Ecosystem Status Report 2022

GULF OF ALASKA

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Support for the assembly and editing of this document was provided jointly by NOAA Fisheries and the NOAA Integrated Ecosystem Assessment (IEA) program. This document is NOAA IEA program contribution #2022_3.

The recommended citation for this document is as follows:
Ferriss, B.E. and Zador, S. 2022. Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

QR code for NOAA Alaska Fisheries Science Center's Ecosystem Status Reports webpage:

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[1,2]. TACs may be set lower than the ABCs due to biological and socioeconomic information. Thus, the ESRs are also presented to the AP and Council to provide ecosystem context to inform TAC and as well as other Council decisions. Additional background can be found in the Appendix (p.208).

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

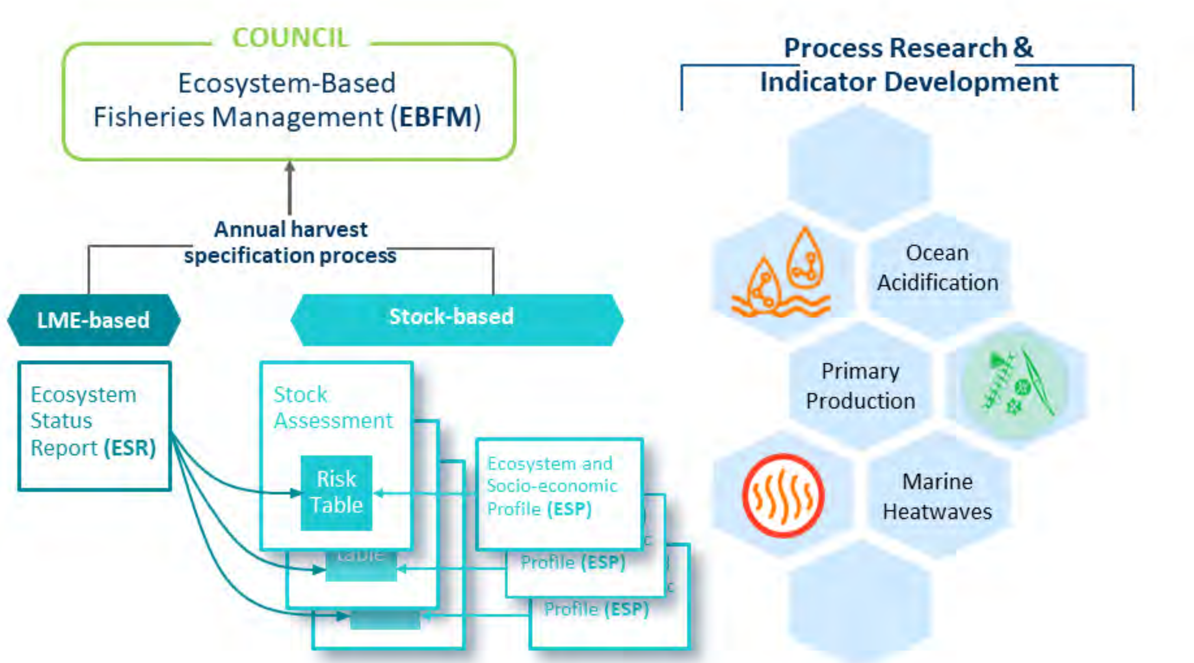

Figure 1: NOAA Fisheries' ecosystem information mapping to support ecosystem-based fisheries management through Alaska's annual harvest specification process. The 'honeycomb' on the right shows examples of ecosystem indicators that are provided to Ecosystem Status Reports (ESRs) at the large marine ecosystem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

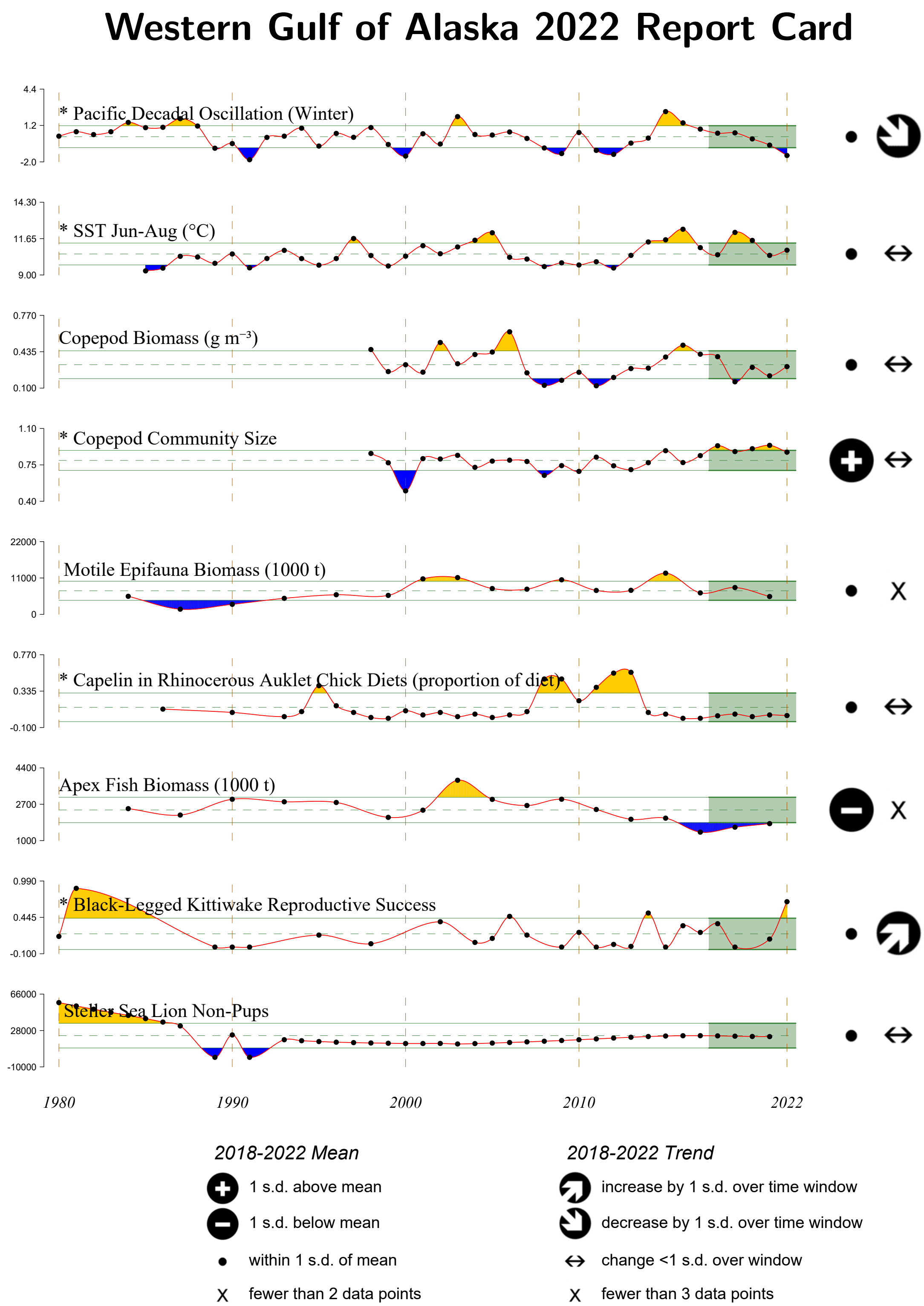

Figure 2: Western Gulf of Alaska report card indicators. For additional information on these indicators, refer to "Report Card indicator Description and Methods" in the Appendix of this Report (p.218) and relevant contributions in this Report. * indicates time series updated with 2022 data.

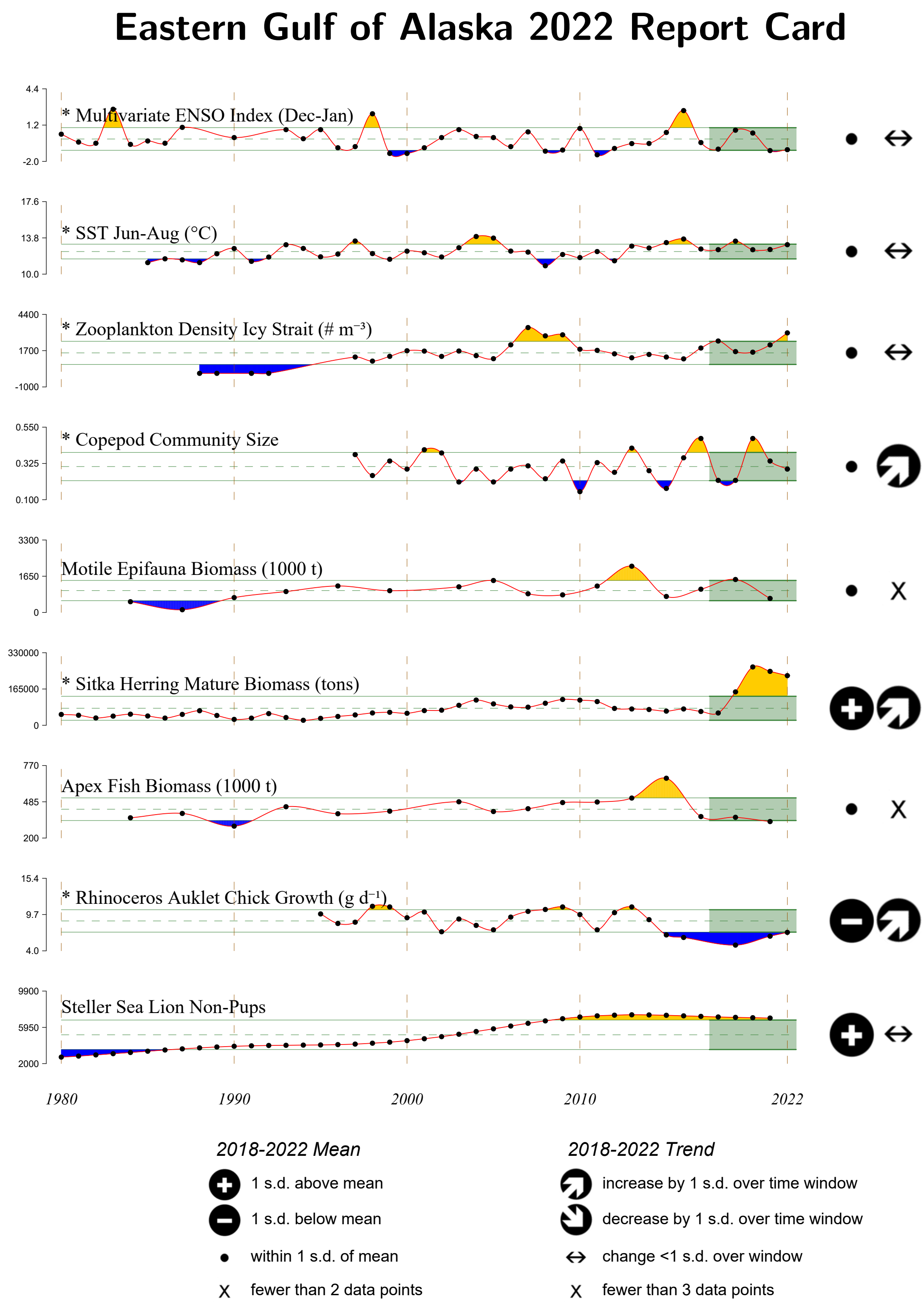

Figure 3: Eastern Gulf of Alaska report card indicators. For additional information on these indicators, refer to "Report Card indicator Description and Methods" in the Appendix of this Report (p.218) and relevant contributions in this Report. * indicates time series updated with 2022 data.

Western Gulf of Alaska 2022 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.218).

- **Winter average PDO index** (Dec.-Feb., 1980–2022) continued its negative trend in 2022, reflecting cooling sea surface temperatures in the GOA.
- **Sea-surface temperatures in the summer (°C)** (Jun.-Aug., 1985–2022) 2022 in the western GOA were warmer than average, but remained within 1SD of the long-term mean.
- **Copepod biomass (g m^{-3})**was approximately average (1998–2022) in 2022, indicating potentially average foraging conditions for planktivorous predators. Total (large and small) calanoid copepods are surveyed south of Seward in May of each year.
- **Copepod community size** (ratio of large calanoid copepods to total calanoid copepods) remained elevated in 2022, approximately 1SD above average (1998–2022), 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.
- **Motile epifauna biomass (1,000 t)**, observed during 2021 the NOAA Fisheries bottom trawl survey (May-Aug., 1984–2021), decreased from 2019 to 2021 but remains within 1SD of the long-term mean. The biomass of this guild is dominated by octopuses, hermit crabs, and brittle stars. Hermit crabs, brittle stars, and octopus are below their long-term means while other echinoderms are above their long term mean.
- **Capelin abundance (proportion of diet by weight)**, as sampled by rhinoceros auklets at Middleton Island (Apr.-Aug., 1986–2022), continue to be minimal in seabird chick diets in recent years, but still remain within 1SD of the long-term mean.
- **Fish apex predator biomass (1,000 t)**, observed during 2021 the NOAA Fisheries bottom trawl survey (May-Aug., 1984–2021), increased from 2019 to 2021 to within just above 1SD below the long-term mean. The primary species driving these trends include Pacific cod biomass, continuing to stay above their low in 2017, but remain below their long term mean, Arrowtooth flounder, which has trended upward since their low in 2017 but also remain below their long-term mean, and sablefish which are well above their long-term mean.
- **Black-legged kittiwakes reproductive success** in 2022 (Jun.-Jul., 1980–2022) increased to 1SD above the long-term mean at the Semidi Islands, potentially, indicating above-average prey availability for these surface-feeding, piscivorous seabirds.
- **Western Gulf of Alaska Steller sea lion non-pup** model predicted counts continued a slightly decreasing trend from previous years, remaining within 1SD of the long-term mean (1980–2021). These data have not been updated since 2021.

Eastern Gulf of Alaska 2022 Report Card

- **Multivariate ENSO Index** was negative, La Niña conditions, in the winter of 2021/2022 (Dec./Jan., 1980-2022). A third consecutive winter of La Niña conditions are predicted for winter 2022/2023.
- **Sea-surface temperatures (°C)** in the summer of 2022 (Jun.-Aug.), were above average (1985–2022) in the eastern GOA, and close to 1SD above the long-term mean.
- **Total zooplankton density (# m^{-3})** in southeastern Alaska inside waters (May-Aug., 1988–2022) increased toabove 1SD of the long-term mean, driven by large and small calanoid copepods. This suggests above-average foraging conditions for planktivorous fish, seabirds, and mammals.
- **Copepod community size** (ratio of large calanoid copepods to total calanoid copepods) remained approximately average in 2022 (May-Aug., 1997–2022). The copepod community is sampled in Icy Strait (southeast Alaska Inside waters).
- **Motile epifauna biomass (1,000 t)**, observed during 2021 NOAA Fisheries bottom trawl survey (May-Aug., 1984–2021), decreased from 2019 to 2021 but remains within 1SD of the long-term mean. Hermit crabs, brittle stars, and other echinoderms are all below their long-term means. Eelpouts have also decreased from 2019 to 2021 but remain above their long term mean.
- **Estimated total mature herring biomass (age 3+) of Sitka herring** in spring 2022 remains 1 SD above average (1980–2022) continuing a 4 year trend of the largest value in the time series (since 1980). 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.
- **Fish apex predator biomass (1,000 t)**, observed during 2021 NOAA Fisheries bottom trawl survey (May-Aug., 1984–2021), trended downward from a high in 2015 to their second lowest value over the time series in 2021, but remaining just within 1SD of the long-term mean. The decrease over this time period has largely been driven by arrowtooth flounder which are at their lowest value over the time series, more than one standard deviation below their long term mean. Pacific halibut, sablefish, and Pacific cod, have all increased from 2019 and are above their long term means.
- **Growth rates of piscivorous rhinoceros auklet chicks (g d^{-1})** remain 1SD below the long-term mean in 2022 (Jun.-Jul., 1995–2022), but continue a multi-year increasing trend.
- **Eastern Gulf of Alaska Steller sea lion non-pups** model predicted counts continue a decreasing trend, but remain above 1SD 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.

Ecosystem Assessment

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Last updated: November 2022

This assessment reflects the recognition that the western and eastern GOA ecosystems (divided at 147°W) have substantial differences. 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 present report cards and assessments of current ecosystem state for the western and eastern GOA ecoregions separately to highlight inherent differences.

During 2022, operational impacts due to COVID-19 had a negligible effect on information used in this report, due in large-part to effective mitigation strategies put in place to protect the health and safety of field research personnel and communities.

The Status of the Gulf of Alaska 2022

The Gulf of Alaska (GOA) shelf marine ecosystem continues an ongoing transition from a marine community responding to previous marine heatwaves (2014–2016 and 2019), to one potentially characterized by cooler ocean temperatures. This year was the most consistently productive year since the last year dominated by marine heatwave conditions (2019). The productivity was consistent spatially, across the GOA, and across numerous ecosystem metrics. Despite the generally productive year, some concerns persist around thermal and foraging conditions for adult groundfish along the shelf edge and upper slope. There are additional concerns regarding the potential impact of warm, summer and fall, ocean surface temperatures on juvenile groundfish overwinter survival in 2023. This year (2022) was an 'off' year in the alternating GOA schedule of NOAA's bottom trawl, summer acoustic, and spring ecosystem (EcoFOCI) surveys, limiting available information related to groundfish ecosystem conditions, especially in the western GOA.

Western Gulf of Alaska Shelf 2022

The western GOA experienced a third consecutive year of non-persistent marine heatwave conditions, and experienced a mixture of cooler and warmer than average conditions throughout the year. Cooler winter and early spring surface temperatures coincided with a productive start to the year (Temperature Synthesis, p.36). Summer and fall temperatures (as of November 1) were above average, at surface and at depth (Temperature Synthesis, p.36). Warming in the second half of the year has the potential to negatively impact growth and lipid storage for groundfish, especially important for survival of juveniles entering their first winter. Surface temperatures are predicted to be cooler than average in the upcoming winter (2023, Bond, p.34).

The winter and spring ocean temperatures were cooler than average, coinciding with generally average to above-average forage conditions, with the exception of zooplankton around the Semidi Islands. Moving from west to east within the western GOA, zooplankton biomass was potentially below average southwest of Kodiak, as indicated by parakeet auklet reproductive success on the Semidi Islands (Seabird Synthesis, p.124). Spring biomasses of copepods and euphausiids were close to the survey average (1998-2022) along the shelf, offshore of Seward (Hopcroft, p.70). These generally favorable prey conditions east of Kodiak were reflected in average to above-average planktivorous seabird reproduction (observed in colonies on E. Amatuli and Middleton Islands, Seabird Synthesis, p.124). Forage fish appeared relatively abundant and available to predators across the western GOA, based on above-average reproductive success in fish-eating seabirds (at the Semidi Islands, Middleton Island, and mixed trends on Amatuli Island, Seabird Synthesis, p.124). Seabird chicks on Middleton Island were fed a variety of herring, sandlance, age-0 sablefish, and other forage fish (but low levels of capelin), reflecting the presence of key forage species in the adult foraging range (Hatch, p.86). Fish-eating and zooplankton-eating seabirds were also observed in higher densities above the middle shelf of the Seward Line in 2022. This expansion follows a period of concentration in the nearshore regions after the 2014-2016 and 2019 marine heatwave periods, and indicates greater forage opportunities across the shelf (Seabird Synthesis, p.124).

Longer-lived species at higher trophic levels may still be impacted by marine heatwave impacts. The endangered western distinct population segment of Steller sea lions have experienced declines of non-pup counts in the GOA regions from 2017-2021, likely associated with the 2014–2016 marine heatwave in the GOA (Sweeney, p.144). This decline follows an increasing trend since the early 2000's. Potential mechanisms for this decline include reduced prey availability (walleye pollock and Pacific cod are key prey species), and reduced reproductive success and juvenile survival.

The frequency and intensity of harmful algal blooms were minimal this year, and appear not to have increased in response to the warmer-than-average summer temperatures (Farrugia, p.149).

Eastern Gulf of Alaska Shelf 2022

The eastern GOA shelf had similar trends in thermal conditions and productivity at lower trophic levels as the western GOA. The region experienced a cooler-than-average winter and early spring. Summer and fall temperatures (as of November 1) were above average at the surface (Temperature Synthesis, p.36), including a brief but widespread marine heatwave in July and a more prolonged marine heatwave period through the month of October (and continuing as of November 1). Warm summer and fall ocean temperatures can negatively impact growth and lipid storage for overwinter survival of groundfish, especially juveniles entering their first winter.

The cooler winter and spring ocean temperatures coincided with an above-average zooplankton and forage fish prey base. Total zooplankton density in Icy Strait (driven by calanoid copepods and euphausiids) was greater than one standard deviation above average (Fergusson, p.72). These positive zooplankton forage conditions were reflected on the shelf, offshore from Sitka, by above-average reproductive success of zooplankton-eating seabirds on St. Lazaria Island (Seabird Synthesis, p.124). Reproductive success of fish-eating seabirds at the same location was also above average, presumably reflecting the availability of nutritious forage fish (Seabird Synthesis, p.124). Herring populations in Sitka Sound and Cross Sound continue to be relatively abundant (supported by a strong 2016 year class) (Hebert, p.91), and numerous young sablefish cohorts appear to be in the GOA system, including age-0's that appeared in Middleton Island seabird chick diets and presumably traveling from eastern GOA nursery habitat to within foraging range of the Middleton Island seabirds (Goethel et al., 2022, Hatch, p.86). Some metrics of forage fish in the eastern GOA are below average, including eulachon population estimates (Pochardt, p.95) and some juvenile salmon CPUE and smolt productivity in southeast Alaska (Strasburger, p.103, Vulstek, p.109).

Commercial harvest of salmon in southeastern Alaska has been below average (1997–2022) since 2017 (sockeye and Chinook salmon), 2018 (coho and pink salmon), and 2019 (chum salmon) (Strasburger, p.103). Juvenile salmon CPUE from Icy Strait, southeastern Alaska, have been consistently below or near average for all species since 2016 (Chinook salmon), 2017 (chum, pink, and sockeye salmon) and 2018 (coho salmon) (Strasburger, p.103). Explanations of these low indicators of juvenile salmon abundance vary by species and life history, but reflect a combination of spawner abundance (pink salmon), marine survival (chum), and freshwater and early marine survival (Chinook, sockeye, and coho salmon). Average fork length and energy densities of these juvenile salmon were all at or above average in 2022, with the exception of chum salmon, reflecting foraging success (Fergusson, p.105).

Marine mammals are experiencing continued impacts of the 2014–2016 and 2019 marine heatwaves. The eastern distinct population segment of Steller sea lions (removed from the threatened listing under the Endangered Species Act in 2013) have experienced declines of non-pup and pup counts in the GOA regions from 2017–2021, likely associated with the 2014–206 marine heatwave (Sweeney, p.144). Potential mechanisms for this decline include adult movement out of the region, reduced prey availability (walleye pollock and Pacific cod are key prey species) and reduced reproductive success and juvenile survival. Glacier Bay, humpback whale calf production declined since 2020 and 2021, and the 2019–2022 crude birth rate has not recovered to the pre-2014 mean. Humpback whales in Prince William Sound are not considered to have returned to pre-2014 levels, although 2022 encounter rates of humpback whales increased from recent years. The decline in Prince William Sound humpback whales is surprising given the return of Prince William Sound herring biomass, a key prey species, to pre-marine heatwave levels.

The frequency and intensity of harmful algal blooms was minimal this year, and appear not to have increased in response to the warmer-than-average summer temperatures (Farrugia, p.149). Invasive green crabs were detected in Alaska for the first time in July, 2022 (Ferriss, p.22). They are known to expand their range northward in summers following warm winters, so their potential range expansion will be important to monitor if warm temperatures persist in the eastern GOA. However, surface temperatures are predicted to be cooler than average in the winter (2023, Bond, p.34).

GOA Shelf/Upper Slope 2022

The GOA shelf edge and upper slope demersal/benthic habitat is an area characterized by limited ecosystem data, but includes some indicators of increased concern. This is habitat for numerous managed groundfish species, including sablefish, rockfish (e.g., shortraker rockfish, rougheye/blackspotted rockfish, thornyhead rockfish, Pacific Ocean perch), and flatfish (deepwater flatfish complex, including Dover sole). A number of these species migrate onto the shelf to spawn (e.g., sablefish, POP) and others are capable of changing depths in response to environmental conditions (Yang et al., 2019), so their ability to mitigate unfavorable habitat and forage conditions may be greater than some shelf groundfish. However, given the data-poor aspect of this habitat, it is important to highlight declining trends in relevant indicators when they arise. For example, temperatures around 250 m depth, along the shelf edge, have been consistently above average since 2016 (Temperature Synthesis, p.36). Also, structural epifauna (primarily sponges), which are important habitat for rockfish, have experienced a multi-year decline in the western GOA (Whithouse, p.172 and AFSC bottom trawl survey CPUE, Palsson, 2021). In addition, adult female sablefish had below-average condition in 2022, potentially indicating that they experienced challenging forage conditions, despite their characterization as opportunistic predators. We have no data on biomass trends on benthic infaunal prey (polychaetes and clams) or invertebrates on or near the bottom (amphipods and other small crustaceans, shrimp, and brittlestars), which are primary prey for numerous flatfish in this region.

The Gulf of Alaska: Multi-Year Trends

The upcoming winter is predicted to be a third consecutive La Niña, which, coupled with a negative Pacific Decadal Oscillation (PDO) and non-persistent marine heatwave conditions, has been associated with a three year period of cooling on the GOA shelf. A triple La Niña would be the third such event to occur in the past 50 years, yet there are numerous reasons to assume the ecological response to the current period will not follow past trends. Differences include: (1) the current La Niña period beginning in warm ocean thermal conditions throughout the water column, following the 2014–2016 and 2019 cumulative marine heatwave period, (2) a marine community in transition from that warm period, (3) the documented weakening of relationships between various climate indices and GOA community responses due in part to a weak Aleutian Low (Litzow et al., 2018), and (4) the continued long-term warming of the GOA (Thoman, p.32) shifting the definition of warming and cooling as they relate to species' temperature thresholds and responses.

Previous triple La Niña periods occurred from 1973–1976 and from 1998–2001. The PDO shifted from a previous cool regime (negative index) to a warm regime (positive index) in 1977, which, along with a strong Aleutian low, induced a regime shift from a GOA community dominated by flatfish and crustaceans (as well as increased seabird and Steller sea lion populations) to one dominated by gadids and rockfish (Chavez, 2003; Mueter and Norcross, 2000; Anderson and Piatt, 1999). The second triple La Niña (1998–2001) was characterized as a cool thermal period in the GOA, with a suite of more temporary community responses, including strong 1999 year classes of walleye pollock and Pacific cod, increased shrimp biomass, and increased presence of capelin in seabird diets (Boldt, 2005; Hatch, 2013). The past two La Niña/ negative PDO years (2020, 2021) have coincided with ocean temperatures cooling from initial warmer-than-average thermal conditions throughout the GOA shelf water column to approximately average temperatures, with extended cooler-than-average temperatures for the first half of 2022. Given the residual heat in the system, the productive, cooler-water affiliated communities, as observed in the

1998–2001 period, took multiple years to materialize in the current period, or still remain elusive. For example, localized large phytoplankton blooms were observed in 2021 and 2022 but not consistently across the GOA (Strom, p.60 and Gann, p.57). Zooplankton productivity has remained patchy across the GOA, but has been the most spatially consistent and highest biomass in 2022 (Hopcroft, p.70, Fergusson, p.72, and Kimmel, p.65). Capelin populations remain relatively low (Hatch, p.86), and there are mixed trends in the productivity of certain groundfish species (e.g., Pacific cod has not yet recovered, Hulson et al., 2022).

If the PDO remains negative in upcoming years, and if there is an absence of persistent marine heatwaves, the GOA could remain in a cooler state, but would not be expected to return to the same ecological community as the pre-70's regime shift. A return to that period is unlikely as there are more than two potential states of the GOA marine system, and there have been multiple ecological and oceanographic shifts, and climate-induced changes since then. However, recently-observed trends may indicate the direction in which the GOA marine community is transitioning. Total apex biomass of groundfish remains low (as of 2021, Whitehouse, 2021) and groundfish surplus production metrics indicate potentially lower productivity (as of 2019) (Mueter, p.187). GOA groundfish biomass remains dominated by arrowtooth flounder, walleye pollock, Pacific Ocean perch, and increasingly sablefish. However, the composition of this group is shifting. Pacific cod has not recovered from the severe decline during the marine heatwave period and arrowtooth flounder has been declining since 2008, while Pacific Ocean perch has steadily increased over many years and sablefish has been increasing since 2016. Other isolated indicators that show differences potentially reflective of community transitions include: (1) the 2022 Papa Trajectory Index (an indicator of winter surface transport) had the second most southerly endpoint since the 1970's (Stockhausen, p.50), (2) tanner crab and shrimp CPUE around Kodiak continue to increase (Worton, p.113), and (3) commercial catches of certain GOA salmon stocks, particulary in southeastern Alaska, remain below-average (Whitehouse, p.100). Another year (2023) of similar ocean conditions would be informative as to the relative persistence of these trends.

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* indicates contribution updated with 2022 data
† indicates new contribution

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Ecosystem Indicators

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 or a one-time event.

Invasive Green Crab in Southeast Alaska

Invasive European green crab *Carcinus maenas*, hereafter referred to as invasive green crab, were observed in Alaska for the first time, on Annette Island in Southeast Alaska; their presence was confirmed, July 2022. The observations were the result of early detection monitoring for the aquatic invasive species by the Metlakatla Indian Community's Fish and Wildlife department, in anticipation of the species' continued northward expansion originating from San Francisco Bay. NOAA Fisheries, Alaska Region began supporting this effort in 2020 after adult green crabs were found in Skidegate Inlet, Haida Gwaii, British Columbia). As a new invasive species in the Gulf of Alaska, the potential impact of green crabs at population scales is still negligible, but they have the potential to disrupt local, intertidal systems.

Green crab are found in rocky nearshore and shallow seagrass habitat, primarily in protected bays and estuaries. They live 4–6 years (northeastern Pacific population) and reach a maximum carapace width of 100 mm (Young and Elliott, 2020). Their larval phase lasts up to 90 days (Ens et al., 2022). Green crab are generalist predators of shellfish, including clams and juvenile Dungeness crabs. Larger crabs (e.g., red rock crabs, *Cancer* spp.) are key predators of green crabs. El Niño events and marine heatwave conditions facilitate range expansion of Green crabs on the eastern Pacific coast (Yamada and Gillespie, 2008), and favorable recruitment events are linked to previous warm winters, allowing for greater larval survival and reproductive success.

The primary ecological impacts of invasive green crab are through shellfish predation and eelgrass habitat disruption which alters nearshore nutrient cycling. Green crabs uproot eelgrass beds while searching for food, and consume plant roots. Eelgrass habitat in Alaska is important for juvenile groundfish, including walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), rock sole (*Lepidopsetta bilineata*), yellowfin sole (*Limanda aspera*), juvenile rockfish (*Sebastes spp.*), and juvenile salmon (*Oncorhynchus* spp.), and forage fish (including Pacific herring, *Clupea pallasi*, capelin, *Mallotus villosus*, surf smelt, *Hypomesus pretiosus*, Pacific sand lance, *Ammodytes hexapterus*, and Pacific sandfish, *Trichodon trichodon*) (as summarized in Johnson et al., 2003; Harris et al., 2012; Mundy, 2005). Grosholz et al. (2011) summarize how the Invasion of green crabs has been linked to declines in shellfish populations in eastern North America, including the soft-shell clam (*Mya arenaria*) fishery in New England and eastern Canada, bay mussels (*Mytilus edulis*), Manila clams (*Venerupis philippinarum*), bay scallops (*Argopecten irradians*), and hard-shell clams (*Mercenaria mercenaria*).

There are no published reports of green crab directly impacting groundfish populations. However, given their documented impacts in other regions, it will be important to monitor the direct and indirect effects on the broader marine ecosystem as they expand into the Gulf.

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Ecosystem Status Indicators

Physical Environment

Physical Environment Summary

Climate: A variety of sea level pressure (SLP) distributions relative to their seasonal norms occurred in the North Pacific atmosphere-ocean climate system during autumn 2021 through summer 2022 (Bond in this Report, p.28). Lower than average SLP in the GOA during autumn 2021 was accompanied by northwesterly wind anomalies and cooling on the southeast Bering Sea shelf; a transition to strongly positive SLP anomalies south of the GOA during the winter of 2021–22 resulted in a reversal in the wind anomalies for much of the North Pacific. Mostly positive SLP anomalies prevailed in the middle latitudes of the North Pacific accompanied by positive sea surface temperature (SST) anomalies. The presence of relatively cool to near-average SSTs in Alaskan waters from late 2021 into 2022 for the most part follows a multi-year interval of mostly above-average temperatures. It is unclear the extent to which the atmospheric circulation of the North Pacific was impacted by external factors, but the period of interest here did include the co-occurrence of moderate La Niña conditions in the tropical Pacific. The PDO was negative, in large part due to long-standing positive SST anomalies in the western and central North Pacific (Bond in this Report, p.26). The climate models used for seasonal weather predictions indicate that La Niña is more likely than not to persist through the remainder of 2022. These models as a group are indicating SST distributions in early 2023 that include colder than average temperatures for the GOA (Bond in this Report, p.34).

Ocean Temperature: Long-term surface temperatures (1900–2022) show a persistent warming across the GOA shelf, driven by increasing temperatures in the summer months (May - Oct.) (Thoman in this Report, p.32). A warmer than average summer and fall have resulted in the 2022 May-Oct average temperature to the top 12 warmest since 1900. Fall 2022 surface conditions (as of Nov. 1) continue to be warmer than average, with persistent marine heatwave conditions in the eastern GOA.

Despite the warm summer and fall, ocean surface temperatures in 2022 started the year cooler than average (baseline 1985–2014). Temperatures at depth were slightly above average in the spring and summer (Temperature Synthesis in this Report, p.36). The winter surface temperatures remained cooler than average from a cool fall (2021), and aligned with a La Niña winter (Bond in this Report, p.27) and upwelling favorable winds from the west (Bond in this Report, p.28). Spring surface temperatures transitioned from cooler than average to warmer than average and summer surface temperatures were on average warmer than average across the GOA shelf, with a variety of subregional surface temperatures varying between average and warmer than average (Kodiak, Seward Line, Icy Strait, Prince William Sound). Summer temperatures at 100 m – 250 m depth on the shelf (western GOA), shelf edge (western and eastern), and in Prince William Sound (known to lag the GOA shelf by $\sim$ one year) were all above their respective long-term means (Temperature Synthesis in this Report, p.36, Campbell, p.156). The longline survey temperatures at $\sim$250m along the shelf edge have been above average since 2017 in the western GOA and 2018 in the eastern GOA. These warm conditions are predicted to transition to slightly cooler sea surface temperatures in the northern GOA (National Multi-model Ensemble Model, Bond, p.34) in alignment with a third consecutive winter La Niña.

Ocean Transport: The 2021/2022 GOA winter experienced eastward and southward transport (winds from the west) (Stockhausen in this Report, p.50). Typical counter-clockwise circulation resumed in the spring as the westerly winds relaxed. Eddy kinetic energy along the shelf edge was moderate in 2022 (reduced from strong and persistent eddies in 2021) indicating moderate transport of nutrients and ichthyoplankton across the shelf (Cheng in this Report, p.46). Spring winds in Shelikof Strait were downwelling-favorable northeasterly winds (conducive to enhanced retention of pollock and potentially other groundfish larvae and juveniles) (Rogers in this Report, p.53).

Climate: North Pacific

Climate: North Pacific Overview

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Last updated: August 2022

Regional Highlights of Gulf of Alaska and Neighboring Regions:

Aleutian Islands. The near-surface waters of the Aleutian Islands were generally warmer than average (1991–2020), especially during winter 2021–22 and summer 2022 in the western portion of the chain. These warm waters were accompanied by relatively shallow upper mixed layer depths in 2022. The mean wind anomalies during the winter of 2021–22 included a component from the east, which are associated with enhanced northward flow through Unimak Pass.

Gulf of Alaska. As discussed in the Ocean Temperature: Gulf of Alaska Synthesis section (p.36), the western portion of coastal GOA underwent a warming in early 2022 of about 1°C relative to seasonal norms to bring it to near-average (1991–2020) temperatures by June 2022. A similar progression occurred in the eastern coastal GOA resulting in slightly above-average temperatures in summer 2022. The coastal GOA experienced a slow start to the wet season in autumn 2021, especially in the west, followed by a relatively wet winter and spring in 2022. Warmer than average weather prevailed in the coastal GOA during summer 2022. The Alaskan Peninsula coastal waters in the vicinity of the Alaska Peninsula were cooler than normal, based on averages for the period of 1991–2020, during the winter and spring of 2022, especially on the north side over the southeastern Bering Sea shelf. The cool waters are consistent with the cold air temperatures that occurred from November 2021 into February 2022, with the exception of a brief period of record-setting warm temperatures in late December 2021. The spring and summer air temperatures in 2022 were near seasonal norms in an overall sense.

British Columbia Coast. This region experienced upper ocean temperatures that transitioned from near-average (1991–2020) during autumn 2021 to 0.5–1.0°C cooler than normal in early 2022 before a return to near-average values again in summer 2022. The latter change was associated with a switch from upwelling favorable wind anomalies during the past winter to downwelling favorable wind anomalies in spring 2022. According to NOAA's Global Ocean Data Assimilation System (GODAS) the offshore mixed layer in this region was about 20 meters deeper than average at the end of winter 2022, and slightly shallower than average during summer 2022[3]. The past year's weather featured a relatively wet autumn and dry winter in its coastal watersheds.

