SST data were averaged within the western (147 °W– 164 °W) and eastern (133 °W – 147 °W) Gulf of Alaska for depths from 10m – 200m (i.e., on the shelf). Detailed methods are online[13] and Watson and Callahan (2021) describes the automation of sst aggregation in depth.

We use the earliest complete 30-year time series (1985–2014) as the baseline period for mean and standard deviation comparisons although the guidance on such choice varies across studies (Hobday et al., 2018; Schlegel et al., 2019). Three notable differences exist between the current marine heatwave indicators and those previously presented to the North Pacific Fishery Management Council (detailed in Barbeaux et al., 2020*b*). First, the current indicator uses a different NOAA SST dataset, with a slightly different time period (beginning mid-1985 instead of mid-1982) and spatial resolution (the current indicator has finer spatial resolution and thus, more data points within the same region). Given the shorter time series, the 30-year baseline period is necessarily different (1986–2015 instead of the previous 1983–2012). Finally, the previous indicator was bounded spatially to target management of Pacific cod in the GOA, whereas the current indicator is bounded spatially by the ESR regions for a broader comparison.

AFSC Summer Longline Survey: The Alaska Fisheries Science Center (AFSC) has been conducting a longline survey since 1987 to sample groundfish from the upper continental slope annually in the GOA, during odd years in the Bering Sea (BS), and during even years in the Aleutian Islands (AI). More details related to this survey can be found in (Siwicke, 2022). The survey samples the GOA from west to east for the western portion of the region during the second half of June before transiting to Ketchikan and sampling from east to west and ending southwest of Kodiak Island in late August. Beginning in 2005, a temperature (depth) recorder (TDR) has been used for the purpose of measuring in-situ bottom temperature at each station. There are 71 stations sampled by the AFSC longline survey located within the GOA ESR region (41 in the western GOA and 30 in the eastern GOA), but sometimes units fail, so not all stations are successfully sampled every year.

The TDR used is an SBE 39 (Seabird Electronics) which is 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). The mean of the temperature while the TDR is on the bottom is a point estimate of the bottom temperature while the longline is fishing (which is usually two to six hours), and the range of temperatures recorded can be useful in interpreting how much variation occurs at a station.

The mean temperature from 1-m increment depths over the 246–255 m depth range was selected as an

[13] https://github.com/MattCallahan-NOAA/ESR/tree/main/SST

index for subsurface temperature because this layer was shallow enough to be consistently sampled across space and time and also deep enough to be below thermoclines and mixed layer dynamics. The depth of the profile does not always reach $\sim$ 250 m depth, but sample sizes have improved since 2019 because the second TDR deployment could be used if the first was unsuccessful or too shallow. Temperatures were weighted relative to the area of the depth-stratified regions the survey stations were in, which are described in Echave et al. (2013).

ADF&G Large Mesh Trawl Survey: The Alaska Department of Fish and Game conducts an annual trawl survey for crab and groundfish in GOA targeting areas of crab habitat around Kodiak Island, the Alaska Peninsula, and the Eastern Aleutian Islands (Spalinger and Knutson 2022). Parts of these areas have been surveyed annually since 1984, but the most consistent time series begins in 1988. While the survey covers a large portion of the central and western GOA, results from Kiliuda and Ugak Bays (inshore) and the immediately contiguous Barnabas Gully (offshore) are generally representative of the survey results across the region. Temperature anomalies were calculated using average bottom temperatures recorded for each haul from 1990 to present.

NOAA Acoustic-Trawl Survey: The MACE program conducts annual acoustic-trawl surveys of pre-spawning walleye pollock (*Gadus chalcogrammus*) in Shelikof Strait in the northern Gulf of Alaska in March (for detailed methods see McGowan et al., 2024). Temperature profiles are measured at survey trawl locations (from near surface to the deepest depth reached by the trawl) using a temperature-depth probe (SBE 39, Sea-Bird Scientific) attached to the trawl headrope. Trawls are not conducted at fixed locations, but are conducted opportunistically throughout the survey area where acoustic backscatter is present and are used to scale the backscatter to the nearest haul's species composition and length distribution for survey estimates of pollock biomass and abundance. Near-surface temperature is also measured along transects at a depth of approximately 1.4 m with a sensor in the flow thru scientific computing system (SBE 38, Sea-Bird Scientific). These higher resolution measurements are available for some but not all past surveys. In surveys where they are available, the averages of these higher-resolution measurements are highly correlated with averages of similar measurements at the more widely-spaced trawl locations. Therefore, we feel confident in reporting the trawl location near-surface temperatures as representative of survey-wide near-surface temperatures.

Eddies

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Last updated: August 2024

Description of indicator: Eddies in the northern GOA have been shown to influence distributions of nutrients (Ladd et al., 2009, 2005, 2007), including dissolved iron (Crusius et al., 2017; Ladd et al., 2009), phytoplankton (Brickley and Thomas, 2004), and ichthyoplankton (Atwood et al., 2010). In addition, the settlement success of arrowtooth flounder (Goldstein et al., 2020), the feeding environment for juvenile pink salmon (Siwicke et al., 2019), and the foraging patterns of fur seals (Ream et al., 2005) can be influenced by the presence of eddies. Eddies propagating along the slope in the northern and western GOA are generally formed in the eastern Gulf in autumn or early winter (Okkonen et al., 2001) and are sometimes associated with gap winds from Cross Sound (Ladd and Cheng, 2016). Using altimetry data from 1993 to 2001, Okkonen et al. (2003) found that strong, persistent eddies occurred more often after 1997 than in the period from 1993 to 1997. Ladd (2007) extended that analysis to 2006 and found that, in the region near Kodiak Island (Figure 22; region c), eddy energy in the years 2002 – 2004 was the highest in the altimetry record. The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS)[14].

Since 1992, a suite of satellite altimeters has been monitoring sea surface height. Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (Ducet et al., 2000), giving a measure of the mesoscale energy in the system. A map of eddy kinetic energy in the GOA averaged over the altimetry record (updated from Ladd, 2007) shows four regions with local maxima (labeled a, b, c and d in Figure 22). The first two regions are associated with the formation of the Haida (a) and Sitka (b) eddies. Eddies that move along the shelf-break often feed into the third and fourth high EKE regions (c and d). By averaging EKE over the regions, we obtain an index of energy associated with eddies in these regions (Figure 23).

The most recent data were downloaded on August 23, 2024 providing daily time series from 1/1/1993 to the present on a 0.25 ° longitude x 0.25 ° latitude grid. Original data set is global, but we subset it to 150 °E – 125 °W and 40 °N – 72 °N during downloading. Data from 1993 to 2020 is the reprocessed product whereas data from 2021 onward is “NRT” (near real time). Maps of long-term mean EKE (Figure 22) and monthly climatology of regional EKE (Figure 23, red line) are computed using data from 1993 to 2023 (period with full year coverage).

Status and trends: From late 2023, EKE in all regions experienced an increase relative the previous years (∼2020 – 2023) and rose above their climatological seasonal cycle; however, starting from late winter/early spring of 2024, EKE in each region transitioned to be below its mean seasonal cycle (Figure 23, black line). In the context of interannual variability over the entire satellite period (1993 to now), in regions a (Haida eddy), the earlier part of 2024 stands out as a period with anomalously high EKE, with EKE on par with those in 1997/1998, 2004, 2016, all of which were ENSO positive years. Region d also stands out as having strong positive EKE anomalies (relative to monthly climatology) from late 2023 to early 2024. Summer decrease of EKE in these regions is likely related to eddies moving out of the boxes. Indeed, large eddies (defined by closed SLA contours, see Figure 24b) and correspondingly high seasonal mean EKEs (Figure 24a) reside next to these boxes. To capture these transit signals, in addition to EKE averaged over the boxes, we may consider EKE averaged over broader areas, e.g., around the GOA coastal domain delineated by a depth range.

EKE has well defined mean seasonal cycles in the eastern and central GOA (Figure 22, regions a-c) with similar phasing (high in winter/spring and low in summer/fall), suggesting their formation mechanisms are inter-related. In contrast, EKE in the western GOA (Figure 22, region d) does not have a well-defined mean seasonal cycle, by it tends to be higher in spring and fall than in the other seasons, suggesting different eddy formation mechanisms in the western GOA.

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

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

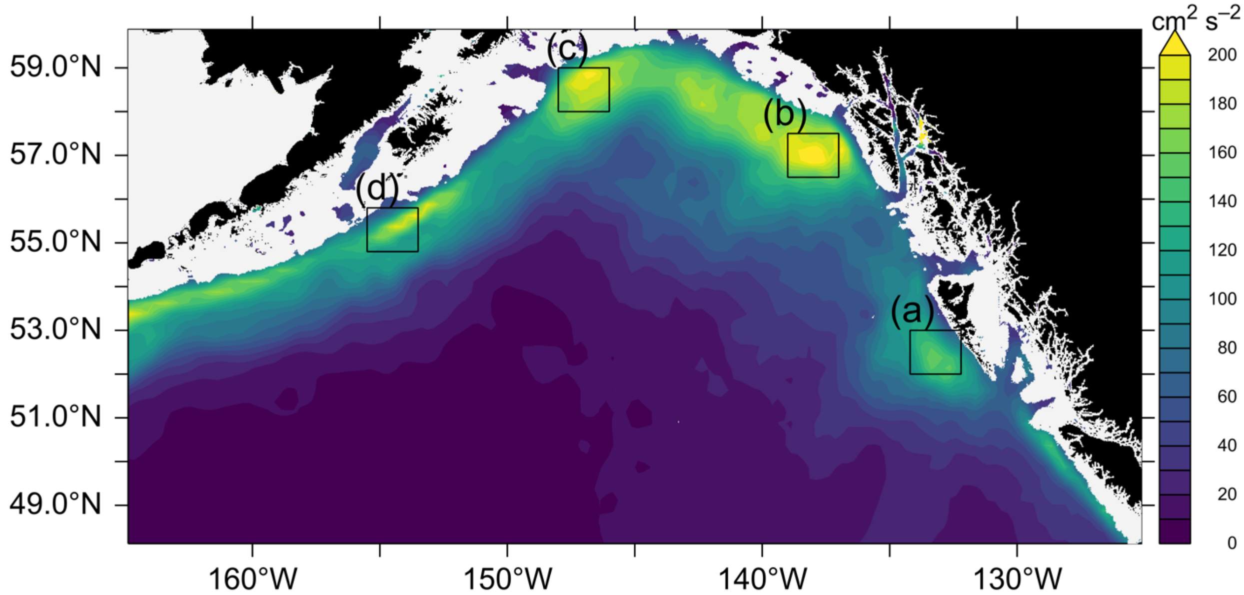

Figure 22: Long-term mean (January 1993 – December 2023) of eddy kinetic energy (EKE; cm ^{2} s $^{-2}$) based on satellite altimetry. EKE hot spots in the eastern GOA are associated with Haida (region a) and Sitka (region b) eddies. Region c and d are named northern GOA and western GOA (NGOA and WGOA), respectively. EKE averaged over each of the regions (a to d) is shown on Figure 23..

from their formation regions in the east and to intrinsic variability. Previous studies suggest that eastern GOA eddy activities (regions a and b) are related to large-scale forcing such that downwelling favorable wind anomalies along the Alaskan coast can generate positive SSH anomalies which promote formation of anticyclonic eddies. Downwelling favorable winds tend to happen during positive phases of PDO, but the correspondence between eddy activities and ENSO events is not always strong. ENSO associated forcing effects can be both local (via local wind anomalies) and remote (via coastal trapped waves arriving from lower latitudes and generate SSH anomalies along the Alaska coast). In comparison, interannual variability of eddies in the western GOA (region c and region d) tends to happen intrinsically and is not necessarily associated with large-scale forcing, although eddies from the eastern GoA could also arrive here.

Implications: Eddies sampled in 2002 – 2004 were found to contain different ichthyoplankton assemblages than surrounding slope and basin waters indicating that eddies along the slope may influence the distribution and survival of fish (Atwood et al., 2010). Carbon isotope values suggest that cross-shelf exchange due to eddies may be important to the marine survival rate of pink salmon (Kline, 2010). And eddies may result in enhanced settlement and recruitment for arrowtooth flounder (Goldstein et al., 2020).

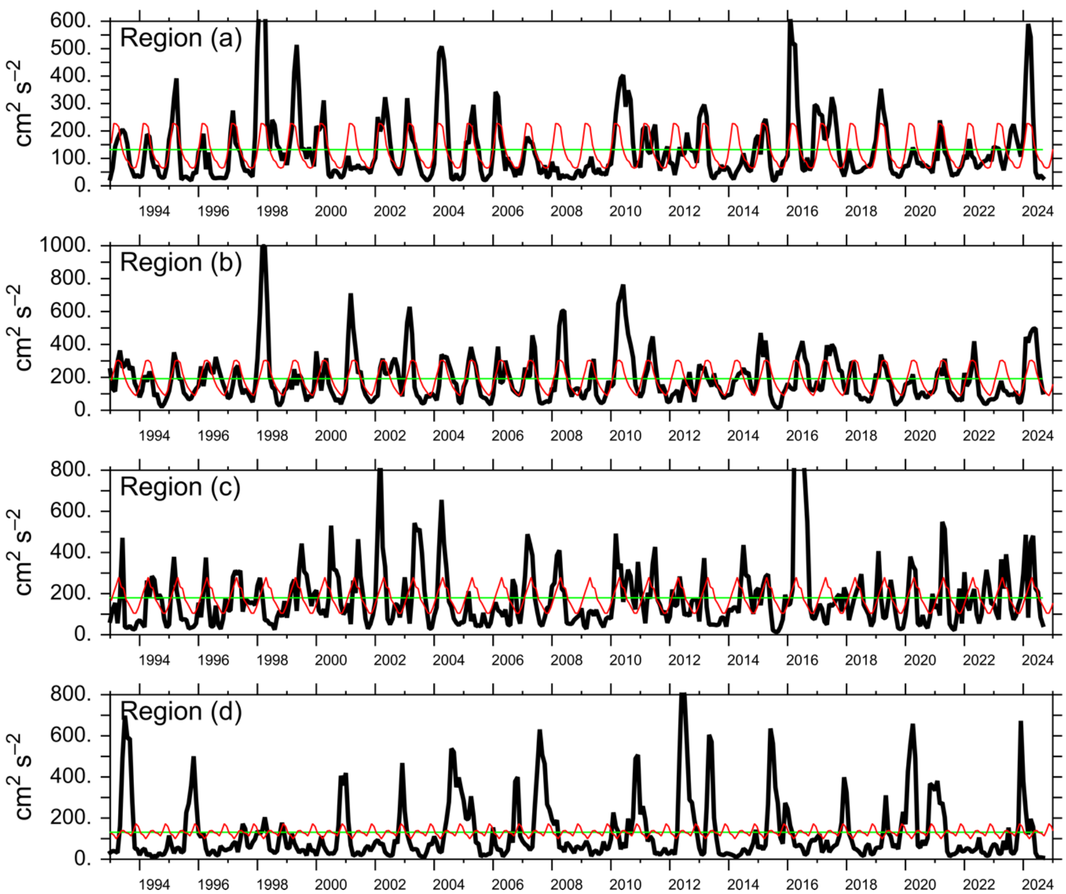

Figure 23: Eddy kinetic energy (cm ^{2} s $^{-2}$) averaged over regions shown in Figure 22. Results shown include monthly averages through August 23, 2004 (black line), monthly climatology from year 1993 – 2023 (red line), and long-term average over the entire time period (green straight line).

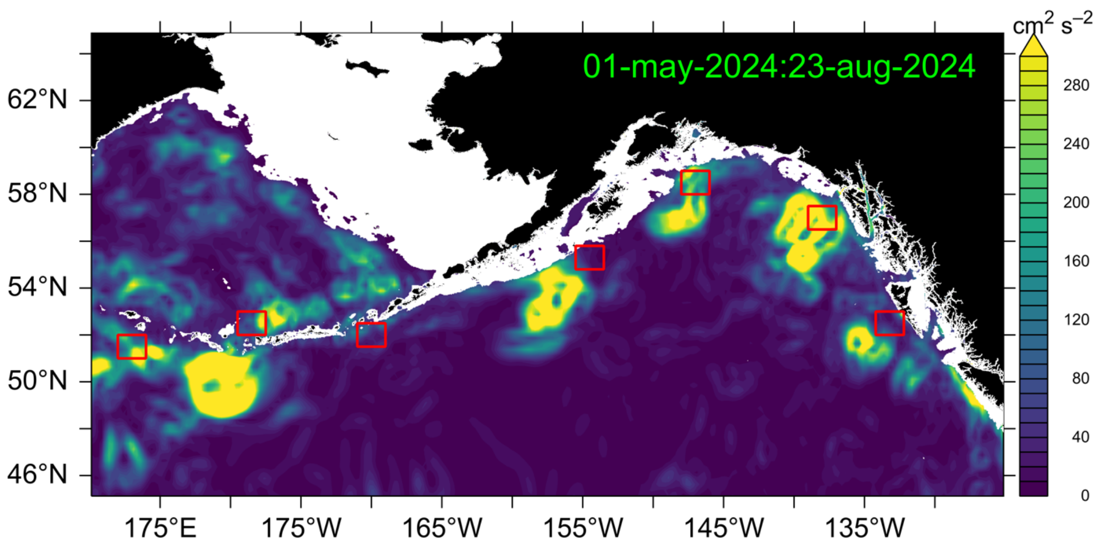

Figure 24: Mean eddy kinetic energy (upper panel) and sea level anomalies (lower panel) averaged over May 1 – August 23, 2024.

Ocean Surface Currents – Papa Trajectory Index

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Last updated: July 2024

Description of indicator: The Papa Trajectory Index (PTI) provides an annual index of near-surface water movement variability, based on the trajectory of a simulated surface drifter released at Ocean Station Papa (50 °N, 145 °W; Figure 25). The simulation for each year is conducted using the "Ocean Surface CURrent Simulator" (OSCURS[15]). Using daily gridded atmospheric pressure fields, OSCURS calculates the speed and direction of water movement at the ocean's surface at the location of a simulated surface drifter. It uses this information to update the position of the simulated drifter on a daily basis over a specified time period. For the index presented here, OSCURS was run for 90 days to simulate a surface drifter released at Ocean Station Papa on December 1 for each year from 1901 to 2023 (trajectory endpoints years 1902 – 2023).

Status and trends: The trajectories for 2023/2024 and 2022/2023 and were fairly typical among the time series (baseline 1968 – 2023), representing a return to more "average" (baseline 1968 – 2023) winter atmospheric conditions. In general, the trajectories fan out northeastward toward the North American continent (Figure 25). The 2021/2022 trajecotry is among the relatively few that initially moved strongly to the southeast and ended south of Ocean Station PAPA. The ending latitude for the 2023/24 trajectory, and thus its PTI value, was closer to the longterm mean (baseline 1968 – 2023) than any year since 2009/10.

The PTI time series (Figure 26) indicates high interannual variation in the north/south component of drifter trajectories, with an average between-year change of greater than 4 ° and a maximum change of greater than 13 ° (between 1968/1969 – 1969/1970). The change in the PTI between 2015/2016 and 2016/2017 was the largest since 1968/69 – 1969/70, while the changes between 2010/2011 and 2011/2012, and between 2020/2021 and 2021/2022, represent reversals with slightly less, but diminishing, magnitude. Such swings, however, were not uncommon over the entire time series. The 2021/2022 value returned below the mean after an excursion above it in 2020/21; the 2022/2023 value also remained below (although closer to) the long-term mean. The PTI has been below the mean for six of the seven previous years, while the 2023/2024 value was almost identical to the mean (baseline 1968 – 2022).

Over the past century, the filtered (5-year running average) PTI has undergone five complete oscillations with distinct crossings of the mean, although the durations of the oscillations are not identical: 26 years (1904 – 1930), 17 years (1930 – 1947), 17 years (1947 – 1964), 41 years (1964 – 2005), and 10 years (2005 – 2015). The filtered index indicates that a shift occurred in the mid 2000s to predominantly southerly anomalous flow following a ∼25 year period of predominantly northerly anomalous flow. This was indicative of a return to conditions (at least in terms of surface drift) similar to those prior to the 1977 environmental regime shift, although this cycle ended rather quickly, as the filtered PTI crossed

[15] http://oceanview.pfeg.noaa.gov/oscurs

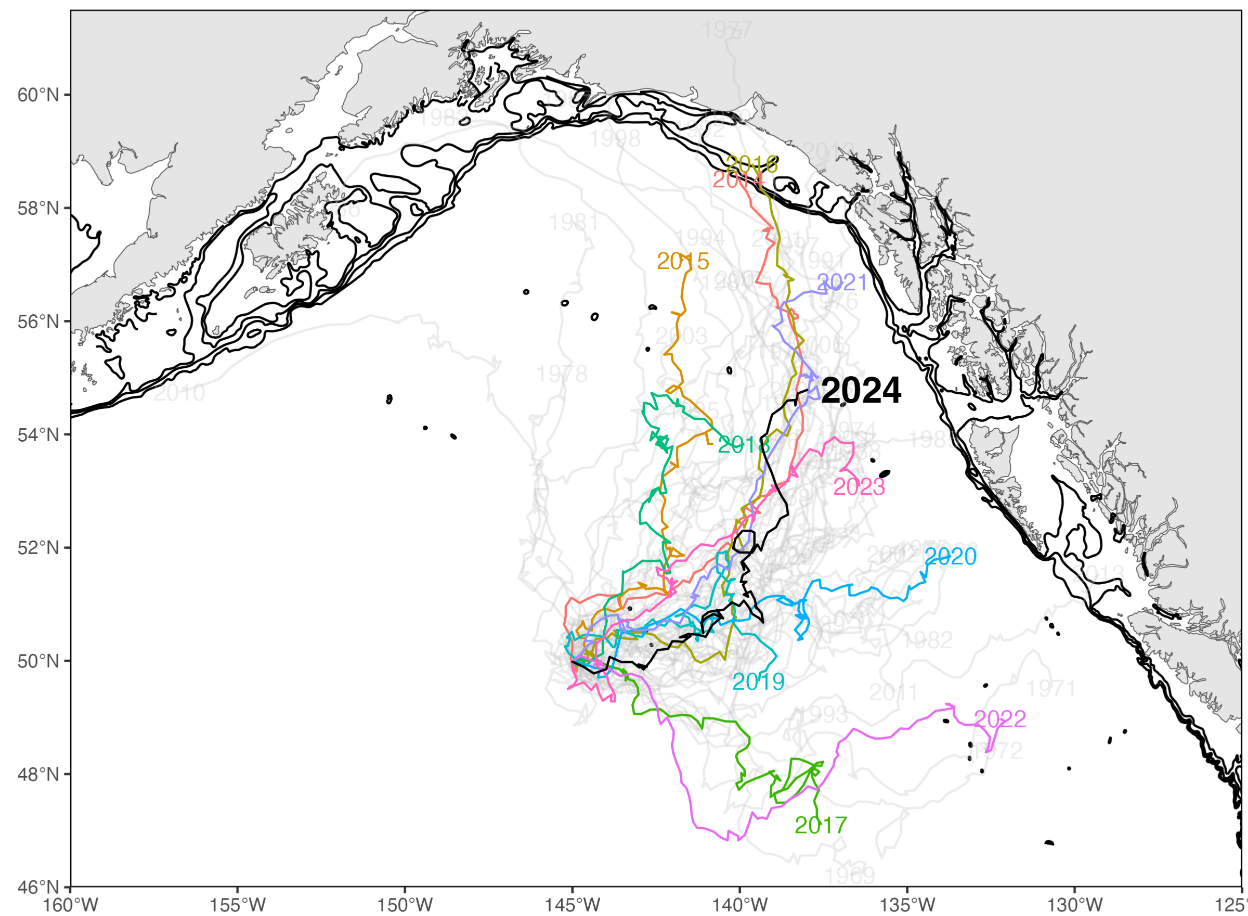

Figure 25: Simulated surface drifter trajectories for winters 2068 – 2024 (endpoint year). End points of 90-day trajectories for simulated surface drifters released on Dec. 1 of the previous year at Ocean Station Papa are labeled with the year of the endpoint (50 °N, 145 °W). The trajectory in black is 2023/2024, those in color end in 2014/2015 – 2022/2023, and those in gray end prior to 2013/2014.

the mean in the opposite direction in 2011. A similar shift back to an anomalous southerly flow appears to have occurred in 2016. Since 2005, the PTI appears to be fluctuating on a much shorter time scale (∼10 years per mean crossing) than previously.

Factors influencing observed trends: Individual trajectories reflect interannual variability in regional (northeast Pacific) wind patterns which drive short-term changes in ocean surface currents, as well as longer term changes in atmospheric forcing that influence oceanic current patterns on decadal time scales.

Implications: The year-to-year variability in near-surface water movements in the North Pacific Ocean has been shown to have important effects on the survival of walleye pollock (*Gadus chalcogrammus*) by affecting its spatial overlap with predators (Wespestad et al., 2000), as well as to influence recruitment success of winter spawning flatfish in the eastern Bering Sea (EBS; Wilderbuer et al., 2002). Filtered PTI values greater than the long-term mean are indicative of increased transport and/or a northerly shift in the Alaska Current, which transports warm water northward along the west coast of Canada and southeast Alaska from the south and consequently plays a major role in the GOA's heat budget. Interdecadal

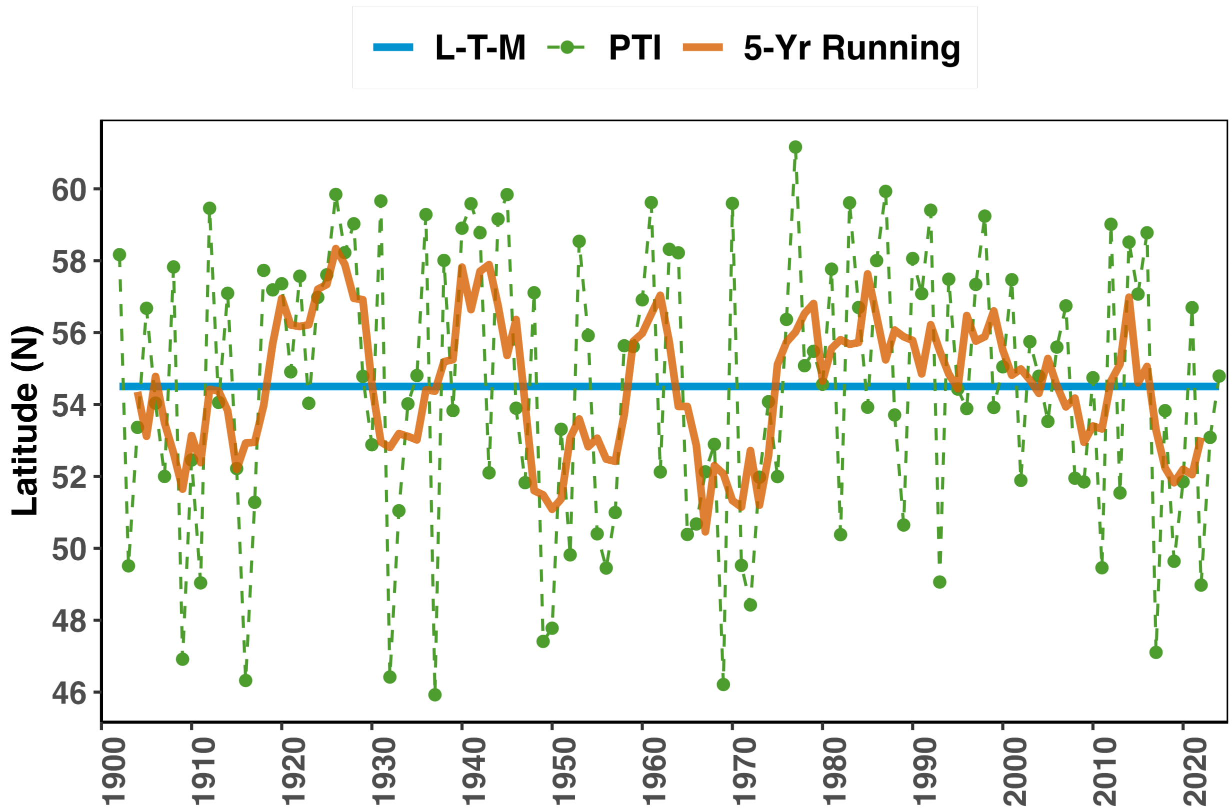

Figure 26: Annual, long-term mean (blue line), and 5-year running mean (orange line and squares) of the Papa Trajectory Index time series end-point latitudes (dotted green line and points) for 1902 – 2024 winters.

changes in the PTI reflect changes in ocean climate that appear to have widespread impacts on biological variability at multiple trophic levels (King, 2005). There is strong evidence that the productivity and possibly the carrying capacity of the Alaska Gyre, and of the continental shelf, were enhanced during the "warm" regime that began in 1977. Zooplankton production was positively affected after the 1977 regime shift (Brodeur and Ware, 1992), as were recruitment and survival of salmon and demersal fish species. Recruitment of rockfish (Pacific ocean perch) and flatfish (arrowtooth flounder, halibut, and flathead sole) also increased. However, shrimp and forage fish such as capelin were negatively affected by the 1977 shift (Anderson, 2003). The reduced availability of forage fish may have contributed to the decline in marine mammal and seabird populations observed after the 1977 shift (Piatt and Anderson, 1996).

Northern Gulf of Alaska Oscillation and Gulf of Alaska Downwelling index

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Last updated: September 2024

Description of indicator: The Gulf of Alaska is characterized by persistent offshore upwelling and coastal downwelling. This results in negative sea surface height (SSH) anomalies offshore and positive SSH anomalies on the continental shelf area.

The Northern Gulf of Alaska Oscillation (NGAO) index describes the strength of the cyclonic circulation in the Gulf of Alaska, and therefore, the intensity of the offshore upwelling in the Alaskan gyre (Hauri et al., 2021). The NGAO corresponds to the primary mode of variability, identified through Empirical Orthogonal Function (EOF) decomposition performed on SSH anomalies (with trends and monthly climatology removed). A positive NGAO phase is characterized by a weak cyclonic circulation leading to weak offshore upwelling and therefore brings less cold, acidic and de-oxygenated waters to the sub-surface. A negative NGAO phase is characterized by a strong cyclonic circulation leading to strong offshore upwelling that brings cold, acidic and de-oxygenated waters to the sub-surface.

The Gulf of Alaska Downwelling Index (GOADI) quantifies the intensity of positive coastal SSH anomalies in the Gulf of Alaska, indicating the strength of coastal downwelling (Hauri et al., 2024). This index is derived from the second mode of variability identified by Empirical Orthogonal Function (EOF) decomposition, applied to SSH anomalies after removing trends and monthly climatology. The GOADI serves as a measure of the intensity of coastal downwelling and, consequently, acts as a proxy for the intrusion of deep water onto the continental shelf's seafloor. A positive GOADI phase is characterized by high SSH anomalies and strong downwelling, making deep water intrusions less likely. During a negative GOADI phase SSH anomalies are low in the shelf area, leading to weaker downwelling that permits intrusion of cold, salty, deoxygenated, and acidic deep water onto the shelf.

Status and trends: Northern Gulf of Alaska Oscillation (NGAO) — The NGAO index remained predominantly negative throughout 2023 and continues to do so in 2024, with a brief, weak positive spike during the winter of 2023/2024 (Figure 27 A&C). This suggests a strong subpolar gyre, which in turn drives significant offshore upwelling. This intensified upwelling transports cold, acidic, nutrient-rich, and oxygen-depleted waters from the deeper layers to the surface offshore. Additionally, a stronger subpolar gyre results in a shift of the boundary between offshore and coastal waters closer to the shore. In other words, the outer shelf limit is pushed nearer to the coast, meaning locations such as GAK9 (on the outer shelf) may be more influenced by offshore waters. In summary, surface waters in the GoA were colder and had a lower pH over the past year.

Gulf of Alaska Downwelling Index (GOADI): — The GOADI index remained positive for most of 2023 (Figure 27 B&D), indicating strong coastal downwelling, which limited the intrusion of deep water onto the continental shelf. As a result, bottom waters on the shelf were likely warmer and more oxygenated in 2023 compared to 2024, when the GOADI index shifted negative and coastal downwelling weakened. This reduction in downwelling allowed deeper, colder, more acidic, and low-oxygen water to spread across the seafloor. Additionally, the change suggests a decrease in Ekman transport across the shelf.

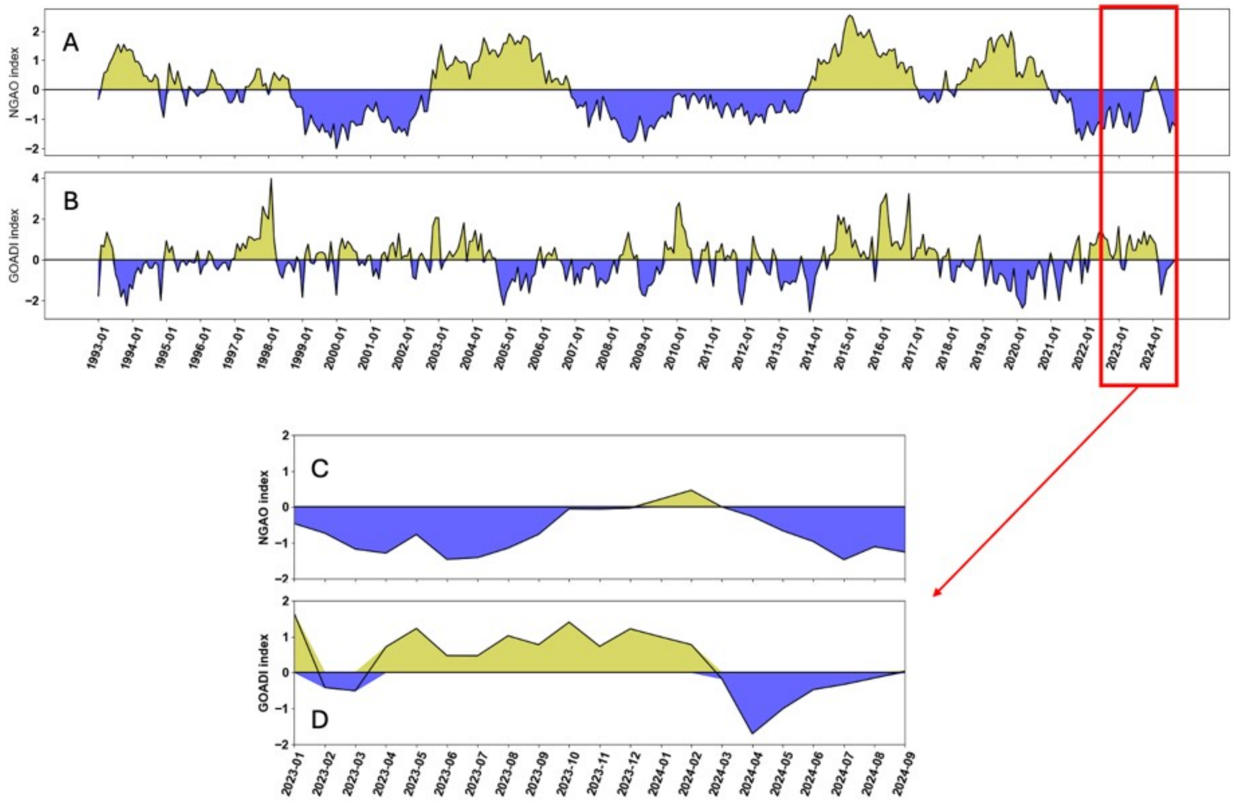

Figure 27: Time-series of the Northern Gulf of Alaska Oscillation and the Gulf of Alaska Downwelling Index. The Northern Gulf of Alaska Oscillation (NGAO) index (A) represents the intensity of offshore upwelling in the Alaskan gyre (updated from Hauri et al., 2021) and is derived from the first mode of variability in SSH anomalies, explaining 24% of the total variance and 50% of SSH variance in offshore areas. The Gulf of Alaska Downwelling Index (GOADI) measures the intensity of coastal downwelling, based on the second mode of variability in SSH, which accounts for 10% of the total variance and 60% of SSH variance on the continental shelf (updated from Hauri et al., 2024). Panels C & D show the period from 2023 until near real time.

Factors influencing observed trends: Ocean circulation in the Gulf of Alaska Gyre, can influence the oceanographic characteristics (dissolved oxygen, pH, temperature, salinity) that can cumulatively impact groundfish habitat, affecting distribution and potentially survival (Hauri et al., 2024). A positive GOADI indicates weaker coastal downwelling, likely allowing intrusion of deeper waters onto the shelf bottom that are low in dissolved oxygen, more acidic, cooler temperature, and more saline. Negative NGAO indicates stronger upwelling in the central GOA gyre due to stronger gyre circulation, bringing deeper waters that are low in dissolved oxygen, more acidic, cooler temperature, and more saline up to the surface in the central gyre (offshore) and potentially onto the shelf.

Implications: Decreased DO at depth may limit the availability of deeper waters as refuge from warmer temperatures. Some deeper-dwelling slope adult groundfish, including thornyhead (*Sebastolobus* spp.; 100 – 1,200m), rougheye (*S. aleutianus*), blackspotted (*S. melanostictus*; 300 – 500m), and shortraker rockfish (*S. borealis*; 300 – 400m), already live in reduced oxygen environments. A decrease in DO in those habitats may drive shifts in distribution to shallower waters (Thompson et al., 2023). Ocean acidification has the potential to adversely affect populations of sensitive species and the fisheries on which they depend; Tanner crab catch and profits, for example, are predicted to decline as pH levels drop below critical levels (Punt et al., 2016). OA thresholds for salmon have yet to be exceeded anywhere in the Gulf of Alaska other than in deeper waters in the southwest which are outside the range of those species. Although the vast majority of the benthic waters in the Gulf of Alaska are below critical thresholds for both Tanner crab juveniles and pteropods, there is not as yet significant intrusion of these waters into the habitats of these species. Tanner crab juveniles generally settle in shallow waters in the Gulf of Alaska (Ryer et al., 2015) where currently the pH levels are above pH 7.8, while pteropods are generally present in the plankton at relatively shallow depths. Currently there is no evidence to suggest that OA is significantly affecting any known species in the Gulf of Alaska (including Tanner crab and red king crab), in part due to this spatial refuge. However, given current trends it is likely that intrusion of low pH waters into the habitats of the species will become a more frequent occurrence with likely negative consequences (Bednaršek and Ohman, 2015). Additionally, other environmental stressors, such as increasing temperature or decreasing dissolved oxygen, can synergistically interact with OA effectively lowering thresholds and making organisms more vulnerable (e.g., Swiney et al., 2017).

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

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Based on a contribution developed by Matt Wilson
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Last updated: August 2024

Description of indicator: Surface wind is fundamental to the oceanography, biology and ecology of the Gulf of Alaska ecosystem. As a driver of coastal circulation, surface wind affects upwelling/downwelling, turbulent mixing (e.g., mixed layer depth), and transport of planktonic organisms. Its relevance to regional groundfish production in the Gulf is illustrated by studies of wind-driven turbulent mixing on walleye pollock larvae (e.g., Porter et al., 2005) and of wind-driven transport on juveniles and recruitment (Wilson and Laman, 2021).

Two complementary datasets were used to indicate springtime (April – May) surface wind in the coastal Gulf. This period coincides with the seasonal occurrence of many groundfish larvae. The first dataset consists of high-resolution empirical measurements recorded by the National Data Buoy Center (NDBC) at site AMAA2. We chose AMAA2 as its location might be considered a gateway of sorts where winds determine whether coastal flow either funnels into and down Shelikof Strait along the Alaska Peninsula or is diverted southward around Kodiak Island (Ladd and Cheng, 2016). Springtime measurements at AMAA2 are currently available for 18 years: 2004 to 2024, except 2007, 2008, and 2018, with measurements recorded at 30 min intervals[16]. The second dataset consists of lower-resolution, reanalysis-based data from the National Centers for Environmental Prediction (NCEP) (Kalnay et al., 1996).

[16]`https://www.ndbc.noaa.gov/`

The NCEP Reanalysis data averaged by month and year from 1948 – 2024 were provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA[17]. We specified the geographic area to be 55 – 60oN latitude and 150 – 160oW longitude.

For both datasets, NDBC-AMAA2 and NCEP, wind was expressed as the components u (+u is wind blowing to the east, "westerly" wind) and v (+v is northward wind, "southerly" wind). Correlation of annual means (n = 18) between the two datasets was r = 0.54 for the u component, and r = 0.75 for the v component. The NDBC-AMAA2 data are used to construct progressive wind diagrams; conceptually, these can be thought of as a progression through time of the hypothetical displacement from AMAA2 station during any given year (Wilson and Laman, 2021).

Status and trends: The progressive wind diagram, or hypothetical displacement, at NDBC-site AMAA2 indicated a brief period of winds blowing offshore in early April, followed by easterly (onshore) winds through May (Figure 28). Spring winds at AMAA2 were most similar to those observed in 2014 and 2019 in both magnitude and direction. Spring winds in 2015 and 2016 were in a similar direction but stronger magnitude. These patterns are in contrast to the most recent period 2020 – 2023, which had winds blowing towards the southwest ("northeasterlies").

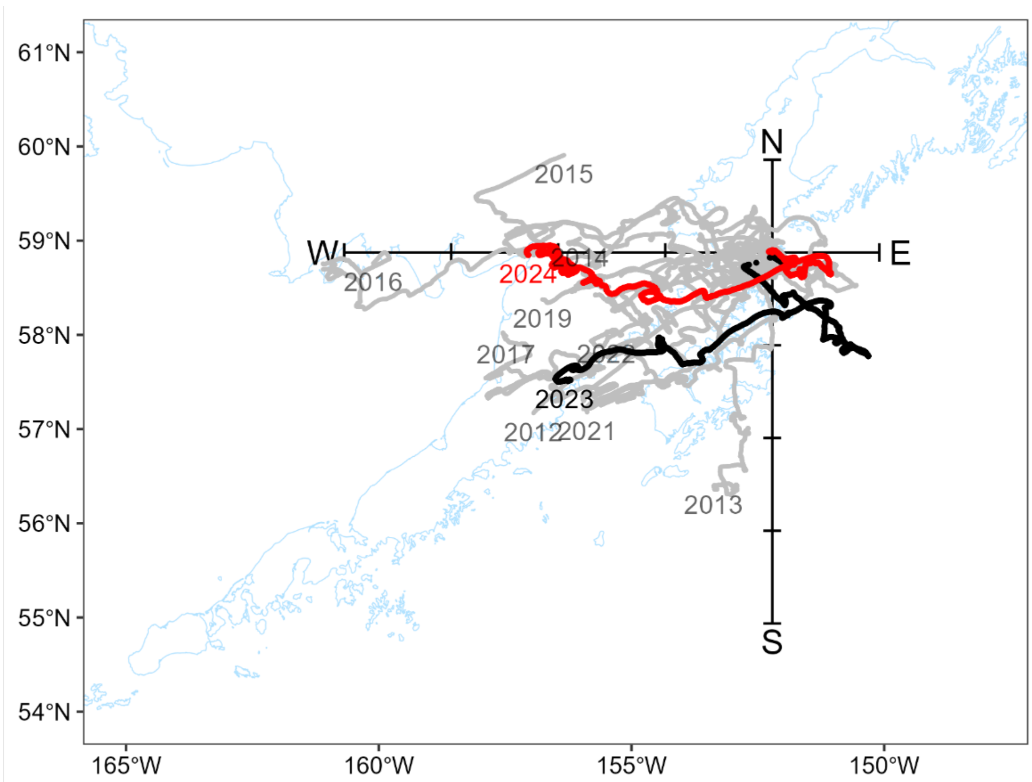

Figure 28: Progressive wind diagrams (PWD) from NDBC-AMAA2 for spring (April – May) 2004 – 2024 (except 2007, 2008, and 2018). Select trajectory endpoints are labeled by year, with the 2024 trajectory in red and the 2023 trajectory in black. The diagram is superimposed on the Alaska coastline with the origin centered on the location of the AMAA2 site. Note, the scale of distance differs between the trajectories and the coastline; PWD 1 tick mark ∼ 2700 nm.

[17] https://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl

The lower-resolution NCEP winds indicated mean April - May wind towards the north (Figure 29). NCEP winds in 2024 were most similar in direction and magnitude to winds in the period 2015 – 2019 when means indicated a relatively strong northward component in this region, and again in contrast to the most recent period 2020 – 2023.

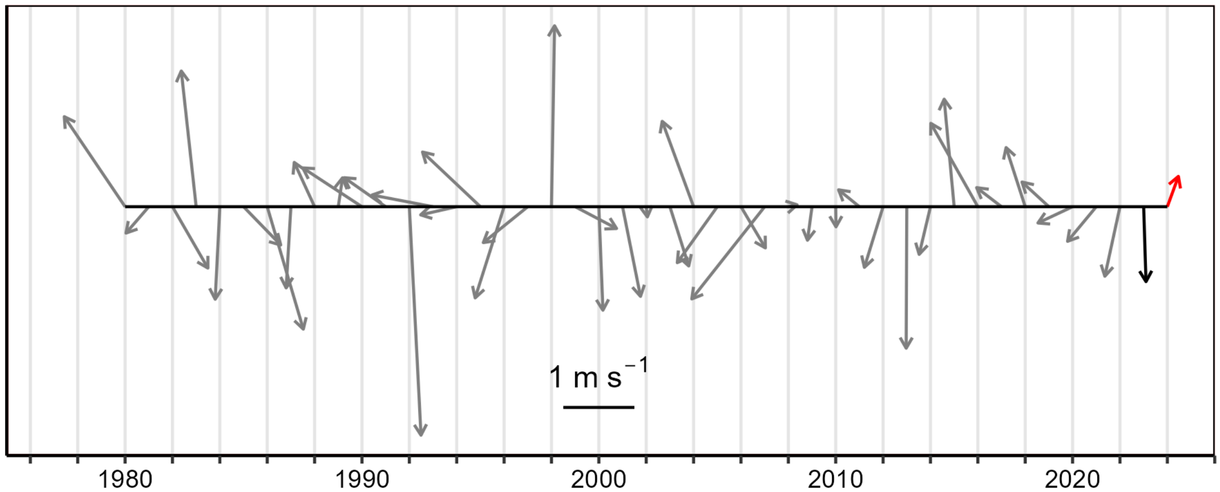

Figure 29: Mean wind from NCEP for spring (April – May) 1980 – 2022 (gray), 2023 (black), and 2024 (red). Each "stick" represents the magnitude (y-axis) and direction (e.g., northward is up, eastward is to the right) toward which the wind is blowing during each year.

Factors influencing observed trends: In the Gulf, winds are dominated by cyclonic storm systems that exhibit pronounced seasonality (Stabeno et al., 2004). During spring, cyclonic winds begin to moderate and anticyclonic winds can drive intermittent upwelling. The Aleutian Low influences wintertime conditions and the El Niño-Southern Oscillation can affect conditions at multi-year intervals. Local terrain effects can intensify flow and lead to "gap" winds that affect oceanographic processes. Gap wind events in the AMAA2 region lead to diversion of the ACC to the outside of Kodiak and reduced transport down Shelikof Strait (Ladd and Cheng, 2016).

Implications: Wind speed and direction influences coastal circulation in the Gulf at multiple scales. At small scales, wind-driven turbulence has implications for vertical stratification of the water column, and the patchiness and vertical distribution of plankton, including fish larvae. At larger scales, wind drives upwelling and downwelling with consequent effects on vertical circulation and transport. At large scales, wind-driven transport influences the replenishment of adult fish and shellfish stocks by transporting larvae to favorable or unfavorable habitat. When the AMAA2 wind trajectories for this period (April - May) are toward the southwest (down Shelikof Strait), estimates of age-1 pollock abundance tend to increase, possibly because downwelling-favorable northeasterly winds enhance retention of larvae (Stabeno et al., 1996, 2004) and juveniles in areas that favor survival (Wilson and Laman, 2021). Historically, the number of gap wind events during spring (January - May) was positively correlated with Pacific cod recruitment and negatively correlated with arrowtooth flounder recruitment (Ladd and Cheng, 2016), and these relationships should be re-evaluated with more recent observations.

Habitat

Structural Epifauna

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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[18] for past reports.

Ocean Acidification

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Last updated: October 2023

The Regional Ocean Modeling System-Carbon, Ocean Biogeochemistry and Lower Trophic (ROMS-COBALT-GOA) marine ecosystem model was not updated in 2024. Please refer to the 2023 Report [19] for the latest update.

Dissolved oxygen

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[18]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

[19]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

Last updated: October 2023

The Regional Ocean Modeling System-Carbon, Ocean Biogeochemistry and Lower Trophic (ROMS-COBALT-GOA) marine ecosystem model was not updated in 2024. Please refer to the 2023 Report [20] for the latest update.

Primary Production

Satellite-derived Chlorophyll-a Trends

Contributed by Jeanette C. Gann[1], Matt W. Callahan[2], Jens M. Nielsen[3,4], and Noel Pelland[3,5]
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Last updated: September 2023

This contribution was not updated this year. Please refer to the archives[21] for past reports.

Seward Line May Phytoplankton Size Index

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Last updated: August 2024

Description of indicator: Since 1998, hydrographic transects have been completed in May (typically during the first 10 days of the month) along a sampling line that extends from the mouth of Resurrection Bay near Seward to the outer continental slope of the northern Gulf of Alaska. Episodically beginning

[20]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands
[21]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

in 2001 and annually beginning in 2011, chlorophyll-a (chl-a) in two size fractions ($< 20\ \mu$m and $> 20\ \mu$m) as well as total chl-a have been measured at 6–7 depths (0 to 50 or 75 m) at stations spanning the continental shelf and offshore waters. Data provided here are an index of size composition of the phytoplankton shelf community, orginally developed by Suzanne Strom of Western Washington University. The index is computed from depth-integrated shelf station chl-a values, for each early May cruise, and is equal to the fraction total chl-a found in the large ($> 20\ \mu$m) size class (i.e., chl-$a_{>20}$ / chl-a_{total}). In most cases, 9 stations are averaged to generate the index. High values of the size index correspond to diatom-dominated communities, while low values of the size index correspond to phytoplankton communities dominated by small flagellates and cyanobacteria. Comparison with remote sensing-based estimates of spring bloom timing and magnitude shows that the size index is a predictor of two important aspects of the spring bloom. 1) When the index is (≤ 0.25, meaning that small cells strongly dominate, the spring bloom begins and peaks relatively late in the year. 2) When the index is ≥ 0.5, meaning that large cells comprise half or more of the total chl-a, the value of the index is strongly correlated ($r^2 = 0.65$) with the cumulative magnitude of the spring bloom (April – June) as measured by remote sensing.

Status and trends: The index for May 2024 was 0.85, predicting an above-average spring bloom magnitude and a return to similar conditions as 2021 and 2022, (baseline: 2001 – 2023, Figure 30). No long-term secular trend is evident in the phytoplankton size index, although there is a suggestion that variance has increased in recent years. The marine heatwave years of 2014 – 2016 show the lowest values in the time series, with the (lesser) heatwave year of 2019 also showing a low value. The past few years (May 2021 and 2022) had some of the highest index values in the time series (0.94 and 0.87, respectively), consistent with the intense diatom blooms that occurred relatively early in those years. Last year, May 2023, had a more typical value of 0.69.

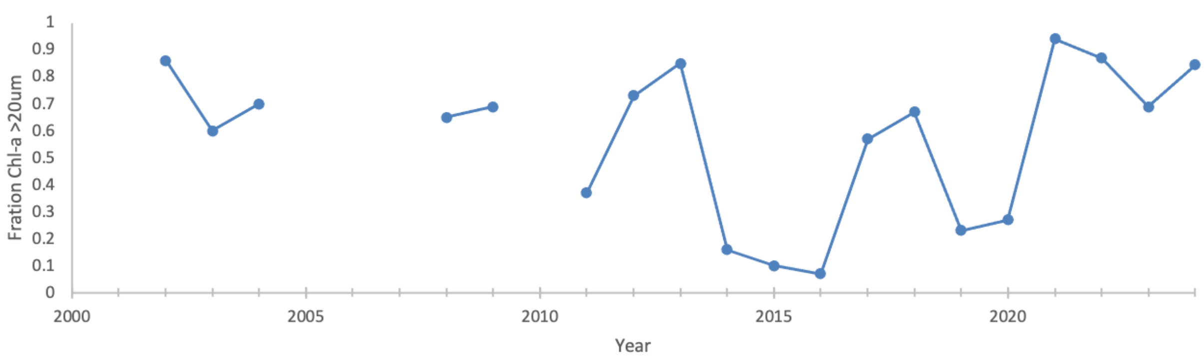

Figure 30: May 2001–2024 time series of phytoplankton size index (fraction of total chl-a present in cells $>$ 20 μm) for the Seward Line shelf stations.

Factors influencing observed trends: The mix of resource availability (light, micro- and macronutrients) and top-down controls leading to shifts in the spring size index is under active investigation. Spring water temperature probably has little direct influence, as the temperature range observed is small relative to the physiological tolerance of these phytoplankton.

Implications: High values of the size index correspond to diatom-dominated communities, which are known to provide high amounts of lipid-rich prey for zooplankton (i.e., copepods and euphausiids). Low values of the size index correspond to phytoplankton communities dominated by small flagellates and cyanobacteria, which are less available to large zooplankton and may lead to less efficient transfer of primary production to higher trophic levels. A late spring bloom could lead to timing mismatches between the emergence/development of important zooplankton grazers and the availability of diatom prey, which would have negative effects on transfer of production to higher trophic levels. Conversely, a larger spring bloom introduces more primary production into the ecosystem in a form that can be efficiently transferred to higher trophic levels, in the water column and the benthos.

Oceanography at the nearshore GAK1 Mooring

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Last updated: September 2024

Description of indicator: Full water column profiles of temperature and salinity have been collected at oceanographic station GAK1 since December 1970. Located at the mouth of Resurrection Bay (59 ° 50.7' N, 149 ° 28.0' W), the site is within the Alaska Coastal Current, so it is well connected with the shelf circulation and depicts thermal anomalies that are representative of a broad swath of the Northern Gulf of Alaska (Danielson et al., 2022). Salinity data from 30 m depth are a proxy for the alongshore baroclinic transport of the Alaska Coastal Current from May to November (Weingartner et al., 2005).

For the first 20 years, sampling was accomplished by ships-of-opportunity, so the time interval varied from several times per month to several times per year. CTD sampling has been accomplished on a nominally monthly basis since 1990. A year-round subsurface mooring with 6 – 7 dataloggers spread between 20 m and 250 m depth has been annually deployed and recovered since December, 1999. Over 100 peer-reviewed publications have applied GAK1 data to climate, environmental and ecological studies.

Status and trends: The Northern Gulf of Alaska GAK-1 record shows a 52-year trend of warming both in near the surface (20-50m: $+0.19 \pm 0.05$ °C decade $^{-1}$) and near the seafloor (200 – 250m: $+0.16 \pm 0.03$ °C decade-1) (figure 31). The salinity record over this time frame depicts significant freshening at the surface (20 – 50m: -0.05 ± 0.02 decade $^{-1}$) and salinization near the seafloor (200 – 250m: -0.04 ± 0.01 decade $^{-1}$) (Figure 31). Seasonally partitioned trend analyses (not shown) suggest that the near-bottom thermal trends most strongly manifest in winter, while the near-bottom salinity trends are driven by spring month conditions. Annual means of water column temperatures have remained within 0.5 °C of the long-term average since 2021. Data averaged from January to May 2024 show both near-surface and near-bottom anomalies of about 0.5 °C. In contrast, the surface and seafloor salinity field shows that 2024 anomalies for this parameter both reinforce the long-term trend, with significant anomalies of opposite sign in the near-surface and near-seafloor.

Factors influencing observed trends: According to NOAA Climate.gov, 2023 was the warmest year on record for earth as a whole. The 2023 – 2024 El Niño was rated "strong", following only the 1997 and 2015 events in the last 30 years. As of Fall 2024, La Niña conditions are forecast for the coming months.

Implications: The GAK1 data depicts a strengthening of water column stratification in the coastal

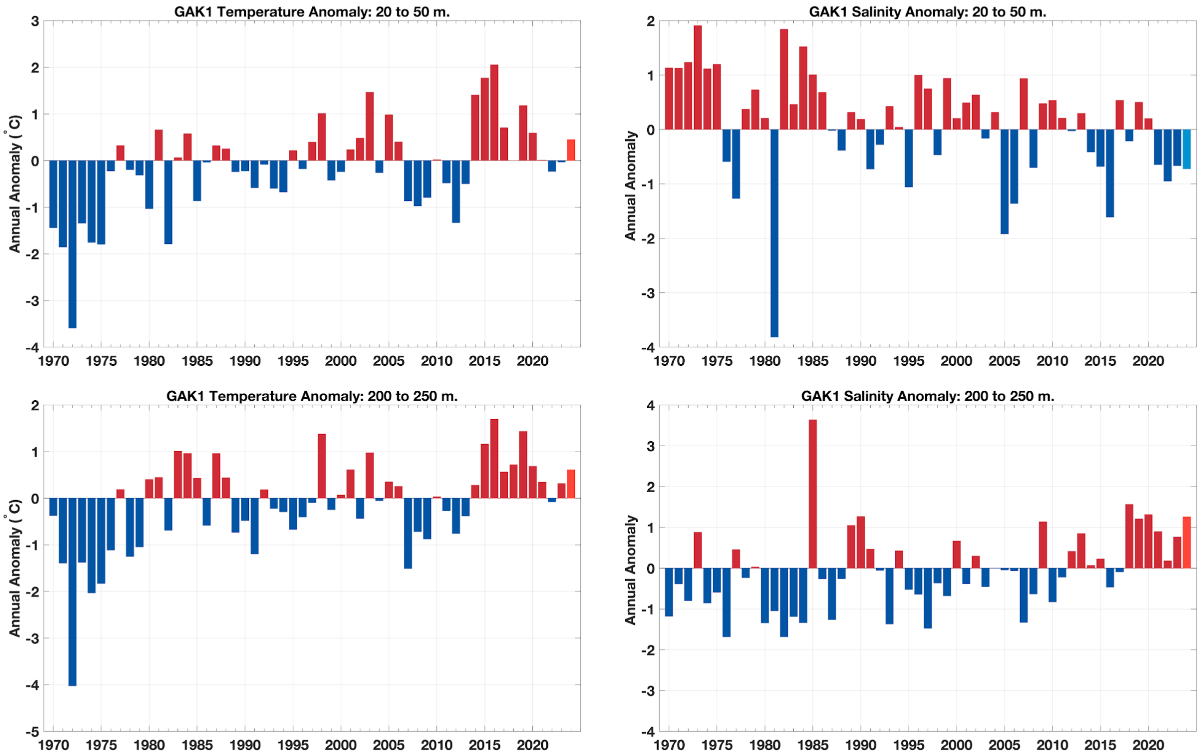

Figure 31: Annual mean anomalies of temperature (left) and salinity (right) from the GAK-1 hydrographic time series station over 12/1970 – 5/2024 for the near-surface (0 – 50m depth range, top) and close to the seafloor (200 – 250m depth range, bottom). Data from 2024 are depicted with a light-colored shading to denote an incomplete sample year.

Gulf of Alaska. Enhanced stratification may diminish the transfer of nutrients from deep waters into the euphotic zone, but it is unknown whether the observed stratification changes are biologically significant. Warmer waters increase metabolism rates in fishes and plankton, suggesting that as waters warm competition for resources would increase across the marine ecosystem. Decreasing salinity in the upper water column implies increasing westward baroclinic transport of the Alaska Coastal Current during fall, winter and spring months. Accelerated westward flows could impact the dispersal and fate of plankton, larvae and biogeochemical constituents of nearshore waters.

Seward Line Spring Oceanography

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Last updated: September 2024

Description of indicator: In the Gulf of Alaska and the Bering Sea, a number of commercially important species (e.g., walleye pollock and Pacific cod) have evolved a life history strategy that distributes eggs and larvae through the months preceding and surrounding the spring bloom (Doyle and Mier). Annually repeated ship surveys and glider transects provide physical and biological data that characterize the spring bloom and key facets of the marine environment. Glider deployments focus data collections on characterizing the transition from the low-productivity late winter season through the massively productive spring bloom.

Data shown here are from a 2024 March-to-June Gulf of Alaska mid-shelf station-keeping glider deployment (about 50 miles offshore, near 59 °N/148.7 °W) and the May 2024 the Northern Gulf of Alaska long-term Ecological Research (NGA LTER) Seward Line ship survey. The ship data place the glider data into a climate context with a longer base of observations (1998 – 2024). Glider data are available for near-real-time viewing and download through the Alaska Ocean Observing System (AOOS) Ocean Data Explorer webpage[22].

Status and trends: May 2024 hydrographic data from the Seward Line (Figure 32) indicate that temperatures were within 0.5 °C of the long-term average over the continental shelf, and slightly cooler than normal over the shelf break and slope. Salinities in the Alaska Coastal Current were lower than average, but a high-salinity anomaly extended over the deepest 100m of the water column (nearshore) and between 100 and 200 m depth over the outer shelf. The glider data (Figure 33) showed that the spring bloom at this station was triggered by a combination of the seasonal increase in light, a period of weak winds, and a shoaling of the mixed layer depth that coincided with a sharp increase of the near-surface stratification. The 2024 spring bloom onset (April 26) at this site was nearly a week later than in 2023.

Factors influencing observed trends: Similar to findings from 2023, the 2024 bloom onset (Figure 32) was the consequence of an alignment of increased light availability, a period of weak winds, and the onset of thermal stratification.

Implications: The characteristics of the spring phytoplankton bloom is influenced by varying subsurface physical oceanographic characteristics. The 2024 spring bloom chlorophyll a fluorescence peaked on the mid-shelf on May 9th but then remained at elevated levels until June 9, 2024, suggesting that the phytoplankton standing stock was not strongly controlled by zooplankton grazing during this month-long period. The timing and magnitude of this event can influence zooplankton productivity, groundfish larval survival, and upper trophic level feeding and reproductive success.

[22] `https://portal.aoos.org/`

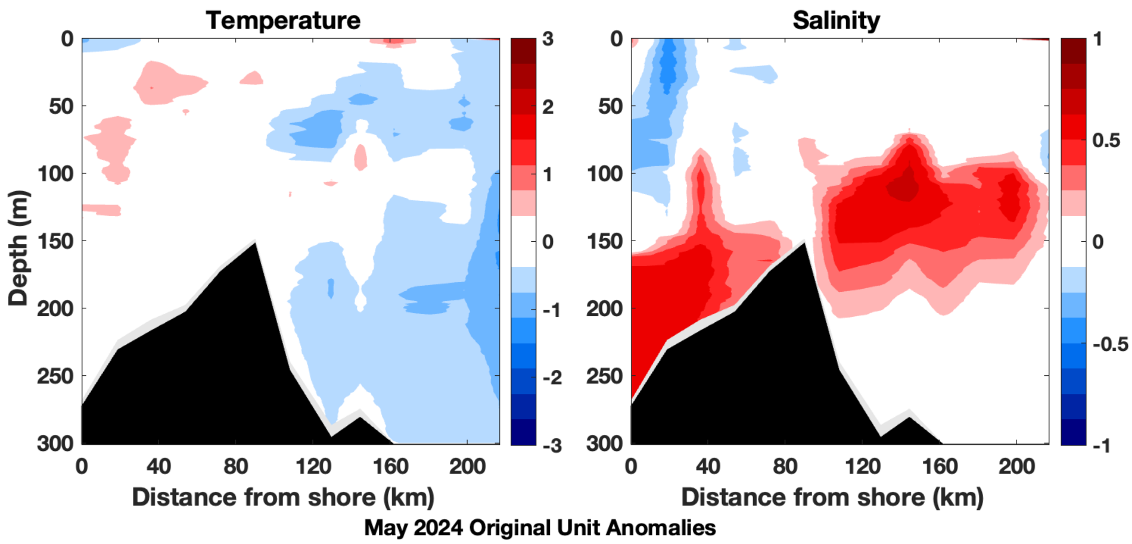

Figure 32: May 2024 anomalies of temperature (left; °C) and salinity (right, PSU) along the Seward Line.

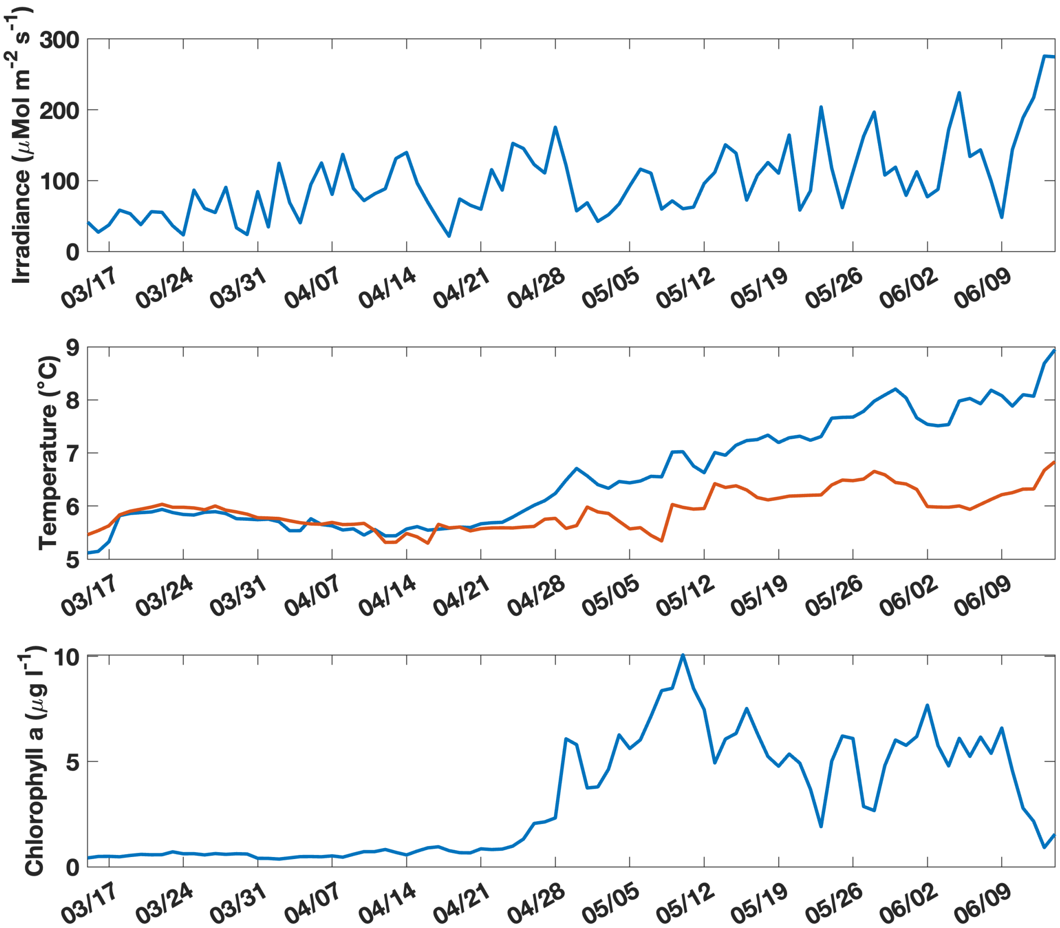

Figure 33: Daily averages of: 0-20 m irradiance (photosynthetically available radiation; top), temperature averaged over 0 – 20 m (blue) and 20 – 100 m depth (red) levels (middle), and 0 – 20 m chlorophyll a fluorescence (bottom) as measured by an underwater glider on the Northern Gulf of Alaska continental shelf over March 17 to June 14, 2024.