[3]https://www.cpc.ncep.noaa.gov/cgi-bin/godas_parameter.pl

Climate Indices

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Description of indices: Climate indices provide a means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, Pacific Decadal Index (PDO), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO) and Arctic Oscillation (AO). The time series of these indices, with the application of three-month running means, from 2011 into spring/summer 2021 are plotted in Figure 4.

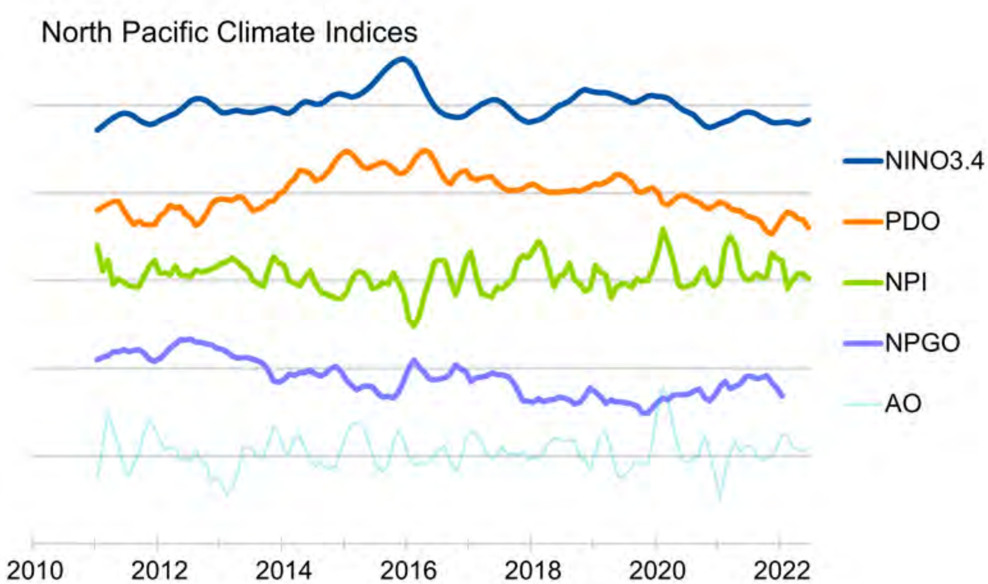

Figure 4: Time series of the NINO3.4 (blue), PDO (orange), NPI (green), NPGO (purple), and AO (turquoise) indices for 2012–2022. Bold lines (all but AO) are the most relevant of these indices for the GOA. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 5 standard deviations. More information on these indices is available from NOAA's Earth Systems Laboratory at `http://www.esrl.noaa.gov/psd/data/climateindices/`.

Status and trends: The NINO3.4 index has been negative from spring 2020 through summer 2022, with values commensurate with La Niña of moderate intensity during the winter and spring of 2022. While a slow return to more average conditions in the tropical Pacific is anticipated, it is more likely than not that at least weak La Niña conditions will remain into the upcoming winter of 2022–2023. If so, that will be the third ENSO-negative winter in a row; that has occurred just twice before in the last 50 years (1998–2001 and 1973–1976).

The PDO (the leading mode of North Pacific SST variability) continued to be in a negative phase following its strongly positive state during the major Northeast Pacific marine heat wave of (MHW) of 2014–2016. The PDO attained a value less than -2 near the end of the 2021 calendar year, moderated during the winter and early spring of 2022, and then decreased again to a value of about -2 during summer 2022. As compared with the previous year, there was more or less persistence in the warm temperatures in the western and central portion of mid-latitudes of the North Pacific; the SST anomalies in the Alaskan waters portion of the PDO spatial pattern also contributed to the negative sense of the index in late 2021 and early 2022.

The state of the Aleutian low is often summarized in terms of the NPI, with negative (positive) values signifying relatively low (high) SLP. The NPI has been positive from autumn 2021 into the following winter, with particularly high values from November 2021 through January 2022. A brief reversal occurred in February 2022, with the return of weakly positive values during the spring and early summer of 2022. The NPI has been positive during 5 out of the last 6 winters, with the exception being the winter of 2018-2019. The systematically positive state of the NPI (weak Aleutian low) is consistent with the overall decline in the PDO during the interval.

The NPGO has also been relatively persistent, with a long-term decline beginning in late 2012 resulting in consistently negative values since 2017. The negative phase of the NPGO is generally accompanied by warmer than normal upper ocean temperatures south of Alaska between 35°N and 50°N and is associated with high SLP over the GOA and low SLP in the vicinity and northeast of the Hawaiian Islands. There was some moderation in the NPGO during the summer into early autumn of 2021, with the resumption of more negative values again late in 2021.

The AO represents a measure of the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the North Pacific at a latitude of roughly 45°N. The AO has been mostly positive since the spring of 2021, with the exception of the autumn of 2021. A positive state of the AO during winter, as occurred during 2021–2022, is generally associated with arctic air being retained in the higher latitudes of the Northern Hemisphere, often leading to relatively cold weather for Alaska. That did not happen to be the case during the winter of 2021–2022, when the regional atmospheric circulation resulted in near-normal temperatures for Alaska.

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

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Last updated: August 2022

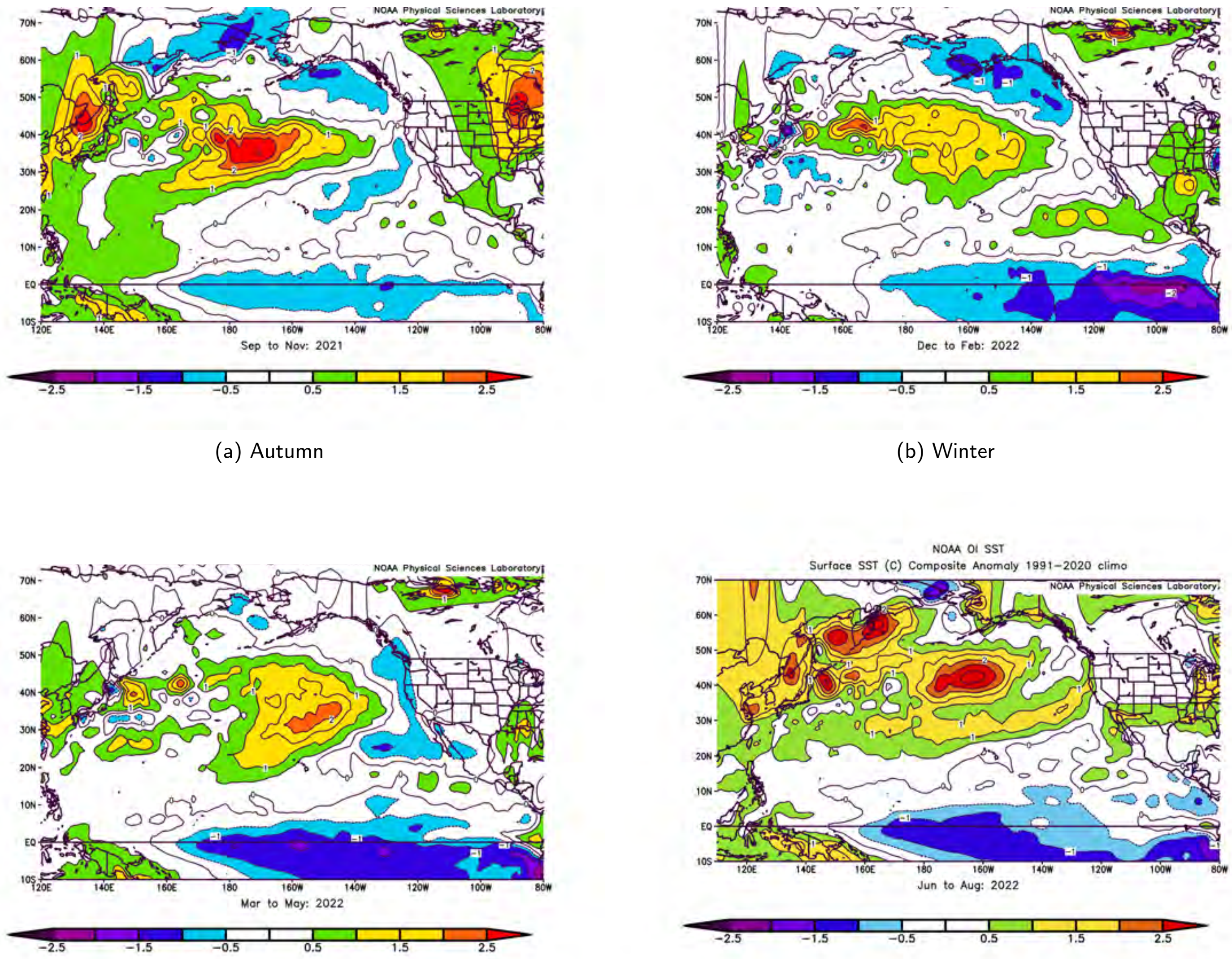
Description of indices: The state of the North Pacific climate from autumn 2021 through summer 2022 is summarized in terms of seasonal mean sea level pressure (SLP) and sea surface temperature (SST) anomaly maps. The SLP and SST anomalies are relative to mean conditions over the period of 1991–2020. The SLP data are from the NCEP/NCAR Reanalysis project; the SST data are from NOAA's Extended SST V5 (ERSST) analysis. Both data sets are made available by NOAA's Physical Sciences Laboratory (PSL) at (urlhttps://www.psl.noaa.gov/cgi-bin/data/composites/printpage.pl).

Status and trends: Autumn (Sep—Nov, 2021): The SST anomaly pattern (Figure 5a) included cooler than normal SSTs for the GOA and the sub-tropical North Pacific from the Hawaiian Islands to California; warm water with peak anomalies exceeding 2°C was present in the central North Pacific between about 25°N and 45°N. The central and eastern tropical Pacific was cooler than normal in association with weak-moderate La Niña conditions. The SLP pattern (Figure 6a) included prominent negative SLP anomalies in the northeastern GOA extending southward off the coast of the Pacific Northwest, and weaker positive anomalies in an arc from the Sea of Okhotsk and western Bering Sea through the central North Pacific to the waters offshore of California. This SLP distribution resulted in anomalous winds from the northwest for the southeast Bering Sea shelf and enhanced storminess for the GOA.

Winter (Dec–Feb, 2021–2022): The overall distribution of SST anomalies persisted through the winter (Figure 5b). This period did feature development of quite cold SSTs in the southeastern Bering Sea shelf, with temperatures on the inner shelf more than 2°C colder than normal. La Niña remained present, with the most prominent anomalies occurring in the eastern tropical Pacific. The winter SLP anomaly pattern for the (Figure 6b) featured a large region of strongly positive SLP anomalies in the northeast Pacific centered south of the GOA, and much weaker negative SLP anomalies extending from the Sea of Okhotsk to the Hawaiian Islands. The accompanying wind anomalies included suppressed westerlies across the central and eastern North Pacific between roughly 25°N and 45°N, and was also associated with a dearth of landfalling storms into Oregon and California. On the other hand, enhanced westerlies were present across the eastern North Pacific farther north, implying anomalous equatorward Ekman transports in the upper ocean mixed layer, consistent with the findings summarized in the Ocean Surface Currents – Papa Trajectory Index section.

Spring (Mar—May, 2022): The large-scale SST anomaly pattern for the North Pacific was more or less static through the spring (Figure 5c). There were some changes since the previous season including intensification of the warm anomaly in the waters north of the Hawaiian Islands, a decline in the magnitude of the negative anomaly on the southeastern Bering Sea shelf, and essentially elimination of the cold water in the GOA. La Niña continued in the tropical Pacific. Much weaker SLP anomalies in the mean were present in the NE Pacific (Figure 6c). Higher than normal SLP occurred between roughly 25°N and 45°N across the basin with weak negative SLP anomalies in the GOA. The latter in combination with relatively high SLP in the northwestern Bering Sea resulted in anomalous winds from the north of about 2 m s^{-1} for the southeastern Bering Sea shelf.

Summer (Jun—Aug, 2022): The summer brought modest warming of the waters offshore of western North America from Northern California to the Bering Sea (Figure 5d). This warming can be attributed in part to the aforementioned downwelling favorable winds along the coast of the Pacific Northwest, and relatively warm weather/air temperatures in coastal Alaska. The tropical Pacific remained cooler than normal, with the most prominent anomalies near the dateline. SLP anomalies were mostly negative in the mid-latitude North Pacific, with the exception of a region of positive anomalies located south of the Alaska Peninsula (Figure 6d). The winds during this period included anomalies of about 1.5 to 2.5 m s^{-1} from the northwest in the western Aleutian Island region, and southerly (downwelling-favorable) anomalies of about 2 m s^{-1} along the coast of Northern California and Oregon. Generally weak wind anomalies prevailed in the eastern Bering Sea and GOA.



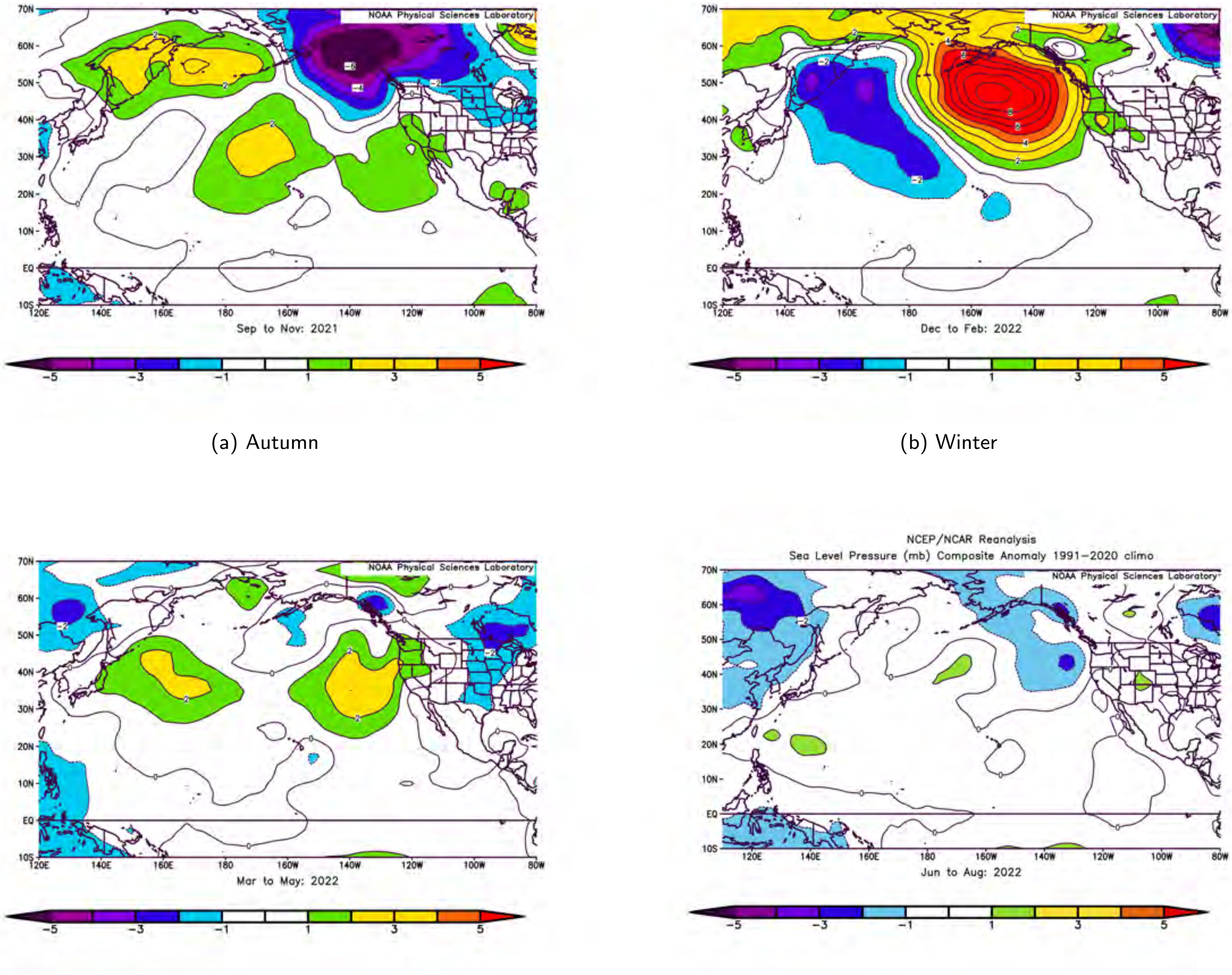
(a) Autumn

(b) Winter

(c) Spring

(d) Summer

Figure 5: SST anomalies for autumn (September–November 2021), winter (December 2021–February 2022), spring (March–May 2022), and summer (June–August 2022).



(a) Autumn

(b) Winter

(c) Spring

(d) Summer

Figure 6: Sea level pressure anomalies for autumn (September–November 2021), winter (December 2021–February 2022), spring (March–May 2022), and summer (June–August 2022).

Long-term Sea Surface Temperature in the Gulf of Alaska (1900-present)

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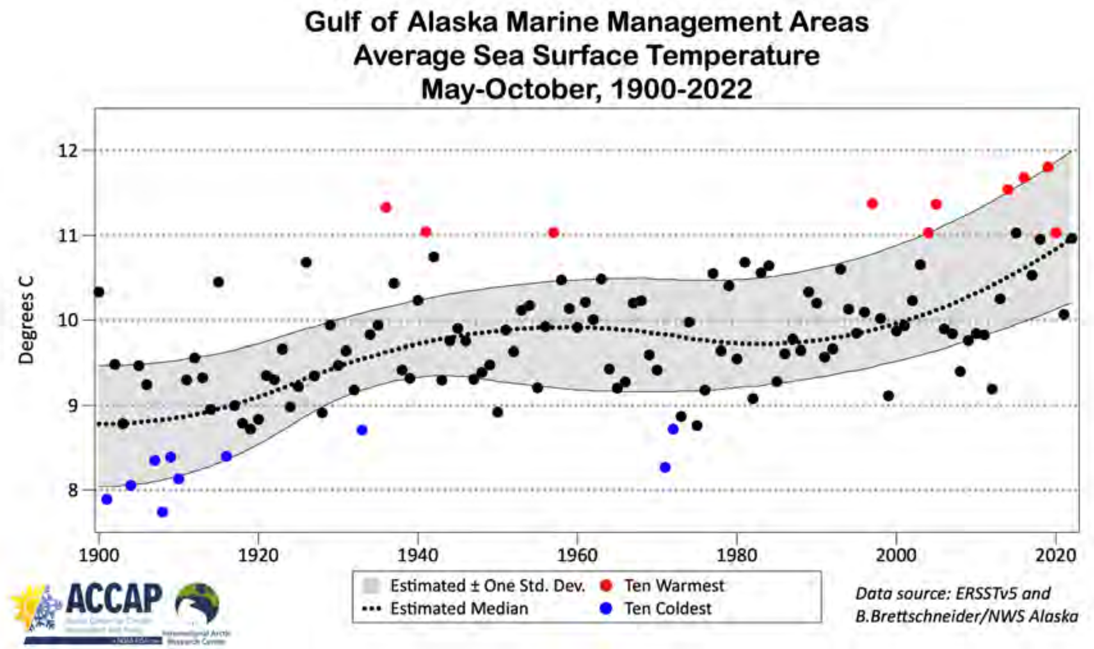
Last updated: August 2022

Description of indicator: Sea surface temperatures in the Gulf of Alaska can be calculated using NOAA's Extended Reconstructed SST V5 data[4]. ERSST is a global monthly sea surface temperature dataset produced at 2º x 2º 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 147ºW) but the regions were combined due to reduced subregional sample sizes and similar trends across the western and eastern shelf.

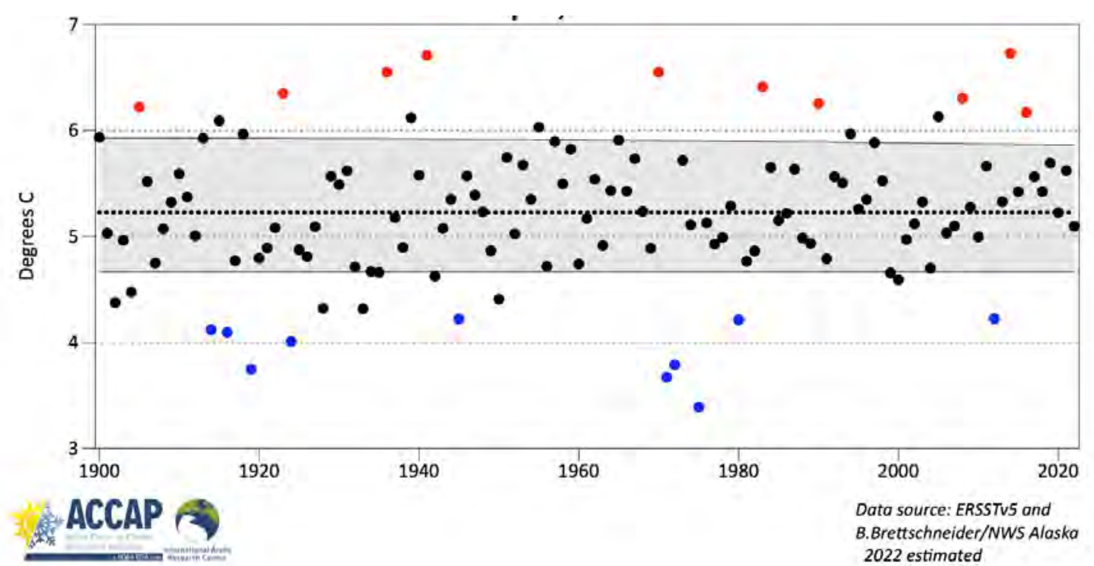
Status and trends: Summer (May - Oct.) sea surface temperatures (Figure 7) over the GOA shelf (10 m - 200 m) were the 12th warmest in the time series (since 1900). This heating trend was largely driven by warmer fall temperatures across the GOA, reaching marine heatwave status in the eastern GOA (Temperature Synthesis in this Report, p.36). The overall trend in summer temperatures show a warming during the first decades of the 20th century followed by an extended period of little long-term trend, with substantial warming resuming in the late 1990s. In contrast, winter (Nov.- April) temperatures show no significant trend over the past 122 years.

Factors influencing observed trends & Implications: The GOA shelf surface waters have been warming since 1900. Summer temperatures are primarily driving this warming trend. This analysis provides context for the short-term sea surface temperature time series presented elsewhere in this report (Temperature Synthesis, p. 36). 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. Research on species-specific thermal ranges can also help interpret potential implications of continued warming of this marine system.

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



(a) Summer (May - Oct.)



(b) Winter (Nov. - April)

Figure 7: Sea surface temperatures for the Gulf of Alaska from 1900–2022 for (a) summer (May-Oct.) and (b) winter (Nov.-April). Presented here are the quantiles representing ± 1 standard deviation of a Gaussian distribution and for completeness the median calculated using constrained B-Spline regression. The present year (2022) are preliminary data.

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

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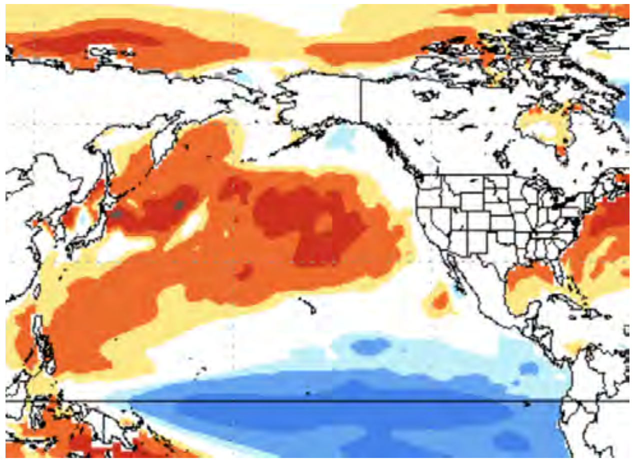
Last updated: August 2022

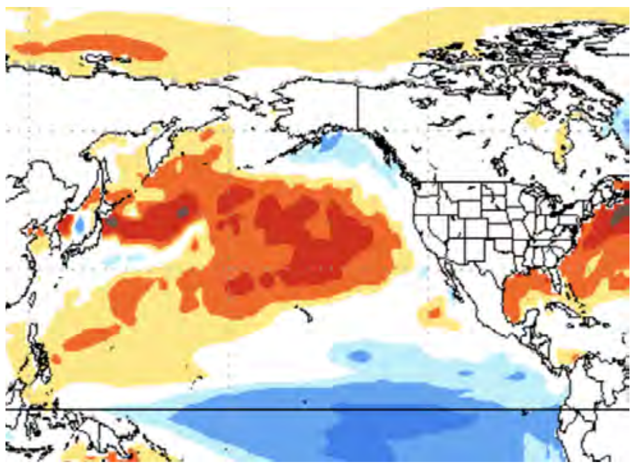
Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 8. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations. The NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.

Status and trends: These NMME forecasts of three-month average SST anomalies indicate a continuation of a large region of relatively warm water in the central and western North Pacific south through the end of the calendar year (Oct–Dec 2022; Figure 8a). Near-average temperatures are predicted for Alaskan waters with the exception of the western Aleutian Islands, where positive anomalies are also predicted. The models also are indicating an atmospheric circulation pattern that would bring enhanced storminess to the GOA. The ensemble of model predictions for December 2022 through February 2023 is quite similar to that of the earlier period, with the exception of cooling for the GOA (Figure 8b) as compared with climatological norms. This change is consistent with what has occurred in past La Niña winters; the models as a group are predicting tropical Pacific temperatures commensurate with a weak-moderate La Niña. The projection for February through April of 2023 (Figure 8c) features a rather static pattern in the SST anomalies aside from weakening of the equatorial Pacific cold anomalies.

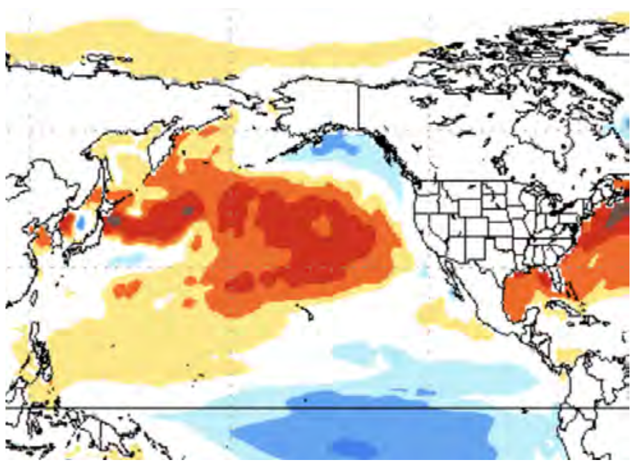
The projections from a year ago are first reviewed briefly. The consensus of the model forecasts from September 2021 for the following fall and winter indicated a continuation of positive SST anomalies across the North Pacific south of 50°N and modest warmth on the southeast Bering Sea shelf. They also indicated weak cool anomalies in the GOA. The extended range projections for spring 2022 included continued cooling of the GOA to anomaly values of 0.5–1°C and near-average temperatures on the southeast Bering Sea shelf. The performance of the climate models as a group was fairly good in an overall sense. For the first period considered of October through December 2021, they correctly forecast warmth in the central North Pacific and negative anomalies in the GOA and Chukchi Sea. But the GOA was actually cooler than predicted and the southeast Bering Sea shelf was cool instead of warm as forecast. The overall SST anomaly pattern was forecast to remain similar for the following winter (Dec–Feb). As with the previous forecast, the models captured the overall pattern for the North Pacific, but underpredicted the cool temperatures in the GOA and on the southeast Bering Sea shelf. The consensus of the model forecasts for February–April 2022 included slight additional cooling of the GOA and southeast Bering Sea shelf whereas in reality the temperatures in these regions moderated. In summary, the model predictions were quite good for the tropics and mid-latitude North Pacific, but were less skillful for the southeastern Bering Sea shelf, perhaps due to the early and unanticipated onset of cold weather for Alaska and the waters to its west and south in autumn 2021.



(a) Months Oct–Nov–Dec



(b) Months Dec–Jan–Feb



(c) Months Feb–Mar–Apr

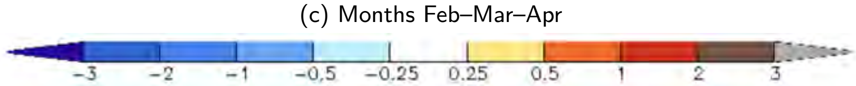


Figure 8: Predicted SST anomalies from the NMME model for Oct–Nov–Dec (1-month lead), Dec–Jan–Feb (3-month lead), and Feb–Mar–Apr (5-month lead) for the 2022–2023 season.

Ocean Temperature: Gulf of Alaska Synthesis

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Matt Callahan, Alaska Fisheries Information Network; Contact: matt.callahan@noaa.gov
Seward Line Survey: Seth L. Danielson and Russell R Hopcroft, University of Alaska, Fairbanks; Contact: sldanielson@alaska.edu, rrhopcroft@alaska.edu
AFSC Southeast Coastal Monitoring Survey: Emily Fergusson, Auke Bay Laboratories, Alaska Fisheries Science Center, NOAA Fisheries; Contact: emily.fergusson@noaa.gov
Bottom Trawl Survey: Ned Laman, Groundfish Assessment Program, Alaska Fisheries Science Center, NOAA Fisheries; Contact: ned.laman@noaa.gov
AFSC Longline Survey: Kevin Siwicke, Marine Ecology and Stock Assessment Program, Alaska Fisheries Science Center, NOAA Fisheries; Contact: kevin.sewicki@noaa.gov
AFSC EcoFOCI Spring Larval Survey: Lauren Rogers, EcoFOCI, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, NOAA Fisheries
Contact: lauren.rogers@noaa.gov
ADF&G Large Mesh Trawl Survey: Carrie Worton, Alaska Department of Fish and Game, Kodiak; Contact: carrie.worton@alaska.gov
Last updated: October 2022

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

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 2022 SST in context of long-term trends (1900-present) using NOAA's Extended Reconstructed SST V5 data[5]. We then present satellite data and reanalysis monthly data for 2022 ocean temperatures at surface and at depth, averaged across the western GOA and eastern GOA shelf. This

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

is followed by a description of trends observed across multiple GOA sub-regional surveys conducted in the spring and summer of 2022. We then show observations related to marine heatwave conditions. Detailed methods are listed at the end of the contribution.

Status and trends: Ocean surface temperatures, averaged broadly across the eastern and western GOA shelf, were cooler than average during winter (continuing from a cool 2021 fall), near normal during spring, and warm during summer, and warm/marine heatwave conditions in the fall, compared to the 1985-2014 baseline (Figure 9). Spring (May) subregional temperatures in the western GOA (Seward Line) were cooler than average at the surface and at depth, and summer subregional temperatures were above average at surface and depth across the western GOA and eastern GOA, except southeast Alaska inside surface waters (slightly below average). Fall 2022 (as of Oct. 31) surface ocean surface temperatures have been warmer than average across the GOA, with persistent marine heatwave conditions for the month of October across the eastern GOA shelf. Two thermal conditions to monitor are the above average (across GOA) /marine heatwave conditions (eastern GOA) fall surface temperatures and the above-average temperatures at depth, including a multi-year warmer than average shelf edge temperatures (∼250m).

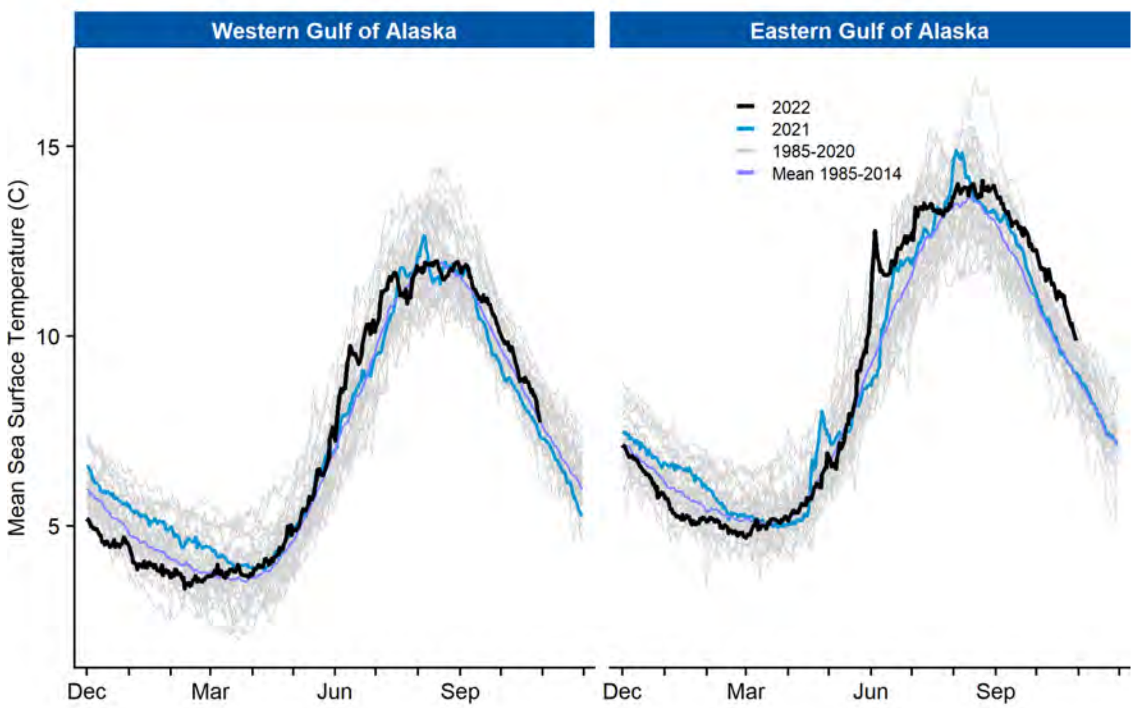

Figure 9: Daily sea surface temperatures (SST) for the western GOA and eastern GOA. Lines illustrate the daily SST for 2022 through Oct. 29 (black), the daily SST for 2021 (blue), the 30-year (1985–2014) mean SST for each day (purple), and daily SST for each year of the time series (1985-2020; gray). Survey details are in the "Methods" section at the end of this contribution.

Spring western GOA: While western GOA and eastern GOA shelf averages of satellite-derived surface temperatures showed average (1985-2015) spring temperatures (Figure 9), May surface temperatures in the western GOA, along the Seward Line, were cooler than average (1998-2022), and approximately 0.8°C below the survey-specific long-term mean (Seward Line Survey: 5.7°C) (Figure 10).

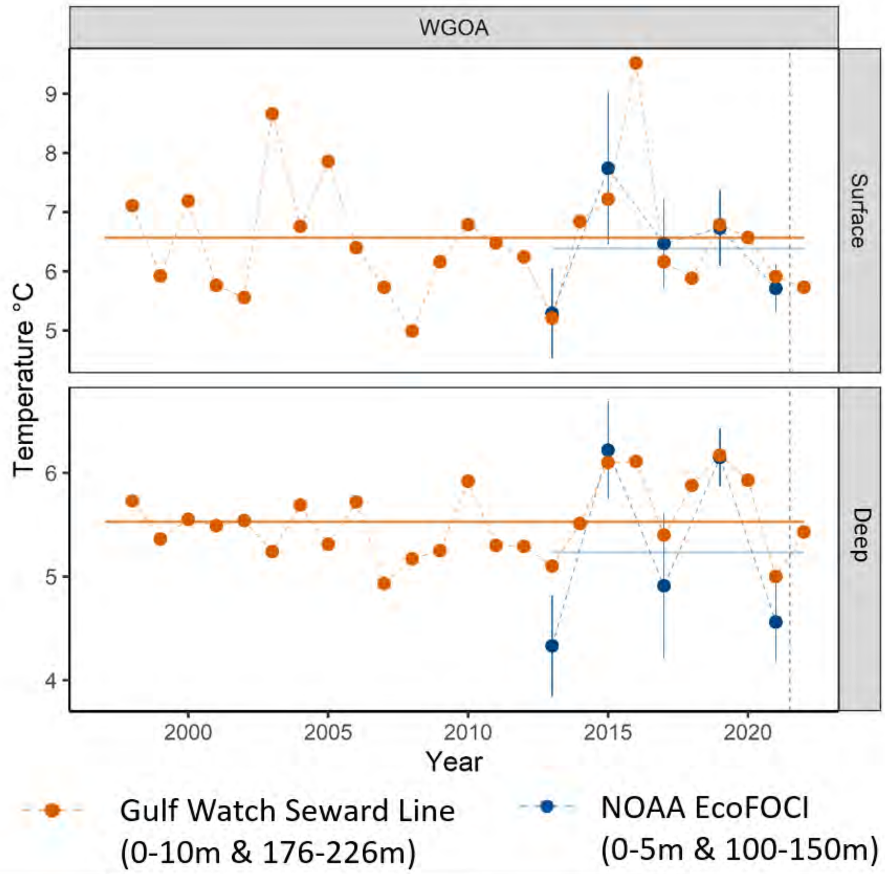

Figure 10: Observed temperatures at surface and depth from the AFSC EcoFOCI spring (May-June, alternating years) larval survey and the Gulfwatch Alaska spring (May) Seward Line survey. Data to the right of the vertical dashed line were collected in 2022. Multiple surveys are shown to reflect commonalities or differences in trends, primarily due to temporal and spatial coverage. Survey details are in the "Methods" section at the end of this contribution.

Summer western GOA: The 2022 summer surface waters warmed from 2021 to above average in the western GOA (Seward Line Survey: 12.84°C) (Figure 11). Temperatures at depth across the western GOA shelf were above average. Bottom temperatures east of Kodiak increased from below to above average (6.1°C, ADF&G large mesh trawl survey). At ∼ 200 m depth the Seward Line (5.5°C) continued a second year of warming to above the long-term mean, while the Longline Survey temperatures (5.2°C; 250m, shelf edge) remained above the long-term mean, a trend since 2017 (Figure 11).

Summer eastern GOA: The 2022 summer surface waters in eastern GOA inside waters (Icy Strait) were cooler than 2019 (Bottom Trawl Survey: 13.4°C) cooling to approximately the long-term mean (Figure 11). The inside surface waters in southeast Alaska (Icy Strait) remained just below the long-term mean for a third consecutive year (9°C). Along the shelf edge at ∼ 250 m depth, temperatures remained warmer than the longterm mean continuing a trend since 2018 (Longline Survey: 5.5°C).

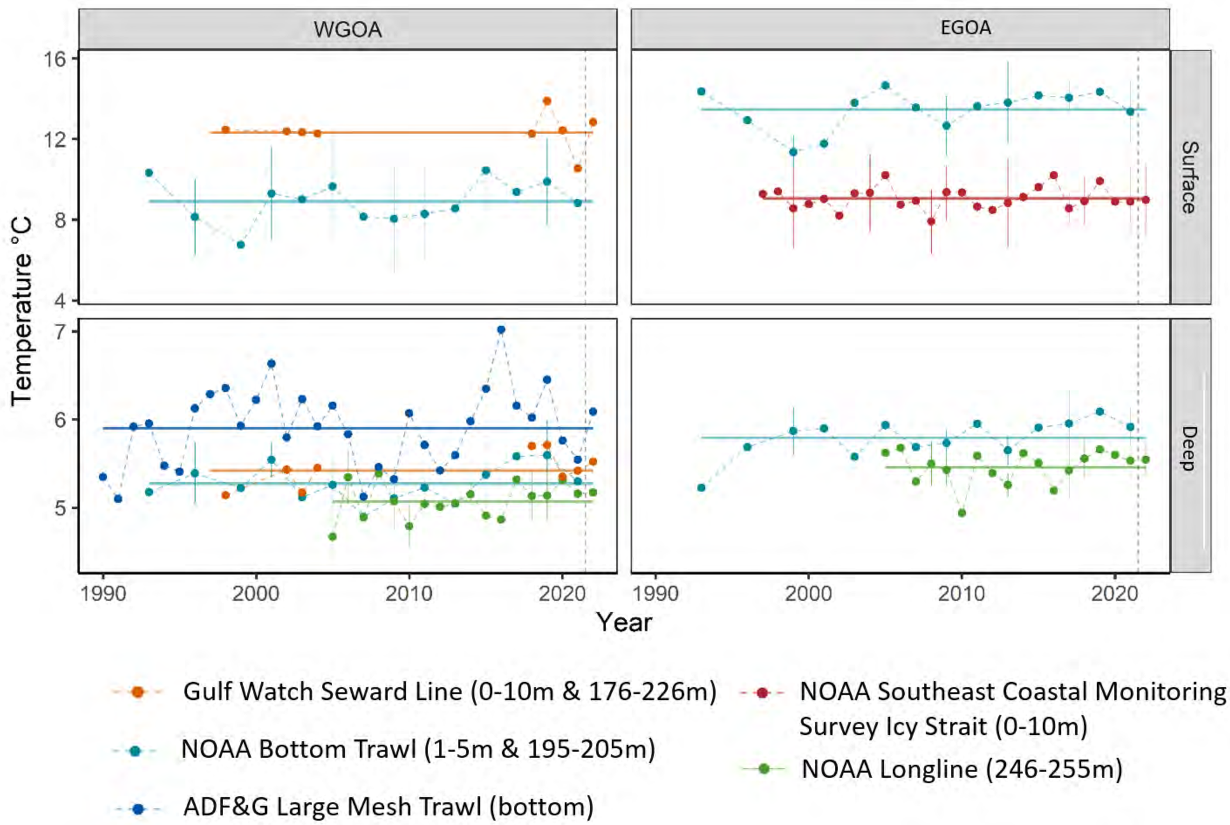

Figure 11: Observed temperatures at surface and depth from the AFSC Bottom Trawl Survey (alternating years, May-Sep.), AFSC Longline Survey (western GOA: June, eastern GOA: August), AFSC Southeast Alaska Coastal Monitoring (SECM Survey; May-Aug.), ADF&G Large Mesh Trawl Survey (Jun./Jul.), and the Gulfwatch Alaska spring (May) Seward Line survey. 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.

Marine Heat Waves: The first half of the year across the GOA did not experience marine heatwave conditions. However, above-average SSTs returned in summer including a strong although brief MHW in the eastern GOA (July) and persisted through the fall including marine heatwave conditions in the eastern GOA for the month of October (most recent data is Oct 29th) (Figures 12 and 13). The GOA experienced 2 consecutive years of non-persistent marine heatwave conditions (2020, 2021) and it remains to be seen how the fall of 2022 will proceed. To-date (Oct. 29th) the number of marine heatwave days in the GOA (driven by October surface temperatures in eastern GOA) is similar in total to 2017 and 2018 (Figure 13) and, in October, covered 76%–100% of the satellite pixels (5 km grid) analyzed in eastern GOA shelf waters (Figure 14). An important ecological consideration with MHWs is the extent of a particular area that experiences the warm conditions, and whether there may be thermal refugia for species within that domain.

Factors influencing observed trends: Ocean temperatures in 2022 reflect a third consecutive year of no persistent MHW conditions in the winter through summer but warm summer and persistent marine

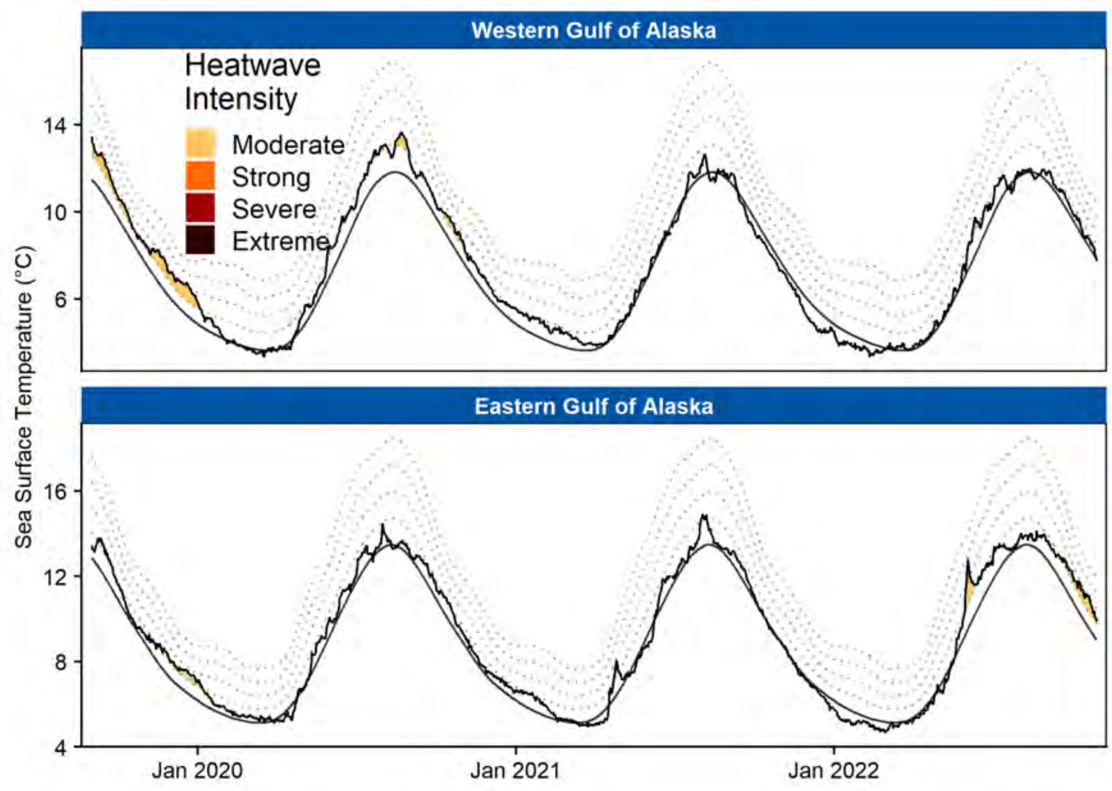

Figure 12: Marine heatwave (MHW) status from Dec. 2019 through Oct. 2022. Filled (yellow) areas depict MHW events. Black lines represent the 30-year baseline (smoothed line; 1985–2014.) and observed daily sea surface temperatures (jagged line). Faint grey dotted lines illustrate the MHW severity thresholds in increasing order (moderate and strong).

heatwave conditions in the fall may now define the thermal conditions of the year. Warm years are often associated with El Niño events (1998, 2003, and 2016). Cool conditions are related to complex winter balances between heat loss, coastal runoff and stratification (Janout et al., 2010; Hermann et al., 2016). The 2022 winter cooling temperatures may relate to La Niña conditions in the winter of 2022/2023 and westerly winds that continued from the fall 2021. Increased surface temperature during summer 2022 may have been influenced by an unusually sunny spring in southern Alaska. SST can also be decoupled from the heat content of the full water column due to stratification. For example, a rapid increase in SST can be due to increased stratification such that the solar heating is predominantly distributed over a shallower layer of water. Similarly, rapid decreases can be due to mixing that erodes that stratification, such as from winds. Predicted La Niña conditions in the winter of 2022/2023 may reverse the warming fall conditions.

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.

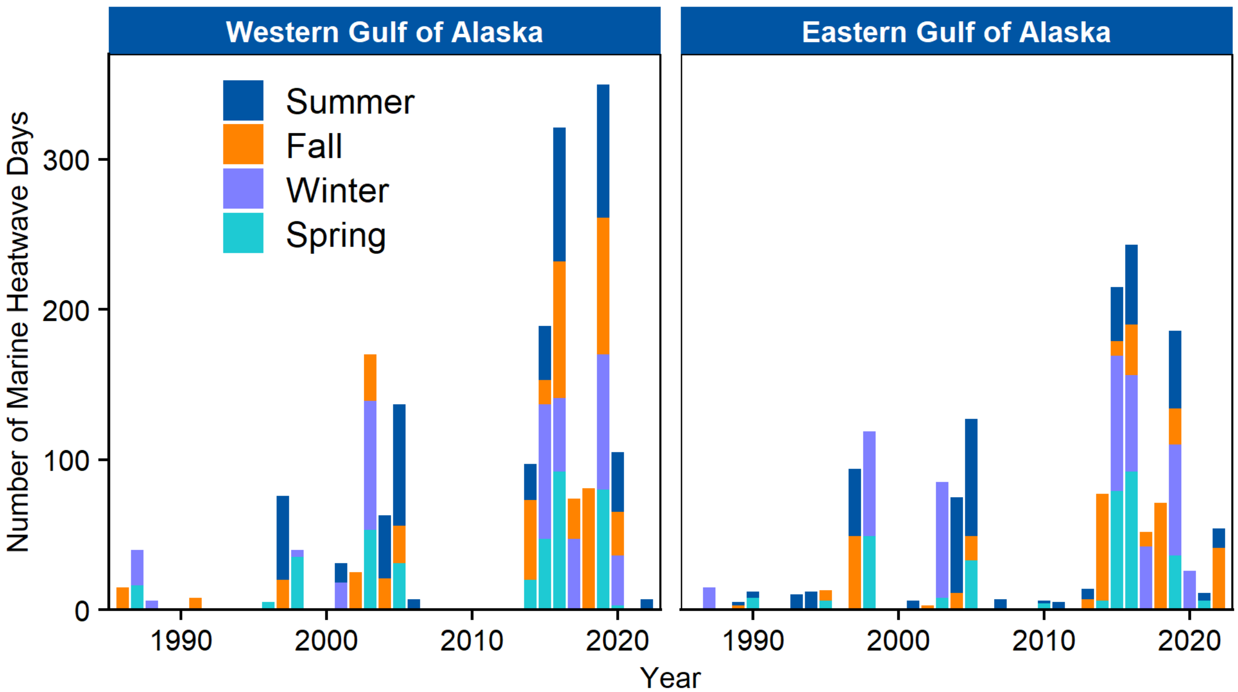

Figure 13: Number of days during which marine heatwave conditions persisted in a given year. Seasons are summer (Jun-Aug), fall (Sept-Nov), winter (Dec-Feb), spring (Mar-Jun). Years are shifted to include complete seasons so December of a calendar year is grouped with the following year to aggregate winter data (e.g., Dec. 2021 occurs with winter of 2022).

Icy Strait differs from the other shelf-oriented temperature datasets, reflecting conditions in the inside waters in southeastern Alaska. This region supports numerous forage species (e.g., herring, juvenile salmon), groundfish, salmon, marine mammals (e.g., humback whales) and seabirds. Icy Strait is a principal migration corridor for juvenile and returning salmon and temperature can influence the species composition of the zooplankton community, thereby affecting prey quality and availability (i.e., warmer temperatures can be associated with smaller zooplankton species with lower lipid densities).

Implications: Barbeaux et al. (2020*b*) provide tangible evidence for the potential implications of warming conditions on groundfish, in particular Pacific cod. Holsman et al. (2020) further emphasize the risk of warming conditions on gadid populations and highlight the value of an ecosystem-based management approach for buffering the impacts of projected temperature increases and more frequent marine heat waves. The conditions in 2022 began persistently cooler at the surface than the previous few years, but increased to persistent warmer conditions in the summer and fall with potential implications for young of year groundfish survival in their first winter. The continued above-average temperatures at depth remain within the known thermal ranges of groundfish but could present a cumulative stress on the demersal and benthic environment. Cool winter and beginning of spring appears to have provided adequate thermal conditions for average to higher spring and early summer productivity in lower trophic levels (zooplankton and forage fish) (Hopcroft, p.70, Fergusson, p.72, and Hatch, p.86, in this report), reflected in above-average seabird reproductive success (Seabird Synthesis, p.124, and Hatch, p.86, in this report). The warm (western GOA and marine heatwave conditions (eastern GOA) conditions in the fall could present challenging conditions for adequate lipid storage for winter survival. As of this report,

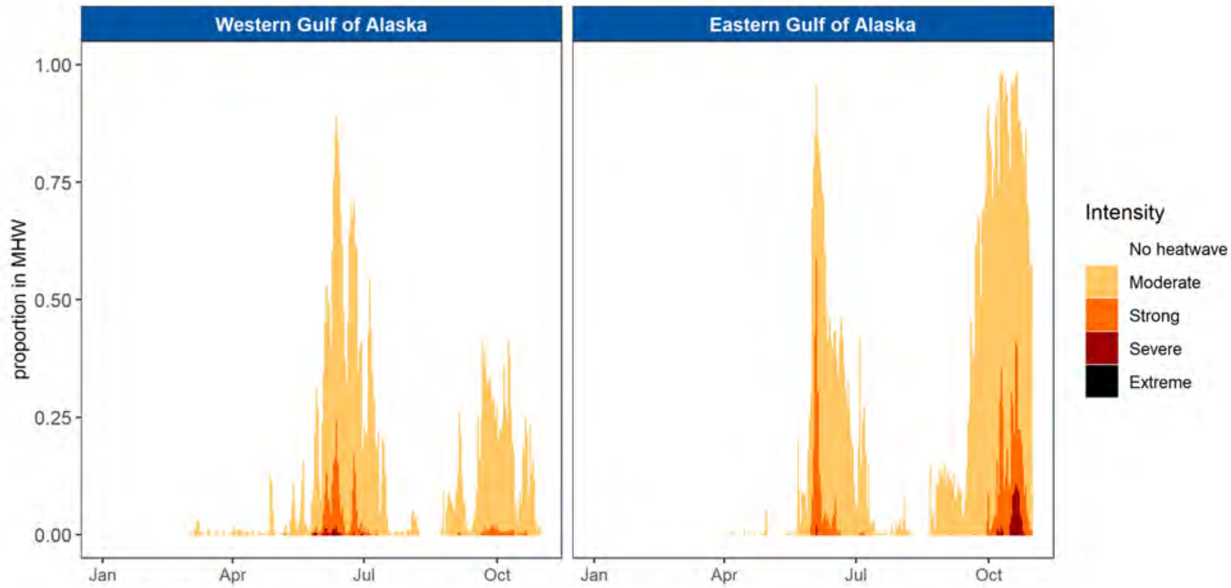

Figure 14: Proportion of region in MHW status. MHW status calculations were performed on each 5 x 5 km grid cell within the GOA. This figure shows a five day rolling average of the proportion of cells within each region that are in MHW status.

surface temperatures are still predicted to cool in the winter 2023 (Bond in this report, p.34).

Methods:

AFSC EcoFOCI Spring Larval Survey: EcoFOCI conducts biennial surveys in spring (May-June) and summer (August- September) in the western GOA, targeting early life stages of fishes and their prey. At each sampling station, a bongo net array is towed obliquely from surface to 100m (spring) or 200m (late summer), or to 10m off bottom in shallower waters. Attached to the wire above the bongo frame is a Seabird FastCAT profiler which measures temperature, salinity, and depth. Up casts were processed and used to generate maps and time-series of temperatures at the surface and at maximum tow depth using the custom R package FastrCAT (https://github.com/Copepoda/FastrCAT). Survey dates were 10–26 May 2021. The late summer EcoFOCI survey was canceled in 2021, so no update of late summer data are provided.

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.

2021 temperatures were not standardized to account for the effect of collection date as in past years, but those methods will resume next year.

Gulfwatch Alaska Seward Line Survey: 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 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 from the NOAA Coral Reef Watch Program were accessed via the NOAA Coast Watch West Coast Node ERDDAP server (`https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html`) for January 1985 - September 2021. A limitation of SST records derived from satellites has been data missing as a result of cloud cover. Using the NASA multi-scale ultra-high resolution (MUR) SST dataset however, a combination of collection modalities creates a gap-free blend of data. Daily SST data were averaged within the western (147°W– 163°W) and eastern (133°W–147°W) GOA (western GOA and eastern GOA, respectively) for depths from 10m – 200m (i.e., on the shelf). Detailed methods are online, including maps of the spatial strata and processing the data in R[6].

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.

<u>AFSC Summer Longline Survey</u>: 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 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).

<u>ADF&G Large Mesh Trawl Survey</u>: 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

[6] `github.com/jordanwatson/EcosystemStatusReports/tree/master/SST`

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. In 2022, a total of 50 stations were sampled from June 29 through July 6. Temperature anomalies were calculated using average bottom temperatures recorded for each haul from 1990 to present.

Eddies in the Gulf of Alaska

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Last updated: September 2022

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 15; 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)[7].

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 15). 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 16).

Analysis updates — The most recent data were downloaded on August 08, 2022 so our daily time series now covers 1/1/1993 to 8/08/2022 on a 0.25 ° longitude x 0.25v latitude grid. Original data set is global but we subset it to 150 °E–125 °W and 40 °N–72 °N during download. Data from 1993 to 2020 are the delayed/reprocessed product whereas data from 2021 onward are from the "NRT" (near real time) products. The horizontal map shown below is averaged over 1993 to 2021, years with full data coverage. The horizontal map (Figure 15) and monthly climatology (Figure 16) shown below are averaged over 1993–2021 (period with full year coverage).

Status and trends: The seasonal cycles of EKE in the eastern and central GOA regions (Figure 15, box a-c) have similar phasing (high in winter/spring and low in summer/fall), suggesting their formation mechanisms are inter-related. As noted, region (d) (western GOA) has an opposite seasonal cycle phase than the other regions (high EKE in the autumn and low EKE in the spring), suggesting separate forcing mechanisms in the western GOA. In 2022, thus far, EKE is all regions (a) through (d) is close to or

[7] `http://www.marine.copernicus.eu`

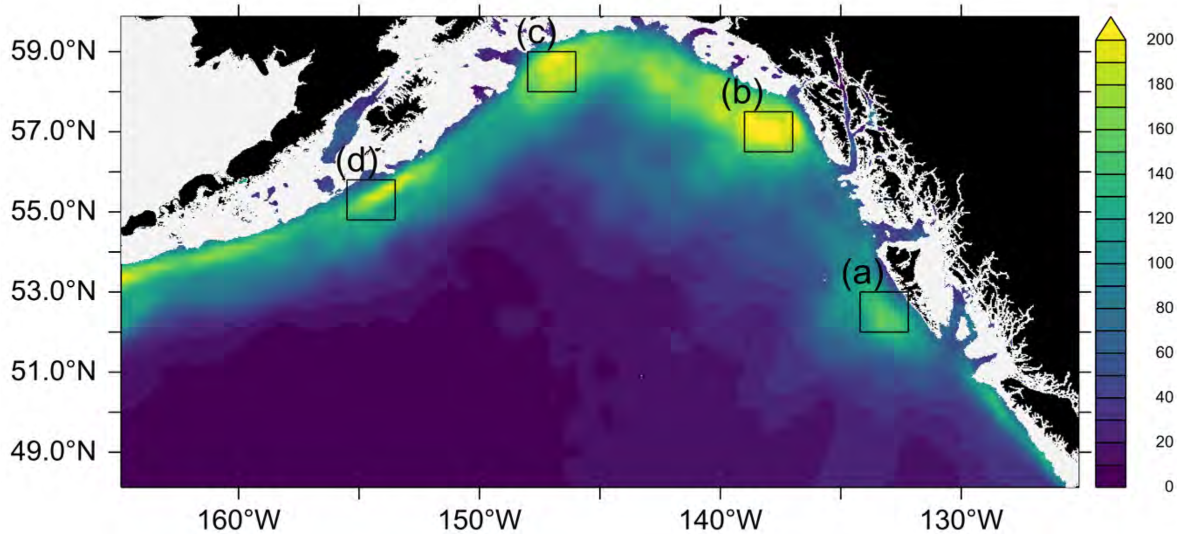


Figure 15: Eddy Kinetic Energy (cm^2 s^{-2}) averaged over January 1993–December 2020 calculated from satellite altimetry. Regions (a)-(d) denote regions over which EKE was averaged for Figure 16.

slightly below its long-term mean climatology. For the eastern boxes (a and b), this "slightly low to average" EKE state is maintained since the late 2010s, whereas boxes (c) and (d) have had high EKE in 2020-2021 (Figure 16).

Temporal variability of EKE in a fixed relatively small box region (like the ones used in this document) is influenced by passing of meso-scale eddies (Figure 17). In addition to these regional EKE indices, we could average EKE over a larger "stripe" next to the shelf break all around the western, central, and eastern GOA, which would provide complementary information to EKE averaged over the boxes. This can be discussed further.

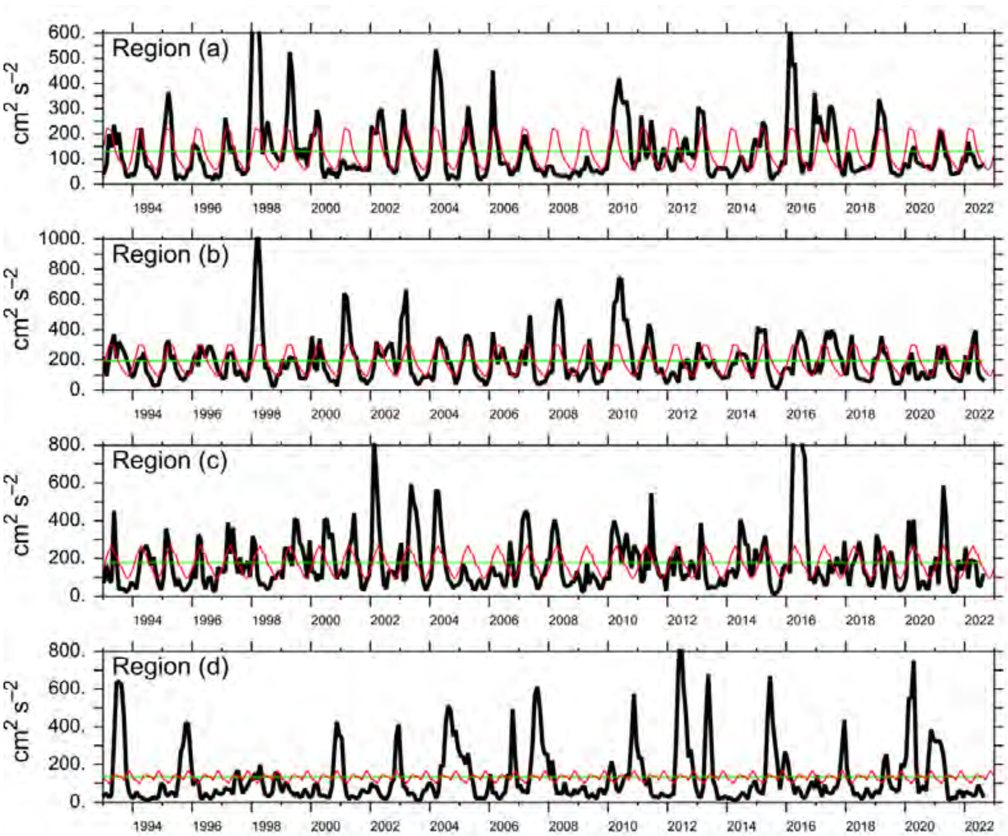
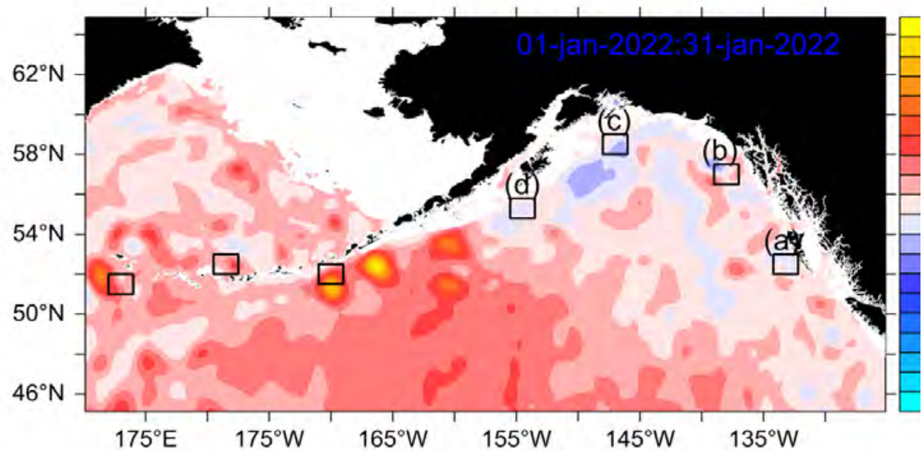
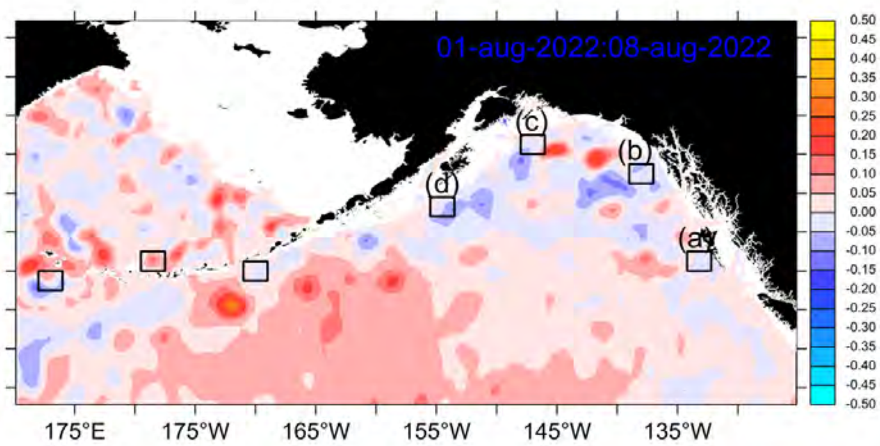


Figure 16: Eddy kinetic energy (cm^2 s^{-2}) averaged over regions shown in Figure 15. Black (line with highest variability): monthly EKE; Red: mean seasonal cycle; Green (straight line): mean over entire time series.



(a) January



(b) Aug

Figure 17: Monthly sea surface height anomalies (unit: meter) in 2022 from January (a) and August (b).

Factors influencing observed trends: In the eastern GOA, 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 GOA (Ladd and Cheng, 2016). In the western GOA, variability is related both to the propagation of eddies from their formation regions in the east and to intrinsic variability.

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).Eddies may result in enhanced settlement and recruitment for arrowtooth flounder (Goldstein et al., 2020) and marine survival rates of pink salmon (Kline, 2010)

Ocean Surface Currents—Papa Trajectory Index

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Description of indicator: The Papa Trajectory Index (PTI) provides an annual index of near-surface water movement variability, based on the trajectory of a simulated surface drifter released at Ocean Station Papa (50°N, 145°W; Figure 18). The simulation for each year is conducted using the "Ocean Surface CURrent Simulator" (OSCURS[8]). 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 2020 (trajectory endpoints years 1902–2022).

Status and trends: In general, the trajectories fan out northeastward toward the North American continent (Figure 1), although the trajectory for 2021/22 is among the relatively few that initially moved strongly to the southeast and ended south of Ocean Station PAPA (baseline 1968–2022). In this respect, the 2021/22 trajectory was most similar to those from 1968/70, 1970/71 and 1971/72, and 2016/17. The 2021/22 trajectory was influenced in December by high sea level pressure (SLP) anomalies centered south of the Alaska Peninsula that gave rise to strong southeasterly wind anomalies east of Ocean Station PAPA. The wind anomalies dropped in strength in January and shifted direction to the north, then increased again in February while shifting more directly eastward as the high pressure anomalies moved eastward. As a result, the ending latitude for the 2021/22 trajectory, and thus its PTI value, was the second-most southerly since the early 1970s (2016/17 having the most southerly). The ending latitude also represents a 8° shift to the south from that in 2020/21, the 10th largest interannual

[8]`http://oceanview.pfeg.noaa.gov/oscurs`

shift in the 121 year time series.

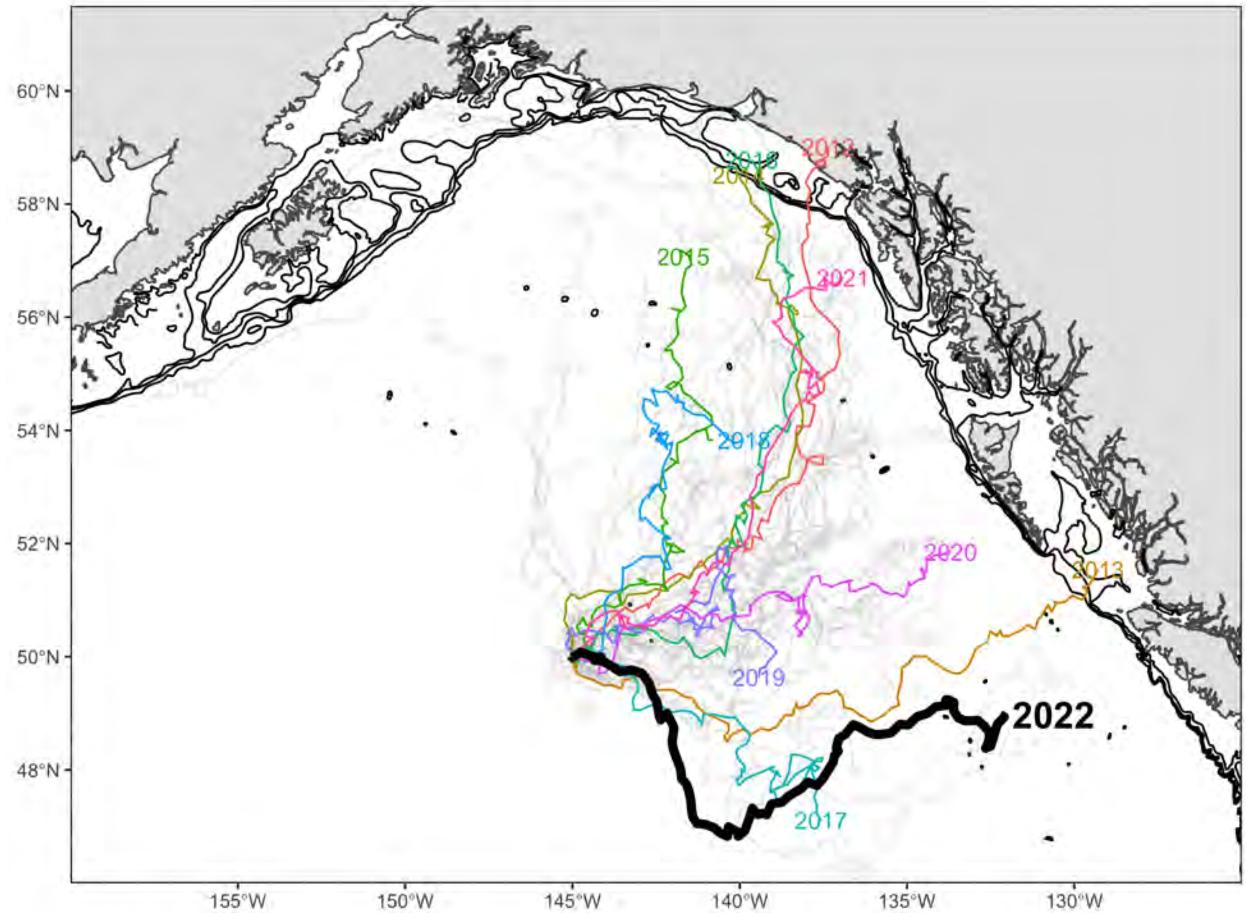

Figure 18: Simulated surface drifter trajectories for winters 2068–2022 (endpoint year). End points of 90-day trajectories for simulated surface drifters released on Dec. 1 of the previous year at Ocean Station Papa are labeled with the year of the endpoint (50°N, 145°W). The trajectory in black is 2021/2022, those in color end in 2012/2013-2020/2021, and those in gray end prior to 2011/2012.

The PTI time series (Figure 19) indicates high interannual variation in the north/south component of drifter trajectories, with an average between-year change greater than 4° and a maximum change of greater than 13° (between 1968/69–1969/70). The change in the PTI between 2015/16 and 2016/17 was the largest since 1968/69–1969/70, while the changes between 2010/11 and 2011/12, and between 2020/21 and 2021/22, represent reversals with slightly less, but diminishing, magnitude. Such swings, however, were not uncommon over the entire time series. While the 20120/21 value represented a return to PTI values above the long-term mean, following 4 consecutive years of values below the mean, the 2021/22 value returns below the mean.

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

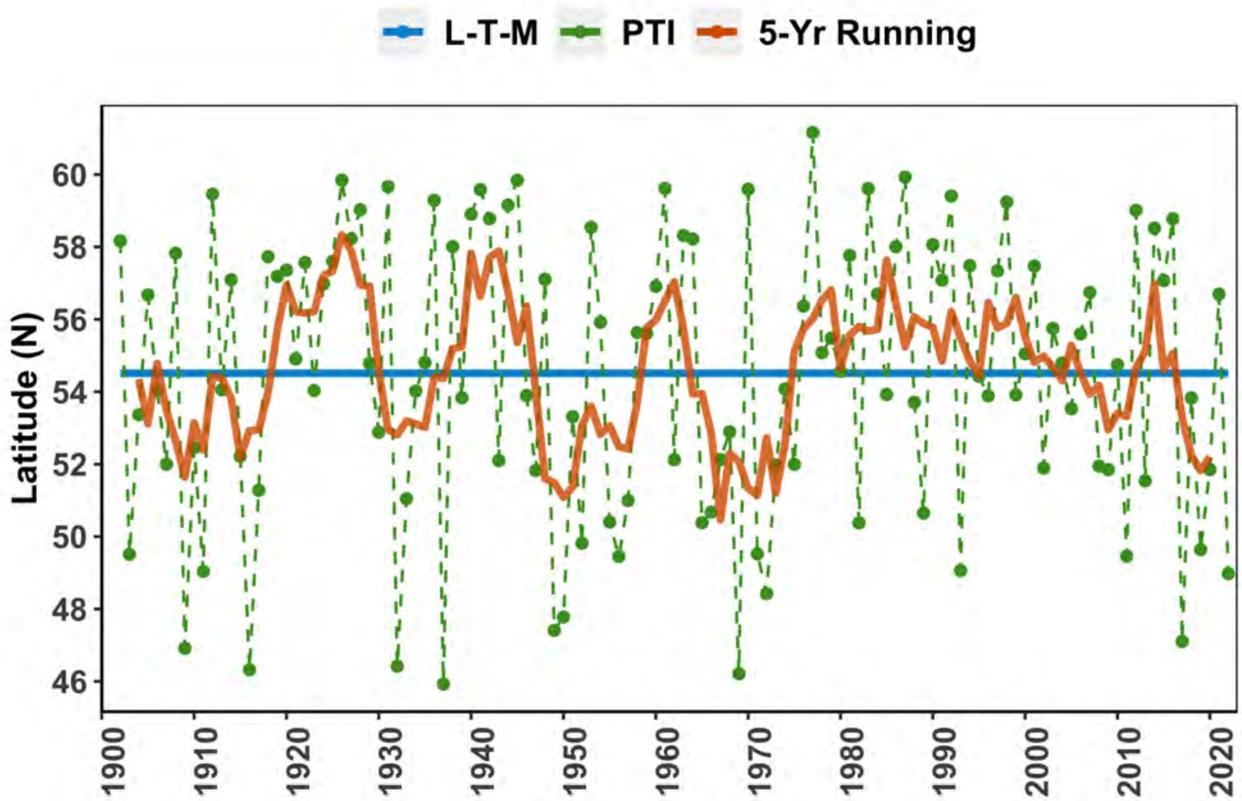

Figure 19: Annual, long-term mean (blue line), and 5-year running mean (orange line and squares) of the Papa Trajectory Index time series end-point latitudes (dotted green line and points) for 1902–2022 winters.

environmental regime shift, although this cycle ended rather quickly, as the filtered PTI crossed the mean in the opposite direction in 2011. A similar shift back to an anomalous southerly flow appears to have occurred in 2016. Since 2005, the PTI appears to be fluctuating on a much shorter time scale ($\sim$10 years per mean crossing) than previously.