Zooplankton

Continuous Plankton Recorder Data from the Northeast Pacific, 2002–2023

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Last updated: July 2024

Description of indicator: Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. Two transects are sampled seasonally, both originating in the Strait of Juan de Fuca, one sampled monthly (∼Apr – Sept) which terminates in Cook Inlet, the second sampled 3 times per year (in spring, summer and autumn) which follows a great circle route across the Pacific terminating in Asia. Several indicators are now routinely derived from the CPR data and updated annually. In this Report we update three indices for three regions (Figure 34); the abundance per sample of large diatoms (the CPR only retains large, hard-shelled phytoplankton so while a large proportion of the community is not sampled, the data are internally consistent and may reveal trends), meso-zooplankton biomass (estimated from taxon-specific weights and abundance data) and mean copepod community size (see Richardson et al., 2006 for details but essentially the length of an adult female of each species is used to represent that species and an average length of all copepods sampled calculated) as an indicator of community composition. Anomaly time series of each index have been calculated as follows: A monthly mean value for each region is first calculated (2002 – 2022 for the GOA). Each sampled month's mean is then compared to the long-term geometric mean of that month and an anomaly calculated ($\log_{10}$). The mean anomaly of all sampled months in each year is calculated to give an annual anomaly.

The indices are calculated separately for the oceanic eastern GOA, oceanic western GOA (divided at 147 °W), and the Alaskan shelf southeast of Cook Inlet (Figure 34). Only the red points within the shaded boxes in Figure 34 are included in the calculations (for example the red points on the shelf outside the shaded box were considered too small a sample size to adequately represent conditions). The oceanic eastern GOA regions have better sampling resolution than the Alaskan shelf and oceanic western GOA region as both transects intersect here. This region has been sampled up to 8 times per year with some months sampled twice. The Alaskan shelf region is sampled 5 – 6 times per year by the north-south transect and the western GOA region is sampled 36 times per year, mostly by the east-west transect.

Status and trends: The diatom abundance anomaly for the shelf region was positive for 2021 – 2023 (relative to a baseline of 2002 – 2022) having been negative in 2020 (Figure 35). On the western and eastern side of the oceanic Gulf of Alaska the diatom anomaly was also positive in 2023. The copepod community size anomaly was negative in 2023 on the Alaskan Shelf and western oceanic GOA, but it was positive in the eastern oceanic GOA. Zooplankton biomass anomalies were positive in both the shelf and eastern oceanic GOA regions in 2023, while the anomaly has remained negative in the western

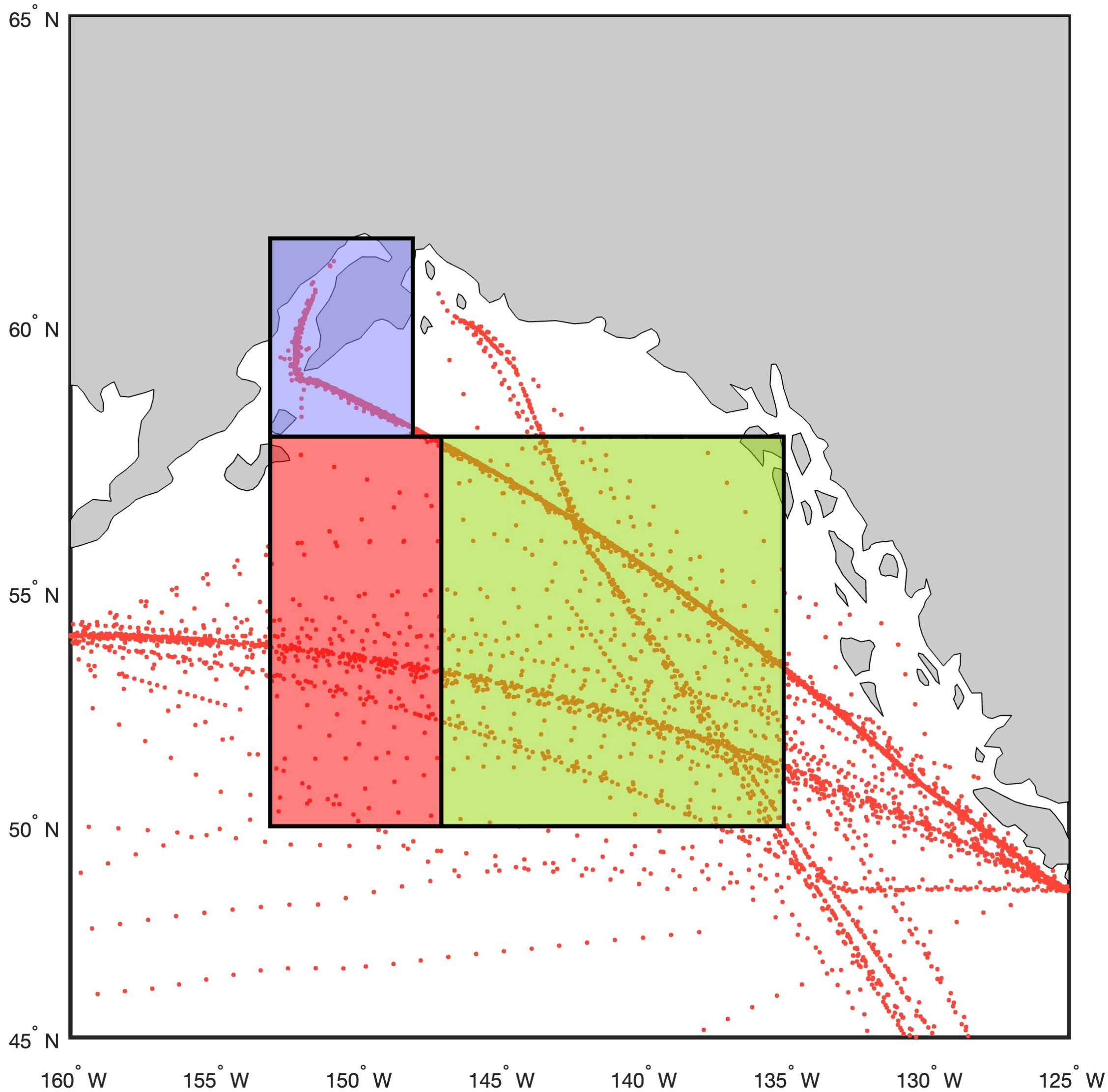

Figure 34: Location of the data used in this report, highlighted as Alaskan shelf (blue rectangle), eastern oceanic Gulf of Alaska (green rectangle), and western oceanic Gulf of Alaska (magenta rectangle). Red dots indicate actual sample positions (note that for the shelf region the multiple transects overlay each other almost entirely).

GOA.

Factors influencing observed trends: The Pacific Decadal Oscillation (PDO) monthly values were often negative in 2017 causing a lower annual mean value compared to the years of 2014 – 2016, which had experienced a marine heat wave (Di Lorenzo and Mantua, 2016). 2022 appears to be another warm year despite a negative PDO and Oceanic Niño Index (ONI). In warm conditions smaller species tend to be more abundant and the copepod community size index reflects this and was mostly negative throughout the marine heat wave periods of 2014 – 2016, and 2018 – 2020. The large diatom abundance was positive in 2023 in all regions. It is unclear what has led to the increase in diatom abundance, but it could be due to a reduction in grazing pressure.

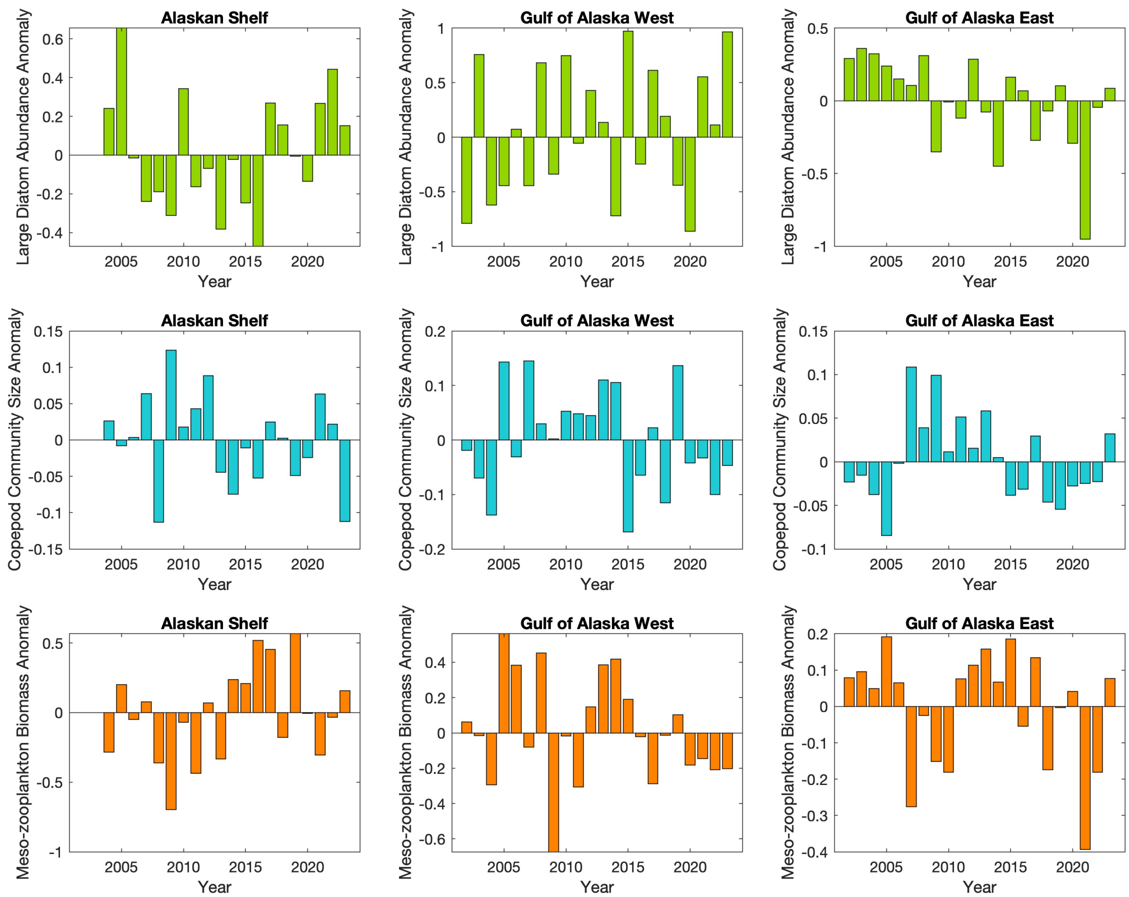

Figure 35: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for all three regions shown in Figure 34. Note that sampling of the shelf region did not begin until 2004.

Implications: Each of these variables is important to the way that ocean climate variability is passed through the phytoplankton to zooplankton and up to higher trophic levels. Changes in community composition (e.g., abundance and composition of large diatoms, prey size as indexed by mean copepod community size) may reflect changes in the nutritional quality of the organisms to their predators. Changes in abundance or biomass, together with size, influences availability of prey to predators.

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

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Last updated: October 2024

Description of indicator: In 2015, AFSC implemented a method for an at-sea Rapid Zooplankton Assessment (RZA) to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20/60 cm oblique bongo tows from 10 m from bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2000). The categories are small copepods ($>$ 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp. and *Oithona* spp.), large copepods ($>$ 2mm; example species: *Calanus marshallae* and *Neocalanus* spp.), and euphausiids ($>$ 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 μm mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 μm mesh, 60 cm bongo net. Other, rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method. RZA abundance estimates may not closely match historical estimates of abundance as methods differ between laboratory processing and ship-board RZA, particularly for euphausiids which are difficult to quantify accurately (Hunt et al., 2016). Rather, RZA abundances should be considered estimates of relative abundance trends overall. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1 year post survey).

Here, we show updated long-term time-series for the western Gulf of Alaska that include processed data for 2023. There were no surveys in 2024, therefore no maps are included. The spring larval survey reports data from 16- - 21 May and the summer age-0 survey from 4 – 11 September 2024.

Status and trends:

Large copepods showed variability across years during spring (Figure 36). Most notable was the rise in abundance of large copepods seen in spring from 2003 – 2006 and the decline in large copepods observed in 2015, 2019, and 2021. Large copepod abundance for 2023 remained low and were similar to estimates since the occurrence of the marine heatwave of 2014 – 2016. Small copepods had elevated abundances during recent sampling, particularly during the marine heatwave of 2014 – 2016 and in 2019, and abundances in 2023 are lower than those observed recently (Figure 36). Euphausiid abundances are typically low during the spring in the historical record; however, recent estimates have been higher, including 2023 (Figure 36). It is important to note the scale in the euphausiid time-series as the recent abundance increases are not large in magnitude, increasing by only 1 – 2 individuals m-3 (Figure 36).

Late summer, large copepod abundance declined from the early 2000s until the marine heatwave of 2014 – 2016 (Figure 37). Overall, large copepod numbers were similar to recent years and slightly higher

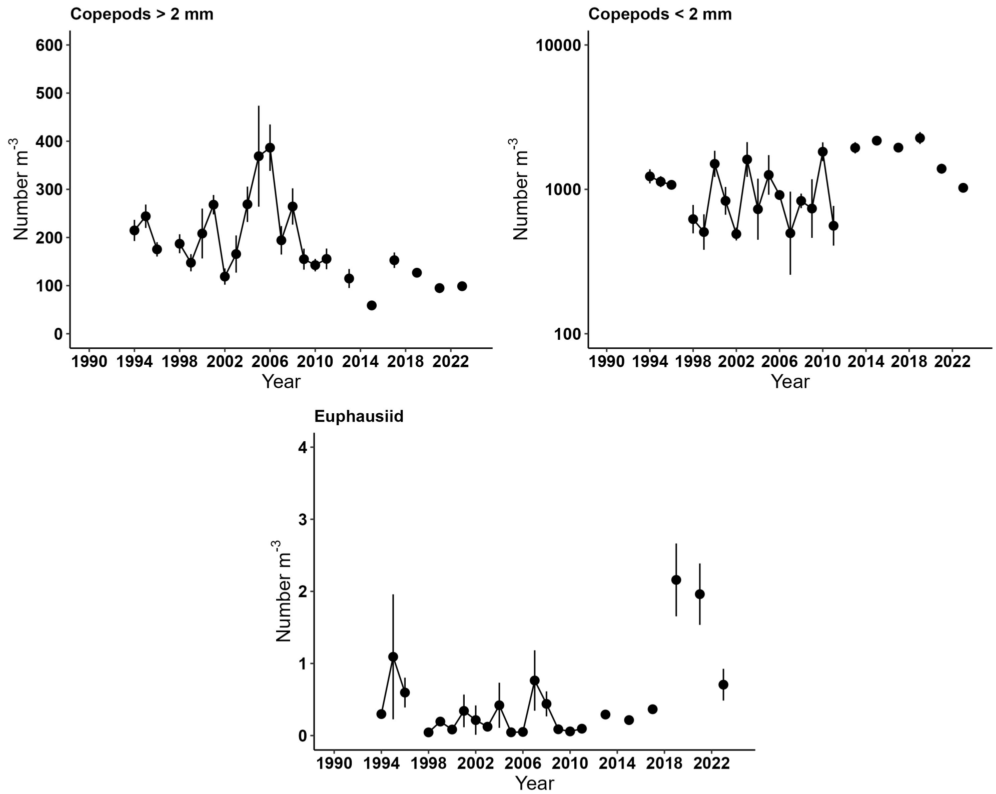

Figure 36: Mean abundance of large copepods (> 2 mm), small copepods (< 2 mm), and euphausiids (< 15 mm) in western Gulf of Alaska during spring (May-June). Black circles represent archived data, blue triangles represent RZA data. Note differences in scale.

than the marine heat wave years (Figure 37). Small copepod abundances show little variability during the summer and the 2023 abundances were average relative to the long-term data record (Figure 37). Finally, average euphausiid abundances appear to have increased since the dip observed in 2015 and abundances in 2023 were higher than more recent years, with the exception of 2019 (Figure 37).

Factors influencing observed trends: Cooler temperatures were observed relative to recent years in the western Gulf of Alaska during 2023. This resulted in average conditions during the spring where large copepods were low on average, but patchily distributed with high abundances in some locations (Figure 36). Large copepods were a mixture of *Neocalanus* spp. and *Calanus marshallae*. Increased abundances of large copepods are typically observed during warm springs, as in 2003 – 2005, likely due to increased abundances of *C. marshallae* (Kimmel and Duffy-Anderson, 2020) that are developing to later stages more quickly. Cooler temperatures likely reduced the development rate of *C. marshallae* into the summer when moderate abundances of these large copepods were observed (Figure 37). Small copepod abundances were reduced in spring (Figure 36) and this makes sense with respect to life history characteristics of small copepods, given their multiple generations per year, faster turnover times, and metabolic rates that scale less dramatically with temperature (Kiörboe and Sabatini, 1995). Thus, cooler temperatures reduced the rate at which small copepod population increased. Recent warm years had high abundances of small copepods in spring and numbers in 2023 were lower than those peaks (Figure 36); summer abundance also showed this trend (Figure 37). Spring euphausiid numbers are typically low; however, numbers appear to have increased in the past three sampling years, though 2023 estimates were still below 1 individual m $^{-3}$ (Figure 36). Euphausiid numbers in late summer were higher

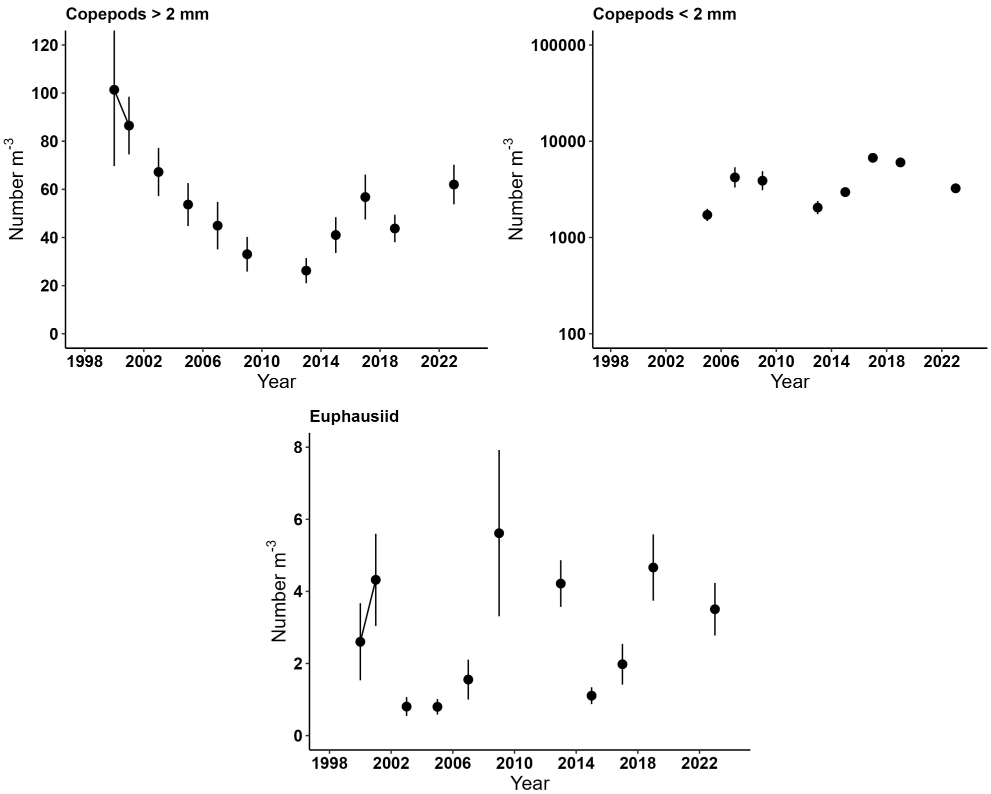

Figure 37: Mean abundance during the summer age-0 survey over time. Line ranges are the standard error of the mean. Note differences in scale.

on average compared to the marine heatwave years (Figure 37). Euphausiid population dynamics remain difficult to explain in the absence of more accurate temporal and spatial sampling.

Implications: Zooplankton are an important prey base for larval and juvenile fishes in spring and summer. While small copepod numbers were reduced relative to recent spring values, numbers remained high indicating that there is likely a significant number of nauplii and smaller copepods available as prey for larval fishes. Note the small copepod proportion does not include nauplii (the primary prey for early larval fishes) and recent work has suggested a decline in nauplii did occur during the recent marine heatwave (Rogers et al., 2020). Given the cooler temperatures in 2023, nauplii numbers should be adequate given the small copepod standing stock. The lack of large copepods is less relevant in spring when larval fishes predominate; however, it may indicate that the system timing for larger copepods is changing or may indicate shifts in overall productivity (Kimmel and Duffy-Anderson, 2020). Thus, phenological changes that have been detected for walleye pollock in the western GOA (Rogers et al., 2018) may also be occurring for copepods. Both large copepod numbers and euphausiid abundances were average during the late summer relative to long-term trends (Figure 37). Both are principal diet items for juvenile fish and these numbers appear to indicate adequate forage. A lack of large copepods and euphausiids leads to diet shifts where less energetically dense prey items are consumed (Lamb and Kimmel, 2021). In conclusion, we suggest the zooplankton community in the western GOA in 2023 was average and likely to provide sufficient forage for the larval and juvenile fish community.

Spring and Fall Large Copepod and Euphausiid Biomass: Seward Line

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Last updated: September 2024

Description of indicator: Transects have been completed south of Seward Alaska typically during the first 10 days of May and during mid-September for over 25 years to determine species composition, abundance and biomass of the zooplankton community. Data is averaged over the top 100 m of the water column to provide estimates of wet-weight biomass of zooplankton summarized here for all calanoid copepods and euphausiids (a.k.a. krill) retained by a 0.15mm mesh net for small copepods and 0.5mm mesh net for large copepods and euphausiids. These categories represent key prey for a variety of fish, marine mammals, and seabirds.

Status and trends: Preliminary analysis suggests large calanoid biomass was still lower than normal in May 2024, but higher than 2023, while small copepod biomass has been below normal for several years (baseline 1998 – 2023, Figure 38). The biomass of small copepods in September has been average to below average since 2020 when ocean temperatures cooled. Large copepod biomass during May often tends to track spring temperatures, because they grow faster and therefore individuals are larger when waters are warmer, however a strong spring bloom can also favor faster growth. By September most large calanoids have descended into offshore waters and their biomass is greatly reduced. Smaller-bodied copepods biomass shows less change between seasons.

In contrast, May euphausiid biomass appears to be negatively impacted by warm springs, with peaks May often driven by high abundances of their larval stages when conditions are favorable. Continued growth and recruitment often lead to higher biomass by September. For May of 2023 and 2024, biomass appears to be above average, although confidence intervals are broad with the means poorly constrained. No biomass estimate for euphausiids is available for September 2023 due to equipment failures.

Factors influencing observed trends: Temperatures during 2021 – 2024 were cooler than the 25-year thermal mean along the Seward Line during spring, but these spring phytoplankton blooms were generally productive (see Danielson et al., p.74, and Hennon, p.70, in this Report). September of 2021 and 2023 was also cool and this may have favored euphausiids, whereas September of 2022 was slightly warmer than normal. May euphausiid biomass appears to be negatively impacted by warm springs, with peaks in May often driven by high abundances of larval stages when conditions are favorable. Continued growth and recruitment often lead to higher biomass by September.

Implications: While high biomass of larger zooplankton does not guarantee success of species dependent upon them (due to a variety of other factors), low biomass does makes predator success challenging. Changes in the mixture (and energetic content) of species contributing to overall biomass may be of consequence to specific predators. With biomass of large copepods has increased since 2023, they still remain below the long-term average and may have created challenges for some of their predators this year. The above average biomass of euphausiids during 2023 and 2024 suggests their predators may have more favorable feeding conditions compared to years when their biomass was low.

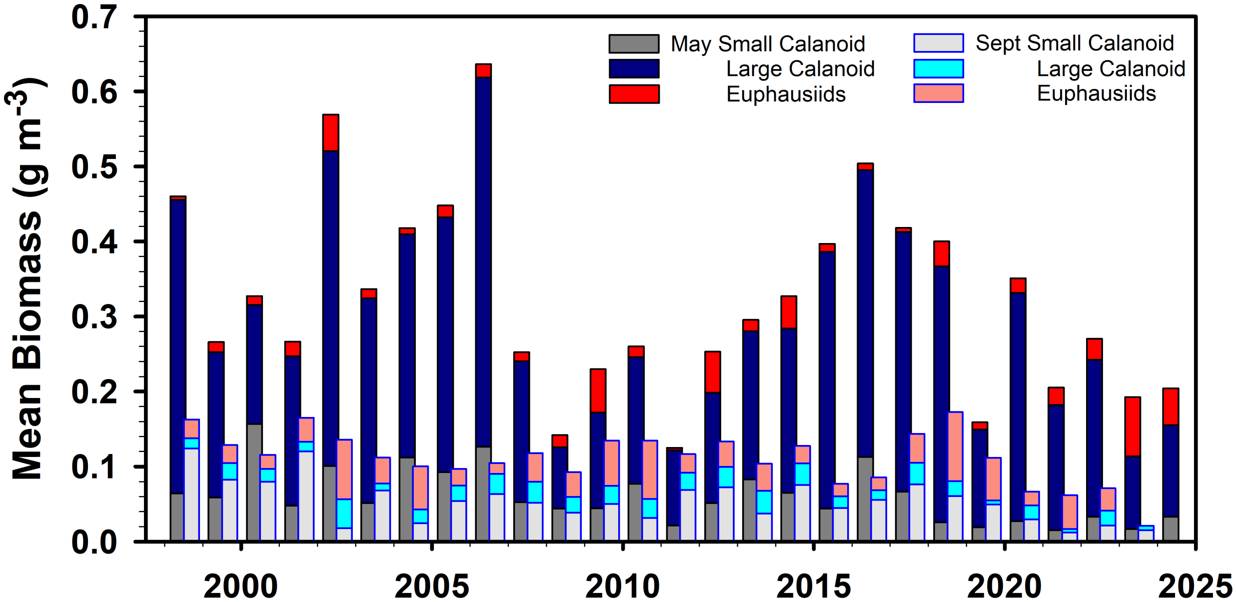

Figure 38: Biomass of calanoid copepods and euphausiids along the Seward Line sampled using a 0.15mm during days and a0.5-mm mesh at night. Transect means are calculated on power-transformed data. Data for 2022–2024 is only available from a subset of stations and may change as more stations are completed.

Zooplankton Trends in Icy Strait, Southeast Alaska

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Last updated: September 2023

This contribution was not included this year. Please refer to the archives[23] for past reports.

Zooplankton Nutritional Quality Trends in Icy Strait, Southeast Alaska

Contributed by Emily Fergusson and Wesley Strasburger, Auke Bay Laboratories, Alaska Fisheries Science Center, NOAA Fisheries
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Last updated: September 2024

Description of indicator: The Southeast Coastal Monitoring project (SECM, Auke Bay Laboratories, AFSC) has been investigating how climate change may affect Southeast Alaska nearshore ecosystems in relation to juvenile salmon and associated biophysical factors since 1997 (Murphy et al., 2020; Fergusson et al., 2020*a*). Spring/summer zooplankton lipid content data have been collected annually in Icy Strait since 2013.

This report presents 2024 zooplankton mean lipid content (% wet weight) anomalies for specific taxa in relation to the 12-year trend in Icy Strait. Taxa examined were chosen based on their importance to larval and juvenile fish diets (Fergusson et al., 2020*b*; Sturdevant et al., 2012). These taxa include: large and small calanoid copepods, *Calanus marshallae* and *Pseudocalanus* spp., respectively, young euphausiids (furcillia and juveniles), *Limacina helicina* (gastropod), and *Themisto pacifica* (hyperiid amphipod). Total percent lipid content was determined using a modified colorimetric method (Van Handel, 1985). Percent lipids of multiple zooplankton taxa over time represents trends in prey quality available to higher trophic levels and their energetic response to climate and ocean conditions. For fish feeding on copepods and amphipods, the average to positive lipid anomalies indicates positive nutritional quality.

Status and trends: In 2024, percent lipid anomalies for small and large copepods were positive, showing a large increase from 2023 values, while anomalies for the amphipod *T. pacifica* were average showing a slight increase from 2023 values (Figure 39). For the second year in a row, abundance of young euphausiids was extremely low which precluded obtaining samples for lipid analysis. Trends from 2013 to 2024 for all taxa showed mean percent lipids ranging from 0.3% to 23%.

[23] `https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands`

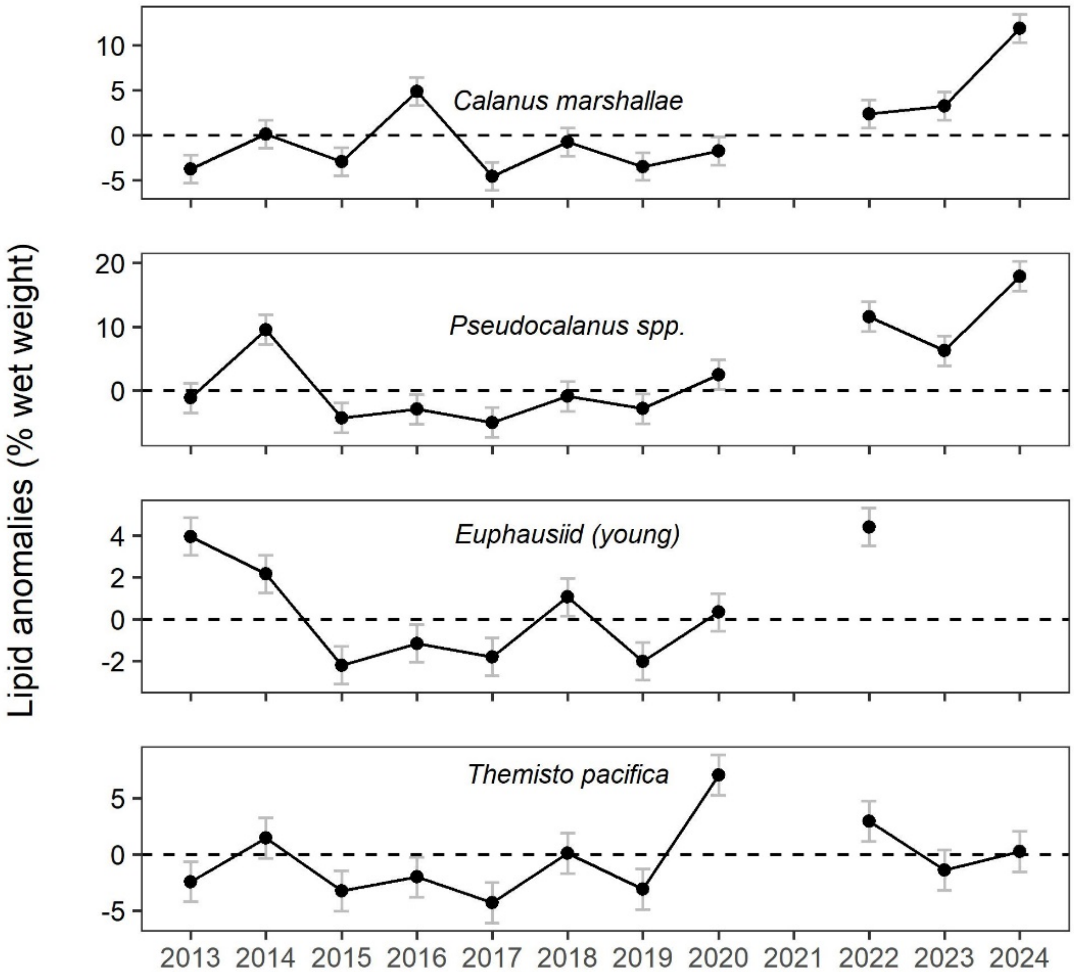

Figure 39: Lipid content (% wet weight) anomalies with error bars (standard error) from key zooplankton taxa collections in Icy Strait, AK by the Southeast Coastal Monitoring project, 2013 – 2024. The dashed line represents the time series mean lipid content. There are no data for 2021 and no data for euphausiids in 2023 or 2024.

Factors influencing observed trends: Subarctic zooplankton communities are influenced by physical and biological factors including basin-scale events, water temperature and salinity, advection, freshwater discharge, phytoplankton community and abundance (zooplankton food), and predator abundance (top-down control). Changes in the zooplankton community influence the food web and trophic relationships, which may alter fish growth and recruitment. For example, a complete restructuring of the North Sea zooplankton community's copepod population was observed after the 1990's regime shift (Beaugrand, 2004) that eventually propagated up the food web (Alvarez-Fernandez et al., 2012). In the Bering Sea, high-lipid copepods are more abundant during cold years relative to warm years, when lower-lipid copepods dominate the prey field (Coyle et al., 2011). The abundance of high-lipid copepods has been trophically linked to the overwinter survival of Bering Sea age-0 pollock (Heintz et al., 2013). During cold years in the Bering Sea, juvenile pollock enter winter with a higher energy content, reached by consuming a lipid-rich diet, which can drive recruitment success of age-1 pollock relative to recruitment during warm years.

Implications: The zooplankton nutritional quality in 2024 suggest positive feeding conditions for larval and juvenile stages of many commercially and ecologically important species of fish (e.g., pollock, salmon, and herring) that reside in Icy Strait, which may directly or indirectly affect fish growth and recruitment. Additionally, a qualitative assessment of zooplankton abundance found that abundance was above average for most zooplankton taxa, which, in conjunction with the nutritional quality, suggests positive feeding conditions available in Icy Strait.

Sea Jellies

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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[24] for past reports.

Ichthyoplankton

Larval Fish Abundance

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Last updated: September 2024

Description of indicator: The Alaska Fisheries Science Center's (AFSC) Ecosystems and Fisheries Oceanography Coordinated Investigations Program (EcoFOCI) conducts spring larval fish surveys in the Gulf of Alaska (GOA), with annual sampling from 1981 – 2011 and biennial sampling thereafter (Matarese et al., 2003, Ichthyoplankton Information System[25]). A subset of data from a consistently sampled time window (mid-May through early June) and area (Fig. 41) has been developed into a time-series of relative larval abundance for 12 taxa. In 2023, time-series calculations were updated to use a model-based approach (sdmTMB; Anderson et al., 2022) instead of the previous area-weighted mean, in part to better account for variable survey coverage in recent years due to ship-time constraints. Correlations between time-series estimated using the two approaches ranged from r = 0.91 – – 0.99. Rapid Larval Assessments are conducted for 7 species by sorting samples at sea, allowing provisional time-series updates in the year of collection; however quantitative data require a year for full laboratory processing and verification. This update provides lab-verified larval data for 12 taxa through 2023. In 2023, the EcoFOCI survey was truncated due to vessel staffing, resulting in only partial coverage of the core survey area.

Status and trends: Reduced survey coverage limited our ability to assess larval fish abundance and

[24] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands
[25] https://apps-afsc.fisheries.noaa.gov/ichthyo/index.php

distribution in 2023, which is partly reflected in larger standard errors; however, based on the stations sampled, all taxa were at or below their long-term means (baseline: 1981 – 2022; Figure 40). Walleye pollock, flathead sole, Northern lampfish, ronquil, and starry flounder abundance was particularly low, at or near long-term record lows. Pacific cod abundance increased very slightly from 2021 but remained low, although catches were higher to the SW of the core sampling area. Arrowtooth flounder, northern rock sole, and rockfish increased towards long-term mean levels.

Factors influencing observed trends: Sea surface temperatures in the Gulf of Alaska were cool-to-average during the winter and spring of 2023 (baseline 1985 – 2014, Lemagie and Callahan in this Report, p.43), which are typically associated with higher abundances of late winter and early-spring spawners including Pacific cod, pollock, and northern rock sole (Doyle et al., 2009; Laurel and Rogers, 2020). We did not see that pattern in 2023. A prolonged period of offshore gap winds in the area of Kodiak in April may have altered the flow of the Alaska Coastal Current and advection patterns for larvae (Wilson and Laman, 2021, and see Rogers in this Report, p.66), but we were unable to investigate whether distributions were unusual with our abbreviated survey. For deep-spawning species such as arrowtooth flounder, halibut, and rockfishes, on-shelf transport is likely important.

Implications: Ichthyoplankton surveys can provide early-warning indicators for ecosystem conditions and recruitment patterns in marine fishes. In both 2015 and 2019, low abundances of walleye pollock and Pacific cod larvae were the first indicators of failed year-classes for those species. In 2023, abundance of walleye pollock and Pacific cod larvae were again low, suggesting another poor year class, although abundances may have been higher outside the surveyed region. Notably, no species or taxa had higher than average abundance in 2023, suggesting mediocre conditions for recruitment, and below average forage for piscivorous predators, including seabirds, who rely on larval and juvenile fish.

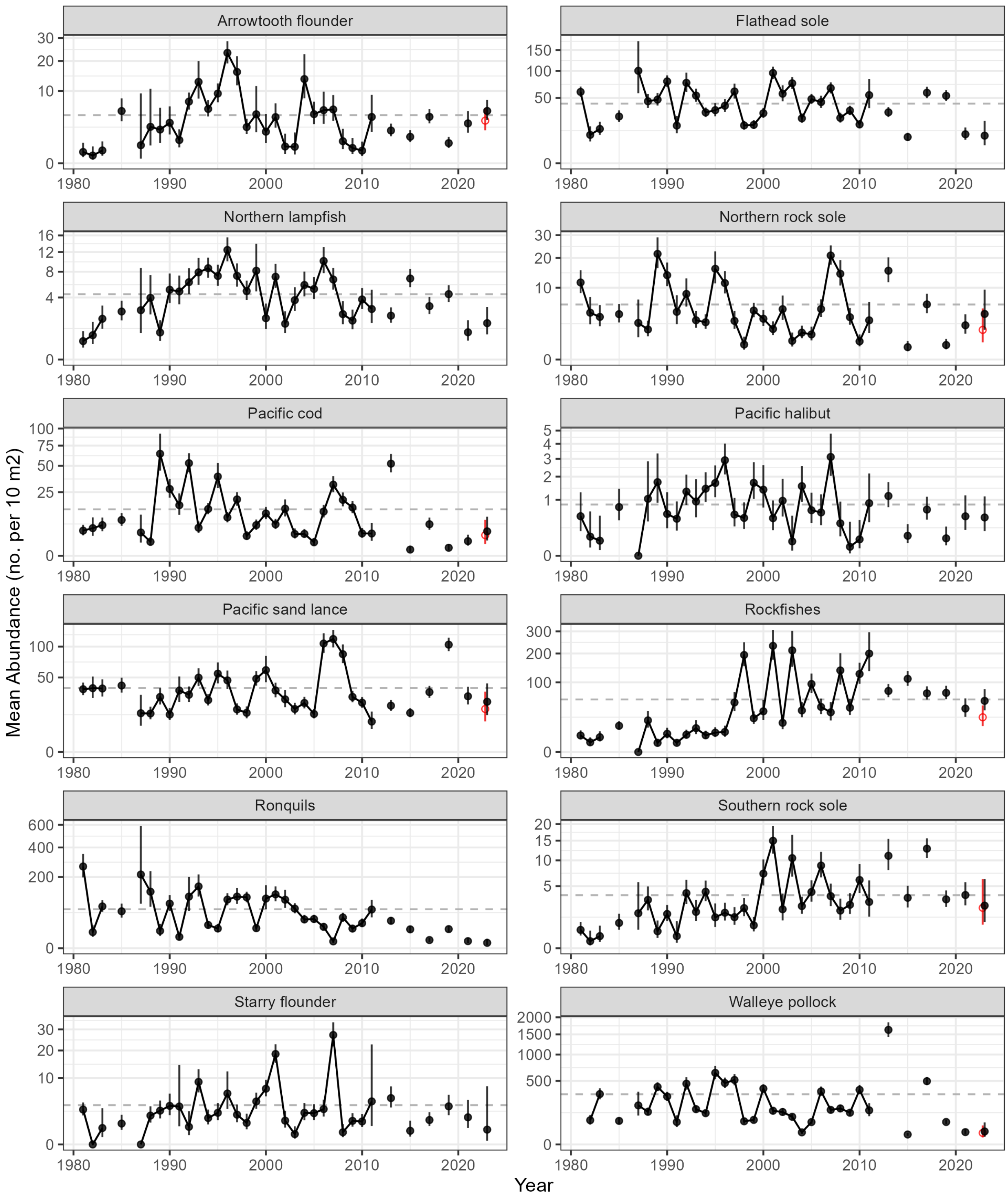

Figure 40: Interannual variation in late spring larval fish abundance in the Gulf of Alaska. The larval abundance index is expressed as the mean density (no. 10 m $^{-2}$), and the long-term mean is indicated by the dashed line. Error bars show ± 1 SE. Values in red show estimates based on the at-sea Rapid Larval Assessment, whereas black shows lab-verified data.

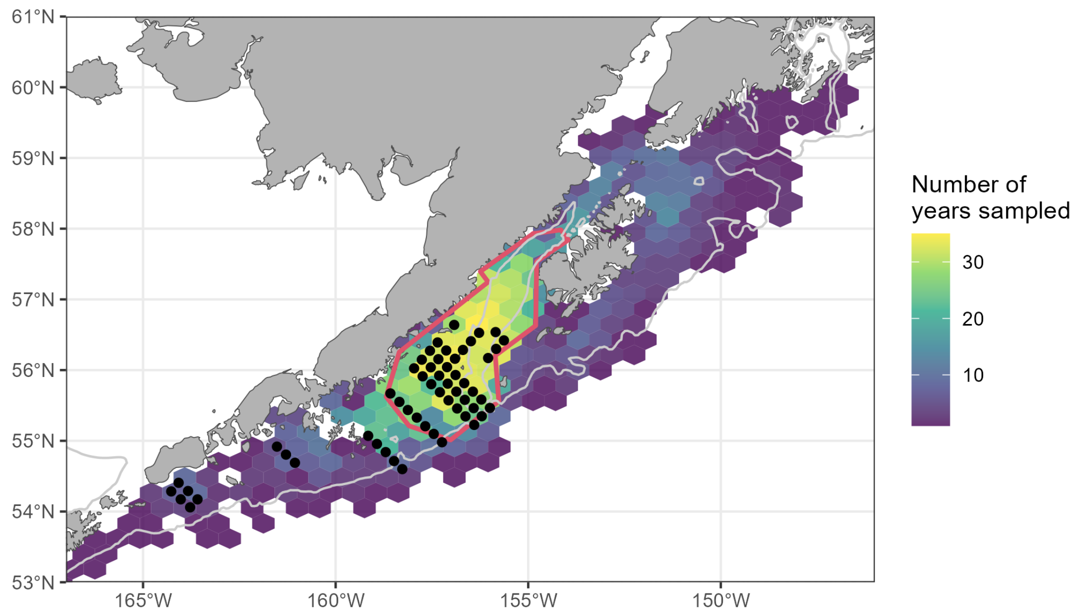

Figure 41: Distribution of historical May-June ichthyoplankton sampling in the Gulf of Alaska by NOAA's Alaska Fisheries Science Center using a 60-cm frame bongo net. Sampling effort is illustrated by the number of years where sampling occurred in each grid cell during late spring. A time-series has been developed for the years 1981 – 2023 from collections in the core area outlined in red where sampling has been most consistent during mid-May through early June. Black dots show sampling locations in 2023.

Forage Fish and Squid

Summary of Forage Conditions

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Last updated: October 2024

The appears to have been average to above-average availability of GOA shelf forage fish in 2024, bouyed by a second year of observed rebound in capelin populations and continued elevated herring populations. Capelin populations functionally rebounded (observed in predator diets and surveys) in 2023 for the first year since their decline during the 2014 – 2016 marine heatwave. While these are traditionally cold water species, they did not immediately return to the GOA once ocean temperatures cooled. Capelin were observed in surveys, seabird diets, and salmon diets across the GOA (Arimitsu et al. , p.96, McGowan et al. , p.101). Herring continued to have relatively elevated populations supported by a strong but fading 2016 year class and an additional strong 2020 year class (Hebert and Dressel, p.105, Morella et al., p.188).

Forage species that are relatively lower in abundance include sandlance, and juvenile salmon, while eulachon had spatially variable trends. Age-1 pollock biomass predation mortality by apex groundfish predators remains below average due to relatively decreased populations of Pacific cod, arrowtooth flounder, and Pacific halibut, but increased from 2023 in response to increasing populations of arrrowtooth flounder (Adams in this report, p.133). Juvenile sablefish and sandlance (both associated with warm surface waters) were observed in relatively low levels in seabird diets (Arimitsu et al. in this Report, p.96). Eulachon populations experienced a range of returns in southeast AK (above-average returns in Yakutat and Ketchikan) but remain below previous population highs (Pochardt et al. in this Report, p.109). Most noteworthy of the 2024 eulachon spawning returns is the above-average returns in the Yakutat area for the second year in a row. This was above what had been observed in over 10 years, according to local knowledge. Also, the Unuk River run was above what had been observed in the last 10 years of Forest Service monitoring. Indicators of juvenile salmon abundance in southeast Alaska have been consistently near or below average for all species since 2016 (Chinook salmon), 2017 (chum, pink, and sockeye salmon), and 2018 (coho salmon). Catch rates of juvenile pink salmon increased in 2024 relative to 2023, but remained well below the long-term mean (Strasburger et al. in this Report, p.116).

Piscivorous surface-feeding and diving seabirds had generally to above-average reproductive success across the western and eastern GOA, with the exception of black-legged kittiwakes on Chowiet Isl., implying adequate amounts of forage fish were available (Drummond and Whelan, p.152). The below average reproductive success of black-legged kittiwkaes on Chowiet Island (western GOA) is potentially due to a lack of sandlance and age-0 pollock, common prey in that regions. The expansion of seabird distribution along the Seward line transect and expanded use of the oceanic region, suggest increased prey availability relative to recent years (Cushing, p.152).

The abundance of forage fish in the GOA is difficult to measure. There are no dedicated large-scale surveys for these species, and the existing surveys are limited in their ability to assess forage species due to issues such as gear selectivity and catchability. The monitoring of seabird diets and reproductive success has provided some useful information on relative forage abundance, but those data are influenced by variation in spatial distribution, foraging behavior, and other factors. Despite these difficulties, it is possible to use multiple indicators to discern some broad trends in forage availability in the GOA.

Abundance of YOY pollock and capelin in Western Gulf of Alaska

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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska EcoFOCI Survey is conducted every other year. Please refer to the archives[26] for past reports.

Body Condition of Age-0 Pollock in Western Gulf of Alaska

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Last updated: August 2024

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

The AFSC EcoFOCI juvenile groundfish survey is a midwater trawl survey that has sampled age-0 walleye pollock throughout the Western Gulf of Alaska in late summer (August - September) since 2000. Individual age-0 pollock were frozen at sea and later measured for length and weight in the laboratory. Body condition was measured as residuals from a regression of log(weight) on log(length),

[26] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

with positive residuals indicating “fatter” fish having larger body mass per unit length. Because body condition can vary with season (Buchheister et al., 2006), and survey timing varied by up to a month between years, we included an additional term in the regression model to account for the day of year fish were collected. Data from 2011 were excluded due to late survey timing (October). Only a subset of fish from each station were measured, thus residuals were weighted by station CPUE when constructing an annual average. The regression model was fit to all measured fish, but only those collected in the consistently sampled Semidi bank region (box in Figure 42) were used to construct the index.

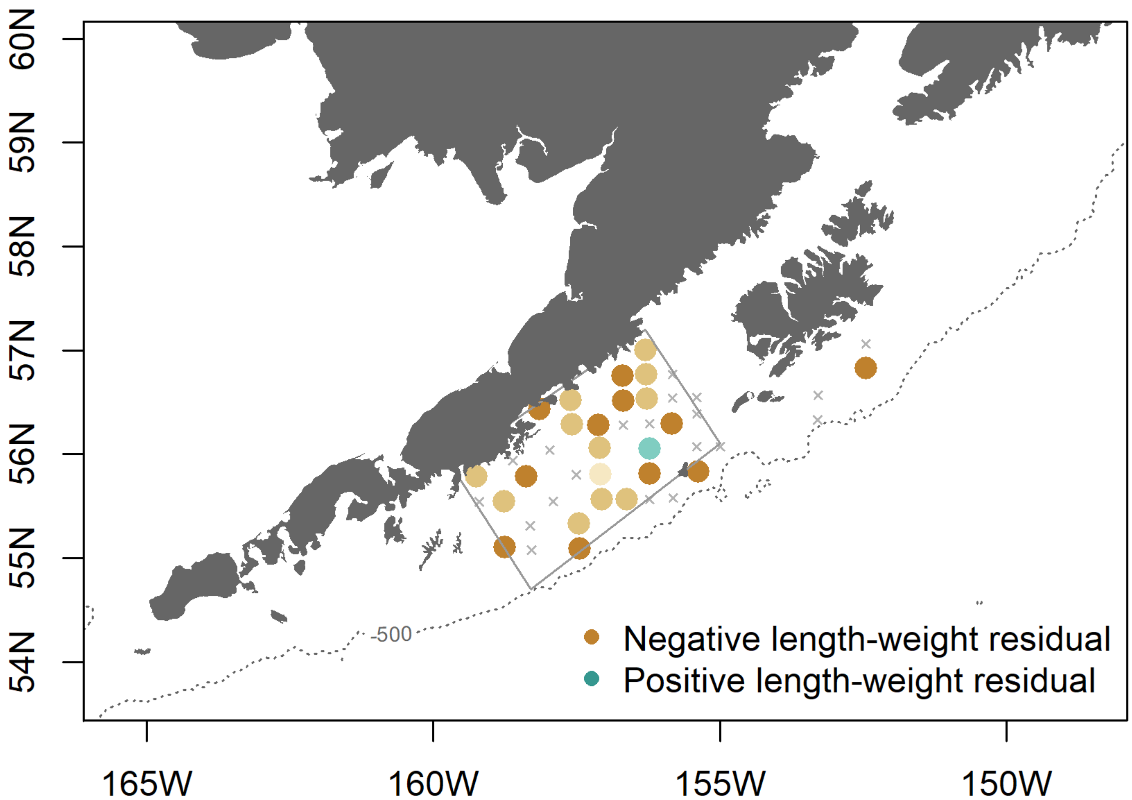

Figure 42: Station averages of age-0 pollock body condition measured in 2023. Color indicates whether condition was above (blue-green) or below (orange) average, whereas shading indicates the relative magnitude of residuals. Gray x's indicate stations where no age-0 pollock were caught or measured. Stations in the core Semidi area (gray box) have been most consistently sampled since 2000 and were used for constructing the condition index.

Status and trends: Average body condition of age-0 pollock in 2023 was among the lowest observed in the time series, similar to 2019. Condition was also low in the two previous years sampled (2015 and 2017) as well as 2005 (Figure 43). Higher than average body condition was observed in 2000, 2001, 2003, 2007 and 2009. In 2019, a spatial pattern was evident, with higher age-0 body condition observed in fish collected in Shelikof Strait and near Kodiak relative to the Semidi area where the index was calculated. We were unable to assess this spatial pattern in 2023 due to a truncated survey and reduced spatial coverage.

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

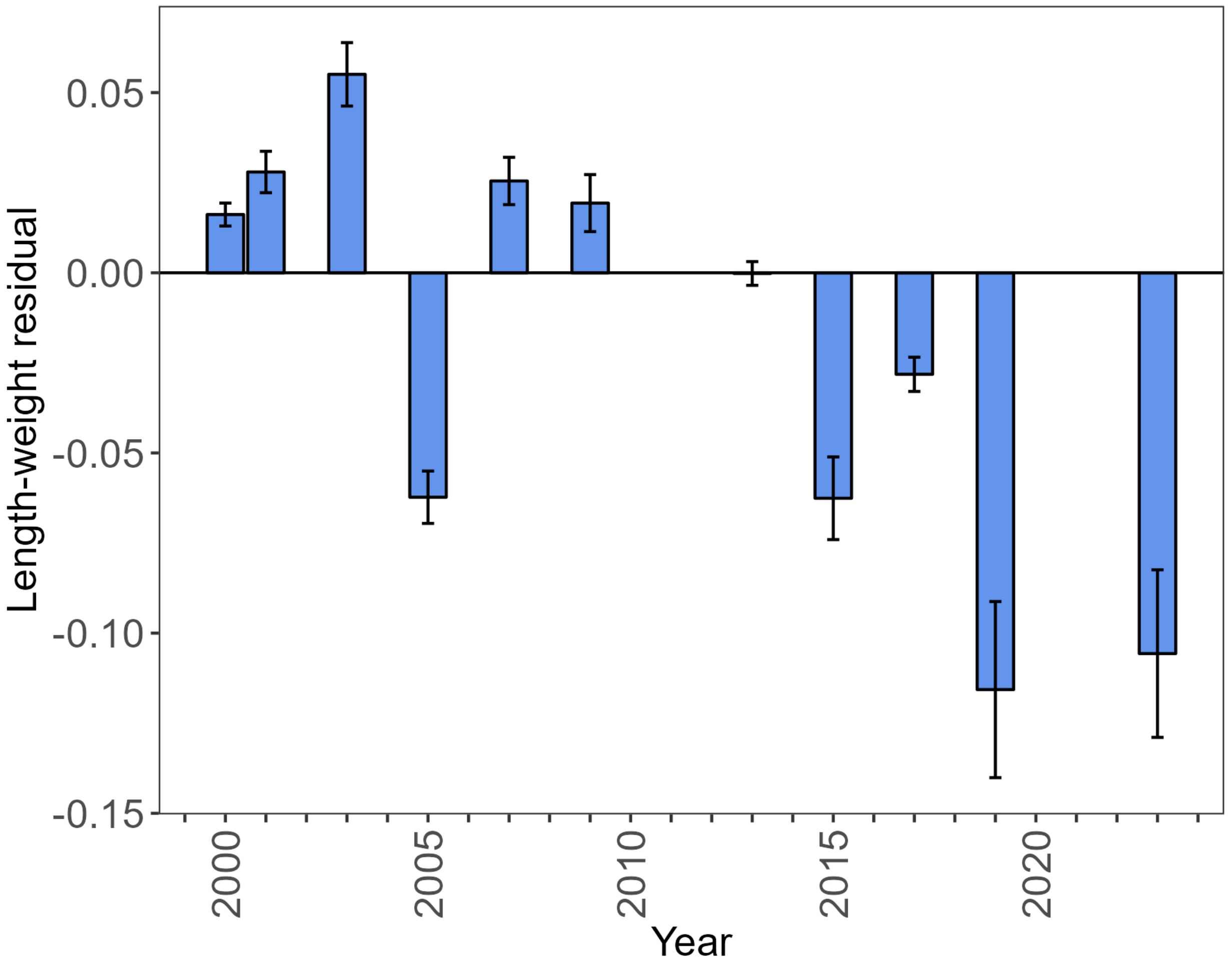

Figure 43: Average CPUE-weighted body condition of age-0 pollock in the core Semidi area ($\pm$ 1 standard error).

ature, which increases metabolic demands, and prey quality and quantity, which determine their ability to meet those demands. In 2015, during the North Pacific marine heatwave, temperatures were warm and prey quality and quantity were reduced, resulting in poor body condition (Rogers et al., 2021). This pattern was simultaneously observed for other forage fishes such as Pacific sand lance (Von Biela et al., 2019). Warm temperatures were also observed in 2005. In 2017, body condition was somewhat higher than in 2015, but still low, matching observations for older stages of groundfishes in the GOA (Boldt et al., 2017). Krill, an important prey for age-0 pollock which has been associated with improved body condition (Wilson et al., 2013), were relatively scarce in 2017 and 2019 (Rogers and Mier, 2017). In 2019, warm conditions returned to the GOA, including at depth, which likely contributed to low condition at end of summer for age-0 pollock. Historically, higher body condition in the Kodiak-Shelikof vicinity, relative to the Semidi area, has been associated with enrichment of krill in the prey field and cooler water (Wilson et al., 2013). In 2023, temperatures were near average and krill abundance was unknown.

Implications: Juvenile pollock rapidly increase their energy storage in late summer, presumably to increase their survival chances during winter, when prey are scarce (Siddon et al., 2013). In the Bering

Sea, low energy storage prior to the first winter has been associated with poor year-class strength for juvenile pollock. Whether this relationship holds for the Gulf of Alaska is yet to be seen, but poor body condition in 2015, 2017, 2019, and 2023 reflects suboptimal ecosystem conditions for pollock growth both during and after the recent marine heatwaves, which may have had adverse effects on overwinter survival. Poor condition of age-0 pollock also results in reduced quality of these fish as prey for seabirds and other piscivorous predators.

Seabird Diets in the Gulf of Alaska 1978 – 2024

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Last updated: October 2024

Description of indicator: Description of Indicator: Seabird diet data span 45 years and >3000 km in the Gulf of Alaska and Aleutian Islands (Figure 44). Puffins (tufted puffins, horned puffins, rhinoceros auklets, hereafter "puffins") feed primarily on small pelagic schooling fish, juvenile groundfish, and mesopelagic species (Sydeman et al., 2017; Piatt et al., 2018). Diets are monitored annually at 4 GOA colonies by the USFWS Alaska Maritime National Wildlife Refuge monitoring program and by the Institute for Seabird Research and Conservation (ISRC) as part of the USGS Gulf Watch Alaska forage fish monitoring program[27]. Western GOA colonies include Aiktak (AIKT), located at Unimak Pass, Chowiet and Suklik (CHOW SUKL), located in the Semidi Islands along the Alaska Peninsula, and Middleton Island (MDO) at the shelf break offshore of Prince William Sound. The eastern GOA colony is St. Lazaria (STLA) near Sitka. At Middleton, surface-feeding black-legged kittiwakes diets are also sampled by ISRC as part of the Gulf Watch Alaska forage fish monitoring program. We updated time series plots of frequency of occurrence (proportion of samples with at least one fish per species per year) to provide indices of forage fish availability over time.

Energy-rich and densely schooling small pelagic species, especially Pacific capelin (*Mallotus catervarius*) and Pacific sand lance (*Ammodytes personatus*), are preferred prey for puffins in the GOA. Pacific herring (*Clupea pallasii*) become more important in puffin diets to the east of 151 °W Longitude, including in the western GOA offshore of Prince William Sound and in the eastern GOA near Sitka. Age-0 sablefish (*Anoplopoma fimbria*) are sampled by seabirds more infrequently than other species, but they are prevalent in some years especially at Middleton. Age-0 walleye pollock (*Gadus chalcogrammus*) are consistently sampled by seabirds at the far western GOA colony at Unimak Pass. Collectively, puffin diets provide information on prey communities across large marine ecosystems and context for multidecadal changes in upper trophic-level biology and ecology in Alaska. Additional information about seabird diet collection efforts and data from long-term monitoring sites in Alaska are available at Hatch et al. (2023) and Turner et al. (2024).

[27]https://gulfwatchalaska.org

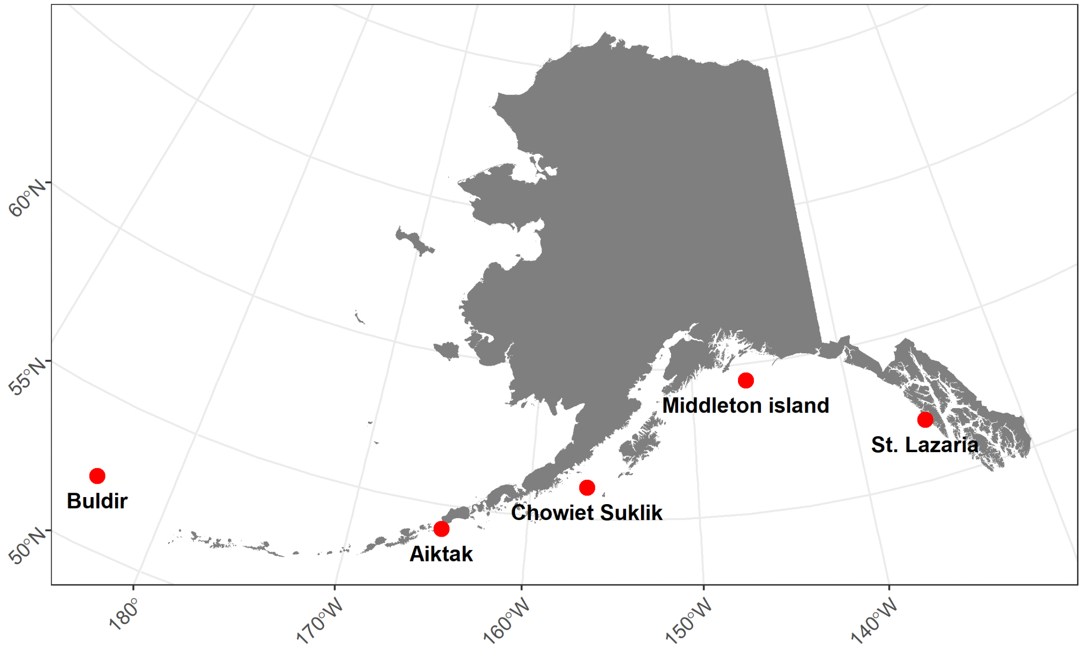

Figure 44: Long-term monitoring of puffin diets at five colonies in the Gulf of Alaska and Aleutian Islands is conducted annually by the USFWS Alaska Maritime National Wildlife Refuge and Institute for Seabird Research and Monitoring. More information is available at `https://doi.org/10.5066/P93I0P67` and `https://doi.org/10.5066/P9WZQJ8N`.

Status and trends: Puffin diets at long-term monitoring sites around the GOA show that sand lance peaked in diets during the mid-1990's then declined in the mid-2000's through the 2014 – 2016 marine heatwave (Figure 45). Following the heatwave sand lance experienced a short-lived recovery, albeit to a lower level than in the 1990's, owing to a strong cohort in 2016 but have since declined again by 2024 (Figure 45). Kittiwake diets at Middleton also show similar trends in sand lance indices during spring (Apr-May) and summer (Jun-Aug), with a post-heatwave recovery and decline to low frequencies by 2024.

In contrast, puffin diets across the GOA show that capelin availability is currently recovering following a population collapse during the 2014 – 2016 marine heatwave. In the eatern GOA, upward trends of capelin indices at St. Lazaria have been observed since 2022. Capelin frequencies also increased at two western GOA sites during 2024, and a strong peak in capelin index occurred at Unimak Pass in 2023 (Figure 45). Additionally, western GOA kittiwake diets at Middleton Isl. also show increases in capelin indices starting in spring 2023, and summer 2023 – 2024 (Figure 46).

Herring have been increasing in importance at Middleton Isl. only since other preferred species (capelin and sand lance) have become less frequent in diets. In 2024 the herring index at Middleton (western GOA) decreased and in the eastern GOA it increased compared to 2023. Frequencies of greenling have generally been increasing over time at Middleton Isl. and are also higher in the eastern GOA colony after the 2014 – 2016 marine heatwave. Age-0 sablefish increased in diets during 2022 at two western GOA colonies and one eastern GOA colony, but indices have been low in 2023 – 2024. Age-0 walleye pollock are generally less important in seabird diets east of Unimak Pass, however, more than 50% of samples at AIKT contained one or more walleye pollock in 2024.

Factors influencing observed trends: GOA sand lance and capelin are known to fluctuate in seabird diets, with sand lance associated with warmer temperatures and capelin associated with cooler temperatures (Sydeman et al., 2017). Combining diets of different predators (rhinoceros auklets, horned puffins, tufted puffins) at the Semidi Complex (Chowiet and Suklik) may contribute to differences among western GOA sites because rhinoceros auklets at Chowiet seem to be accessing a locally available and stable source of sand lance which overwhelms the signal in years when tufted puffins and horned puffins at Suklik (5 km away from Chowiet) were not sampled. Trends of sand lance and capelin appear track closely at Aiktak and Middleton. GOA capelin populations crashed during the marine heatwave (Arimitsu et al., 2021) but have been recovering since 2021 (western GOA – Aiktak Isl.) or 2022 (eastern GOA). A citizen science project[28] has helped to document capelin spawning events around Alaska since the heatwave, with 2023 standing out for reports of beach spawning events in Kodiak, Cook Inlet, Kachemak Bay, Gustavus, and Sitka. Capelin indices in the eastern GOA concur with three years of fall spawning observations reported from Sitka National Park.

Implications: Seabird diets provide indicators of under-monitored forage fish species in the Gulf of Alaska. Forage fish (e.g., capelin, herring, and sandlance) are found in numerous groundfish diets, including sablefish, Pacific cod, and arrowtooth flounder. Seabird diets can also help identify ecosystem trends in the Gulf of Alaska, such as shifts from warm-associated (e.g., herring and sandlance) to cold-associated (e.g., capelin) dominant species. Declines across numerous forage species, such as during the 2014-2016 marine heatwave, can indicate poor productivity across the GOA shelf marine ecosystem (Arimitsu et al., 2021).

[28] `https://www.usgs.gov/media/images/capelin-flyer`

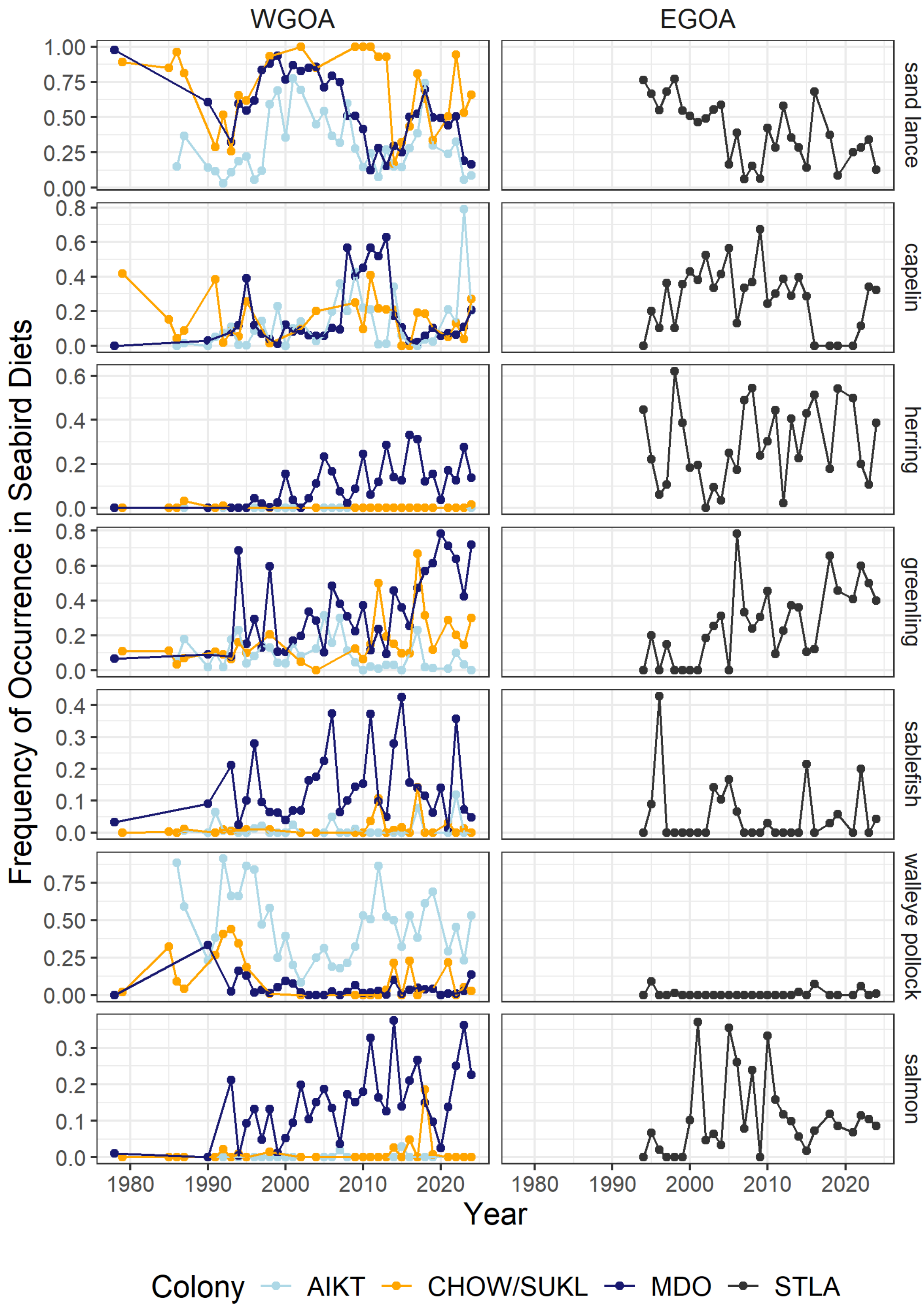

Figure 45: Time series of forage fish indices (frequency of occurrence, proportion of samples containing one or more of each species) derived from seabird diets at colonies in the western Gulf of Alaska (Chowiet and Suklik, CHOW/SUKL, Middleton Island, MDO) and eastern Gulf of Alaska (St. Lazaria, STLA).

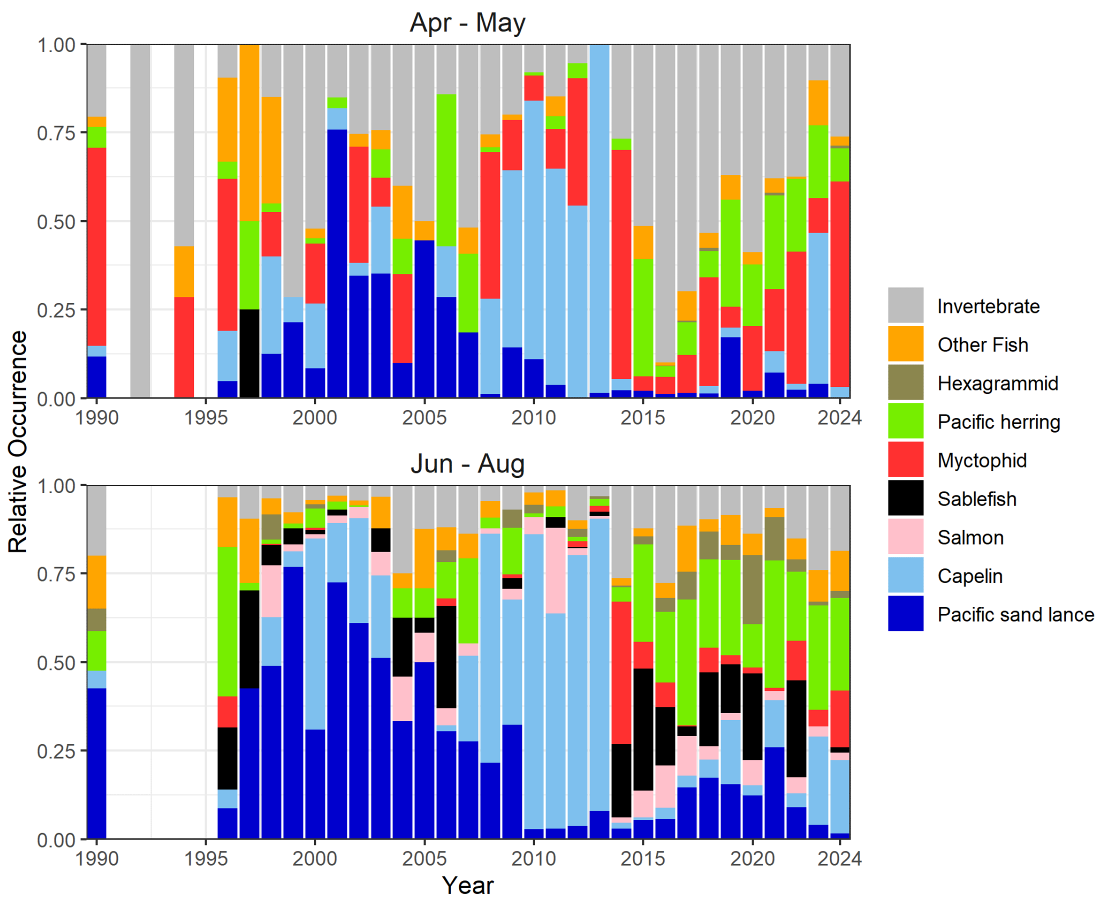

Figure 46: Black-legged kittiwake diet composition at Middleton Island during spring and summer.

Fisheries-independent Survey-based Indices of Capelin Relative Abundance

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Last updated: August 2024

Description of indicator: Pacific capelin (*Mallotus catervarius*, hereafter capelin) abundance was estimated using reanalyzed survey data from the 2013 – 2023 summer Gulf of Alaska (GOA) pollock acoustic-trawl surveys. This survey is designed for estimating abundance of age-1+ walleye pollock (*Gadus chalcogrammus*, hereafter pollock) over the GOA continental shelf, but is also used to estimate the abundance of capelin and Pacific ocean perch (POP, *Sebastes alutus*). Conducted by the Alaska Fisheries Science Center in eight summers since 2003, the survey has consistently sampled from ∼170 ° W near the Islands of Four Mountains to 140 ° W off Yakutat Trough biennially since 2013; surveys conducted prior to 2013 had reduced spatial coverage (Guttormsen and Yasenak, 2007; Jones et al., 2015) and are not currently used in the GOA pollock stock assessment (Monnahan et al., 2023). While this survey is not designed specifically to sample capelin, it has been used to track years of relatively high and low capelin abundance (Arimitsu et al., 2021; McGowan et al., 2020). Since 2013, the survey has sampled key areas around the Kodiak Archipelago where capelin has concentrated the past two decades (McGowan et al., 2020; Piatt et al., 2018), as well as areas near seabird nesting colonies (e.g., Middleton Island) that have provided long-term predator-based indices of capelin abundance used as ecosystem indicators (see western GOA ESR report card in this report).

Acoustic-trawl data from the 2013 – 2021 surveys were reanalyzed to 1) improve the estimation of capelin and 2) provide standardized survey estimates across the full time series used in the GOA pollock stock assessment for pollock, capelin, and POP based on the current analytical approach used by the MACE program (Jones et al., 2022; Levine et al., 2024). This effort entailed re-examination of acoustic echograms, correcting trawl catches for net selectivity using updated multiyear data sets, apportioning acoustic backscatter to all species based on the catch at the nearest haul location, using species-specific target strength to length relationships for capelin and other forage species, and calculating survey estimates within the current database/analysis framework (details in McGowan et al., In Prep*b*). Capelin estimates are calculated for fish $>$ 6 cm fork length (FL) that are presumed to be age-1+ (Arimitsu et al., 2021). Previously, the capelin estimates from the summer GOA pollock acoustic-trawl survey were biased and less comprehensive, typically including only areas where capelin were concentrated in monospecific aggregations and where capelin was the dominant species in trawl catches. The revised survey estimates provide a more comprehensive view of capelin spatial patterns at a range of densities, and include abundance estimates in 2015 and 2017 when capelin densities were too low to be measured using the survey analysis methods in place at the time.

Status and trends: Capelin abundance increased sharply in 2023 to 71,800 t (21.1 billion fish) from persistent low levels of less than 15,000 t ($<$ 4.2 billion fish) observed since 2015 (Figure 47). Biomass in 2023 remains well below the 2013 estimate (147,000 t, 41.2 billion fish), which is presumed to be the population's peak abundance since 2000 (Arimitsu et al., 2021). In 2023, capelin concentrated in high densities within NMFS management area 630 over Portlock and Albatross Banks east and south of Kodiak, and was more widely distributed in lower densities southwest of Kodiak (area 620) in the southern areas of Shelikof Strait compared to historical distributions (Figure 48). The 2023 distribution indicates capelin occupied most of its core areas in the GOA (McGowan et al., 2020; Piatt et al., 2018). A notable exception was that capelin was not observed in area 640 near Middleton Island in 2023, in contrast to historical distributions in years of both high and low abundance. Within each NMFS management area, geostatistical metrics indicate capelin distributions are distributed relatively consistently, with the exception of more pronounced shifts within area 620, particularly between 2013 and 2023 (Figure 48). Capelin was mostly limited to shallow waters less 100 m in 2023, dominated by fish 7 – 8 cm FL (not shown) that are presumed to be age-1 (Arimitsu et al., 2021). In other years, capelin $>$ 10 cm FL (presumed age-2+) have often been observed in deeper waters within troughs along the GOA shelf (McGowan et al., 2020).

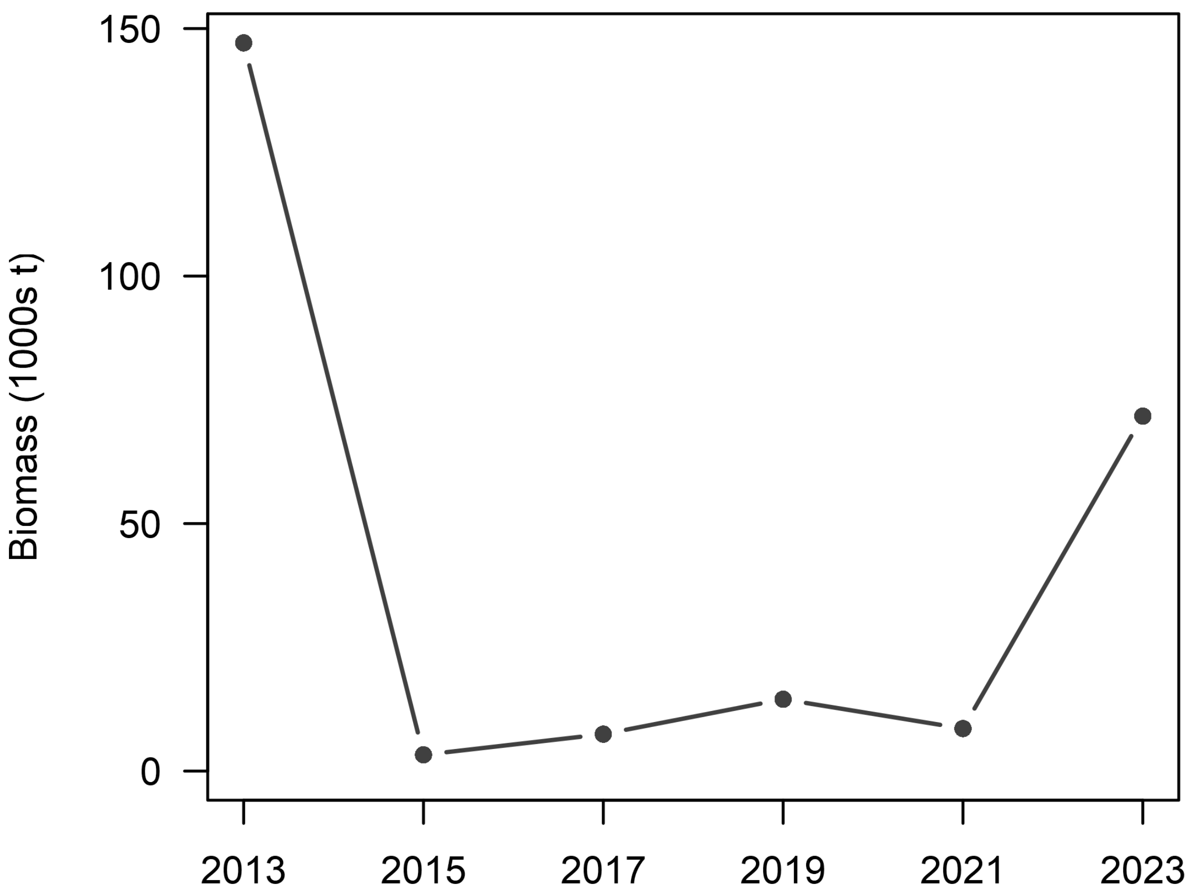

Figure 47: Index of capelin biomass (thousand metric tons) from biennial summer pollock acoustic-trawl surveys of the Gulf of Alaska from 2013 – 2023.

Factors influencing observed trends: Our current understanding of which factors contribute to changes in capelin abundance in the northeast Pacific is limited to observational studies. Historically, fluctuations in capelin abundance have coincided with large-scale shifts in ocean temperatures.

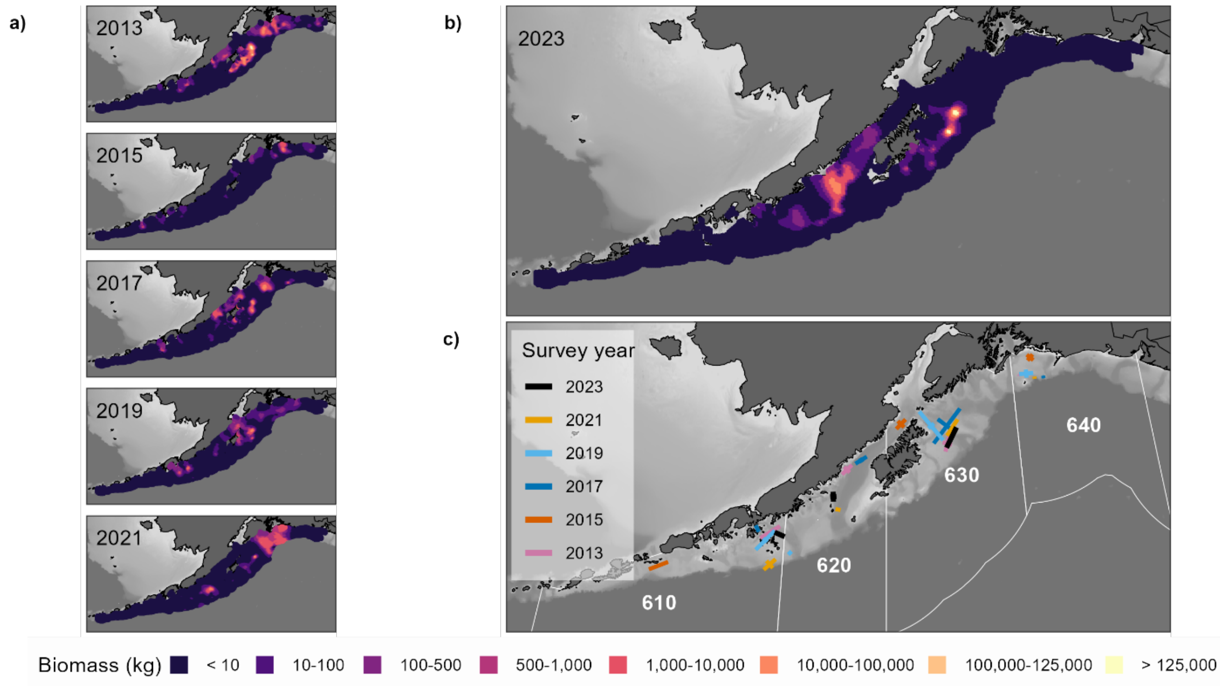

Figure 48: Capelin biomass distributions from a) 2013 to 2021 and b) 2023 summer pollock acoustic-trawl surveys of the Gulf of Alaska shelf. Note that the total amount of capelin biomass varies widely between surveys, but all surveys are plotted using a common color scale. Values have been interpolated within the survey area via universal kriging. c) Center of gravity and inertia (colored crosses) indicating the mean location and dispersion of capelin within each NMFS management area by year.

The first well documented decline of capelin in the GOA was attributed to the onset of warmer ocean temperatures that followed the late 1970s regime shift (Anderson and Piatt, 1999). Over the past three decades, increases in capelin abundance and/or expansion of its distribution coincided with cooler temperatures in the GOA (Hatch, 2013; Mueter and Norcross, 2002; Sydeman et al., 2017) and eastern Bering Sea (Andrews et al., 2016). The summer GOA pollock acoustic-trawl survey index indicates that capelin abundance peaked in 2013, coinciding with the end of a period of cold years (2008 – 2013), and collapsed during the 2014 – 2016 marine heatwave (Arimitsu et al., 2021; Bond et al., 2015), and abundance levels recovered slowly over the next decade during which ocean temperatures fluctuated between warm and cold conditions. With relatively cooler or average conditions in the GOA since 2020 (Ferriss, 2023), it is reasonable to speculate the recent increase in GOA capelin has occurred because environmental conditions have been more favorable, but much work is needed to better understand the mechanisms that drive capelin productivity in the GOA.

The absence of capelin in the northern GOA near Middleton Island (NMFS management area 640) in the 2023 survey results (Figure 48) may be attributable to drastically fewer midwater trawls in this area, due to an unexpected reduction of survey days by 1/3 (McGowan et al., In Prep*a*).

Implications: While capelin are not formally assessed in the GOA, it's evident that the capelin population effectively collapsed across the GOA during the 2014 – 2016 marine heatwave and has only recently started to recover. Low abundance in 2015 and 2017 are likely the lowest levels observed during the past three decades (Arimitsu et al., 2021). This likely resulted in reduced availability of capelin to predators during this period, and is consistent with an abrupt decline in forage species hypothesized to be a major contributing factor to mass mortality of fish and apex predators in the Northeast Pacific from 2014 – 2017 (Arimitsu et al., 2021; Piatt et al., 2020). Current abundance in the GOA is well above observations from 2015 – 2021, but remains below peak levels observed in 2013 prior to the marine heatwave. Capelin is occupying most of its historical core areas, but the lack of observations in the northern GOA warrant continued monitoring. The high densities of presumed age-1 capelin (7 – 8 cm FL) over shallow banks and the lack of larger fish ($>$ 10 cm FL) that have been observed historically within deeper troughs suggests the population experienced a strong recruitment event in 2022 and that a single cohort is largely responsible for the population's recovery, but it is unknown if larger fish were distributed in other areas outside the survey area (i.e., nearshore waters). Ongoing surveys conducted by the US Geological Survey as part of the Gulf Watch Alaska program within Lower Cook Inlet and Prince William Sound may offer insights as to the current size- (age-) structure of the population. This would allow for a better risk assessment of the potential for another population collapse for this short-lived species.

Fisheries-independent Survey-based Indices of Forage Fishes in the Gulf of Alaska

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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[29] for past reports.

Southeastern Alaska Herring

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Last updated: August 2024

Description of indicator: Pacific herring (*Clupea pallasi*) stocks that reside in Southeast Alaskan waters are defined on a spawning-area basis. In recent decades, there have been about nine spawning areas where spawning events have typically been annual and meaningful in size in terms of potential for commercial exploitation. These areas include Sitka Sound, Craig, Seymour Canal, Hoonah Sound Hobart Bay-Port Houghton, Tenakee Inlet, Ernest Sound, West Behm Canal, and Kah Shakes-Cat Island (Figure 49). Sitka Sound and Craig are considered "outside stocks" as they are exposed directly to Gulf of Alaska waters, while all others except Kah-Shakes are considered "inside stocks" and less exposed to open ocean influence (Kah Shakes/Cat Island is not distinctly outside or inside). Monitoring of spawning stock size has been conducted at some of these areas for over 50 years by the Alaska Department of Fish and Game, primarily by combining estimates of egg abundance made using SCUBA with herring age and size information (Hebert, 2019). Starting in 2016, surveys and stock assessments were suspended for many stocks in southeastern Alaska due to budget cuts, which coincided with a decrease in spawning of many spawning stocks. Although the nine surveyed areas account for a large proportion of the spawning biomass in Southeast Alaska in any given year, other areas typically of more limited spawning also exist throughout Southeast Alaska. However, little or no stock assessment activity occurs at these minor locations other than occasional and opportunistic aerial surveys to document the miles of milt along shoreline. The herring that spawn in all areas of Southeast Alaska are believed to be affected by the broad-scale physical and chemical characteristics of Gulf of Alaska waters, though the spawning areas directly exposed to the open coast (Sitka Sound, Craig, Kah Shakes-Cat Island) may be affected the greatest or the soonest.

[29] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

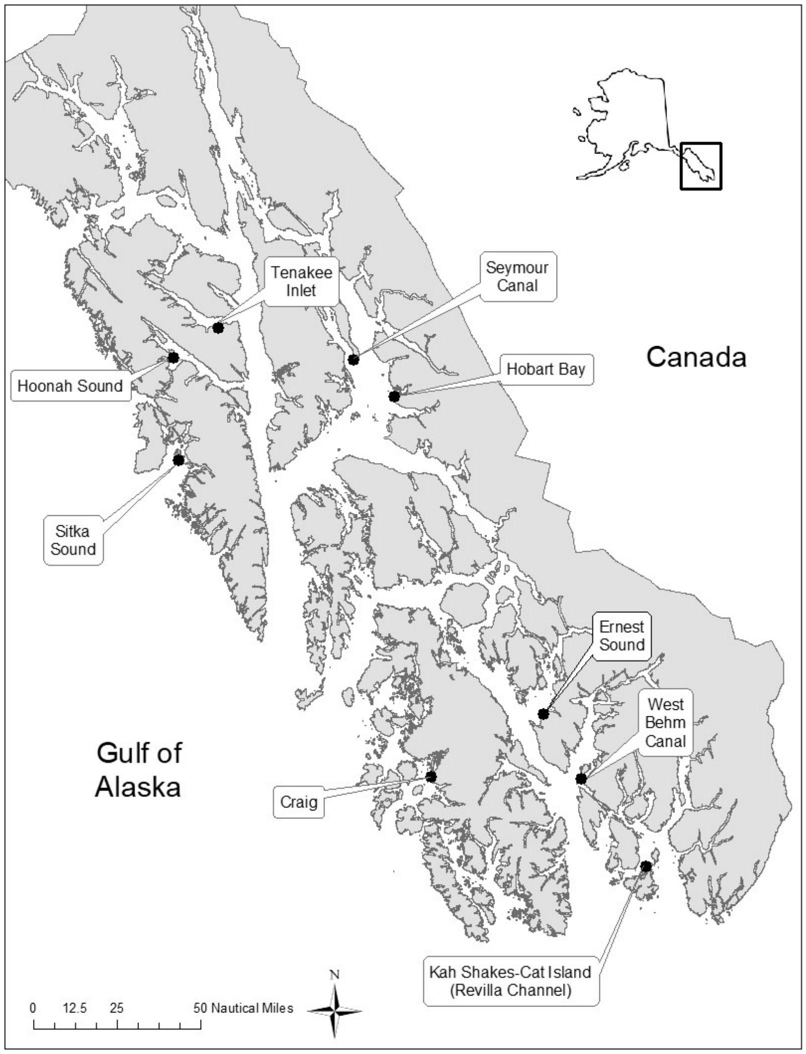

Figure 49: Location of nine Pacific herring spawning locations, historically surveyed in Southeast Alaska. Sitka Sound, Craig, and Kah-Shakes/Cat Island are considered "outside stocks" with greater ocean exposure, while all others are considered "inside stocks", less exposed to open ocean influence.

Status and trends: Mature biomass for Sitka Sound and Craig herring remains at a high level, as the extremely large 2016-year class continues to dominate these stocks. The 2019 age-3 recruitment event is by far the largest recruit class in the Sitka Sound and Craig model time-series (since 1976 for Sitka Sound and since 1988 for Craig). Model estimates indicate that the 2023 mature biomass and the proportion of herring from 2016-year class (then age-7) for Sitka and Craig stocks were again very high. The age-3 recruitment in 2023 (2020-year class) was also relatively high (very high in Sitka), leading to continued high biomass for these stocks (Figure 50).

Although industrial-scale herring oil reduction fisheries and foreign fisheries operated in Southeast Alaska beginning in the early 1900s, with catch peaking in 1935, the most reliable estimates of biomass exist from those data collected by the State of Alaska within the last 50 years, which are discussed here. Prior to Alaska statehood (1959), herring fisheries were first managed and studied by the U.S. Department of Commerce, Bureau of Fisheries, in the 1930s, then by the U.S. Department of the Interior, Fish and

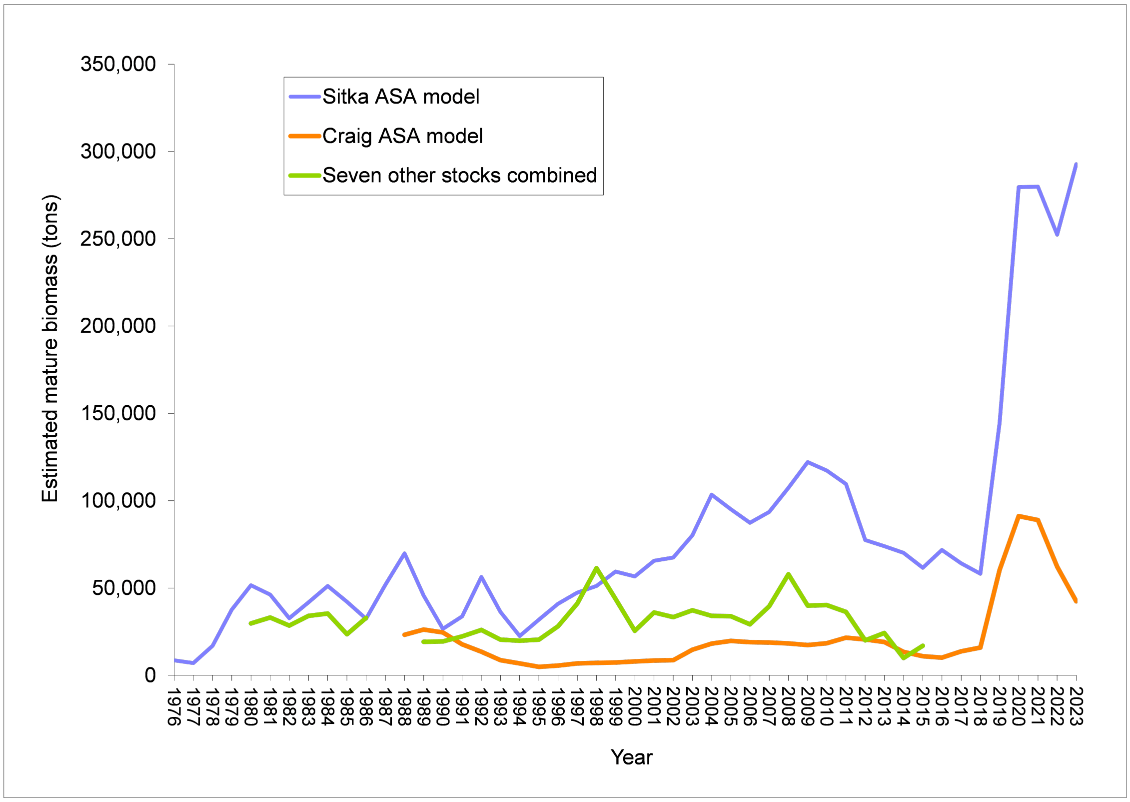

Figure 50: Estimated mature herring biomass (i.e., pre-fishery biomass) and forecasts for herring spawning areas historically surveyed in Southeast Alaska. Biomass estimates for Sitka Sound and Craig are based on integrated statistical catch-at-age models (the Sitka model starts in 1976 and Craig model starts in 1988). For all other stocks, biomass estimates are based on spawn deposition or hydroacoustic estimates, which began in different years, but for simplicity are shown starting in 1980. Estimated combined annual mature herring biomass (including and excluding Sitka) at major southeastern Alaska spawning areas, 1980 – 2011. For years 1987 – 1988, biomass estimates for the combined seven stocks were excluded from the plot because not all stocks were surveyed in those years. For years 2016 – 2023, biomass estimates for the combined seven stocks were excluded because starting in 2016 stock assessment surveys were suspended for most of the seven areas due to budget reductions and low spawn activity.

Wildlife Service in the 1940s and 1950s. Over the past 50 years, Sitka Sound and Craig herring have increased in biomass, whereas other Southeast stocks have been variable and are currently at relatively low levels (Figure 50). Following low biomass in the 1970's and a period of intermediate biomass during the 1980s through the mid-1990s, Sitka Sound herring increased to relatively high levels between 2008 and 2011. Craig and other Southeast stocks were variable until 2011. Southeast stocks then declined substantially until around 2016 – 2018. Sitka Sound and Craig, the two largest and most consistently abundant stocks, declined to moderate levels during this time. They then increased dramatically in 2019 following the highest recruitment of age-3 herring documented for these areas. The large 2016 year class has been documented across the Gulf of Alaska in aerial surveys of age-1 herring in Prince William Sound (Pegau et al., 2022), high mean frequency of occurrence of age-0 and age-1 herring in both diving and surface feeding birds at Middleton Island in 2016 and 2017 (Arimitsu et al., 2021), and age-3 herring in age composition samples and population abundance indices of mature herring in Prince William Sound (Pegau et al., 2022), Southeast Alaska and Kodiak Island (Hebert, 2022). Biomass levels for stocks in Southeast Alaska other than Sitka Sound and Craig are currently unknown because most egg abundance surveys were suspended starting in 2016, but limited aerial surveys of spawn events suggest that these stocks remain at relatively low levels compared to observations based on cumulative spawn mileage since 1980.

Factors influencing observed trends: Herring abundance is known to fluctuate dramatically between years, and is susceptible to environmental influences (Toresen, 2001). The underlying causes for the overall increase in herring biomass in Sitka Sound and Craig and the general decline in other stocks since 2011 may be due to multiple factors. Contributing factors may include fluctuating population levels of predatory marine mammals, such as humpback whales and Stellar sea lions (Muto et al., 2016; Fritz et al., 2016), varying levels of predatory fish, or recent shifts in water temperatures, which could affect herring food sources, life history, spawn timing, and metabolism. While commercial fishing has occurred during some years for some inside water stocks, the similarity in declines among inside water stocks, which for some occurred in the absence of fishing, suggests that environmental factors may have contributed to the declines.

The increase in Sitka Sound mature biomass observed in 2023 was due to continued presence of the unprecedented high 2016-year class, but also due to another dramatically high age-3 recruitment observed in 2023 (i.e., 2020-year class). Each of these year classes hatched during notable marine heat waves documented in the Northeast Pacific Ocean (Gentemann et al., 2017; Amaya et al., 2020). As ocean temperature has been positively correlated with recruitment in Atlantic herring (Clupea harengus) (Toresen, 2001), and Pacific herring (Zebdi and Collie, 1995), the marine heat waves may have led to extreme success of these year classes by providing favorable early-life marine conditions. While the age-3 recruitment for the Craig stock was exceptionally high like that in Sitka Sound, the age-3 recruitment in 2023 was much lower than 2019, although it was high relative to other years in the Craig recruitment time series. Consequently, biomass of the Craig stock declined between 2022 and 2023, although it remains at a relatively high level. Age composition sampling of other Southeast Alaska stocks in 2023 suggests that age-3 recruitment was variable among stocks.

Implications: The high herring biomass along the outer coast has persisted for five years through 2023 and is expected to remain at relatively high levels to support marine predators and fisheries for the next few years as the strong 2016 and 2020 year classes continue to contribute. Marine species that may benefit are numerous and include those that rely on adult or juvenile herring, such as demersal fishes, humpback whales, salmon and eagles, and those that consume herring eggs, such as gray whales, scoters, and gulls. The high biomass may also benefit traditional subsistence harvests, which have great cultural importance and are shared widely (Sill and Barnett, 2023), and commercial fisheries, which are economically important to fishermen, seafood processors and communities in and around the areas of Sitka Sound and Craig/Klawock and beyond. In contrast, the persistent low biomass for inside water stocks may hinder or cause behavior shifts in herring predators and subsistence activities in these areas and will continue to restrict commercial fishery opportunities until stocks rebound to substantially higher levels. However, because adult Pacific herring are known to migrate seasonally up to hundreds of kilometers from their natal grounds (Flostrand et al., 2009; Roundsfell and Dahlgren, 1935) it is plausible that the very high herring abundance originating from outside waters may contribute to the forage base for marine species of inside waters of Southeast Alaska during feeding and overwintering months, thereby buffering the impact of continued low spawning biomass in inside waters to some degree.

Southeast Alaska Eulachon

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Last updated: September 2024

Description of indicator: In Southeast Alaska, eulachon (*Thaleichthys pacificus*) are a culturally and biologically important anadromous fish. Eulachon populations have declined throughout their range since the 1990's and today all populations south of the Nass River in British Columbia have been severely depleted or become extinct (Hay and Mccarter, 2000). There are at least thirty-five rivers in Alaska where eulachon are known to spawn (Moffitt et al., 2002); however, it is thought that most runs are either unknown or anecdotal (Betts, 1994). To better understand the eulachon spawning population in northern Southeast Alaska the Chilkoot Indian Association initiated a mark-recapture study on the Chilkoot River in 2010. In 2014 this was complemented with the addition of environmental DNA (eDNA) sampling at the Chilkoot River. Furthermore, in 2017 eDNA sampling was expanded to include the Berners, Lace and Antler Rivers in Berners Bay and the Skagway and Taiya Rivers near Skagway, AK in partnership with the Skagway Traditional Council. In 2022 the use of eDNA to monitor eulachon spawning populations was expanded to include the Unuk River in southern Southeast Alaska in partnership with the Ketchikan Indian Community and US Forest Service. And in 2023 the Southeast Alaska Eulachon Monitoring Network was further expanded with eDNA monitoring on the Situk and Ahrnklin Rivers near Yakutat in partnership with the Yakutat Tlingit Tribe and US Forest Service (Figure 51).

Status and trends: In 2024, eulachon populations in southeast Alaska saw a range of returns from below average to above average (Table 1). In recent decades a decline in eulachon populations has increased concern about the health of eulachon across their range. In 2007 the Cowlitz Indian Tribe petitioned NOAA Fisheries to list eulachon under the Endangered Species Act. And in May 2010, the southern Distinct Population Segment (SDP) including California, Oregon, and Washington was listed as"threatened" under the Endangered Species Act (NOAA, 2010). In May 2011 the Canadian Committee on the Status of Endangered Wildlife listed three British Columbia populations for protection including the Central Pacific Coast, Fraser River, and Nass/Skeena River populations (COSEWIC, 2011). In Southeast Alaska there has been limited monitoring of eulachon spawning populations. The Forest Service has conducted aerial surveys along the Unuk River since 2001 and a mark-recapture population estimate on rivers within Berners Bay from 2004 – 2008. However, these studies only represent a small portion of the eulachon spawning habitat in Southeast Alaska. On the rivers north of Berners Bay there was no population data being collected until the Chilkoot Indian Association initiated a mark-recapture study in 2010 out of concern for declining eulachon populations elsewhere and a lack of data available.

The mark-recapture population estimate for the Chilkoot river near Haines, Alaska has seen a wide range in eulachon spawning abundance; estimates have ranged from a couple hundred thousand to over 20 million (Figure 52). The 2024 Chilkoot River eulachon mark-recapture population estimate was 4.9 million (2.5 – 7.4 million 95% CI). This population estimate was very similar to the 2023 mark-recapture

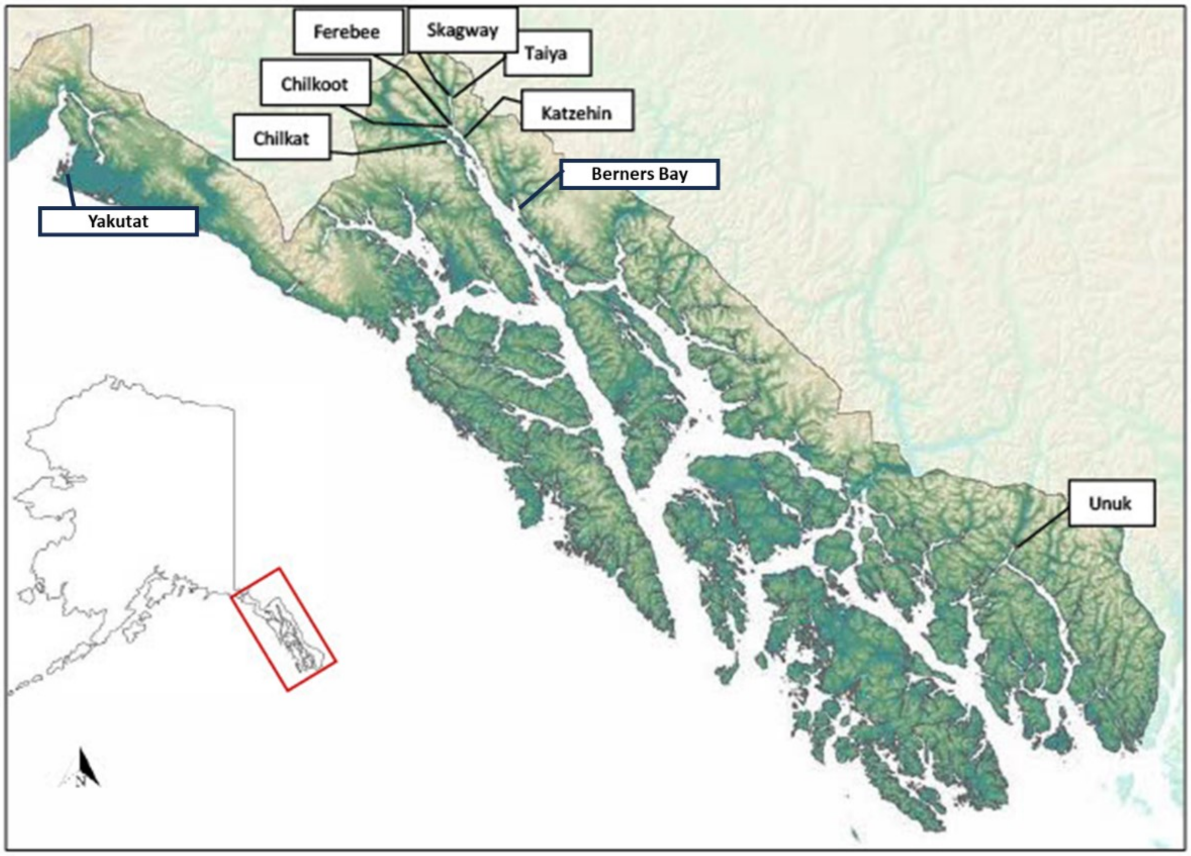

Figure 51: Location of Eulachon eDNA population monitoring sites in 2024.

estimate of 4.7 million. This is slightly below the overall average of 7.7 million, but sustaining an increase after no returns in 2021 and 2022.

The eulachon eDNA surveys were conducted at the Chilkoot River from 2014 – 2024. The log eDNA rate for 2023 indicates that the Chilkoot River eulachon return was average (baseline 2014 – 2023) compared to the previously monitored years (Figure 53). The eDNA concentration at the Chilkoot River followed similar trends to the mark-recapture data in the years that the methods coincided. Sample years 2014, 2015, 2016, 2017, 2018, 2021, and 2022 were much lower than the large returns observed in 2019 and 2020 (Figure 53). The metrics for eDNA comparison between years includes examining the maximum eDNA rate, or the size of the eDNA peak concentration (SOP) and the area under the curve of the eDNA concentration throughout the run (AUC). eDNA data for 2024 is still pending.

The regional population structure of eulachon initiated the need to begin a regional population monitoring effort in 2017 through the use of eDNA. The 2024 eDNA data is still pending, but the regional trends observed are depicted in Table 1. Most noteworthy of the 2024 eulachon spawning returns is the above-average returns in the Yakutat area for the second year in a row. This was above what had been observed in over 10 years, according to local knowledge. Also, the Unuk River run was above what had been observed in the last 10 years of Forest Service monitoring.

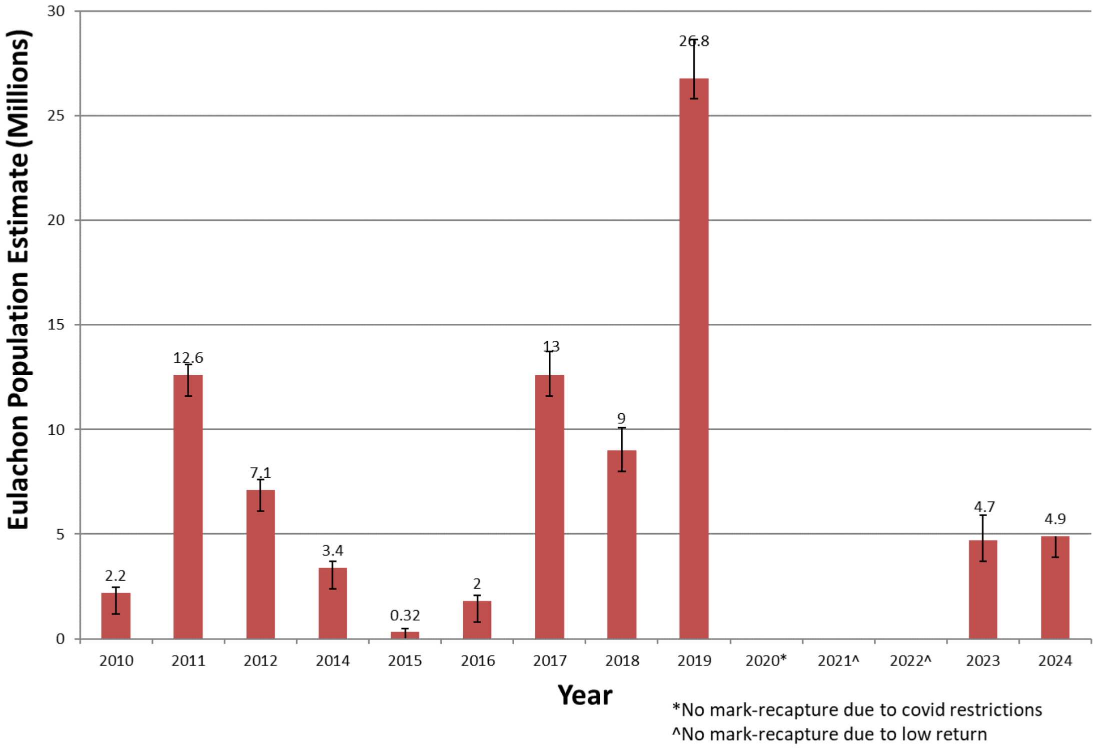

Figure 52: Eulachon population estimate on the Chilkoot River using mark-recapture method. Error bars represent 1 standard deviation.*No mark-recapture survey conducted in 2020 due to covid-19 restrictions. ^No survey conducted in 2021 and 2022 due to lack of return.

Table 1: 2024 Southeast Alaska eulachon return observations

River	Adjacent community	2024 Eulachon Return Observations
Chilkoot	Haines	Slightly below average
Chilkat	Haines	Slightly below average
Ferebee	Haines	Unknown/observations difficult
Katzehin	Haines	Unknown/observations difficult
Taiya	Skagway	Below average
Skagway	Skagway	Below average
Berners Bay	Juneau	Average
Unuk	Ketchikan	Below average
Situk	Yakutat	Above average
Ahrnklin	Yakutat	Above average

Factors influencing observed trends: Eulachon populations are sensitive to environmental influences and the annual spawning population at a river can vary substantially (Olds et al., 2016). Additionally, there is little known about the life history of eulachon (Spangler, 2002), which makes assessing trends

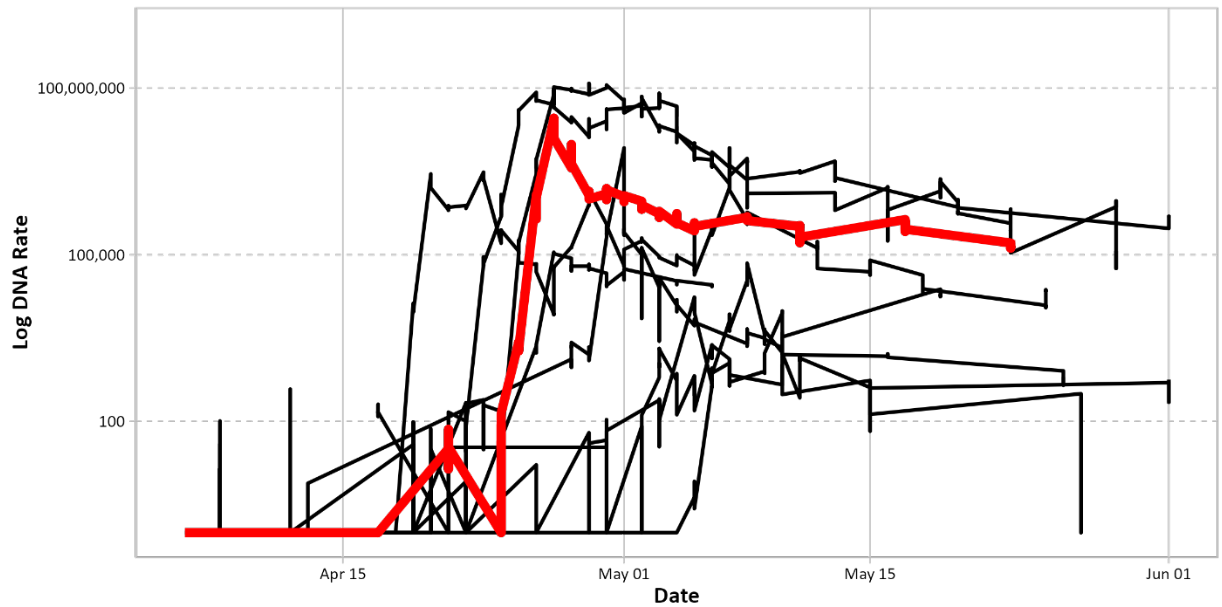

Figure 53: Chilkoot River Eulachon spring eDNA rate 2014–2023 (eDNA concentration x Discharge) for low return years (top panel) and big return years (bottom panel).

between parent-year and offspring difficult. It is thought that eulachon in Alaska are approximately two to five years of age at spawning (Spangler, 2002). Most eulachon are thought to be semelparous (Clarke et al., 2007), however it has been observed that eulachon do move back into the marine environment after spawning.

Implications: Anecdotal information and traditional knowledge indicates that eulachon spawning populations have historically varied in abundance (Olds et al., 2016). The limited timeseries of data available on eulachon spawning populations across the Southeast Alaska region limits any inference concerning the health of the overall eulachon population. Continued, and expanded, monitoring will be necessary to reliably assess the overall eulachon spawning population. A decline in the eulachon population in Southeast Alaska would have adverse impacts both culturally and ecologically. Eulachon have been termed the "salvation fish" by Northwest Coast Native peoples and eulachon oil was the most important trade item on a network of 'grease trails' between coastal and interior peoples (Moody and Pitcher, 2010). Today, eulachon are still valued as a subsistence resource. Additionally, eulachon are an important prey item for seabirds and marine mammals. Eulachon spawn prior to the breeding season for many predators, thus providing a high-energy resource at an energetically demanding time (Sigler et al., 2004).

Salmon

Trends in Alaska Commercial Salmon Catch

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Last updated: October 2024

Description of indicator: This contribution provides historic and current commercial catch information for salmon of the Gulf of Alaska. This contribution summarizes data and information available in current Alaska Department of Fish and Game (ADF&G) agency reports (e.g., Donnellan and Munro, 2024) and on their website[30].

Pacific salmon in Alaska are managed in four regions based on freshwater drainage basins[31], Southeast/Yakutat, Central (encompassing Prince William Sound, Cook Inlet, and Bristol Bay), Arctic-Yukon-Kuskokwim, and Westward (Kodiak, Chignik, and Alaska peninsula). ADF&G prepares harvest projections for all areas rather than conducting run size forecasts for each salmon run. There are five Pacific salmon species with directed commercial fisheries in Alaska; they are sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*).

Status and trends: *Statewide*—Combined catches from directed fisheries on the five salmon species have fluctuated over recent decades but in total have been generally strong statewide (Figure 54a). The salmon commercial harvests from 2023 totaled 232.2 million fish, which was 42.8 million more than the preseason forecast of 189.4 million fish. The 2023 total commercial harvest was elevated by the harvest of 154 million pink salmon, primarily from Prince William Sound and Southeast Alaska. While the 2024 harvest data are not yet final, preliminary data from ADF&G for 2024 indicates a statewide total commercial salmon harvest of about 98 million fish (as of 23 September), which is below the preseason projection of 135.7 million fish. In particular, the preliminary statewide pink salmon harvest of 38 million fish is below the harvest projection of 69 million pink salmon.

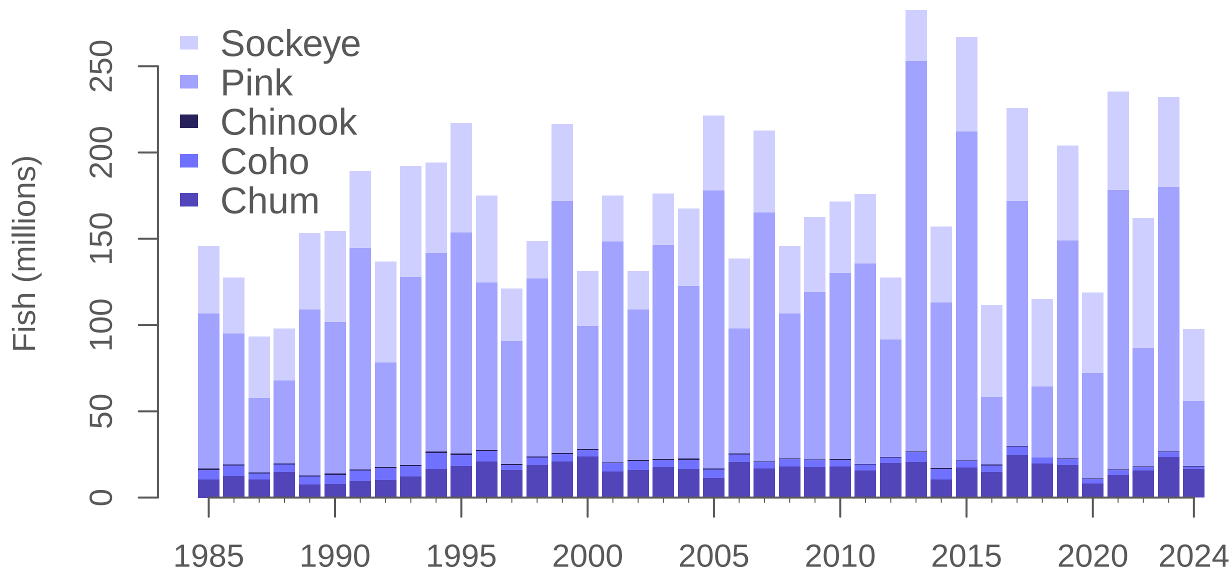
Gulf of Alaska—The total commercial salmon harvests in the Gulf of Alaska are dominated by pink salmon which follow a cycle of strong odd years and weak even years (Figure 54b). In the Prince William Sound Area of the Central region, the 2023 pink salmon harvest continued to follow the pattern of strong odd years with a harvest of 58.8 million which was nearly equal the odd-year average of 58.1 million fish. Preliminary harvest numbers for 2024, indicate maintenance of the weak even-year pattern with a commercial harvest of about 10 million fish.

In the Southeast region, the 2023 commercial salmon harvests totaled 66.5 million fish, which was more than double the 2022 total harvest in this region. The 2023 harvest of 47.8 million pink salmon was greater than the preseason forecast of 19 million fish. Preliminary data for 2024 from ADF&G indicates

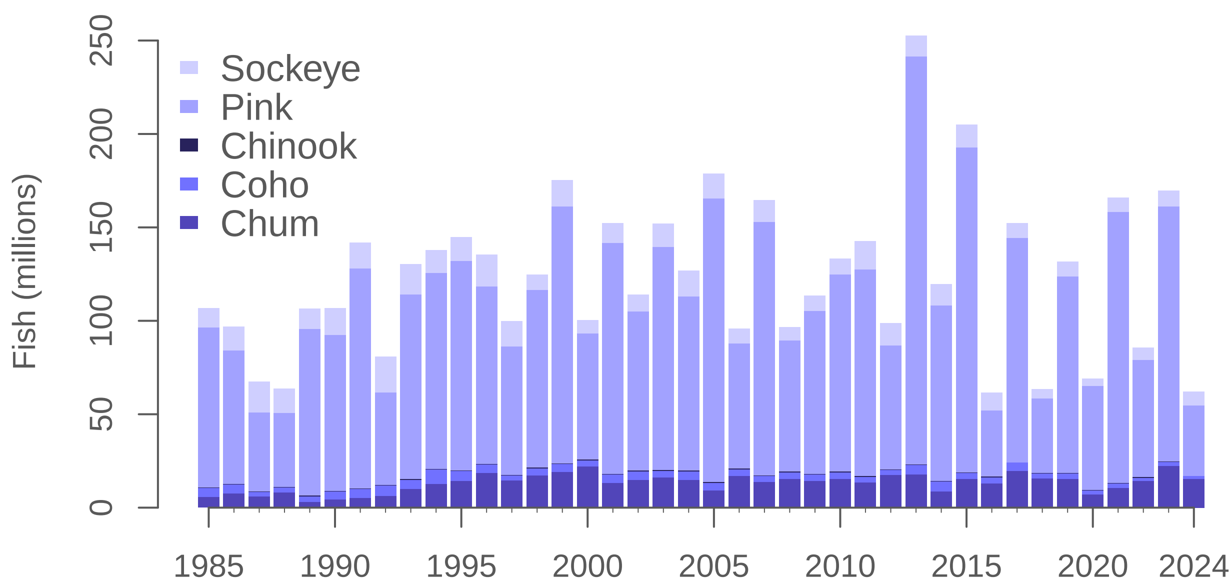
[30] https://www.adfg.alaska.gov/
[31] https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmonareas

the catch of pink salmon are maintaining the pattern of weak even years with a catch of approximately 19.8 million.

In the Kodiak management area, the 2023 total commercial salmon harvest of 28.4 million fish was above the recent 10-year average harvest of 23.9 million fish. The 2023 sockeye salmon commercial harvest of 2.6 million was also above the recent 10-year average of 2.5 million fish. The 2023 chum salmon harvest of 828,000 fish was above the forecast of 457,000 fish. Preliminary data from ADF&G on the 2024 commercial harvest in the Kodiak management area indicates a decrease in total harvest to about 9.1 million fish, including about 7.1 million pink salmon.



(a) Alaska



(b) Gulf of Alaska

Figure 54: Contemporary commercial salmon catches from Alaska statewide (a) and GOA (b), 1985-Sept 2024. Values from 2024 are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data, subsequent analysis, or interpretation.)

Factors influencing observed trends: Historically, pink salmon catches increased in the late 1970s to the mid-1990s and have generally remained high in all regions in the last decade (Figure 54a). While both natural and hatchery populations return to Prince William Sound, a large majority of the returning fish are hatchery fish, with up to one half billion released from four hatcheries (Kline et al., 2008). Pink salmon have an abbreviated life cycle, consisting of three phases 1) brood year, 2) early marine year, and 3) return year (Kline et al., 2008). Interannual variation in Alaska statewide total salmon abundance is partly due to the even-year, odd-year cycle in pink salmon, which typically have larger runs in odd years. Pink salmon run strength is established during early marine residence and may be influenced by diet and food availability (Cooney and Willette, 1997). Survival rates of Alaska pink salmon are positively related to sea surface temperatures and may reflect increased availability of zooplankton prey during periods with warmer surface temperatures (Mueter and Norcross, 2002).

Chinook runs have been declining statewide since 2007. Size-dependent mortality during the first year in the marine environment is thought to be a leading contributor to low Chinook run sizes (Beamish and Mahnken, 2001; Graham et al., 2019).

Implications: Salmon have important influences on Alaska marine ecosystems through interactions with marine food webs as predators on lower trophic levels and as prey for other species such as Steller sea lions. In years of great abundance, salmon may exploit prey resources more efficiently than their competitors, affecting the body condition, growth, and survival of competitors (Ruggerone et al., 2003; Toge et al., 2011; Kaga et al., 2013; Rand and Ruggerone, 2024). In odd years when pink salmon are most abundant they can initiate pelagic trophic cascades (Batten et al., 2018) which may negatively impact the population dynamics of several other species, including other salmonids, forage fishes, seabirds, and whales (Ruggerone et al., 2023). A biennial pattern in seabird reproductive success has been attributed to a negative relationship with years of high pink salmon abundance (Springer and van Vliet, 2014). Directed salmon fisheries are economically important for the state of Alaska. The trend in total statewide salmon catch in recent decades has been for generally strong harvests despite annual fluctuations and lower catches for some species in specific management areas.

Juvenile Salmon Abundance in Icy Strait, Southeast Alaska

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Last updated: September 2024

Description of indicator: Juvenile salmon catch-per-unit-effort (CPUE), zooplankton abundance and quality, and data on oceanographic conditions have been collected during the Southeast Alaska Coastal Monitoring (SECM) surveys from 1997 – 2024 (Fergusson et al., 2021; Murphy et al., 2021). SECM data are used in a variety of research applications. Juvenile salmon (*Oncorhynchus spp.*) CPUE is a key data product due to its use in harvest and run forecast models (Murphy et al., 2019). SECM surveys and salmon forecast models (Brenner et al., 2021) are part of a cooperative research effort by NOAA's Alaska Fisheries Science Center (AFSC) and the Alaska Department of Fish and Game (ADF&G) in support of salmon stocks and fisheries in southeastern AK. This research supports salmon management in the US/Canada Pacific Salmon Treaty Northern boundary area and southeast Alaska domestic fisheries.

Juvenile salmon CPUE indices are constructed from surface (0–23m) rope trawl catches in Icy Strait, the northern migratory corridor between the inside waters of southeastern AK and the GOA. CPUE indices are the peak monthly average log-transformed catch per 20-min trawl set in Icy Strait during the months of June and July. Data have been standardized to the long-term mean to visualize anomalies. These indices are adjusted for fishing power differences between the survey vessels that have conducted SECM surveys over time (Wertheimer et al., 2010). CPUE data for juvenile chinook (*O. tshawytscha*), chum (*O. keta*), coho (*O. kisutch*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon are included in Figure 55.

Status and trends: Peak CPUEs have been consistently near or below average for all species of juvenile salmon in recent years; Chinook salmon since 2016; chum, pink, and sockeye salmon since 2017; and coho salmon since 2018 (Figure 55). Catch rates of juvenile pink salmon increased in 2024 relative to 2023, but remained well below the long-term mean. Catch rates of Chinook, coho and sockeye salmon decreased in 2024, all well below their respective long-term mean CPUEs. Chinook experienced the largest drop, and Chinook and coho experienced new all time lows for the time series. Chum salmon CPUE experienced a slight increase in CPUE yet remained well below the long-term average.

Factors influencing observed trends: Multiple factors contribute to the variation in juvenile salmon catch rates (i.e., CPUE) over time and the relative importance of these factors differ by species. Early life-history ecology and mortality are the primary factors influencing juvenile CPUE; however, spawner abundance and the migratory patterns of juveniles can also influence the year-to-year variation in juvenile CPUE. Spawner abundance goals were not met in even-year runs of pink salmon from 2012 to 2020 within the northern inside region of southeast AK (Piston and Heinl, 2020), and unpublished ADF&G data, and this is likely an important factor contributing to lower even-year catch rates of juvenile pink salmon. However, the lower bound of the escapement goal was met in 2022, and the juvenile pink salmon index increased slightly in 2024 over recent odd year juvenile indices. Catch rates of juvenile

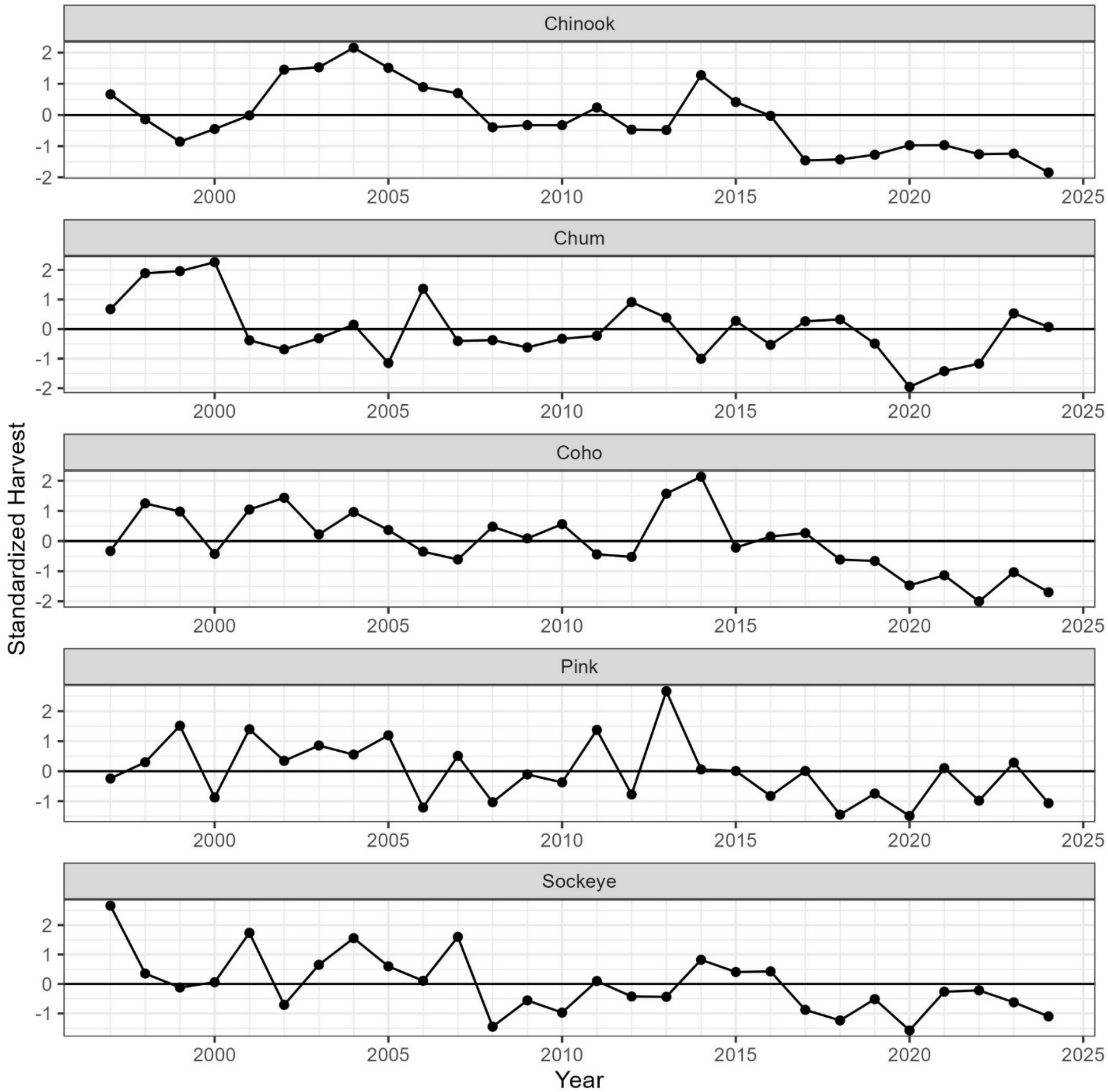

Figure 55: Standardized catch-per-unit-effort (CPUE, log-transformed catch per 20-min trawl set) of juvenile salmon during NOAA's Southeast Coastal Monitoring surveys in Icy Strait, 1997–2024. The CPUE index is the peak monthly average catch rate during the months of June and July. The ADF&G is not responsible for the reproduction of data, subsequent analysis, or interpretation.

pink salmon are corrected for temperature in harvest forecast models, and this correction is believed to reflect the influence of temperature on juvenile migration and juvenile pink salmon catch rates (Murphy et al., 2019). Juvenile pink salmon catches therefore reflect a combination of early life history ecology and mortality, escapement, and migration. Hatchery fish typically account for >80% of the chum salmon harvested in southeast AK; therefore, spawner abundance has minimal influence on juvenile chum salmon catch rates. Chinook, sockeye, and coho salmon typically spend at least one full year in freshwater before migrating to sea; therefore, both freshwater and early marine survival contribute to the juvenile catch rates of these species of salmon.

Implications: Juvenile pink salmon catch rates increased in 2024, relative to 2023, but remained well below the long-term average (Figure 55). The harvest of southeast AK pink salmon in 2024 was above the last 3 even year harvest (Figure 56). This may reflect improved offshore survival or reduced survey catchability (during juvenile migration) in 2023.