Factors influencing observed trends: The 2021/22 trajectory was influenced by a sea level pressure anomaly pattern for the winter (Dec-Feb) of 2021-22 (Bond in this report, p.28). A large region of strongly positive SLP anomalies was featured in the northeast Pacific centered south of the GOA, and much weaker negative SLP anomalies extending from the Sea of Okhotsk to the Hawaiian Islands. Enhanced westerlies were present across the eastern North Pacific farther north, implying anomalous equatorward Ekman transports in the upper ocean mixed layer, consistent with the findings summarized by the OSCURS model in this section.

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 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).

Spring Surface Wind in the Coastal Western Gulf of Alaska

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Last updated: June 2022

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

Two complementary datasets were used here to indicate springtime (April – May) surface wind in the coastal Gulf. We focus on spring to coincide with the seasonal occurrence of many groundfish larvae. The first dataset consists of high-resolution empirical measurements recorded by the National Data Buoy Center (NDBC) at site AMAA2. We chose AMAA2 as its location might be considered a gateway of sorts where winds determine whether coastal flow either funnels into and down Shelikof Strait along the Alaska Peninsula or is diverted southward around Kodiak Island as demonstrated by Ladd and Cheng (2016). This bifurcation is a prominent feature in the circulation dynamics of the western Gulf. Springtime measurements at AMAA2 are currently available for 16 years: 2004 to 2022, except 2007, 2008, and 2018. Measurements were recorded hourly during 2004 and at 30 min intervals during other years (`https://www.ndbc.noaa.gov/` for data and additional methodological detail). The second dataset consists of lower-resolution, reanalysis-based data from the National Centers for Environmental Prediction (NCEP) (Kalnay et al., 1996). The NCEP Reanalysis Derived data averaged by month and year from 1948–2022 were provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, from their Website (`https://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl`). We specified the geographic area to be 55 – 60°N latitude and 150 – 160°W 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 = 16) between the two datasets was r = 0.65 for the u component, and r = 0.73 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 was toward the southwest during spring 2022 (Figure 20), although less towards the south than recent years (2020, 2021). In contrast, the trajectories for 2015 and 2016 were northwestward and westward, respectively, while the trajectory for 2013 was strongly southward. In 2022, no observations were available for most of May 2–10, resulting in an incomplete trajectory, which adds uncertainty for this most recent year.

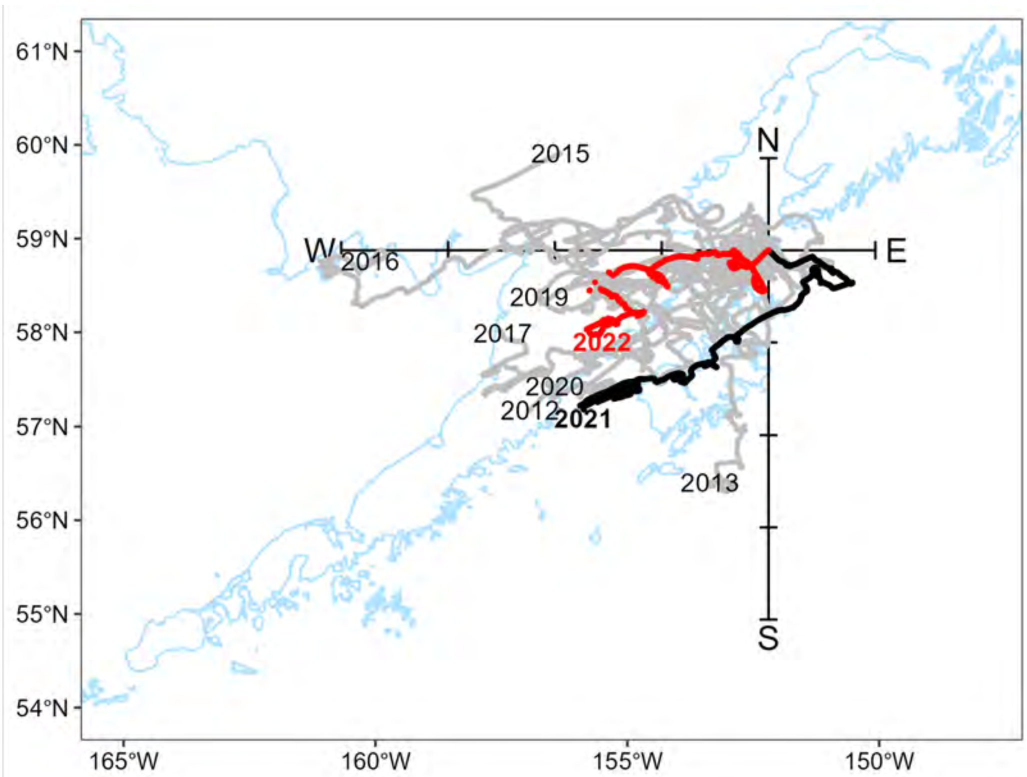

Figure 20: Progressive wind diagrams from NDBC-AMAA2 for spring (April–May) 2004–2022 (except 2007, 2008, and 2018). Select individual trajectory endpoints are labeled by year. The wind trajectories are superimposed on the Alaska coastline with the trajectory origin centered on the location of the AMAA2 site. Note, the scale of distance differs between the trajectories and the coastline. One tick mark ∼2700 nm.

The lower-resolution NCEP winds also indicated mean April-May wind towards the southwest (Figure 21), although with a stronger southward component than measured at NDBC-AMAA2. NCEP winds in 2022 were similar in direction and magnitude to 2012, 2014, and 2021, and in contrast to the period 2015–2019 when means indicate a relatively strong northward component.

Factors influencing observed trends: In the Gulf, winds are dominated by cyclonic storm systems that exhibit pronounced seasonality (Stabeno et al., 2004). During spring, cyclonic winds begin to moderate and anticyclonic winds can drive intermittent upwelling. While the Aleutian Low influences wintertime

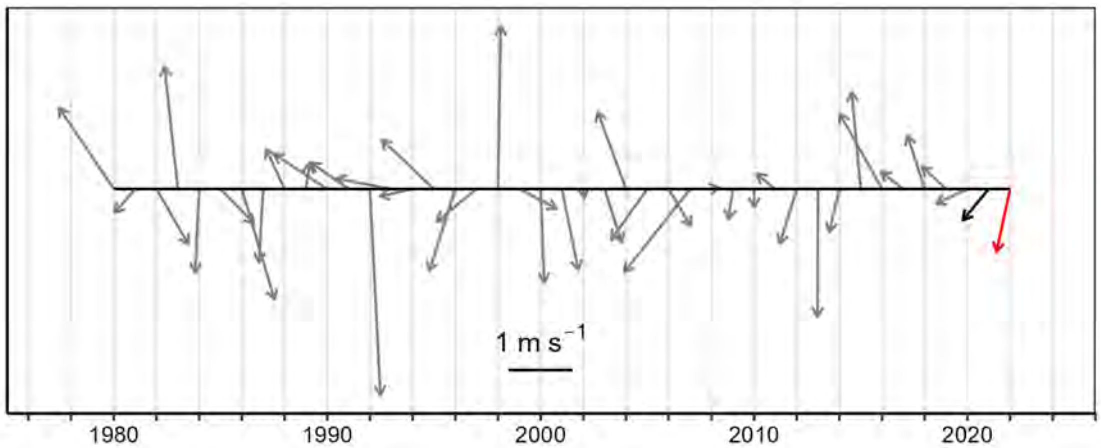

Figure 21: Mean wind from NCEP for spring (April – May) 1980–2020 (gray), 2021 (black), and 2022 (red). Each "stick" represents the magnitude (y-axis) and direction (e.g., northward is up, eastward is to the right) toward which the wind is blowing during each year

conditions and the El Nino-Southern Oscillation can affect conditions in the Gulf at multi-year intervals, factors influencing the coastal environment are complicated by numerous coastal mountains. Local terrain effects can lead to "gap" winds that profoundly affect oceanographic processes. For example, the strong northerly winds during 2013 were locally intensified at AMAA2 by orographic gaps in the Alaska Peninsula (Ladd and Cheng, 2016). We specifically chose the AMAA2 site to indicate winds at a point where they are likely to affect the bifurcation of coastal flow. Interestingly, the strong northerly wind in 2013 agreed between the two datasets; however, the disparity between the datasets in other years might reflect the difference in spatial representation and location.

Implications: Wind speed and direction greatly influences coastal circulation in the Gulf at multiple scales. At small scales, wind-driven turbulence has implications for vertical stratification of the water column, and the patchiness and vertical distribution of plankton, including fish larvae. At larger scales, wind can determine the occurrence of upwelling and downwelling with consequent effects on vertical circulation and transport. At large scales, wind-driven transport influences the life history strategy of organisms, and the variation in transport has long been hypothesized to affect the replenishment of adult fish and shellfish stocks by transporting larvae to favorable or unfavorable habitat. For walleye pollock, the period April-May is particularly important because that is when the eggs and larvae are in the water column and subject to wind-driven transport. In fact, when the AMAA2 wind trajectories for this period (Apr-May) are toward the southwest (down Shelikof Strait), estimates of age-1 abundance tend to increase presumably because downwelling-favorable northeasterly winds enhance retention of larvae (Stabeno et al., 1996, 2004) and juveniles in areas that favor survival (Wilson and Laman, 2021).

Habitat

Structural Epifauna—Gulf of Alaska

NOAA Fisheries Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Primary Production

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

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Description of indicator: Phytoplankton provide the basal resources for secondary consumers like zooplankton and larval fish. During spring, a large bloom occurs once the upper surface of the water column stratifies, and light intensity is sufficient to support phytoplankton growth. This bloom takes advantage of nutrient stores remaining in surface waters after winter storms when phytoplankton activity is low. The spring bloom is critical for nourishing zooplankton, which in turn provide food for fish populations.

The timing and magnitude of the bloom can play an important role in the success of fish cohorts each year. The timing and magnitude of spring phytoplankton blooms vary annually, and satellite data capture their large scale spatio-temporal dynamics and trends. Several studies that include *in situ* data comparisons have shown that satellite chlorophyll data provide reasonable proxies for phytoplankton concentrations in surface waters (Batten et al., 2018; Waite and Mueter, 2013). We used 8 day composite chlorophyll-a concentration data across the eastern and western GOA (divided at 147^0W) to examine phytoplankton dynamics from the MODIS satellite obtained from NOAA coastwatch[9]. No composite data were available for either April 11 or April 19, 2022. We calculated average concentrations from April–June to capture the spring bloom period. We summarized the magnitude of the annual spring event (Figure 22) as well as a chronology of phytoplankton concentrations throughout the season to improve resolution of annual phenologies. We focus on coastal areas (on the continental shelf; depths -10 m to -200 m) as these regions are the major feeding and spawning areas for fish. Data were further filtered to include only waters $>$ 3 miles offshore, as chlorophyll estimates from nearshore areas can be highly uncertain due to river outputs. After filtering, the spatial grids contained up to ~4,000 and ~11,000 records for the eastern and western GOA, respectively. The spring bloom tends to initiate inshore and progresses offshore for the eastern GOA, while in the western Gulf, bloom patterns are generally more complex. Additionally, springtime variation in river runoff can affect stratification which may in turn affect timing of the spring bloom (Waite and Mueter, 2013). Detailed methods are available

[9]https://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMH1chla8day.graph? from 2003–June 14, 2022 and https://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMH1chla8day_R2022NRT.graph? for June 22–30, 2022

at https://github.com/MattCallahan-NOAA/ESR/tree/main/Chla.

Status and trends: A high degree of inter-annual variability was observed for average spring (April–June) chlorophyll-a values (Figure 22) and the timing of peak spring bloom (Figure 23) in both the western and the eastern GOA. In the western GOA, chlorophyll-a concentrations were particularly low in 2016, 2019, 2021, and 2022 (Figure 22), years that also appear to have had an average to late spring bloom peak (Figure 23). Meanwhile, 2022 was the 7th consecutive year of spring chlorophyll concentrations below the time series average (2003–2021) in the eastern GOA. The eastern GOA bloom timing during these recent low years has been average to early.

The timing of the 2022 spring bloom was about average in both GOA regions. Peak chlorophyll-a during 2022 in the western GOA occurred around day 141 (the 2003–2021 mean occurred on day 136) (Figure 23) while the eastern GOA peaked around day 133 (the 2003–2021 mean occurred on day 131).

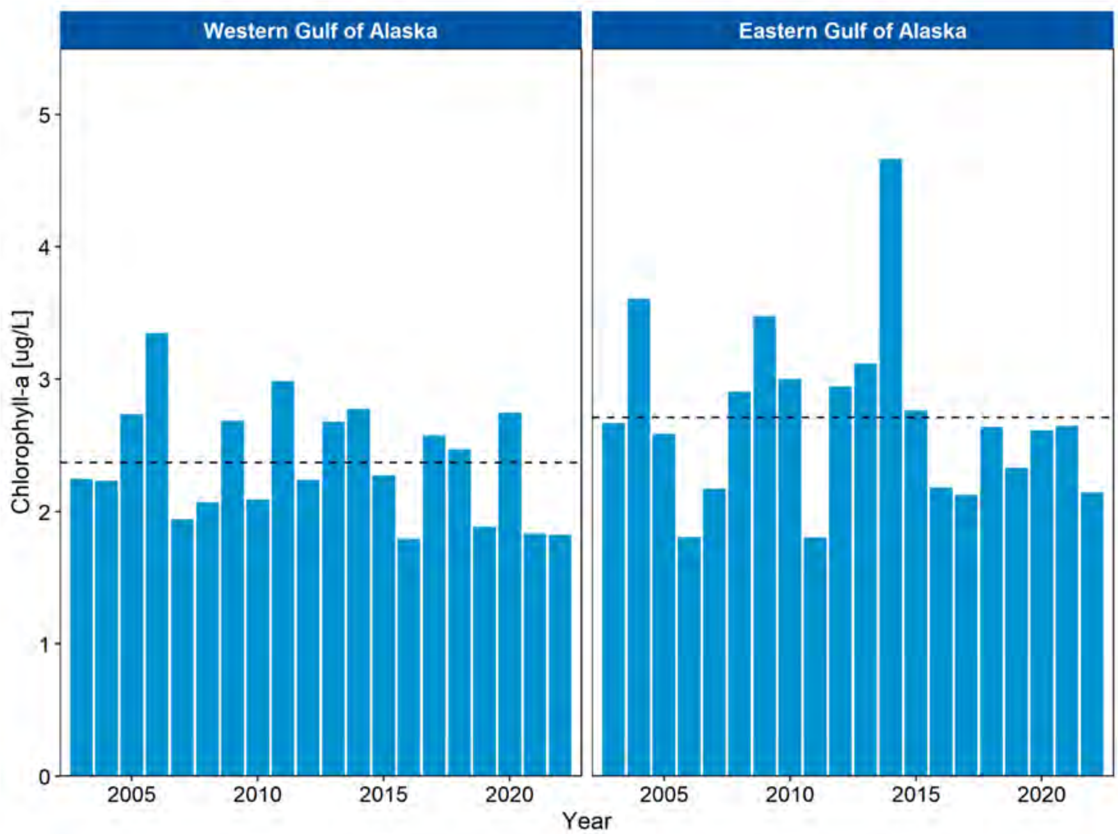

Figure 22: Average spring (April-June) chlorophyll-a concentrations based on MODIS satellite 8 day composites for the western and eastern GOA. The horizontal dashed line is the long-term mean (2003–2022).

Factors influencing observed trends: Some sea surface temperature relationships were evaluated and found no significant correlations in either region. However, given the complexity of the spring bloom and indirect effects from a variety of factors, this relationship is far from exhaustive, as temperatures alone are unlikely to drive phytoplankton concentrations. It is known that mesoscale eddies play a large role in the GOA chlorophyll patterns offshore of the continental shelf, though there is evidence that eddy-moderated shelf-slope exchange can play a role in the patchy nature of phytoplankton 'hot spots' over the shelf as well (Okkonen et al., 2003). Additionally, spring runoff and ambient nutrient

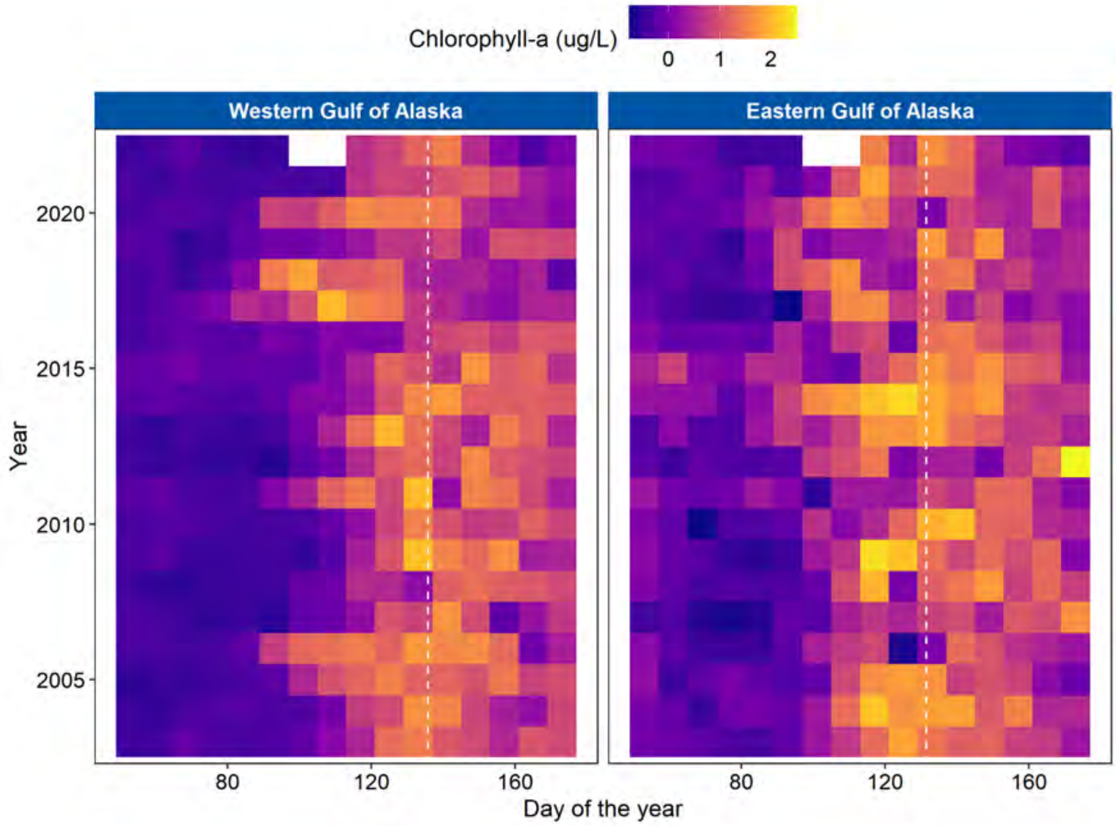

Figure 23: Average 8-day composite chlorophyll concentrations (log-transformed) for the western and eastern GOA from 2003–2022. The brightest (yellow) color within each year will represent the peak bloom (less bright yellow reflects a lower peak). All years are on the same color scale. Vertical dashed lines illustrate the mean day (± 4 days) of the year of spring bloom peak for the western (day 136; approximately May 16) and the eastern (day 131; approximately May 11) GOA. For reference, days of year 100 and 180 fall around April 9 and June 30, depending on leap years.

concentrations can affect timing of blooms over the shelf (Waite and Mueter, 2013).

A persistent consideration with satellite-based chlorophyll data is the effect of cloud cover, which precludes quality data collection. On average, about 25% of data were missing during the spring periods examined for each year, which adds uncertainty to our assessments. Additionally, data from the 11th and 19th of April were missing from MODIS during 2022, adding additional uncertainty during a potentially critical time. In lieu of the absent data from MODIS 8-day products, VIIRS satellite images were assessed, where a spring bloom was noted in the eastern GOA around April 19. Additionally, three daily records in MODIS for the period (April 17–19) were available. Comparisons of the available data found no change in peak bloom timing and still below-average spring mean chl-a in both regions.

Implications: Timing and magnitude of peak chlorophyll concentrations are important for gauging general food availability for zooplankton and are thus also relevant for many of the planktivores that rely on zooplankton. In the eastern GOA, chlorophyll interannual variations are correlated with zooplankton biomass, which in turn are correlated with annual catch yields of resident fishes (Ware and Thomson, 2005). Factors affecting phytoplankton blooms can be complicated, and more extensive work will be required to resolve any direct connections between groundfish recruitment and chlorophyll concentrations. In the western GOA, our analyses for 2022 were low, and show similar bloom patterns to 2021, 2019 and 2016.

Seward Line May Phytoplankton Size Index

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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 in 2001 and annually beginning in 2011, chlorophyll-a (chl-a) in two size fractions (< 20 μm and > 20 μm) 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 comprising the shelf community. The index is computed from transect averages of depth-integrated shelf station values, for each early May cruise, of the fraction total chl-a found in the large (> 20 μm) size fraction (i.e., chl-$a_{>20}$ / chl-a_{total}). 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 show that the size index is a predictor of two important aspects of the spring bloom. 1) When the index is low (≤ 0.25, meaning that small cells strongly dominate), the spring bloom begins and peaks relatively late in the year. 2) When the index is $\geq$0.5, meaning that large cells comprise half or more of the total chl-a, the value of the index is strongly correlated ($r^2 = 0.61$) with the cumulative magnitude of the spring bloom (April – June) as measured by remote sensing.

Status and trends: The index for May 2022 was high (0.87), relative to the time series (2001–2022, Figure 24). This indicates favorable feeding conditions for large zooplankton consumers and the higher trophic levels dependent upon them. 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. May 2021 had the highest size index observed to date (0.94).

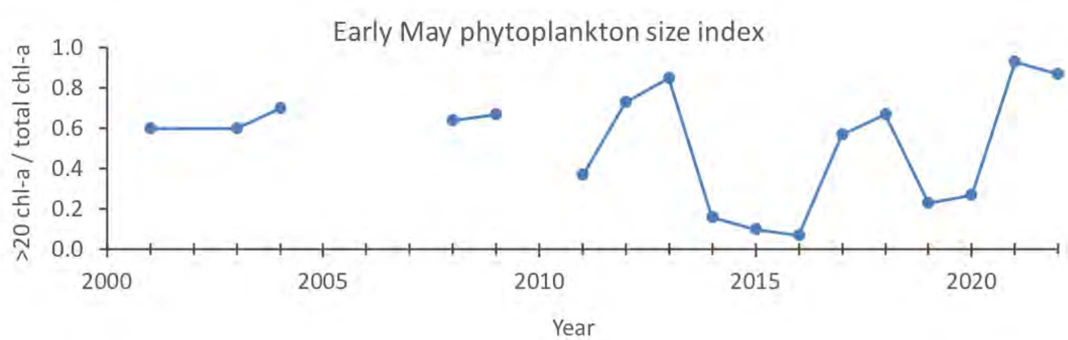

Figure 24: May 2001–2022 time series of phytoplankton size index (fraction of total chl-a present in cells $>$ 20 μm) for the Seward Line shelf stations.

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 per se probably has little direct influence, as the 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., large copepod, euphausiid) consumers. Low values of the size index correspond to phytoplankton communities dominated by small flagellates and cyanobacteria, which are less available to large zooplankton and lead to less efficient transfer of primary production to higher trophic levels. A late spring bloom may 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, including the benthos.

Zooplankton

Continuous Plankton Recorder Data from the Northeast Pacific, 2000–2021

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Last updated: August 2022

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 25); the abundance per sample of large diatoms (the CPR only retains large, hard-shelled phytoplankton so while a large proportion of the community is not sampled, the data are internally consistent and may reveal trends), 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 (2002–2019 for the GOA). Each sampled month's mean is then compared to the long-term geometric mean of that month and an anomaly calculated (Log_{10}). The mean anomaly of all sampled months in each year is calculated to give an annual anomaly.

The indices are calculated separately for the oceanic eastern GOA, oceanic western GOA (divided at 147°W), and the Alaskan shelf southeast of Cook Inlet (Figure 25). Only the red points within the shaded boxes in Figure 25 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 (relative to a 2002-2019 baseline) having been negative in 2020 (Figure 26). On the western side of the oceanic GOA the diatom anomaly was also positive in 2021. On the eastern side of the oceanic GOA the diatom abundance anomaly was negative for the last two years, with the strongest negative anomaly of the time-series appearing in 2021. The copepod community size anomaly was mostly negative in all regions in the last 5-7 years, but it has oscillated in the Alaskan shelf to a positive anomaly in 2021. Zooplankton biomass anomalies were positive in both the Shelf and eastern GOA regions in 2020, but have switched to negative in 2021, while the anomaly has remained negative in the western side of the

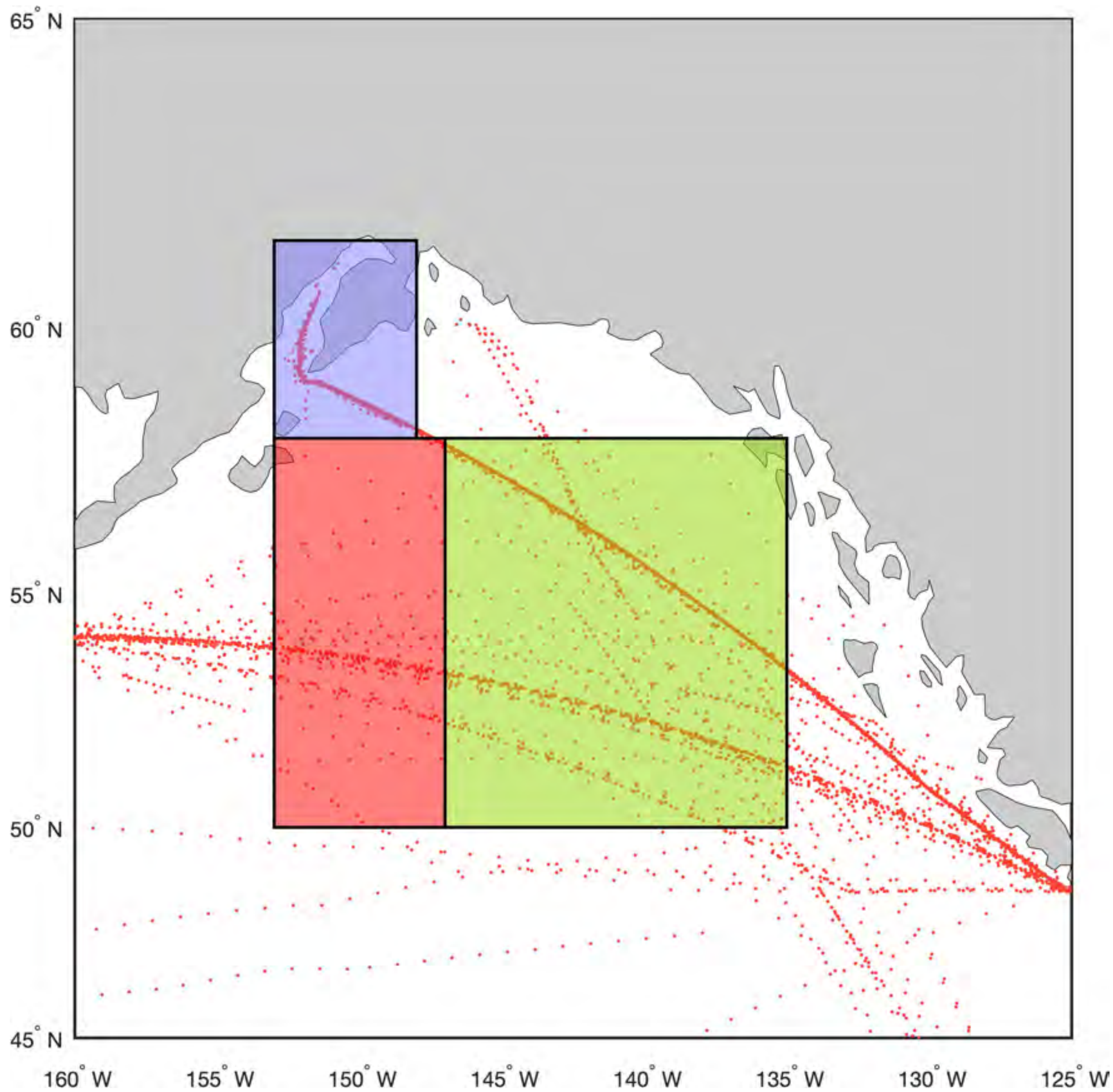

Figure 25: Location of the data used in this Report, highlighted as Alaskan shelf (yellow rectangle), eastern Gulf of Alaska (magenta rectangle), and western Gulf of Alaska (red rectangle). Red dots indicate actual sample positions (note that for the shelf region the multiple transects overlay each other almost entirely).

GOA. The zooplankton biomass anomaly in 2021 in the eastern GOA is the most negative it has been for the timeseries presented.

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 and 2018–2020, which experienced marine heat waves (Di Lorenzo and Mantua, 2016). 2021 appears to be not as warm as the previous 7 years. 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 2021 in the shelf and western regions, however in the eastern GOA regions there is a lower than average diatom anomaly. It is unclear what has led to the decrease in diatom abundance in this region, but it could be that the decreased meso-zooplankton biomass provided decreased grazing pressure and therefore an increase in

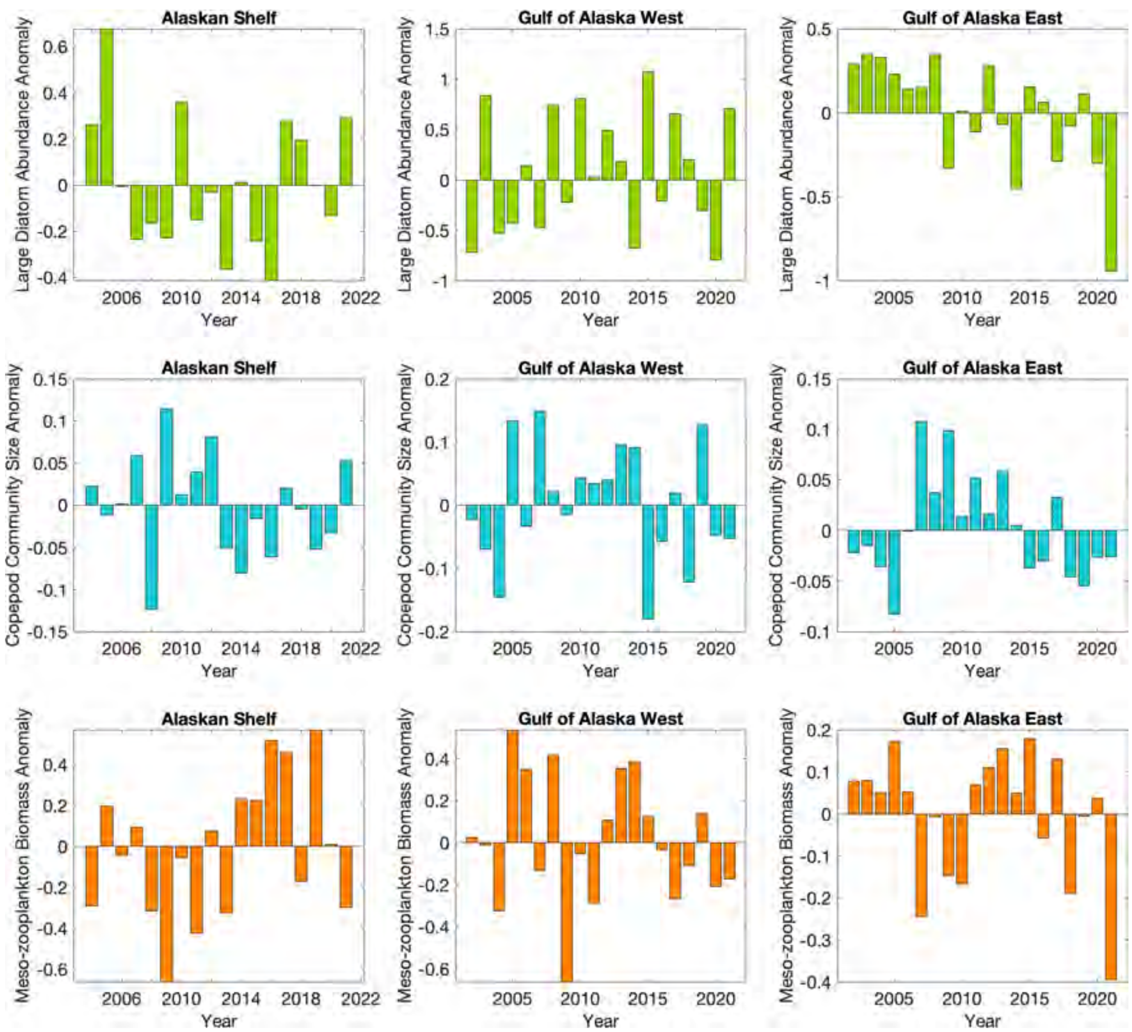

Figure 26: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for all three regions shown in Figure 25. Note that sampling of the shelf region did not begin until 2004.

the diatom abundance in the shelf and western GOA. It is likely that the high temperatures can lead to high mesozoopankton biomass and a decrease in diatom abundance due to increased predation, in both the shelf and western oceanic GOA regions.

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: August 2022

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 10m from bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. Paired with this assessment are measurements of total lipid content from selected zooplankton categories within the same RZA sample. The RZA 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. In spring, there is a possibility that earlier stages of the large copepods (e.g., *Calanus* spp.) may be counted as small copepods, as some life-history stages may be ¡ 2 mm. A 2 ml Stempel pipet is used to estimate small copepods, as opposed to the larger 10 ml pipet used to subsample for large copepods. Therefore, we are much more likely to be counting smaller species such as *Oithona* spp. and *Pseudocalanus* spp. as opposed to members of the annual cohort of the large species, such as *Calanus* spp. 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 an updated long-term time-series for the western GOA. There were no surveys in 2022 in the western GOA, so we present results from 2021. The only significant update from the prior year's report is a change to the euphausiid time-series. We adjusted the inclusion of euphausiid estimates to more closely match the RZA to net samples by comparing total adults and juveniles estimated from the RZA to total adults and juveniles from the counted samples. Previously we had reported the abundance of earlier life-history stages (*furcilia*, *calyptopis*), which had caused the two time-series to differ at times. We believe this adjustment makes the RZA a better estimator of adult and juvenile euphausiid abundance. The mean abundance of each RZA category was plotted for the western GOA and represented primarily May and early June in spring. The summer/fall survey was not conducted in 2021 in the western GOA, and updates are not shown for fall time-series. In the spring, we expanded the spatial area beyond the traditional "Line 8" sampling to match the region where pollock larval rough counts are conducted (Rogers and Dougherty, 2019) southwest of Kodiak Island (an area approximately bounded by 57.46–57.73°N and 154.67–155.30°W) (Rogers and Dougherty, 2019, Deary in this Report, Figure 33, p.77, for area description). The total lipid content from RZA samples were performed on the designated zooplankton categories of large copepods and euphausiids, which were collected separately in glass vials from each station, stored frozen, and analyzed at NOAA Auke Bay Laboratories. Briefly, the measured lipid content was compared to the respective wet-weight for the zooplankton in each vial. Lipid analysis was performed via a rapid colorimetric technique employing a modified version of the sulfo-phospho-vanillin (SPV) assay and his method was proven to be highly accurate for analyzing zooplankton lipids in a recent inter-laboratory cross validation study (Pinger et al., 2022).

Status and trends: Large copepods were most abundant in Shelikof Strait and southwest of Kodiak Island (Figure 27). Small copepods were abundant throughout the sampling area and were most abundant in the same areas as the large copepods (Figure 27). Euphausiid abundances were low throughout the region (Figure 27). Large copepods showed interannual variability during the spring survey period (Figure 28). 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. Small copepods showed very little variability over time during spring (Figure 28). Euphausiid abundances showed considerable variability over time and were low during 2003–2006 and during 2015, 2019, and 2021 (Figure 27). High euphausiid abundances were observed in 2017 (Figure 28). For percent lipid content, a total of 36 and 31 samples of large copepods and euphausiids were analyzed. Large copepods were on average higher and more variable (mean = 6.5, SD = 4.1) in percent lipid than were euphausiids (mean= 1.4, SD = 0.9), with both taxa showing highest values nearshore and southwest of Kodiak Island (Figure 29).