Catch rates of juvenile chum salmon have improved after the all-time low in 2017, but remain below the long-term average. Due to the primary contribution of hatchery fish to commercial fisheries, it is difficult to interpret how this may influence the fishery. Marine survival is more likely the limiting factor for this species.

It's challenging to interpret the 2024 harvest of southeast Chinook and coho salmon in light of the juvenile CPUE record, primarily because decreased fishing effort has likely influenced these harvest figures. Nevertheless, the declining juvenile CPUE for both species might signal reduced harvest opportunities in the future. Additionally, it's worth noting that Icy Strait may not be the most suitable indicator for these species, as many Chinook salmon reside in inside waters for extended periods, and both species likely occupy different ocean habitats compared to other juvenile salmon species.

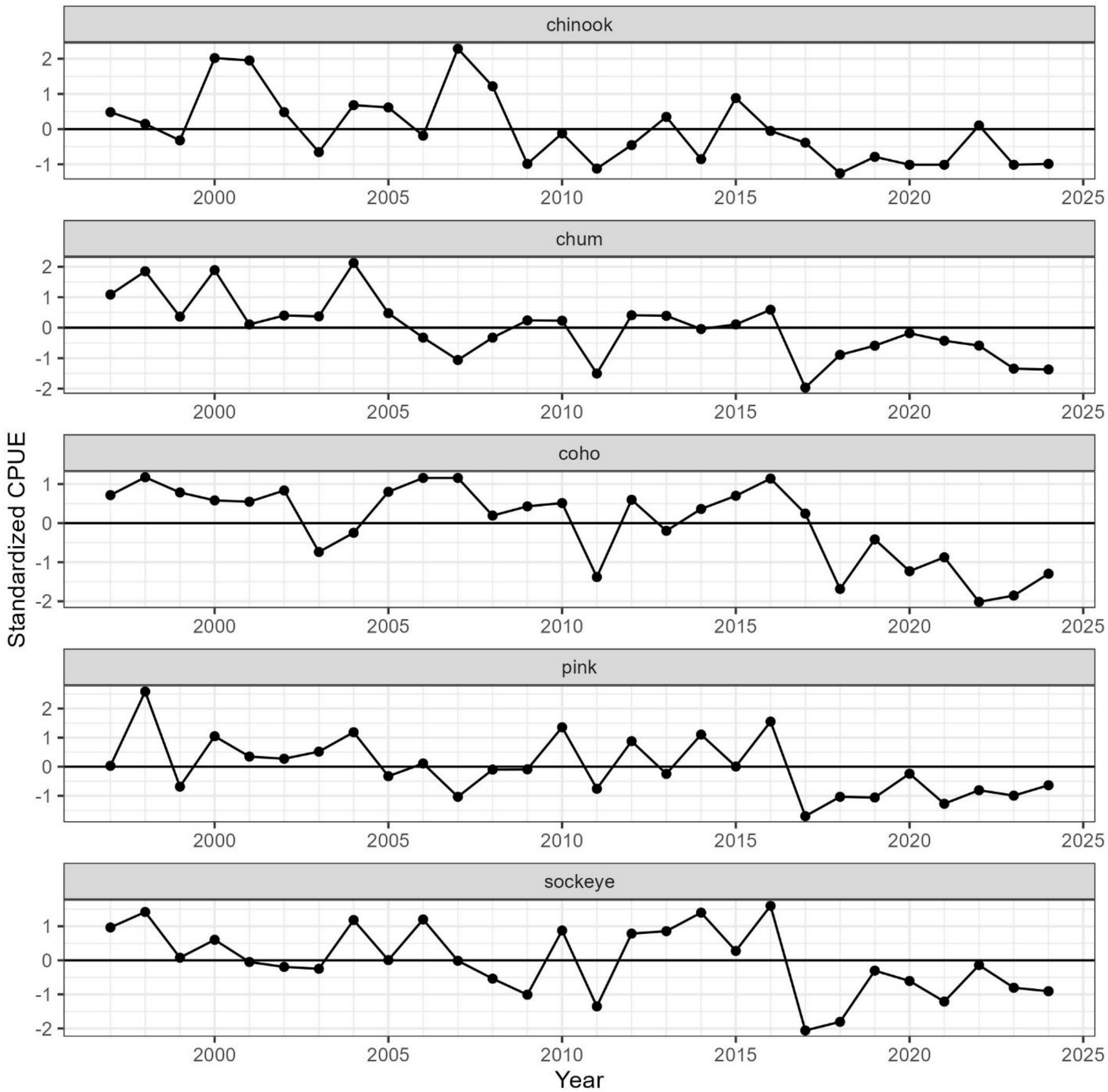

Figure 56: Standardized commercial harvest (metric tons) of salmon in Southeast Alaska, 1997 – 2024. The 1997 – 2023 harvest data are provided by ADF&Ghttps://npafc.org/statistics/. The 2024 harvest data are preliminary data retrieved on Sep 26, 2024, provided by ADF&Ghttps://www.adfg.alaska.gov/index.cfmadfg=commercialbyfisherysalmon.bluesheet

. The ADF&G is not responsible for the reproduction of data, subsequent analysis, or interpretation.

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

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Last updated: September 2024

Description of indicator: The Southeast Coastal Monitoring project (SECM, Auke Bay Laboratories, AFSC) has been investigating how climate change may affect southeastern Alaska nearshore ecosystems in relation to juvenile salmon (*Oncorhynchus* spp.) and associated biophysical factors since 1997 (Fergusson et al., 2020*a*; Murphy et al., 2020). Juvenile pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and coho (*O. kisutch*) salmon size and nutritional condition data have been collected annually in Icy Strait during monthly (June and July) fisheries oceanographic surveys. This Report presents July 2024 size (fork length) and energy density data in relation to the past 28 year trend from Icy Strait.

Status and trends: In 2024, juvenile salmon length anomalies were below average for all four species. Juvenile salmon pink and chum salmon length anomalies were similar to values observed in 2023 and remained below average (baseline 1997 – 2023). Juvenile sockeye salmon length anomalies showed a marked decrease from average to clearly below average. Juvenile coho salmon length anomalies increased but remained below average (Figure 57).

In 2024, energy density anomalies (ED, kJ/g dry weight) varied among the four juvenile salmon species (Figure 58). For juvenile pink and sockeye salmon, ED anomalies increased from below to above values in 2023 to above average. Juvenile chum salmon ED anomalies continued the trend of increasing values observed over the past two years, remaining positive. For juvenile coho salmon, ED was similar to the previous three-year trend, remaining just negative of average.

Factors influencing observed trends: During early marine entry and residency, juvenile salmon must grow quickly to avoid predation while also acquiring enough lipid reserves to survive winter when food is severely limited (Beamish and Mahnken, 2001; Moss et al., 2005). The record low numbers of outmigrating juvenile pink and coho salmon in 2017 through 2019 may have resulted from low escapements in the previous years and/or low freshwater survival (Murphy et al., 2020). Size trends over time represent differences in growth, migration routes, and timing of hatch, outmigration, and hatchery releases of the fish in response to climate and ocean conditions during early marine residency. Energy density trends over time can represent the condition of juvenile salmon and other taxa in response to climate and ocean conditions during their early marine residency.

Implications: The length anomalies observed in 2024 for juvenile salmon continue to reflect the colder water temperatures experienced in their early marine residency in Icy Strait. Larger fish generally have increased foraging success and a decreased predation risk resulting in higher survival. Based on the 2024 length frequency results relative to the long-term averages by species, juvenile salmon are entering the Gulf of Alaska (GOA) in 2024 with below-average size. Further growth and survival will be dependent on favorable over-winter conditions in the GOA.

Juvenile pink, chum, sockeye, and coho salmon entered the Gulf of Alaska in 2024 with average to positive energy stores which may contribute to higher survival and escapement especially as it pertains to their overwinter survival when food is limited.

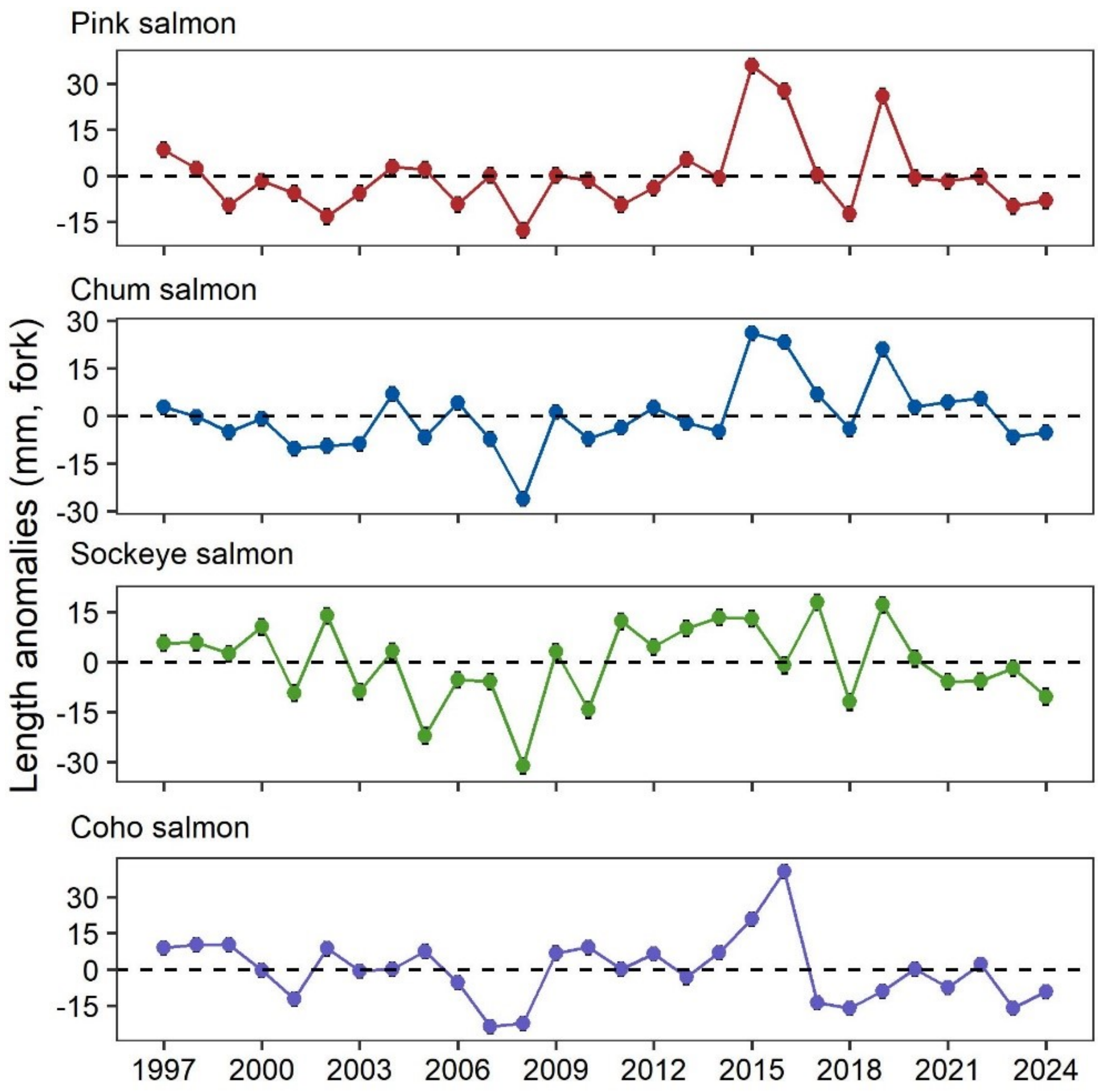

Figure 57: Average fork length (mm; ±1 standard error) anomalies of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997 – 2024. Time series average is indicated by the dashed line.

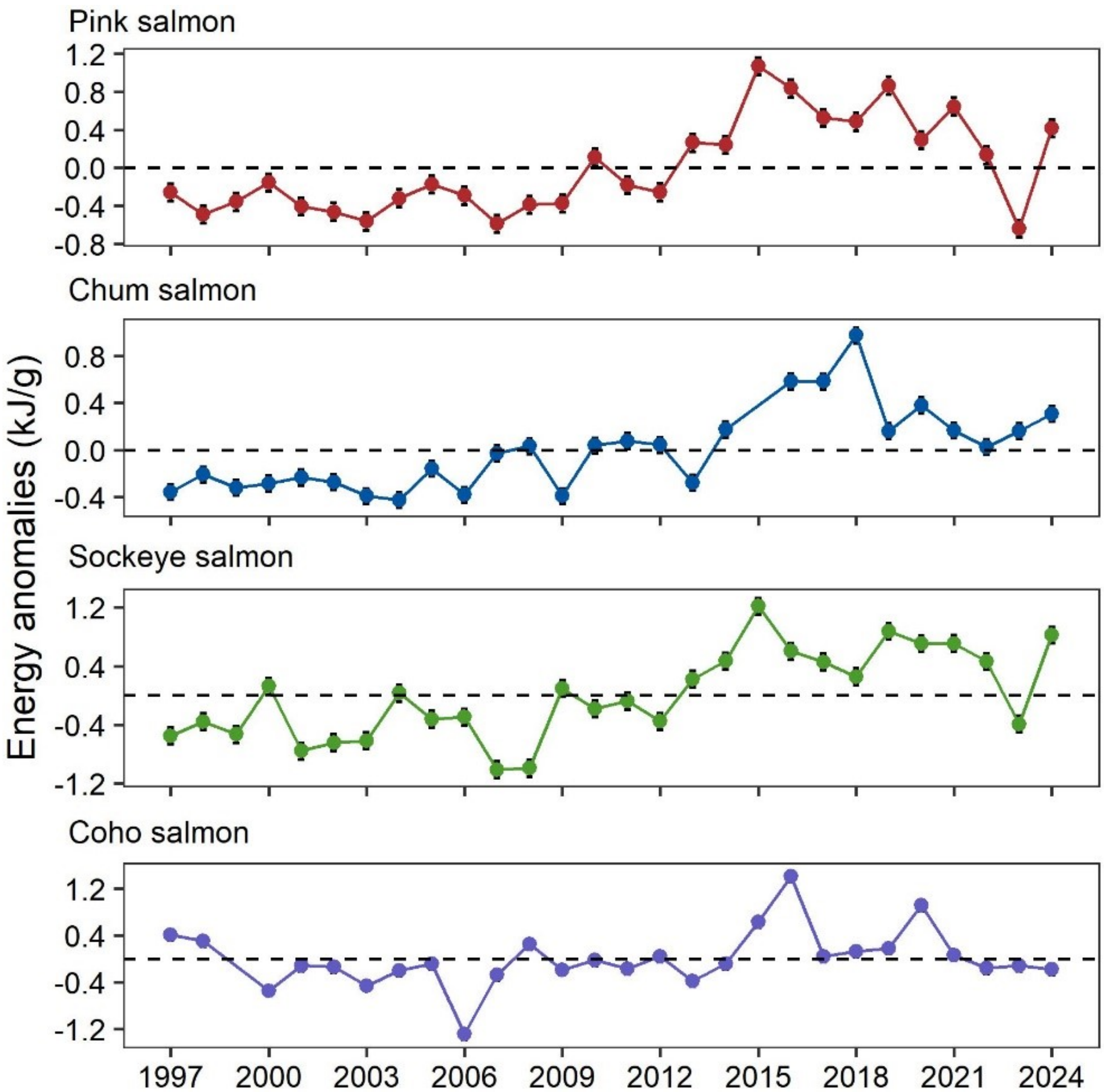

Figure 58: Average energy density (kJ/g, dry weight; ±1 standard error) anomalies of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997 – 2024. The dashed line indicated the time series average.

Survival of Coho, Sockeye, and Pink Salmon from Auke Creek, Southeast Alaska

Contributed by Scott C. Vulstek, Joshua R. Russell, and M. Padraig New
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Last updated: September 2024

Description of indicator: The time series of marine survival estimates for wild coho, sockeye, and pink salmon from the Auke Creek Weir in Southeast Alaska is the most precise and longest-running continuous series available in the North Pacific. Auke Bay Laboratory began monitoring wild salmon survival in 1980. The Auke Creek weir structure facilitates near-complete capture of all migrating sockeye smolt and returning adults and is the only weir capable of such precision on a wild system in the North Pacific. All coho salmon smolts leaving the Auke Lake watershed have been counted, subsampled for age and length, and injected with coded wire tags (CWT). These migrating fish included those with both 1 and 2 freshwater annuli and 0 or 1 ocean annuli. Coho marine survival is estimated as the number of adults (harvest plus escapement) per smolt. The index is presented by smolt (outmigration) year. It is the only continuous marine survival and scale data set in the North Pacific that recovers all returning age classes of wild, CWT coho salmon as ocean age 0 and 1. The precision of the survival estimate was high due to 100% marking and high sampling fractions that minimized the variance in the survival estimate and made the series an excellent choice for model input relating to nearshore and gulf-wide productivity. While no stock-specific harvest information is available for Auke Creek sockeye and pink salmon for a direct estimation of marine survival, the precision of this long-term dataset is still unmatched, and the series is an excellent choice for model input relating to nearshore and gulf-wide productivity.

Status and trends: The historical trends show marine survival of wild coho salmon from Auke Creek varies from 5.2% to 45.0%, with an average survival of 20.6% from smolt years 1980 – 2023 (Figure 59a). Marine survival for 2023 was the ninth lowest on record at 13.9% and overall survival averaged 11.3% over the last 5 years and 10.3% over the last 10 years. The survival index for ocean age-0 coho varies from 0.2% to 11.2% from smolt years 1980 – 2023 (Figure 59b).

Productivity of wild sockeye salmon smolts from Auke Creek varies from 1619 to 33616, with an average productivity of 15535 from ocean entry years 1980 – 2024. Productivity for 2024 saw 7187 outmigrant smolts, the seventh lowest on record (Figure 59c). Escapement of wild sockeye salmon from Auke Creek has varied from 325 to 6123, with an average escapement of 2493 from return years 1980 – 2024. The 2024 season saw the fourth lowest escapement of sockeye salmon to Auke Creek with 797 returning adults (Figure 59d).

Marine survival of wild pink salmon from Auke Creek varies from 1.1% to 53.3%, with an average survival of 11.8% from ocean entry years 1980 – 2023 (Figure 59e). Marine survival for the 2023 ocean entry year was 24.1% and overall survival averaged 18.6% over the last 5 years and 17.0% over the last 10 years. 2024 saw the seventh lowest return of pink salmon to Auke Creek with 1588 returning adults (Figure 59f).

Factors influencing observed trends: Factors influencing observed trends in coho survival include:

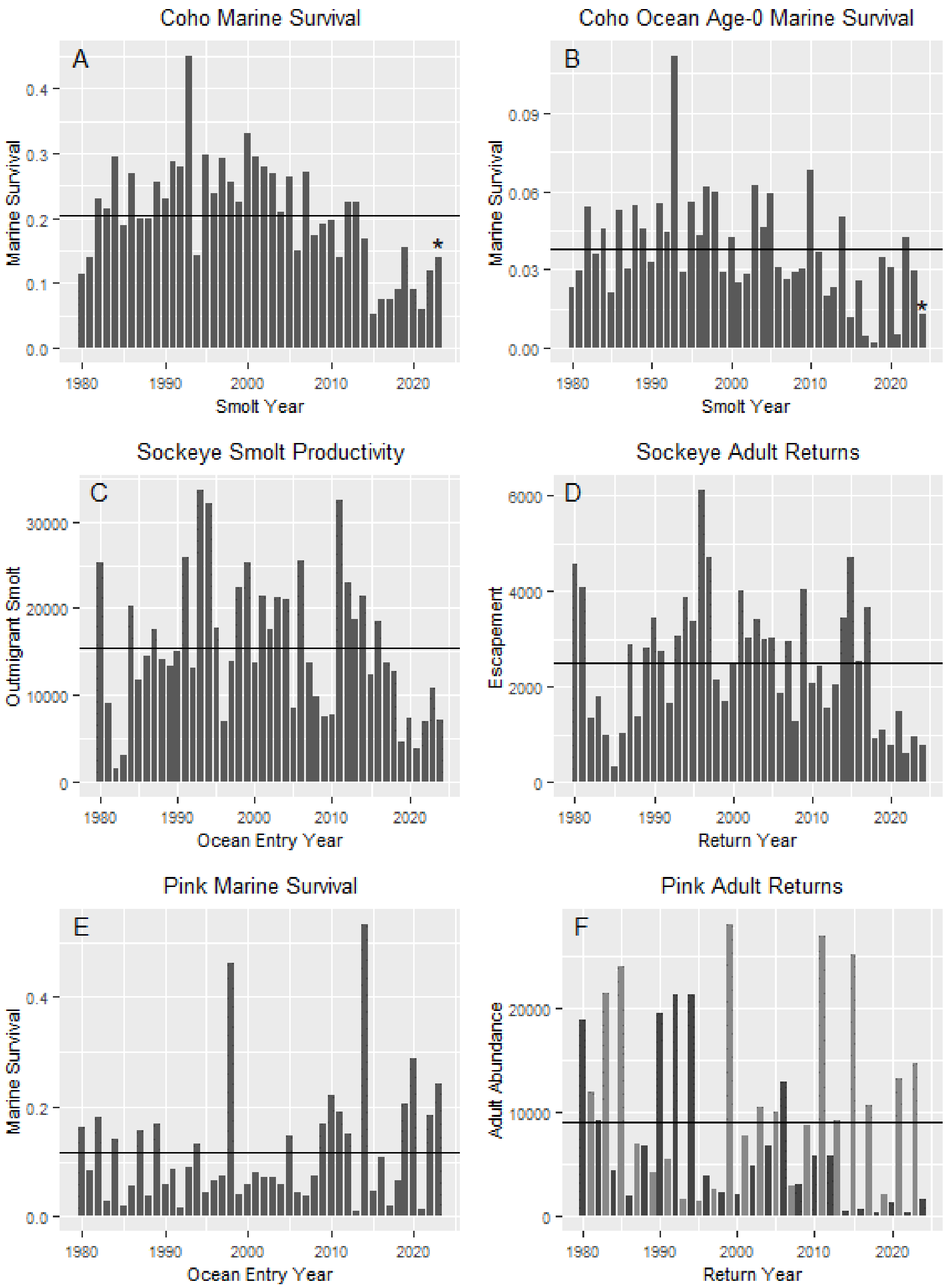

Figure 59: Auke Creek (SE Alaska) salmon marine survival and productivity indices. Coho salmon are represented by total marine survival (ocean age-0 and age-1 harvest plus escapement) (A), and percentage of ocean age-0 coho per smolt (escapement only) by smolt year (B). Sockeye salmon are represented by smolt productivity by ocean entry year (C) and adult returns (D). Pink salmon are represented by marine survival index is represented by ocean entry year (E) and adult returns by year (F). Return year 2024 data are denoted with an asterisk as these may change by the end of the year. For coho, sockeye and pink indices, the solid, horizontal line indicates the 1980 – 2023 average.

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

Sockeye salmon marine survival has been influenced by trends that include: smolt age, smolt size, migration timing, predation, and marine environmental conditions. Age and size at saltwater entry, along with regional sea surface temperature have been shown to influence juvenile mortality at ocean entry (Yasumiishi et al., 2016). Within the Auke Creek watershed, a system undergoing rapid climatic change, climate-induced phenological shifts have been shown to influence a trend of later migration of sockeye adults and age-1.0 smolts, while age-2.0 smolts are trending earlier (Shanley et al., 2015; Kovach et al., 2013*a*). Additionally, positive effects of temperature have been observed on sockeye biomass and length of age-2.0 smolts in the Auke Creek system (Kovach et al., 2014). In Southeast Alaska, sablefish have been observed to prey upon juvenile sockeye in early summer before more abundant food resources become available (Sturdevant et al., 2009).

Factors that have influenced these observed trends in pink salmon survival include: migration timing, fishery effort and timing, predation, growth rates, maintained genetic variation, and stream conditions. Within the Auke Creek system, a system undergoing rapid climatic change, climate-induced phenological shifts have been shown to influence the trend of earlier migration of both the early and late run of pink adults, as well as juvenile fry migration (Kovach et al., 2013*b*; Shanley et al., 2015). The effect of fishing pressure on pink salmon has some obvious effects on marine survival, as well as, unapparent impacts including decreases in body weight, variations in length, increases in earlier-maturing fish, and increases in heterozygosity at PGM (Hard et al., 2008). As pink salmon are one of the most numerous and available food sources of larger migrating juvenile salmon and other marine species, their early marine survival can be heavily impacted by predation (Parker, 1971; Landingham et al., 1998; Mortensen et al., 2000; Orsi et al., 2013). One resistance to this predation is that pink salmon fry are able to quickly outgrow their main predators of juvenile coho and sockeye salmon and become unavailable as a food resource do to their size (Parker, 1971). During juvenile development, the local conditions of stream discharge and temperature are strong determinants of egg and fry survival. In addition, many of these influencing factors have been shown to have a genetic component that can strongly influence survival (Geiger et al., 1997; McGregor et al., 1998; Kovach et al., 2013*a*).

Implications: The marine survival index of coho, sockeye and pink salmon at Auke Creek is related to ocean productivity indices and to important rearing habitats shared by groundfish species. The productivity and escapement indices of Auke Creek salmon provide an opportunity for the examination of annual variation in habitat quality of rearing areas and general ocean conditions and productivity. Ocean age-0 coho leave freshwater in May through June and return in August through October, the same time sablefish are moving from offshore to nearshore habitats. In contrast, ocean age-1 coho salmon occupy those nearshore habitats for only a short time before entering the Gulf of Alaska and making a long migratory loop. They return to the nearshore habitats on their way to spawning grounds after the first winter that age-0 sablefish spend in nearshore habitats. The relative growth and survival of ocean age-0 and age-1 coho salmon from Auke Creek may provide important proxies for productivity, overwintering survival of sablefish, and recruitment of sablefish to age-1. Within Southeast Alaska, sockeye salmon productivity and escapement are of great interest to the Pacific Salmon Commission with relation to the Transboundary and Northern Boundary areas and indices such as Auke Creek help in assessment. As a result of these implications, the productivity and escapement of Auke Creek sockeye salmon provide valuable proxies for Gulf of Alaska and Southeast Alaska productivity and may provide insight to the overwintering survival and recruitment of sablefish and other groundfish species. Due to the one ocean year life history of pink salmon, we are able to use their marine survival as a proxy for the general state of the Gulf of Alaska. Additionally, as pink fry are a numerous food resource in southeast Alaska, their abundance and rate of predation allow for insights into the groundfish fisheries. Pink fry have been shown to be an important food resource for juvenile sablefish, making up a large percentage of their diet (Sturdevant et al., 2009, 2012). The growth and marine survival of Auke Creek pink salmon provide valuable proxies for Gulf of Alaska and southeast Alaska productivity, as well as the overwintering survival and recruitment of sablefish.

Groundfish

Groundfish Condition

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Last updated: September 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[32] for past reports.

ADF&G Gulf of Alaska Trawl Survey

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Last updated: September 2024

Description of indicator: The Alaska Department of Fish and Game conducts an annual trawl survey for crab and groundfish in Gulf of Alaska targeting areas of crab habitat around Kodiak Island, the Alaska Peninsula, and the Eastern Aleutian Islands (Spalinger and Silva, 2024). Parts of these areas have been surveyed annually since 1984, with the most consistent time series beginning in 1988. The trawl survey uses a 400-mesh eastern otter trawl constructed with stretch mesh ranging from 10.2 cm in the body, decreasing to 3.2 cm in the codend. Constructed to sample crab, it can also reliably sample a variety of fish species and sizes, ranging from 15 cm to adult sizes, but occasionally capturing fish as small as 7 cm for some species. While the survey covers a large portion of the central and western GOA, results from Kiliuda and Ugak Bays (inshore) and the immediately contiguous Barnabas Gully (offshore) are generally representative of the survey results across the region (Figure 60).

In 2024, 50 stations were sampled from June 27 through July 4. The survey catches (mt/km) from Kiliuda and Ugak Bays and Barnabas Gully were summarized by year for selected species groups. Using a method described by (Link et al., 2002), standardized anomalies, a measure of departure from the mean catch (kg) per distance towed (km), were also calculated for selected species: arrowtooth flounder *Atheresthes stomias*, flathead sole *Hippoglosoides elassodon*, Tanner crab *Chionoecetes bairdi*, Pacific cod *Gadus macrocephalus*, skates, walleye pollock *G. chalcogrammus* and Pacific halibut *Hippoglossus stenolepis*. Temperature anomalies were calculated using average bottom temperatures recorded for

[32] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

each haul from 1990 to 2023 (data not available for 2024).

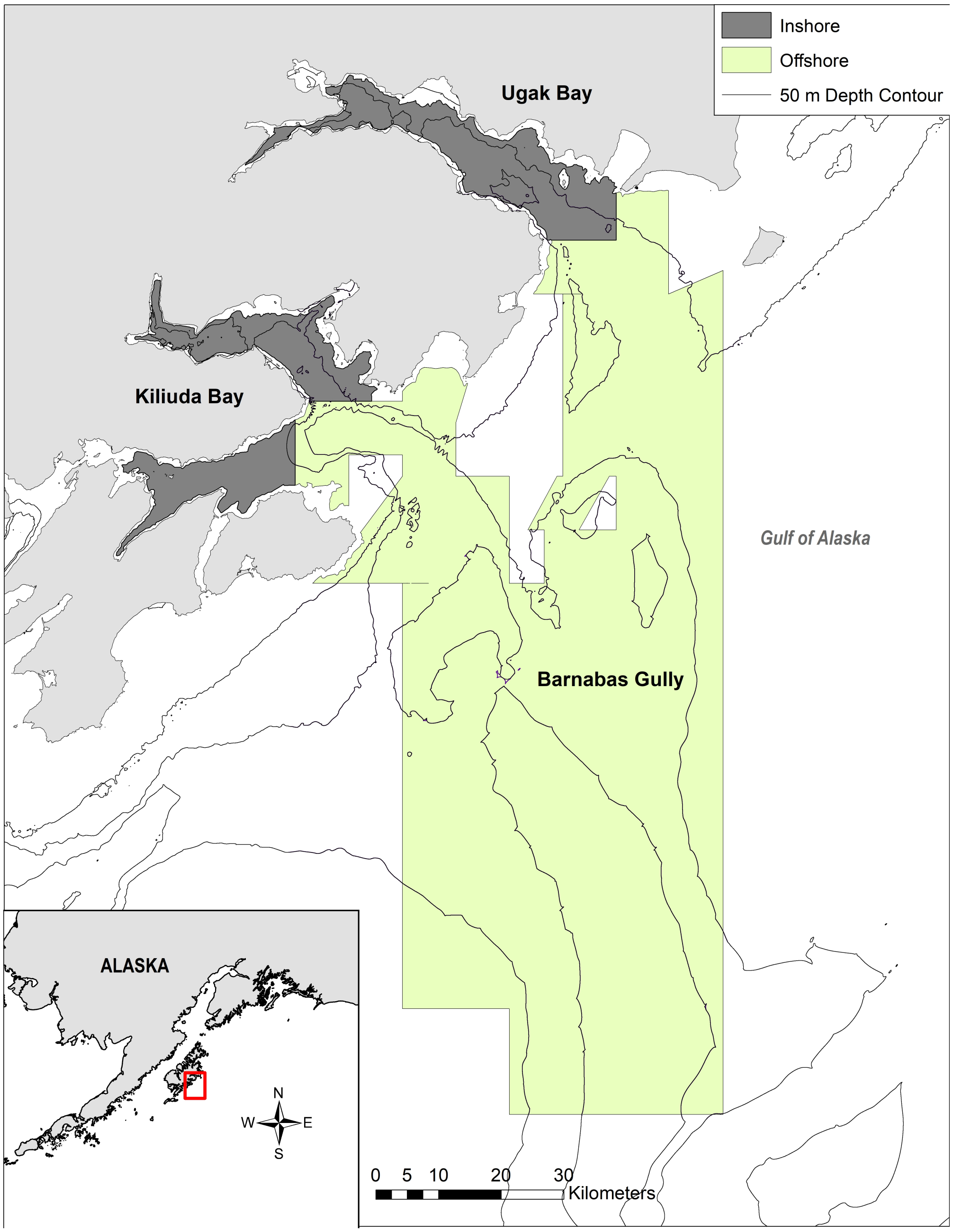


Figure 60: Kiliuda Bay, Ugak Bay, and Barnabus Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 36 stations) trawl survey results.

Status and trends: The 2024 survey data showed an increase in overall biomass in both the inshore and offshore stations (Figure 61). Arrowtooth flounder and Tanner crab have been the predominant species in the ADF &G trawl survey catches in the last 3 years. In 2024, arrowtooth slightly increased while Tanner crab significantly decreases in both the inshore and offshore stations. Flathead sole and starfish increased in the inshore stations, while gadids and starfish showed slight increases in the offshore stations. Of the starfish group, *Pychnopodia helianthoides* (sunflower sea star) continues to be the predominant starfish species in both inshore and offshore stations. Increases in the number of small animals indicate this species may be recovering from the significant die off that started in 2014. A sharp decrease in survey overall biomass is apparent from 2007 to 2017 from the years of record high catches occurring from 2002 to 2005.

Prior to the start of our standard trawl survey in 1988, Ugak Bay was the subject of an intensive seasonal trawl survey in 1976 – 1977 (Blackburn, 1977). Today, the Ugak Bay species composition is markedly different than in 1976. Red king crabs (*Paralithodes camtschaticus*) were the main component of the catch in 1976 – 1977, but now are nearly non-existent. Flathead sole, skate, and gadid catch rates have all increased roughly 10-fold. While Pacific cod made up 88% and walleye pollock 10% of the gadid catch in 1976 – 1977, catch compositions have reversed with Pacific cod making up 14.7% of catch, down from 19.4% in 2023, and walleye pollock 85.3% in 2024. an increase from 80.6% in 2023.

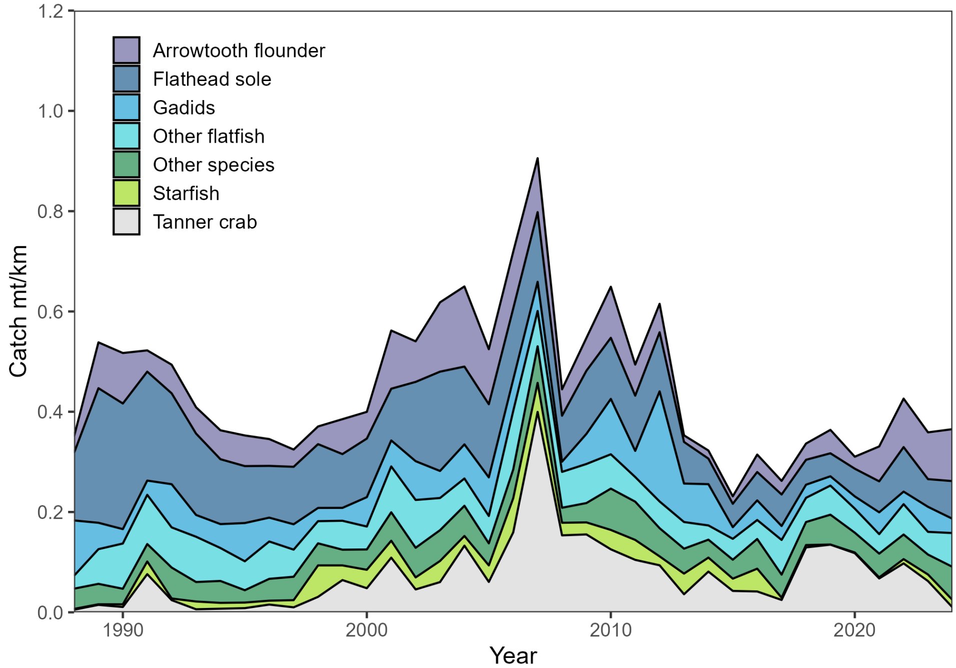
The catches of flathead sole, Pacific cod, Pacific halibut, and walleye pollock continue to have below average anomaly values (baseline 1988 – 2022) for both the inshore and offshore stations, while arrowtooth and skates were above average in both inshore and offshore stations in 2024 (Figure 62). Tanner crab dropped below average in both the inshore and the offshore stations signaling the decline of a large recruitment class first observed in 2018 (Spalinger and Silva, 2024).

Summer temperature anomaly values for both inshore and offshore stations were below average in 2023 (no data for 2024) in contrast to the previous year (see western GOA summer temperatures in this Report, p.49). The higher-than-average temperatures in past years frequently occurred during moderate and strong El Niño years[33].

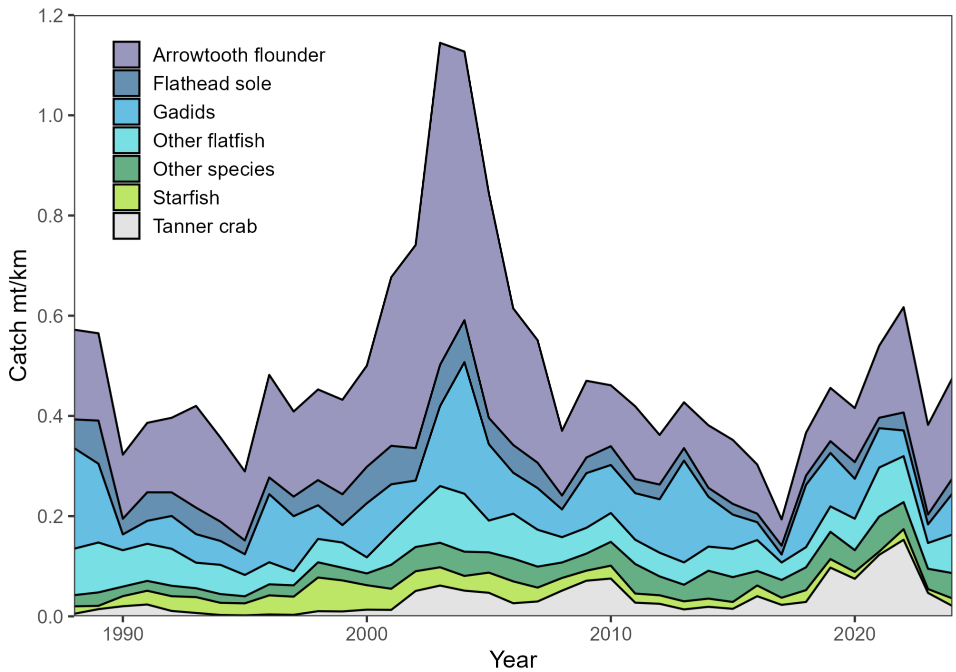
Factors influencing observed trends: It appears that significant changes in volume and composition of the catches on the east side of Kodiak are occurring, but it is unknown to what extent predation, environmental changes, and fishing effort are contributing. The lower overall catch from 1993 to 1999 (Figure 61) may reflect the greater frequency of El Niño events on overall production, while the period of less frequent El Niño events, 2000 to 2003, corresponds to years of increasing production and correspondingly higher catches. Lower than average temperatures were recorded from 2006 to 2009 along with decreasing overall abundances in 2008 and 2009. This may indicate a possible lag in response to changing environmental conditions or some other factors may be affecting abundance that are not yet apparent. Declines in Pacific cod abundance during the 2014 – 2016 period of the anomalously warm water event in the GOA were well documented (Barbeaux et al., 2020*a*; Suryan et al., 2021). Recent increases in Tanner crab abundance are likely influenced by the decrease in predation during years with lower-than-average Pacific cod, arrowtooth flounder, flathead sole, and halibut catches.

Implications: Although trends in abundance in the trawl survey appear to be influenced by major oceanographic events such as El Niño, local environmental changes, predation, movements, and fishery effects may influence species specific abundances. Monitoring these trends is an important process used in establishing harvest levels for state water fisheries. These survey data are used to establish guideline harvest levels of state managed fisheries and supply abundance estimates of the nearshore component of other groundfish species such as Pacific cod and pollock. Decreases in species abundance will most likely be reflected in decreased guideline harvest levels.

[33] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml



(a) Kiliuda and Ugak Bay



(b) Barnabas Gully

Figure 61: Total catch per km towed (mt/km) of selected species from Kiliuda and Ugak Bays (a) and Barnabas Gully (b) survey areas off the east side of Kodiak Island, 1987–2024.

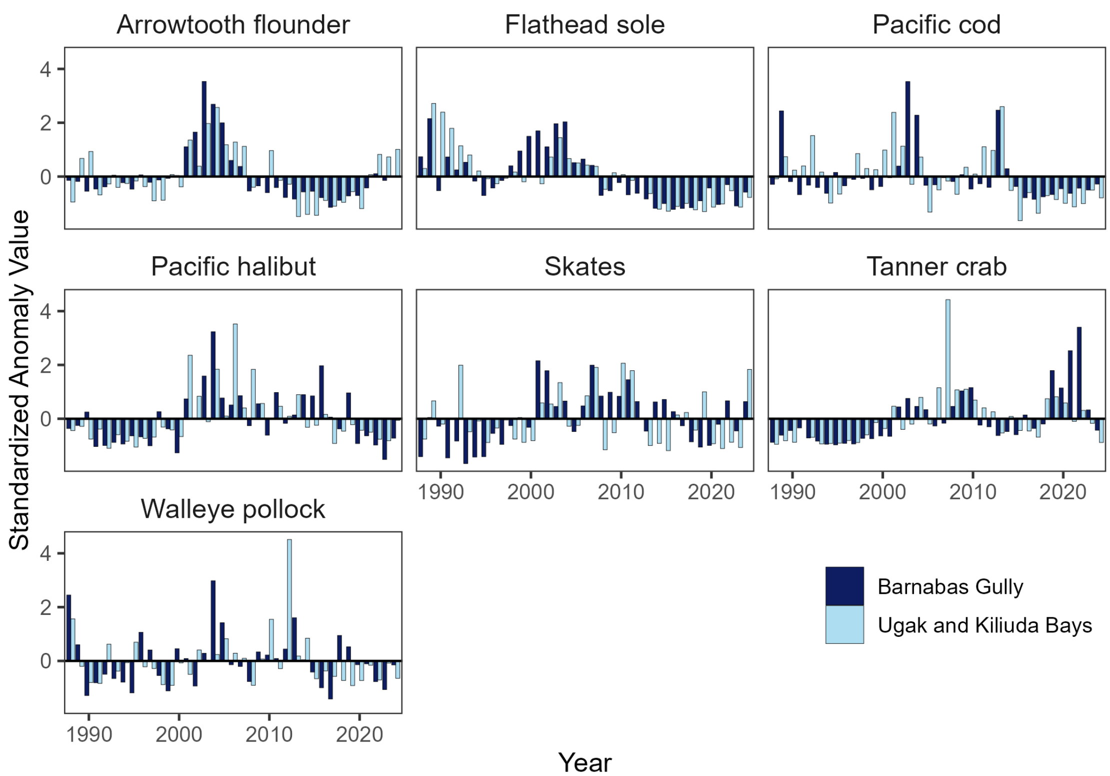


Figure 62: A comparison of standardized anomaly values, based on catch (kg) per distance towed (km) for selected species caught from 1988 to 2024 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

Distribution of Rockfish Species along Environmental Gradients

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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[34] for past reports.

Multispecies Model Estimates of Time-varying Natural Mortality of Groundfish

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Last updated: November 2024

Description of indicator: We report trends in age-1 natural mortality for walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*) and arrowtooth flounder (*Atheresthes stomias*), from the Gulf of Alaska (USA). Total natural mortality rates are based on model estimated sex-specific, time- and age-invariant residual mortality (M1) and model estimates of time- and age-varying predation mortality (M2) produced from the multi-species statistical catch-at-age assessment model (known as CEATTLE; Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics). The model is based, in part, on the parameterization and data used for recent stock assessment models of each species (see Adams et al., 2022, for more details). The model is fit to data from five fisheries and seven surveys between 1977 and 2024 and includes inputs of abundance-at-age from recent stock assessment models for Pacific halibut scaled to the proportion of age-5+ biomass in IPHC management area 3 (Stewart and Hicks, 2021). Model estimates of predation mortality are empirically derived by bioenergetics-based consumption information and diet data from the GOA to inform predator-prey suitability (Holsman and Aydin, 2015; Holsman et al., 2019).

Status and trends: The climate-enhanced multispecies model (CEATTLE) for the Gulf of Alaska (GOA) estimates that natural mortality due to all sources for age-1 pollock and arrowtooth flounder

[34]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

has increased in recent years, but remain below the long-term mean. However, natural mortality for age-1 Pacific cod has decreased slightly since 2023 and remains below the long-term mean. Estimates of biomass consumed of pollock, Pacific cod, and arrowtooth flounder as prey across all ages remains below the long-term mean.

Estimated age-1 natural mortality (M) for walleye pollock, Pacific cod, and arrowtooth flounder peaked in 2003 for pollock, 2005 for Pacific cod, and 2001 for arrowtooth flounder (Figure 63). Average age-1 M estimated by CEATTLE was greatest for pollock (1.5 yr^{-1}) and lower for Pacific cod (0.7 yr^{-1}) and arrowtooth (0.39 yr^{-1} for females and 0.48 yr^{-1} for males). After varying in recent years, pollock age-1 M increased in 2024 to 1.45 yr^{-1} and is currently below the long-term mean of 1.5 yr^{-1}, but above the value used for single species assessment (age-1 M = 1.39; Figure 63). Pacific cod age-1 M decreased slightly to 0.69 yr^{-1} and remains below the long-term mean of 0.7 yr^{-1} (Figure 63), but above the age-invariant values estimated in the single species assessment of 0.492 yr^{-1}. Similarly, arrowtooth flounder age-1 M remains below the long-term mean after increasing slightly in recent years (Figure 63). However, arrowtooth age-1 M remains above the values used for the single species assessment of 0.2 yr^{-1} (arrowtooth females) and 0.35 yr^{-1} (arrowtooth males), with total age-1 M at around 0.38 yr^{-1} for arrowtooth females and 0.48 yr^{-1} for arrowtooth males. 2024 age-1 M across species is 4.05% to 32.79% lower than in peak years.

On average 120,379 mt of age-1 pollock, 2,465 mt of age-1 Pacific cod, and 5,294 mt of age-1 arrowtooth flounder was consumed annually by species included in CEATTLE between 1977 and 2024. For 2024, we estimated 50,726 mt of age-1 pollock, 1,763 mt of age-1 Pacific cod, 4,025 mt of age-1 arrowtooth females, and 1,763 mt of age-1 arrowtooth males was consumed by species included in CEATTLE. Across all ages 394,583 mt of pollock, 25,560 mt of arrowtooth flounder, 4,877 mt of Pacific cod was consumed annually, on average, by species included in CEATTLE. The total biomass consumed of pollock and arrowtooth flounder as prey across all ages increased in 2024 compared to 2023 (Figure 64). The total biomass consumed of Pacific cod has decreased in recent years. The total biomass consumed as prey across all ages for all species is currently below the long-term mean.

Factors influencing trends: Temporal patterns in total natural mortality reflect annually varying changes in predation mortality by pollock, Pacific cod, Pacific halibut, and arrowtooth flounder that primarily impact age-1 fish (but also impact older age classes). Predation mortality at age-1 for all species in the model was primarily driven by arrowtooth flounder (Figure 65) and arrowtooth flounder biomass has increased in recent years. Combined annual predation demand (annual ration) of age-4+ pollock, Pacific cod, and arrowtooth flounder in 2024 was 5.16 hundred thousand tons, below the 6.17 hundred thousand ton annual average (Figure 66).

Implications: We find evidence of increased predation mortality on age-1 pollock, Pacific cod, and arrowtooth flounder due to the species modelled in CEATTLE. Previous ecosystem modelling efforts have estimated that mortality of pollock is primarily driven by Pacific cod (16%), Pacific halibut (23%) and arrowtooth flounder (33%) (Gaichas et al., 2015). Recent increases in predator biomass are contributing to the increase in total consumption and therefore increased predation mortality. Between 1990 and 2010, relatively high natural mortality rates reflect patterns in annual demand for prey from arrowtooth flounder, whose biomass peaked during this time period.

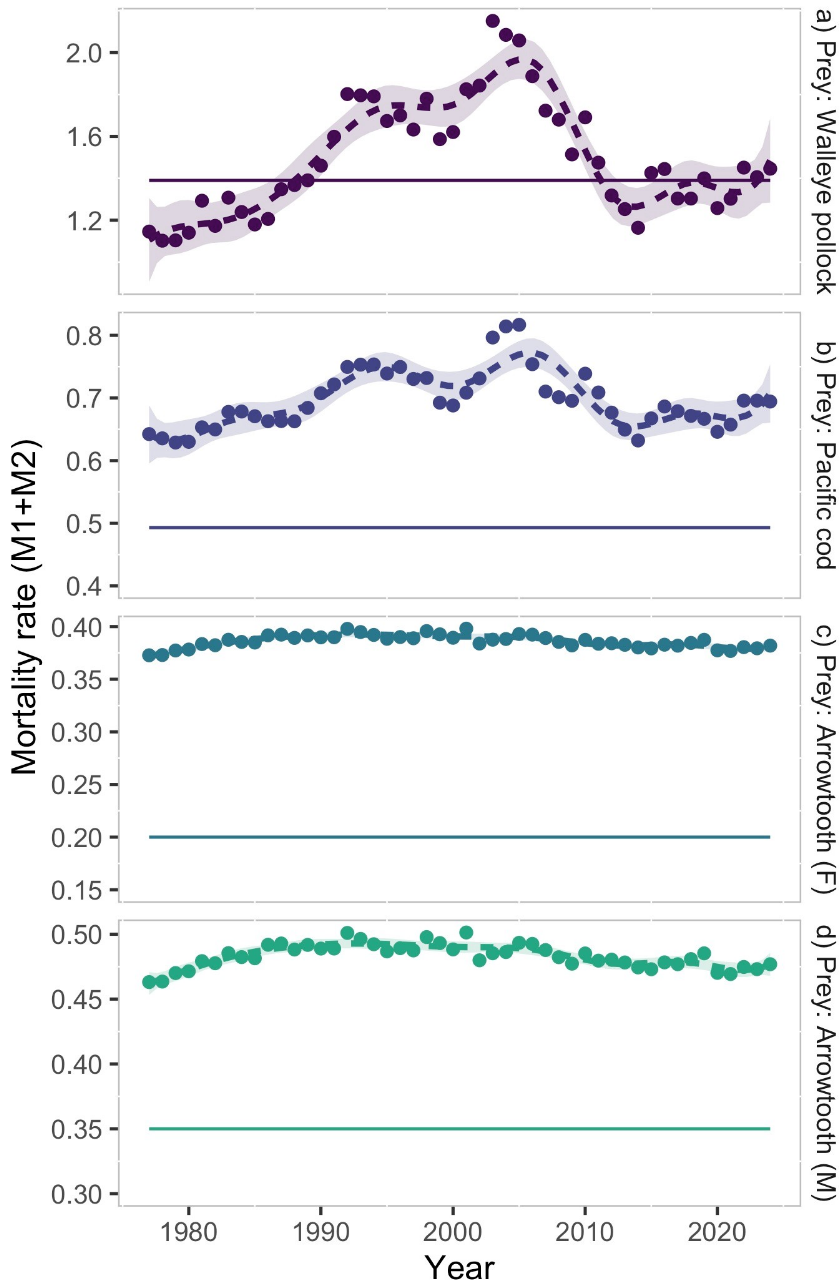

Figure 63: Annual variation in natural mortality (M1+M2) of age-1 pollock (a), Pacific cod (b), and arrowtooth flounder (females and males) (c/d) from the single-species models (dashed line), and the multi-species models with temperature (points; solid line is a loess polynomial smoother indicating trends over time)

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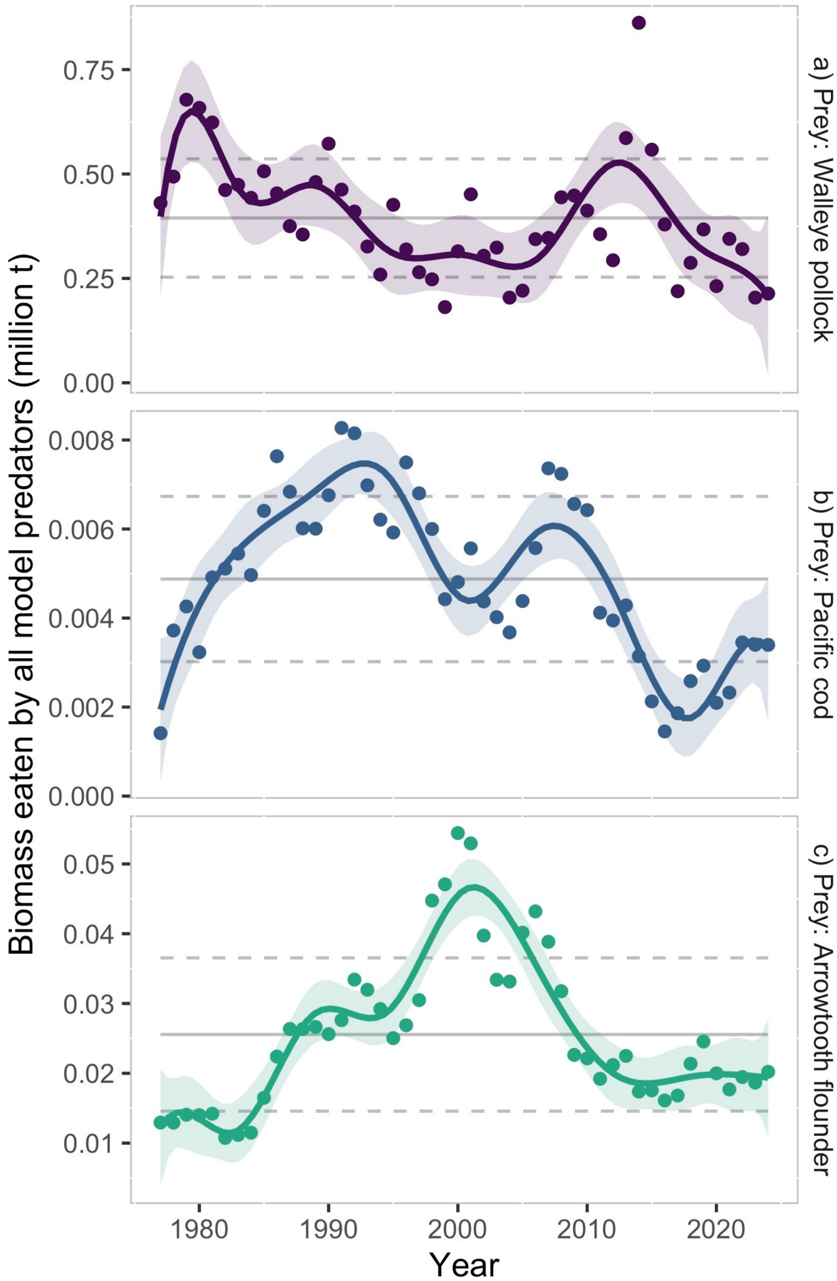

Figure 64: Multispecies estimates of biomass consumed as prey across all ages by all predators annually in the model of walleye pollock (a), Pacific cod (b), and arrowtooth flounder (c). Points represent annual estimates, gray lines indicate 1979 – 2024 mean estimates for each species, and the solid line is a 10 year (symmetric) loess polynomial smoother indicating trends over time.

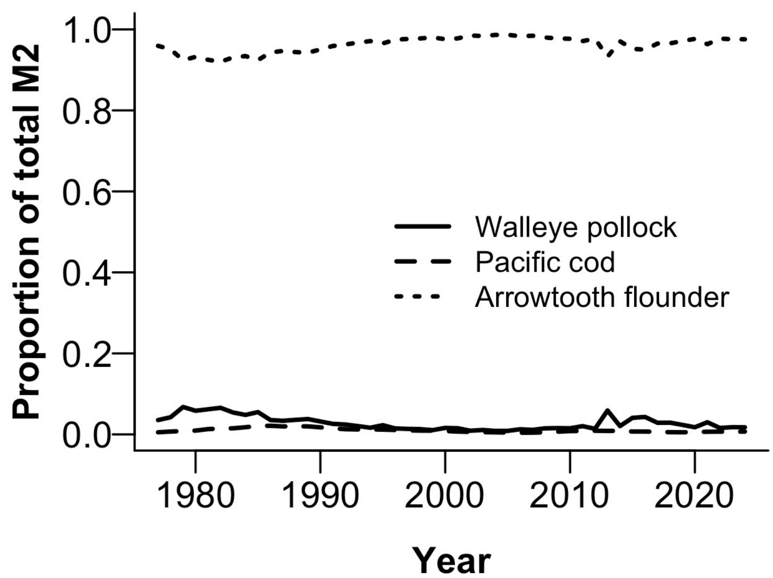

Figure 65: Proportion of total predation mortality for age-1 pollock from pollock (solid), Pacific cod (dashed), and arrowtooth flounder (dotted) predators across years. Updated from Adams et al. (2022).

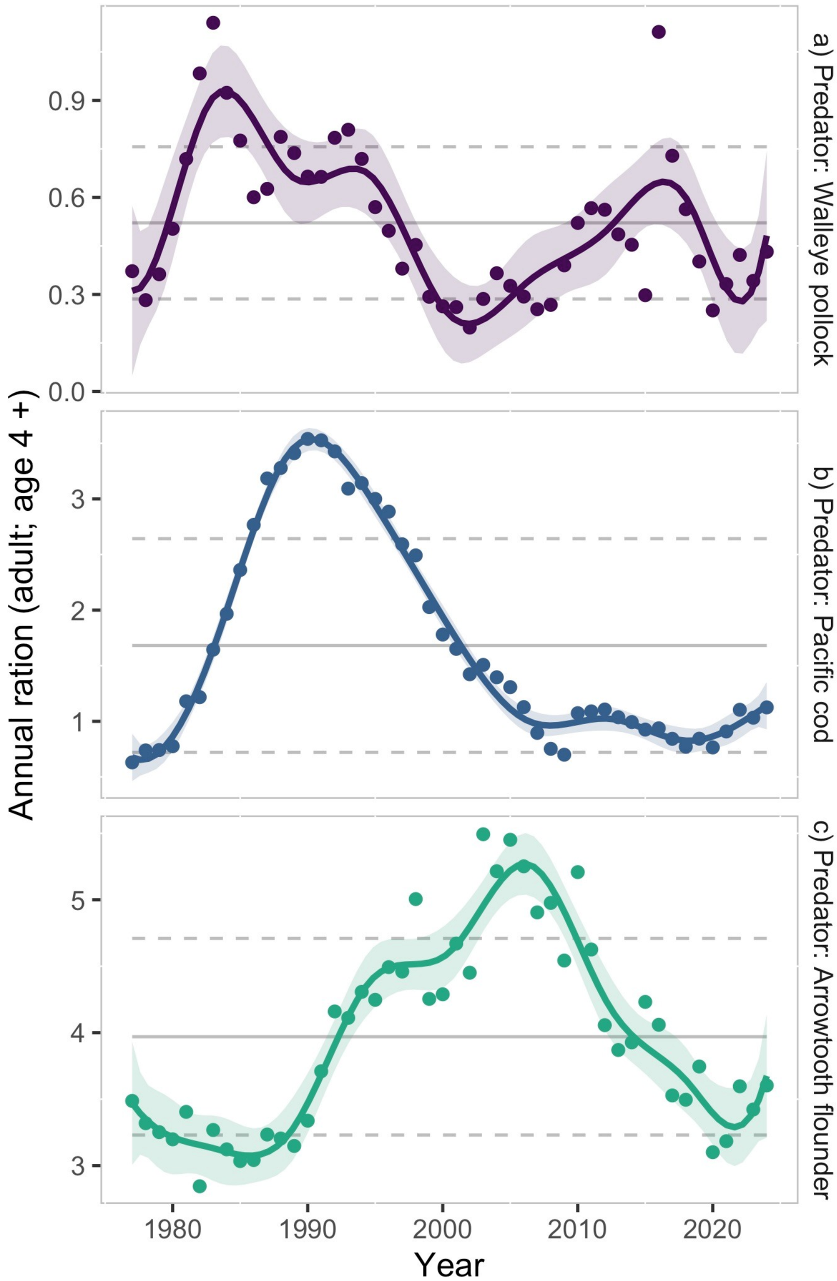

Figure 66: Multispecies estimates of annual ration (hundred thousand tons consumed per species per year) for adult (age 4 +) predators: pollock (a), Pacific cod (b), and arrowtooth flounder (c). Gray lines indicate 1979 – 2024 mean estimates and 1 standard deviation for each species; solid line is a 10 y (symmetric) loess polynomial smoother indicating trends in ration over time.

Trends in Groundfish Biomass

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Last updated: October 2024

Description of indicator: Examining trends in survey-estimated biomass multiple groundfish species in the Gulf of Alaska can identify broadscale changes in the marine ecosystem. Common trends across species within similar functional groups can indicate shared responses to environmental conditions, including changes in physical habitat suitability (e.g., temperature, dissolved oxygen) and prey availability. In addition, identifying trends in biomass within the groundfish community can inform food web dynamics with respect to predation pressure and energy flow.

The data are collected from the NOAA AFSC Gulf of Alaska bottom trawl survey (Siple et al., 2024). The survey has been conducted using the same randomized stratified design and season (late May to early August) every three years from 1990 – 1999 and then alternating years (odd years) to 2023. Annual design-based estimates of population biomass estimates are provided by the AFSC groundfish assessment program[35] accessed from the AKFIN database[36]. Species selected for this contribution are listed below, and include those supporting federally managed commercial groundfish fisheries, in addition to Pacific halibut (*Hippoglossus stenolepis*). In some years species-specific estimates were not available due to low confidence in ability to consistently identify that species during earlier years.

1. Flatfish: arrowtooth flounder (*Atheresthes stomias*), Pacific halibut (*Hippoglossus stenolepis*), northern rock sole (*Lepidopsetta polyxystra*), southern rock sole (*Lepidopsetta bilineata*), Dover sole (*Microstomus pacificus*), rex sole (*Glyptocephalus zachirus*), and flathead sole (*Hippoglossoides elassodon*).
2. Rockfish: Pacific ocean perch (*Sebastes alutus*), northern rockfish (*Sebastes polyspinis*), dark rockfish (*Sebastes ciliates*), dusky rockfish (*Sebastes variabilis*), rougheye rockfish (*Sebastes aleutianus*), blackspotted rockfish (*Sebastes melanostictus*), shortraker rockfish (*Sebastes borealis*), shortspine rockfish (*Sebastolobus alascanus*), and yelloweye rockfish (*Sebastes ruberrimus*).
3. Roundfish: walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*).
4. Skates: big skate (*Beringraja binoculata*) and longnose skate (*Beringraja rhina*).

Status and trends: The groundfish species with the highest biomass (mt) in the Gulf of Alaska bottom trawl survey in 2023 were (in descending order) Pacific ocean perch, arrowtooth flounder, walleye pollock,

[35]Design-Based Production Estimates generated by the gapindex R package (NOAA Fisheries Alaska Fisheries Science Center, Groundfish Assessment Program, 2024)
[36]`https://github.com/MattCallahan-NOAA/gapproductssynopsis/tree/main/ESR`

Pacific halibut, Pacific cod, sablefish, and flathead sole (Figure 67). Arrowtooth flounder had been the most abundant species in the survey until Pacific ocean perch surpassed it in 2017. Of the flatfishes, the 2023 survey biomass of northern rock sole, Dover sole, and flathead sole continue a multi-year declining trend (Figure 69). Three of the four roundfish species' biomass increased from 2021 to 2023, while sablefish biomass available to the survey declined after a multi-year increasing trend. Pollock in particular had a large increase in abundance since the prior survey year. Skate species don't show major changes in biomass from 2021 to 2023. The surveyed biomass of rockfish species show a generally declining trend.

Factors influencing observed trends: The biomass estimates of groundfish species in the NOAA AFSC Gulf of Alaska bottom trawl survey reflect changes in population size but can be influenced by changes in catchability. Specifically, spatial availability to the survey may be changing due to changes in species distributions. The roundfish species show a mixture of responses to the 2014 – 2016 marine heatwave, including a biomass decline (P. cod, walleye pollock) and biomass increase (sablefish, adults of which generally reside deeper than surveyed habitat). The biomass of some species respond more rapidly to large recruitment classes or environmental changes (e.g., walleye pollock) while other more long-lived species are typically less variable on the short-term (e.g., rockfish). Some under-exploited species experiencing long-term declining biomass (e.g., Dover sole) indicate potential environmental drivers causing changes in population size or distribution (and thus availability to the survey). The recent decline in sablefish could be due to the large year classes after 2016 maturing and moving off the shelf (and survey area) to deeper slope habitat. The short-term variable survey biomass of rockfish (long-lived species) may be due to changes in catchability or distribution. Some of these species, such as Dover sole, have low fishing mortality and changes in survey biomass would be more driven by environmental conditions and population dynamics.

Implications: The decrease in arrowtooth flounder and increase in Pacific ocean perch, as two of the more abundant species in the bottom trawl catch, can indicate ecological implications for the GOA marine food web. Arrowtooth flounder are piscivorous and predominantly prey on juvenile walleye pollock, other fishes, euphausiids and shrimps. Pacific ocean perch are planktivorous, predominantly feeding on copepods and euphausiids. Common trends across species with similar functional groups can indicate responses to environmental conditions including physical conditions (temperature, dissolved oxygen) and prey availability. The declining trend in certain flatfish species could be examined for changes in environment, prey, or other environmental factors. Monitoring groundfish biomass from a multi-species perspective can inform management level decisions on environmental-driven trends in the marine ecosystem.

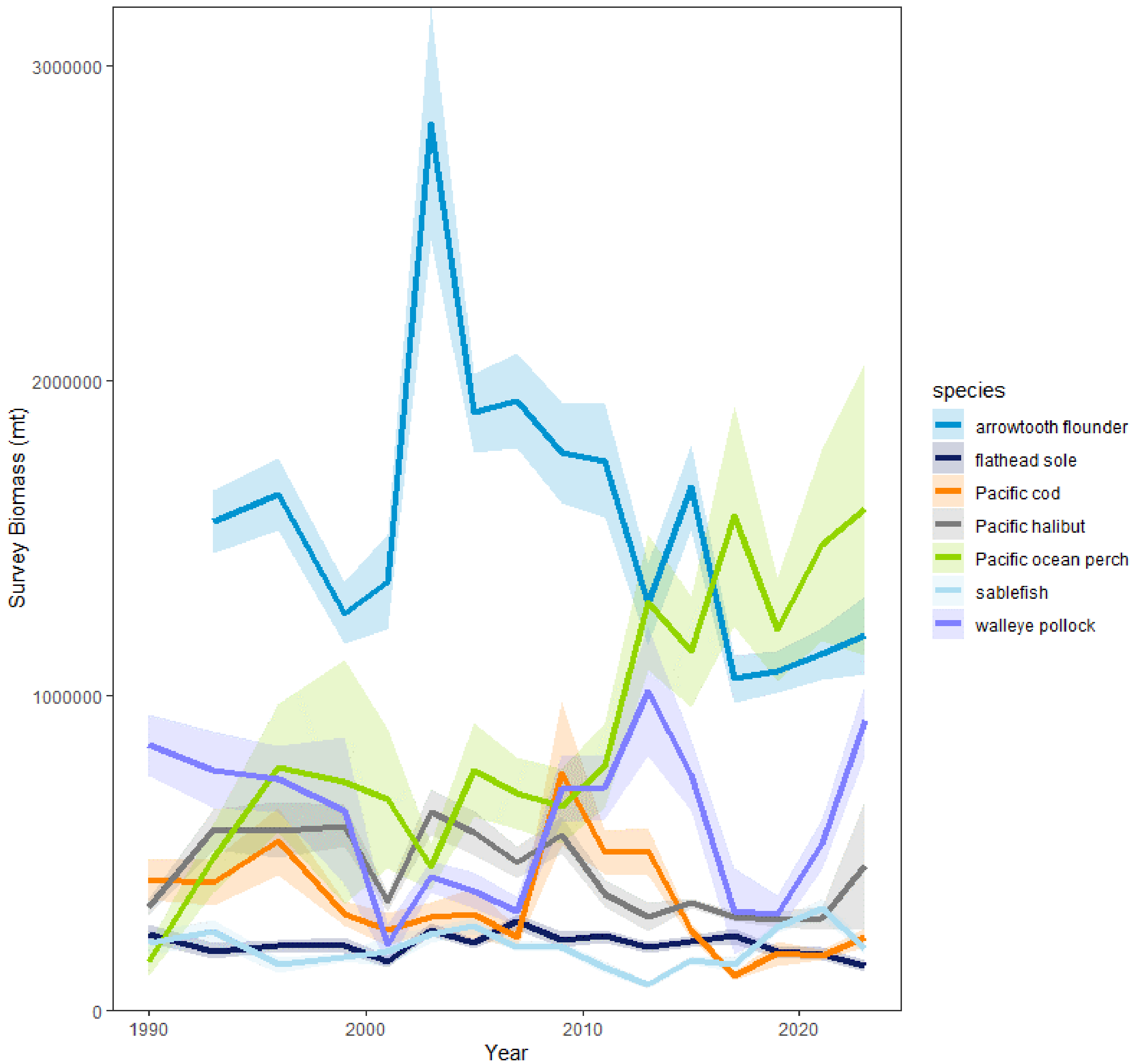

Figure 67: Design-based estimates of survey biomass (mt) of groundfish species with the highest biomass in the Gulf of Alaska bottom trawl survey in 2023. Shaded area representes ± 1 standard deviation (not shown for groups > 1 stocks). The NOAA AFSC bottom trawl survey is conducted from May-August every three years from 1990 – 1999 and every 2 years 2001 – 2023

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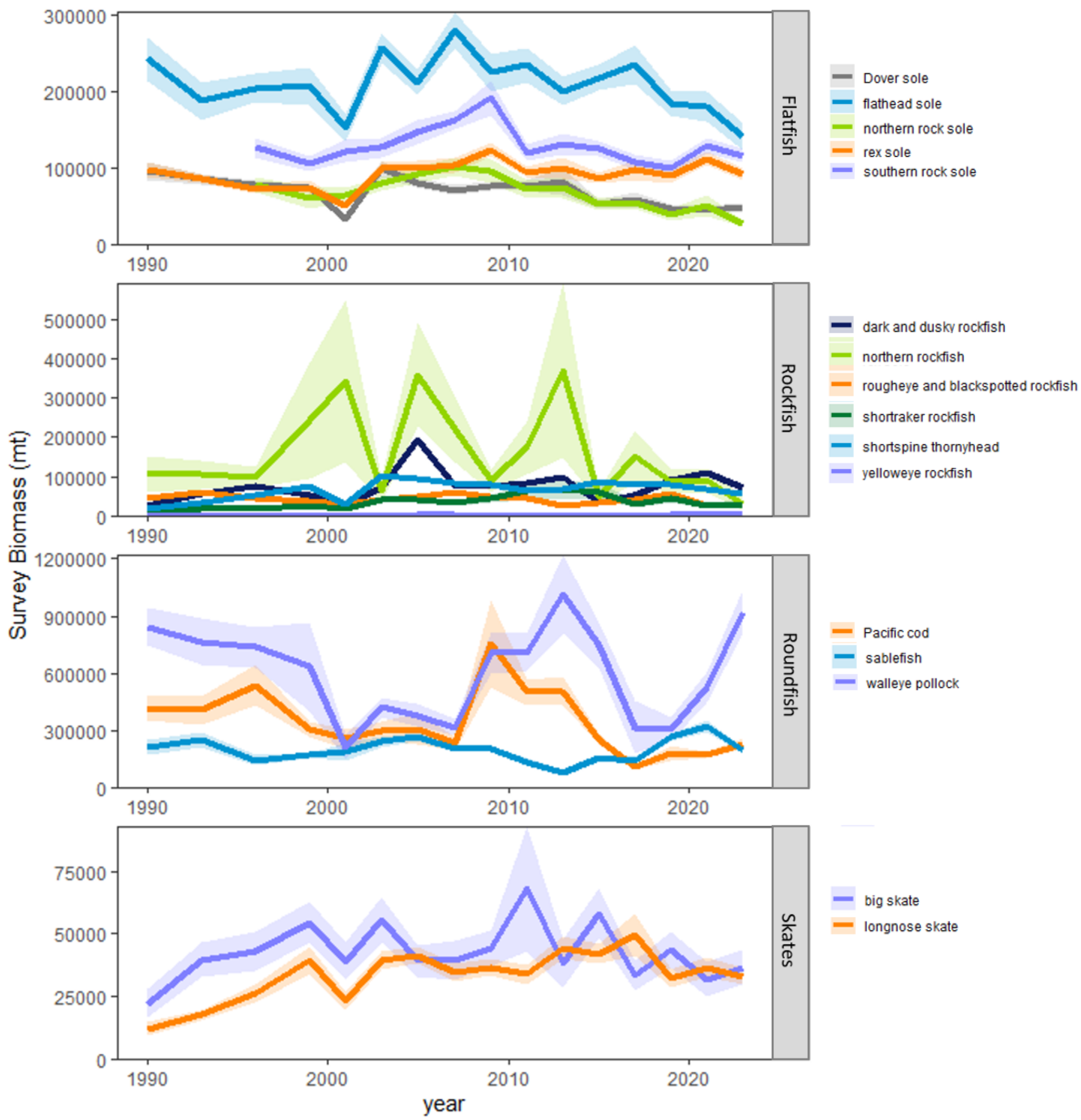

Figure 68: Design-based estimates of survey biomass (mt) of groundfish species grouped by flatfish (excluding arrowtooth flounder), roundfish, rockfish (excluding Pacific ocean perch), and skates. Shaded area representes ± 1 standard deviation (not shown for groups > 1 stocks). The NOAA AFSC bottom trawl survey was conducted every three years from 1990 – 1999 and every 2 years 2001 – 2023

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Environmental Conditions Experienced by Groundfish

Contributed by Parkes Kendrick[1], James T. Thorson[2], Bridget Ferriss[2]
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Description of indicator: Ocean conditions can influence fish survival, distribution, growth, and productivity of groundfish. Some fish are able to change depth or horizontal distribution in response to changing conditions, while others are more restricted in their ability to move (Pinsky2020). Identifying ocean temperatures experienced by fish species can indicate potential impacts on their population.

The fish biomass, fish location, and bottom temperature data are collected from the biannual NOAA AFSC bottom trawl survey in the Gulf of Alaska (Pinsky et al., 2020). The survey has been conducted using the same randomized stratified design, May-August, from 1990-1999 (every three years) and then alternating years (odd years) through 2023. The haul-specific bottom temperature, location, and species' biomass are analyzed using the spatio-temporal modelling package tinyVAST (Thorson et al., 2024). We specifically fit a spatial index standardization model (sensu Thorson, 2019 using a log-linked Tweedie distribution, an annual varying intercept, a spatial Gaussian Markov random field (GMRF), and a spatio-temporal GMRF independently for each year. We then calculate the average temperature utilization by calculating the area-expanded average temperature, weighted at each location by the predicted density for a given species. This metric is analogous to the center-of-gravity used previously as a spatial indicator for distribution shifts, except it calculates distribution with respect to a covariate that varies over time (i.e., temperature instead of geographic coordinates). It therefore integrates both changes in temperature across the landscape, as well as species distribution shifts among years.

Species selected for this contribution are listed below and include those supporting federally managed commercial groundfish fisheries, those that are relatively well-sampled by the survey.

1. Flatfish: Alaska plaice (*Pleuronectes quadrituberculatus*), arrowtoowth flounder (*Atheresthes stomias*), Pacific halibut (*Hippoglossus stenolepis*), northern rock sole (*Lepidopsetta polyxystra*), southern rock sole (*Lepidopsetta bilineata*), Dover sole (*Microstomus pacificus*), rex sole (*Glyptocephalus zachirus*), and flathead sole (*Hippoglossoides elassodon*), and Pacific halibut (*Hippoglossus stenolepis*).
2. Pelagic rockfish: Pacific ocean perch (*Sebastes alutus*) and dusky rockfish (*Sebastes variabilis*),
3. Shelf rockfish: northern rockfish (*Sebastes polyspinis*), yelloweye rockfish (*Sebastes ruberrimus*), and sharpchin rockfish (*Sebastes zacentrus*)
4. Slope rockfish: blackspotted rockfish (*Sebastes melanostictus*), shortspine rockfish (*Sebastolobus alascanus*) and rougheye rockfish (*Sebastes aleutianus*), and shortraker rockfish (*Sebastes borealis*)

5. Roundfish: walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), and sablefish (*Anoplopoma fimbria*)

6. Skates: big skate (*Beringraja binoculata*) and longnose skate (*Beringraja rhina*).

Status and trends: All species remained within known temperature thresholds for summer adult habitat for 2023 (Figure 69). Within the survey period, the average experienced temperature ranged from ∼4.3 °C (blackspotted rockfish) to ∼7 °C (big skate). Flatfish experience average temperatures between ∼5.5 °C and ∼6.4 °C in 2023, cooler than 2021 across all flatfish species. The largest decline in temperature within this group was experienced by northern rock sole and AK plaice (>0.5 °C). These species are approaching average temperatures last experienced in 2013.

Skates experienced average temperatures that cooled by ∼1.5 °C (big skate) and ∼0.5 °C (AK skate) from 2021 to 2023. The key species group experienced lower average temperatures in 2023 relative to 2021, continuing a cooling trend in temperatures that are approaching values previously measured in 2013. Temperatures experienced by slope rockfish show little variability and 2023 values remained similar to those of 2021, following a decrease from 2019 (with the exception of blackspotted rockfish). Pelagic rockfish experienced temperatures similar to 2021, and are returning close to 2013 values. Shelf rockfish experienced temperatures similar to 2021.

Factors influencing observed trends: Ocean temperatures at depth on the Gulf of Alaska shelf can be influenced by mixing from the surface (particularly in the stormier and less stratified winter), coastal downwelling that transfers warmer surface waters to depth, and deep water intrusion that brings cooler water from the continental slope onto the shelf bottom. El Niño events (e.g., winters of 2023/2024, 2016) are associated with warmer surface waters while La Niña events (e.g., 2020 – 2023) are associated with cooler surface waters. The 2014 – 2016 marine heatwave persisted long enough that the warm surface water mixed to the shelf bottom. Over the longer-term, the Gulf of Alaska ocean temperatures are warming (see Thoman, p.43, and Danielson, p.72, in this Report). Deeper dwelling species, such as slope rockfish and Dover sole, experience more stable ocean temperatures, but could have less ability to move away from stressful conditions due to being close to other environmental thresholds, such as low dissolved oxygen.

Implications: Knowing actual temperatures experienced by commercially important fish species can identify time periods in which fish exceed optimal thermal windows for survival. It can also give insight into implications for fish growth in the summer months. Knowing temperatures that fish actually experience provides insight into their ability to adapt to challenging conditions, such as moving to cooler areas in warmer years.

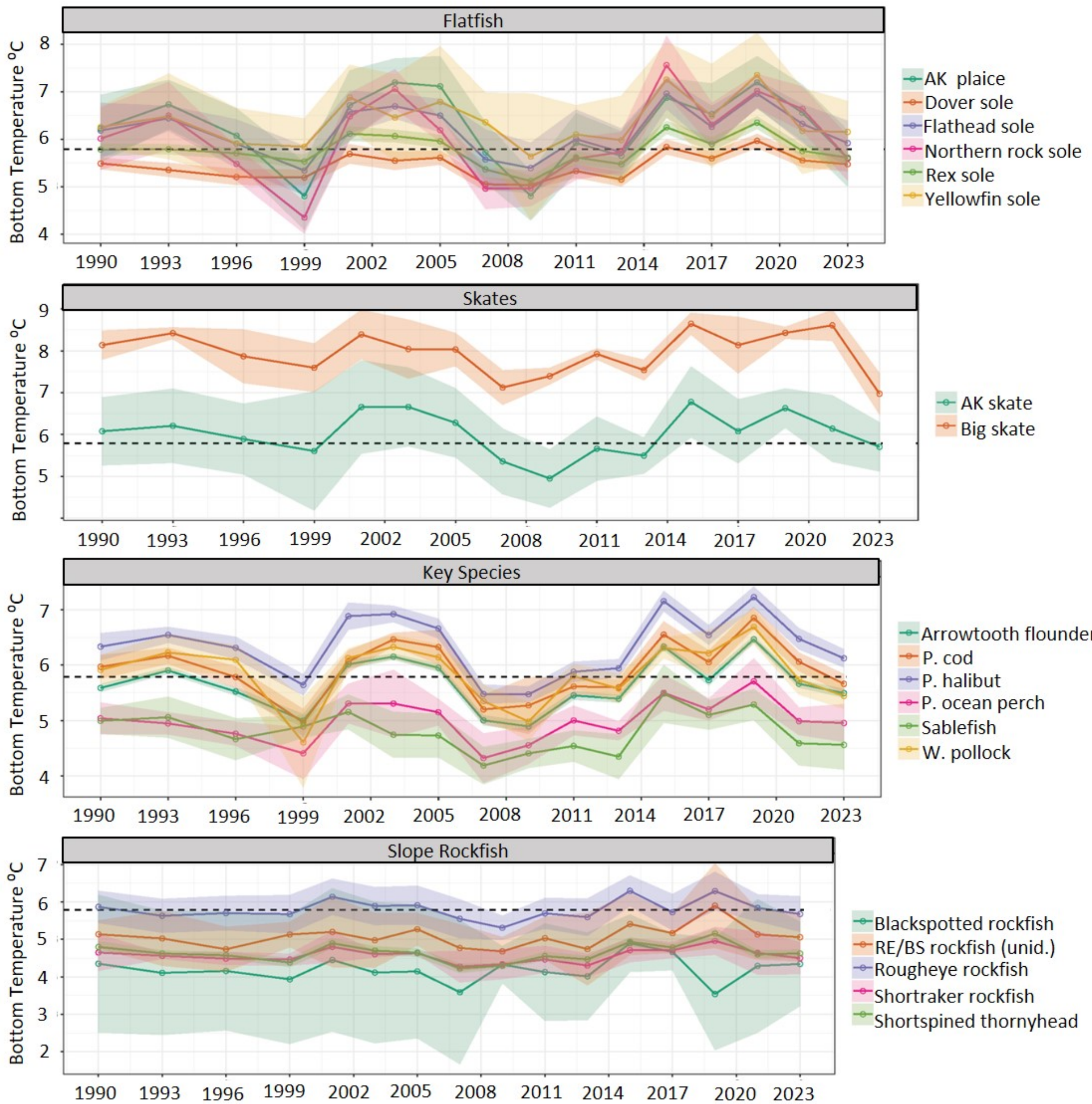

Figure 69: Time series of the mean temperatures experienced by groundfish species in the Gulf of Alaska. Figures are produced by combining AFSC bottom trawl survey catch data, analyzed using tinyVAST, with bottom temperature obtained from the NOAA Fisheries bottom trawl survey.

Summer Food Habits of Major Groundfish in the Gulf of Alaska

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Last updated: October 2024

Description of indicator: Stomachs of walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), arrowtooth flounder (Atheresthes stomias), Pacific halibut (*Hippoglossus stenolepis*), sablefish (*Anoplopoma fimbria*), and Pacific Ocean perch or POP (*Sebastes alutus*) have been collected on the Alaska Fisheries Science Center's western Gulf of Alaska (WGOA) shelf survey between 1990-2023, although not all species were collected in all years. These species combined represent over half of the total western GOA ecosystem consumption by upper trophic level species (species with trophic levels above plankton, benthic invertebrates, and forage fish; see Table 2).

Samples were preserved in formalin and prey contents identified to the lowest resolvable taxonomic category and weighed - to estimate diet proportions for the population, samples are stratified by length and survey stratum and weighted by the survey biomass for each length class and stratum and estimated ration for each size class. Ration for each predator was estimated using Von Bertalanffy growth functions fit to western GOA age-length data for each predator. Ration at length was fixed and did not vary by year, temperature or stomach content weights; further, these ration estimates do not account for differences between predator and prey caloric densities. While these assumptions may obscure some consumption variability, these simplified common assumptions allow for summation of consumption across species. Since the bottom trawl survey biomass is used to scale consumption, these results represent primarily adult (>25cm fork length) predators. Ration and expansion to juvenile size classes may be refined in future iterations of this contribution. Collection, analysis, and stratification methods are described in Livingston et al. (2017) while ration estimation is described in Holsman and Aydin (2015). Prey groups listed in Figures 71, 72, 73 are primarily comprised of the following key species:

- *Western GOA Apex predators*: The biomass of apex predators in the western GOA is dominated by arrowtooth flounder, Pacific cod, P. halibut, sablefish, and to a lesser extent skates.
- *Western GOA Pelagic foragers*: The biomass of pelagic foragers in the western GOA includes P. ocean perch, walleye pollock, and forage fish (e.g., P. herring, capelin, and sandlance.
- *Western GOA Benthic foragers*: The biomass of benthic foragers in the western GOA includes small-mouthed flatfish.
- *Western GOA Motile epifauna*: The biomass of motile epifauna is dominated by crabs, brittle stars, other echinoderms, and octopus.
- *Western GOA Infauna*: The infauna guild includes polychaetes and bivalves.
- *Western GOA Mesozooplankton*: The mesozooplankton group is dominated by euphausiids (*Thysanoessa* spp.), and also includes larval fish, gelatinous plankton, and pteropods.

- *Western GOA Shrimp*: The shrimp guild includes pandalid and non-pandalid shrimp.
- *Western GOA Copepods*: The copepod group includes small copepods (e.g., *Acartia* spp., *Pseudocalanus* spp. and *Oithona* spp.) and large copepods (e.g., *Calanus marshallae* and *Neocalanus* spp.).

Table 2: Proportion of total ecosystem consumption by upper trophic levels (trophic levels above plankton and forage fish in the western GOA) based on 1990 – 1994 survey data, as estimated by a western GOA Ecopath model (Gaichas et al., 2015). "Measured" groundfish are the six species included in this contribution.

Group	Percent of consumption
Measured Groundfish	62%
Other Groundfish	28%
Mamals	8%
Birds	2%

Status and trends: The community composition of the six tracked groundfish species has varied significantly over time leading to variation in consumption-by-species (Figure 70 bottom), with arrowtooth flounder extremely high from 2001 – 2009, and an increase in consumption by zooplanktivores (pollock and POP) from 2009 – 2023. An increase in sablefish consumption in the ecosystem is evident in 2019 and 2021, though their contribution to consumption declined in 2023. Despite this variation, the total consumption by these predators (Figure 70 top) has remained relatively stable over time.

The variation in diets across years and between predators (Figures 71 and 72) shows that each predator has a relatively consistent diet between years, with the greatest variation being between different predators. Some interannual variation is evident; for example, during 2017 mesozooplankton was low in diets across the board, being replaced by copepods in the diets of walleye pollock and POP.

The total consumption by prey guild (Figure 73) shows the mix of zooplanktivores and apex predators in these groundfish, with mesozooplankton and pelagic foragers (forage fish) being the largest and most consistent diet items in the ecosystem over time. From 2009 – 2023, total mesozooplankton consumption increases, with the exception of 2017 that had the lowest mesozooplankton composition on record.

Factors influencing observed trends: Overall, the stability in total consumption summed across these predators maintained stable while the community composition of these predators shifted (Figure 70); this stability in the face of underlying species shifts may indicate an overall carrying capacity or feeding limitation throughout the ecosystem - this stability was evident even as the whole ecosystem became more zooplanktivorous as arrowtooth flounder declined while pollock and POP increased.

Sablefish showed an increased contribution towards the total predation in 2019 – 2021 as an extremely strong year class of sablefish moved through the system (Figure 70)- the decrease in 2023 may be due to this year class maturing and moving to deeper waters outside the survey boundaries.

The diet variation in 2017, in particular the decreased contribution of mesozooplankton consumed by these predators (Figures 71, 72, 73), is likely the result of the marine heat wave that occurred during that year.

Implications: Changes in diet composition of fish may be an indicator of fish health condition, growth, or later recruitment, and may also signal potential changes in productivity that would come with longer-

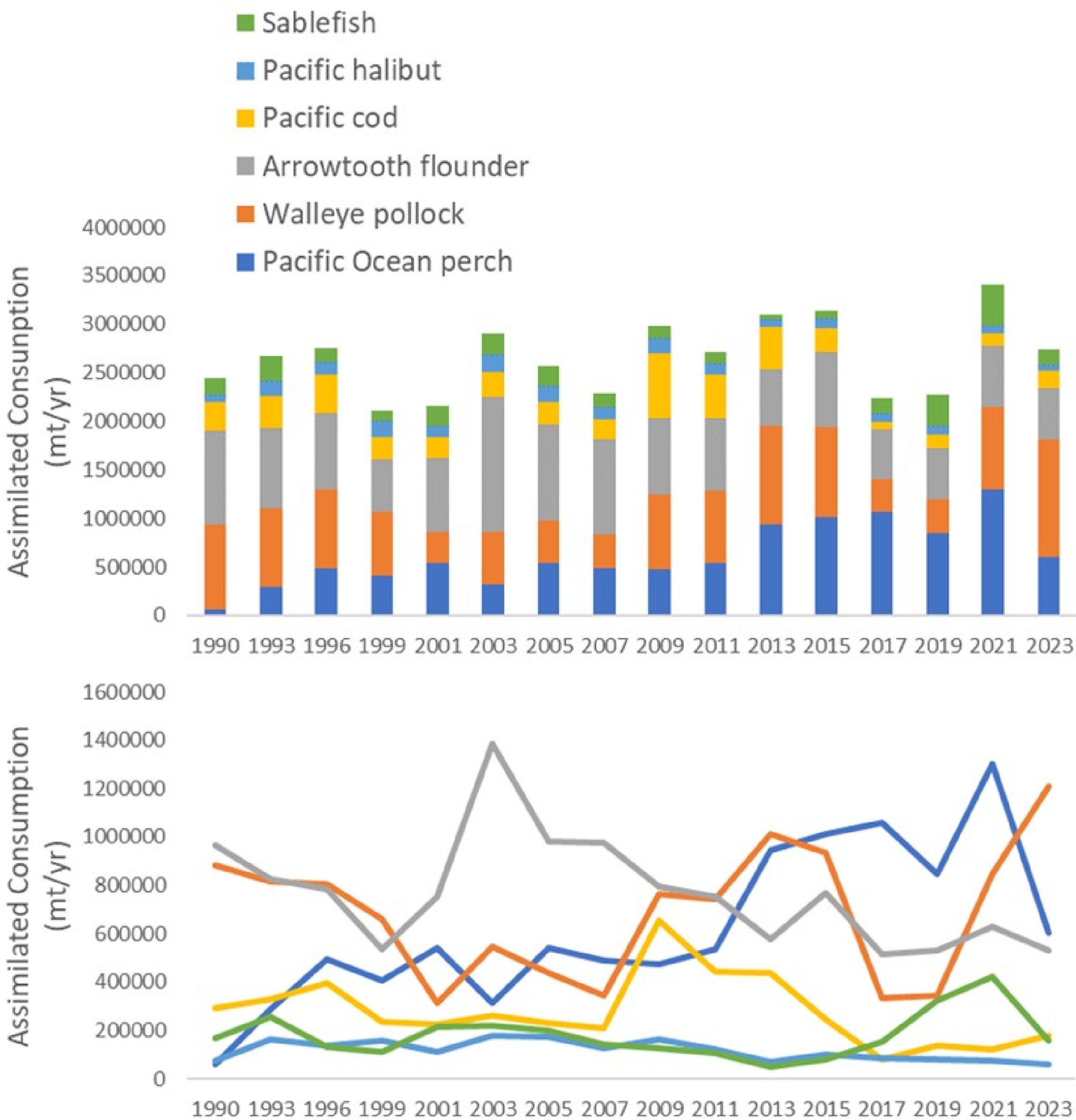

Figure 70: Total assimilated consumption by six major groundfish predators in the western Gulf of Alaska, as calculated from bottom-trawl survey biomass-at-length and ration as estimated from fits of non year-specific western GOA age-length data to Von Bertalanffy growth curves. The same data is displayed on top and bottom graphs.

term climate change. Changes in prey flow when summed across predators and guilds may result from large-scale perturbations such as the 2017 heat wave conditions.

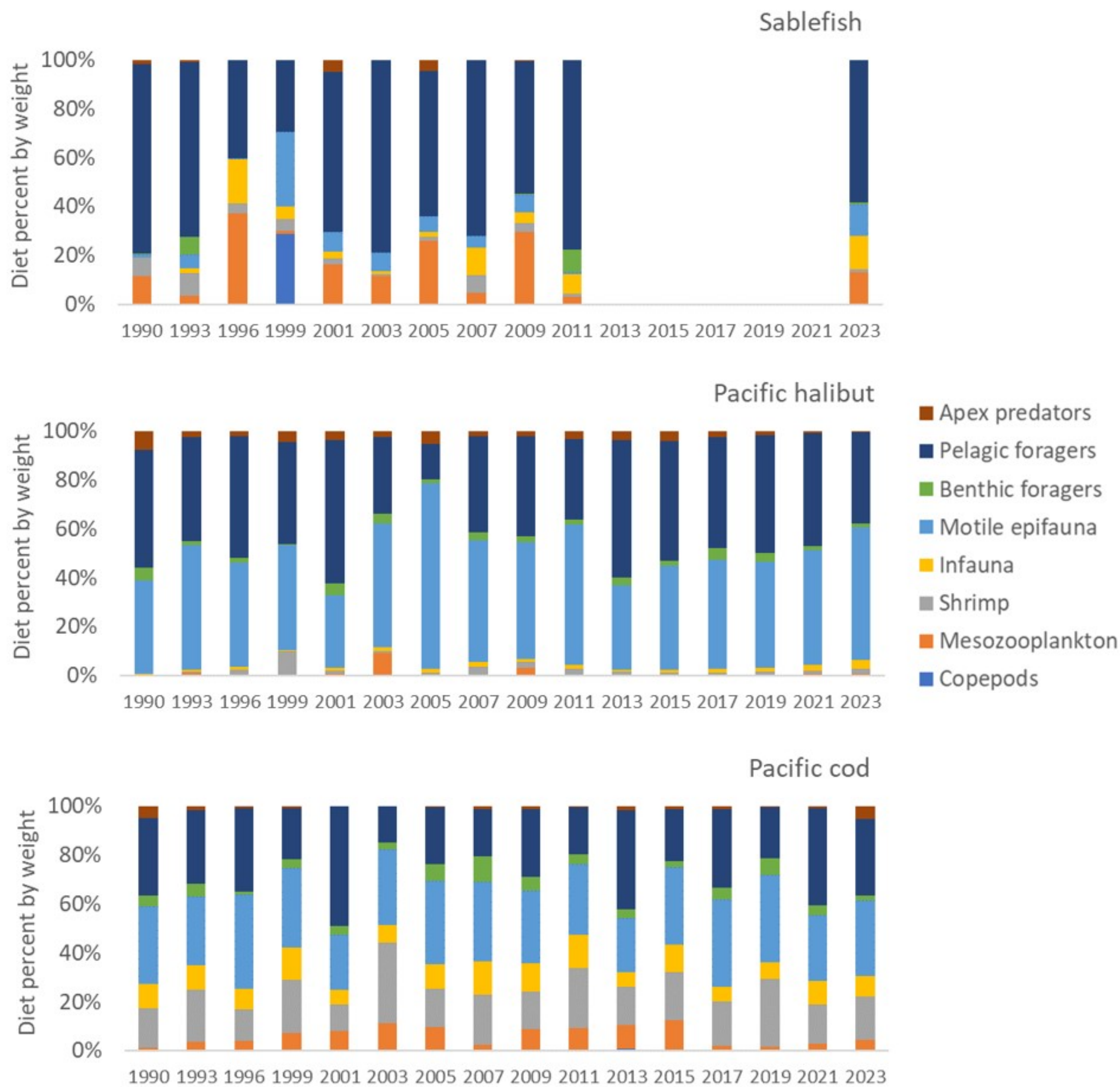

Figure 71: Summer diets (% weight in stomach contents) of sablefish (*Anoplopoma fimbria*), Pacific halibut (*Hippoglossus stenolepis*), and Pacific cod (*Gadus macrocephalus*) caught in AFSC bottom-trawl surveys of the western GOA, by foraging guild of prey type.

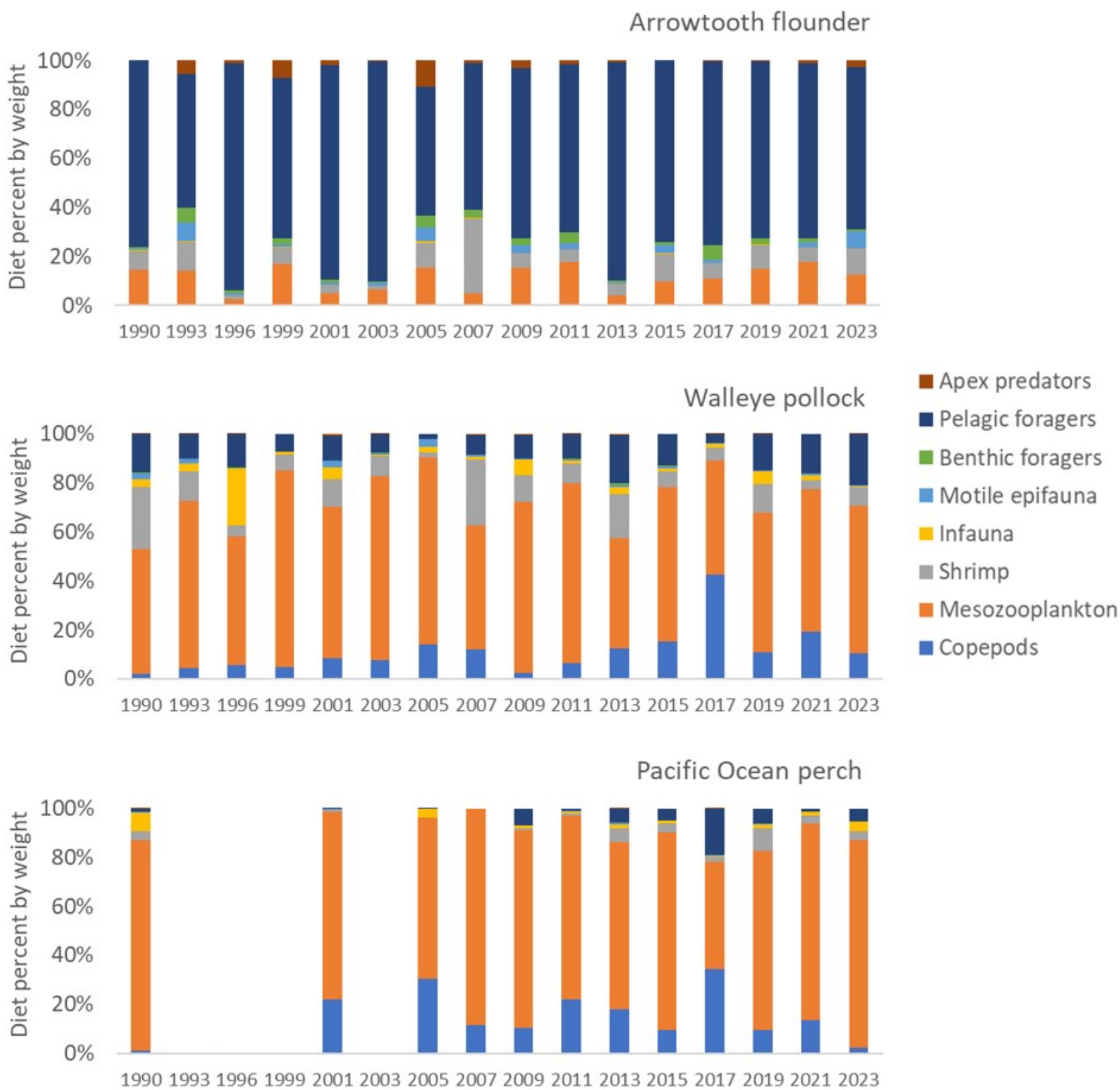

Figure 72: Summer diets (% weight in stomach contents) of arrowtooth flounder (*Atheresthes stomias*), walleye pollock (*Gadus chalcogrammus*), and Pacific Ocean perch (*Sebastes alutus*), caught in AFSC bottom-trawl surveys of the western GOA, by foraging guild of prey type.

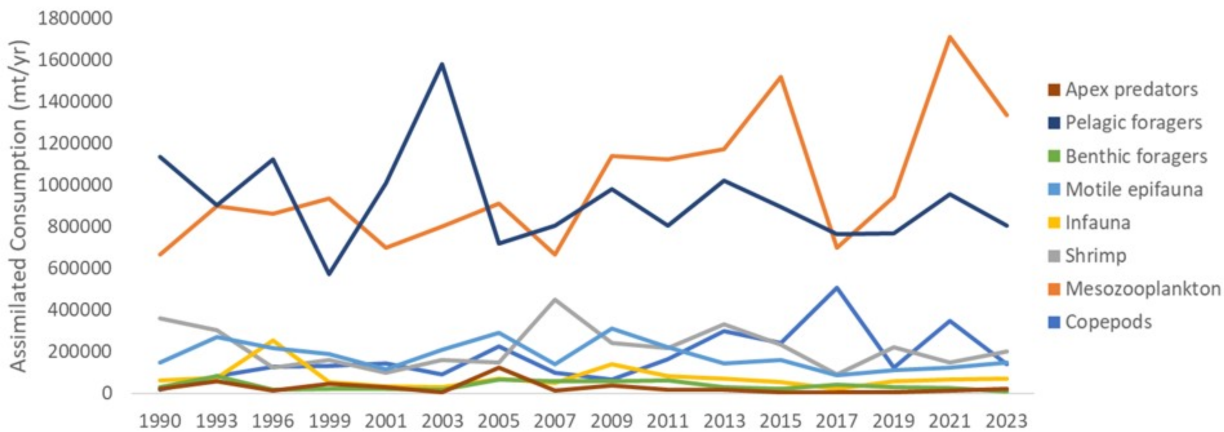

Figure 73: Total consumption, by prey guild, of the six groundfish predators tracked in this contribution. For years in which diets were not collected for a particular predator, the all-years average diet composition for that predator was used instead.

Benthic Communities and Non-target Fish Species

Miscellaneous Species — NOAA Bottom Trawl Survey

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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[37] for past reports.

Seabirds

Seabird Synthesis

Contributed by Mayumi Arimitsu[1], Daniel Cushing[2], Brie Drummond[3], Scott Hatch[4], Robert Kaler[5], Elizabeth Labunski[5], Jackie Lindsey[6], John F. Piatt[1], Heather Renner[3], and Shannon Whelan[4]
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Last updated: October 2024

Summary Statement: Indicators of seabird reproduction, mortality events, and distribution indicated approximately average to above average environmental conditions in the Gulf of Alaska, in 2024, with signs of increasing ecosystem productivity from 2023 (Figure 74). There were no large-scale mortality events recorded via monthly beach surveys in the Western Gulf of Alaska. Reproductive success for fish-eating seabirds across the GOA (an indicator of sufficient forage fish as prey) generally increased from 2023 and was above average, with the exception of pelagic cormorants (Middleton Isl.), rhinoceros

[37]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

auklets (Middleton Isl.), and black-legged kittiwakes (Chowiet Isl.). Zooplankton-eating seabirds had close to one standard deviation above-average reproductive success across the GOA in 2024, reflecting higher availability of zooplankton biomass in the spring. These metrics indicate adequate to good prey resources to meet reproductive needs and a more productive pelagic system in 2024. These observations align with higher zooplankton biomass observed on the Seward Line survey (Hopcroft in this Report,83), relatively elevated herring populations (Hebert in this report, p.105, Morella in this report, p.188), increasing capelin populations (McGowan in this report, p.101) and seabird diet analysis (Arimitsu in this Report, p.96). Low pink salmon returns to the GOA in 2024 may have released competition pressure on zooplankton biomass, to the benefit of planktivorous seabirds (Whitehouse in this report, p.113, Vulstek in this report, p.124). The distribution of seabirds observed on the Seward Line spring survey (central GOA cross shelf transect) returned to approximate 2014 levels of use across the inner and middle shelf, with reduced outer slope use and the highest use of oceanic/slope habitat in the time series. The dispersed nature of the surveyed distribution (Seward Line) and foraging trips (Middleton Isl.) is an indicator of a more available prey base, in contrast to a seabird distribution compressed to the inner domain during lower productive marine heatwave years (2014 – 2016). The prediction of La Niña-related cooler sea surface conditions in the winter of 2025 favors increased seabird productivity. Implications for groundfish include sufficient to good zooplankton (e.g., prey for juvenile groundfish and adult Pacific ocean perch, walleye pollock, dusky rockfish) and forage fish (e.g., prey for sablefish, Pacific cod, arrowtooth flounder) prey resources to meet metabolic needs in 2024.

Description of indicator: Seabirds are sensitive indicators of changes in the productivity of marine ecosystems, and their populations can signal processes affecting the availability of prey for commercial fish stocks (Warzybok et al., 2018). From field data and observations collected by government, university and non-profit partners, we provide a summary of the best available data on seabird productivity in the Gulf of Alaska in 2024. We forefront environmental impacts on seabirds (e.g., heatwaves) and interpret changes in seabird mortality, attendance, and reproduction as a reflection of ecosystem productivity and prey availability (Koehn et al., 2021).

In this synthesis, we divide seabirds by preferred prey: fish or plankton, and foraging location: deep or surface because each group responds to a different part of the ocean ecosystem. To describe the status of seabird groups we use three types of information that represent different spatial and temporal scales of seabird responses:

1. **Breeding timing** can represent conditions prior to breeding and/or phenological variation in the environment. Birds arriving to breed at a later date can reflect poor winter and/or spring foraging conditions, or later peaks in ocean productivity. This metric is defined as the mean hatch date for data from USFWS and Middleton Isl.

2. **Reproductive success** which can represent food availability around the colony during the breeding season (summer), with a lower number of fledged chicks generally reflecting a decrease in the local abundance of high-quality prey. This metric is defined as the following:

   - The ratio of fledged chicks to eggs for murres, auklets, puffins, and storm-petrels (USFWS)
   - The ratio of nests producing fledglings to nests for black-legged kittiwakes (USFWS)
   - Chicks fledged per nest built for pelagic cormorants on Middleton Isl.
   - Late-stage chicks per egg laid for rhinoceros auklets on Middleton Isl.
   - Chicks fledged per pair for black-legged kittiwakes on Middleton Isl.

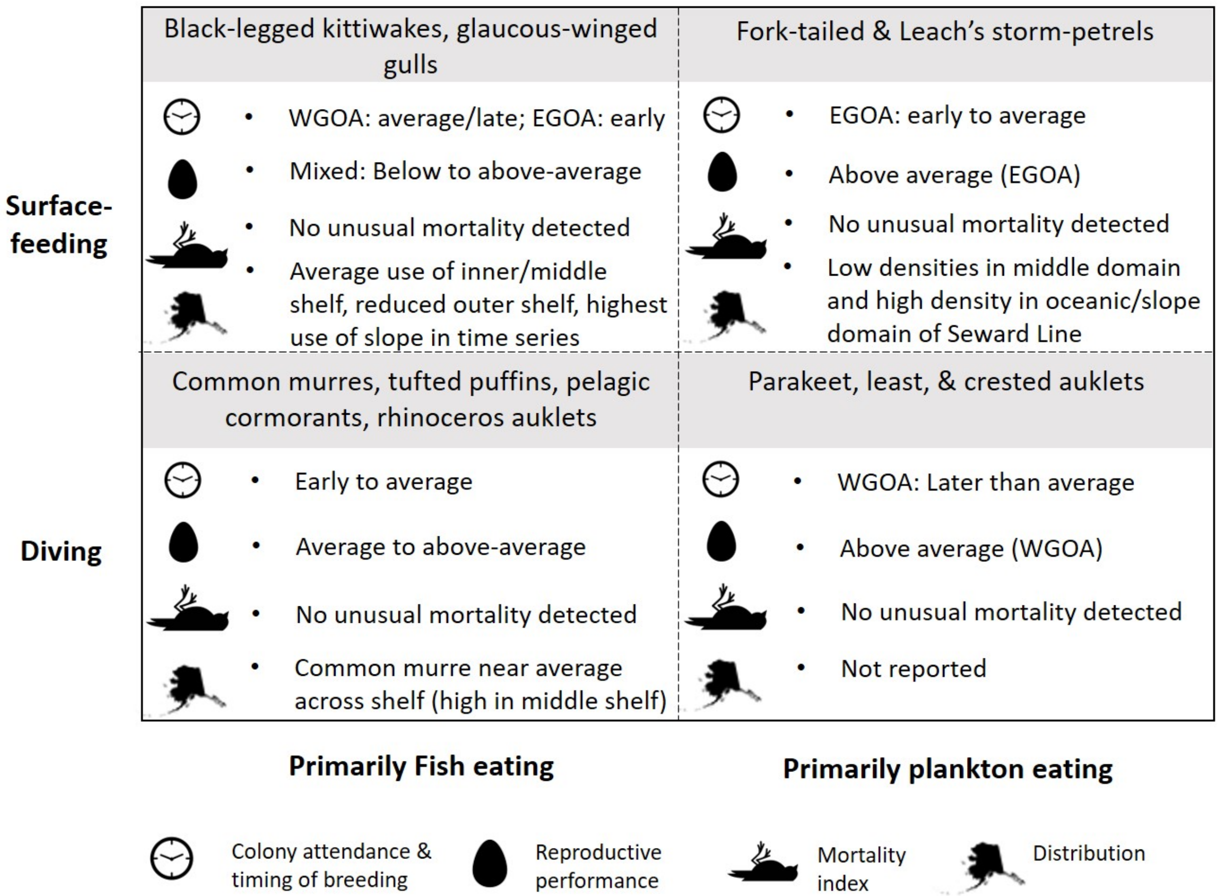

Figure 74: Summary of 2024 indicators for timing of breeding, reproductive performance, mass mortality events, and distribution of seabird feeding guilds (surface-feeding and diving, fish and plankton-eating) in the Gulf of Alaska.

3. **Mortality** which gives insight into environmental and ecosystem impacts beyond breeding colonies and the breeding season. Unusual mortality events in the Gulf of Alaska have been linked to declines in prey abundance and quality during recent marine heatwaves (Piatt et al., 2020).

4. **Distribution** which provides area-specific and season-specific index of use as a function of physical environmental drivers that affect the characteristics of the habitat and influence the distribution and availability of prey.

Status and trends:

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

Breeding timing: *Breeding timing was approximately average to late in the western GOA and early in the eastern GOA in 2024.* In the western GOA (Chowiet Isl. and Middleton Isl.), hatch dates for black-legged kittiwakes were approximately average across Chowiet (baseline, 1990 – 2023) and Middleton Isl. (baseline, 1996 – 2023) (Figure 75). Hatch dates for glaucous-winged gulls on Chowiet Isl. approached one standard deviation later than the time series average (baseline, 1990 – 2023), and later than 2023. On Middleton Isl. (central GOA near shelf edge), the timing of breeding (hatch date) by black-legged kittiwakes was slightly earlier than average (June 27; Figure 75). Birds part of the experimental, supplemental feeding program initiated laying their clutches 3 days earlier than naturally foraging birds in 2024, compared to 6 days earlier in 2023 (average = ±4 days, range = 0 to + 9), suggesting improved foraging conditions during the pre-lay period (April through mid-May) in 2024. Hatch timing for glaucous-winged gulls on St. Lazaria Isl. (eastern GOA) remained slightly earlier than average (1996 – 2023) (Figure 76).

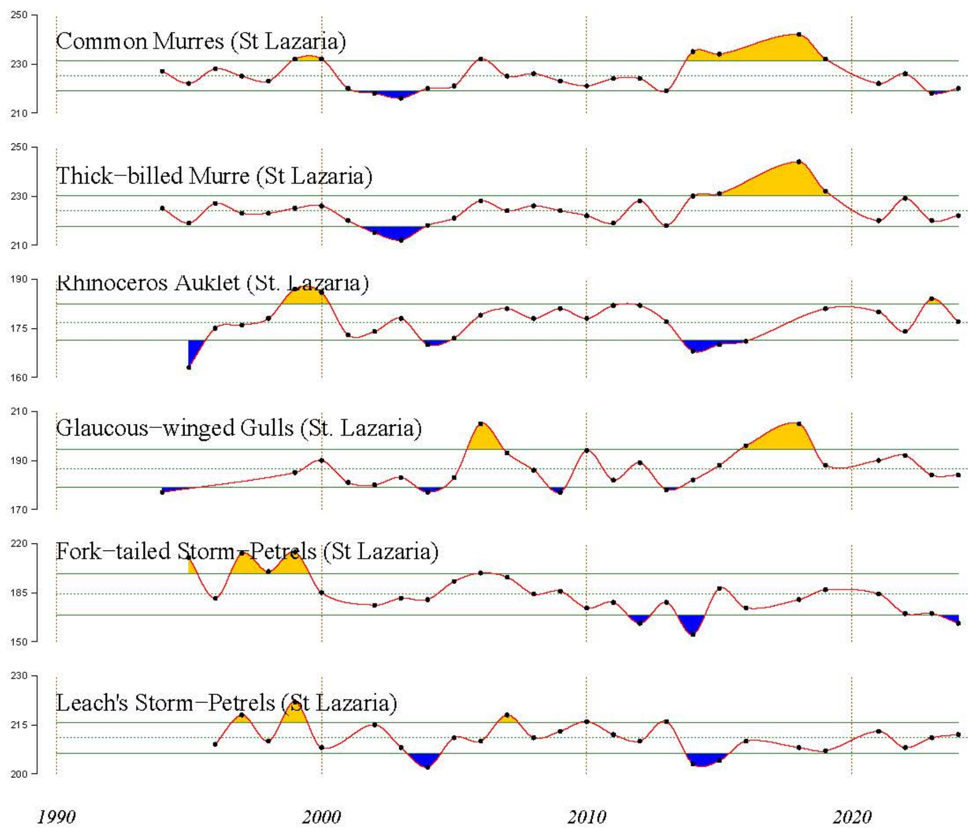

Figure 75: Reproductive timing of western Gulf of Alaska piscivorous (common murres, thick-billed murres, horned puffins, tufted puffins, black-legged kittiwakes) and planktivorous (parakeet auklets) seabird species on Chowiet Isl. and Middleton Isl. The dashed line is the long-term average and solid green lines are ± 1 standard deviation. Yellow/blue shading indicates values greater than 1 standard deviation above/below the mean. Data provided by the U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge and the Institute for Seabird Research and Conservation.

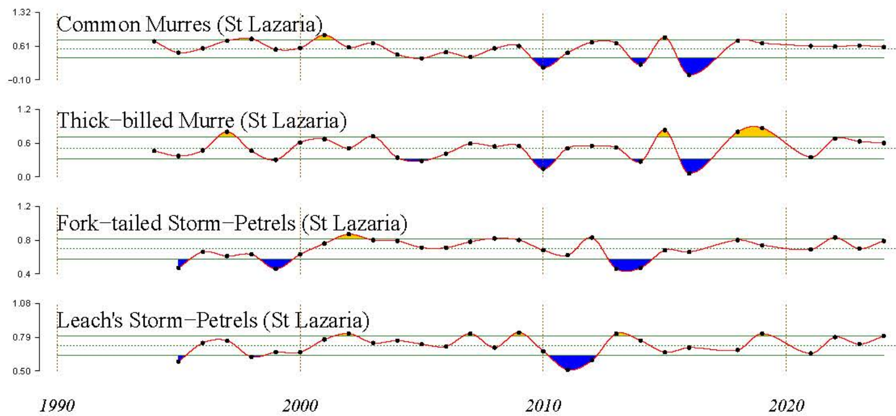

Figure 76: Reproductive timing of eastern Gulf of Alaska piscivorous (common murres, thick-billed murres, rhinoceros auklets, glaucous-winged gulls) and planktivorous (fork-tailed storm-petrels, Leach's storm-petrels) seabird species on St. Lazaria Isl. The dashed line is the long-term average and solid green lines are ± 1 standard deviation. Yellow/blue shading indicates values greater than 1 standard deviation above/below the mean. Data provided by the U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge.

Reproductive success: *Reproductive success ranged from below average (AK peninsula) to above average (central GOA) in 2024.* Black-legged kittiwakes (Chowiet Isl.) continue a multi-year trend of below-average (baseline 1990 – 2023) reproductive success in 2024, despite an increase from 2023 (Figure 77). Black-legged kittiwakes on Chowiet Isl. experienced reproductive failure in 2023 after a record high (baseline 1989 – 2023) in 2022. Naturally foraging kittiwakes on Middleton Isl. had slightly above-average productivity (Figure 77).

Mortality: *No large-scale mortality event of fish-eating surface-feeding birds was recorded in 2024* based on beach surveys in the Western Gulf of Alaska (Figures 79, 80). Like much of Alaska, beach surveys show a late summer, post-breeding mortality pattern; however the values observed in 2024 were similar to those observed in previous monitored years (2006 - present), suggestive of typical rates of mortality. Black-legged kittiwakes and glaucous-winged gulls were observed on Middleton Isl. exhibiting symptoms consistent with avian botulism. This disease was first documented on Middleton Isl. in a large 2021 die-off and has been observed every year since then, however fewer individuals were affected in 2024.

Distribution: *Use of middle shelf returned to pre 2014 – 2016 levels; increased use slope domain*. Historical GPS-tracking shows that kittiwakes tagged on Middleton Isl. tended to forage close to the island when capelin were abundant prior to the heatwave, then expanded their foraging range during and after the heatwave (Osborne et al., 2020). Relative to other post-heatwave years, foraging distances from Middleton Isl. were intermediate in 2024, and may indicate an increase in local food availability. GPS-tracking showed that kittiwakes used both neritic and oceanic foraging areas throughout the breeding season.

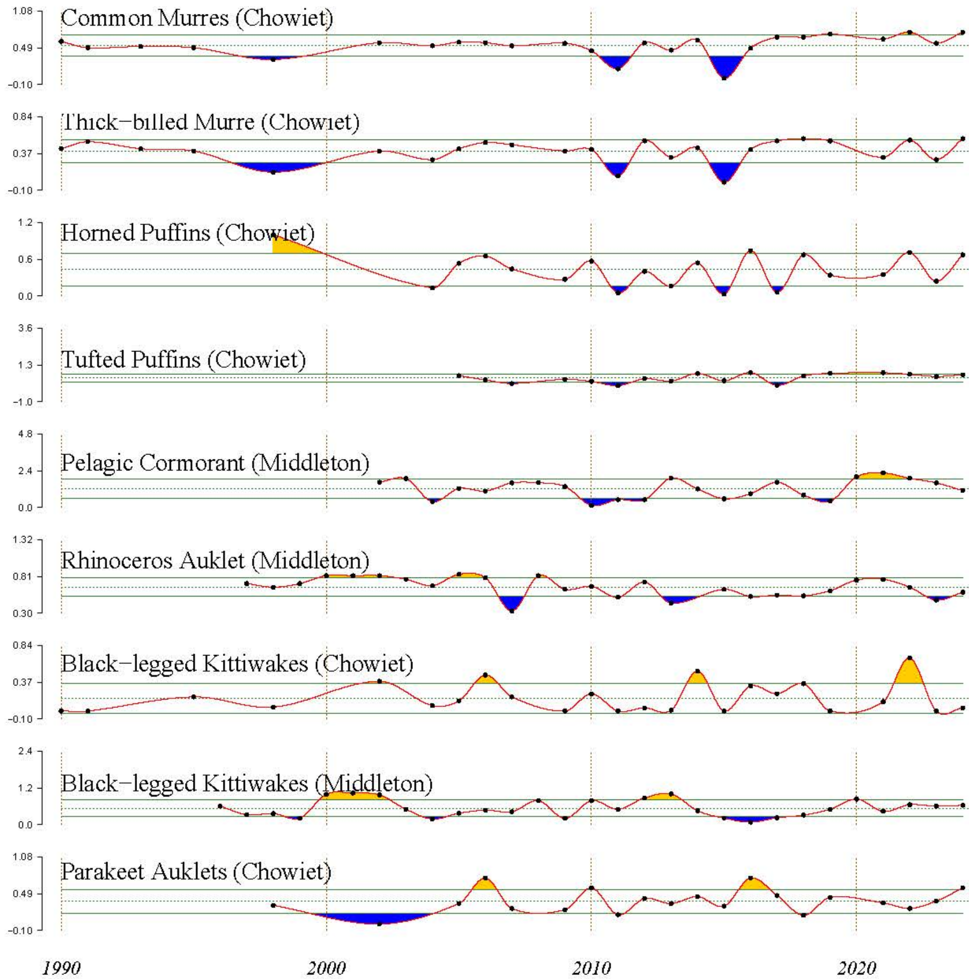

Figure 77: Reproductive success of western GOA piscivorous (common murres, thick-billed murres, horned puffins, tufted puffins, pelagic cormorants, rhinoceros auklets, black-legged kittiwakes) and planktivorous (parakeet auklets) seabird species on Chowiet Isl. and Middleton Isl. The dashed line is the long-term average and solid green lines are $\pm$ 1 standard deviation. Yellow/blue shading indicates values greater than 1 standard deviation above/below the mean. Data provided by the U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge and the Institute for Seabird Research and Conservation.

Along the Seward line transect, black-legged kittiwake densities in spring 2024 were near average on the inner shelf and middle shelf, but below average on the outer shelf (Figure 81). However, densities of kittiwakes in the oceanic domain (continental slope) were the highest observed in the time-series.

Primarily fish-eating, diving seabirds: Fish-eating, diving seabirds in the Gulf of Alaska include common murres *Uria aalge*, rhinoceros auklets *Cerorhinca monocerata*, tufted puffins *Fratercula cirrhata* and

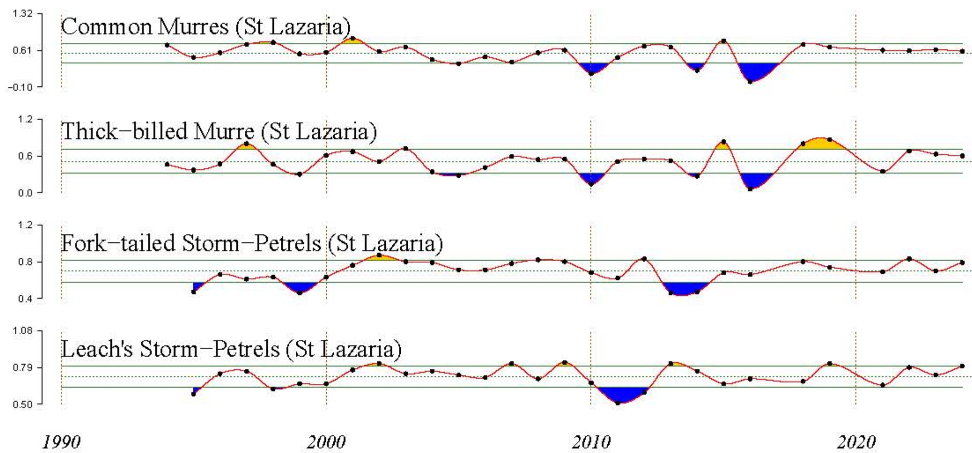

Figure 78: Reproductive success of eastern GOA, piscivorous (common murres, thick-billed murres) and planktivorous (fork-tailed storm-petrels, Leach's storm-petrels) seabird species on St. Lazaria Isl. The dashed line is the long-term average and solid green lines are $\pm$ 1 standard deviation. Yellow/blue shading indicates values greater than 1 standard deviation above/below the mean. Data provided by the U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge.

pelagic cormorants *Urile pelagicus*. The status of this group is impacted by changes in the availability of small, schooling fish up to $\sim$ 90 m (300 feet) below the surface, making them potential indicators of feeding conditions that may affect fish-eating groundfish species.

Breeding timing: *Breeding timing was early (AK peninsula), average (central GOA), and early/average (southeast Alaska) in 2024*. Breeding timing of these seabirds on Chowiet Isl. was earlier than the time series average (baseline: 1990 – 2023) for common and thick-billed murres, and horned and tufted puffins (Figure 75). Common murres continue a multi-year trend of hatch times 1 standard deviation earlier than average. Mean hatching dates of rhinoceros auklets (June 25) and pelagic cormorants (June 21) were close to average (baseline: 2002 – 2023) on Middleton Isl. in 2024 (Figure 75). In the eastern GOA (St. Lazaria Isl.) common murres remain around one standard deviation earlier than average (baseline 1996 – 2023) and rhinoceros auklets hatch times were earlier than 2023, returning to approximately average (Figure 76).

Reproductive success: *Reproductive success was above-average (AK peninsula) to average (central GOA) to average/above average (southeast AK) for fish-eating, diving seabirds in 2024.* In the western GOA, this group of seabirds all had increased reproductive success on Chowiet Isl. relative to 2023. Common murres, thick-billed murres, and tufted puffins rose to approximately 1 SD above average (Figure 77). Breeding success of rhinoceros auklets and pelagic cormorants was at or slightly below average (baseline 1994 – 2023) on Middleton Isl. in 2024 (Figure 78). In the eastern GOA, common murres and thick-billed murres on St. Lazaria continued a multi-year trend of slightly above average reproductive success (baseline 1994 – 2023; Figure 78).

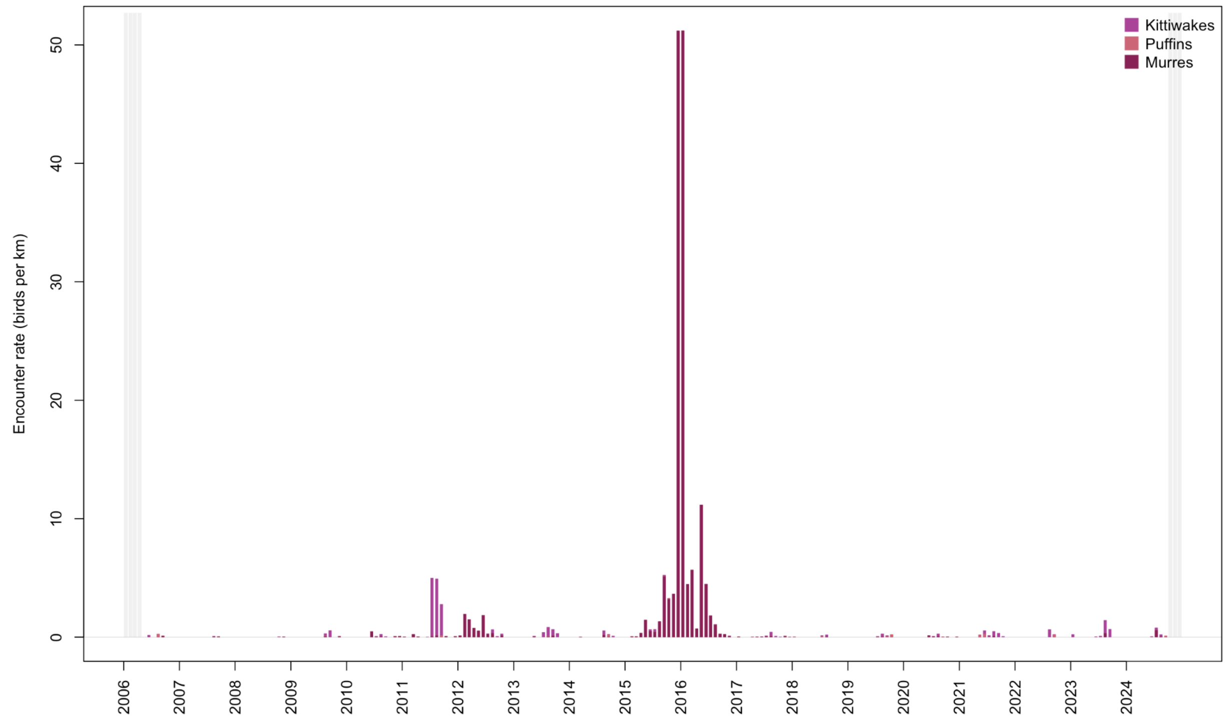

Figure 79: The number of kittiwakes, puffins, and murres (fish-eating seabirds) encountered per km of beach surveyed by citizen scientists in the Gulf of Alaska. Data were insufficient to produce meaningful measures of long-term baseline variation. Data indicate regional trends, but are biased toward more accessible beaches in areas of higher human population density. Light gray shading indicates time-periods where surveys were not performed. Figure provided by the Coastal Observation and Seabird Survey Team (COASST), October 2024.

Mortality index: *No large-scale mortality event was recorded for fish-eating, diving seabirds based on beach surveys in the Western Gulf of Alaska in 2024.* This marks 8 years since the mass mortality event of common murres linked to the 2014 – 2016 marine heatwave (Figure 79).

Distribution: *Common murres near average on Seward Line; high on middle shelf).* Densities of common murres along the Seward Line in spring 2024 were near average on the inner shelf and the middle shelf (Figure 81). Spring murre densities on the middle shelf were the highest observed since 2015. An influx of murres into coastal waters preceded an unprecedented mass-mortality event during the winter of 2015 – 2016. Following this dieoff event, spring densities of murres on the middle shelf were below average from 2016 – 2023.

Primarily plankton-eating seabirds: Plankton-eating seabirds in the Gulf of Alaska include surface-feeding species such as Leach's and fork-tailed storm-petrels (*Hydrobates leucorhous*, *Hydrobates furcatus*), and diving species such as least auklets (*Aethia pusilla*), crested auklets (*Aethia cristatella*), and parakeet auklets (*Aethia psittacula*). The status of these groups is impacted by changes in zooplankton production, making them potential indicators of feeding conditions that may affect planktivorous groundfish species, including the larvae and juveniles of fish-eating species.

Breeding timing: *Breeding timing was late (western GOA) to early/average (eastern GOA).* In the

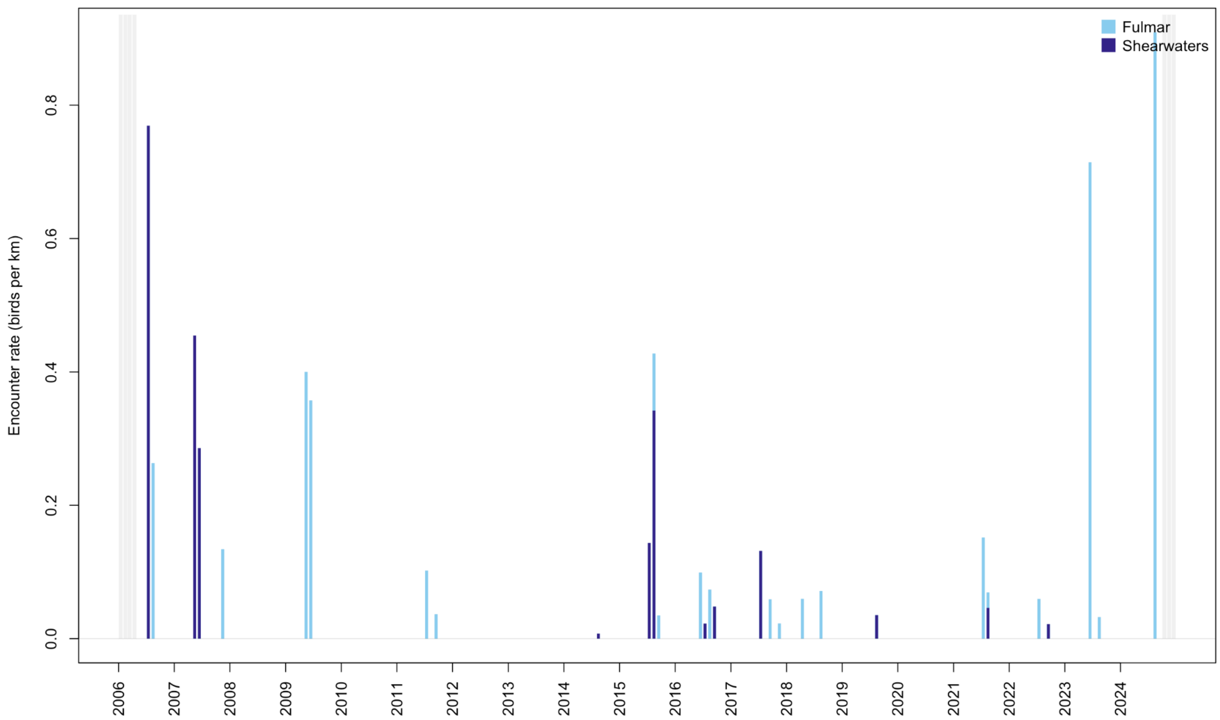

Figure 80: The number of fulmars and shearwaters (fish-eating seabirds) encountered per km of beach surveyed by citizen scientists in the Gulf of Alaska. Data indicate regional trends, but are biased toward more accessible beaches in areas of higher human population density. Light gray shading indicates time-periods where surveys were not performed. Figure provided by the Coastal Observation and Seabird Survey Team (COASST), October 2024.

western GOA, Parakeet auklets breeding timing was 1 SD later than average on Chowiet Isl. (July 7, baseline: 2002 – 2023; Figure 75). In the eastern GOA (St. Lazaria Isl.), fork-tailed storm-petrel timing was 1 standard deviation earlier than average, a third year of earlier than average breeding timing (June 19th, baseline 1995 – 2023) while Leach's storm-petrels had approximately average timing (July 30th, baseline 1996 – 2023) (Figure 76).