Factors influencing observed trends: Large zooplankton abundances appeared to respond to different environmental conditions, notably temperature (Sousa et al., 2016; Kimmel and Duffy-Anderson, 2020). The survey occurred approximately two weeks earlier in the year in 2019 and 2021 relative to historical timing, thus we would have expected larger numbers of *Neocalanus* spp. We conclude that warmer temperatures likely accelerated the entry into diapause for the larger copepods *Neocalanus cristatus* and *N. plumchrus/flemingeri* lowering overall large copepods numbers. This was most pronounced during the recent marine heatwaves in 2015 and 2019 and 2021 had similar low abundance values. Spring 2021 was warmer than average (Callahan in this Report, p.36) and likely accelerated the exit of larger *Neocalanus* spp. from the western Gulf. During less extreme warm conditions as in 2003–2005, large copepod numbers increase and this is likely due to the increased abundances of *Calanus marshallae* (Kimmel and Duffy-Anderson, 2020) that are developing to later stages more quickly. Large copepod numbers have remained low in the summer recently as *C. marshallae* may either enter into diapause earlier due to more rapid development times or is subject to increased mortality. The exact mechanism is not known and increased temperatures may lead to a second cohort of *C. marshallae*, whose earlier stages would not be considered large copepods (Banas et al., 2016; Kimmel and Duffy-Anderson, 2020). Small copepod abundances appear to be less impacted by warming as opposed to the larger copepods and showed little variability in spring. This makes sense with respect to life history characteristics of small copepods, for example multiple generations per year, faster turnover times, and metabolic rates that scale less dramatically with temperature (Kiörboe and Sabatini, 1995). The large error bars occurring from 1999 to 2011 represent the fact that these samples only came from Line 8. The error for small copepods was dramatically reduced when the sampling area increased in 2013 (Figure 28).

The significant decline in euphausiid numbers during the spring (Figure 28) can be partially explained by the development of euphausiids resulting in larger sized individuals that can effectively avoid the 60 cm bongo net. This reflects the inability of the bongo nets to capture adequately older euphausiids. Furthermore, it should be noted that the RZA and processed estimates of abundances do differ (Figure 28). This is expected due to the patchy nature of euphausiid distribution and the difficulty in accurately estimating euphausiid abundances (Hunt et al., 2016). Overall, variability in lipids were high for both taxa, but there was a general trend of higher lipid content in nearshore waters, and more specifically a region just southwest of Kodiak Island (Figure 29). This may be a result of higher primary production

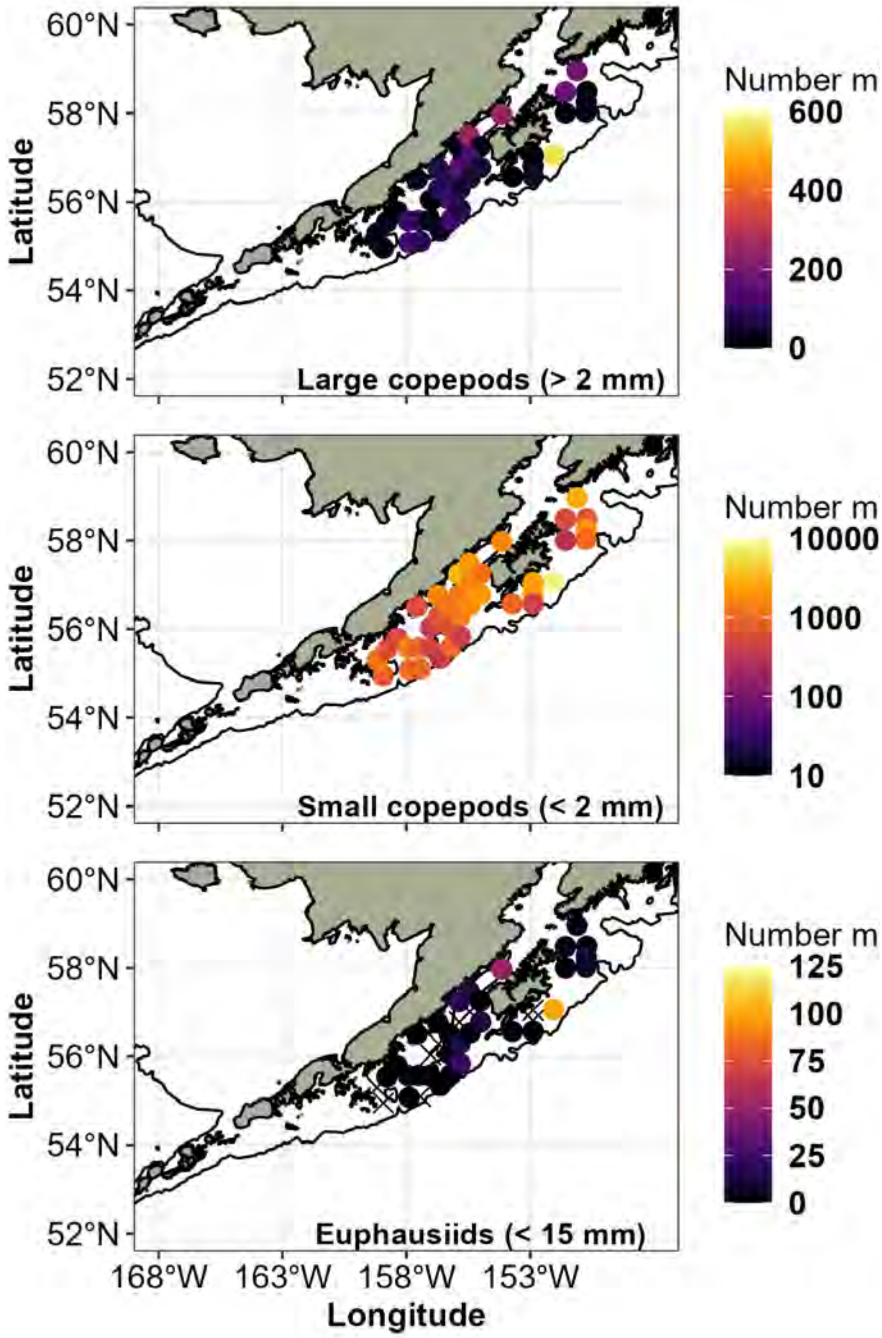

Figure 27: Maps show the spring abundance of large copepods, small copepods, and euphausiid larvae/juveniles estimated by the rapid zooplankton assessment. Note all maps have different abundance scales (Number m^{-3}). X indicates a sample with abundance of zero individuals m^{-3}

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in nearshore waters, and potential entrainment and concentration of lipid-rich phytoplankton in the lee

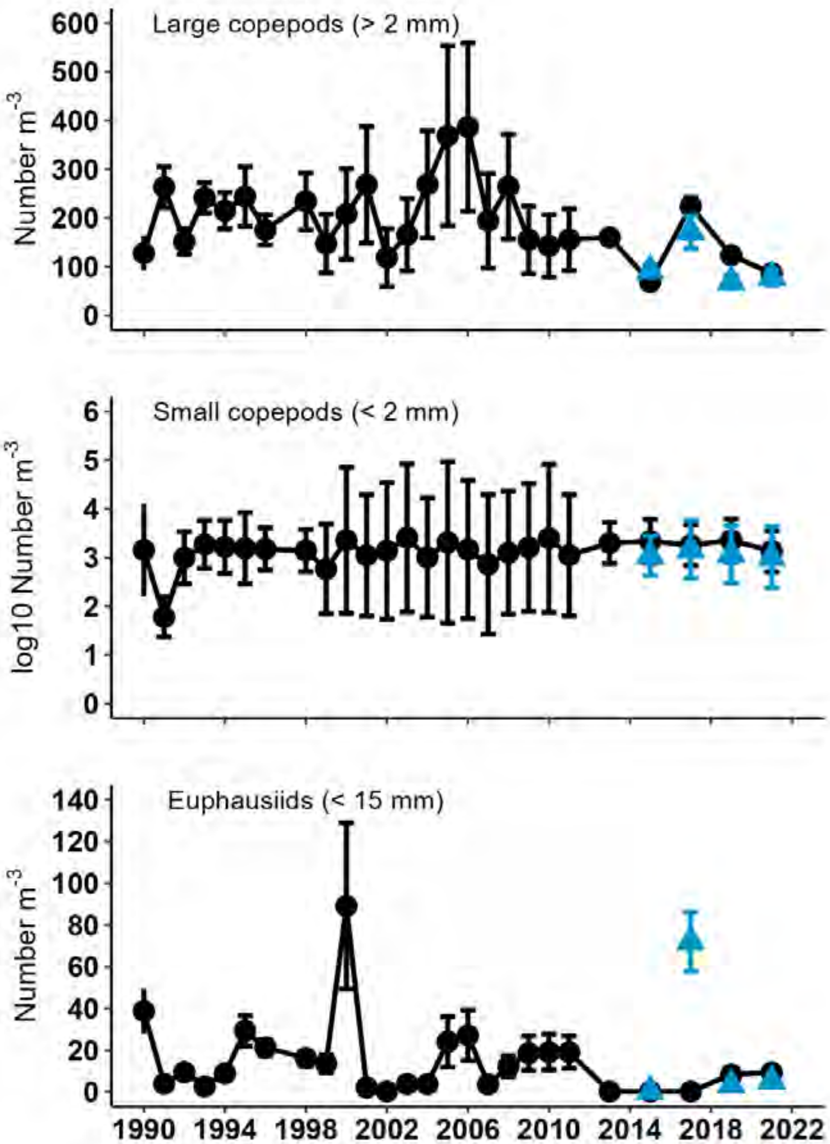

Figure 28: Mean abundance of large copepods (> 2 mm), small copepods (< 2 mm), and euphausiids (< 15 mm) in western Gulf of Alaska during spring (May-June). Black circles represent archived data, blue triangles represent RZA data. Note differences in scale.

side of Kodiak Island, as has been noted in the past (Napp et al., 1996). The larger lipid content in some copepods reflected large *Neocalanus* spp. that were accumulating lipid prior to overwintering, whereas *C. marshallae* copepods were generally lower in lipid.

Implications: Zooplankton are an important prey base for larval and juvenile fishes in spring and summer. Numbers of small copepod remained high during spring and this indicates that there was 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).

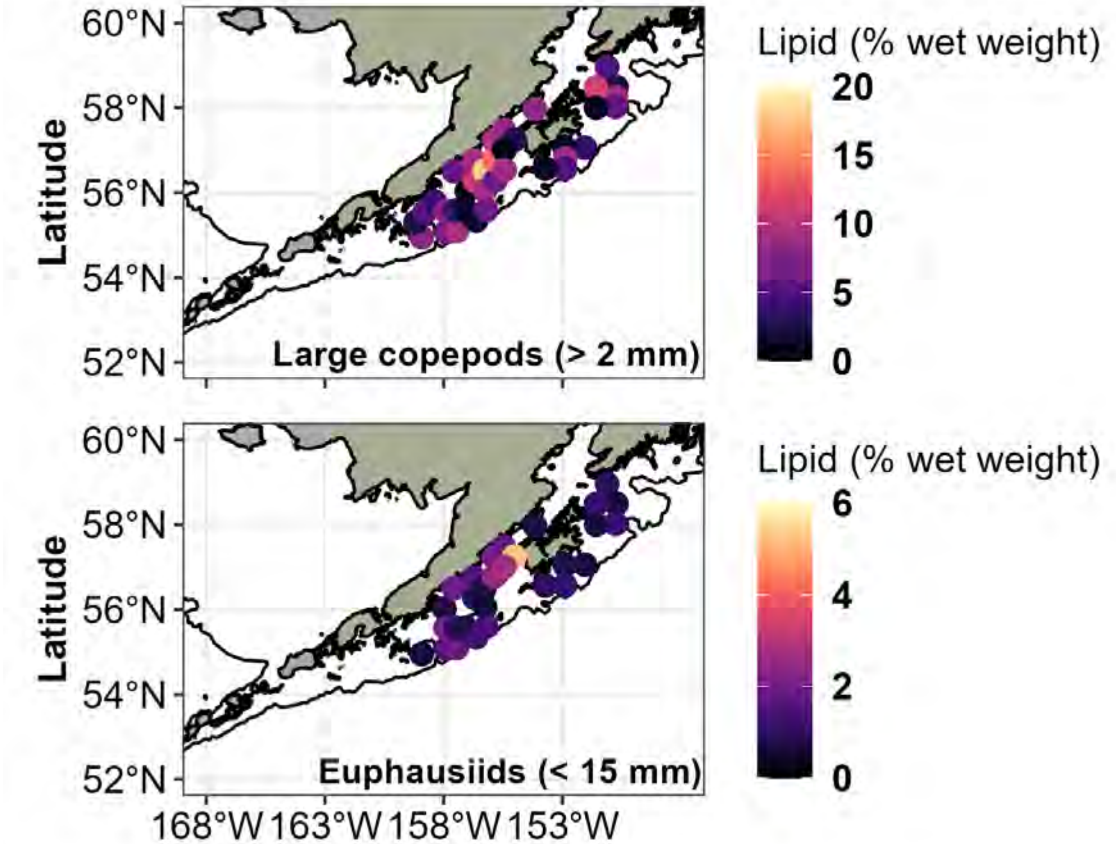

Figure 29: Lipid content (% wet weight) for large copepods (> 2mm) and euphausiids (> 15 mm) collected during the survey.

The lack of large copepods is less relevant in spring for larval fishes; however, it may indicate that the system timing for larger copepods is changing or may indicate shifts in overall productivity (Kimmel and Duffy-Anderson, 2020). The overall higher lipid content in large copepods relative to euphausiids underscores their value as an energy source to higher trophic levels. The recent, low large copepod abundances in summer suggest the standing stock of *C. marshallae* is lower during warming events. A lack of large copepods leads to diet shifts where less energetically dense prey items are consumed (Lamb and Kimmel, 2021). Euphausiid numbers are variable in the spring, but low numbers have persisted in recent years. This suggests that warming results in reduced euphausiid abundance during spring.

Spring and Fall Large Copepod and Euphausiid Biomass: Seward Line

Contributed by Russell R Hopcroft, University of Alaska, Fairbanks
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Last updated: October 2022

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 two decades to determine species composition, abundance and biomass of the zooplankton community. Data are averaged over the top 100 m of the water column to provide estimates of wet-weight biomass of zooplankton summarized here for all calanoid copepods and euphausiids (a.k.a. krill) retained by a 0.5 mm mesh net. These categories represent key prey for a variety of fish, marine mammals and seabirds.

Status and trends: Large copepod biomass in May 2022 and 2021 were approximately average (baseline 1998–2022, Figure 30). Euphausiid biomass in May 2022, and May and September 2021, appear to be above average, although confidence intervals are so broad that the mean is poorly constrained (Figure 30). 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 copepod 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.

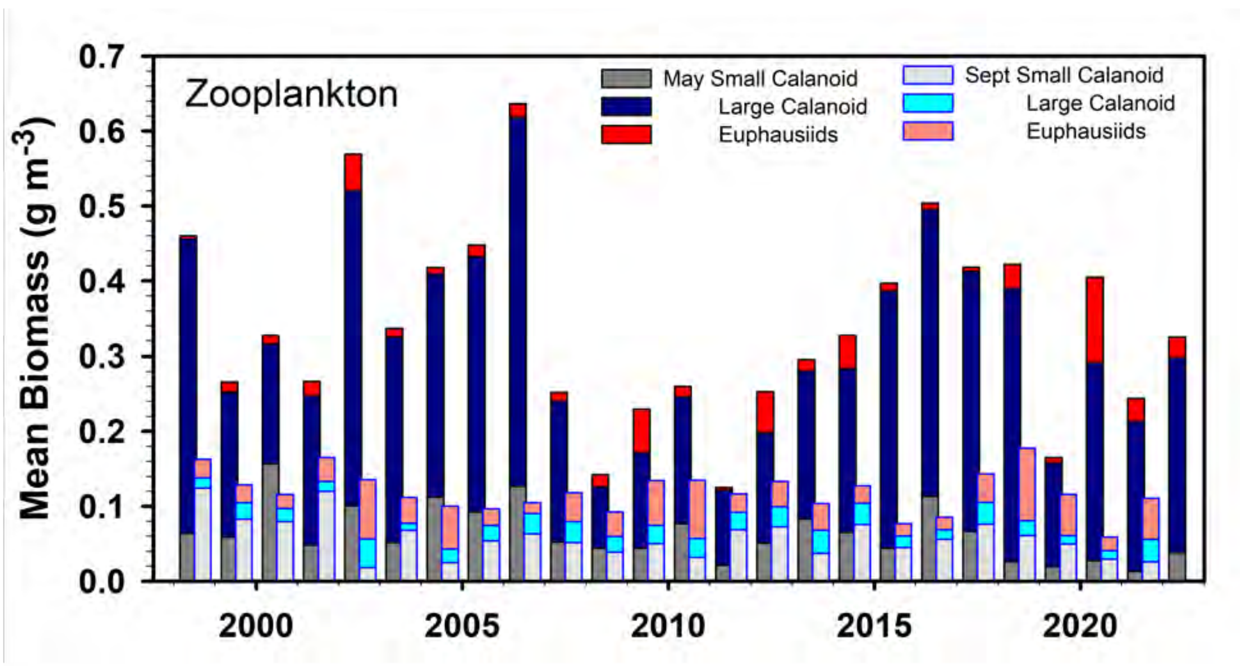

Figure 30: Biomass of calanoid copepods and euphausiids along the Seward Line sampled using a 0.5 mm mesh at night. Transect means and 95% confidence intervals are calculated on power-transformed data. Data for 2019–2022 are only available from a subset of stations and will change as more stations are completed.

Factors influencing observed trends: Temperatures during 2021 and 2022 were cooler than the 24-year mean along the Seward Line during spring (see Seward Line temperatures in this Report, p.36), which could have led to fewer large copepods (as described above), but the spring phytoplankton blooms were approximately average. September 2021 was also cool and this may have favored euphausiids. Large copepod biomass during May often tends to track spring temperatures, not because there are more of them, but because they grow faster and therefore individuals are larger when waters are warmer. By September most large calanoids have descended into offshore waters and their biomass is greatly reduced.

In contrast, May euphausiid biomass appears to be negatively impacted by warm springs, with peaks in May often driven by high abundances of 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 energy content) of species contributing to overall biomass may be of consequence to specific predators. With biomass of large copepods roughly average during 2021 and 2022, relatively normal prey resources can be expected for copepod predators those years. The above-average biomass of euphausiids during fall 2021 suggests their predators may have more favorable feeding conditions compared to 2020 when fall biomass was low.

Zooplankton Trends in Icy Strait, Southeast Alaska

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Last updated: September 2022

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

This Report presents 2022 annual values of zooplankton data in relation to the long-term (1997–2022) trends in Icy Strait. Zooplankton density (number per m^3) was computed from 333-μm bongo net samples ($\leq$200 m depth) (Orsi et al., 2004; Park et al., 2004). Zooplankton density anomalies were computed as deviations from the long-term annual mean values for small copepods (species whose adults are $\leq$ 2.5mm), and large copepods (species whose adults are $>$ 2.5 mm).

Status and trends: During 2022, densities of large and small calanoid copepods, hyperiid amphipods, and gastropods increased from 2021, and all were at or above the long-term average (1997-2022). Euphausiid larvae decreased from the 2021 above-average density to just below average. The 2022 zooplankton total density was the second highest throughout the 26 year time-series. Recent trends in zooplankton abundance indicated increases in density of all zooplankton taxa with the exception of euphausiids, which showed a decrease from 2021 to just below the long-term average (Figure 31). Total zooplankton density ranged from 922 to 3,420 organisms per m^3 from 1997 to 2022.

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

Implications: The above-average densities for most zooplankton taxa in 2022 suggest beneficial feeding conditions for larval and juvenile fish such as larval herring, juvenile gadids, and juvenile salmon that reside in Icy Strait and inland waters of southeastern AK. Favorable feeding conditions in terms of an abundance of prey and potentially high prey quality can directly and indirectly influence early-stage fish growth and recruitment.

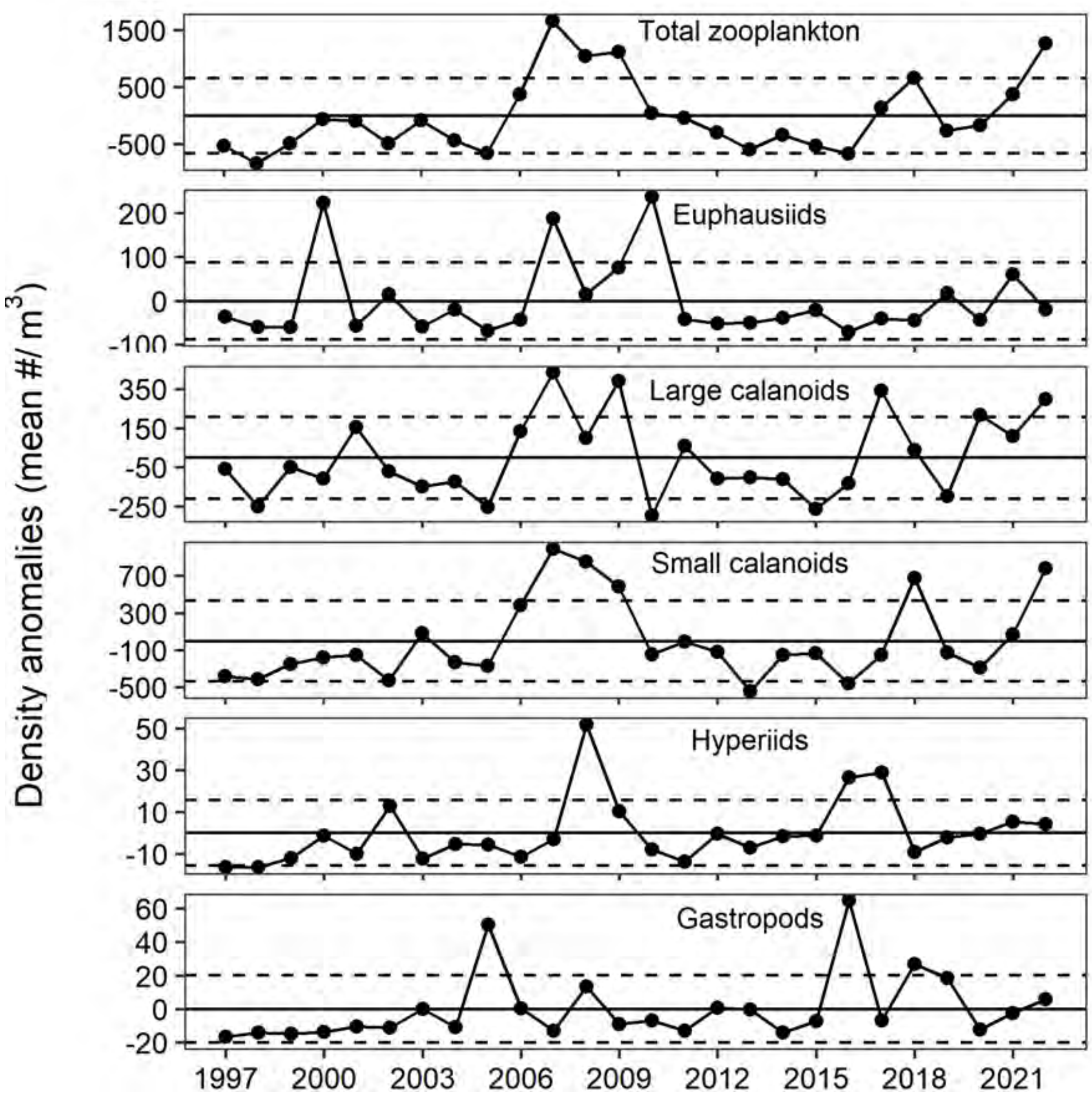

Figure 31: Average annual total zooplankton and taxa specific density anomalies for the northern region of southeastern Alaska (Icy Strait) from the Southeast Coastal Monitoring project time series, 1997–2022. One standard deviation above and below the mean is indicated by the dashed lines. Annual densities are composed of zooplankton samples collected monthly from May to July in Icy Strait. No samples were available for May 2007.

Zooplankton Nutritional Quality Trends in Icy Strait, Southeast Alaska

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Last updated: September 2022

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

This Report presents 2022 annual values of zooplankton lipid content for specific taxa in relation to the 10- year trend in Icy Strait. These zooplankton are an important prey resource to fish that reside in Icy Strait. Total percent lipid content was determined using a modified colorimetric method (Van Handel, 1985). Taxa examined were chosen based on their importance to larval and juvenile fish diets (Fergusson et al., 2020; Sturdevant et al., 2012). These taxa include: large and small calanoid copepods, *Calanus marshallae* and *Pseudocalanus* spp., respectively, young euphausiids (furcillia and juveniles), *Limacina helicina* (gastropod), and *Themisto pacifica* (hyperiid amphipod).

Status and trends: In 2022, percent lipids for all zooplankton taxa were above average (2013–2022) and showed an increase from 2020 values except for *T. pacifica* (Figure 32). Trends from 2013 to 2022 for all taxa show mean percent lipids ranging from >0.01% to 17%. This increase in lipid content indicates an increase in the nutritional quality of the prey field utilized by larval and juvenile fish in Icy Strait.

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

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

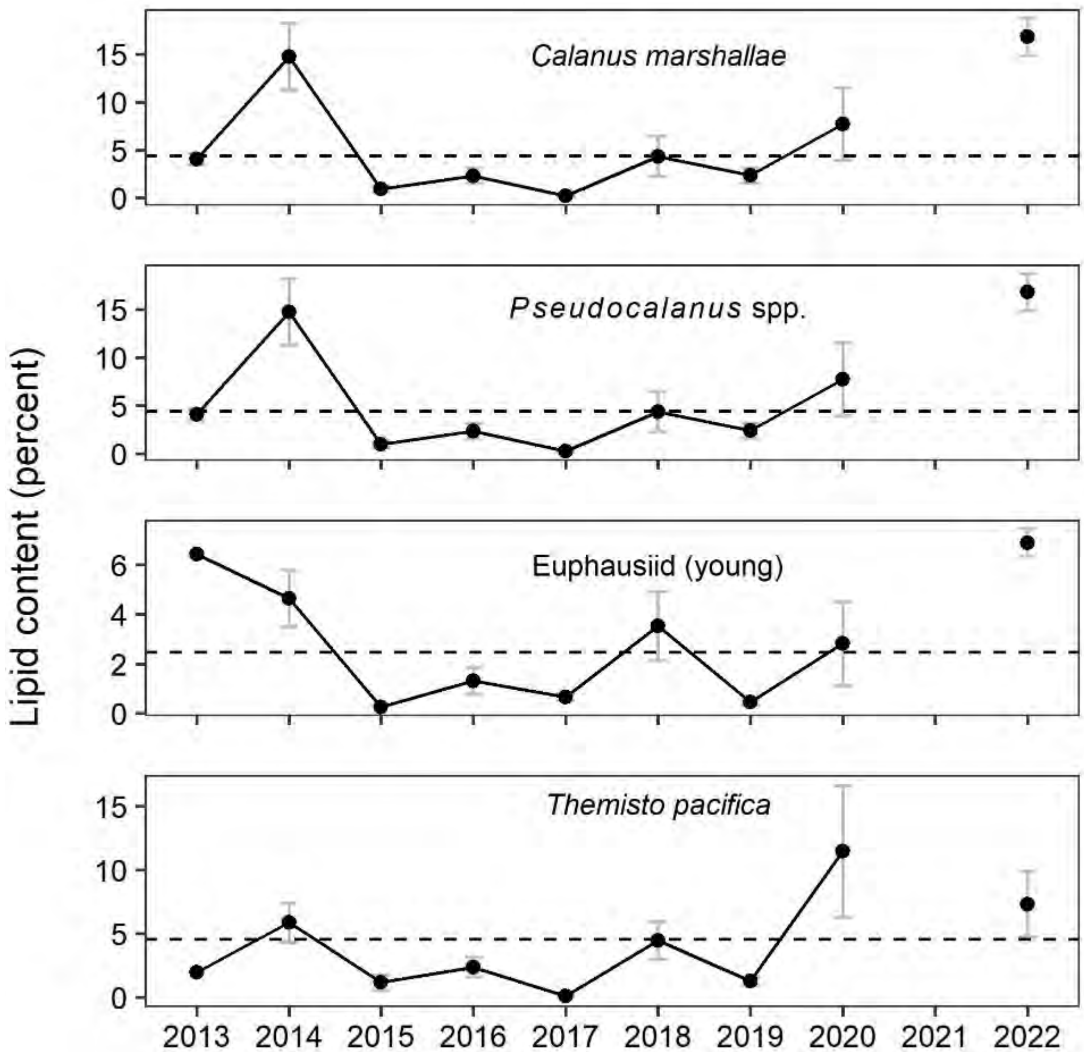

Figure 32: Mean percent annual zooplankton lipid content (error bars are standard error) from zooplankton collections in Icy Strait, AK by the Southeast Coastal Monitoring project, 2013–2022 (no data for 2021). Time series average is indicated by the dashed line.

Jellyfish—Gulf of Alaska Bottom Trawl Survey

NOAA Fisheries Gulf of Alaska Bottom Trawl Surveys are conducted every other year. Refer to the archives for the latest report.

Ichthyoplankton

Larval Fish Abundance in the Gulf of Alaska 1981–2021

Contributed by Alison Deary, Lauren Rogers, and Kelia Axler
EcoFOCI Program, Resource Assessment and Conservation Engineering, Alaska Fisheries Science Center, NOAA Fisheries
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Last updated: September 2022

Description of indicator: The Alaska Fisheries Science Center's (AFSC) Ecosystems and Fisheries Oceanography Coordinated Investigations Program (EcoFOCI) has been sampling ichthyoplankton in the Gulf of Alaska from 1972 to the present, with annual sampling from 1981–2011, and biennial sampling during odd-numbered years thereafter. The primary sampling gear used is a 60-cm bongo sampler fitted with 333 or 505 μm mesh nets. Oblique tows are carried out mostly from 100 m depth to the surface or from 10 m off bottom in shallower water (Matarese et al., 2003, Ichthyoplankton Information System[10]). Historical sampling has been most intense in the vicinity of Shelikof Strait and Sea Valley during mid-May through early June (Figure 33). However, in 2019 and 2021, sampling occurred several weeks earlier than the historical sampling starting in early May and concluding in late May. From this area and time, a subset of data has been developed into a time series of ichthyoplankton abundance (after Doyle et al., 2009) for the 12 most abundant larval taxa in the GOA, including commercially and ecologically important species (Figure 34). These time series are updated in even years, one year after collection, due to processing time required for quantitative data. On-board counts of a limited number of taxa give rapid estimates of relative abundance (Rapid Larval Assessment), which are presented in the year of collection.

Status and trends: Northern rock sole had low abundances in 2021 and catch was marginally higher than what was observed in 2019 (Figure 34). Southern rock sole had above-average abundance in 2021 (relative to a 1981-2021 baseline), which was greater than what was expected from the on-board counts. These species were not common in the core survey area but were consistently captured along the southeastern margin of the core (Chirikof Island to Kodiak) as in prior years. Arrowtooth flounder increased in abundance in 2021 from 2019, approaching the 40-year average for the time series. Arrowtooth flounder was consistently caught in the southwestern portion of the core survey area as in prior years. Pacific cod abundance was below average in 2021, which has been consistent since 2013, with individuals sparsely distributed throughout the core area (Figure 36). Walleye pollock abundance remained low in 2021, similar to observations in 2015 and 2019. For both walleye pollock and Pacific cod, abundances were highest outside of the core area along the southeastern margin of the Kodiak Archipelago (Figures 35 and 36). Rockfish abundance remained elevated in 2021 relative to the first two decades of observations, but declined from the high abundances of the most recent decade to the time series average. Unlike in prior years, rockfish were not as common along the southwestern margin of the core survey area, which parallels the shelf break (Figure 37). Pacific sand lance larvae declined in abundance from a peak in 2019, returning to the time series average, but were present at most stations sampled in 2021 (Figure 38). The abundance of ronquils was below the time series average in 2021, consistent with patterns observed since 2011. Ronquils were sparsely distributed within the core area and along the southern margin of the Kodiak Archipelago in 2021. Similar to previous years, the

[10] https://apps-afsc.fisheries.noaa.gov/ichthyo/index.php

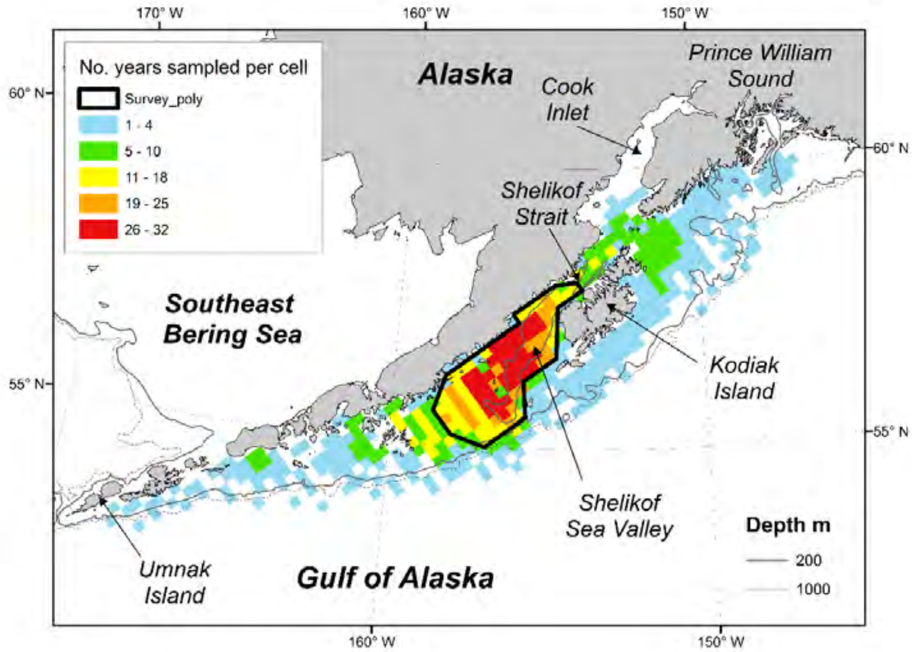

Figure 33: Distribution of ichthyoplankton sampling effort in the Gulf of Alaska by NOAA's Alaska Fisheries Science Center using a 60 cm frame bongo net. Sampling effort is illustrated by the number of years where sampling occurred in each 20 km^2 grid cell during late spring. A time series has been developed for the years 1981–2021 from collections in the polygonal area outlined in black where sampling has been most consistent during mid-May through early June. Note that this polygon was updated in 2018 to reflect sampling intensity through the most recent years.

abundance of starry flounder was slightly below the time series average in 2021 with most individuals caught at the northern margin of the core area in Shelikof Strait. Northern lampfish decreased in 2021 relative to 2019 and, unlike previous years, was sparsely distributed near the shelf break. Flathead sole abundance was highest in the northern part of the core sampling area, yet declined in 2021 relative to 2017 and 2019. The abundance of Pacific halibut in 2021 increased slightly from 2019, yet remained below the time series average as it has since 2013. Similar to prior years, Pacific halibut was caught mainly in the southern part of the core sampling area.

Factors influencing observed trends: Sea surface temperatures in the GOA were warmer than average during the winter of 2021, with several intervals matching the marine heatwave criteria (1 interval in January and 2 in February; see Satellite data in the Ocean Temperature Synthesis in this Report, p.36). In March, heatwave conditions subsided as sea surface temperature decreased to the time series average, which persisted through the survey in May. This was confirmed by in-situ temperature profiles (see EcoFOCI survey in Ocean Temperature Synthesis in this Report, p.36), with the 2021 temperatures at surface and at depth being similar to 2013 and the time series average. Survey timing may also impact the trends observed in 2021 since the survey occurred about two weeks earlier than the historical time series but was consistent in timing with the 2019 survey.