Reproductive success: *Reproductive success was above average for plankton-eating seabirds in 2024.* In the western GOA (Chowiet Isl.), the reproductive success of parakeet auklets increased to approximately 1 standard deviation above average (baseline: 1998 – 2023), potentially reflective of local foraging conditions around the colony (Figure 77). In eastern GOA, earlier breeding St. Lazaria fork-tailed and later breeding Leach's storm-petrels both increased to approximately 1 standard deviation above average success (baseline starting in 1994 and 1995 respectively) (Figure 78).

Mortality index: *No large-scale mortality event was recorded for plankton-eating seabirds based on beach surveys in the Gulf of Alaska in 2024.* Only parakeet auklets (*Aethia psittacula*), were observed in 2024, in abundances not suggestive of unusual/elevated mortality (Figure 82). Crested auklets last appeared dead on beaches, 2015 – 2016, following the marine heatwave; no least auklets have been found in the Gulf of Alaska since monitoring was established (2006).

Distribution: *Change in distribution or decrease in density on Seward Line.* Densities of fork-tailed

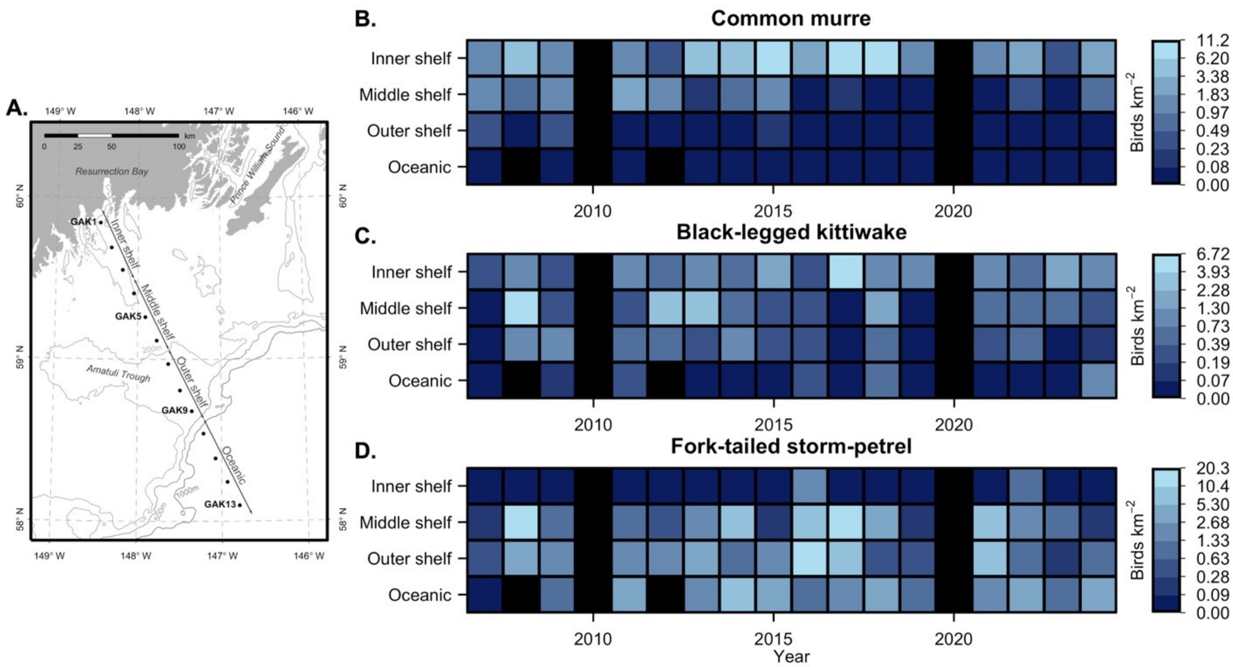

Figure 81: The spring Seward Line in the Northern Gulf of Alaska, and four domains used for analysis (A). Mean densities (birds km $^{-2}$) of common murres, black-legged kittiwakes, and fork-tailed storm-petrels within domains during spring Seward Line cruises, 2007 – 2024 (B-D). Black indicates no seabird surveys were conducted. Figure provided by Pole Star Ecological Research, and US Fish and Wildlife Service, Migratory Birds – Alaska.

storm-petrels along the Seward Line in spring 2024 were well below average on the middle shelf, near average on the outer shelf, and above average in the oceanic domain (Figure 81).

Factors influencing trends and implications for ecosystem productivity: Seabirds represent different aspects of prey resources, depending on species-specific life histories and foraging characteristics. Rhinoceros auklets can represent a broader spatial range of foraging conditions, given their ability to dive and broad foraging range. Kittiwakes have more variable reproductive performance in response to short-term environmental fluctuations, while murres have more consistent breeding patterns, indicative of broader foraging conditions and more extreme events. Early breeding timing can indicate increased prey availability, however other environmental and phenological aspects can influence this metric. The distribution of seabirds observed during the Seward Line spring survey can reflect spatial trends in prey availability, such as compression closer to shore during the lower productive marine heatwave years of 2014 – 2016. The three seabird colonies summarized in this section span the Gulf of Alaska shelf from west (Chowiet Isl.), central (Middleton Isl.), to east (St. Lazaria Isl). Seabird diet data, relevant to reproductive success and timing and distribution, are presented in the Seabird-Derived Forage Fish Indicators chapter of this Report (Arimitsu, p.96).

On Middleton Island, the relatively early breeding phenology of black-legged kittiwakes was likely driven by high availability of myctophids in oceanic foraging areas south of the island. Similarly, densities of both kittiwakes and storm-petrels were high over the continental slope along the Seward Line, suggesting enhanced availability of oceanic prey. Breeding success was slightly higher among surface-foraging black-legged kittiwakes relative to the two diving species (pelagic cormorants and rhinoceros auklets). The

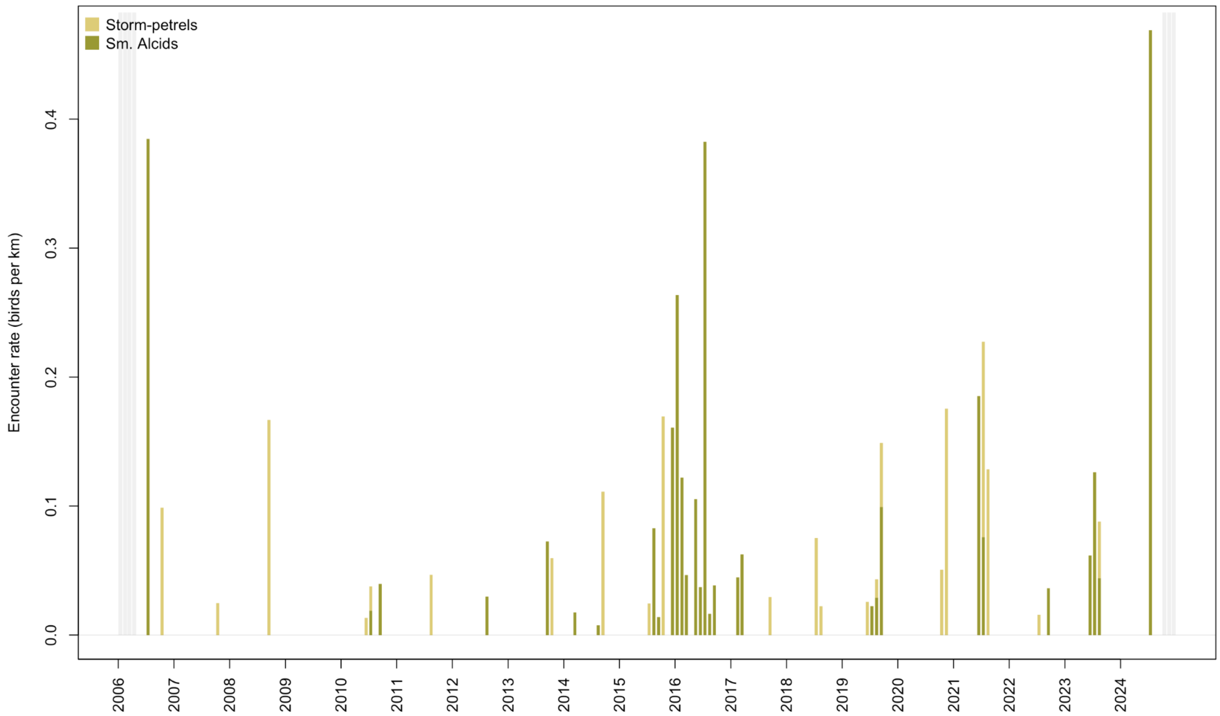

Figure 82: The number of plankton-eating seabirds (storm-petrels and small alcids) encountered per km of beach surveyed by citizen scientists in the Gulf of Alaska. Data indicate regional trends, but are biased toward more accessible beaches in areas of higher human population density. Light gray shading indicates time-periods where surveys were not performed. Figure provided by the Coastal Observation and Seabird Survey Team (COASST), October 2024.

persistence of myctophids in the kittiwake diet throughout their 2024 breeding season may account for these differences in productivity (Arimitsu in this Report, p.96). Rhinoceros auklets and pelagic cormorants on the island do not forage on myctophids during the breeding season and may therefore be more sensitive to the decline in availability of Pacific sand lance (Arimitsu in this Report, p.96).

The abundance of capelin, a highly nutritious forage fish, has been aligned with cooler ocean temperatures and more successful seabird reproduction in the past. Capelin populations continue to rebound in the GOA in 2024 (post 2014 – 2016 population lows) (McGowan in this report, p.101, Arimitsu in this Report, p.96). The increased reproductive performance of zooplankton-eating seabirds is in agreement with observations of increased spring zooplankton biomass, including euphausiids (Hopcroft in this Report,83), and decreased competition by low returns of pink salmon in 2024 (Whitehouse in this report, p.113, Vulstek in this report, p.124).

Increasing densities of common murres on the middle shelf during spring 2024 may be an indicator of improving foraging conditions for piscivorous birds in this habitat. Piscivorous surface and diving birds increased their use of the middle shelf along the Seward Line in 2024, after continued below-average use of that area (and an influx to coastal waters) following the 2014 – 2016 marine heatwave.

Methods:

- The Coastal Observation and Seabird Survey Team (COASST) and regional partners provided a standardized measure of relative beached bird abundance collected by citizen scientists. Information for the two most data-rich species are included in this Report: common murres and black-legged kittiwakes, representatives of the diving, fish eating group and the surface feeding, fish eating group respectively. Note that data collection is biased toward accessible beaches close to human population centers.

- The Institute for Seabird Research and Conservation (ISRC) provided data on breeding timing and/or reproductive performance of pelagic cormorants, rhinoceros auklets and black-legged kittiwakes on Middleton Island. These data have been collected since the mid-1990s, including an experiment involving feeding a group of kittiwakes to highlight the effect of food availability on the reproductive performance of wild-foraging birds.

- USFWS used vessel-based seabird surveys conducted as a component of multidisciplinary sampling of the Seward Line, during spring (typically the first 10 days of May), 2007 – 2023, to examine cross-shelf distribution of numerically dominant seabird taxonomic groups. Seabird surveys were conducted while the vessel was underway using USFWS modified strip transect protocol (Kuletz et al., 2008), subsequently divided into $\sim$ 3 km transects. For each year, transects within 10 km of each of the 13 stations along the Seward Line were used to calculate densities (birds km $^{-2}$) for each station-centered cell; these station-centered values were then averaged within each of 4 domains (Inner shelf, Middle shelf, Outer shelf, Oceanic). Alcids (murres, murrelets, puffins, auklets) are sub-surface divers that exploit prey in the water-column but have high energetic costs of flight. The most abundant alcid species in this region are primarily fish-eaters. Gulls (kittiwakes, gulls, terns) have highly maneuverable low-speed flight and forage on prey (primarily fish) at and near the water surface. Tubenoses (Procelariiformes: storm-petrels, shearwaters, fulmars, and albatrosses) have efficient long-range flight and use their acute olfactory sense to locate food. They feed on squid and other invertebrates and a variety of fish. Two abundant local breeders (fork-tailed storm-petrel and northern fulmar) are surface-feeders, while migratory shearwaters feed both at the surface and dive for prey.

- The Alaska Maritime National Wildlife has monitored seabirds at colonies around Alaska in most years since the early to mid-1970's. Time series of annual breeding success and phenology (and other parameters) are available from over a dozen species at eight Refuge sites in the GOA, Aleutian Islands, and Bering and Chukchi Seas. Monitored colonies in the GOA include Chowiet (Semidi Islands), East Amatuli (Barren Islands), and St. Lazaria (southeast Alaska) islands.

Marine Mammals

Trends in Humpback Whale Calving in Glacier Bay and Icy Strait

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Last updated: September 2024

Description of indicator: Here we summarize humpback whale (*Megaptera novaeangliae*) reproductive success in Glacier Bay and Icy Strait as an indicator of changes in prey quantity and/or quality available for groundfish in the eastern Gulf of Alaska. Groundfish and humpback whales target the same lipid-rich prey i.e., forage fish and euphausiids. Annually since 1985, Glacier Bay National Park biologists have used consistent methods and levels of effort from June 1 – August 31 to photographically identify individual humpback whales and document their reproductive parameters in Glacier Bay and Icy Strait (Gabriele et al., 2017).

We match each year's photographs of the flukes and dorsal fin of each whale to curated catalogs of identified individuals and tabulate their sighting histories. From these data we documented 1) number of whales; 2) number of calves; 3) crude birth rate (CBR) (defined as the number of calves divided by the total whale count for June - August each year); and 4) within-season calf survival. Using the collaborative Southeast Alaska Database and Happywhale.com automated humpback whale fluke identification system (Cheeseman et al., 2023) we document the survival and reproductive status of Glacier Bay and Icy Strait whales when they are elsewhere in the North Pacific. This allows us to assess 5) return rate of calves in subsequent years as juveniles and adults. Individual sightings from other collaborators are reported with their permission.

Status and trends: We observed 24 calves in 2024 (Table 3) the highest number since the monitoring program began in 1985. Our preliminary whale count for 2024 was 189 whales. During and after the Northeast Pacific Marine Heatwave (PMH) humpback whale abundance declined by 56% between 2013 and 2018 (Gabriele et al., 2022). After a sharp decline that reached its nadir in 2018, whale numbers have stabilized to about 70% of their former abundance (Neilson et al., 2024). The 2024 preliminary humpback whale crude birth rate (CBR) was 12.7% (Table 3, Figure 83). For the first time in many years (Figure 83) this year's CBR not only reached, but exceeded, the pre-PMH mean (9.2%). The CBR has only exceeded 10% in a handful of years during the study. The high CBR also reflects that the total whale count is about 30% lower than it would have been pre-PMH (Neilson et al., 2024).

Most of the 2024 calves appeared to be in relatively good body condition with a healthy amount of nuchal fat, but several had questionable skin conditions (Figure 84). Two calves had dorsal fins that appeared to have been damaged/severed (possibly from vessel collisions) and one calf acquired a superficial vessel propeller injury on its flank in June or July.

Calf survival in Glacier Bay and Icy Strait has improved after an abrupt decline during and after the PMH.

All but one of the 2024 calves were with their mothers on our final observations of the cow/calf pairs for the season. Female #1846 was sighted without her calf in a 35-minute observation on September 26, 2024. However, in the fall, an absent calf could indicate weaning or temporary separation rather than calf mortality. We have not detected a definitive mid-summer calf mortality since 2021 (Table 3). Calf survival had previously dropped by a factor of ten (from 39% to 3%) during and immediately after the PMH (Gabriele et al., 2022).

Juvenile survival has also improved, as shown by several calves born between 2019-2023 that have been re-sighted in subsequent years, in the study area or elsewhere (Table 3). Juvenile survival was extremely poor between 2014 – 2018 (Table 3) as evidenced by the almost complete lack of resightings of Glacier Bay/Icy Strait calves in the study area or elsewhere. Notably, the survival of a 2014 calf has been newly documented using Happywhale; whale #2772 was documented in 2024 in Baja Mexico (Whalewatch Cabo and Cabo Trek) and in California (Monterey Bay Whale Watch).

Table 3: Humpback whale calf production and survival in Glacier Bay & Icy Strait, Alaska. Crude birth rate is calculated by dividing the number of calves by the total number of whales in June-August. In this table, crude birth rate is based on a preliminary total number of whales in 2024. Gray shading indicates the years of the Northeast Pacific marine heatwave.*Calves that do not show their flukes are much harder to re-identify in future years. **The median age at which juveniles tend to return to the study area is 3 years (Gabriele et al., 2017). *** Calf absences in the fall might indicate weaning or temporary separation rather than calf mortality.

Time Period	Number of Calves	# Fluke-identified Calves (June-Aug)*	Crude Birth Rate (%)	Number of calves lost (%)	# Fluke-identified Calves Resighted in Later Years (%)**
1985–2013	mean 9.1 (range 2–21)	191 (range 3.3–18.2)	mean 9.2	8 (4%)	128 (67%)
2014	14*	6	7.9	5 (36%)	1(17%)
2015	5*	1	3.0	0	0
2016	0*	0	0.0	0	0
2017	2*	1	1.6	1 (50%)	0
2018	1*	0	1.0	1 (100%)	0
2019	2	1	1.3	0	1(100%)
2020	12	8	7.4	0	4(50%)
2021	11	8	6.5	1(9%)	3(38%)
2022	6	2	3.6	0	2(100%)
2023	11	8	6.4	0	2(25%)
2024	24	16	12.7	1(4%)***	NA

Factors influencing observed trends: Humpback whales in southeastern Alaska are in the process of recovering from a major ecological disruption. Research suggests that a high humpback whale calving rate in a given year reflects oceanographic conditions in the prior two feeding seasons (Frankel et al., 2022). Thus, this year's high CBR likely reflects favorable feeding conditions in 2022 and 2023 that allowed many females to regain body condition sufficient to calve successfully. This year's cohort of mothers contains adult females exhibiting unusually long calving intervals, and several females who had their first known calf, similar to 2023. In 2024, two females (#1088 and #1486) highlighted in last year's Ecosystem Status Report (Gabriele et al., 2023) for their notable lack of calving since the PMH both had calves in 2024, after 10- and 11-year calving intervals, respectively. Another female (#397) sighted every year since the PMH had a 9-year calving interval (2019 sighting thanks to Alaska Whale Foundation and Juneau Flukes, unpublished data). These are much longer than the typical 2 – 3 year calving interval for this population (Baker et al., 1987; Gabriele et al., 2017). Calving intervals greater than 6 years are rare; female #1246 had an 11-year calving interval (1999 – 2010) after her first calf

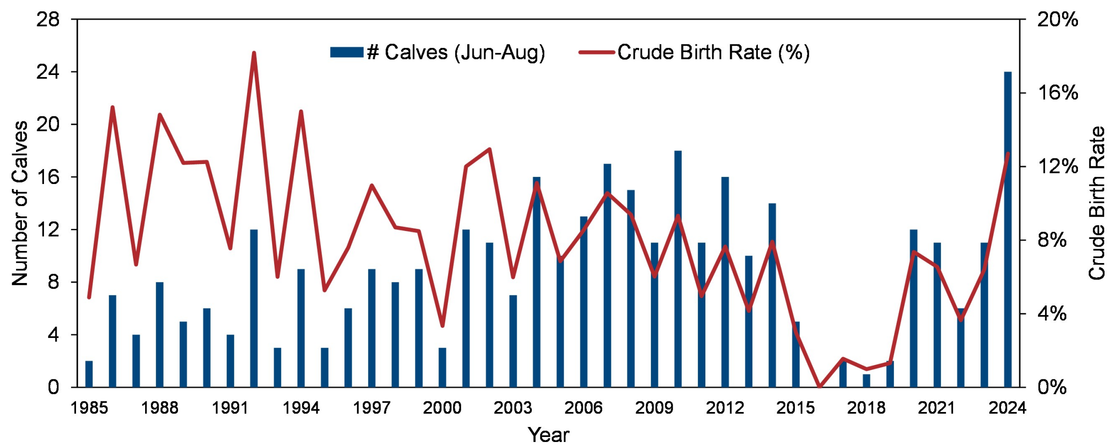

Figure 83: Annual number of calves (blue bars) and crude birth rate (CBR, red line) in Glacier Bay-Icy Strait, 1985 – 2024. CBR is calculated by dividing the number of calves by the total number of whales identified in June - August each year. The preliminary CBR for 2024 is 12.7% based on a preliminary whale count of 189 individually identified whales during the monitoring period.

(Gabriele et al., 2017) and post-PMH she had a 9-year interval 2014 – 2023 (Gabriele et al., 2023). The long intervals documented since the PMH are likely to be a response to physiological stress (Kraus et al., 2007; Kershaw et al., 2021), insufficient prey resources to support conception or pregnancy, or may indicate increased neonatal mortality before or during the migration to Alaska.

We continue to document females having their first known calf at much greater than the average of 10 – 11 years that was documented for this population using data from 1985 – 2014 (Gabriele et al., 2017). This suggests that female age at first calving may have increased due to the PMH and its aftermath. One of this year's first-time mothers, #2310, is 18 years old and has a complete sighting history. Two other females with their first documented calf this year (#2032 – 18 years; #2055 – 17 years) first calved at what appear to be older ages, but these females have incomplete sighting histories and may have had a calf in years that they were not sighted.

Implications: The quantity and quality of forage fish and zooplankton prey available to humpback whales in southeastern Alaska and groundfish appear to have been favorable in 2022 and 2023. The improvement in humpback whale juvenile survival presumably reflects sufficient prey resources that inexperienced juveniles are capable of exploiting and may suggest favorable conditions for groundfish. The long recovery of humpback whale productivity after the PMH may indicate they have a slower demographic response as compared to groundfish.

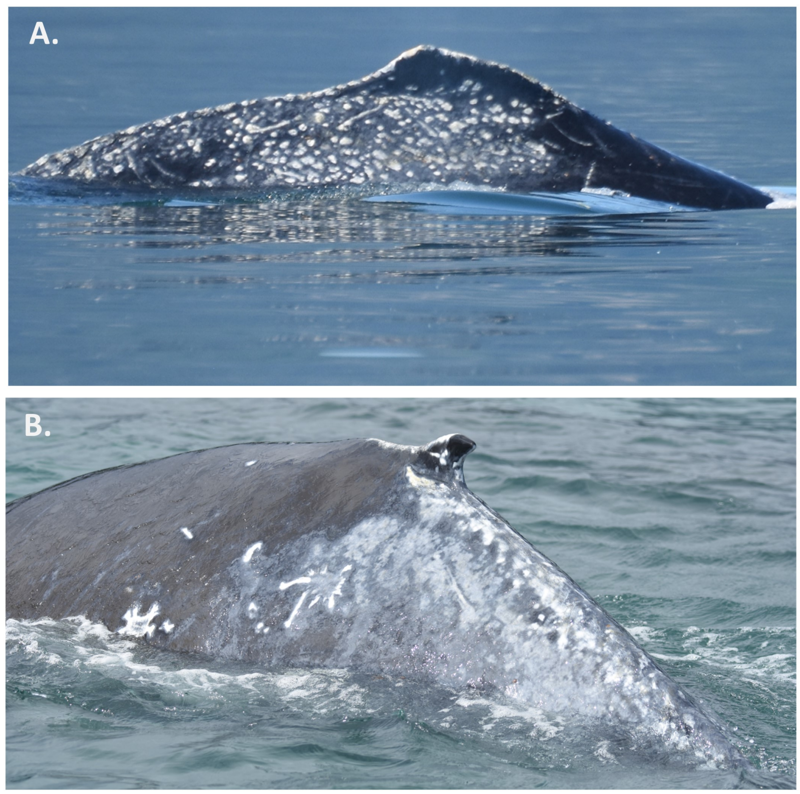

Figure 84: Examples of unusual calf skin conditions of unknown etiology in #2589's 2024 calf (left) and #2157's 2024 calf (right).

Marine Mammal Strandings

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Last updated: September 2024

Description of indicator: Since 1985, members of the NMFS Alaska Marine Mammal Stranding Network (AMMSN) have collected and compiled reports on marine mammal strandings throughout Alaska. These reports are indices of events witnessed by members of the stranding network, the scientific community, and the general public, with varying degrees of knowledge regarding marine mammal biology and ecology. A marine mammal is considered "stranded" if it meets one of the following criteria: 1) dead, whether found on the beach, ice, or floating in the water; 2) alive on a beach (or ice) but unable to return to the water; 3) alive on a beach (or ice) and in need of apparent medical attention; or 4) alive in the water and unable to return to its natural habitat without assistance. The causes of marine mammal strandings are often unknown but some causes include disease, exposure to contaminants or harmful algal blooms, vessel strikes, and entanglement in or ingestion of human-made gear or debris.

When a stranded marine mammal is reported, information is collected including species, location, age class or size. In some cases, the initial photos and observations reported to AMMSN may be the only opportunity to collect information on the event. When possible, trained and authorized AMMSN members respond and collect life history data and samples as part of a partial or full necropsy. Photos and carcasses are evaluated for potential human interactions such as vessel strike. These responses are conducted under the Marine Mammal Protection Act authorization either under a 112 (c) agreement issued by NMFS to AMMSN members through a Stranding Agreement or under 109 (h) authority exercised by local, state, federal or tribal entities. All responses involving ESA-listed species and some enhanced responses (e.g., remote sedation) are authorized under the NOAA Permit No. 24359.

Status and trends: The number of confirmed strandings in Alaska has increased over time. As of September 18, 2024, 189 confirmed stranded marine mammals have been reported for the year within Alaska; 93 occurred in the Gulf of Alaska (Table 4). These numbers do not include entangled pinnipeds with no response or live, entangled baleen whales. The majority of reports were from populated areas where AMMSN members are located (Figure 85). Further, increased outreach and dedicated surveys (e.g., Kodiak Island, 2023 Copper River Delta) associated with high priority species or events (e.g., 2019 gray whale Unusual Mortality Event) also contributed to reported strandings in some area and years. Reported strandings in the Gulf of Alaska since 2020 varied between years without an overall pattern or consistent increase in reports (Table 4). The 2024 stranding data includes confirmed strandings reported between January 1, 2024 and September 18, 2022. These data are preliminary and the details may change as we review reports and receive additional information.

Factors influencing observed trends: It is important to recognize that stranding reports represent effort which has varied substantially over time and location. Overall, this effort has increased over time and area, particularly in areas with higher human population densities. Unusual Mortality Events (UME), including the 2019 gray whale UME, can have large influence on variability between years in this area (Table 4). Under the Marine Mammal Protection Act, an UME is defined as "a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response." Other factors that may influence the number and species of marine mammals being reported

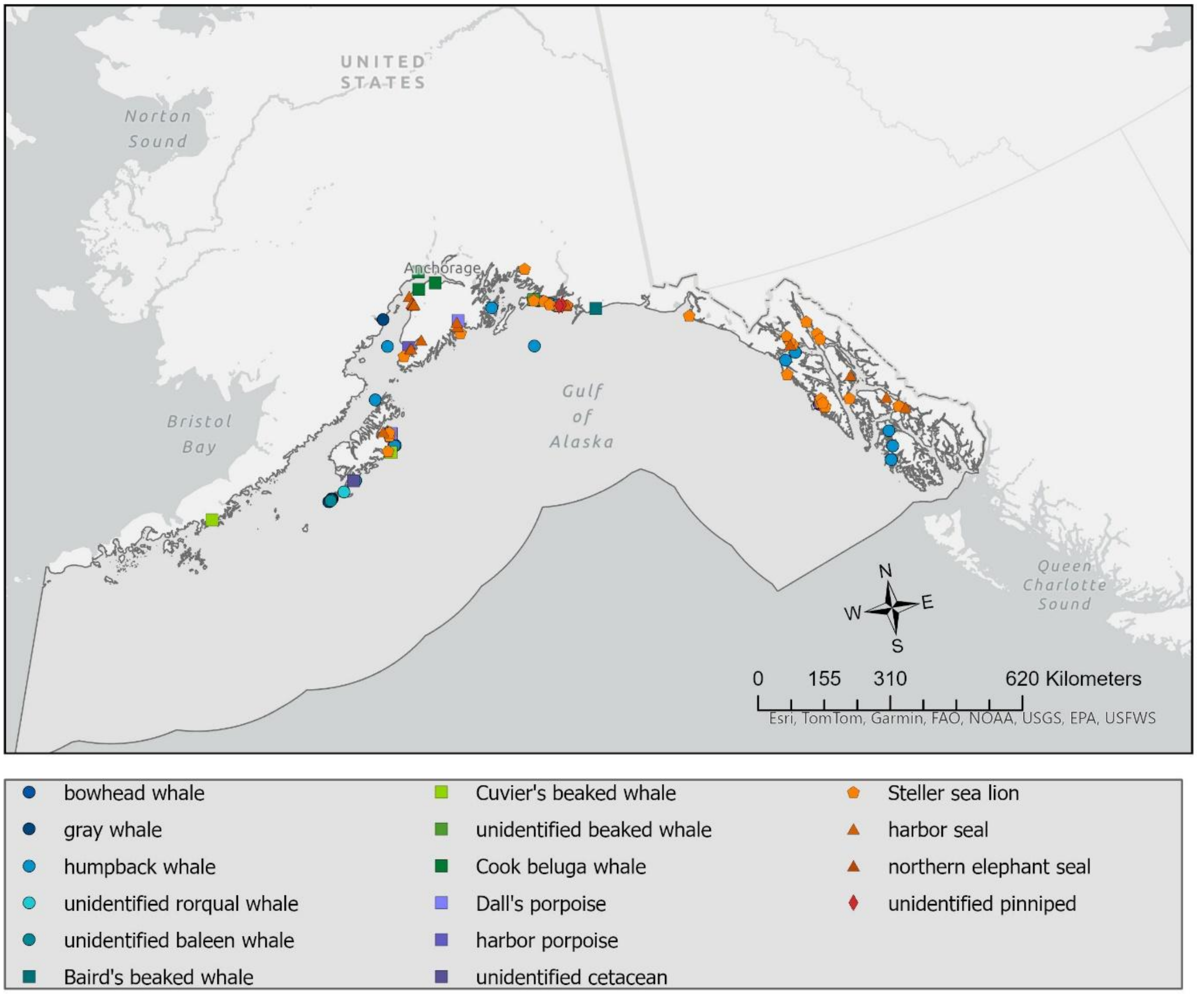

Figure 85: Reported stranded marine mammals in the Gulf of Alaska Region reported between January 1, 2024 and September 18, 2024.

include changing populations of some species and increased public awareness through outreach such as with the endangered Cook Inlet beluga, a NOAA Fisheries Species in the Spotlight. Further, the number of stranded marine mammals in an area can vary due to potential conflict with fishery resources either directly through prey competition or indirectly through interactions with fishing gear.

Implications: Across Alaska, reported marine mammal strandings have been varied by year and location. In 2019, the increase in gray whale starndings across the migration route between Mexico and Alaska led to the declaration of an UME which continued until it's closing on November 9, 2023. There were 146 stranded gray whales in Alaska during this UME. The UME Investigative Team concluded that the preliminary cause of this UME was localized ecosystem changes in the whale's subarctic and Arctic feeding areas that led to changes in food, malnutrition, decreased birth rates, and increased mortality. All these factors were documented during the gray whale UME. Increases in strandings of marine mammals may signal changes in the environment or other stressors (e.g., entanglements).

Marine mammal stranding data can be paired with other datasets and may give clues to ecosystem-wide changes.

Table 4: Reported stranded NMFS marine mammal species for 2024* (through Sept. 18) and the previous five years in the Aleutian Islands by species and year. The number of live stranded animals is reported in parenthesis by species and year.

Species	2020	2021	2022	2023	2024*
Bowhead whale	-	-	-	-	1(1)
Fin whale	3	2	-	1	-
Gray whale	27(1)	14	11	5(1)	5
Humpback whale	14	18	11	26	16
Minke whale	-	1	1	-	-
Unidentified rorqual whale	-	1	-	1	2
Unidentified balaenopeterid	-	-	-	1	-
Unidentified baleen whale	1	2	1	2	1
Baird's beaked whale	-	-	-	-	1
Cuvier's beaked whale	2	-	1	1	2
Unidentified beaked whale	1	1	1	-	1
Cook Inlet beluga	31(21)	10	5	20(7)	3
Killer whale	3	2(1)	1	2(2)	-
Pacific white-sided dolphin	-	2	-	-	-
Sperm whale	-	1	-	1	-
Unidentified dolphin	-	-	-	1	-
Dall's porpoise	2	-	1	2	2
Harbor porpoise	4	5	6	5	3
Unidentified porpoise	-	-	-	1	-
Unidentified cetacean	12	4	3	2	1
Total cetaceans	100	63	42	71	38
Harbor seal	24	28	26	29	22
Northern elephant seal	-	-	3(3)	-	1
Ringed seal	-	-	-	-	-
Unidentified seal	-	1	-	2	-
California sea lion	-	-	-	1	-
Northern fur seal	1	3	-	1(1)	-
Steller sea lion	35	26	37(2)	75(4)	30(3)
Unidentified sea lion	-	-	-	-	1
Unidentified pinniped	-	1	1	-	1
Total pinnipeds	60	59	67	108	55
Total	160	122	109	179	93

Steller Sea Lions

Contributed by Katie Sweeney and Tom Gelatt, Alaska Ecosystem Program, Marine Mammal Lab, Alaska Fisheries Science Center, NOAA Fisheries
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Last updated: September 2022

NOAA Fisheries' GOA Steller sea lion survey is usually every other year (odd years). The survey did not occur in the GOA in 2023. Please refer to the archives[38] for past reports.

[38] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

Ecosystem or Community Indicators

Foraging Guild Biomass

Contributed by George A. Whitehouse[1] and Kerim Y. Aydin[2]
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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[39] for past reports.

Stability of Groundfish Biomass

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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[40] for past reports.

Mean Length of the Fish Community

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[39] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands
[40] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[41] for past reports.

Mean Lifespan of the Fish Community

Contributed by George A. Whitehouse[1] and Geoffrey M. Lang[2]
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Last updated: October 2023

NOAA Fisheries' Gulf of Alaska Bottom Trawl Survey is conducted every other year. Please refer to the archives[42] for past reports.

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates

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Last updated: October 2021

NOAA Fisheries Bottom Trawl Surveys are conducted every other year (odd years). This contribution was not updated in 2023. Please refer to the archives for past reports.

[41]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands
[42]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

Species Richness and Diversity of the Groundfish Community

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Last updated: October 2021

NOAA Fisheries Bottom Trawl Surveys are conducted every other year (odd years). This contribution was not updated in 2023. Please refer to the archives for past reports.

Disease & Toxins Indicators

Harmful Algal Blooms

Contributed by Thomas Farrugia[1], Kari Lanphier[2], Shannon Cellan[2], Bruce Wright[3], Jackie McConnell[3], Jasmine Maurer[4], Kim Schuster[4], Andy Wall[5], Kasie-Jo Wright[5], Maile Branson[6], Allison Carl[6] [1] Alaska Ocean Observing System, Anchorage, AK
[2] Sitka Tribe of Alaska, Sitka, AK
[3] Knik Tribe of Alaska, Palmer, AK
[4] Kachemak Bay National Estuarine Research Reserve, Homer, AK
[5] Kodiak Area Native Association, Kodiak, AK
[6] Alutiiq Pride Marine Institute, Seward, AK
Contact: farrugia@aoos.org

Last updated: September 2024

Sampling Partners:

Alaska Ocean Observing System
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*
Organized Village of Kake*
Organized Village of Kasaan*
Petersburg Indian Association*
Qawalangin Tribe of Unalaska
Sitka Tribe of Alaska*
Skagway Traditional Council*
Southeast Alaska Tribal Ocean Research
Sun'aq Tribe of Kodiak*
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 paralytic shellfish toxins (PST) which can cause paralytic shellfish poisoning (PSP) and has been responsible for five deaths and over 100 cases of PSP in Alaska since 1993 (State of Alaska, 2022). Analyses of paralytic shellfish toxins are commonly reported as μg of toxin/100 g of tissue, where the FDA regulatory limit is 80μg/100g. Toxin levels between 80μg - 1000 μg/100 g are considered to potentially cause non-fatal symptoms, whereas levels above 1000 μg/100g ($\sim$ 12x regulatory limit) are considered potentially fatal.

Testing for PSTs is done for all commercial species, and for many marine subsistence food items, primarily shellfish. Different species tend to accumulate and depurate these toxins at different rates. Blue mussels (*Mytilus trossulus*) have been found to accumulate and depurate PSTs relatively quickly (on the order of days to weeks). This makes blue mussels a good sentinel species to use as an indicator of when a HAB may have happened. Therefore, this report focuses on the toxin levels of blue mussels from around the state, in addition to the presence of the harmful algal species.

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.

Dinophysis spp., produces okadaic acid which can lead to diarrhetic shellfish poisoning. This primarily impacts the gastrointestinal system and is not usually life-threatening but can lead to nausea, vomiting, abdominal cramping, and diarrhea. Although there have not been recorded cases of diarrhetic shellfish poisoning in Alaska, Dinophysis has been detected throughout Alaska, and okadaic acid is at times detected in shellfish.

The Alaska Department of Environmental Conservation (ADEC) tests bivalve shellfish harvested from classified shellfish growing areas meant for commercial market for marine biotoxins including paralytic shellfish toxin (PST) in all bivalve shellfish and domoic acid (DA) specifically in razor clams. The Environmental Health Laboratory (EHL) is the sole laboratory in the state of Alaska certified by the FDA to conduct regulatory tests for commercial bivalve shellfish. The EHL also does testing for research, tribal, and subsistence use.

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 reduce human health risk. 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 can be found on the Alaska HAB Network website [43] or through the sampling partners listed above.

Status and trends:

Alaska Region: Results from shellfish and phytoplankton monitoring showed a slight downtick in the presence of harmful algal blooms (HABs) and toxins throughout all regions of Alaska in 2024 compared to 2023, and the overall levels were 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, 2024 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, primarily between May and September in 2024.

Over the last few years, the dinoflagellate *Dinophysis* has become more common and abundant in water samples, and 2024 continued that trend. We are also seeing a geographic expansion of areas that are sampling for phytoplankton species. In the Bering Sea, HABs were being monitored through the opportunistic placement of Imaging FlowCytobots (IFCB) on the USCGC Healy as it transited the Bering, Chukchi and Beaufort Seas on research cruises.

Eastern GOA:
Southeast Alaska — In 2024, the Southeast Alaska Tribal Ocean Research (SEATOR) partner Tribes

[43] ahab.aoos.org

collected 119 blue mussel samples to be tested for paralytic shellfish toxins (PSTs) by the Sitka Tribe of Alaska Environmental Research Lab (STAERL). The samples are tested using enzyme-linked immunosorbent assay (ELISA), and the results are shared with the Tribes to inform their subsistence harvests. Twenty-seven of the 119 samples exceeded the FDA regulatory limit of 80 µg of toxins per 100 g of tissue (Figure 86). The first location to record a blue mussel sample above the regulatory limit was in Kasaan, on May 9, 2024. The highest PST result in 2024 was a blue mussel from Yakutat, collected on May 28, 2023. This sample contained 768 µg of toxins per 100 g of tissue, almost 10x the regulatory limit. Levels continued to be consistently above the regulatory limit at most locations into July, although Juneau and Kasaan continued to show elevated toxin levels in August and September, respectively. If previous years' trends hold, we expect to see a fall bloom in southern Southeast Alaska in October. STAERL is continuing the expansion of its toxin testing program to look at the presence of 'emerging' toxins of concern (i.e., okadaic acid, which causes diarrhetic shellfish poisoning and domoic acid, which causes amnesic shellfish poisoning) that can impact communities in Southeast Alaska. (Kari Lanphier, SEATOR and Shannon Cellan, Sitka Tribe of Alaska)

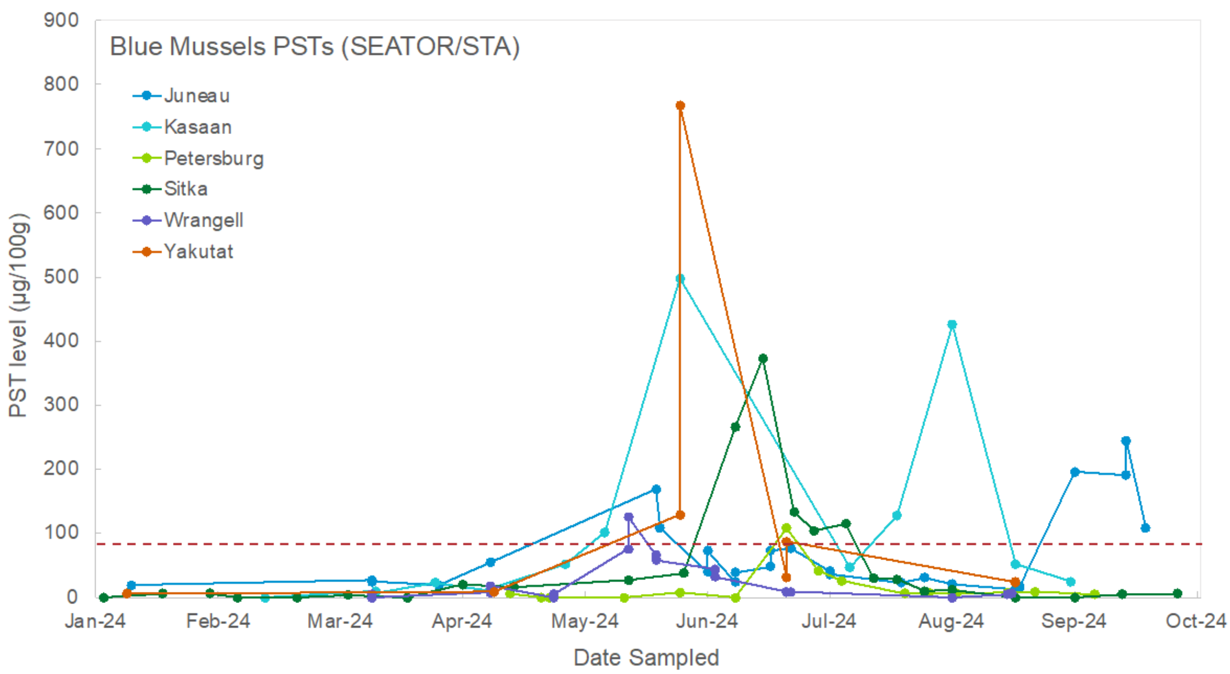

Figure 86: Paralytic shellfish toxin levels in blue mussels tested by the Southeast Alaska Tribal Ocean Research (SEATOR) and Sitka Tribe of Alaska (STA) around six different communities. The red horizontal dashed line represents the FDA regulatory limit is 80μg/100g. Testing for these data was done using the ELISA testing method.

Juneau and Haines — The Knik Tribe also conducted some PST testing of blue mussels from Southeast Alaska, specifically from Juneau and Haines. The Knik Tribe's harmful algal blooms (HABs) project, Paralytic Shellfish Poisoning Risk Management, is a 4-year project working closely with the Alaska Department of Environmental Conservation's Environmental Health Laboratory, testing shellfish, fish, and invertebrate samples sent to us from across Alaska. Paralytic shellfish toxin levels are analyzed using mouse bioassay or high-performance liquid chromatography analysis. In Southeast, most of the blue mussel samples tested by Knik Tribe were below the regulatory limit, except for one sample from Haines that tested at 164 μg/100g on June 7, 2024 (Figure 87). Blue mussels collected after July 2024 in Southeast Alaska are still being analyzed. (Bruce Wright and Jackie McConnell, Knik Tribe).

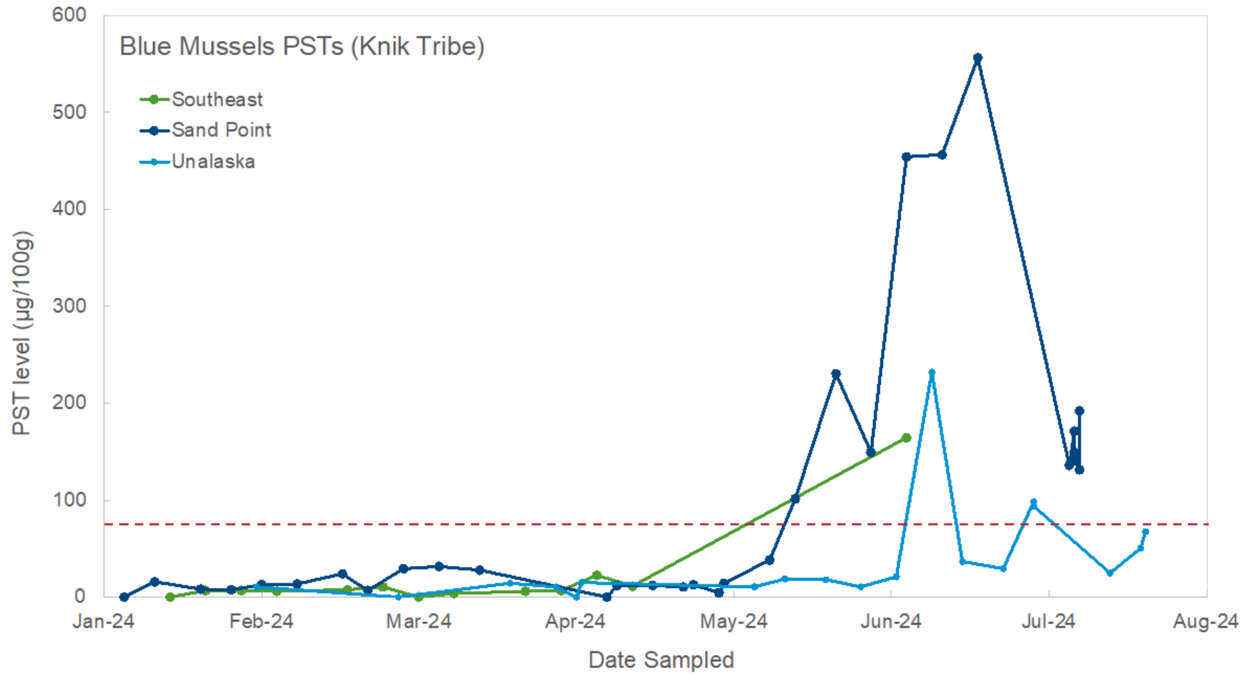

Figure 87: Paralytic shellfish toxin levels in blue mussels tested by the Knik Tribe in three regions in Southeast Alaska. The red horizontal dashed line represents the FDA regulatory limit is 80μg/100g. Testing for these data was done using the mouse bioassay or high-performance liquid chromatography testing method.

Western GOA:
The Kachemak Bay National Estuarine Research Reserve (KBNERR) collected and identified phytoplankton in 177 samples so far in 2024. *Alexandrium* spp. were seen in only 11% of samples this year, only from May to August, and only at relatively low levels (Figure 88). *Dinophysis* spp. were present in 45% of samples between April and August and at low levels in all but one sample. *Pseudo-nitzschia* spp. were present in almost every sample (87%), from January to August and were found at bloom levels on six occasions, primarily in July and August. In addition, a very dense and short-lived bloom of *Dinophysis* in Sadie Cove was reported to KBNERR in August. Two blue mussel samples were collected and sent to the Washington State environmental lab for analysis and the samples came back with detectable levels of okadaic acid, at 7 and 13 μg/100g, just below the FDA regulatory level of 16 μg/100g. (Jasmine Maurer and Kim Schuster, KBNERR)

Lower Cook Inlet and Prince William Sound — The Chugach Regional Resources Commission and the Alutiiq Pride Marine Institute (APMI) have been conducting phytoplankton and shellfish monitoring at seven locations in the Lower Cook Inlet and in the Prince William Sound since 2021. The phytoplankton monitoring did not observe bloom levels of *Alexandrium* or *Pseudo-nitzschia* at any of the sample locations in 2024. Blue mussel samples have not shown levels about the regulatory limit since 2021, including in 2024 (Figure 89). However, in both 2023 and 2024, the toxin levels increased slightly during the May-June timeframe each year. Testing for toxins will continue into fall and over winter. Additionally, APMI is working to establish the capacity to conduct receptor binding assays. Phytoplankton and toxin testing data can be found on the Alutiiq Pride Marine Institute website[44]. (Maile Branson and Allison Carl, APMI)

[44] alutiiqprideak.org/hab-watch

Figure 88: Detection timing of three species of harmful algae from community samples sent to the Kachemak Bay National Ecological Research Reserve (KBNERR). Height of vertical bars represent when samples contained cells at three qualitative levels (present, abundant, bloom).

Kodiak Island — The Kodiak Area Native Association's (KANA) Environmental Department have taken 95 phytoplankton samples in 2024 have identified *Pseudo-nitzschia* spp., *Dinophysis* spp., and *Alexandrium* spp. in 16, 8 and 2 samples, respectively. Alexandrium were only seen in May and June and were at an elevated level on May 29, 2024 (Figure 90). Blue mussels sampled in 2024 around Kodiak were tested by the Sitka Tribe of Alaska, and were found to have toxin levels about the regulatory limit in June, July and August (Figure 91). The maximum toxin level detected was 327 μg/100g, over 4x the regulatory limit on June 10. In addition to the baseline toxin monitoring, nine samples from community members were submitted as part of KANA's harvest and hold program from April to September. (Kasey-Jo Wright and Andie Wall, Kodiak Area Native Association)

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

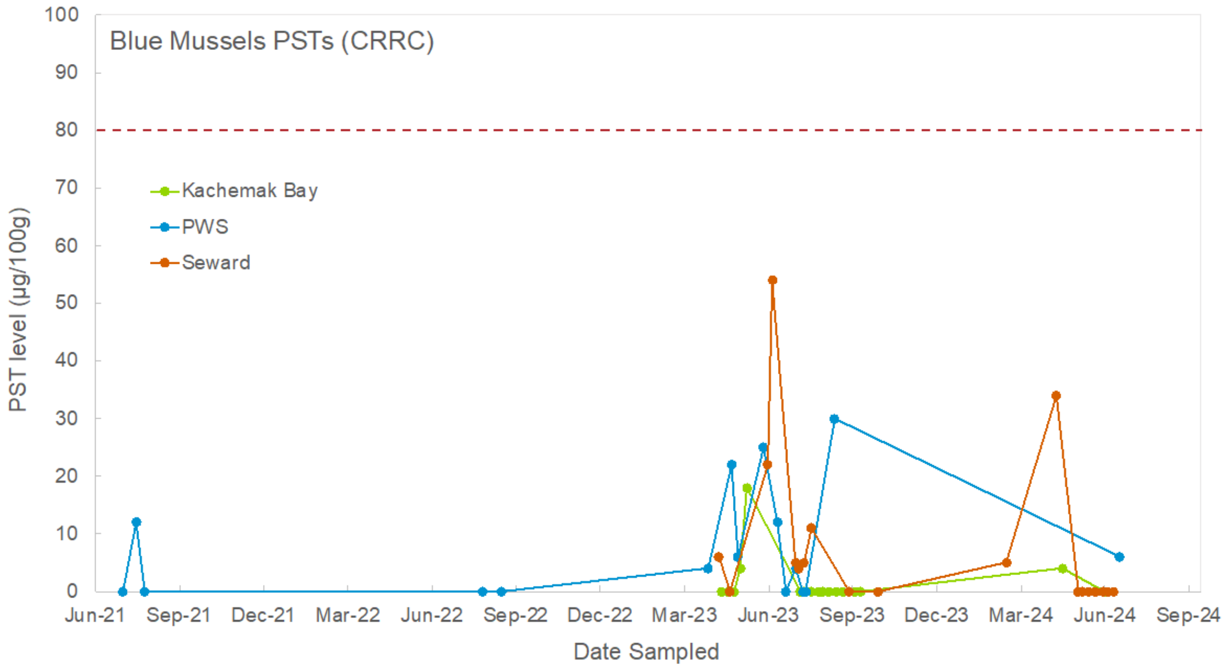

Figure 89: Paralytic shellfish toxin levels in blue mussels from three regions tested by the Chugach Regional Resources Commission (CRRC) at the Alutiiq Pride Marine Institute. The red horizontal dashed line represents the FDA regulatory limit is 80μg/100g. Testing for these data was done using the ELISA testing method.

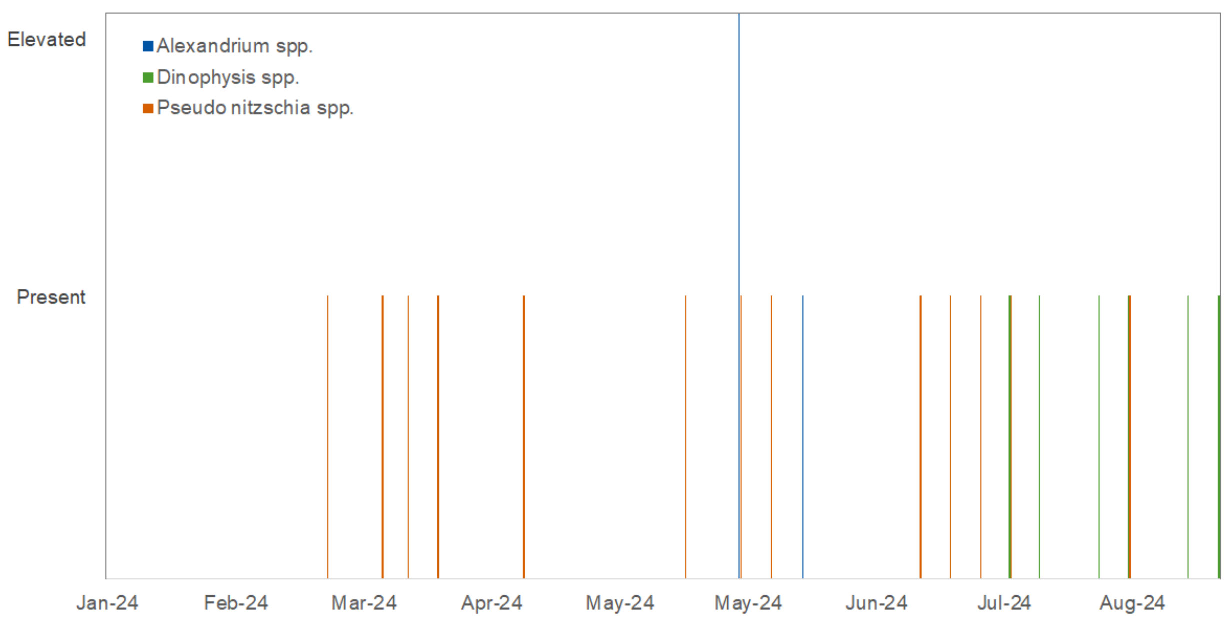

Figure 90: Detection timing of three species of harmful algae from in samples collected and analyzed by the Kodiak Area Native Association. Height of vertical bars represent when samples contained cells at two qualitative levels (present or elevated).

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

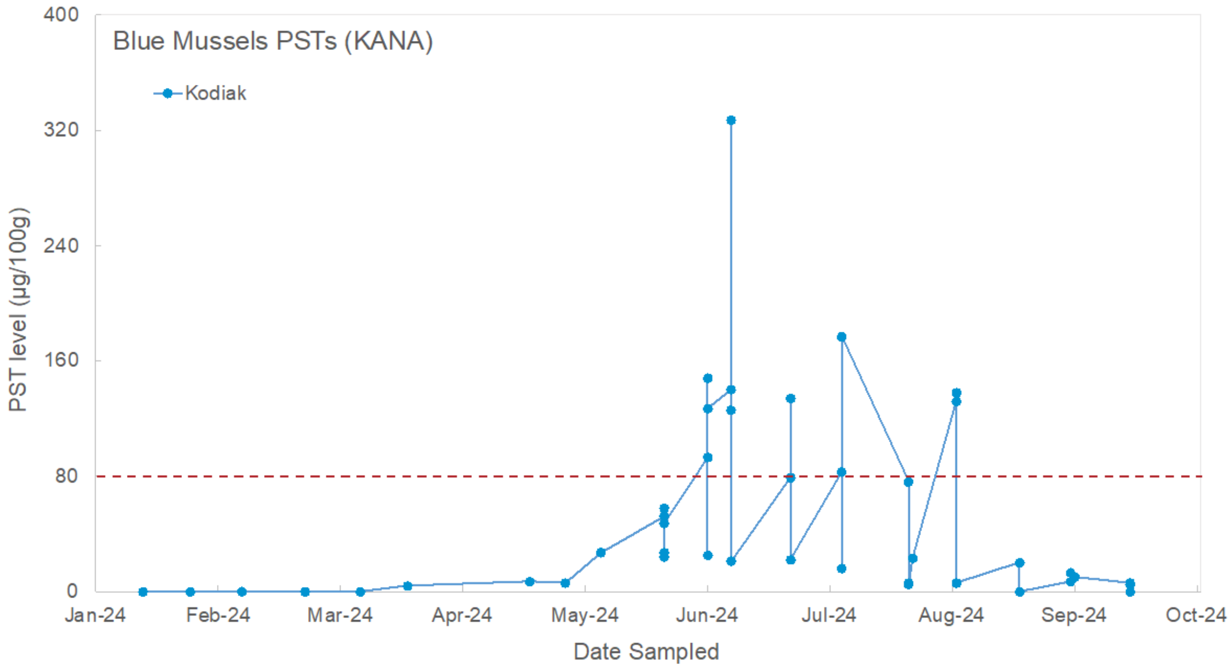

Figure 91: Paralytic shellfish toxin levels in blue mussels from Kodiak collected by the Kodiak Area Native Association and tested by the Sitka Tribe of Alaska (STA). The red horizontal dashed line represents the FDA regulatory limit is 80μg/100g. Testing for these data was done using the ELISA testing method.

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 sediments samples, water samples, zooplankton samples, krill samples, copepod samples, multiple species of fish, bivalves, and the continuation of sampling subsistence-harvested and dead stranded marine mammals.

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 ppm (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.

The Alaska Department of Health, Section of Epidemiology (SOE) continues to partner with the AHAB network. Nurse consultants join in on the monthly meetings and collaborate with stakeholders so they can be made aware of reportable illness such as Paralytic shellfish Poisoning (PSP). SOE published an Epidemiology Bulletin describing cases of PSP from 1993 – 2021[45]. More information about PSP and other shellfish poisoning can be found on the SOE website[46].

[45] https://epi.alaska.gov/bulletins/docs/b2022_05.pdf
[46] https://health.alaska.gov/dph/Epi/id/Pages/dod/psp/default.aspx

“Mushy” Halibut Syndrome Occurrence

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Last updated: October 2024

Description of indicator: Mushy Halibut Syndrome was first detected in GOA halibut in 1998. When prevalent, it is most often observed in smaller halibut of 15 – 20 lbs in the Cook Inlet area, but has also been noted in Kodiak, Seward, and Yakutat. Alaska Department of Fish and Game (ADF&G) describes the typical condition consisting of fish having large areas of body muscle that are abnormally opaque and flaccid or jelly-like. The overall body condition of these fish is usually poor, and often they are released because of the potential inferior meat quality. Data are collected through searches of ADF&G fishing reports[47]) and queries to IPHC and ADF&G staff. Incidence of mushy halibut is reported opportunistically in recreational fishing reports and by port samplers, and may not represent true trends. In particular, for these types of qualitative indicators, absence of reporting does not prove absence in the environment.

Status and trends: In 2024, there were very few sightings of mushy halibut by port samplers early in the spring (pers. comm. Marian Ford, ADF&G). There were no mentions in the ADF&G central Alaska fishing reports. Increased prevalence occurred in 2005, 2011, 2012, 2015, and 2016. It was apparently absent in 2013 and 2014. Since 2017 there have been very few to no reports of mushy halibut.

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

Implications: The relatively few reports of mushy halibut since the end of the 2014–2016 marine heatwave in the GOA may indicate that foraging conditions for young halibut have been more favorable in recent years. However, the absence of mushy halibut reports during the 2019 heatwave year suggests there there is not a simple link between environmental conditions and the prevalence of this condition.

[47] `http://www.adfg.alaska.gov/sf/fishingreports/`

Prince William Sound

Intertidal Ecosystem Indicators in the Northern Gulf of Alaska

Contributed by Heather Coletti, Sarah Traiger, Daniel Esler, Katrin Iken, James Bodkin, Brenda Ballachey, Kim Kloecker, Brenda Konar, Mandy Lindeberg, Daniel Monson, Brian Robinson, Robert Suryan, and Benjamin Weitzman
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Contact: heather_coletti@nps.gov

Last updated: September 2024

Description of indicator: Nearshore monitoring in the Gulf of Alaska (GOA) provides ongoing evaluation of status and trends of more than 200 species associated with intertidal and shallow subtidal habitats (Suryan et al., 2023). The spatial extent of sampling includes 21 sites distributed across four regions in the northern GOA: western Prince William Sound (WPWS), Kenai Fjords National Park (KEFJ), Kachemak Bay (KBAY), and Katmai National Park and Preserve (KATM). Since 2018, we have reported on one physical indicator (intertidal water temperature; U.S. Geological Survey - Alaska Science Center, National Park Service - Southwest Alaska - Inventory and Monitoring Network, and University of Alaska Fairbanks - College of Fisheries and Ocean Sciences, 2016) and three biological indicators monitored annually beginning in 2005 – 2007. Respectively, these indicators represent key nearshore ecosystem components of primary production (algal cover; U.S. Geological Survey - Alaska Science Center, National Park Service - Southwest Alaska Inventory and Monitoring Network, 2022), prey abundance (mussel density; U.S. Geological Survey - Alaska Science Center, National Park Service - Southwest Alaska Inventory and Monitoring Network, 2016), and predator abundance (sea star density; U.S. Geological Survey - Alaska Science Center, National Park Service - Southwest Alaska Inventory and Monitoring Network, 2022). The algal cover indicator used is percent cover of rockweed (*Fucus distichus*) in quadrats sampled at the mid intertidal level (1.5 m). Intertidal prey are represented by density estimates of large ($\geq$ 20 mm) Pacific blue mussels (*Mytilus trossulus*) sampled quantitatively within mussel beds. The nearshore predator abundance indicator is density of sea stars, estimated along an approximately 200 m^2 transect at each rocky intertidal monitoring site. Indicators are presented as annual anomalies compared to the long-term mean of the data record, which is an average across sites within each region.

Status and trends: Nearshore water temperature across the GOA from Prince William Sound to the Alaska Peninsula was elevated from 2014 through 2016 across all regions and into 2017 in WPWS and KEFJ (Figure 92). These results confirm that the 2014 – 2016 Pacific marine heatwave (PMH) in the GOA was expressed in intertidal zones in addition to known patterns in open ocean environments. While temperatures returned to cooler conditions in 2017, another heat spike was recorded in all regions in 2019. Temperatures then started to cool again the following year, although with much higher among-region variability, which was not observed prior to the heat wave. In 2024, at the time of collection (mid-summer), all four regions remain cooler than the average through the data record, though somewhat warmer than 2007 – 2014.

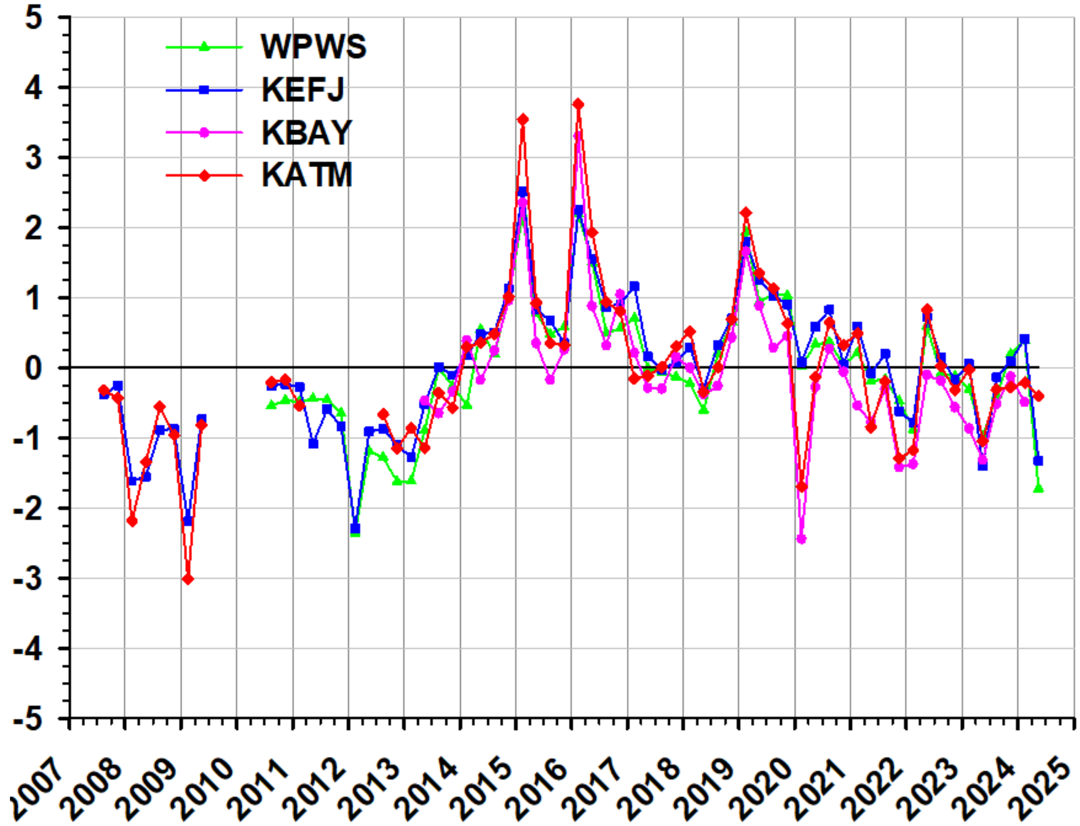

Figure 92: Seasonal intertidal water temperature anomalies at the 0.5 m tide level four regions of the western Gulf of Alaska (west of 144 ˚W), western Prince William Sound (WPWS; 2011 – 2024), Kenai Fjords National Park (KEFJ; 2008 – 2024), Kachemak Bay (KBAY; 2013 – 2024), and Katmai National Park adjacent to Shelikof Strait (KATM; 2006 – 2024). Long tick marks indicate the start of the calendar year (January) while short tick marks are quarterly divisions within the year (April, July, October).

Despite considerable variability in algal percent cover among regions and generally average to positive anomalies through 2014, the KATM region showed consistently negative values since the recent PMH through 2023, only becoming positive this year (2024). KEFJ had negative anomalies that started in 2014 and ended in 2021, with 2022 – 2024 being positive. *Fucus* in WPWS also indicated negative values since 2016, with the exception of 2019. KBAY did not show any specific trend over time with roughly average *Fucus* cover without a noticeable response in percent cover of *Fucus* to temperature fluctuations. It should be noted however, that in all regions, the variability around the mean appears to be decreasing within regions during more recent years (Figure 93).

Large mussel densities ($\geq$ 20 mm) showed an overall positive trend across regions consistent with timing of the PMH, in this case switching from generally negative prior to 2014 to positive for the regional long-term mean after 2014 (Figure 94); this is an opposite response compared to algal cover and sea stars (Figures 93 and 95). However, starting in 2022, KATM experienced negative large mussel density anomalies, concurrent with positive to strongly positive anomalies in sea star abundance. This trend continued through 2024 (Figures 94 and 95). Patterns in the other three regions are less clear. KBAY and KEFJ have had positive large mussel anomalies through 2023, but strongly negative in 2024.

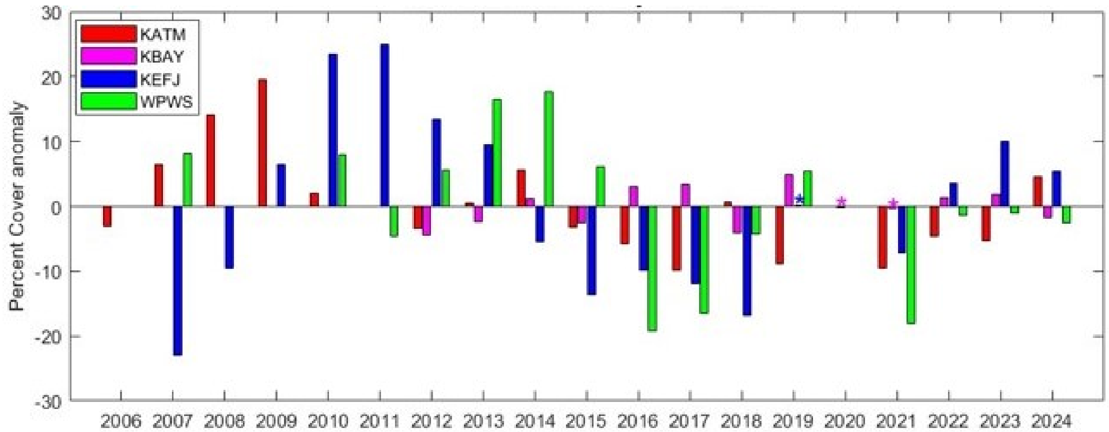

Figure 93: Percent cover anomalies for rockweed (*Fucus distichus*) in four regions of the western Gulf of Alaska, WPWS (2007, 2010 – 2019, 2021 – 2024), KEFJ (2008 – 2019, 2021 – 2024), KBAY (2012 – 2024), and KATM (2006 – 2010, 2012 – 2019, 2021 – 2024). WPWS, KEFJ and KATM were not sampled in 2020 due to COVID-19. Note: KBAY anomaly in 2020 and 2021 were close to 0, hence the lack of clearly visible bars for KBAY in 2020 (symbolized by an asterisk in 2020) and 2021.

Conversely, WPWS was the only region in 2024 with a positive large mussel anomaly, the first positive anomaly observed in this region since 2018 (Figures 94). As oceanographic conditions returned to cooler temperatures after the PMH, variability in mussel abundance at these regional spatial scales supports our conclusion that, in the absence of broad-scale perturbations, other variables and local conditions become the primary drivers of mussel abundance (Bodkin et al., 2018; Traiger et al., 2022; LaBarre et al., 2007).

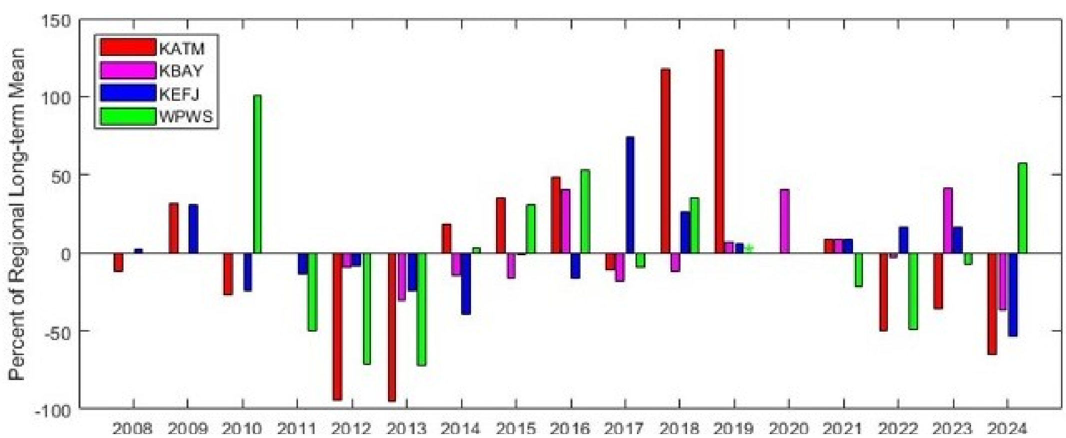

Figure 94: Percent of density anomalies for large mussels ($\geq$ 20 mm) in four study regions spanning the northern Gulf of Alaska. WPWS (2010–2019, 2021–2024), KEFJ (2008–2019, 2021–2024), KBAY (2012–2024), and KATM (2008–2010, 2012–2019, 2021–2024).

Variability in density and species composition of sea stars varied greatly among regions through 2015. Starting between 2015 and 2017, densities declined and remained strongly negative across all regions through 2019 (Figure 95), with average to below average densities continuing through 2021. Declines were likely due to sea star wasting (Konar et al., 2019), possibly exacerbated by the PMH (Harvell et al., 2019). However, 2024 is the first year since monitoring began that all four regions have exhibited positive anomalies, although to varying degrees. Density anomalies indicated that WPWS and KBAY were approximately just above average compared to the long-term mean density within each respective region. KATM density was strongly positive (highest sea star anomaly recorded in KATM since monitoring began) and KEFJ density remained strongly positive starting in 2022 through 2024.

Data from 2024 also indicated that variability in sea star composition among (and within) regions has increased. For example, in 2023 *Pisaster* was the dominant species in KEFJ (72%) and KATM (76%). However, in KEFJ during 2024 sampling, *Pisaster* only accounted for 46% with *Dermasterias* and *Evasterias* at 34% and 18%, respectively. In KATM, *Evasterias* dominated the sea star assemblage with 66% (up from 19% in 2023) and *Pisaster* accounting for 32%. In WPWS, *Dermasterias* continues to be the dominant species with 54% (an increase from 34% in 2023) followed by *Evasterias* at 10% (down from 26% in 2023), *Pisaster* at 4% (down from 19% in 2023), and *Pycnopodia* increasing to 32% (up from 20% in 2023). In KBAY, densities were slightly higher than average. *Orthasterias* was proportionally dominant at 64% in 2023 but that proportion declined to 8% in 2024. *Evasterias* dominated the observed sea star assemblage in 2024 with 83% (up from 14% in 2023). Variability in the sea star assemblage (both by density and species composition) among regions and across years within regions may be an indication of the ecosystem returning to one dominated by local-scale conditions as opposed to driven by large-scale perturbations such as sea star wasting and the PMH.

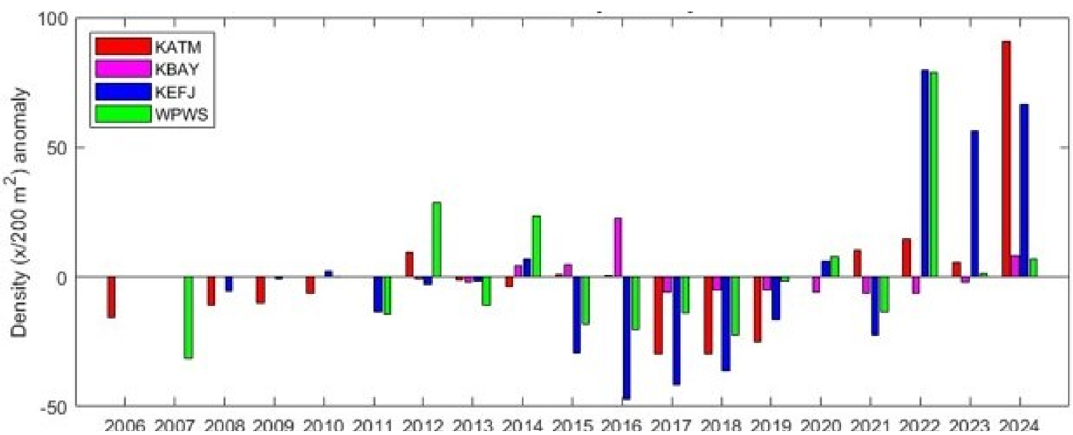

Figure 95: Density anomalies of sea stars (primarily *Dermasterias imbricata*, *Evasterias troschelii*, *Pisaster ochraceus*, and *Pycnopodia helianthoides*) in four study areas spanning the northern Gulf of Alaska. WPWS (2007, 2010–2024), KEFJ (2008–2019, 2021–2024), KBAY (2011–2024), and KATM (2006, 2008–2010, 2012–2019, 2021–2024).

Factors influencing observed trends: During the PMH, negative anomalies of *Fucus* in three of the four regions and of sea stars across all regions were coincident with warm water temperatures in nearshore areas. The decline in sea star abundance across the Gulf was likely due to sea star wasting (Konar et al., 2019), first detected south of Alaska in 2013 and generally thought to be exacerbated by warm water temperature anomalies (Eisenlord et al., 2016; Harvell et al., 2019). Warming waters and declines in sea stars were associated with increased mussel densities across our study regions (Traiger et al., 2022; Weitzman et al., 2021), with a general trend of algal dominated systems turning more into invertebrate dominated systems (Weitzman et al., 2021). This pattern is similar to those observed in other rocky intertidal systems of the North Pacific following the recent large-scale perturbations (Meunier et al., 2024). However, as nearshore waters cooled after the PMH, especially in recent years, large-scale patterns of abundance of the three biological indicators are becoming less synchronous across regions. Cooler temperatures have not led to large increases in *Fucus* percent cover in all regions (Figure 93). Only KEFJ has had a positive anomaly for *Fucus* percent cover since 2022. All other regions have oscillated around the mean. Even with average to low cover of *Fucus* continuing to provide open space for mussel settlement, high densities of large mussels have not persisted through time. Variation in these three biological indicators will continue to be evaluated. Currently, it appears that regional patterns are diverging from one another, perhaps reflecting a shift from broader, synchronous responses to a large-scale phenomenon (i.e., the PMH) to more local conditions specific to each region.

Implications: Collectively, these indicators demonstrate responses to consistent and persistent, broad-scale perturbations of nearshore ecosystems coincident with the PMH throughout much of the western GOA, including areas both inside (WPWS, KBAY) and outside (KEFJ and KATM) of protected marine waters. Even though *Fucus* did not decline markedly in KBAY (Figure 93), a comprehensive analysis of rocky intertidal community structure was completed, indicating a change of autotroph-macroalgal dominated communities to heterotroph-filter-feeder communities, ultimately resulting in a homogenization of community structure across all four regions (Weitzman et al., 2021). Concurrently, we found that the loss of sea stars likely contributed to the increase in large mussel density due to a decline in predation pressure from sea stars (Traiger et al., 2022). However, other factors such as predation pressure from a suite of nearshore invertebrates and vertebrates, shifts in primary productivity, and changes in environmental variables (e.g., salinity) may also influence mussel density (Traiger et al., 2022) and will be evaluated over time. Synergistic phenomena, like invertebrate disease outbreaks, predation and marine heatwaves may be driving apparent shifts in rocky intertidal communities (Meunier et al., 2024). Continued monitoring will provide insights to the temporal and spatial scales of ecosystem responses, where sites may differ in how they change over time. We hypothesize that more local conditions will drive regional nearshore communities, now that broad, Gulf-wide effects of the PMH have dissipated. Intertidal and nearshore ecosystems provide valuable habitat for early life stages of various commercially important species in the GOA, including Dungeness crab (*Metacarcinus magister*), Pacific cod (*Gadus macrocephalus*), salmonids and several species of rockfish (*Sebastes spp*). Our indicators suggest that some nearshore biological responses to the PMH appeared to continue into 2021 in some regions and could have affected recruitment and survival of species whose life stages rely on nearshore habitat. For some metrics, evidence of return to more average conditions in nearshore habitats suggests that PMH effects, both positive and negative, are dissipating. A major pattern that is emerging, however, is that the variability of biological indicators across regions is larger than it was before the PMH. Marine heatwaves are expected to become more common and widespread as a consequence of climate change (Frölicher et al., 2018). From primary producers to top-level consumers, our studies offer insight as to the varying extent of species' responses to these wide-scale perturbation and the timescales over which effects are expressed. Further, we also hypothesize that in the long-term, we may see responses of nearshore-reliant, upper trophic level species (such as sea otters and sea ducks) to shifts in prey availability from changing ocean conditions across the GOA.

Prince William Sound Herring

Contributed by Jennifer Morella[1], W. Scott Pegau[2], C. L. Roberts[3], and Joshua Zahner[3]
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Last updated: August 2024

Description of indicator: Prince William Sound (PWS) Pacific herring (*Clupea pallasii*) population estimates are generated annually by *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) researchers with an age-structure-assessment (ASA) model using data collected by EVOSTC researchers and Alaska Department of Fish and Game (ADF&G). The original catch-age analysis for PWS herring, developed by Funk and Sandone (1990) for ADF&G stock assessment and management, was later adapted for research and described by Hulson et al. (2008). The results presented here are from a Bayesian version of the ASA model described by Muradian et al. (2017) (hereafter referred to as BASA) that was developed and run by the University of Washington as part of the *Exxon Valdez* Oil Spill Trustee Council sponsored Herring Research and Monitoring program. The model inputs include aerial surveys of mile-days of spawn, acoustic surveys of spawning biomass, age-sex-size, historical egg deposition, and disease prevalence data. An output of the model is the annual median estimate of the pre-fishery biomass.

The PWS surveys used by the model are conducted in the spring. The survey area covers traditional spawning regions within Prince William Sound and occasional surveys in the Kayak Island area, although Kayak Island is not included in the inputs to the ASA model. The mile-days of spawn surveys collected by ADF&G extend back to the early 1970s, but the approach used became more consistent beginning in 1980. It is the sum of miles of spawn observed each day during the spawning season. While the mile-days of milt survey is a relative index of abundance, it is the longest abundance time series used in the model. Acoustic surveys collected by the Prince William Sound Science Center started in the mid-1990s and ended in 2021. ADF&G has also collected herring age, sex, and size data from PWS commercial fisheries and fishery-independent research projects since 1973. Egg deposition scuba surveys were conducted by ADF&G in 1983, 1984, and 1988–1997. Recently, we began an annual survey of the number of age-1 herring schools in PWS. The entire coastline of PWS is flown and the schools and school size identified by an observer. The number of schools is then weighted by the school size to provide an index of abundance.

Status and trends: A rapid rise in the estimated prefishery biomass occurred in the 1980s and a subsequent decline in the 1990s (Figure 96). There is not agreement about the cause of the decline in the early 1990s, but an outbreak of viral hemorrhagic septicemia (VHS) is one mechanism thought to be possibly responsible for the decline. After that decline, the population remained fairly steady. In recent years the BASA model estimated a declining trend in herring biomass, with a rapid increase beginning in 2019 and continued through 2022 (Figure 96). The decline in the observed mile-days of milt is more rapid than the model decline (Figure 97) but also shows a rapid increase starting in 2019. The rapid increase is associated with the recruitment of the large 2016 year class to the spawning biomass. The observed mile-days of milt in 2020 continued to increase as the 2016 year class continued to recruit into the spawning biomass. By 2021 the 2016 year class was fully recruited to the spawning biomass and the mile-days of milt continued to increase through 2022 due to other recruit classes or increased fecundity as the herring grew older. In 2023 the observed mile-days of milt decreased from the previous year. The 2016 cohort reached age-7 and annual mortality was likely not offset by new recruitment. A similar trend in mile-days of milt was observed at Kayak Island between 2021 and 2023, the limited time series when aerial surveys were flown more consistently.

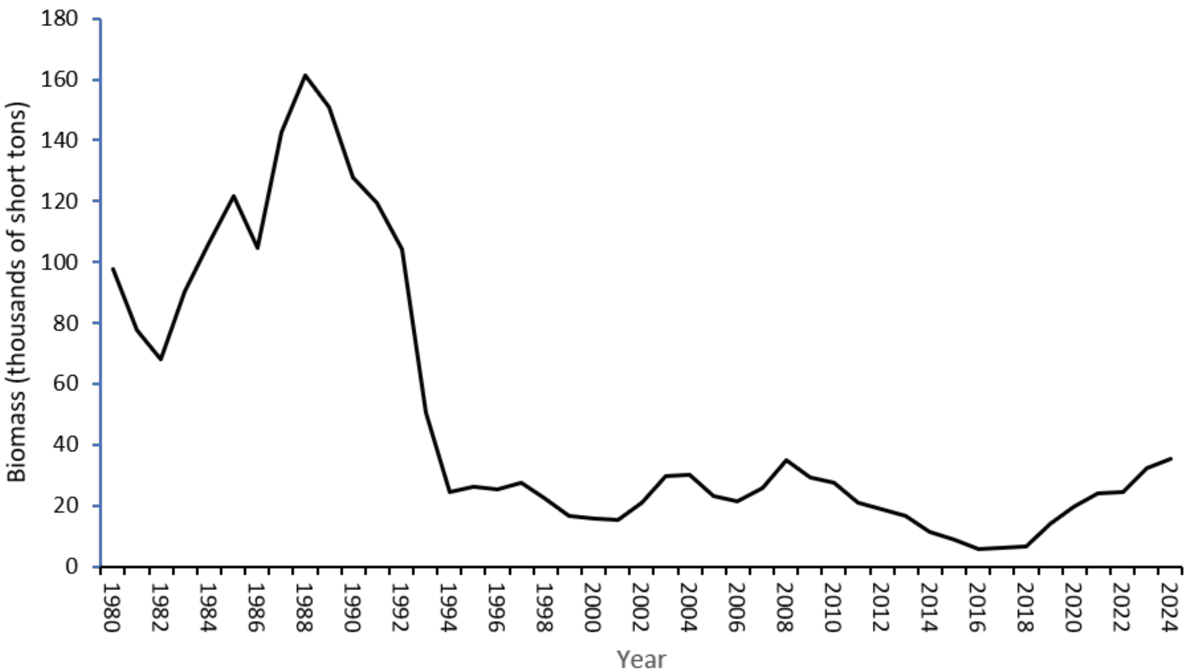

Figure 96: The Bayesian age-structured assessment model median estimate of the pre-fishery biomass.

The time series of the age-1 herring school observations is shown in Figure 98. The 2016 year class appears in the 2017 survey of age-1 herring. While the 2012 herring year class was strong at other locations, it was not a strong year class in PWS. This year we observed fewer schools than in the recent past. The level is consistent with what is expected after a potentially large year class such as those observed the last two years.

Factors influencing observed trends: The building trend in herring biomass was associated with the recruitment of the 2016-year class. The 2016-year class was a productive year class for herring throughout the Gulf of Alaska, with recruit to spawner metrics across the region being nearly four times greater than the next most successful year class (1980). In 2024, this cohort reached age-8 and there is concern that new recruitment may not offset the mortality of this strong age class. However, 2024 ASL data indicates high proportions of age-4 and age-5 fish and mile-days of milt and biomass increased from 2023 suggesting multiple cohorts may be able to replace fish aging out of the population.

Implications: The PWS herring population has increased from the historic low biomass that occurred in 2017 and remains near the level for consideration of a commercial fishery. 2024 age compositions show age-4 and 5 fish represent a significant portion of the spawning population and may nearly offset natural mortality of the 2016-year class. The number of age-1 herring observed in 2024 is the lowest since 2016 and suggests it may be an especially small cohort.

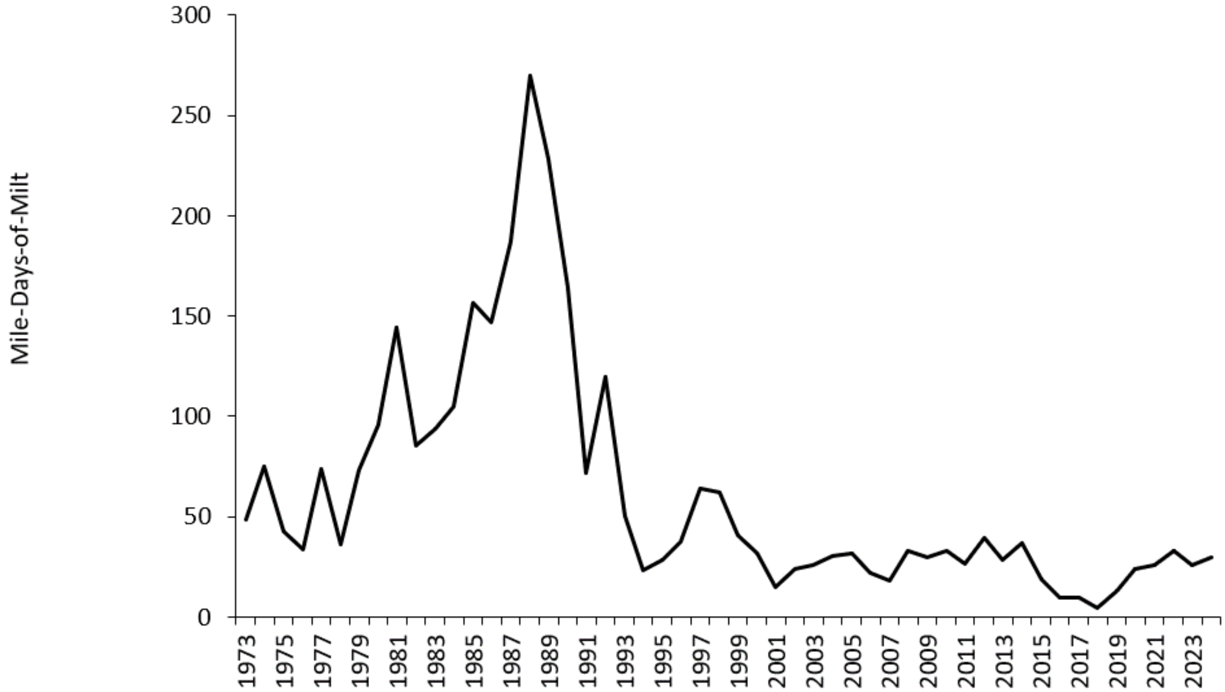

Figure 97: Mile-days of milt in Prince William Sound based on aerial surveys, and biomass estimates from acoustic surveys. Includes preliminary results of the 2023 survey from Alaska Department of Fish and Game.

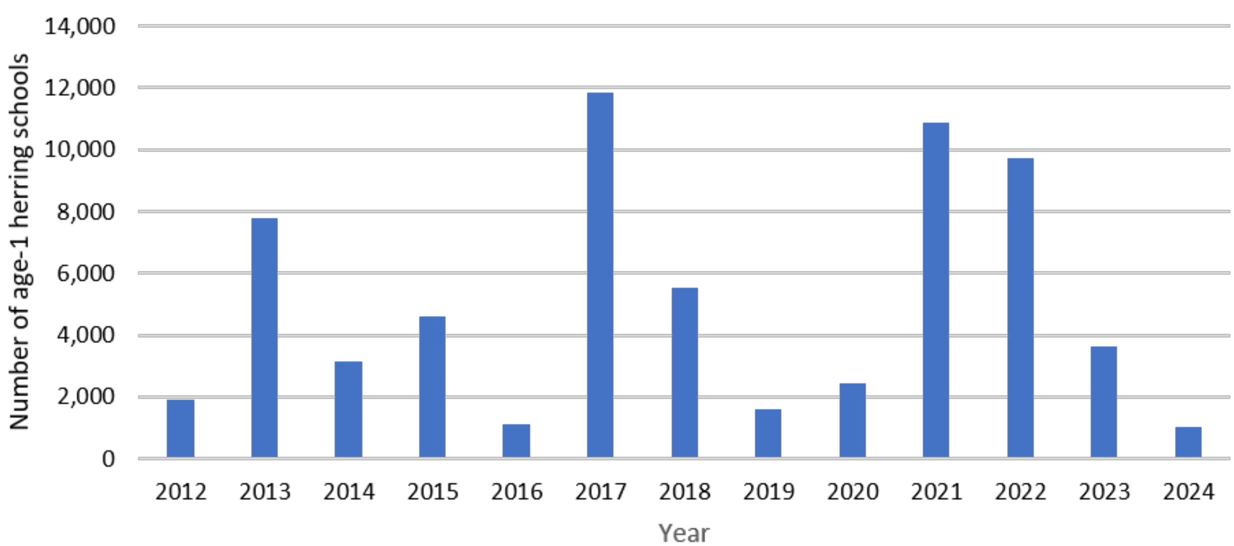

Figure 98: The school-size weighted number of age-1 herring schools in Prince William Sound.

Fall Surveys of Humpback Whales in Prince William Sound

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Last updated: Ocotber 2024

Description of indicator: The humpback whale population in the North Pacific rebounded from near extinction from commercial whaling in the late 1960s to an estimated population size of 34,000 individuals in 2012 (Barlow et al., 2011; Cheeseman et al., 2024). During 2014 – 2016, however, the northeast Pacific marine heatwave reduced prey availability resulting in a loss of 7,000 humpback whales, a 20% decline in the North Pacific basin (Cheeseman et al., 2024). Over much of the same period in Prince William Sound, the abundance of the dominant forage fish, Pacific herring, shifted from an abundant state to a diminished state. A commercial fishing moratorium has not restored the herring population to its former abundance. Humpback whale abundance and calf production within Prince William Sound often tracks herring abundance and indicates the ability of the ecosystem to support populations of large vertebrate predators.

Status and trends: Pre-heatwave foraging observations from 2008 – 2013, documented up to 80 individual whales targeting shoals of energy rich adult herring in predictable locations as they moved into the Sound. During and post- heatwave surveys found far fewer whales and changes in foraging behaviors and target prey. The few whales present were feeding individually on small schools of prey. Our September 2024 survey, yielded similar post-heatwave results in foraging. Five mother calf pairs were seen in September of 2024 which was comparable to the four seen in 2023, suggesting that foraging conditions in Prince William Sound are improving but not to pre-heatwave levels. The encounter rate for humpback whales (number of whales/nm traveled) in 2024 was on par with 2023, showing a slight increase relative to the 2017 – 2022 surveys (Table 5). Preliminary observations from acoustic surveys for prey in 2024 suggest that herring and euphausiids abundance is lower than last year. A potential decline in prey abundance was supported by observations of the whales foraging behavior. As in 2023, whales were targeting euphausiids in the Whale Bay, Bainbridge Pass area and small schools of juvenile herring throughout the rest of the Sound. Three whales were seen feeding on adult herring near Glacier Island during the September survey.

Factors influencing observed trends: The abundance of suitable whale prey in Prince William Sound seems to be fairly stable. Humpback whale numbers are slowly recovering within Prince William Sound from the impacts of the northeast Pacific marine heatwave yet remain well below their pre-heatwave abundance. We did not encounter any exceptionally large concentrations of prey as in 2022 and 2023, however, an increase in humpback whale calf production across the Gulf of Alaska in 2024 implies improved prey availability in the previous two years. A female humpback whale requires three years of successful forage to rear a calf. She must be in good condition in year one to successfully migrate and conceive in year one, carry the fetus to term in year two, and nurse the calf in year three.

Implications: The trend in low whale numbers within Prince William Sound continues to differ with

Table 5: Index of humpback whale abundance and counts of calves in Prince William Sound.

Month/year	Whale counts	Calves counts	Nautical miles surveyed	Encounter rate whale/nm
Sep-08	71	7	412	0.17
Oct-11	62	2	441	0.14
Sep-12	81	5	444	0.18
Sep-13	113	6	355	0.32
Sep-14	181	1	427	0.42
Sep-17	12	0	543	0.02
Sep-18	17	1	541	0.03
Sep-19	35	0	573	0.06
Sep-20	14	2	331	0.04
Sep-21	23	0	525	0.04
Sep-22	19	1	504	0.04
Sep-23	34	4	497	0.07
Sep-24	38	5	540	0.07

observations from Southeast Alaska and Hawaii where sightings of adults are showing signs of recovery towards pre-heatwave levels. The continued increase in calf production seen in 2023 and 2024 demonstrates that whales are foraging successfully, a positive sign for ecosystem recovery. However, lower observation of prey during 2024 within Prince William Sound may be of some concern.

Fishing Indicators

Maintaining Diversity: Discards and Non-Target Catch

Time Trends in Groundfish Discards

Contributed by Anna Abelman, Resource Ecology and Fisheries Management Division, AFSC, NOAA Fisheries, and Alaska Fisheries Information Network, Pacific States Marine Fisheries Commission
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Last updated: September 2023

This contribution was not updated this year. Please refer to the archives[48] for past reports.

Time Trends in Non-Target Species Catch

Contributed by George A. Whitehouse[1] and Sarah Gaichas[2]
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Last updated: August 2024

Description of indicator: This indicator reports the catch of non-target species in groundfish fisheries in the Gulf of Alaska (GOA). 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).

[48]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

The catch of non-target species/groups from the GOA includes the reporting areas 610, 620, 630, 640, 649, 650, and 659[49]. 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 trend in the catch of jellies in from 2020 – 2023 has been flat, with the time series low in 2022. The catch of Scyphozoan jellies in the GOA has been variable from 2011 – 2020, with peaks in 2012, 2015, 2016, and 2019 (Figure 99). Scyphozoan jellies are primarily caught in the pollock fishery. The catch of structural epifauna gradually increased from 2011 to 2016, and has since trended downward to the time series low in 2023. Sea anemones comprised the majority of the structural epifauna catch from 2011 – 2019, and were co-dominant with unidentified corals and bryozoans from 2020 – 2022. Sponges were the dominant component of structural epifauna catch in 2023/ Structural epifauna has primarily been caught in hook and line and non-pelagic trawl fisheries. The catch of assorted invertebrates increased from 2012 to a peak in 2015 then decreased each year to a low in 2021 and has remained low in 2022 and 2023. Sea stars dominate the assorted invertebrate catch, accounting for more than 86% of the total assorted invertebrate catch in each year. Sea stars are caught primarily in pot and hook and line fisheries.

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

Jellyfish population dynamics are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, wind-mixing, ocean currents, and prey abundance (Purcell, 2005; Brodeur et al., 2008). The lack of a clear trend in the catch of scyphozoan jellies may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries.

Implications: The catch of structural epifauna and assorted invertebrates is very low compared with the catch of target species. Abundant jellyfish may have a negative impact on fishes as they compete with planktivorous fishes for prey resources (Purcell and Sturdevant, 2001), and may prey upon the early life history stages (eggs and larvae) of fishes (Purcell and Arai, 2001; Robinson et al., 2014). Additionally, jellyfish may be an important prey resource for predators, including commercially important groundfishes (Brodeur et al., 2021).

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

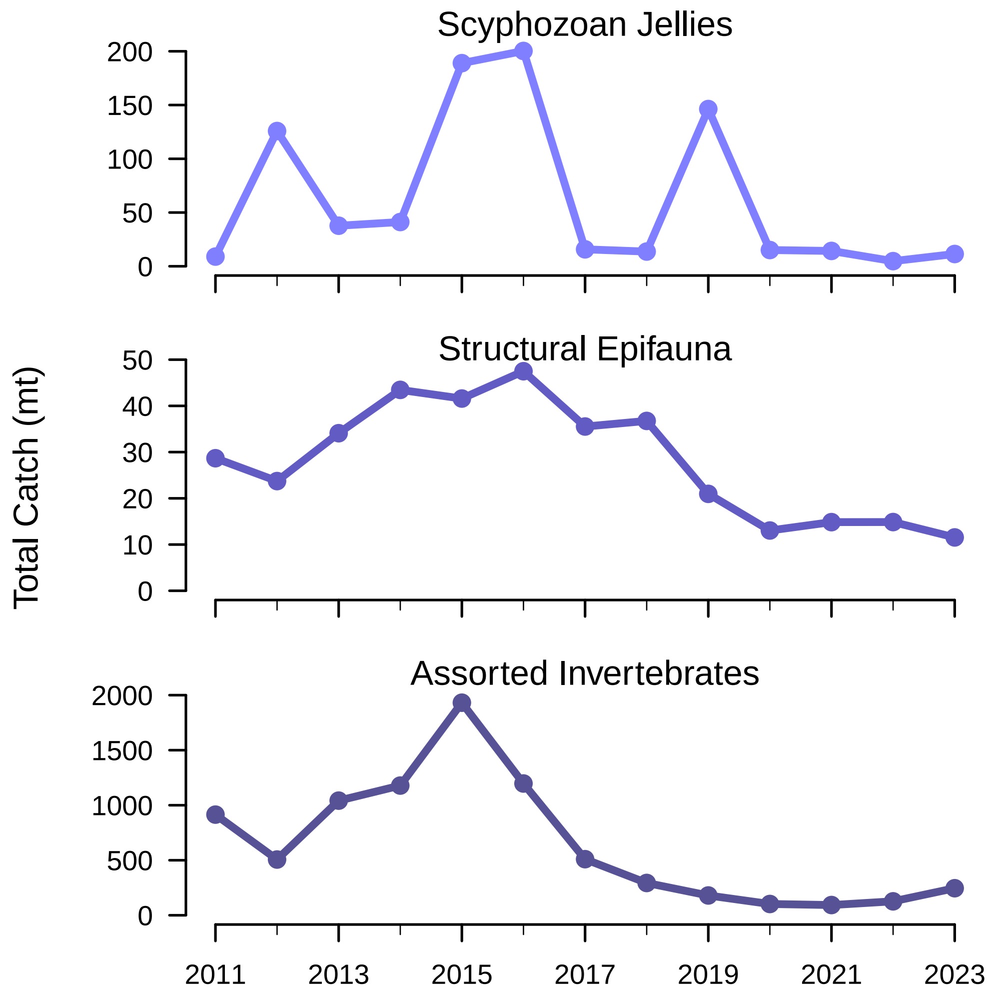

Figure 99: Total catch of non-target species (tons) in the GOA groundfish fisheries (2011 – 2023). Note the different y-axis scales between species groups.

Seabird Bycatch Estimates for Groundfish Fisheries

Contributed by Jessica Beck[1], Adam Zaleski[2], and Cathy Tide[2]
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Last updated: September 2024

Description of indicator: This Report provides estimates of the numbers of seabirds caught as bycatch in commercial groundfish fisheries operating in federal waters of the U.S. Exclusive Economic Zone of the Gulf of Alaska for the years 2012 through 2021, and halibut fisheries for the years 2013 through 2021. Data collection on the Pacific halibut longline fishery began in 2013 with the restructured North Pacific Observer Program. Estimates of seabird bycatch from earlier years using different methods are not included here. Fishing gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic trawl. These numbers do not apply to jig, gillnet, seine, or troll fisheries[50].

The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2014, 2010) and provides near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. These estimates are based on three sources of information: (1) data provided by NMFS-certified fishery observers deployed to vessels and floating or shoreside processing plants, (2) video review of electronically monitored (EM) fixed gear vessels, and (3) industry reports of catch and production. CAS also estimates non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. The three data sets used by CAS are subject to change over time. Observer deployment plans are reviewed and updated annually in the Annual Deployment Plan[51].

This Report delineates and separately discusses estimates of seabird bycatch in the eastern GOA and the western GOA (divided at 147 °W). . Estimates of seabird bycatch from the eastern Gulf of Alaska include reporting areas 659, 650, 640, and 649 (east of 147 °W). Estimates from the western GOA include reporting areas 649 (west of 147 °W), 630, 620, and 610 (east of 164 °W)[52].

Status and trends: The number of seabirds estimated to be caught incidentally in eastern Gulf of Alaska fisheries in 2023 (332 birds) was substantially more than in 2022 (45 birds), and was above the 2013 – 2022 average of 239 birds by 38% (Table 6; Figure 100). Laysan albatross (*Phoebastria immutabilis*), black-footed albatross (*Phoebastria nigripes*), and gulls (Larid spp.) were the most common species caught incidentally in eastern Gulf of Alaska fisheries. In 2023, the number of Laysan albatross (119 birds) was 14 times greater than the 2013 – 2022 average of 8 birds per year. There was also increased

[50]This report does not include estimates of seabird bycatch in fisheries using jig, gillnet, seine, or troll gear because NOAA Fisheries does not have independent observer data from these fisheries. These estimates also do not apply to State of Alaska-managed salmon, herring, shellfish (including crab), or dive fisheries.

[51]https://www.fisheries.noaa.gov/resource/document/2023-annual-deployment-plan-observers-and-electronic-monitoring-groundfish-and

[52]https://www.fisheries.noaa.gov/alaska/commercial-fishing/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones

take of black-footed albatross in 2023 (93 birds) compared to 2022 (13 birds) but this level of take was 24% below the 2013 – 2022 average. The estimated number of gulls caught in 2023 (77 birds) was slightly above the 2013 – 2022 average (75 birds). Take of shearwater species (*Ardenna* spp.) in 2023 (38 birds) was higher than the 2013 – 2022 average of 3 birds a year.

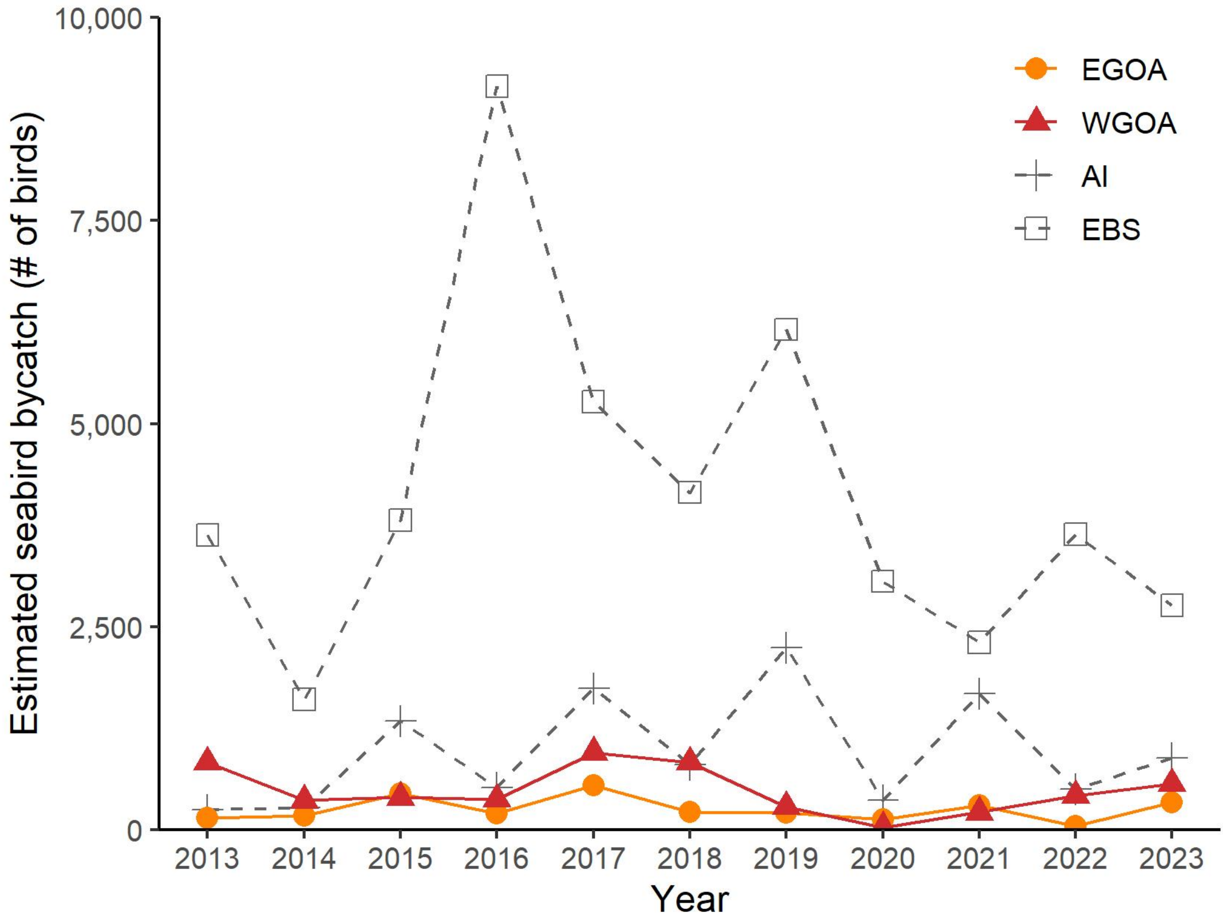

Figure 100: Total estimated seabird bycatch in eastern Gulf of Alaska (EGOA), western Gulf of Alaska (WGOA), Aleutian Islands (AI), and eastern Bering Sea (EBS), groundfish and halibut fisheries, all gear types combined, 2013 through 2023.

The number of seabirds estimated to be caught incidentally in western Gulf of Alaska fisheries in 2023 (566 birds) increased from that in 2022 (419 birds) by 21%, and was above the 2013 – 2022 average of 469 birds for the region (Table 7, Figure 100). The increase in 2023 compared to 2022 and the 10-year average was largely due to a very high number of unidentified birds (n = 404). Overall, seabird bycatch has increased in this region since 2020, which likely reflects a return to pre-pandemic fishing effort and observer coverage. Of note, black-footed albatross take in this region decreased in 2023 by 98%, in comparison to both 2023 and the 2013 – 2022 average. Shearwater take (49 birds) was higher in 2023 than in 2022 (0 birds). Northern fulmar (*Fulmarus glacialis*) take also decreased in this region, although this may be related to the high number of unidentified seabirds.

Table 6: Estimated seabird bycatch in the eastern Gulf of Alaska groundfish and halibut fisheries for all gear types, 2013 through 2023. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Unidentified Albatross	29	0	0	0	0	42	1	0	0	0	0
Short-tailed Albatross	0	0	0	0	0	0	0	0	0	0	0
Laysan Albatross	9	3	6	4	2	4	36	13	5	0	119
Black-footed Albatross	44	82	220	95	238	105	100	74	254	13	93
Northern Fulmars	13	5	23	8	37	21	47	2	12	2	4
Shearwaters	0	0	1	2	24	2	2	6	0	0	38
Storm Petrels	0	0	0	0	0	0	0	0	0	0	0
Gulls	51	78	152	87	244	41	22	19	29	30	77
Kittiwake	0	0	0	0	0	0	0	0	0	0	0
Murre	0	0	0	0	0	0	0	0	0	0	0
Puffin	0	0	0	0	0	0	0	0	0	0	0
Auklets	0	0	1	0	0	0	0	0	0	0	0
Cormorants	0	0	25	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0
Unidentified Birds	0	0	17	2	1	0	0	14	0	0	0
Grand Total	147	168	444	198	546	215	207	128	300	45	332

Table 7: Estimated seabird bycatch in the western Gulf of Alaska groundfish and halibut fisheries for all gear types, 2013 through 2023. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Unidentified Albatross	2	0	0	0	0	8	18	0	0	11	0
Short-tailed Albatross	0	0	0	0	0	0	0	0	0	0	0
Laysan Albatross	57	23	29	39	23	19	2	9	15	0	29
Black-footed Albatross	384	177	115	75	441	202	112	8	86	169	3
Northern Fulmars	239	46	57	173	230	224	85	5	81	193	28
Shearwaters	51	0	4	17	12	38	30	2	0	0	49
Gulls	88	74	126	55	231	199	35	3	23	46	52
Kittiwake	0	0	0	0	0	0	0	0	0	0	0
Murre	0	0	0	0	0	0	0	0	0	0	0
Puffin	0	0	0	0	0	0	0	0	0	0	0
Auklets	0	1	45	0	0	0	0	0	0	0	0
Other Alcids	0	37	0	0	0	0	0	0	0	0	0
Cormorants	0	0	2	0	0	0	0	0	0	0	0
Other	0	0	2	0	0	0	0	0	0	0	0
Unidentified Birds	7	0	17	16	13	140	0	3	10	0	404
Grand Total	828	360	394	375	951	831	283	29	216	419	566

Figure 101: Total estimated albatross bycatch in eastern Gulf of Alaska (EGOA), western Gulf of Alaska (WGOA), Aleutian Islands (AI), and eastern Bering Sea (EBS) groundfish and halibut fisheries, all gear types combined, 2013 through 2023.

Factors influencing observed trends: Many factors influence annual variation in bycatch rates, including seabird distribution and ecology, population trends, prey supply, and fleet dynamics.

Overall, seabird bycatch in the groundfish and halibut fisheries in the Gulf of Alaska increased in 2023 compared to 2022. These increases are primarily observed in the Laysan albatross takes in eastern Gulf of Alaska, and in "unidentified" bird takes in western Gulf of Alaska. One possible factor behind this increase, especially for the unidentified takes in the western Gulf of Alaska, may be that fishing effort and observer coverage are returning to pre-pandemic levels. In 2023, the 404 "unidentified" bird takes in the western Gulf of Alaska are extrapolated from 4 unidentified birds observed in fixed gear electronic monitoring review and 8 unidentified birds recorded by onboard observers. Efforts are being made by NOAA to see if this number can be reduced for future reporting. For overall fishing effort trends in the region, the COVID-19 pandemic disrupted normal fishing operations throughout Alaska, and the number of fishing trips in 2020 (13,493) and 2021 (12,873) were the lowest recorded since 2012 (Tide and Eich, 2022). Less fishing effort would reduce the opportunities for interactions with seabirds and less seabird bycatch. With the exception of the eastern Bering Sea, seabird bycatch increased in 2023 but was still lower than many pre-pandemic years.

The increase in Laysan albatross takes in the eastern Gulf of Alaska in 2023 occurred in hook-and-line fisheries. This level of Laysan albatross bycatch in the region is unusual since the species is often associated with less productive, pelagic waters and is more frequently caught as bycatch in the Aleutian Islands and southeastern Bering Sea regions. This distinct pulse of bycatch in the eastern Gulf of Alaska may be related to fleet dynamics in the region. It is also possible that there were increased numbers of Laysan albatross in that area, possibly following oceanographic or ecological cues such as strong westerly winds coming from the Aleutian region. Streamer lines are required for hook-and-line vessels greater than 26 ft. overall length in this region [53].

Shearwater take in both Gulf of Alaska regions increased in 2023, compared to 2022. While this may be due to many factors, including fishing fleet dynamics, there may be some possible oceanographic and ecological drivers. Shearwaters rely extensively on wind to fly between foraging regions. They are also more frequently caught as bycatch in fisheries in the Aleutian Islands region. The same strong, westerly wind that may have increased Laysan albatross abundance in the eastern Gulf of Alaska region could have also increased shearwater abundance in both Gulf of Alaska regions. Foraging conditions may have been more limited in the Aleutian Islands region, as possibly indicated by a shearwater die-off on Akutan Island (Ortiz and Zador, 2023). Additionally, data from black-legged kittiwake (*Rissa tridactyla*) colonies at the Semidi Islands indicated that there was reduced availability of sandlance and age-0 pollock (Ferriss, 2023). Reductions in the natural prey of shearwaters may lead to increased reliance on fishery bait and discards, and subsequently to increased bycatch.

In the sablefish IFQ fishery, vessels continued to expand the use of pot gear in place of hook-and-line gear in 2023. This was primarily done in an attempt to avoid whale depredation on sablefish catch, but has had the added bonus of also reducing seabird interactions, particularly for black-footed albatross in the western Gulf of Alaska where only 3 were caught in 2023. Take of seabirds by pot gear is relatively rare compared to take of seabirds by hook-and-line gear. If the sablefish IFQ fishery continues to increase its use of pot gear over hook-and-line gear, we would expect to see reduced take of seabirds in this fishery.

It is important to note that standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates may be downward biased for trawl fisheries in these regions.

ESA species: On December 8, 2023 there was a lethal take of an endangered short-tailed albatross (*Phoebastria albatrus*) in the Gulf of Alaska, Pacific cod (*Gadus macrocephalus*) hook-and-line fishery. The take occurred approximately 33 nautical miles southeast of Unalaska Islands, in NMFS reporting area 610. The bird was a juvenile which was banded at the Hatsunezaki colony on Torishima Island in Japan in March 2023. This is the first recorded take of a short-tailed albatross by any fisheries operating in the Bering Sea and Aleutian Islands (BSAI) or GOA Management Areas since October 16, 2020. Since 1995 this is only the second take of a short-tailed albatross south of the Aleutian Islands. The vessel used dual streamer lines as deterrents during the setting, which were in good condition. This observed take is extrapolated to a total of 3 estimated birds, 2 of which are accounted for in the Aleutian Islands Ecosystem Status Report due to fishing area estimation methodology.

Implications: Estimated seabird bycatch in the Gulf of Alaska fisheries off of Alaska increased in 2023 when compared to 2022, but remained comparable to pre-pandemic levels of bycatch in the region.

It is difficult to determine how seabird bycatch estimates and trends are linked to changes in ecosystem components. Many seabird species caught in groundfish and halibut fisheries in Alaska are wide-ranging

[53] https://www.fisheries.noaa.gov/alaska/bycatch/seabird-avoidance-gear-and-methods

and can fly hundreds of miles per day, resulting in less restricted foraging areas. Of the species caught as bycatch in the Gulf of Alaska in 2023, only gulls and northern fulmars breed in the region. Changes in fleet dynamics also affect seabird bycatch estimates, further complicating direct links with ecosystem components.

Fisheries bycatch can also affect seabird populations directly. In Alaska, bycatch of federally listed species is tightly regulated, and NOAA works in conjunction with outside agencies and partners to assess and manage the risk of bycatch to unlisted seabird species, including requiring seabird bycatch mitigation tools in hook-and-line groundfish and halibut fisheries.

Maintaining and Restoring Fish Habitats

Fishing Effects to Essential Fish Habitat

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Last updated: August 2023

This contribution was not updated this year. Please refer to the archives[54] for past reports.

Sustainability (for consumptive and non-consumptive uses)

Fish Stock Sustainability Index

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Last updated: August 2024

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[55]. 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

[54] https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands
[55] https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates

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.

In the GOA region there are 14 FSSI stocks including sablefish. The assessment for sablefish is based on aggregated data from the GOA and BSAI regions. Additionally, in Alaska there are 26 non-FSSI stocks, three ecosystem component species complexes, and Pacific halibut, which are managed under an international agreement. Two of the non-FSSI crab stocks in the BSAI region are overfished but are not subject to overfishing. None of the other non-FSSI stocks are known to be subject to overfishing, are overfished, or known to be approaching an overfished condition. For more information on non-FSSI stocks see the Status of U.S. Fisheries webpage[56].

Status and trends: The GOA FSSI in 2024 remains at 86.6%, after increasing from 84.8% in 2022 to 86.6% in 2023 (Figure 102). As of June 30, 2024, none of the GOA groundfish stocks or stock complexes are subject to overfishing, are known to be overfished, or known to be approaching an overfished condition (Table 8). Points continue to be deducted for the shortraker rockfish stock, the demersal shelf rockfish complex, and the thornyhead rockfish complex for unknown status determinations and not estimating B/B_{MSY}.

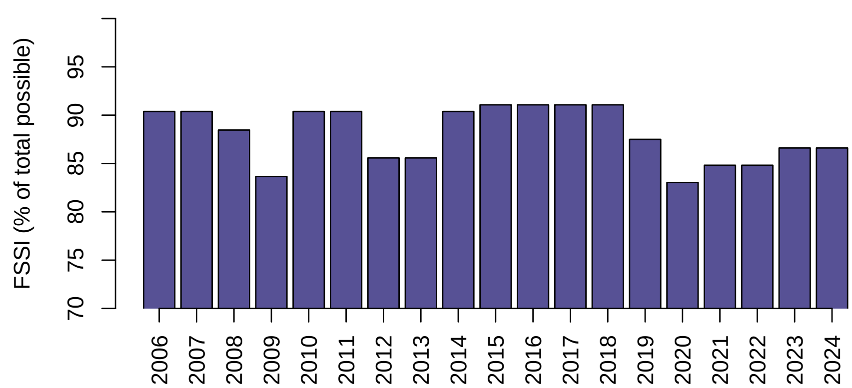

Figure 102: The trend in GOA FSSI from 2006 through 2024 as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the NOAA Fishery Stock Status Updates[57].

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

Table 8: GOA FSSI stocks under NPFMC jurisdiction updated June 2024 adapted from the NOAA Fishery Stock Status Updates[58]. See FSSI and Non-FSSI Stock Status Table on the Fishery Stock Status Updates webpage for definitions of stocks and stock complexes. The multiple B/B_{MSY} values in a given row represent western/central and eastern regions for northern and southern rock sole (shallow water flatfish) and rex sole.

Stock	Overfishing	Overfished	Approaching	Progress	B/B_{MSY}	FSSI Score
GOA Arrowtooth flounder	No	No	No	N/A	2.05	4
GOA Flathead sole	No	No	No	N/A	2.83	4
GOA Shallow water flatfish complex[a]	No	No	No	N/A	1.44/2.40/1.86/2.19	4
GOA Rex sole	No	No	No	N/A	2.79/2.18	4
GOA Blackspotted and rougheye rockfish complex[b]	No	No	No	N/A	1.68	4
GOA Shortraker rockfish	No	Unknown	Unknown	N/A	Not estimated	1.5
GOA Demersal shelf rockfish complex[c]	No	Unknown	Unknown	N/A	Not estimated	1.5
GOA Dusky rockfish	No	No	No	N/A	1.79	4
GOA Thornyhead rockfish complex[d]	No	Unknown	Unknown	N/A	Not estimated	1.5
Northern rockfish-western / central GOA	No	No	No	N/A	1.37	4
GOA Pacific ocean perch	No	No	No	N/A	1.91	4
GOA Pacific cod	No	No	No	N/A	0.88	4
Walleye pollock-western / central GOA	No	No	No	N/A	1.93	4
GOA BSAI Sablefish[e]	No	No	No	N/A	1.49	4

The overall Alaska FSSI generally trended upwards from 80% in 2006 to a high of 94% in 2018, then trended downward from 2018 to 2020 (Figure 103). It has remained generally flat since at 88.9% in 2023.

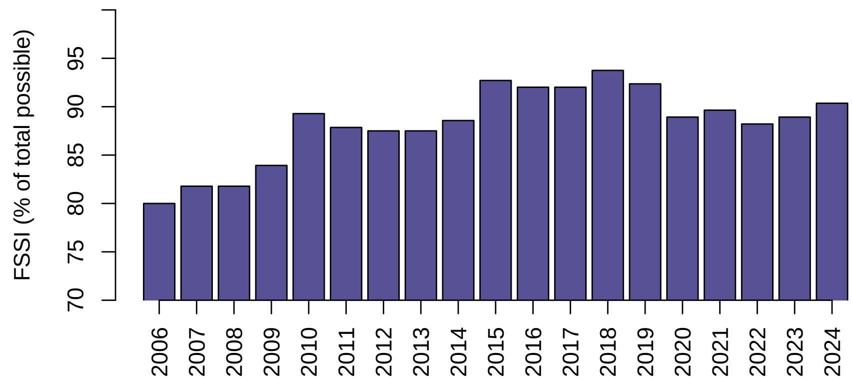

Figure 103: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2024. The maximum possible FSSI is 140 for 2006 to 2014, 144 from 2015 to 2019, and 140 since 2020. All scores are reported through the second quarter (June) of each year, and are retrieved from the NOAA Fishery Stock Status Updates website[59].

Factors influencing observed trends: Since 2006, the GOA FSSI has been generally steady, fluctuating between a low of 83% in 2020 to a high of 91% from 2015–2018 (Figure 103). There were minor drops in the FSSI in 2008–2009, in 2012–2013, and 2019–2020. In 2008 and 2009, a point was lost each year for B_{MSY} walleye pollock in the western/central GOA dropping below 0.8. In 2009, an additional 2.5 points were lost for the Rex sole stock having unknown status determinations and for not estimating B_{MSY}. In 2012 and 2013, 2.5 points were lost for having unknown status determinations and not estimating B_{MSY} for the deepwater flatfish complex. The drop in 2019 was due to biomass dropping below 80% B_{MSY} for Pacific cod and sablefish. An additional point was gained in 2023 for GOA Pacific cod biomass increasing above B_{MSY}.

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

Total Annual Surplus Production and Overall Exploitation Rate of Groundfish

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Last updated: August 2022

This contribution was not updated this year. Please refer to the archives[60] for past reports.

[60]https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

Skipper Science 2024 Observation Report

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Last updated: October 2024

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Introduction: This is a summary report by the Skipper Science Partnership outlining significant observations submitted by fishers and others on the ocean in Alaska through the Skipper Science iOs/Android app from January 1- August 30th of 2024, as well as data collected in 2023 that remained a consistent theme or throughline in 2024. The mission of the Skipper Science Partnership is to center communities in fisheries management by connecting fishermen and scientists to support resilient fisheries and build trust[61]. The central goal of the program is to facilitate community-driven monitoring and citizen science programs for real-time data collection on ecosystems, fisheries, species at risk, and climate trends. The app software provides a flexible data collection tool utilized by fishers and persons on the ocean who are registered users. It is a goal of the program to foster trust and collaboration in identifying priority areas for climate adaptation in frontline Alaskan communities.

This report has been written specifically for submission to the Resource Ecology and Fisheries Management (REFM) Division of the National Oceanic and Atmospheric Administration (NOAA) in consideration of the forthcoming 2024 Ecosystem Status Report published by NOAA. Citizen science as a methodology has been recognized by NOAA as a valuable contribution of "...non-traditional data sources [with] the potential to provide meaningful, high-quality data [therefore which] should be routinely considered for use in fisheries science and management when designed appropriately" (Oremland et al., 2022), further demonstrated in the 2021 NOAA Citizen Science Strategy (NOAA, 2021), and detailed in the 2023 NOAA Citizen Science Action Plan (NOAA, 2023). The Skipper Science program has demonstrated success in leveraging technology with trusted partnerships within fishing communities to capture real-time data relevant to changing ocean conditions, and species managed by NOAA (Reda-Williams et al., 2023). This report outlines general observations made in 2023 and 2024, showing what observers within the program deemed notable, as they were not operating under specific guidance from program managers on what to report on. Skipper Science hopes to share what fishermen in 2023 – 2024 have felt are significant to submit, and communicate through our program that would also be meaningful to share with REFM and contribute to the Ecosystem Status Report.

This report will cover three main categories of observations from this season's data throughout the Aleutians and Gulf of Alaska presented in chapters: 1. Citizen science walrus observations in the western Aleutian Islands, 2. Citizen science forage fish observations in the Gulf of Alaska, 3. Citizen

[61]https://www.skipperscience.org/about-1

science fishing and predator/prey interactions in the Gulf of Alaska. Chapter 2 and 3 are included in this 2024 GOA Ecosystem Status Report, and include data from 2023 and 2024 as forage fish predation and fishing and predator interactions have remained significant and numerous observations across the years. These three categories were defined after analyzing the 2024 data submitted to Skipper Science, and assessing the trends that emerged. We also selected, through quality assurance processes, for the most complete and detailed pieces of data (or 'observations'). The three main categories listed above illustrate major themes, largest amounts of data (relative to the data set as a whole), and the most complete observations.

Methodology: We engage with citizen science here as a method by which those who do not hold a formal title as a 'scientist' engage in data collection and monitoring. The main demographics of citizen scientists that engage with Skipper Science are commercial fishers who share and submit observations through a smartphone data collection app. Fisheries citizen science is a continuously used and growing component of scientific processes to inform a myriad of fisheries science and management areas of inquiry and concern (McKinley et al., 2015). It is a methodology that rests on the understanding that fishers are a group that are already observing and witnessing marine environments and ecosystem health at many times of the year over long continuous and repeating periods of time, and are invested in and can participate in data collection and monitoring of fisheries and marine environments. As a practiced method, it can better relationships between fishers, scientists, and managers; better communication concerning marine environmental research and management and fisheries across and between groups; fill data gaps/strengthen data sets by expanding elements such as seasonality and geographic range (Bonney et al., 2021; McKinley et al., 2017; DiBattista et al., 2021).

The observations included in this summary report were sent in through the Skipper Science standard general observation data collection form. The general observation form allows for fishers to submit data that they feel compelled to submit through a standard form which allows for flexibility in observation topic and type while being standardly formatted which allows for the compiling and combining of data from many individuals on different topics and species. The following fields are included in the data collection form: data and time; name of observer; species/object; ID confidence; text comments; audio recording/comments; GPS; photo capture/selection. The addition of text and audio comments allows for an interdisciplinary approach to the type of data collected, analyzed, and utilized. The analysis and usage of qualitative data is expanded upon in more detail in each of the following chapter's methods sections. Outside of chapter specific selection, quotes included have been edited to some degree for readability, grammar, spelling, and sentence formatting, tense, and conjugation. Edits are illustrated by the usage of brackets. Any quotes that have portions cut from them will be illustrated by the usage of ellipses. The general data collection form was created by the Skipper Science Partnership in 2021 and refined over time with feedback from fishers and other Skipper Science participants. All data is collected through the Skipper Science app and is viewed and processed by the Skipper Science Partnership.

Ch.2 Citizen science forage fish observations in the of Gulf of Alaska

Summary: Data collected in 2023 and 2024 indicates the presence of capelin and Pacific herring (heretofore referred to as 'herring') in the stomach content of harvested salmon, particularly king salmon. The data was logged by salmon trollers in the Southeast region around Sitka. The predominant species observed in stomach contents was herring. Observations noting the presence of forage fish in 2023 and 2024 were sometimes also noted the presence of whales and seabirds. Direct predation was not often mentioned. Forage fish species identification in these instances is less exact; this data is available upon request if it is of interest. The following observations focus on the presence of specific forage fish species as stomach contents within salmon.

Introduction: Forage fish are generally defined as fish that are small, high in nutrient content, and are an important food source for many apex predators in the ecosystem including seabirds and larger fish such as salmon. Common forage fish in the Gulf of Alaska include herring, capelin, sand lance, and eulachon. Abundance and population fluctuations of forage fish can be important ecosystem indicators (Livingston et al., 2005). The importance of these species in the food web is recognized and acknowledged by Skipper Science observers through logging observations noting the presence of forage fish as stomach contents in troll caught salmon. Represented in the data collected in both the 2023 and 2024 Skipper Science seasons are three species of forage fish: herring, capelin, and sand lance (also known as needlefish).

Region(s): All observations of forage fish as stomach contents occurred in the Southeast region of the Gulf of Alaska, data collection points are displayed in Figure 104.

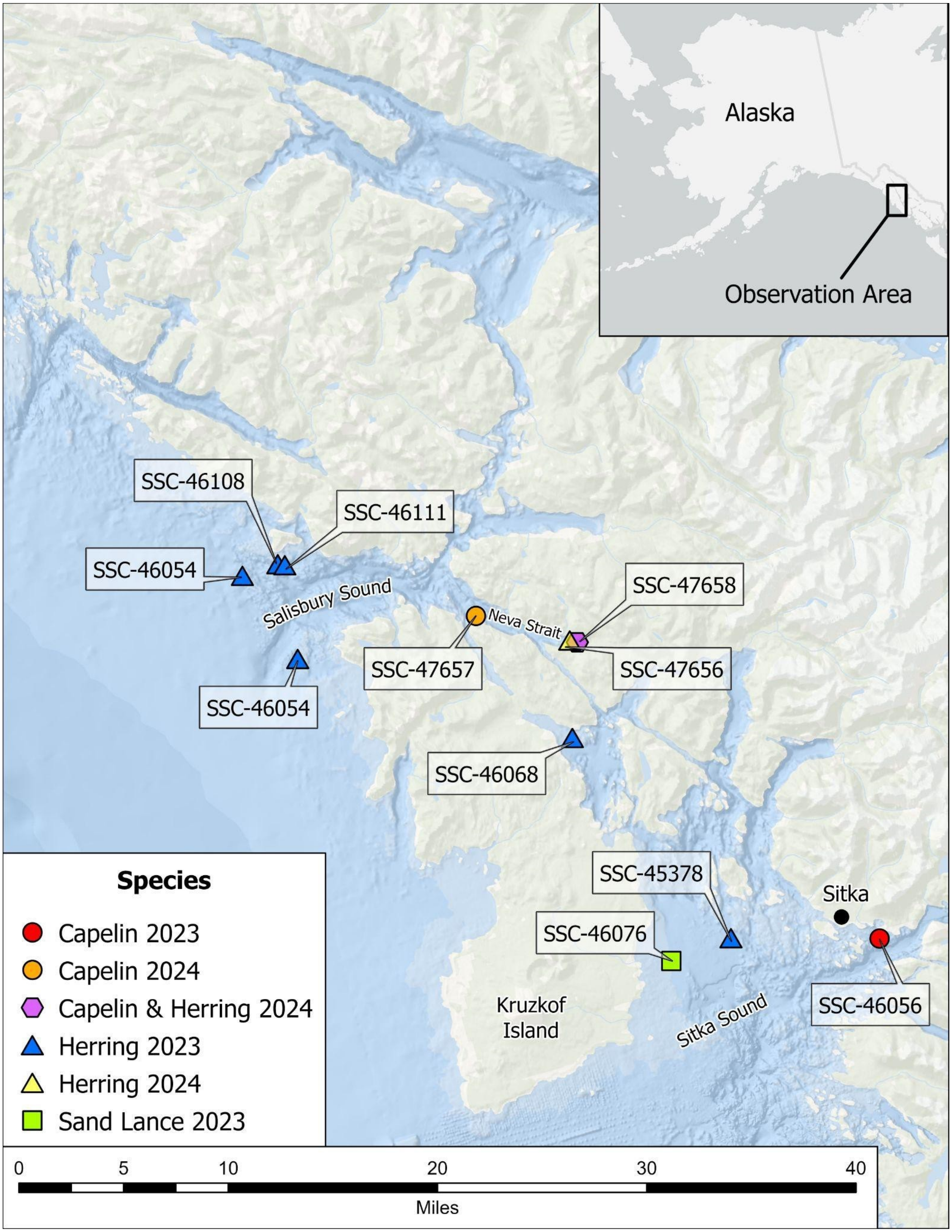

Figure 104: Map showing observations of forage fish in Southeast region in and around Sitka Sound and the surrounding area.