Previous work has explored trends in abundance of these species in relation to atmospheric and oceano-

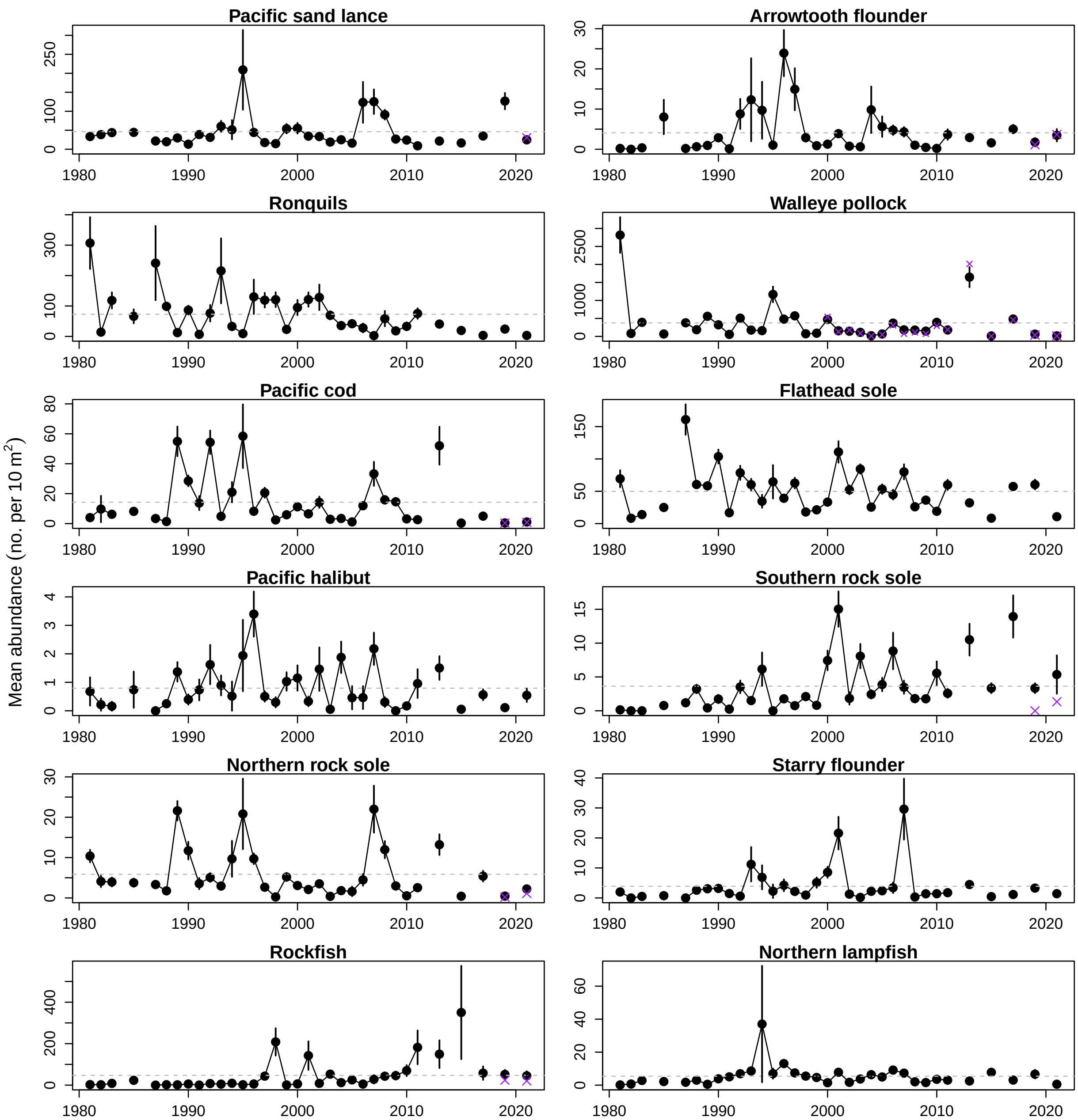

Figure 34: Interannual variation in late spring larval fish abundance in the Gulf of Alaska, 1981–2021. The larval abundance index is expressed as the mean abundance (no. 10 m^{-2}), and the long-term mean (1981-2021) is indicated by the dashed line. Error bars show ± 1 SE. No data are available for 1984, 1986, 2012, 2014, 2016, 2018, or 2020. Purple x's denote rough count estimates from onboard Rapid Larval Assessments. Points with red outlines indicate preliminary quantitative data for 2019. Due to laboratory restrictions in 2020/2021, data were not available for select species.

graphic conditions (Doyle et al., 2009; Doyle and Mier, 2012). Similarities in response to environmental forcing were apparent among species with analogous early life history strategies (Doyle et al., 2009). For instance, years of high abundance for the late winter to early spring shelf spawners (i.e., Pacific cod, walleye pollock, and northern rock sole) were associated with cooler winters and enhanced alongshore winds

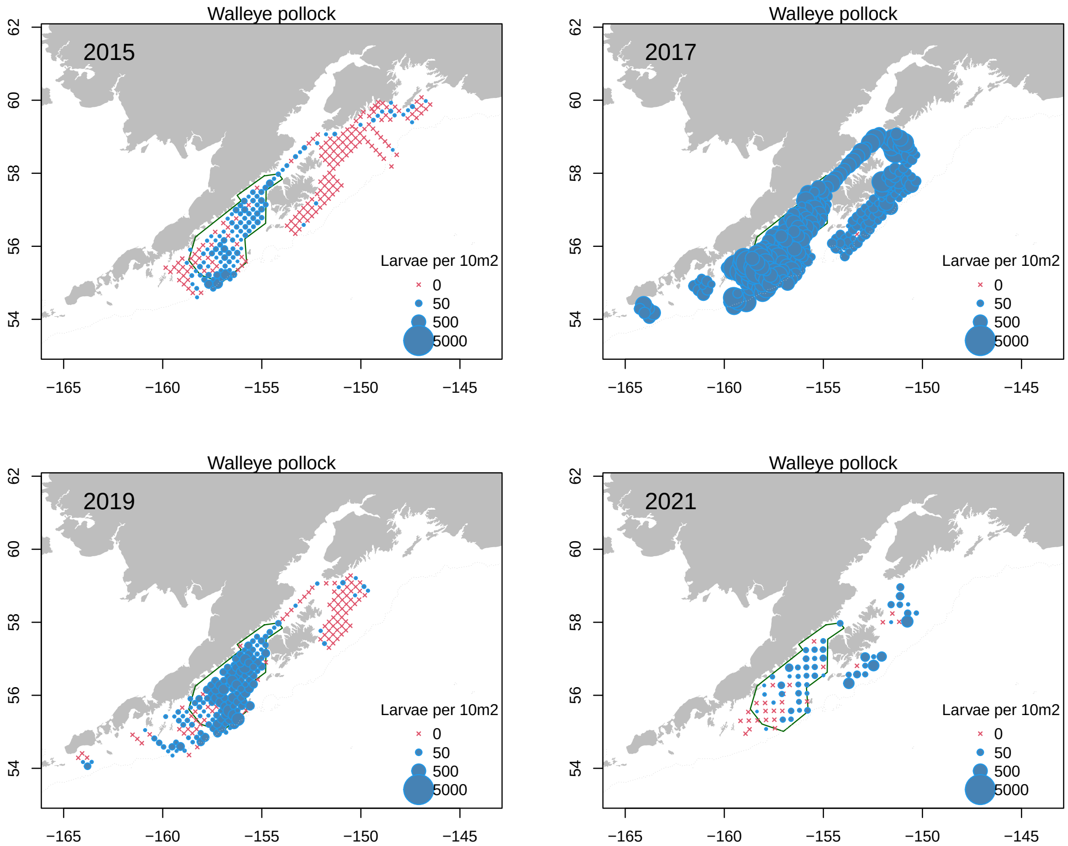

Figure 35: Abundance of larval walleye pollock from NOAA's EcoFOCI spring larval survey for 2015–2021.

during spring. With temperature conditions being consistent with an "average" climate year (baseline 1985–2014, Lemagie in this Report, p.36), we expected to observe average abundances of Pacific cod and walleye pollock. However, walleye pollock abundance was especially low and the highest catches were outside of the core area, which is unusual. The predominant wind pattern during the spring 2021 survey was to the southwest, which is consistent with enhanced larval retention and increased age-1 abundance the following year (Wilson and Laman, 2021, and see Wilson and Rogers in this Report, p.53). Pacific sand lance recruitment and abundance are notably higher at warmer temperatures, which was not the case in 2021, likely contributing to the average abundance observed after a peak in 2019 corresponding to a warm year ((Hedd et al., 2006; Sydeman et al., 2017)).

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 2021, the warming that had been persistent in the GOA between 2014–2016 and 2019–2020 eased, and 7 of the 12 indicator species were found to have abundances approaching the time series average. However, in 2021, similar to 2019, walleye pollock, Pacific cod, northern rock sole, and ronquils remained below average in terms of abundance. With potential average year classes, it is difficult to forecast survival into later stages because many environmental factors can act over the first summer to impact year class strength. The late-summer Young-of-Year survey was canceled in 2021, therefore, we lack the final assessment of abundance and condition prior to overwintering, especially for walleye pollock, Pacific

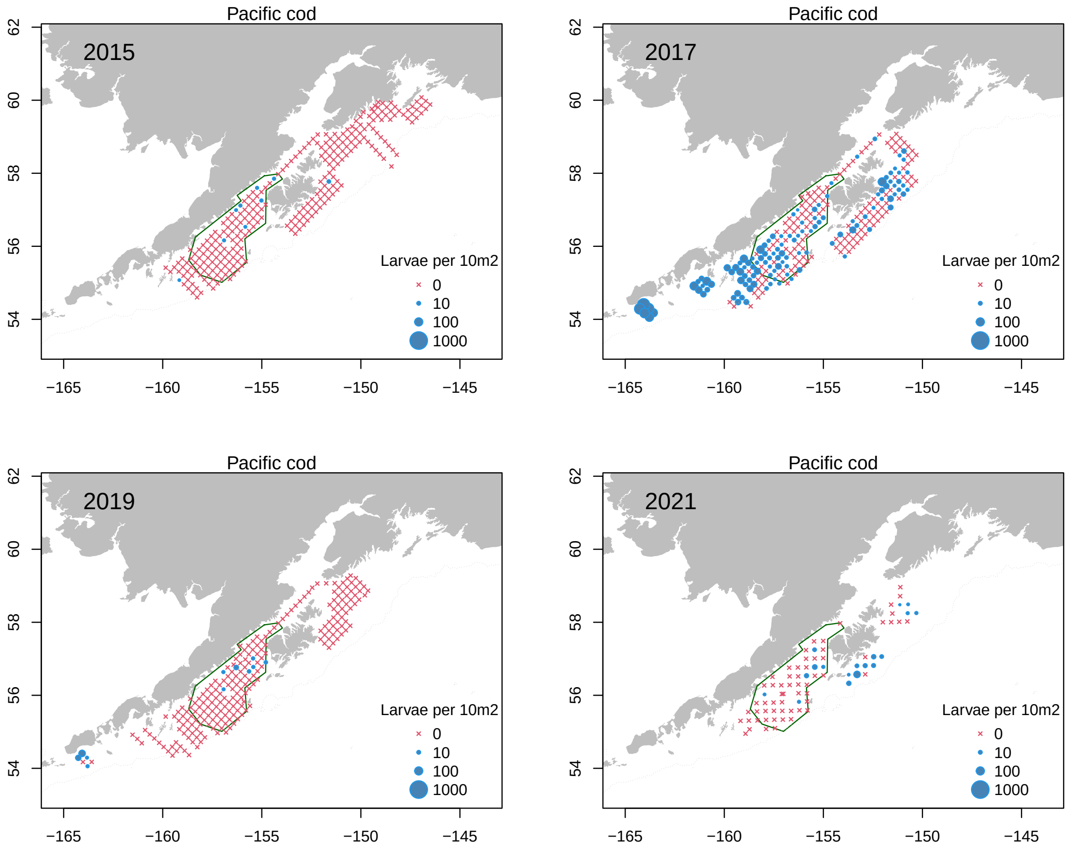

Figure 36: Abundance of larval Pacific cod from NOAA's EcoFOCI spring larval survey for 2015–2021.

cod, and forage fishes. If the prey field in the spring and summer is not bioenergetically rich enough for larvae and juveniles to provision for their first winter, then a year class can still fail to recruit (Lamb and Kimmel, 2021, Kimmel in this Report, p.65).

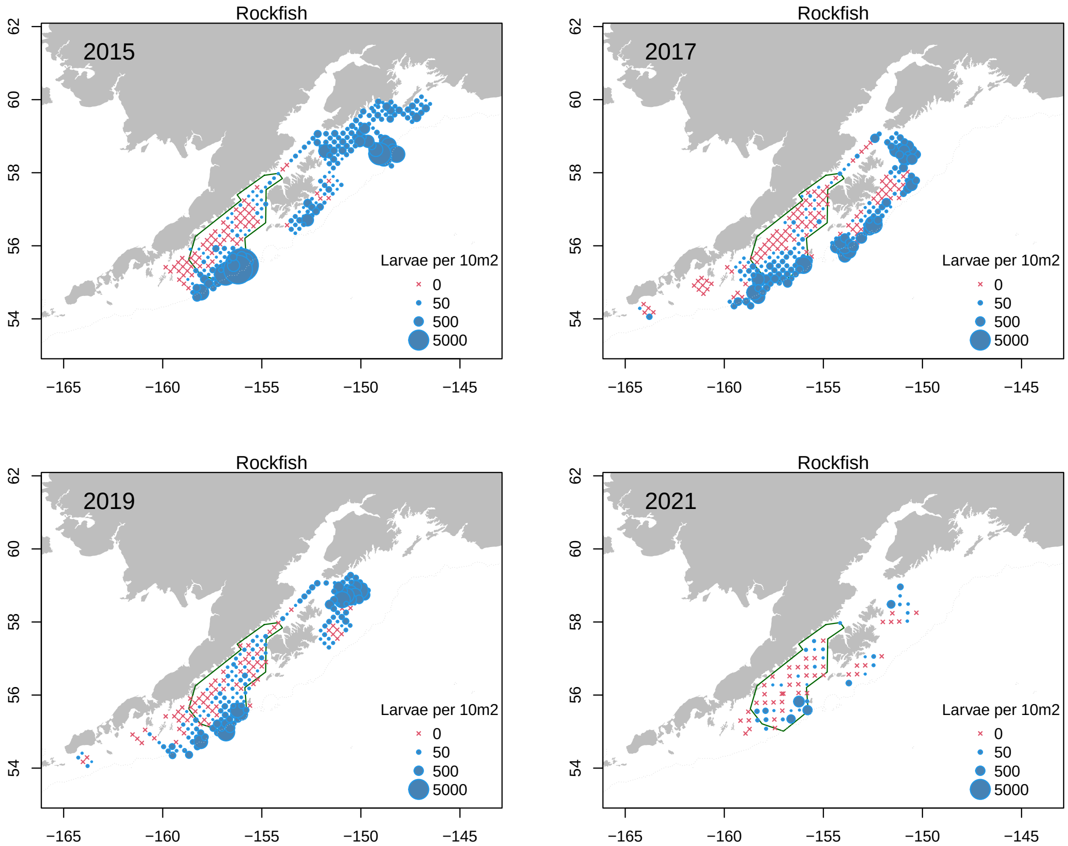

Figure 37: Abundance of larval rockfish from NOAA's EcoFOCI spring larval survey for 2015–2021.

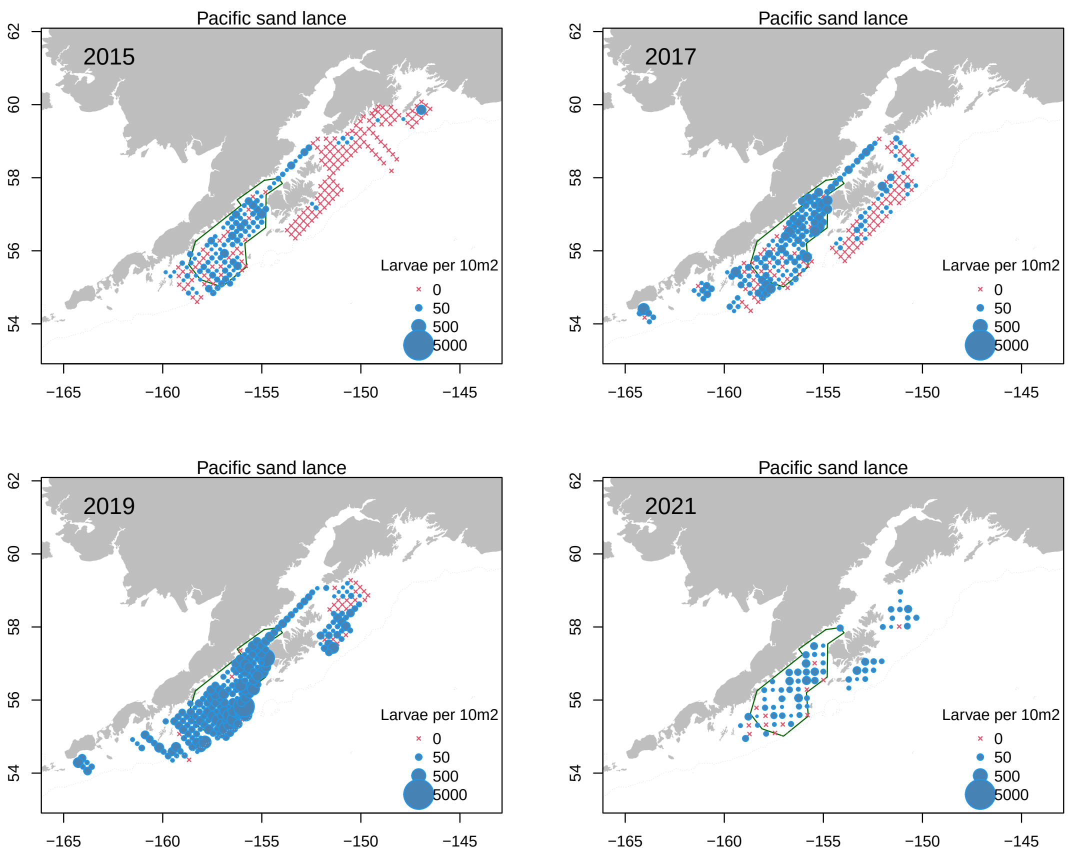

Figure 38: Abundance of larval Pacific sand lance from NOAA's EcoFOCI spring larval survey for 2015–2021.

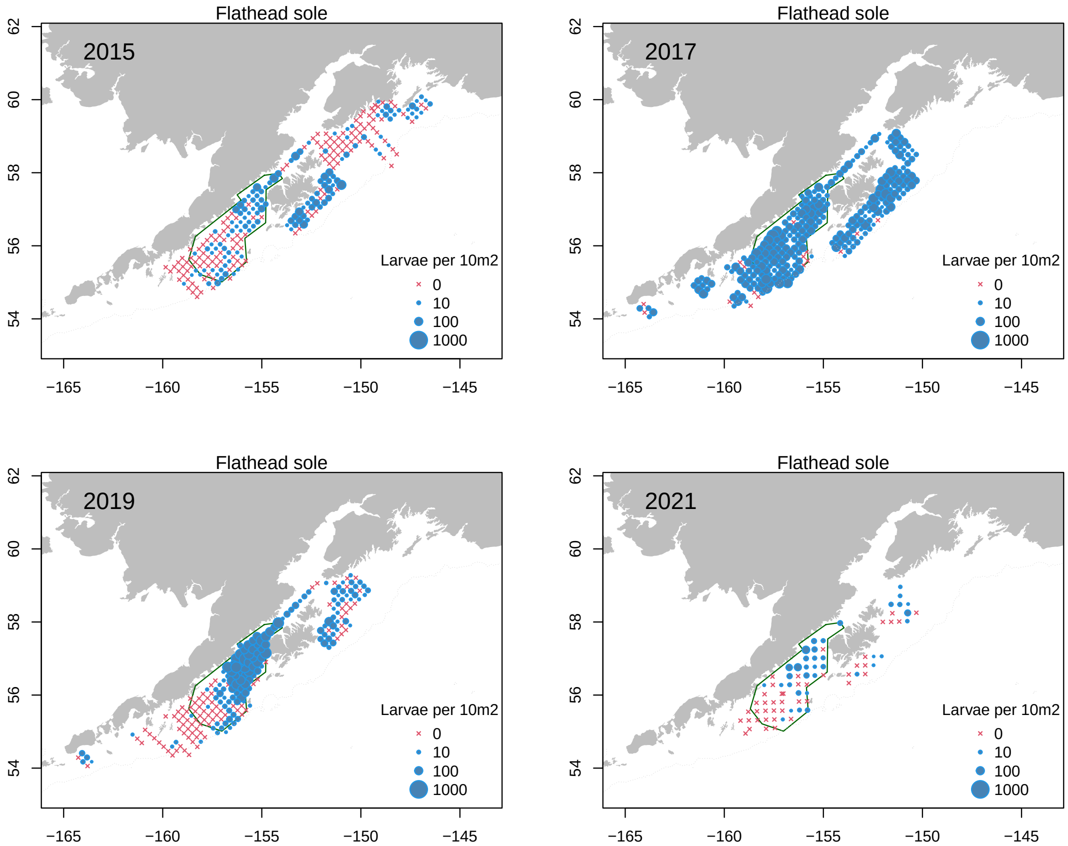

Figure 39: Abundance of larval flathead sole from NOAA's EcoFOCI spring larval survey for 2015–2021.

Multispecies Larval Indicator for the Gulf of Alaska

NOAA Fisheries EcoFoci spring ichthyoplankton surveys are conducted every other year. See archives for the latest report.

Forage Fish and Squid

Summary of Forage Conditions

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Last updated: October 2022

The appears to have been moderate to above-average availability of GOA shelf forage fish in 2022, based on species-specific indicators of abundance and indicators of successful foraging at higher trophic levels. As might be expected from this complex ecosystem, patterns vary considerably among forage species, and species groups as some are still responding (increasing and decreasing) to the 2014-2016 and 2019 marine heatwave periods. Forage species with positive trends in 2022 include herring, juvenile pollock, juvenile sablefish, and a variety of less prominent forage species (e.g., greenlings). Herring continue to be at relatively elevated populations levels, compared to recent years, with continued high estimates of Southeast Alaska spawning populations (Hebert in this Report, p.91), and continued increases in Prince William Sound population estimate (Pegau in this Report p.164), driven by the large 2016 year class. Herring are also well-represented in piscivorous seabird diets on Middlelton Island (Hatch in this Report, p.86). Age-1 pollock (2021 year class) may not have been as abundant in 2022 as the age-1s were in 2021 (2020 year class), given the lower biomass observed by NOAA's acoustic survey in Shelikof Strait in 2022 (although this survey does not target small pollock specifically). Sandlance remains moderately present in seabird diets (Hatch in this Report, p.86). Age-0 sablefish were observed at relatively high levels in seabird diets, an increased from 2021 (Hatch in this Report, p.86), and there are potentially multiple strong juvenile year classes of sablefish currently in the GOA (including a large 2019 year class and potentially from more recent years).

Forage species that are relatively lower in abundance include capelin, eulachon, and juvenile salmon. Seabird diets at Middleton Island (Hatch in this Report, p.86) indicated that the GOA capelin population increased in the years prior to the 2014-2016 marine heat wave, declined dramatically during the heat wave, and have yet to make a substantial recovery. Eulachon populations experienced a second straight year of the lowest returns in northern Southeast Alaska since 2010 (Pochardt in this Report, p.95). Indicators of juvenile salmon abundance in southeast Alaska have been consistently near or below average for all species, although Chinook salmon and sockeye salmon CPUE increased to approximately average in 2022 (Strasburger in this Report, p.103).

Piscivorous surface-feeding and diving seabirds had above-average reproductive success across the western and eastern GOA, implying adequate amounts of forage fish were available (Seabird Synthesis in this Report, p.124). The capacity for predators to switch prey depending on availability is not well understood, but the seabird diets at Middleton Island (along shelf edge in central GOA) suggest that some species groups that are not typically considered to be forage species (e.g., juvenile greenlings, Hatch p.86) may be especially important when other species are low in abundance.

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.

Seabird-Derived Forage Fish Indicators from Middleton Island

Contributed by Scott A. Hatch[1], Mayumi Arimitsu[2], John F. Piatt[2]
[1] Institute for Seabird Research and Conservation, Anchorage, AK
[2] Seabird and Forage Fish Ecology Program, Marine Ecosystems Office, Alaska Science Center U.S. Geological Survey, Anchorage, AK
Contact: shatch.isrc@gmail.com
Last updated: September 2022

Description of indicator: The time series of forage fish population trends derived from seabird diet monitoring at Middleton Island in the north-central Gulf of Alaska are among the longest available from any Alaska location. Being situated near the continental shelf edge (59.4375°N, -146.3277°W), Middleton's seabirds sample both neritic shelf habitat and deep ocean waters beyond the shelf break. Tagging data suggest the foraging range of seabirds at Middleton varies across years but can be approximated by a 100 km radius from the colony. Consequently, important shelf forage species (e.g., capelin, sand lance) figure prominently in seabird diets at Middleton, but additionally, certain other species of high ecological importance (e.g., myctophids) and/or economic concern (e.g., 0-age sablefish, pink and chum salmon) regularly occur in diets that have been monitored since the late 1970's.

Diet data collection began in 1978, and, in most years since 2000, regurgitated food samples have been collected from adult and/or nestling black-legged kittiwakes (*Rissa tridactyla*) from April to August (>6,000 samples to date). The preferred metric for kittiwakes is prey relative occurrence (Hatch, 2013), for which the relevant sample unit (denominator for calculations of frequency) is total occurrences of identified prey types in a given collection of samples. Kittiwake diets reflect the availability of surface-oriented prey within their foraging range.

Rhinoceros auklet (*Cerorhinca monocerata*) diets are monitored by collecting bill-loads from chick-provisioning adults, about twice a week from early July through early or mid-August. Samples consist of whole prey specimens from one or more species, and therefore the reported data are simple calculations of percentage biomass per species. Since 1978, 5337 auklet prey samples have been collected on Middleton Island, and auklet diet monitoring provides the single best available indicator of forage fish dynamics and forage community stability over time for the region (Hatch, 2013; Sydeman et al., 2017; Arimitsu et al., 2021).

Status and trends: Totals of 1129 kittiwake diet samples and 369 rhinoceros auklet samples were obtained in 2022. Following an apparent "bust" in 2021, age-0 sablefish showed a strong comeback in 2022, comprising 20% of prey biomass in rhinoceros auklets and 27% relative occurrence in kittiwakes (Figure 40). Pacific herring continued their run (since 2015) as important prey of Middleton seabirds this year, and information not depicted in Figure 40 suggests the 2022 year class will be strong. In the kittiwake diet, for example, age-0 herring were 12% of all herring occurrences in 2021, while that figure increased to 70% of occurrences in 2022.

In 2022, hexagrammid species (kelp and rock greenlings, lingcod, and Atka mackerel) continued to decline after surging over a 3-year period (2018–2020) post-heatwave (Figure 41). Capelin (4% of prey mass delivered to auklet nestlings, 3% relative occurrence in kittiwakes) continued to be scarce in 2022 — a puzzling finding given our expectation to see a positive response of capelin to cold ocean conditions. Judging by the Pacific Decadal Oscillation Index, relatively cold surface conditions have now prevailed in the Gulf for more than 2 years (since ∼January 2020). We speculate that persistent heat storage at depth following the 2014–2017 heatwave is still affecting the behavior and/or population dynamics of cold-associated species such as capelin.

Consistent with the last point was the occurrence this year of two species included as "other fish" in Figure 40 — Pacific saury (*Cololabis saira*) and chub mackerel (*Scomber japonicas*). Both species are generally thought to be associated with warmer water than normally occurs in the northern GOA. Sauries, taken late in our sampling interval by rhinoceros auklets (first specimen on 14 August), had previously been encountered as a single specimen in 2014, at the height of the marine heatwave. In 2022, sauries (mean length 210 mm, range 185-255 mm — large prey by auklet standards) occurred in 9 of 15 samples collected 19–21 August. Chub mackerel, taken only by black-legged kittiwakes, also appeared late—first occurrence on 13 August, with 15 occurrences among 51 kittiwake samples collected 13–30 August 2022. Previously, chub mackerel were encountered at Middleton only in 2019 (4 occurrences) and 2020 (15 occurrences).

On average, Middleton kittiwakes take about equal amounts of Pacific sand lance, capelin, and invertebrates, with lesser amounts of herring, sablefish, salmon, and myctophids, depending on stage of the season. The juxtaposition of time series for kittiwakes and rhinoceros auklets since 1978 (Figure 40) shows general agreement between a sustained decline of sand lance and, beginning in 2007, the emergence of capelin as a dominant forage species through the cool period that lasted through 2013. However, in years when neither sand lance nor capelin were prevalent (e.g., 2014—2017), the diets of surface feeding kittiwakes and diving auklets diverged in respect to behavioral prey-switching to alternate species such as myctophids, salmon, greenlings, sablefish, and herring.

Auklet data plotted separately by prey type highlight the interannual dynamics of particular species of interest (Figure 41). Sand lance were the overwhelmingly dominant forage species in the northern Gulf in the late 1970s through the early 1980s. Following a period of reduced availability in the mid-1990s, sand lance made a strong comeback by the end of that decade. However, sand lance steadily declined in importance after 2000 and contributed little to seabird diets from 2009 through 2015. The appearance of about 30% sand lance in the auklet diet in 2016 and 2017 is consistent with a known association of sand lance with warm-water conditions (Hatch, 2013; Sydeman et al., 2017). The re-emergence of sand lance continued in 2018, when this species constituted about 50% of the auklet diet by weight (Figure 41). In 2019, sand lance declined slightly as compared with the previous year, the difference being offset by a modest increase in capelin. Greenlings were prominent in the auklet and kittiwake diets during 2018–2021, to a consistent high degree not seen since sampling began (Figure 40). The occurrence of herring and other coastal species in seabird diets from Middleton possibly reflects greater use of nearshore/inner shelf habitats because of reduced availability of offshore prey resources. Indeed, GPS tracking of foraging seabirds conducted during chick-rearing reveals that in recent years birds from Middleton have commuted a considerable distance (∼80 km one-way) and foraged principally in nearshore waters, especially at the southern end of Montague Island.

Factors influencing observed trends: Seabird diets at Middleton reflect ecosystem shifts in the GOA. This includes specific events recorded and widely discussed in the ecological literature such as the notable shift from "warm" (positive Pacific Decadal Oscillation, PDO) conditions to "cold" (negative PDO) conditions around 1999–2000 (Greene, 2002; Peterson et al., 2003; Batten and Welch, 2004), a similar but stronger and more persistent shift in 2008 (Hatch, 2013; Sydeman et al., 2017), and a widely reported warm-water anomaly that dominated the system for several years beginning in late 2013 (Bond et al., 2015). A salient finding during the anomaly was the virtual disappearance of capelin from seabird diets on Middleton, following the 6 prior years when capelin were predominant (Figure 40). An apparent trade-off between Pacific sand lance (warm conditions) and capelin (cold conditions) may have been a hallmark of the forage fish community in the region for several decades (Sydeman et al., 2017); however, this pattern apparently changed during the marine heatwave. Notably, large-scale seabird die-offs have occurred when seabird diets at Middleton suggested low availability of both capelin and sand lance at the same time, for example in 1993 (Piatt and Van Pelt, 1997) and in 2015–2016 (Piatt et al., 2020).

The PDO turned negative in early 2020 and has remained mostly so to the present time (September 2021), a development discussed elsewhere in relation to seabird responses on Middleton (Seabird Synthesis in this Report, p.124). Unlike previous intervals with cool-water conditions, capelin have not yet made any appreciable comeback in seabird diets. Rather, the salient response to date has been the ascendance of greenlings and other hexagrammids, as described above.

Implications: Seabird diets provide evidence that capelin disappeared from the ecosystem in recent warm years. Chick diets at Middleton may also be informative for sablefish studies. In recent years, the Alaska Fisheries Science Center began using specimens from seabird diet sampling at Middleton for phenology and growth studies of age-0 sablefish, which are difficult to sample by other means. Seabird diet indicators are potentially applicable to other management concerns in the region, including Pacific herring stocks, which crashed and have not recovered after the Exxon-Valdez Oil Spill in 1989, and year-class strengths of pink and chum salmon, which occur regularly in Middleton seabird diets.

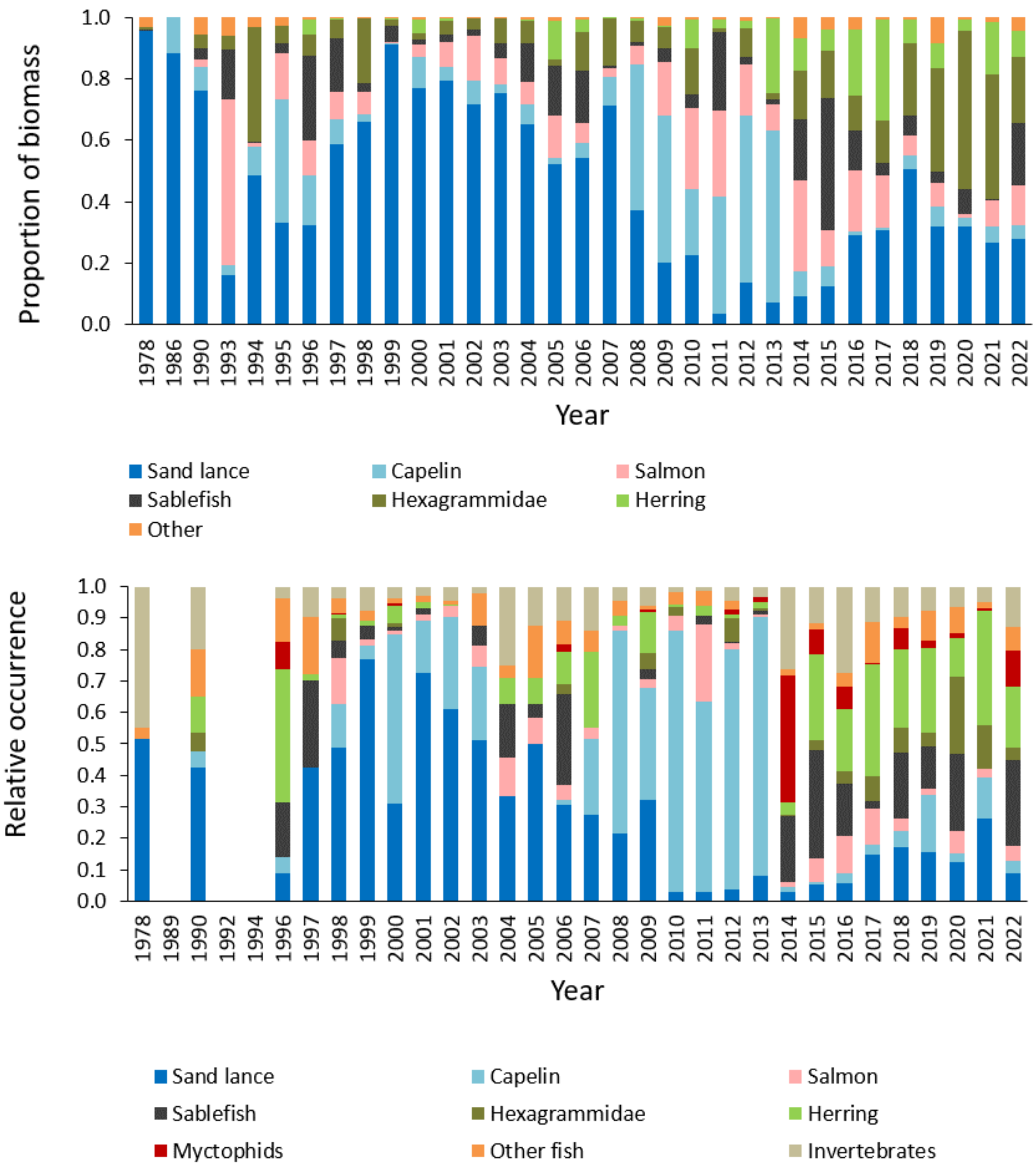

Figure 40: Interannual variation in diet composition of chick-rearing rhinoceros auklets (upper panel) and black-legged kittiwakes (lower panel) on Middleton Island, 1978–2022.

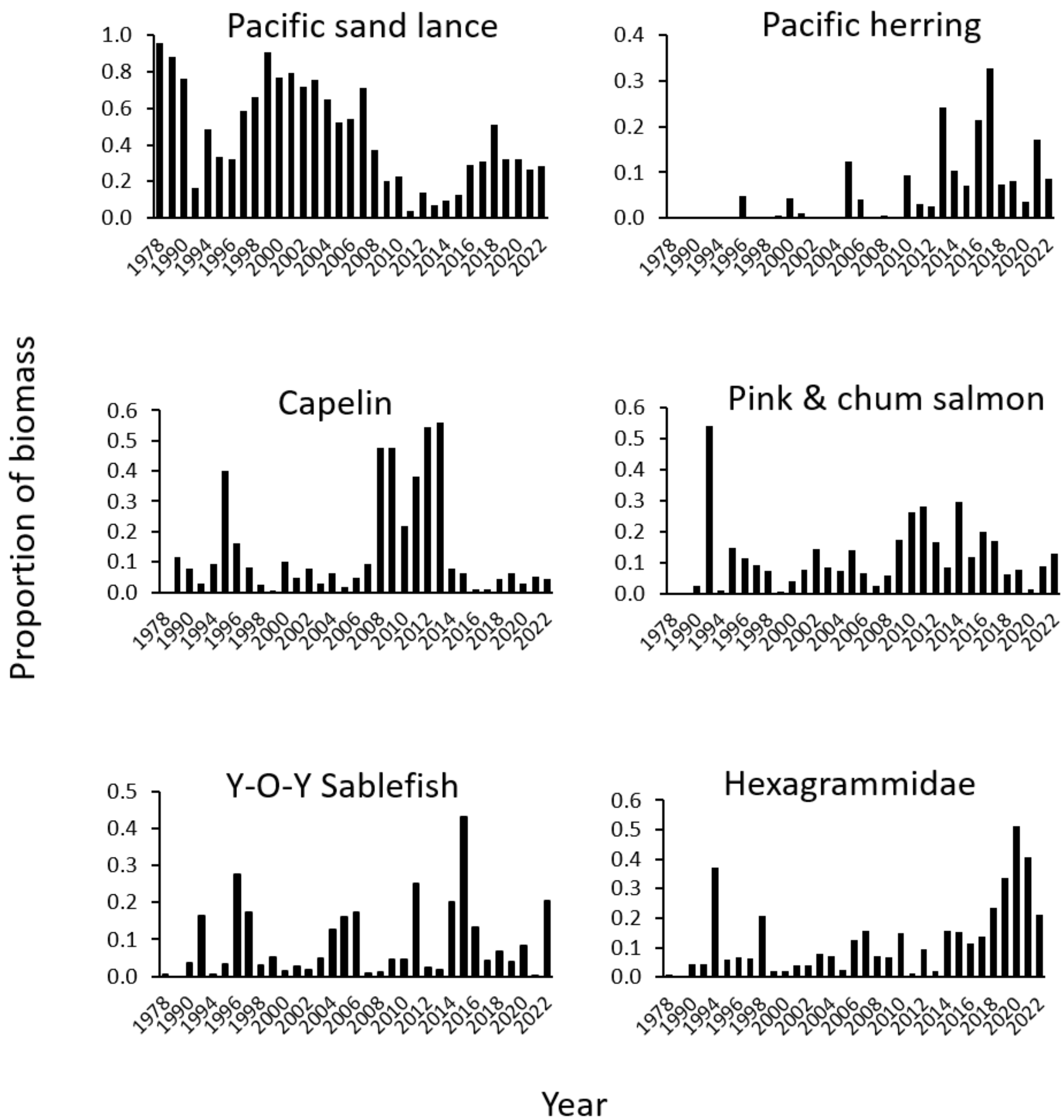

Figure 41: Yearly signal strength of selected prey species in the nestling diet of rhinoceros auklets on Middleton Island from 1978–2022.