Methodology: Form fields relevant to this report include: GPS, species/object, date and time, text comments, and photo capture/selection. The quotes included have been edited by the Skipper Science team to include most relevant information deemed appropriate for this report. Quotes were analyzed for elements such as location, species presence, stomachs/stomach contents, All forage fish observations that were specific to stomach contents included comments by observers that made explicit mention of forage fish in salmon stomachs, while almost all forage fish observations sent in from 2023 – 2024 were directly noting herring, capelin, and sand lance presence in salmon stomachs.

Results: Three forage fish species were observed within King and Coho salmon stomachs across 2023 – 2024 being: herring, capelin, and sand lance (the names "King" and "Chinook" are used interchangeably throughout this report). Sand lance was only found in coho and king stomachs in 2023 observations. Capelin and herring are found in king salmon stomachs for both years with herring being the overall dominant species found. As evidenced in the photographs included in the data entries, many of the herring and capelin are adults with one observation notably documenting "Young of this Year herring as stomach content in King salmon in Sitka sound region" (SSC-46112, Skipper Science Partnership, 2023). Table 9 outlines the results of the 2023 and 2024 season in terms of number of observations of forage fish as stomach contents.

Table 9: Total number of Skipper Science observations in 2023 and 2024 (total in parenthesis for each year) and the total number of observations that noted forage fish (herring, capelin, and sand lance) in salmon stomachs.

Prey species	2023 (173)	2024 (67)	Predator salmon species
Herring	6	2	King salmon
Capelin	1	2	King salmon
Sandlance	2	0	Coho, King salmon
Total	9	4	

Herring: Between 2023 and 2024, a total of eight observations were sent in by trollers reporting on herring being found as king salmon stomach contents during the Southeast summer and winter king salmon troll fishery. Observations in 2024 included significantly less herring data than 2023, with observers noting "king salmon with capelin and herring in its stomach. Most had capelin very few with herring" (SSC-47658, Skipper Science Partnership, 2024), however, king salmon were still observed to have herring in their stomachs (SSC-47656, Skipper Science Partnership, 2024). Table 9 outlines the results of the 2023 and 2024 season in terms of number of herring observations as stomach content in salmon (also shown in Figures 105, fig.SSFig3herringphoto).

Figure 105: Left: Photo submitted in 2024 of herring taken out of a king salmon stomach sent in with observation SSC-47656. Right: Photo submitted of herring and capelin in 2024 taken out of a king salmon stomach sent in with observation SSC-47658.

Figure 106: Top Left: Photo submitted in 2023 of herring from a king salmon stomach sent in with observation SSC-46068. Top Right: Photo submitted in 2023 of herring that was still in the mouth of a king salmon sent in with observation SSC-46111. Bottom: Photo submitted in 2023 of 'young of this year' herring in a king salmon stomach sent in with observation SSC-46112.

Out of the six total observations that noted herring in king salmon stomachs for 2023, five included comments noting specifically herring in stomachs with some referencing "When [they] started finding the larger kings a lot of them had big herring in their stomachs" (SSC-46054, Skipper Science Partnership, 2023), "all [three first fish of the winter troll day] had herring in their stomachs" (SSC-45378, Skipper Science Partnership, 2023), and 'young of this year' herring found in [the] stomachs of king salmon"

(SSC-46112, Skipper Science Partnership, 2023) (SSC-46068, Skipper Science Partnership, 2023; SSC-46111, Skipper Science Partnership, 2023).

Capelin: A total of three observations were submitted of capelin in the stomachs of king salmon caught and reported by Southeast trollers in 2023 and 2024. Observation SSC-47658 notes both herring and capelin in the stomach of one king salmon and therefore is counted as a capelin and herring observation. While there are less capelin observations overall compared to herring, it is relevant to refer back to the comment from observation SSC-47658 that notes that in 2024 "most [stomachs] had capelin[,] very few with herring" (SSC-47658, Skipper Science Partnership, 2024). One comment from 2023 referenced "capelin found in [the] stomachs of the king salmon [they had] been catching" (SSC-46056, Skipper Science Partnership, 2023) with a comment from 2024 noting "Stomachs of King Salmon full of Capelin." Capelin were identified by observers by their smell with one individual noting that "Capelin smells like cucumber…" which contributed to their ability to identify the fish (SSC-46056, Skipper Science Partnership, 2023). Table 9 outlines the results of the 2023 and 2024 seasons in terms of number of capelin observed in salmon species' stomachs (also shown in Figures 107.

Figure 107: Left top and bottom: Photo submitted in 2023 of herring that was still in the mouth of a king salmon sent in with observation SSC-46111. Right: Photo submitted in 2023 of capelin taken out of a king salmon stomach sent in with SSC-46056, noting the cucumber smell of capelin.

Sand lance: Sand lance (or needlefish) were only submitted as forage fish observations in 2023, both were submitted as stomach contents of salmon. This is the only set of forage fish observations that references coho salmon stomach contents with one observer noting specifically "needle fish in a coho belly" (SSC-

46846, Skipper Science Partnership, 2023), with the other observation noting "needlefish/sandlance found in stomach of king salmon caught in Sitka Sound offshore of Kruzof Island out front of Fred's Creek" (SSC-46076, Skipper Science Partnership, 2023). These observations are the most scarce of the three forage fish as prey observations, however, they both take place in 2023 alone and are the only set of observations that mention coho predation on any forage fish. This is possibly caused by a dominant percentage of observations coming from trollers catching king salmon and not coho. Table 9 outlines the results of the 2023 and 2024 seasons in terms of number of sand lance observed in salmon species' stomachs (also shown in Figure 108.

Figure 108: Left: Photo submitted in 2023 of sand lance taken out of a coho salmon stomach sent in with observation SSC-46846. Right: Photo submitted in 2023 of a sand lance taken out of a king salmon stomach sent in with observation SSC-46076.

Discussion: It is notable that the forage fish observations across these two years were submitted by vessels within the salmon trolling fishery. This indicates that the nature of the trolling fishery poses the Skipper Science observers in this fishery to be sources for data on stomach contents of fish, as the opportunity to investigate stomach contents fits within the workflow of processing catch. Several observations were accompanied by photographs, which show the size and inferred age of the forage fish consumed.

Ch. 3 Citizen science fishing and predator/prey interaction observations in the Gulf of Alaska

Summary: The data is categorized by the animal observed interacting with fishing gear, or engaging in a predator/prey interaction. All data here was collected during the 2023 and 2024 seasons. The four predator types observed are orcas, sea lions, seals, and sharks. Some observations include species details when noted with confidence by the observer, with the dominant species being Stellar sea lions, harbor seals, and blue and salmon sharks.

Introduction: In analysis of all data collected in 2023 and 2024, a common theme that emerged are reports of marine mammal and shark interactions, and loss of catch due to animal predation on fish caught in troll lines, longlines, and nets (gillnet and/or seine). The data within this section is presented in a slightly different format from previous chapters. Observations are presented more as raw data. The reason for this is due to these observations being made in relation to fisheries and fisher's experiences with predation on gear, rather than comments and observations that make notes related more to specific species/ecosystem elements and indicators. These observations are numerous and detailed and felt significant to share.

Methodology: Comments were coded based on our analysis of what the person writing/submitting the comment was communicating, not our personal knowledge concerning what is a technical definition or designation of a fisheries interaction. These are the themes that the data presented to us that we then understood through the data submitted by individuals and their word choice.

Fishing Interaction: Fishing interaction was identified whenever an observation comment mentioned an interaction with marine life during fishing activities, including gear interactions, loss of fish, and marine mammal presence around gear with no direct interaction. This last identifier was included considering the further context of the observation comment where the observer mentioned explicitly presence with no gear interaction or fish loss.

Predator/Prey Interaction: Predator/Prey Interaction was identified based on the description and/or behavior of the animal observed. A majority of comments noted a type of interaction while also making notes on predation by marine mammals and sharks on fish both in relation and not in relation to the fishing interaction.

Region: In the 2023 and 2024 seasons observations were submitted throughout the Gulf of Alaska region, with heavy representation in the Eastern Gulf of Alaska Region, as well as some observations in the Western Gulf of Alaska Region. Figures 109 and 110 shows the location of each observation.

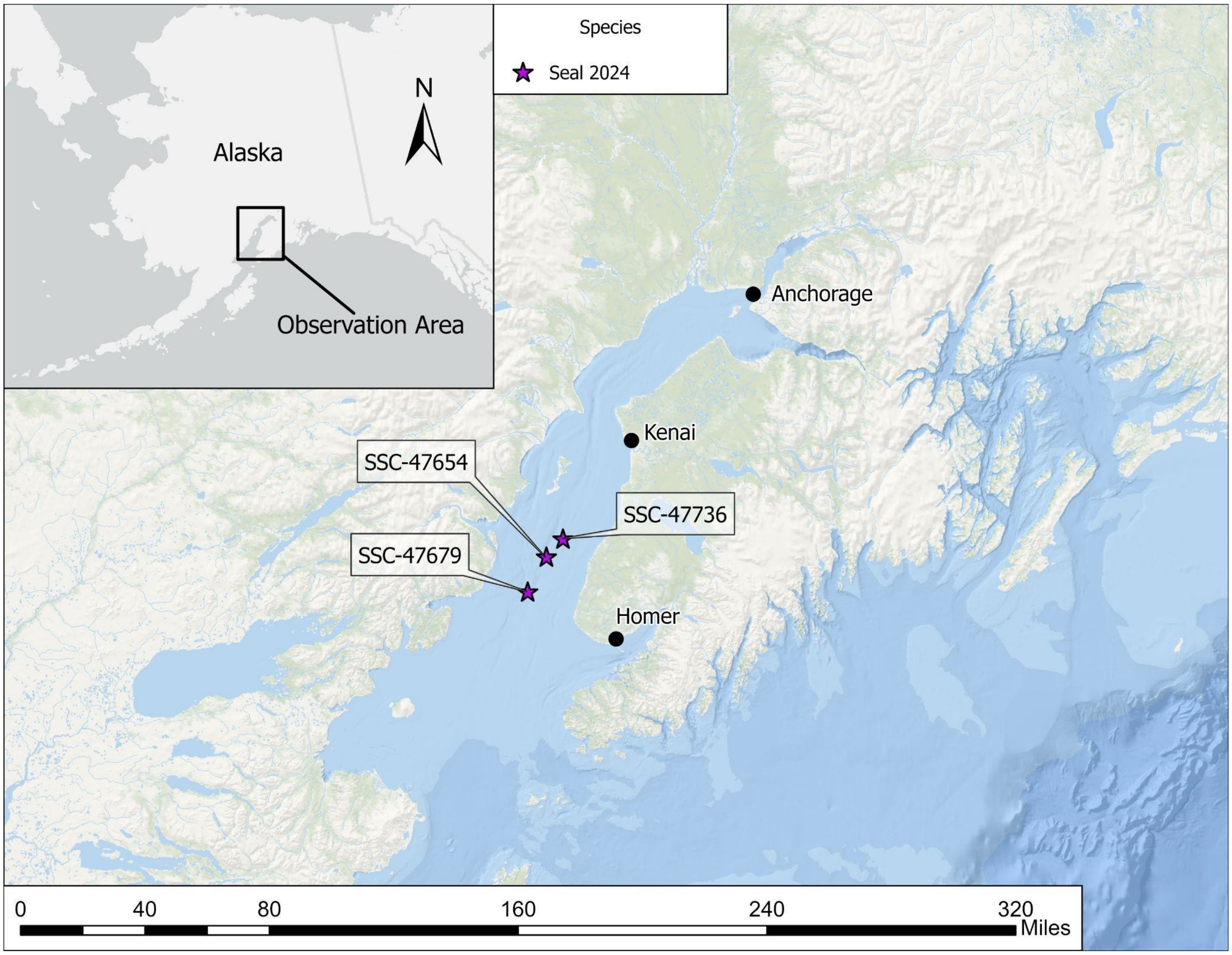

Figure 109: Map of 2024 Southcentral Gulf of Alaska observations noting seal fishing interactions.

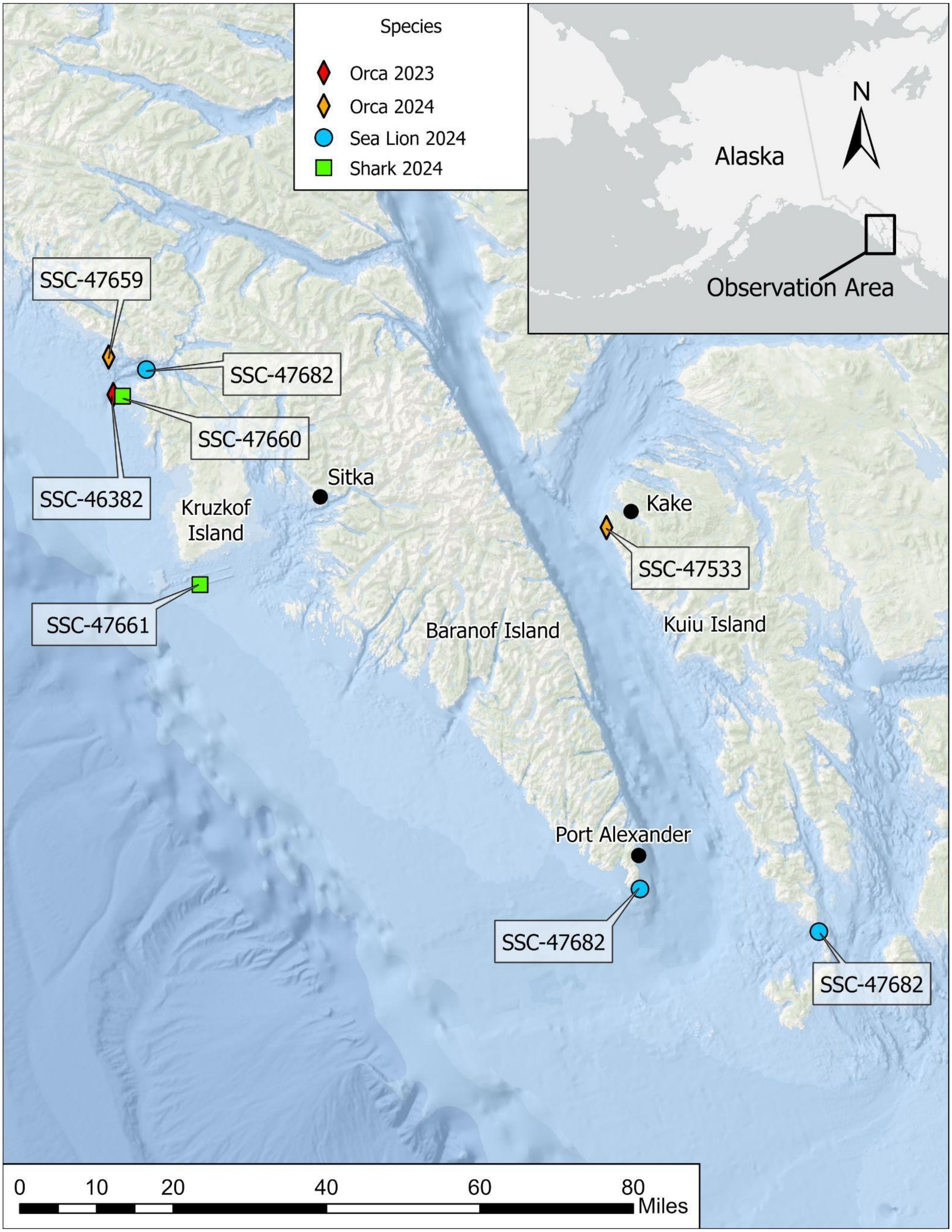

Figure 110: Map of 2023 and 2024 Southeast Gulf of Alaska observations noting orca, sea lion, and shark fishing interactions.

Observation Data: Observation details include the observation number, distinction of eastern or western Gulf of Alaska region when possible, species when identified, summary of observation, fishery gear and type where noted, and edited comments from observers. Data is presented from both 2023 and 2024 seasons, with titles distinguishing the year observations were collected for each section. Table 10 below outlines the total number of observations for both 2023 and 2024.

Table 10: Total number of observations for sea lion, seal, orca, and shark fishery interactions for 2023 and 2024 seasons.

	2023	2024
Sea lion	3	3
Seal	0	3
Orca	2	2
Shark	6	2

Orcas: In 2024 two interactions with orcas were reported by vessels in the eastern Gulf of Alaska region, close to Sitka (Table 11). In 2023 some observers reported groups of orcas swimming close to fishing vessels, and predating on sea lions that were interacting with fishing gear and eating catch. Some observations noted that orcas did not interact with their gear or catch directly, but animals were seen in close proximity to and moving between groups of fishing vessels.

Sharks: In 2024 observers recorded two shark observations, both of which report sharks interacting with fishing gear, feeding on catch in gear, and observations of wounds from sharks on fish (Table 12). In 2023 observers similarly noted interactions of sharks with gear, consuming catch from gear, and wounds from sharks. These observations in 2023 capture details about the quality and quantity of damage to fish, rate of interaction and fish species preference for shark interactions. Species of sharks observed from both years include salmon and blue sharks.

Sea Lions: In both 2023 and 2024 data observers recorded observations of Stellar sea lions often with a perceived increase in sea lion population, and consistent interactions of sea lions with fishing gear and catch (Table 13). A few of the observations include detailed comments on the rate and quality of interaction. Observations note sea lion predation on Chinook salmon.

Seals: In 2024 observers reported Harbor seals interacting with fishing gear, and feeding on fish caught in gear (Table 14). Observations were reported in Western Gulf of Alaska. No seal observations were reporting in the 2023 season.

Table 11: Skipper Science Orca fishery interaction observations 2024.

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-47533	Eastern GOA	Orca	Reports of chasing	Longline Gear
Observer comment: "Killer whales, chasing longline gear"				
SSC-47659	Eastern GOA	Orca	No chasing or interaction, close proximity to vessel	Troll
Observer comment: "Fishing off shore outer coast. Pod of 12 – 20 killer whales in amongst the troll fleet and then moving towards Salsibury sound. 2 – 3 miles offshore from Klokachef. No interactions with the boats. They did some tail slaps though. Adults and young ones at least 5 – 7 young."				
SSC-46382	Eastern GOA	Orca	Proximity to fishing vessels, unknown interaction with fishing gear/catch.	Salmon, trolling
Observer comment: "Mom and baby killer whale and one other adult whale came around the boat, followed us as we pulled our gear in. Baby was tail slapping and the adult came over alongside our boat and tail slapped... No clear evidence of them predating on our fish- one spread was missing, but hard to say what took it. Whales then proceeded to head towards the other cluster of trollers fishing. Others started pulling gear too. Final hours of the king opener. Also saw another pod- one very large male (great big fin) and 3 or 4 females, maybe juveniles, maybe more- pulled gear to run north. Different ones than this group. That was around lunchtime 23 miles south of here off Cape Edgecumbe in front of the sea caves."				
SSC-46852	Eastern GOA	Orca	Orca predation of Stellar sea lion interacting with gear	Salmon, trolling
Observer comment: "Watched a pod of killer whales kill a Stellar sea lion that was stealing fish from our gear. After the kill they jumped out of the water many times over a period of 5 minutes all around our boat...The photo is of a young one trying to mimic the jumps of the adults. The killer whales are very adept swimmers and never touched our gear or any of the 30+ cohos dangling from it even though they were literally in it. Obviously the Killer Whales had no problem at all feeding right next to our boat and even seemed to target us because they came directly to us."				

Table 12: Skipper Science shark fishery interaction observations 2024.

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-47660	Eastern GOA	Shark, uncertain. Observation based on gear and fish damage and loss of catch	Fishery interaction. Shark taking fish and damaging gear, affecting catch. Fish observed to have marks from shark bites	Salmon, trolling
Observer comment: "Problems with sharks biting through gear, stealing fish, and taking the whole spread. Sometimes only the snap or part of the line is left. Also had marks from sharks on fish."				
SSC-47661	Eastern GOA	Shark, uncertain	Fishery interaction. Shark taking fish from gear	Salmon, trolling
Observer comment: "Shark predation on the King Salmon we are catching. Hitting the ones on the bottom spread. Just got the tail of this one. Lost two lower spreads of gear too fully taken. Fishing in deep water so wasn't lost to bottom contact."				
SSC-45660	Eastern GOA	Shark, unidentified	Historical observation of shark entanglement in fishing gear	Longlining
Observer comment: "Grew up fishing- longlining with his father. Never caught sharks (WWII time or earlier) very few back then. Maybe 1967 or 1968 caught one on own boat were really big then- much smaller since the 70s. Sleeper Sharks- used to call 'em mud sharks. Just didn't see them much until early 80's all of a sudden lots of small ones- 3ft long or so on the gear- longline gear when fishing black cod. Have had up to 20 sharks on a set in the 80s/90s. Still happening now from time to time but mostly big ones 9-12ft (half the size of the ones in the 70's). Get wrapped up in the gear. Most of them survive the tanglings and are released- fishermen have developed a system for releasing them."				
SSC-46004	Eastern GOA	Shark, possibly salmon or blue	Signs of shark bites on catch in gear	Salmon, trolling
Observer comment: "Sharks bit salmon- likely a salmon shark or blue shark bit. Only one that we had get chomped on the line in 3 days- but signs of shark bite/slash wounds on a few other fish"				
SSC-46109	Eastern GOA	Shark, unidentified	Shark fin sighting	Salmon, trolling
Observer comment: "Saw what I think was a Shark fin on the surface- No evidence of predation on the fish on our lines (like the first few days of the opener). Not positive but not sure what else it could have been."				

Table 12 continued.

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-46110	Eastern GOA	Shark, unidentified	Evidence of wounds from sharks on salmon catch	Salmon, trolling

Observer comment: "Various wounds on the Salmon at various stages of healing. At least 3 of the last 9 we caught had obvious gash marks some of which were healed over. Skipper believes it might be Shark gashes. Skipper said- it seems more common that they remember it being 30 or so years ago. Finds this often in the outer coast caught fish, especially in the last few years."

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-46134	Eastern GOA	Salmon shark	General observations on fish showing signs of shark encounters	Salmon, trolling

Observer comment: "Observing more fish the past few years (didn't notice when started trolling maybe? Could be decades or just the last five years) only looking at the survivors- so many near misses lots are getting eaten. Maybe 20 – 30% of the fish this year have been showing signs of previous encounters with predators often healed over or in various stages of healing. You can see smaller scales where they regrew. Seems to disproportionately be kings that this is observed on. Hardly any pinks like that. Coho often have really nasty wounds from time to time. But not all the scarring and as many old healed over wounds like this."

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-46851	Eastern GOA	Blue shark	Shark interaction with gear	Salmon, trolling

Observer comment: "Recent years when water temperature approaches 60 degrees we start seeing blue sharks. They attempt to bite our lures, especially hoochies. We know when it was a blue shark that we had an interaction with because every now and then they get hooked in a way their teeth can't cut the line. We found if we troll faster than normal(normal is 2.5 knots, faster about 3.5 knots) we don't have as many interactions. They seem to have a problem rolling over to eat the lure or fish if it's moving faster. If we go slow we lost about 3 – 5 pieces of gear and or fish an hour. There is also an interesting fact that the blue sharks rarely get the whole salmon. Usually they bite in half very raggedly or just chew on it and ruin it for sale. The amount of time we soak the gear is another factor. The longer the soak, the more marked fish. It was especially bad this year. I estimate that 10 – 15 percent of our daily catch was devalued by blue sharks. Another observation is that the separate species of salmon sharks will bite a fish off cleanly or entirely. No chewing. Not sure if the blue sharks have the jaw strength or ability to effectively predate salmon but they are sure trying. We also saw about 3 percent of salmon we retained had bite wounds that were not fresh and they had obviously escaped. It's my guess those were blue sharks."

Table 13: Skipper Science sea lion interaction observations 2024.

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-47628	Eastern GOA	Stellar sea lion	Interaction with gear and predation reported	Salmon, trolling
Observer comment: "First day of salmon trolling in the Goddard spring troll area. From the moment we put gear in we were being followed at a distance of 50-100 yards by at least one Stellar sea lion. We never caught a fish or had a bite until the sea lions lost interest. I could see them on the depth finder and in our gear waiting to snatch a fish. I've seen this before many times. Certain Stellars have developed a skill set of predating salmon as soon as they strike our gear, before we can run the line the fish is gone... They will either eat the fish under water or surface several hundred yards behind the boat to tear the fish up into bite size pieces or some will surface in front of the bow of the boat... This never happened when I first started trolling back in the early 1980s. In the mid to late 1990s we started having rare instances of this. It got steadily worse since 2000 and is now a daily occurrence."				
SSC-47681	Eastern GOA	Stellar sea lion	General observations on sea lion predation	Salmon, trolling
Observer comment: "Summer troll season opened on July 1 for all salmon species on the ocean. We observed over 8 days of Chinook trolling a notable number of Stellar sea lions who have developed a skill set for targeting Chinook salmon... we observed daily occurrences of Stellars targeting Chinook... In order to find the Chinook this year we had to go deeper and out further (3-6mi) to 50-60 fa in order to catch. We still had Stellars in our gear every day... Traveling along the beach from Puffin Bay to Cape Omaney on the south end of Baranof Island we saw 1000s of Stellars. We even witnessed a band of at least Stellars 20 jump into the water and follow us (we didn't put gear in for obvious reasons). We used to fish in this area but it is now impossible..."				
SSC-47708	Eastern GOA	Stellar sea lion	Sea lion interaction with fishing/gear	Salmon, trolling
Observer comment: "Very good king salmon fishing near the hazy islands. Severe harassment from Stellar sea lions on the fleet fishing there. I watched numerous trollers gear get raided. We were constantly running gear and didn't lose any fish to the local mob of sea lions but got checked out by them so many times we lost track. They were obviously running our lines to check for hooked king salmon. This problem has truly gotten worse this year."				
SSC-45364	Western GOA	Stellar sea lion	Orca predation on sea lion	Unreported
Observer comment: "Orca hunting Stellar sea lions."				

Table 13 continued.

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-46005	Eastern GOA	Stellar sea lion, unidentified	Interaction with gear, taking catch	Salmon, trolling
Observer comment: "Had problems this morning with a large bull sea lion. He stole at least 4 fish from us while we were really on the bite."				
SSC-46850	Eastern GOA	Stellar sea lion	General observations of increased population and interactions with sea lions	Unreported
Observer comment: "Increased numbers of Stellar sea lions and a noticeable increase in interactions and gear loss/deprivation associated with Stellar sea lions... At Cape Cross we lost 2 – 5 fish off of our gear on every single pass. We make about 20 passes a day. The number of interactions, the amount of gear loss tripled this year... They swim in the gear and wait for a salmon to bite. Then they grab it before we can pull it."				

Table 14: Skipper Science seal interaction observations 2024.

Observation Number	Region	Species	Summary	Fishery and Gear Type
SSC-47654	Western GOA	Harbor seal	Seal picking fish from net	Unreported
Observer comment: "Seal was picking fish out of my net as soon as they hit. It was probably in the water as I set the net."				
SSC-47679	Western GOA	Harbor seal	Seal picking fish from net.	Unreported
Observer comment: "2 seals working my net taking salmon out for lunch. One seal removed 4-6 salmon that I could see from the boat."				
SSC-47736	Western GOA	Harbor seal	Seal picking fish from net.	Unreported
Observer comment: "Two seals working in tandem to pick salmon out of the net. They've been working the net for an hour. How many (fish) can two seals eat?"				

Discussion: The orca observations recorded are distinct from shark, seal, and sea lion observations in that they are not recorded to interact directly with active fishing gear, but are observed near fishing vessels and traveling between groups of actively fishing vessels. They are observed in predation of the sea lions which are actively feeding from the gear, but do not target the vessel caught fish directly. It is notable that observers include detailed descriptions of age, size, and number of orcas observed. It is also notable that there is only one instance of orcas being perceived as "chasing" gear (SSC-47533, Skipper Science Partnership, 2024). That language choice and perception of orcas does not show up outside of that one isolated observation within the rest of the 2023 or 2024 data. These observations prompt further inquiry into the behavior of orcas- is there a pattern of targeting fishing vessels to predate on the sea lions which are close to vessels to feed from their gear? Is there a preference for orcas between gear types, ie. trollers versus longliners? Does the type of interaction with fishing vessels - either direct interaction with catch, or predation on predators of catch - reflect pod-specific prey preference, and perhaps distinct ecotypes of orcas? The data collected from these two seasons is not sufficient nor intended to answer such broad questions, but the detail and perspective of the observers from the water adds detail and color to orca behavior in interaction with fishing activity.

The shark, seal, and sea lion data between 2023 – 2024 consistently reflects observed interactions between these marine predators and fishing gear and catch. The combined number of shark observations in 2023 and 2024 is 8, followed by 6 sea lion observations, 4 orca, and 3 seal. The comments in the shark observations reflect some historical context of size and occurrence of shark interactions with gear both entanglements, and sharks eating catch from gear. Observers also note the occurrence of wounds on salmon caught from sharks, and damage to sellable catch from shark interactions. The comments in the sea lion data reflect a perceived increase of sea lion population in fishing grounds, and a consistent occurrence of sea lions targeting active fishing gear to feed on catch. The seal observations are limited to 2024, but also consistently note similar behavior of seals actively feeding from fishing gear.

To cite quotes directly: "..." (Skipper Science, observation code/number ex. SSC-0000, year).

Example: "Seal was picking fish out of my net as soon as they hit. It was probably in the water as I set the net." (Skipper Science, SSC-SSC-47654, 2023).

To Cite: Drummond, K., Reda-Williams, M., C. Tran, and L. Divine. (2024). Skipper Science 2024 observation report: citizen science observations of walrus, forage fish, and fishing and predator interactions in the Aleutians and Gulf of Alaska. Chapter 3: Citizen science fishing and predator interactions in the Gulf of Alaska. Skipper Science Partnership. [page number/range].

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Appendices

A1. 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[62].

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

In 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—

[62] The Arctic report is under development

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 (and revised in 2024), based on a recommendation from the SSC, the levels of risk were reduced to 3: Level 1 ("Normal"), Level 2 (Increased concern), and Level 3 (Extreme concern). For stock assessments which include an 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.

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

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 111). 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.

It was requested that contributors to the Ecosystem Status Reports provide actual time series data or make them available electronically. The Ecosystem Status Reports and data for many of the time series presented within are available online at: `https://alaskaesr.psmfc.org`. 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`

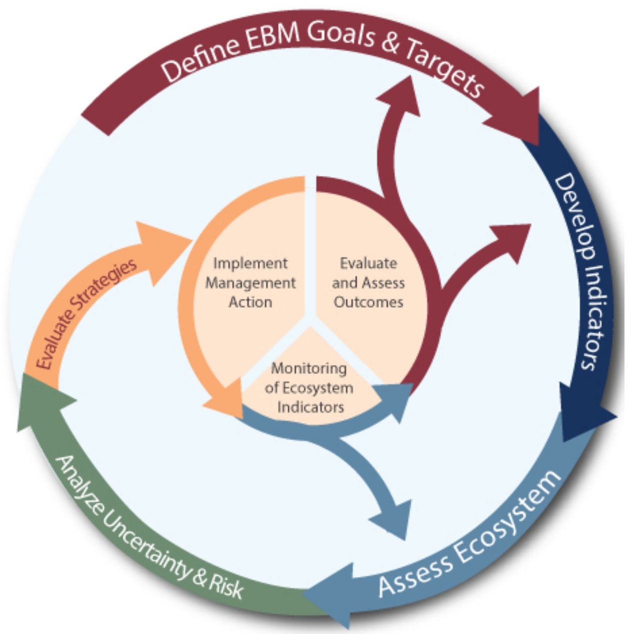

Figure 111: The integrated ecosystem assessment (IEA) process.

A2. Responses to Comments from the North Pacific Fishery Management Council's Science and Statistical Committee (December 2023 and October 2024 meetings) and the Groundfish Plan Team (September 2024 meeting)

December 2023 SSC Final Report to the NPFMC

C-3 BSAI and C-4 GOA Ecosystem Status Reports
The SSC received presentations from Elizabeth Siddon (NOAA-AFSC) for the eastern Bering Sea (EBS), Ivonne Ortiz (University of Washington) for the Aleutian Islands (AI), and Bridget Ferriss (NOAA-AFSC) for the Gulf of Alaska (GOA). Christopher Tran (Aleut Community of St. Paul Island) and Terese Vicente (Kuskokwim River Inter-Tribal Fish Commission) provided public testimony on the EBS ESR. There was no public testimony for the AI or GOA ESRs. The SSC thanks the ESR authors for their continued progress in collecting a large number of indicators and summarizing this information to better understand the status of marine ecosystems that support federally managed fisheries off Alaska. The SSC appreciated the structure of the reports, especially the consolidated information provided in the Report Card, Ecosystem Assessment, Noteworthy Topics, and Indicator Summary sections. The SSC acknowledges the continued value of the graphics in each report and separate "In Briefs" that visually translate how information is incorporated into Council processes and to inform broader audiences.

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
There appear to be different seasonal warming patterns among the ESR regions with winter warming more prominent in the EBS, winter and summer in the AI, and summer in the GOA. This will affect recruitment of different groundfish species, depending on seasonality of early life stages, and is another aspect by which to sustain efforts in addressing prior comments from the SSC regarding how different species might respond to changing temperatures. **The SSC appreciates the inclusion of case studies in this year's document addressing life stage phenology and temperature thresholds, and encourages continued efforts along these lines**.

The ESR editors agree these case studies of phenology and temperature can be useful and will continue to explore their integration into ESRs when applicable and when resources are available.

The SSC suggests more focus on multi-year patterns and whether they are similar to other periods during the time series. *This moves us beyond comparing the current year to previous years. The SSC recommends these comparisons are independent of warm or cold stanzas so that there is no a priori determination and to account for possible changes in climate-biology relationships.*

The ESR editors continues to explore ways to examine and communicate multi-year patterns. The

Gulf of Alaska ESR will include an updated ecosystem state analysis based on Ferriss et al. (Submitted) in 2025. The eastern Bering Sea Ecosystem Assessment addresses the ecosystem response (both SEBS and NBS) to the shift from interannual variability (prior to 2000) to the recent prolonged warm period to the return to average thermal conditions since 2021. The Aleutian Islands Ecosystem Assessment has addressed biennial patterns, and shifts in ecosystem structure potentially related to either the step increase of Eastern Kamchatka pink salmon as well as a shift in pelagic foragers now dominated by rockfish, which might be relaled but not driven by climate. Likewise, it has looked at shifts in diets. We welcome the feedback and will strive to increase the focus on multi-year patterns.

The SSC recommends considering options for identifying step changes in times series that might indicate a new "baseline" or "regime" for that indicator*. These efforts might also be relevant for time series beyond the ESRs. The SSC recognizes the sensitivity of referring to regime changes and management implications, however it is important to be vigilant of step changes in metrics and how to adapt to them.*

The ESR editors continues to explore ways to examine and communicate multi-year patterns. The Gulf of Alaska ESR will include an updated ecosystem state analysis based on Ferriss et al. (Submitted) in 2025. The eastern Bering Sea Ecosystem Assessment addresses the ecosystem response (both SEBS and NBS) to the shift from interannual variability (prior to 2000) to the recent prolonged warm period to the return to average thermal conditions since 2021. The Aleutian Islands Ecosystem Assessment has addressed biennial patterns, and shifts in ecosystem structure potentially related to either the step increase of Eastern Kamchatka pink salmon as well as a shift in pelagic foragers now dominated by rockfish, which might be relaled but not driven by climate. Likewise, it has looked at shifts in diets. We welcome the feedback and will strive to increase the focus on multi-year patterns.

Several recent publications note that the position of the Aleutian Low affects climate in the Bering Sea. All three ESRs share the North Pacific Index contribution which reflects the strength of the Aleutian Low. Whereas current atmospheric pressure anomaly maps in ESRs show the average position of the Aleutian Low graphically, its mean position cannot be compared to previous years. **The SSC recommends that ESR authors evaluate ways to present a time series of the position of the Aleutian Low for this contribution.**

The three ESRs included a new contribution this year from Jim Overland and Muyin Wang that describes the strength and position of the Aleutian Low. Likewise, We worked with Emily Lemagie, NOAA-PMEL, to include new graphics of climate conditions that represent the Aleutian Low climatology and current year.

The SSC appreciates the one to five month lead forecasts of expected El Niño effects in Alaska. Given that as of November 9, 2023, the NOAA National Center for Environmental Prediction suggests a 35% chance of a historically strong El Niño this winter, **the SSC encourages continued monitoring of El Niño development and potential ecosystem affects, especially in the GOA**.

The ESR team monitored the El Niño event through the winter of 2023/2024 including satellite-derived sea surface temperatures, NOAA's winter acoustic-trawl survey in Shelikof Strait, and most thoroughly, through presentations of various monitoring, industry, and commmnity observations at our spring Preview of Ecosystem and Economic Conditions workshop. By May the ENSO index had already transitioned from a positive (El Niño) to a neutral value, and the impacts of the El Niño were appearing to be more moderate in AK than some predicted. If the impacts had been more extreme, the ESR team was prepared to discuss developing impacts with the Council a their June or October meeting (if requested).

The SSC notes that the ESR process has matured over several decades to effectively use ecosystem trends to inform annual specifications and encourages the use of trans-disciplinary approaches for linking ESR and ESPs to stock assessments in the future. **The GOA pollock assessment was suggested as a potential case study, particularly in contrasting differences in the strength of 2018 vs. 2019 year classes**.

A research model is presented in the Gulf of Alaska walleye pollock assessment Appendix 1E (Monnahan et al., 2024) that explores incorporating environmental data into the GOA pollock stock assessment. This model embeds a dynamic structural equation model (DSEM) into the assessment, and uses complex causal relationships among eight environmental indicators (sourced from the GOA Ecosystem Status Report and GOA pollock Ecosystem and Socio-economic Profile) to explain recruitment variation. Preliminary results are encouraging, with strong statistical evidence that this approach can substantially reduce unexplained recruitment variation and improve short-term projections like those used for management.

The SSC further discussed the process of selecting and refining indicators to minimize redundancy and ensure key information is included.

The ESR team continues to refine the process of minimizing redundancy while ensuring a holistic perspective based on spatially- and temporally-restricted datasets. Some redundancy is intentionally baked into the process to ensure data are available in alternating years when NOAA surveys are not conducted (even years for GOA and odd years for AI). In addition, (Ferriss et al., Submitted) conducted a dynamic factor analyses on a subset of ESR time-series to identify those that produce a common trend over time, informing the potential reduction of redundancy.

The SSC notesd that many satellite-derived chlorophyll-a time series have a declining trend. To be certain these reflect real, in situ conditions, the SSC recommends that ESR authors work with contributors of these metrics to identify what calibration efforts have occurred, what additional calibrations might be needed, and how interpretation of the satellite time series might be affected.

We thank the SSC for this comment. Contributors have continued to cross-validate globcolour satellite chla data from globcolour that is used in the annual ESRs with both single sensor data (e.g., VIIRS) and another combined product (i.e., OC-CCI). While contributors have done similar cross-product comparisons in the past - these were prior to 2023. In 2024, new cross-product comparisons showed relatively larger discrepancies among products than those from previous years. Consequently, contributors have paused contributions of satellite-derived chla trends to this year's ESRs until they have confidently resolved what is causing these discrepancies. They noted all combined (multi satellite sensor) chla products that are currently available are from external sources. Unfortunately that limits the ability to directly apply calibrations and corrections to the satellite data products.

GOA Ecosystem Status Report

The SSC suggests plotting Sitka air temperature anomalies with one or two other baselines (in addition to the GAK1 Ocean Temperature Anomaly that was presented) could be helpful for depicting more recent relative changes in the time series.

While it is agreed that additional datasets could be helpful in adding context to the GAK1 water temperature / Sitka air temperature correlations, investigators unfortunately did not have the disposable time this year to significantly build upon this analysis. However, incorporating several other growing time series, such as oceanographic observations made in Sitka Sound and the Gulf of Alaska Ecosystem Observatory (GEO) mooring, is an objective for next year's Gulf of Alaska ESR.

Broad-scale climate patterns reflect a transition from La Niña to El Niño conditions in the GOA, with anticipated warmer ocean temperatures arriving in early spring 2024. The National Multi-Model Ensemble predictions of sea surface temperatures in 2024 currently predicts a moderate warming in surface waters in 2024, with more pronounced warming predicted in the eastern GOA. In light of some uncertainty related to the duration, depths, and timing of the warmer conditions the authors provided an evaluation of which species may be at highest risk, and most vulnerable, to warming conditions and which species appear to be more resilient. For example, low zooplankton biomass observed in 2023 may be further exacerbated under El Niño conditions. Groundfish that may be vulnerable in 2024 due to warm surface waters and reduced zooplankton quality potentially include the larvael and age-0 juveniles of Pacific cod, walleye pollock, and northern rock sole. It was noted that most groundfish populations have one or more recent strong year classes that could help the population persist through a challenging year, except the Pacific cod stock, which is still at low biomass. The SSC appreciates this addition to the GOA ESR, and notes that synthesizing across multiple indicators provides a robust assessment of how resilient the GOA system may be to a range of potential climate scenarios. **The SSC suggests a similar section could be incorporated into other ESRs**.

The authors are glad this section was helpful. The ESR team will consider future applications of this approach in years in which larger environmental changes are predicted (e.g., an El Niño event).

October 2024 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 (University of Washington) previewing the Ecosystem Status Reports (ESR) for the Eastern Bering Sea (EBS), the Gulf of Alaska (GOA) and the Aleutian Islands (AI). The SSC appreciates the authors and contributors providing near real-time data that are within months to days of collection. This is only possible because of the dedication of the ESR team, the rapport they have fostered with data contributors, and the value placed on this information by all involved in the Council process..

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.

The SSC recommended investigating potential competitive interactions associated with changes in pink salmon abundance, in addition to potential bottom-up effects on upper trophic levels. *The SSC also notes the importance of considering biomass in addition to numbers when evaluating the potential effects of the salmon populations on other ecosystem components.*

The 2024 GOA ESR includes a brief literature review of pink salmon competitive interactions in the pink salmon noteworthy contribution. The editor will more thoroughly investigate the topic in the 2025 ESR.

September 2024 Groundfish Plan Team

Joint Plan Team

Ecosystem Status Report – Climate Overview

The Teams appreciated the presentation and found it well presented and concise. In particular, the new format showing mean monthly winds compared to the climatology (longer-term mean) were useful to understand some of the cooling/warming processes and how seasons evolve.

The ESR editors would like to acknowledge Emily Lemagie and Shaun Bell for their extensive efforts to evolve this contribution in 2024.

One minor suggestion was to align the colors of years among slides to facilitate easier comparison of different environmental variables in the same year.

The ESR editors will work with contributors to align the colors of years among slides.

A3. Report Card Indicator Descriptions & Methods

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

Western Gulf of Alaska

Winter Pacific Decadal Oscillation

The leading mode of monthly sea surface temperature anomalies in the North Pacific Ocean, poleward of 20 °N. The monthly mean global average SST anomalies are removed to separate this pattern of variability from any "global warming" signal that may be present in the data. The winter index is the average monthly values from December – February. Data from `https://oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_OC_PDO.htmlTable?time,PDO`. (See Lemagie and Bell, p.30)

Contact: emily.lemagie@noaa.gov

Summer Sea Surface Temperature

The NOAA Coral Reef Watch Program provides a gap-free daily SST dataset (`https://coralreefwatch.noaa.gov/product/5km/`) that was accessed via the NOAA Coast WatchWest Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html`). Daily summer temperatures (June-August) were averaged for the western GOA (147 °W – 163 °W). (See Lemagie and Callahan, p.43)

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Copepod biomass

Total copepod biomass (g m^{-3}) is the sum of large and small calanoid copepod biomass, sampled south of Seward Alaska typically during the first 10 days of May. Data are averaged over the top 100 m of the water column to provide estimates of wet-weight biomass of zooplankton represented by all calanoid copepods retained by a 0.150 mm mesh net. (See Hopcroft, p.83)

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Copepod community size

The ratio of large calanoid copepods to total large and small calanoid copepods is used to represent copepod community size. Zooplankton are sampled south of Seward Alaska typically during the first 10 days of May. Data are averaged over the top 100 m of the water column to provide estimates of wet-weight biomass of zooplankton represented by all calanoid copepods retained. Small copepods data is taken from a vertical 0.15 mm net and large copepod data is taken from a towed 0.5 mm mesh net. (See Hopcroft, p.83)

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Motile epifauna biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 1999. The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community in the western GOA. (See Whitehouse, p.172)

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Capelin

Previously we used the common trend identified by Dynamic Factor Analysis of capelin in prey composition time series from various piscivorous seabird and groundfish species, considered to be "samplers" of the forage fish community. In 2019, data were not available in time for this indicator to be updated and we use the time series that loaded most strongly on the DFA trend: the percent biomass of capelin from rhinoceros auklets (*Cerorhinca monocerata*) chick diets at Middleton Island (ISRC). This alternative metric was used again in 2020 as the full suite of data were not available in 2020 due to COVID-19 related seabird survey cancellations. We have continued using the percent biomass of capelin from rhinoceros auklets (*Cerorhinca monocerata*) chick diets at Middleton Island since then (See Arimitsu et al., p 96).

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Apex predator biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 1999. The apex predator foraging guild is calculated from the survey data modified by an Ecopath-estimated catchability. Fish in this guild include: Pacific cod, arrowtooth flounder, Pacific halibut, sablefish, large sculpins, rougheye/blackspotted rockfish, and skates. (See Whitehouse, p.172)

Contact: andy.whitehouse@noaa.gov

Black-legged kittiwake reproductive success

Black-legged kittiwakes are common surface-foraging, piscivorous seabirds that nest in the GOA. Reproductive success is defined as the proportion of nest sites with fledged chicks from the total nest sites that were built. Reproductive success of this species is considered to be more sensitive to foraging conditions than that of common murres, another common seabird that has less variable reproductive success due to behaviors that can buffer the effects of poor food supply. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service. These data were not updated in 2020 due to COVID-19 related survey cancellations. (See AMNWR data in Seabird Synthesis, p 152)

Contact: brie_drummond@fws.gov

Steller sea lion non-pup estimates

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

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Eastern Gulf of Alaska

Multivariate ENSO Index (MEI)

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

Key features of composite positive MEI events (warm, El Niño) include (1) anomalously warm SSTs across the east-central equatorial Pacific, (2) anomalously high SLP over Indonesia and the western tropical Pacific and low SLP over the eastern tropical Pacific, (3) reduction or reversal of tropical Pacific easterly winds (trade winds), (4) suppressed tropical convection (positive OLR) over Indonesia and Western Pacific and enhanced convection (negative OLR) over the central Pacific. Key features of composite negative MEI events (cold, La Niña) are of mostly opposite phase. For any single El Niño or La Niña situation, the atmospheric articulations may depart from this canonical view. Data are from `http://www.esrl.noaa.gov/psd/enso/mei/table.html`. (See Lemagie and Bell, p.30)

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Summer Sea Surface Temperature

The NOAA Coral Reef Watch Program provides a gap-free daily SST dataset (`https://coralreefwatch.noaa.gov/product/5km/`) that was accessed via the NOAA Coast WatchWest Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html`). Daily summer temperatures (June - August) were averaged for the eastern GOA (133 °W – 147 °W). (See Lemagie and Callahan, p.43)

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Mesozooplankton biomass

Zooplankton biomass is represented by zooplankton density (number per m ^{3}) as captured by 333-μm bongo net samples during summer months in Icy Strait. (See Fergusson, p.85)

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Copepod Community size

The ratio of large calanoid copepods to total large and small calanoid copepods as sampled in Icy Strait is used to represent copepod community size. (See Fergusson, p.85)

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Motile epifauna biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 1999. The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community in the GOA. These values are summarized for the eastern region, where survey efforts vary among years. (See Whitehouse, p.172)

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Sitka mature herring biomass

The stock assessment estimates of the Sitka herring stock is used to represent forage fish trends in the eastern GOA region. Previously, total mature herring biomass was estimated from nine primary sites for which regular assessments are conducted and probably account for the majority of the spawning biomass in southeastern Alaska in any given year. The Sitka stock has the longest time series of assessed biomass. (See Hebert, p.105)

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Apex predator biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 1999. The apex predator foraging guild is calculated from the survey data modified by an Ecopath-estimated catchability. Fish in this guild include: Pacific cod, arrowtooth flounder, Pacific halibut, sablefish, large sculpins, rougheye/blackspotted rockfish, and skates. These values are summarized for the eastern region, where survey efforts vary among years. (See Whitehouse, p.172)

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Rhinoceros auklet chick growth rate

Mean growth rates of rhinoceros auklet chicks at St. Lazaria Island. Reproductive success is difficult to determine for these burrow-nesting seabirds because they are sensitive to disturbance. Data are only included for chicks that were measured at least three times during the linear phase of growth; chicks that did not exhibit linear growth were excluded. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service. The colony was not monitored in 2017. These data were not updated in 2020 due to COVID-19 related seabird survey cancellations. (See AMNWR data in Seabird Synthesis, p.152)

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Steller sea lion non-pup estimates

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

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Methods Description for the Report Card Indicators

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

The shaded green window shows the most recent 5 years prior to the date of the current report. The symbols on the right side of the graph are all calculated from data inside this 5-year moving window (maximum of 5 data points). The first symbol represents the "2017–2021 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 "2017–2021 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 purpose 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 $\pm$1 SD from the mean within 5 years or less) for further consideration, rather than serving as a full statistical analysis of recent patterns.

A4. Risk Table Ecosystem Considerations for Selected GOA Groundfish

Risk tables are produced annually for every full and updated stock assessment in the Gulf of Alaska. The Ecosystem Status Report and the Ecological and Socioeconomic Profile (where available) inform the Ecosystems Considerations part of each risk table. These stock-specific risk table descriptions are generally included in the relevant stock assessment, risk table sections. A few stock assessments only include summary text in their assessment, and the detailed Ecosystem Considerations sections are presented here.

Gulf of Alaska Pacific Cod: Ecosystem Considerations

Summary: The most recent data available suggest an ecosystem risk Level 1 – Normal. The 2023/2024 El Niño event had moderate impacts in the GOA, bringing warmer waters to the surface in winter and at depth in the winter and spring, but not exceeding known thermal thresholds for cod or elevating adult metabolic demands. Spawning conditions were average to slightly below average based on heatwave and habitat suitability with average cross-shelf transport to nursery habitat. Prey availability for larval/juvenile cod (zooplankton) was average to above average (increased euphausiids), while prey availability for adult cod was mixed but less well-monitored (e.g., declining Tanner crab biomass). Adult ration current year projection remains below average. There is no expected change in cod predation (moderate), but biomass consumed projections were higher than in 2023. Competition for zooplankton may be reduced due to low returns of pink salmon. Upcoming 2025 winter and spring surface temperatures are predicted to be cooler than average, in alignment with weak La Niña conditions, allowing more dissipation of heat at depth. An extended written description of these Ecosystem Considerations can be found in Appendix 4 of the Gulf of Alaska Ecosystem Status Report (Ferriss, 2024). Appendix 2.1 of the Gulf of Alaska Pacific Cod stock Assessment provides a detailed look at environmental/ecosystem considerations specific to this stock within the ecosystem and socioeconomic profile (Shotwell and Dame, 2024). Broad-scale information on environmental and ecosystem considerations are provided by the Gulf of Alaska Ecosystem Status Report.

Environmental Processes: Thermal conditions for 2024 are within known optimal ranges for Pacific cod life history stages: spawning (Feb-Apr: 20m - 290m, 1 °C - 7 °C), egg (Mar-Apr: 20m - 200m, 3 °C - 6 °C), larvae (Apr-May: 0m - 45m, 5 °C - 6 °C), as referenced in Appendix 2.1. The 2023/2024 El Niño event brought warmer surface temperatures to the GOA in the winter, but it was moderate and short-lived, resulting in approximately average surface temperatures by spring in the western GOA and continued warm surface waters through the spring in the eastern GOA. Despite warmer than average surface temperatures averaged across the western GOA shelf in January (5.1 °C, satellite-derived, see Lemagie and Callahan, p.43) NOAA's January acoustic survey in Shelikof Str. (key spawning habitat and time) observed cooler temperatures in the top 10m (3.2 °C) and and at depth (4 °C at 100m, see Jones et al., p.43). Warmth was observed at GAK1 (the nearshore mooring off Seward) at 200 – 250m depth but within 0.5 °C of the long-term average (see Temperature Synthesis, p.43). Surface waters in the western GOA cooled to approximately average temperatures in March, and remained average through early fall. spring, and fall with warmer waters in the summer (Satellite: see Lemagie and Callahan, p.43; Appendix 2.1: Callahan; Seward Line: see Danielson et al., p.43). The central GOA experienced below average marine heatwave events this year, a decrease from last year Appendix 2.1:

Barbeaux). Spawning conditions were considered average to good, based on the lack of heatwave events during the spawning period (Appendix 2.1: S. Barbeaux) and slightly below average habitat suitability index (based on temperatures at GAK1 of the Seward line (Appendix 2.1: L. Rogers). Mesoscale eddy kinetic energy in the Kodiak region was near average, implying neutral retention in the area and normal cross-shelf transport to suitable nearshore nursery environments (Appendix 2.1: W. Cheng). Upcoming 2025 winter and spring surface temperatures are predicted to be cooler than average, in alignment with weak La Niña conditions (see Lemagie, p. 39).

Prey: Foraging conditions for larvae and juveniles was average to above average while the prey base for adults was mixed, but is less well monitored. Juvenile condition was not updated this year due to this being an off cycle year for the bottom trawl survey. Zooplankton biomass, primary prey for larval and juvenile cod, was average to above average on the GOA shelf in the spring and summer. Spring zooplankton biomass along the central GOA Seward Line included above average euphausiids, below average large copepods, and average small copepods (see Hopcroft, p.83). Planktivorous and piscivorous seabird reproductive success, an indicator of zooplankton, forage availability, and nutritional quality, was generally above average and increased from 2023 (Drummond and Whelan, p.152, Appendix 2.1: S. Zador). Survival of the age-0 cod year class increased slightly from 2023 but is still slightly below average CPUE in western GOA nearshore beach seine (Appendix 2.1: B. Laurel and M. Litzow). This could be tied to cooler overall spring temperatures. GOA forage fish prey base was average to above average in 2024 (similar to 2023). Capelin continues to rebound in the GOA (McGowan et al., p.101, Arimitsu et al. , p.96), and herring continue to have relatively elevated populations supported by the strong 2016 and 2020 year classes (see Hebert and Dressel, p.105). Forage species that are relatively lower in abundance include eulachon, sandlance, and juvenile salmon. The reproductive success of piscivorous, diving seabirds (with an overlapping prey base with juvenile sablefish), was generally above average across the GOA (see Drummond and Whelan, p.152). Tanner crab biomass dropped below average in the ADF&G survey around Kodiak, a decline of the strong year class first observed in 2018 (see Worton, p.128). Pandalid and non-pandalid shrimp CPUE declined between the 2021 and 2023 NOAA bottom trawl surveys in Chirikof, Kodiak, and Yakutat (Laman and Dowlin, 2023). Other important prey of P. cod include poorly monitored crabs, amphipods, and other benthic invertebrates. Adult ration continues to remain below average (Appendix 2.1: G. Adams).

Predators and Competitors: There is no cause to suspect increased predation pressure on Pacific cod, and competition may be reduced in 2024. Predators of Pacific cod appear to be stable or at relatively low population levels. The most recent data available suggest that Steller sea lion trends have stabilized (eastern GOA) or continued to be at low levels (western GOA) in the Gulf of Alaska (Appendix 2.1: K. Sweeney). In general, apex fish predators in the GOA are at relatively low abundances, however biomass consumed from the CEATTLE model was projected to increase likely due to 2023 survey increases in Pacific cod and arrowtooth flounder (Appendix 2.1: Adams, Whitehouse 2023). The population status of other potential predators is not well known (salmon shark, northern fur seals, harbor porpoises, various whale species, and tufted puffin). Potential competitors of planktivorous juveniles include low returns of pink salmon (see Whitehouse, p.113, and Vulstek et al., p.124), a relatively large population of Pacific Ocean perch, large year classes of juvenile sablefish (Goethel and Cheng, 2024), and an increasing population of walleye pollock.

Alaska Sablefish

Summary: The most recent data available suggest an ecosystem risk Level 1 – Normal, accounting for conditions in the Gulf of Alaska (GOA), Eastern Bering Sea (EBS), and Aleutian Islands (AI). In 2024, environmental conditions (temperature and cross shelf transport) were potentially favorable for survival and growth of larvae in the eastern GOA, average to above average for YOY/juvenile sablefish, and average/unknown for adult slope habitat in the GOA and EBS. Young of the year (YOY) and pre-recruit spring and summer foraging conditions (planktivorous and piscivorous) included average to above average in the GOA, declining planktivorous conditions from east to west in the AI, and mixed planktivorous conditions in the EBS. Adult foraging conditions (slope) in the GOA are less known as there was no longline survey in 2024 but appear above average due to above average large female adult condition in the fishery. Competition for zooplankton prey (primarily larval/juvenile sablefish) was lower in the GOA due to low pink salmon returns, but potentially increased for all prey in the AI (generally low groundfish body condition) and remained approximately average in the EBS (average apex groundfish predator biomass). Predation (of most importance to juvenile/pre-recruits) generally decreased (AI) or remained approximately average (EBS, GOA), due to continued reduced (AI) or average biomass of apex groundfish predators in 2024, although arrowtooth flounder biomass increased in the EBS. Upcoming 2025 winter and spring surface temperatures are predicted to be cooler than average, in alignment with weak La Niña conditions, less favorable for larval sablefish in the eastern GOA. An extended written description of these Ecosystem Considerations can be found in Appendix 4 of the Gulf of Alaska Ecosystem Status Report (Ferriss, 2024). Detailed descriptions of the environmental/ecosystem considerations specific to this stock can be found within the Ecosystem and Socioeconomic Profile or ESP (Appendix 3C, Shotwell and Dame, 2024) and Ecosystem Status Reports for the Gulf of Alaska, Eastern Bering Sea, and Aleutian Islands (Siddon, 2024; Ferriss, 2024; Ortiz and Zador, 2024).

Environmental Processes: In 2024, environmental conditions (temperature and cross shelf transport) were potentially favorable for survival and growth of larvae in the eastern GOA, average to above average for YOY/juvenile sablefish, and average/unknown for adult slope habitat in the GOA and EBS. The 2023/2024 El Niño event brought warmer surface temperatures to the GOA in the winter, but it was moderate and short-lived, resulting in approximately average surface temperatures by spring in the western GOA There were no heatwave events at the Alaska-wide (EBS, AI, GOA) level and spring sea surface temperatures in the GOA, EBS and AI were below average (Appendix 3C: M. Callahan). However, the eastern GOA (an important larval region) experienced warmer than average spring and summer surface temperatures (maximum monthly average of 13.8 °C in August, optimal SST: 12 °C-16 °C; satellite-derived, see Lemagie and Callahan, p.43) and increased eddy kinetic energy (Cheng 2024) that could favor growth and survival of larval sablefish. There is no evidence that the warm surface waters mixed to the shelf bottom (see Jones and Danielson, p.43). Larval entrainment, which can enhance foraging, was slightly below average near Amchitka Pass (corridor to the Bering Sea slope)(Appendix 3C: W. Cheng). Bottom-up productivity in the central GOA isare average to above average, with increased diatoms and above-average biomass of euphausiids but below-average biomass of large and small copepods (Hopcroft, p 83).

Thermal conditions in the SEBS (Aug 2023 - Aug 2024) were close to the historical baseline of many metrics. Beginning in May and continuing through summer 2024, persistent storms resulted in a deeper mixed layer, which entrained deeper, cooler water, such that SSTs remained cooler into fall of 2024. The strength and location of the Aleutian Low Pressure System during winter 2023 – 2024 were near climatological averages. Thus, cold winds from the Arctic helped advance sea ice to near-normal extent by mid-winter. The 2024 cold pool (<2 °C water) was similar in extent to 2022 and 2023, however, the extent of coldest waters (<0 °C) was smaller in 2024. In the Aleutians, both spring sea surface and summer bottom temperatures were near the long term average with above average temperature in winter and late summer-early fall.

Upcoming 2025 winter and spring surface temperatures are predicted to be cooler than average, in alignment with weak La Niña conditions, less optimal for larval sablefish (see Lemagie, p.39).

Prey: Young of the year (YOY) and pre-recruit spring and summer foraging conditions (planktivorous and piscivorous) included average to above average in the GOA, declining planktivorous conditions from east to west in the AI (Rojek et al., 2024), and mixed planktivorous conditions in the EBS. Adult slope foraging conditions in the GOA are less known as there was no longline survey in 2024 but appear above average due to above average large female adult condition in the fishery (Appendix 3C).

In the GOA, YOY growth from seabird diets at Middleton Island was average but length was below average, while nearshore juvenile CPUE from the ADF&G large mesh survey in the GOA (Appendix 3C: K. Spalinger) and AI was slightly above average suggesting good overwinter survival. These forage conditions appear sufficient for young sablefish transitioning from nearshore nursery environments to adult habitat. In the EBS, there were zero counts of hauls capturing small (likely age-1) sablefish as incidental catch in the early part of the fishery (Appendix 3C).

The spring zooplankton biomass in the GOA was average to above average, with observations of increased biomass of euphausiids, reduced biomass of large and small calanoid copepods and generally above average reproductive success of planktivorous seabirds (Seward Line, see Hopcroft, p.83, seabird reproductive success, see Drummond and Whelan, p.152).

In the EBS, planktivorous conditions were mixed. In 2023, large diatom abundance was above average and increased from 2022, indicating potentially favorable forage for secondary producers like copepods. The abundance of small copepods was sufficient in 2023 and 2024, while large copepods and euphausiids were quite low. The 2024 Rapid Zooplankton Assessment in the southeastern Bering Sea in spring noted a moderate abundance of small copepods, but low abundance of large copepods and euphausiids. In fall, the moderate abundance of small copepods continued, and while the abundance of large copepods and euphausiids remained low, abundances increased somewhat from south to north (Kimmel et al., 2024).

In the Aleutian Islands, seabird reproductive success signals a gradient of favorable zooplankton and forage fish prey conditions in the eastern Aleutians shifting to unfavorable conditions in the west (Rojek et al., 2024). Large diatoms and meso-zooplankton biomass were above the long-term mean in the AI in 2023. 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 (Ostle and Batten, 2024). Likewise, piscivorous and planktivorous seabirds had an average or above average reproductive success while in the west most seabirds had below average reproductive success, signaling a gradient of favorable conditions in the eastern Aleutians shifting to unfavorable conditions in the west (Rojek et al., 2024).

GOA forage fish prey base was average to above average in 2024 (similar to 2023). Capelin continues to rebound in the GOA (McGowan et al., p.101, see Arimitsu et al., p.96), and herring continue to have relatively elevated populations supported by the strong 2016 and 2020 year classes (Hebert and Dressel, p.105). Forage species that are relatively lower in abundance include eulachon, sandlance, and juvenile salmon. The reproductive success of piscivorous, diving seabirds (with an overlapping prey base with juvenile sablefish), was generally above average across the GOA (see Seabird Synthesis, p.152).

Competitors: Competition for zooplankton prey (primarily larval/juvenile sablefish) was lower in the GOA due to low pink salmon returns, but potentially increased for all prey in the AI (generally low groundfish body condition, Howard et al., 2024) and remained approximately average in the EBS (average apex groundfish predator biomass). Competition for sablefish is expected to be low for YOY/juveniles and moderate for adults. Competitors of YOY/juveniles for zooplankton in 2024 include dramatically low returns of pink salmon (see Whitehouse, p.113 and Vulstek et al., p.124), a relatively large population of Pacific ocean perch, an increasing and elevated population of walleye pollock (GOA and EBS) and reduced production of large year classes of juvenile sablefish in more recent years (2020 and 2021 were potentially large year classes).

Competitors of piscivorous juveniles and adults (shelf/slope) in the GOA include relatively reduced populations of adult Pacific cod, P. halibut, and reduced but increasing arrowtooth flounder. In the EBS, competition and predation pressures from groundfish such as arrowtooth flounder and Pacific cod have remained at long-term averages (1982 – 2024) since 2022. In 2024, the apex predator guild decreased slightly, driven by a 26% increase in arrowtooth flounder balanced by a 5.5% decrease in Pacific cod and decline in other predatory groundfish. Arrowtooth flounder biomass remains high in the EBS and the center of gravity for Pacific cod shifted north and west this year in the EBS, though the overall biomass for the shelf-wide stock declined slightly. This may imply a decreased overlap of these competitors with the new year classes of sablefish moving into the EBS from the south. In the Aleutian Islands, the apex predator guild decreased and the condition factor of all species (except small pollock) remained below the long-term mean, signaling potential increased competition for prey (Howard et al., 2024; Ortiz and Zador, 2024).

Predators: Predation (of most importance to juvenile/pre-recruits) generally decreased (AI) or remained approximately average (EBS, GOA), due to continued reduced (AI) or average biomass of apex groundfish predators in 2024, although arrowtooth flounder biomass increased in the EBS. Predatory impacts on the population are assumed to remain moderate. In general, stocks of groundfish predators of sablefish in the GOA, including P. cod, P. halibut, and arrowtooth flounder, have remained relatively low in the past few years, although arrowtooth flounder has been increasing. Population trends in sperm whales are not well known, and their predatory impacts on line-caught sablefish are addressed within the stock assessment model.

In the EBS, competition and predation pressures from groundfish such as arrowtooth flounder and Pacific cod have remained at long-term averages (1982 – 2024) since 2022. In 2024, the apex predator guild decreased slightly, driven by a 5.5% decrease in Pacific cod and a 26% increase in ATF.