Fisheries-independent Survey-based Indices of Capelin Relative Abundance

NOAA Fisheries Gulf of Alaska Summer Acoustic Trawl Survey is conducted every other year. Please see the archives for past reports.

, and Ellen Yasumiishi, Auke Bay Laboratories Division, Alaska Fisheries Science Center, NOAA Fisheries

Southeastern Alaska Herring

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Last updated: August 2022

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 42). Monitoring of spawning stock size has been conducted by the Alaska Department of Fish and Game at some of these areas for most years, since at least the 1980s, primarily by combining estimates of egg abundance 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. A large proportion of spawning biomass in southeastern Alaska comes from these nine areas. However, limited spawning also occurs throughout southeastern Alaska. 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 the 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 to the greatest extent or the most immediately.

Status and trends: Mature biomass for Sitka Sound and Craig herring remains at a high level (relative to baselines starting in 1976 and 1988 respectively), as the extremely large 2019 recruitment (2016 year class) continues to dominate these stocks. The 2019 age-3 recruitment event was 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). Although model estimates indicate that the 2021 mature biomass and the proportion of herring from 2016 year class (age-5 in 2021) for Sitka and Craig stocks were again very high, providing continued corroboration that the recruitment event in 2019 was indeed exceptional, the biomass was lower than in 2020 and in 2022 a further decrease was forecasted (Figure 43).

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 data collected since 1980, which are discussed here. In aggregate (all nine consistently monitored spawning areas combined), the biomass of Southeast Alaska herring has generally increased since 1980 (Figure

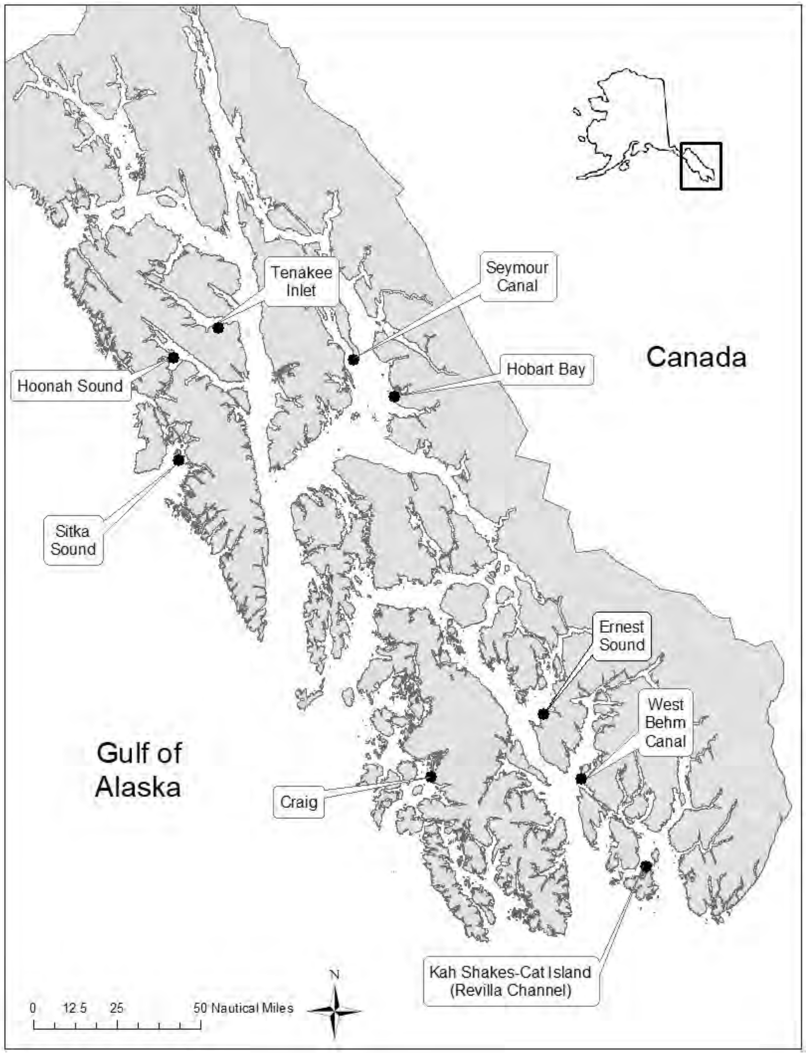

Figure 42: Location of nine Pacific herring spawning locations, historically surveyed in Southeast Alaska. Sitka Sound, Craig, and Kah-Shakes/Cat Island are considered "outside stocks" with greater ocean exposure, while all others are considered "inside stocks", less exposed to open ocean influence.

43).

Following a period of generally low biomass during the 1980s through the mid-1990s, most Southeast Alaska stocks increased to relatively high levels between 2008–2011. Southeast stocks then declined substantially until 2016–2018. Although the two largest and most consistently abundant stocks, Sitka Sound and Craig, declined substantially from their peaks of 2009 and 2011, respectively, they continued to be at moderate levels and well above the thresholds established to allow commercial fisheries. They then increased dramatically in 2019 following the highest recruitment of age-3 herring documented for these areas. In 2019, exceptionally high age-3 recruitment was also observed elsewhere in the GOA (e.g., Prince William Sound, Kodiak). Current biomass levels for other Southeast Alaska stocks are currently unknown because stock assessment surveys were suspended starting in 2016, due to budget reductions and coincident low spawning activity for some areas. Although biomass has not been routinely estimated in recent years for most Southeast Alaska stocks other than Sitka Sound and Craig, limited aerial surveys

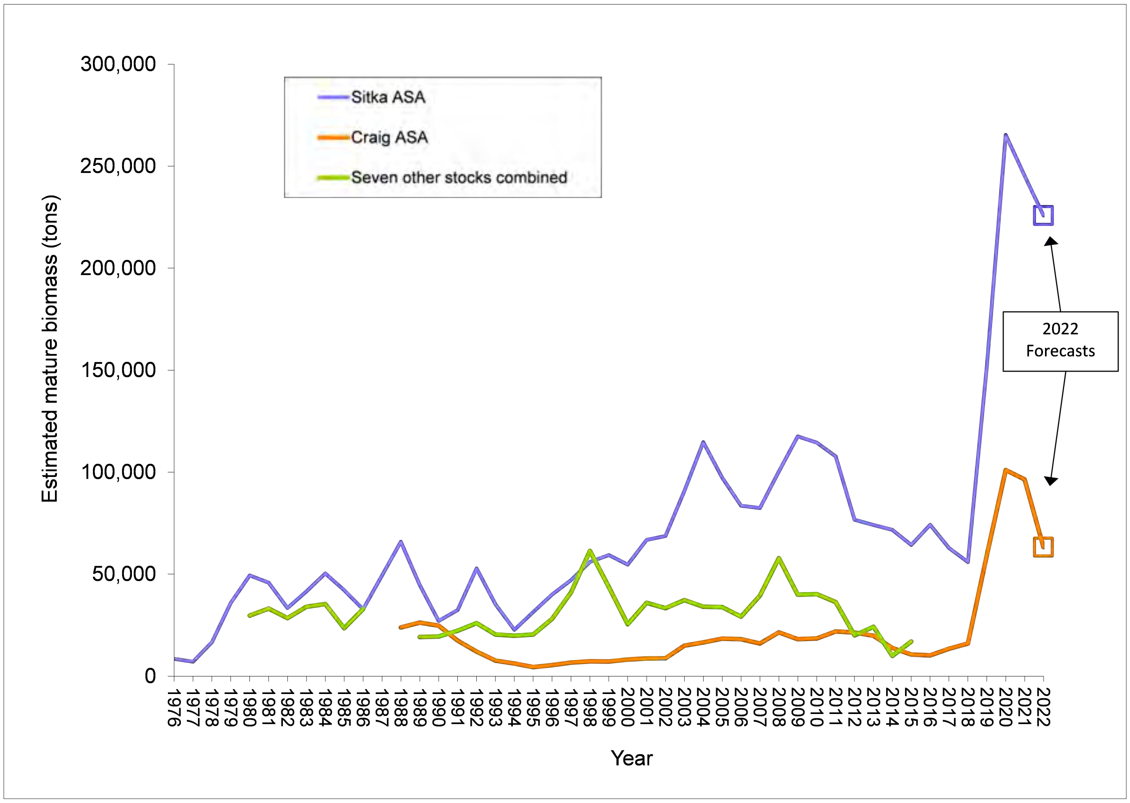

Figure 43: Estimated mature herring biomass (i.e., pre-fishery biomass) and forecasts for herring spawning areas historically surveyed in Southeast Alaska. Biomass estimates for Sitka Sound and Craig are based on integrated statistical catch-at-age models (the Sitka model starts in 1976 and Craig model 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. 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 2016-2021, 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.

of spawn events suggest that these stocks remain at relatively low levels compared to cumulative spawn mileage observed since 1980.

Factors influencing observed trends: Herring population abundance is known to fluctuate dramatically, and is susceptible to environmental influences (Toresen, 2001). The declines observed in 2021 and forecasted for 2022 for Sitka and Craig mature biomass since their peaks in 2020 are primarily due to the aging of the 2016 year class and the cumulative effects of natural and fishing mortality. While the 2021 age-3 recruitment is estimated to be sizeable in relation to recruitments over the last 50 years, it is not large enough to offset the natural mortality of the record 2016 year class.

The very high recruitment event of 2019 (2016 year class) in Sitka Sound and Craig is unprecedented in recent times, since standardized stock assessments have been conducted in Southeast Alaska. In Prince William Sound and Kodiak extremely high percentages of age-3 herring were also observed, indicating that the influencing factors were large scale. One possibility is that the unusually warm water mass that circulated through the northern Pacific Ocean during 2014–2016 (Gentemann et al., 2017), known commonly as "the Blob", contributed to increased survival of larval and/or juvenile stages of the 2016 year class. Ocean temperature has been positively correlated with recruitment in Atlantic herring *Clupea harengus* (Toresen, 2001), and Pacific herring (Zebdi and Collie, 1995).

The underlying causes for the overall increase in herring biomass in Sitka Sound and Craig and the general decline in other stocks since 2011 are likely due to multiple factors. Contributing factors may include increasing populations of predatory marine mammals, such as humpback whales and Stellar sea lions (Muto et al., 2016; Fritz et al., 2016),, varying levels of predatory fish, or recent shifts in water temperatures, which could affect herring food sources, life history, spawn timing, and metabolism. While commercial fishing has occurred during some years for some stocks, the similarity in declines of inside stocks, which for some occurred in the absence of fishing, suggests that the declines may have been primarily environmentally driven.

Implications: There are distinct differences between herring biomass trends estimated for Southeast Alaska spawning stocks that are exposed directly to GOA waters (outside stocks) and those found in inside waters. Sitka Sound and Craig are considered "outside stocks" with greater ocean exposure, 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). While all spawning stocks exhibited a decline from about 2010 to 2018, spawning stocks along the outer coast (Sitka Sound and Craig) declined to moderate levels, while those of inside waters declined to low levels. The 2019 recruitment event has made the differences more pronounced. While all Southeast Alaska spawning stocks sampled revealed a dominant 2016 year class, the outer stocks increased from moderate to high biomass, whereas smaller inside stocks remained low. The high herring biomass along the outer coast is expected to be available to support marine predators and fisheries for the next year or two as the strong 2016 year class continues to dominate the population; however the peak abundance of that year class has passed as losses to natural mortality exceed additions due to maturation. Lower abundance of herring in inside waters may not support predators that rely on herring to the same extent as in the 2010s, although there is not adequate information about populations of other forage species to understand the broader net impact on predators.

Southeast Alaska Eulachon

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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 undocumented 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. Furthermore, to monitor the annual eulachon spawning populations in 2017 eDNA sampling was expanded to five additional rivers within the northern Southeast Alaska region. In 2022, in partnership with the Ketchikan Indian Community and US Forest Service, the use of eDNA to monitor eulachon spawning populations was expanded to include the Unuk River in southern Southeast Alaska (Figure 44).

Status and trends: In 2022, eulachon populations experienced a second straight year of the lowest returns in northern Southeast Alaska since 2010 (time series 2010–present) (based on mark-recapture and eDNA studies). In recent decades, the decline in eulachon populations has increased concern about the health of eulachon across their range. In 2007, the Cowlitz Indian Tribe petitioned the National Marine Fisheries Service (NMFS) 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" (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 were 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 of hundred thousand to over 20 million (Figure 45). The mark-recapture population estimate was not conducted in 2020 due to covid-19 restrictions and was not conducted in 2021 and 2022 due to a lack of return. The 2021 return had been the lowest observed since the study was initiated in 2010, and 2022 showed two years in a row of unprecedented low return to the Chilkoot River. Interestingly though, eulachon are thought to exhibit a regional population structure (Flannery et al., 2013) and the extent to which they return to their natal stream to spawn is not well documented. Rather, it is thought that eulachon home to

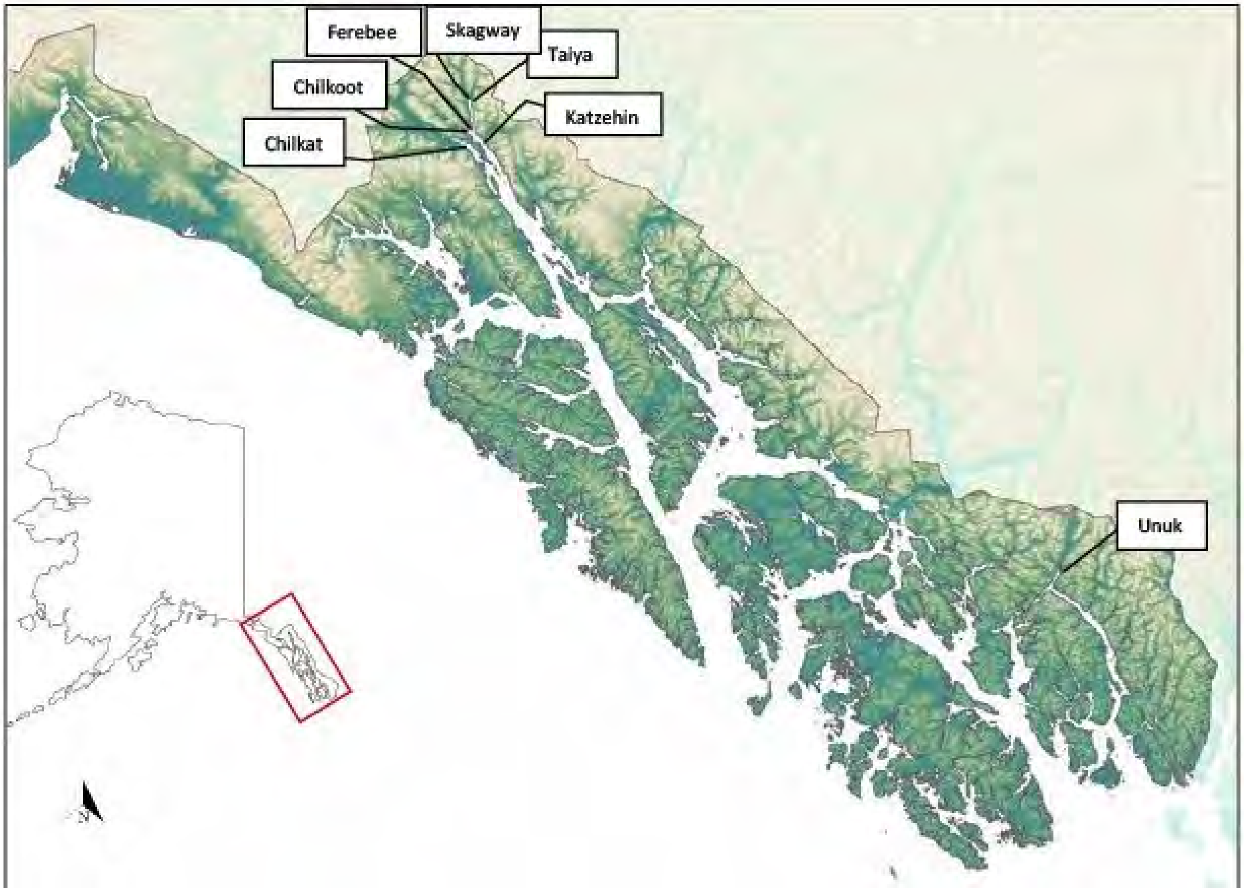

Figure 44: Location of Eulachon eDNA population monitoring sites in 2022.

a broader regional area and not necessarily a specific river (Candy et al., 2015). This can complicate population monitoring since trends exhibited at one river may not be indicative of the larger regional population.

The eulachon eDNA surveys were conducted at the Chilkoot River from 2014–2022. The ease of collecting eDNA samples (i.e., only one technician necessary to collect samples) and the sensitivity of the methods allowed for eDNA surveys to be conducted in years when the mark-recapture method was not done at the Chilkoot River (2020–2022). 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 46).

The regional population structure of eulachon initiated the need to begin a regional population monitoring effort in 2017 through the use of eDNA. The northern Southeast Alaska eulachon eDNA concentrations were similarly low across all monitoring locations in 2022 (Figure 47). The Chilkat River, which did have a sizeable return in 2021, had a lower than previously observed return in 2022. The Chilkat river monitoring location was changed in 2021 to a channel that better represented eulachon spawning habitat. The site monitored from 2017–2020 is no longer being utilized for eulachon spawning. Overall, 2019 was a large return across the northern Southeast Alaska region.

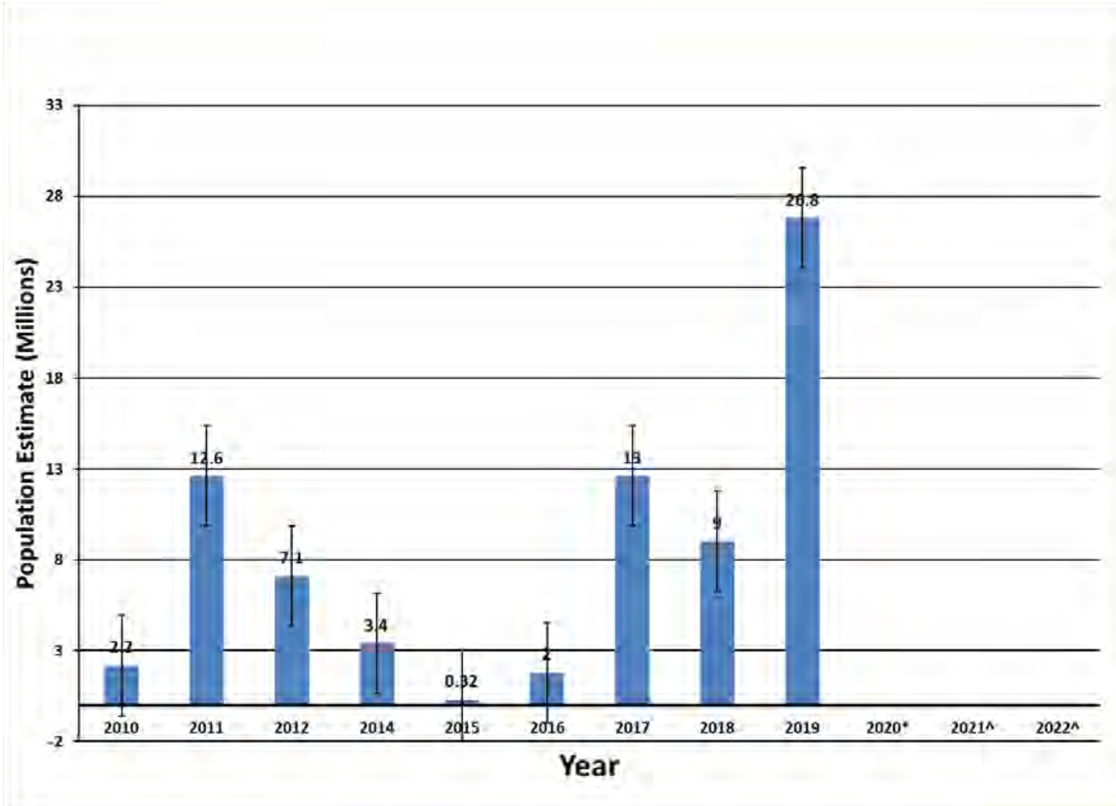

Figure 45: Eulachon population estimate on the Chilkoot River using mark-recapture method. Error bars represent 1 standard deviation.*No mark-recapture survey conducted in 2020 due to covid-19 restrictions. ^No survey conducted in 2021 and 2022 due to lack of return.

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 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. The low returns observed in 2021 and 2022 could be the offspring of the 2015 and 2016 parent years, although that would indicate that eulachon that spawn in northern Southeast Alaska are approximately 6 years old.

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,

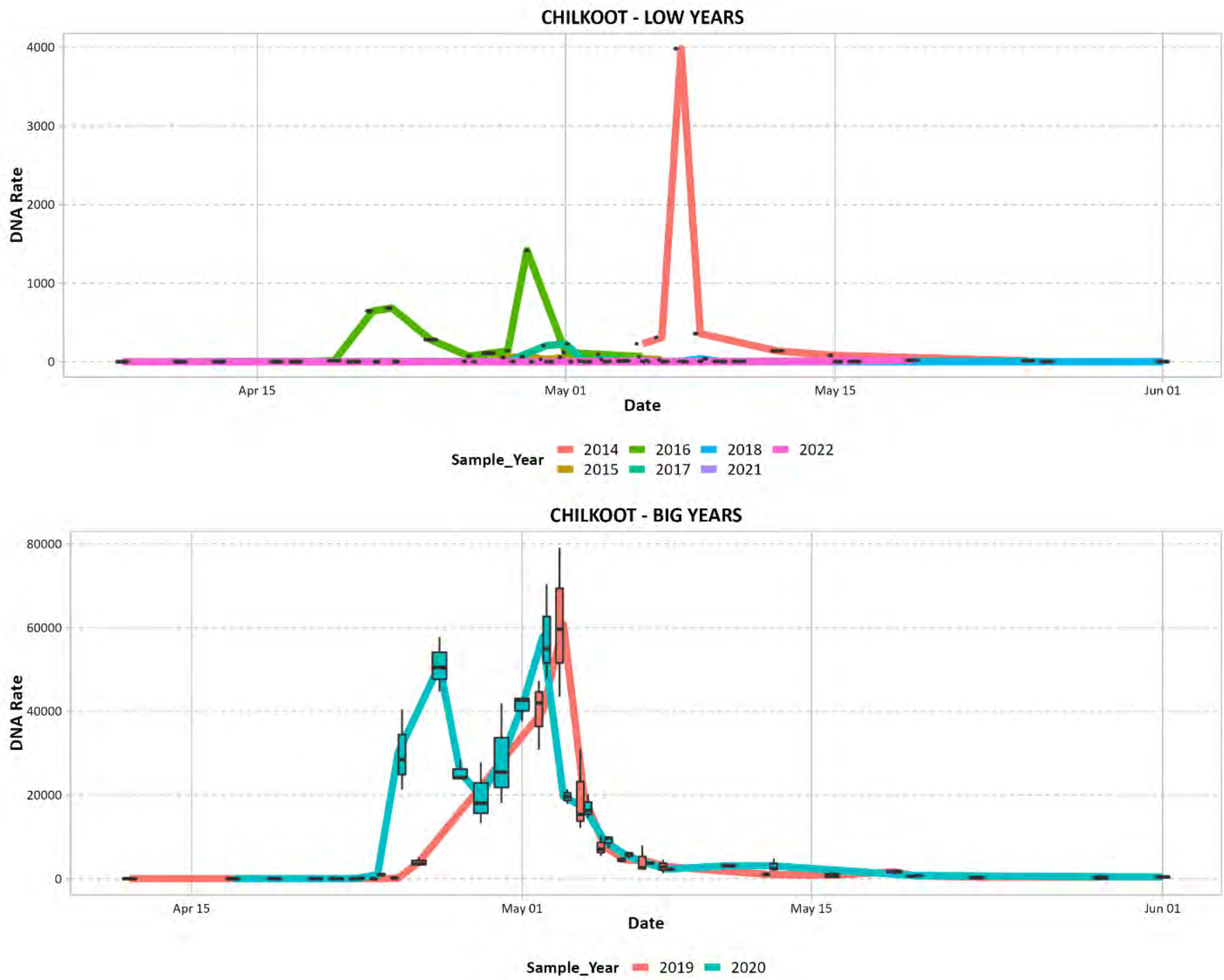

Figure 46: Chilkoot River Eulachon spring eDNA rate (eDNA concentration x Discharge) for low return years (top panel) and big return years (bottom panel).

thus providing a high-energy resource at an energetically demanding time (Sigler et al., 2004).

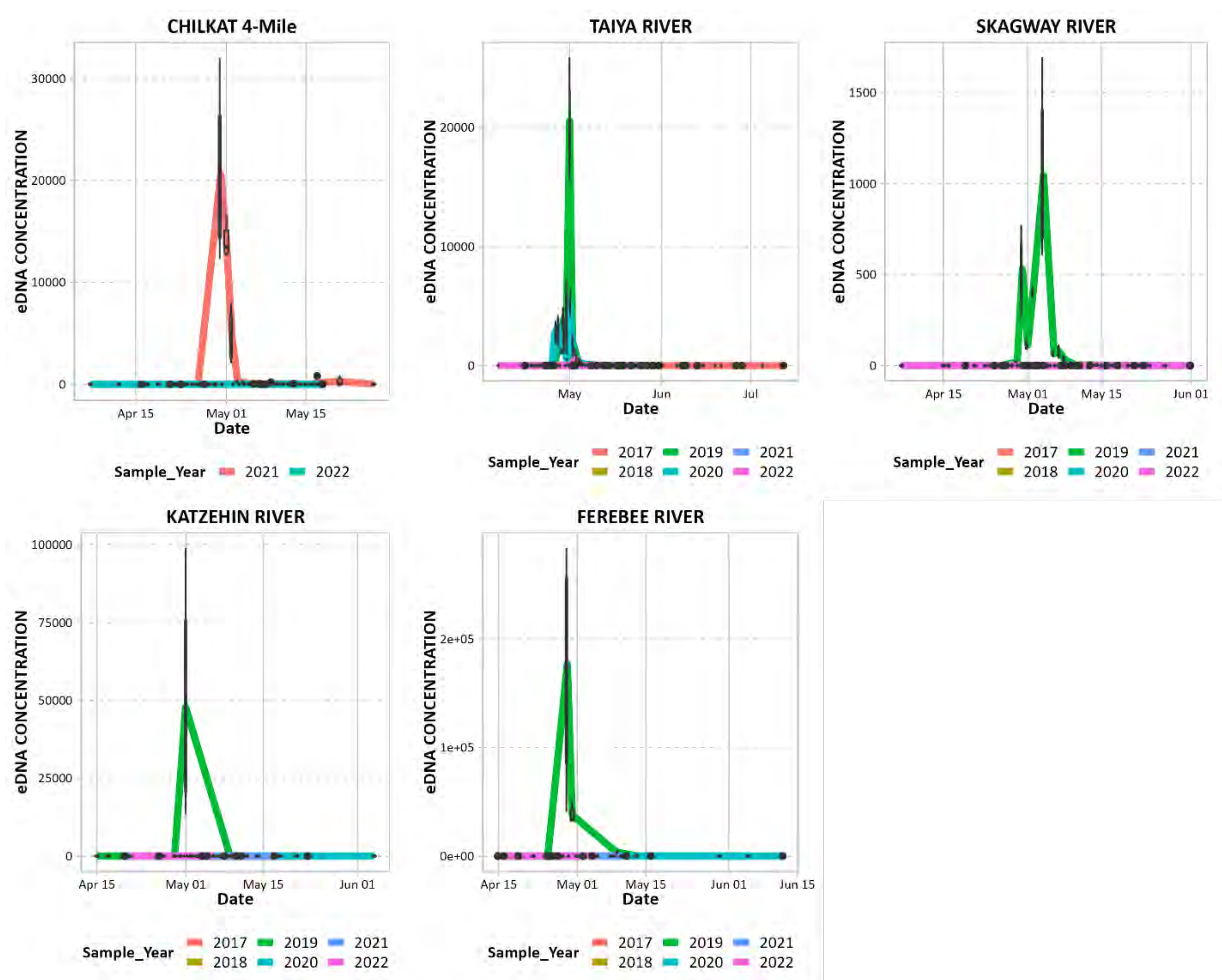

Figure 47: Eulachon eDNA concentration for five rivers in northern Southeast Alaska 2017–2022; Chilkat River location only 2021–2022.

Salmon

Trends in Alaska Commercial Salmon Catch—Gulf of Alaska

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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., Brenner et al., 2022, and on their website[11]).

Pacific salmon in Alaska are managed in four regions based on freshwater drainage basins[12], Southeast/Yakutat, Central (encompassing Prince William Sound, Cook Inlet, and Bristol Bay), Arctic-Yukon-Kuskokwim, and Westward (Kodiak, Chignik, and Alaska peninsula). ADF&G prepares harvest projections for all areas rather than conducting run size forecasts for each salmon run. There are five Pacific salmon species with directed commercial fisheries in Alaska; they are sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*).

Status and trends: *Statewide*—Catches from directed fisheries on the five salmon species have fluctuated over recent decades but in total have been generally strong statewide (time-series 1985–present; Figure 48a). The commercial harvests of salmon from 2021 totaled 235.2 million fish, which was 45.1 million more than the preseason forecast of 190.1 million fish. The 2021 total commercial harvest was elevated by the harvest of 161.8 million pink salmon, primarily from Prince William Sound and Southeast Alaska. Preliminary data from ADF&G for 2022 indicates a statewide total commercial salmon harvest of about 154 million fish (as of 22 September), which is below the preseason projection of 160.6 million fish. The 2022 harvest has been bolstered by the catch of 74.5 million sockeye salmon, primarily from Bristol Bay.

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 48b). In the Prince William Sound Area of the Central region, the 2021 total commercial salmon harvest was 70.7 million fish, of which 66.4 million were pink salmon. The 2021 pink salmon harvest was 4% above the odd-year average of 64.1 million. Preliminary harvest numbers for 2022, indicate that Prince William Sound pink salmon are continuing to follow the pattern of weak even years with a total commercial harvest of 28.4 million fish.

In the Southeast region, the 2021 commercial salmon harvests totaled 58.9 million, which was four times greater than the total harvest in this region in 2020. The 2021 harvests of sockeye, chum, Chinook, and coho were below average. However, the pink salmon commercial harvest of 48.5 million fish was nearly equal to their recent odd-year average of 49 million fish. Preliminary data for 2022 from ADF&G indicate that catches of Chinook and chum are higher in 2022 and that pink salmon are maintaining

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

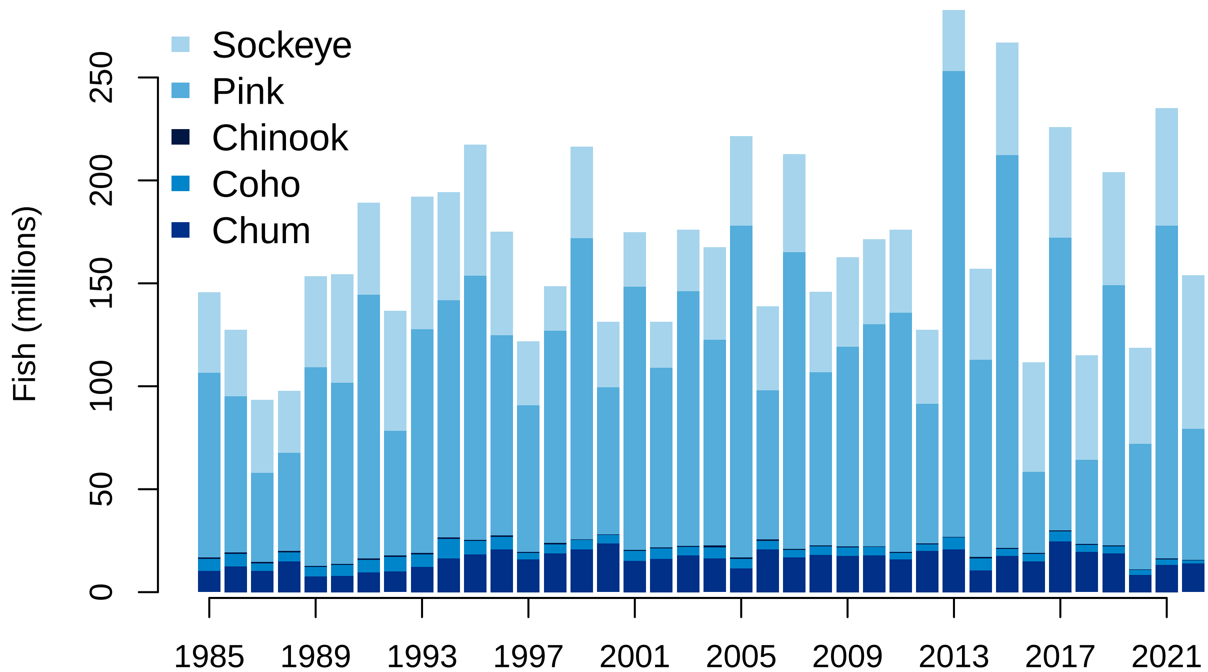
the pattern of weak even years.

In the Kodiak management area, the 2021 total salmon harvest of 30.6 million fish was above the long-term and recent 10-year average harvests. The 2021 commercial harvest of 3.3 million sockeye salmon exceeded the preseason forecast of 2 million fish. The 2021 harvest of 26.6 million pink salmon was above the recent 10-year average harvest of 19.8 million fish. Preliminary data from ADF&G on the 2022 commercial harvest indicate the total harvest of pink salmon has decreased to about 18.2 million fish.

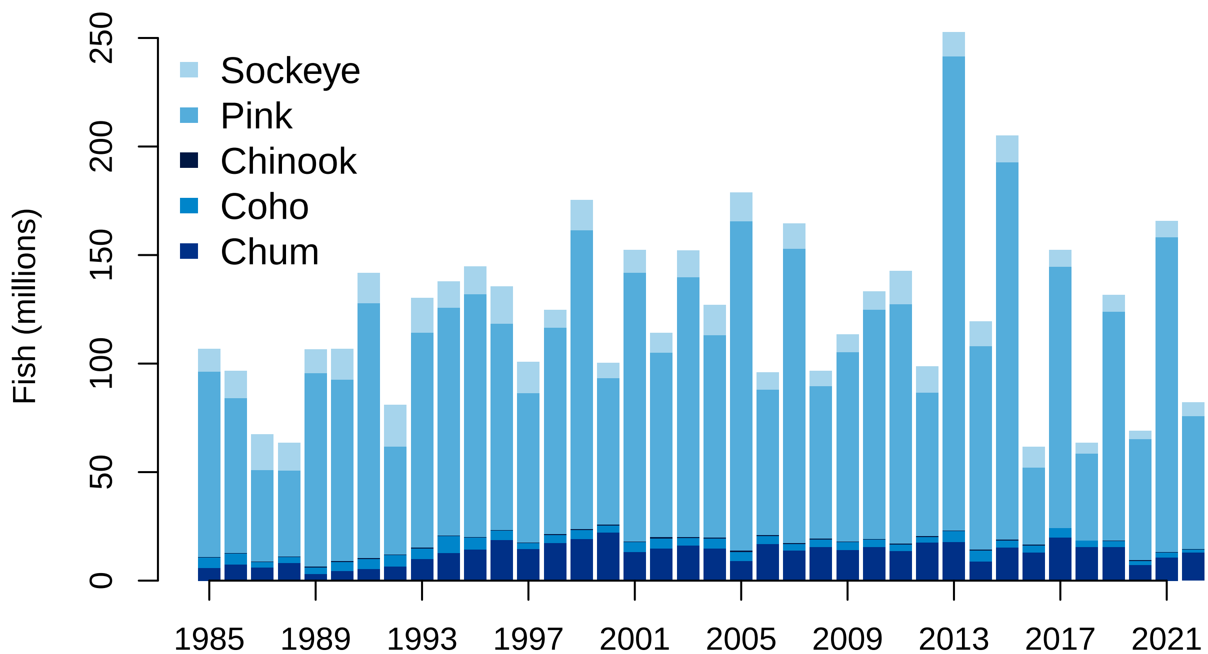
Factors influencing observed trends: Historically, pink salmon catches increased in the late 1970s to the mid-1990s and have generally remained high in all regions in the last decade (Figure 48a). While both natural and hatchery populations return to Prince William Sound, a large majority of the returning 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). A negative relationship between seabird reproductive success and years of high pink salmon abundance has recently been demonstrated (Springer and van Vliet, 2014). Directed salmon fisheries are economically important for the state of Alaska. The overall abundance of salmon in Alaska has been high in recent decades, and despite annual fluctuations, the trend in total statewide salmon catch in recent decades has been for generally strong harvests.



(a) Alaska



(b) Gulf of Alaska

Figure 48: Contemporary commercial salmon catches from Alaska (a) and GOA (b), 1985-Sept 2022. Values from 2022 are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data, subsequent analysis, or interpretation.)

Juvenile Salmon Abundance in Icy Strait, Southeast Alaska

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Last updated: September 2022

Description of indicator: Juvenile salmon catch-per-unit-effort (CPUE), zooplankton abundance, and data on oceanographic conditions have been collected during the Southeast Alaska Coastal Monitoring (SECM) surveys from 1997–2022 (Fergusson et al., 2021; Murphy et al., 2021). SECM data are used in a variety of research applications. The information on 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., 2020) are part of a cooperative research effort by the Alaska Fisheries Science Center (AFSC) and the Alaska Department of Fish and Game (ADF&G) in support of salmon stocks and fisheries in southeastern AK.

Juvenile salmon CPUE indices are constructed from surface (0–20m) 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-unit-effort (CPUE, log-transformed catch per 20-min trawl set) in Icy Strait during the months of June and July. 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 49.

Status and trends: Peak CPUE has been consistently near or below average (baseline 1997–2022) 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 49). Catch rates of juvenile pink salmon increased in 2022 relative to 2021, but remained well below the long-term mean. Catch rates of Chinook and sockeye increased in 2022, both are at or nearing the long-term mean. Catch rates of chum decreased slightly in 2022, remaining below the long-term mean. Catch rates of coho decreased to the lowest level observed during the entire time series.

Factors influencing observed trends: Multiple factors contribute to the variation in juvenile salmon catch rates (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 year-to-year variation in juvenile CPUE. Spawner abundance goals have not been met in recent even-year runs of pink salmon within the northern inside region of southeastern AK (Piston and Heinl, 2020), and this is likely an important factor contributing to lower odd-year catch rates of juvenile pink salmon, including in 2021. Catch rates of juvenile 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. Hatcheries accounted for approximately 87% of the chum salmon harvested in southeastern AK from 2010 to 2020; therefore, spawner abundance has minimal influence on juvenile chum salmon catch rates. Chinook, sockeye, and coho salmon spend

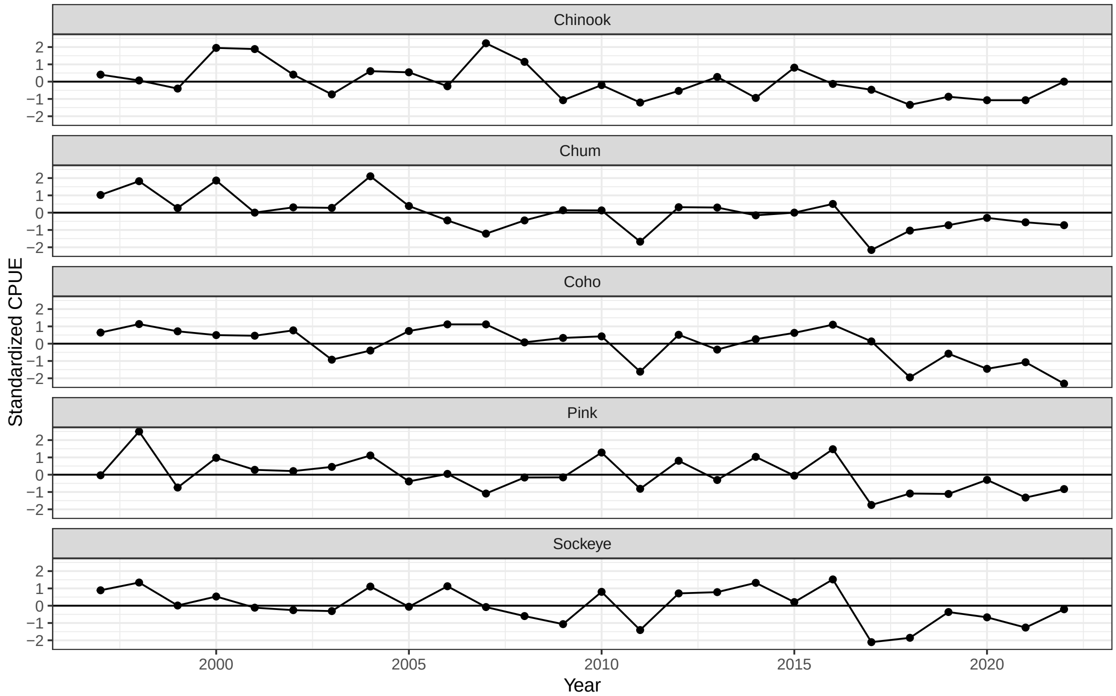

Figure 49: Catch-per-unit-effort (CPUE, log-transformed catch per 20-min trawl set) of juvenile salmon during Southeast Alaska Coastal Monitoring (SECM) surveys in Icy Strait, 1997–2022. The CPUE index is the peak monthly average catch rate during the months of June and July. The average index for each species (1997-2022) is identified by the dashed line. The ADF&G is not responsible for the reproduction of data, subsequent analysis, or interpretation.

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 to average levels during 2020 (Figure 49); however, the harvest of southeastern AK pink salmon in 2021 was above the recent 20-year average (Figure 50). This may reflect improved offshore survival or reduced survey catchability (during juvenile migration) in 2020. The decline in juvenile pink salmon catch rates in 2021 and 2022 indicates that pink salmon harvests will likely remain below average in 2023. Although the relationship between juvenile and adult Chinook salmon abundance is poor (Orsi et al., 2016), the survival and harvest of northern southeastern AK Chinook salmon has the potential to increase given that the juvenile catch rate returned to the long-term average during 2022. Catch rates of juvenile chum salmon have improved after the all-time low in 2017, but remain below the long-term average. This may provide increased harvest potential in the coming years, relative to recent commercial catches. The harvest of southeast coho has been below average and falling since 2018. With the lowest peak cpue in the entire time series occurring in 2022, this harvest trend is likely to continue.

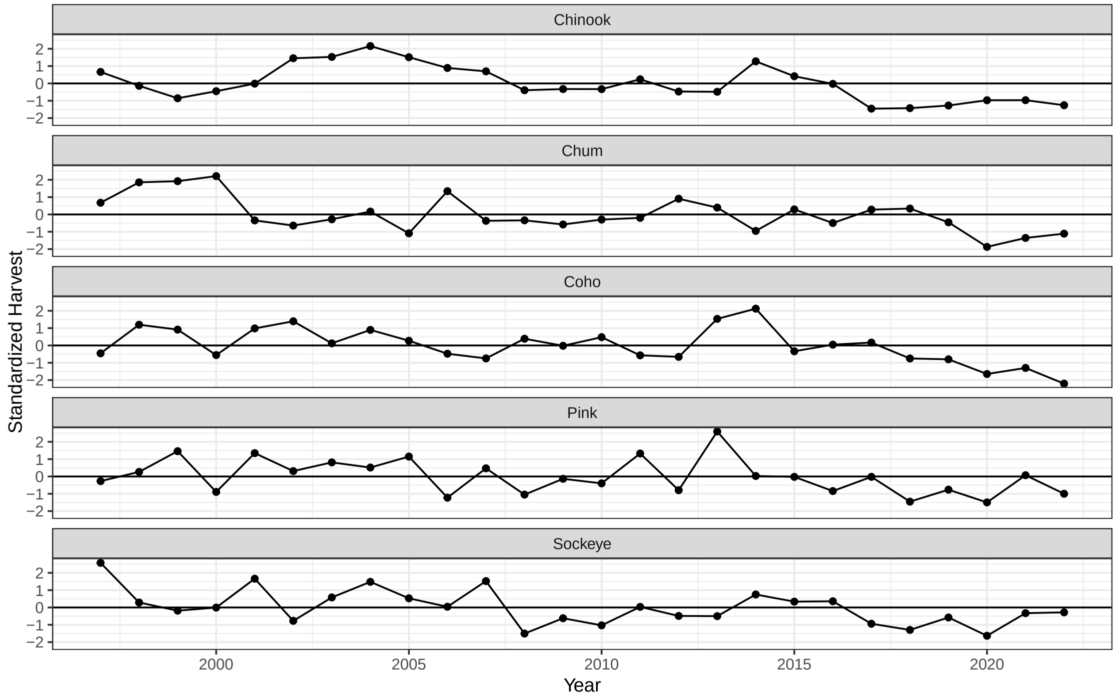

Figure 50: Commercial harvest (mt) of salmon in Southeast Alaska, 1925–2022. The 1925–2022 harvest data are provided by ADF&G and available at `https://npafc.org/statistics/`. The 2022 harvest data are preliminary data up to September 19, 2022, provided by ADF&G and available at `https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.bluesheet`

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

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Last updated: September 2022

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; 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 2022 size data (fork length) and energy density data through 2021 for juvenile salmon in Icy Strait in relation to the past 26 years.

Status and trends: In 2022, juvenile salmon lengths were very similar to lengths observed in 2021. Juvenile pink salmon length values increased very slightly but remained below average (baseline 1997–2022). Juvenile chum salmon length values increased slightly and remained above average. Juvenile sockeye salmon length values were very similar to 2021 values which were at the average of the time series (Figure 51). Juvenile coho salmon length values increased to slightly above the overall average length.

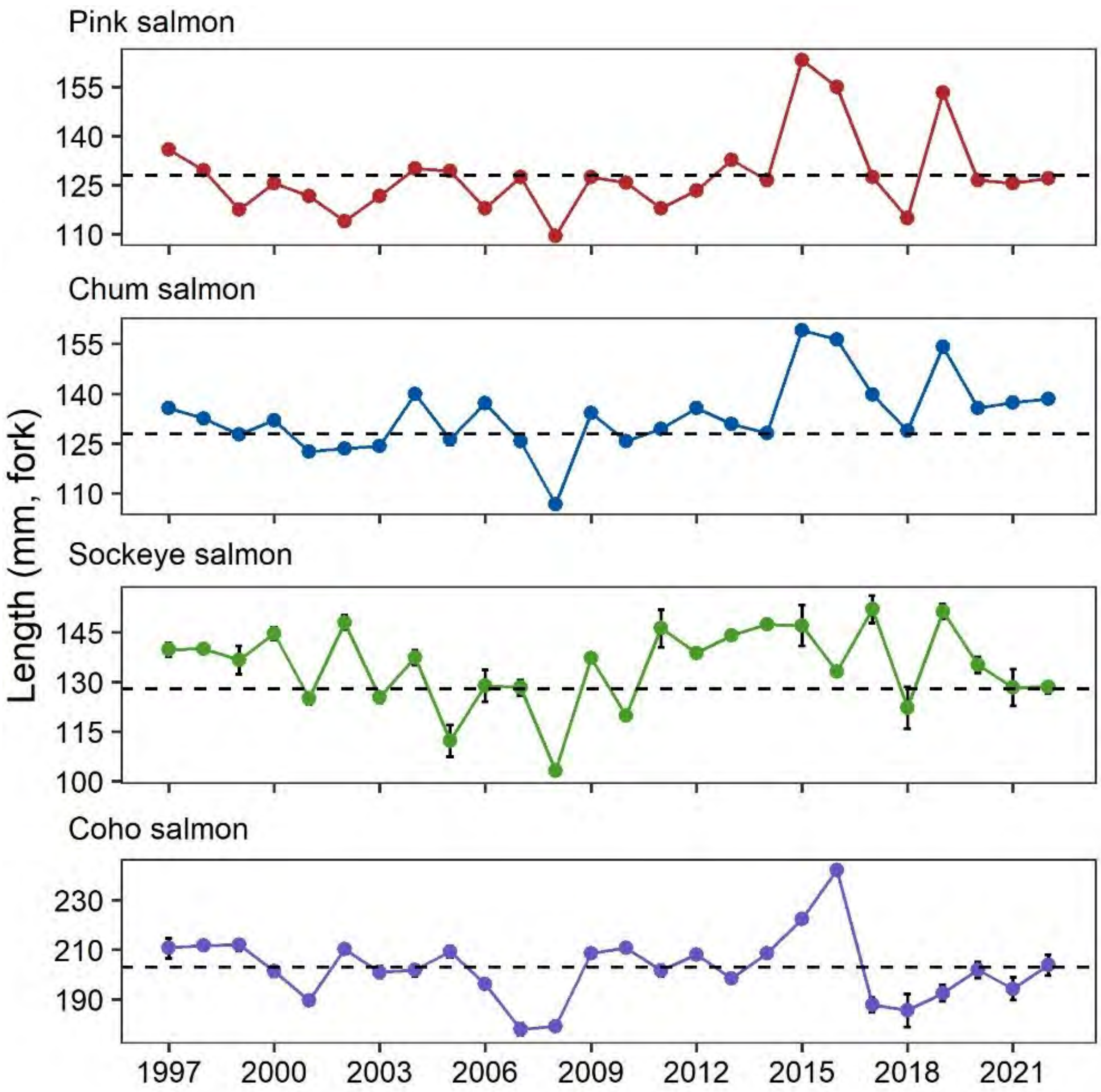

Figure 51: Average fork length (mm; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2022. Time series average is indicated by the dashed line.

In 2021, energy densities (ED, kJ / g dry weight) in three of the four juvenile salmon species were at or above average (Figure 52). For juvenile pink and sockeye salmon, ED increased or was similar to 2020 values. For juvenile coho and chum salmon, ED decreased from 2020 values with chum ED remaining below 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 out-migrating 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 2022 length values similar to those observed for juvenile salmon in the previous year reflect the continuation of 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 2022 length frequency results relative to the long-term averages by species, juvenile salmon entered the GOA in 2022 with an average size. Further growth and survival will be dependent on favorable over-winter conditions in the GOA. Juvenile pink, sockeye, and coho salmon entered the GOA in 2021 with at or above-average energy stores which may contribute to higher survival and escapement. Juvenile chum salmon entered the GOA in 2021 with below-average energy stores which could have negative implications in their overwinter survival, a time when food is limited.

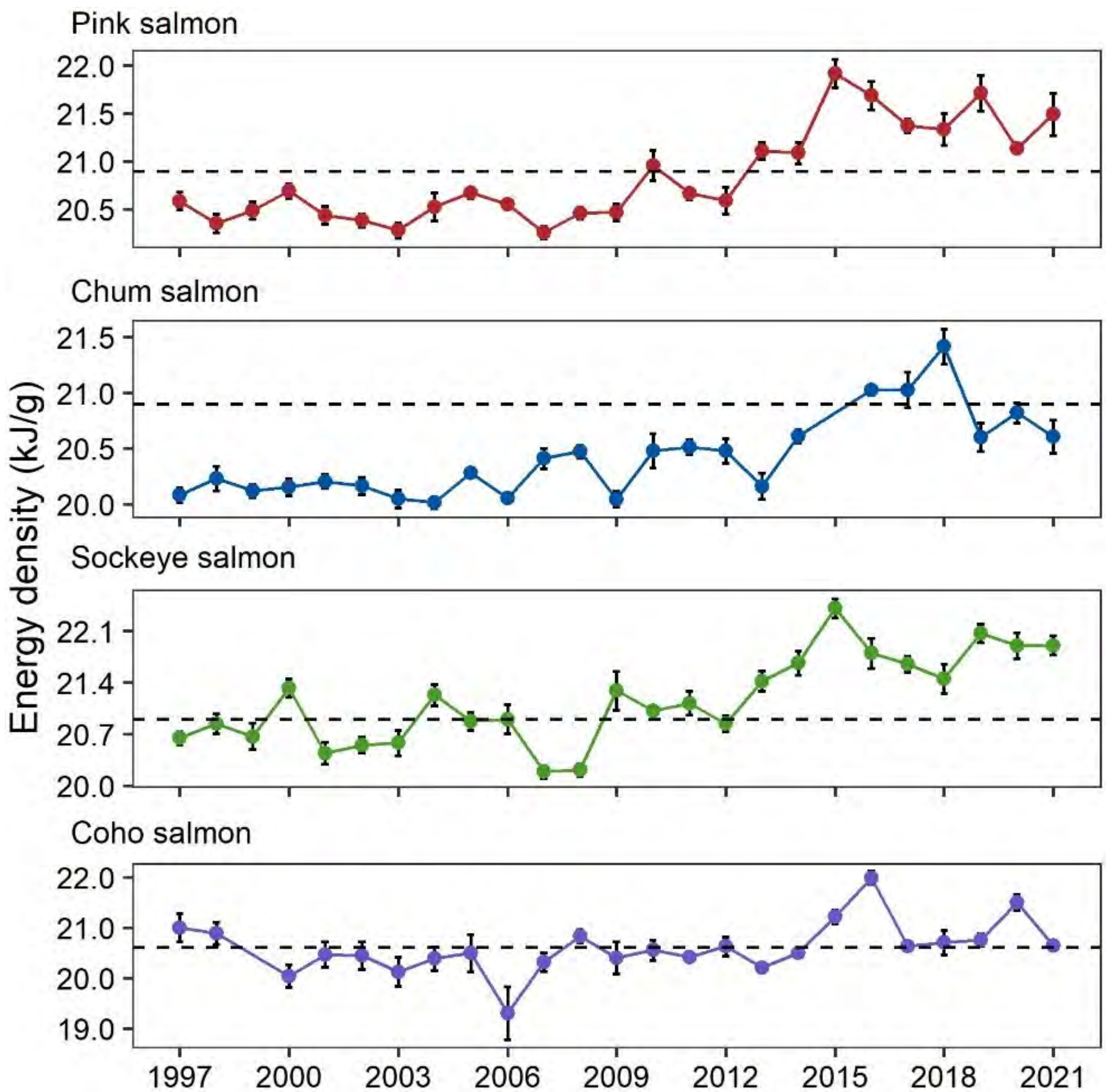

Figure 52: Average energy density (kJ/g, dry weight; ±1 standard error) of juvenile salmon captured in Icy Strait, AK by the Southeast Coastal Monitoring project, 1997–2020. Time series average is indicated by the dashed line.

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

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Last updated: September 2022

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 5.1% to 47.8%, with an average survival of 21.3% from smolt years 1980–2021 (Figure 53a). Marine survival for 2021 was the second lowest on record at 5.6% and overall survival averaged 9.4% over the last 5 years and 12.2% over the last 10 years. The survival index for ocean age-0 coho varies from 0.2% to 11.2% from smolt years 1980–2021 (Figure 53b).

Productivity of wild sockeye salmon smolts from Auke Creek has varied from 1619 to 33616, with an average productivity of 15837 from ocean entry years 1980–2022. Auke Creek produced 6959 outmigrant smolts in 2022, the fifth lowest on record (Figure 53c). Escapement of wild sockeye salmon smolts from Auke Creek has varied from 325 to 6123, with an average escapement of 2568 from return years 1980–2022. The 2022 season saw the second lowest escapement of sockeye salmon to Auke Creek with 596 returning adults (Figure 53d).

Marine survival of wild pink salmon from Auke Creek varies from 1.1% to 53.3%, with an average survival of 11.3% from ocean entry years 1980–2021 (Figure 53e). Marine survival for the 2021 ocean entry year was 1.2% and overall survival averaged 11.9% over the last 5 years and 14.4% over the last 10 years. 2022 saw the 2nd lowest return of pink salmon to Auke Creek with 378 returning adults (Figure 53f).

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

Implications: The marine survival indices of coho, sockeye and pink salmon at Auke Creek are 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 GOA 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. 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. Due to the one ocean year life history of pink salmon, their marine survival is useful as a proxy for the general state of the GOA. 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 salmon 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 coho, sockeye, and pink salmon provide valuable proxies for GOA and southeast Alaska productivity, as well as the overwintering survival and recruitment of sablefish.

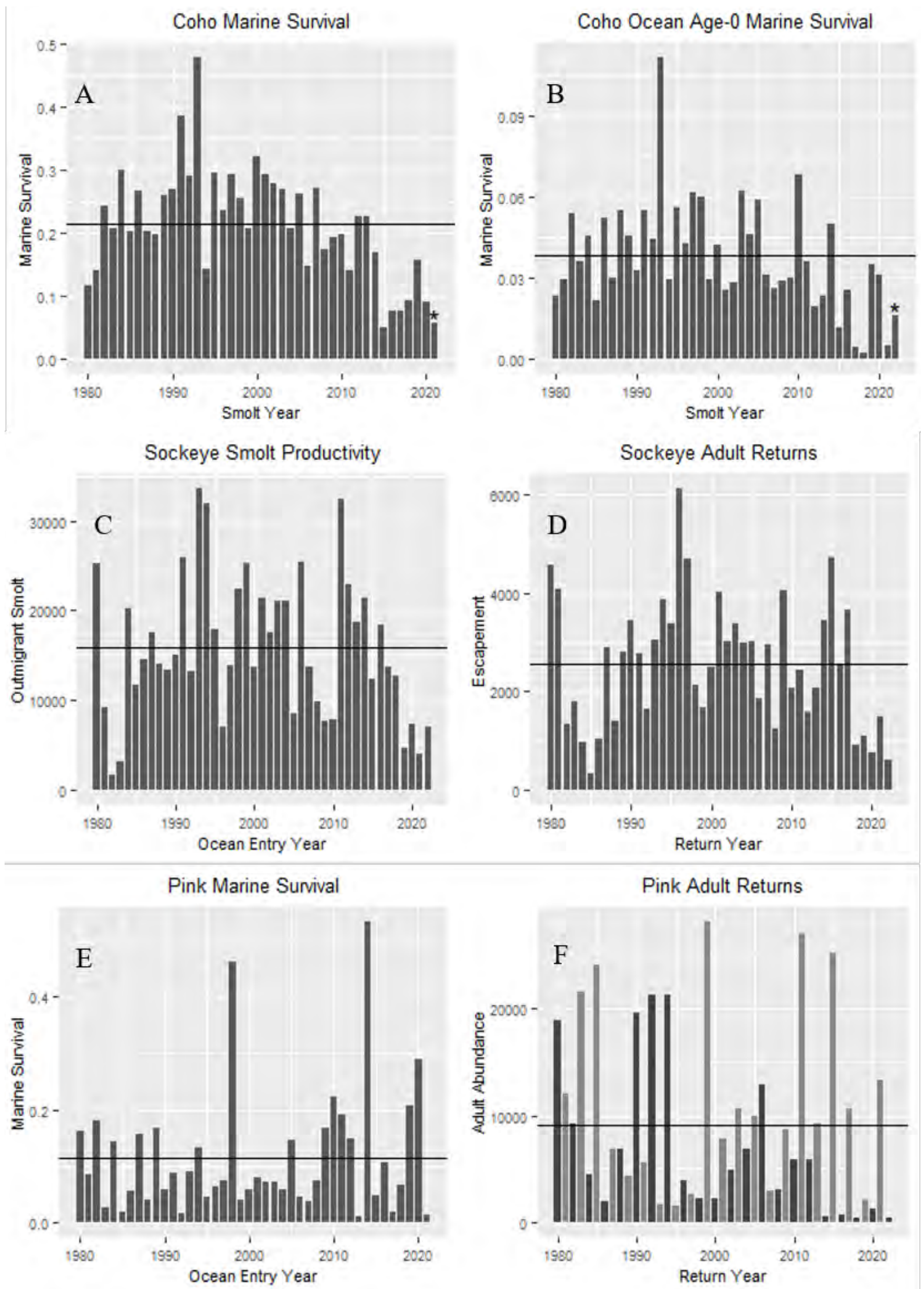

Figure 53: Auke Creek (SE Alaska) salmon marine survival and productivity indices. Coho salmon are represented by total marine survival (ocean age-0 and age-1 harvest plus escapement) (A), and percentage of ocean age-0 coho per smolt (escapement only) by smolt year (B). Sockeye salmon are represented 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 2022 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 1980–2022 average.

Groundfish

Gulf of Alaska Groundfish Condition

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

ADF&G Gulf of Alaska Trawl Survey

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Last updated: September 2022

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, 2020). 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 54). In 2022, a total of 50 stations was sampled from June 29 through July 6. 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 each haul from 1990 to present.

Status and trends: Overall biomass caught in both the inshore and offshore stations increased in 2022 (Figure 55). Arrowtooth flounder and Tanner crab have been the predominant species in the ADF&G trawl survey catches in the last 3 years, with significant increases in both the inshore and offshore stations. Flathead sole also showed a slight increase in 2022. Starfish catches show increasing trends in 2022, from the dramatic decline in 2017. A sharp decrease in overall biomass is apparent from 2007 to 2017 from the years of record high catches occurring from 2002 to 2005.

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 10% of catch and

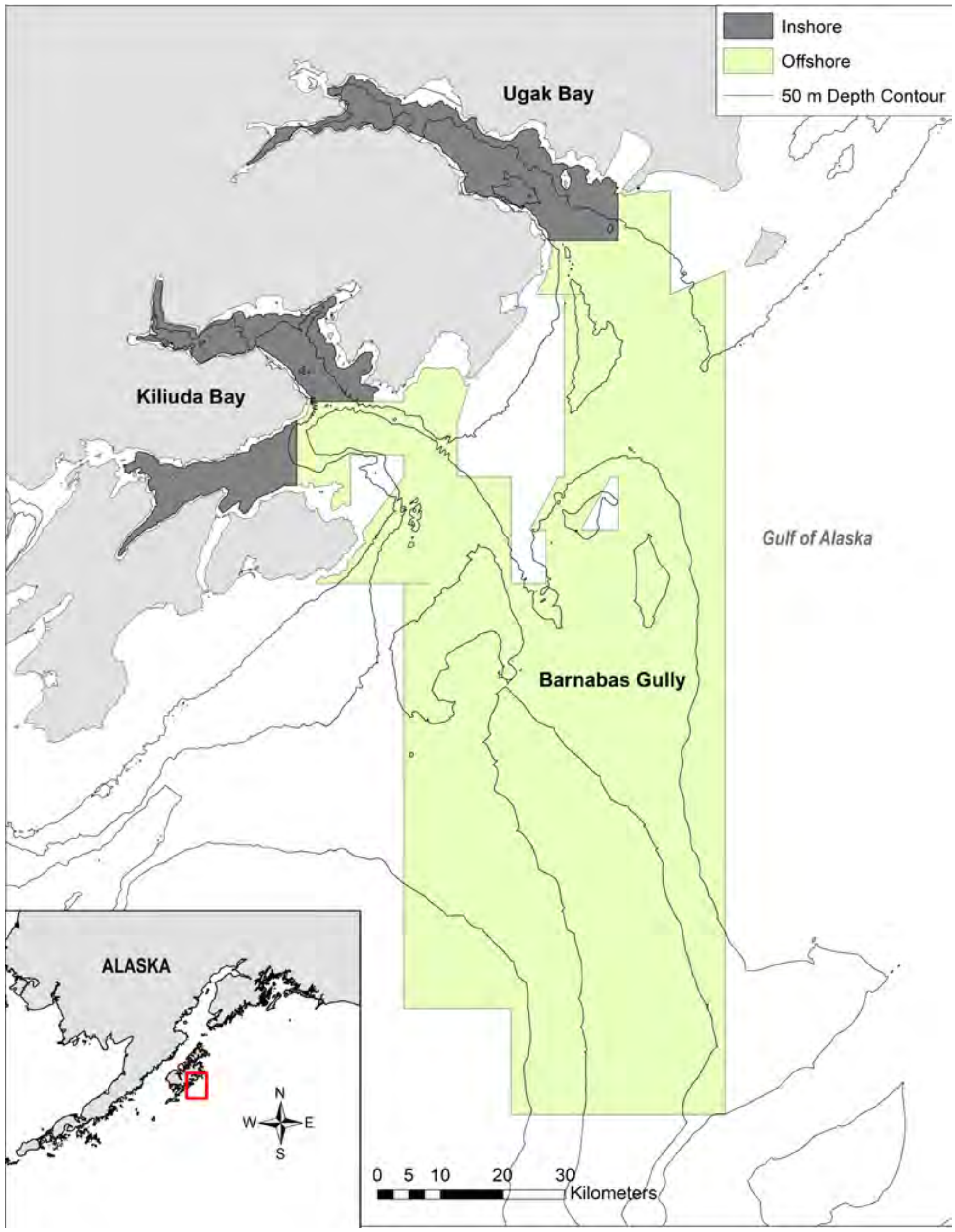


Figure 54: Kiliuda Bay, Ugak Bay, and Barnabus Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

walleye pollock 90% in 2022.

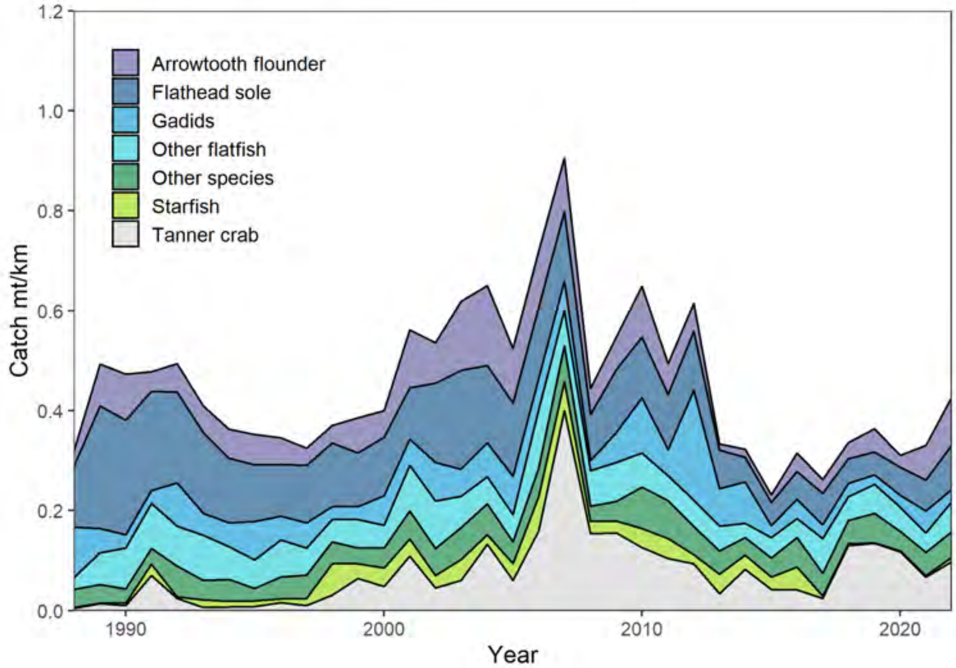
Below-average anomaly values (baseline 1988–2021) for flathead sole were recorded in 2022 for both offshore and the inshore areas, while arrowtooth were above-average (Figure 56). Pacific cod, Pacific halibut, and walleye pollock were also below average for both inshore and offshore, while skates showed a large increase in the offshore stations. The above- average anomaly values for Tanner crab continued in 2022 in the offshore areas, due to a large recruitment event (Spalinger and Knutson, 2022).

Temperature anomalies for both inshore and offshore stations were above-average in 2022 in contrast to previous years (see western GOA summer temperatures in this Report, p.39). The higher-than-average temperatures in past years frequently occurred during moderate and strong El Niño years[13].

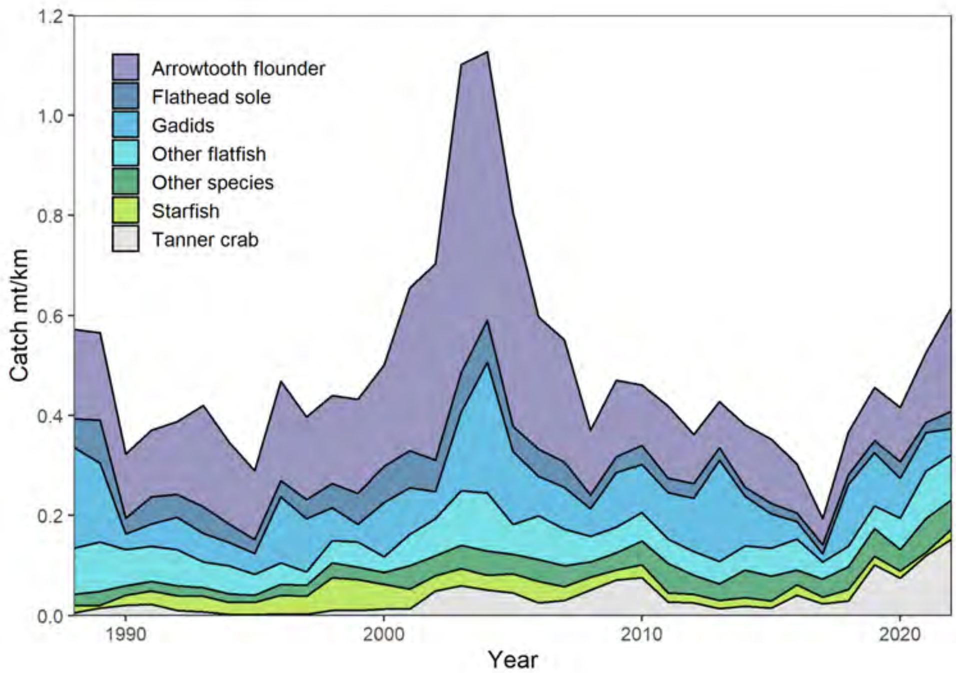
Factors influencing observed trends: It appears that significant changes in volume and composition of the catches on the east side of Kodiak are occurring, but it is unknown to what extent predation, environmental changes, and fishing effort are contributing. The lower overall catch from 1993 to 1999 (Figure 55) 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.

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



(a) Kiliuda and Ugak Bay



(b) Barnabas Gully

Figure 55: 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, 1987–2022.

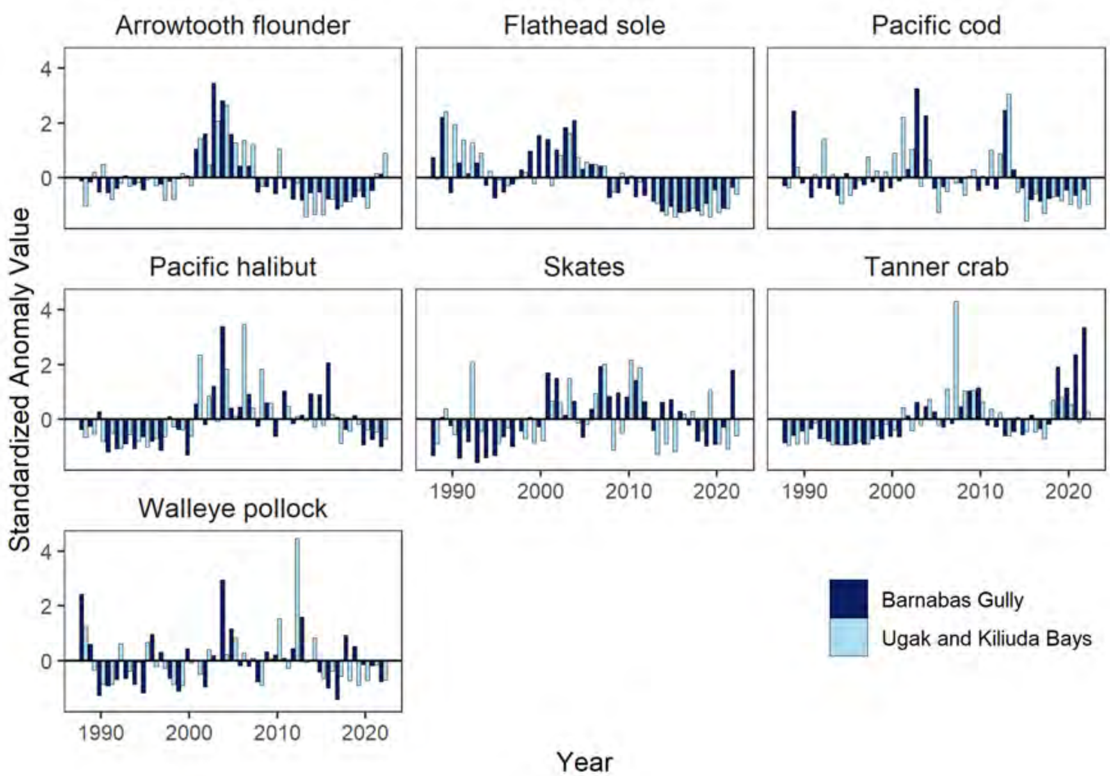


Figure 56: A comparison of standardized anomaly values, based on catch (kg) per distance towed (km) for selected species caught from 1988 to 2022 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

Distribution of Rockfish Species in Gulf of Alaska Trawl Surveys

NOAA Fisheries Gulf of Alaska Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Multispecies model estimates of time-varying natural mortality of groundfish in the Gulf of Alaska

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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 (GOA). 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 annual 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, Holsman and Aydin, 2015). CEATTLE has been modified for the GOA and implemented in Template Model Builder (Kristensen et al., 2015) to allow for the fitting of two-sex models, multiple sources of data, time-varying selectivity, time-varying catchability, and random effects. 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 2022, 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: After increasing slightly in recent years, pollock age-1 M still remained lower in 2022 at 1.09 yr^{-1} (SD = 0.12) relative to the long-term mean (1977–2022; 1.26 yr^{-1} and the values used for single species assessment (age-1 M = 1.39; Figure 57). Additionally, Pacific cod and arrowtooth flounder age-1 M were below the long-term mean after decreasing in recent years (Figure 57), but above the values used/estimated for the single species assessments of 0.50 yr^{-1} (Pacific cod), 0.2 yr^{-1} (arrowtooth females), and 0.35 yr^{-1} (arrowtooth males), with total age-1 M at around 0.79 yr^{-1} (SD = 0.06) for Pacific cod 0.35 yr^{-1} (SD = 0.02) for arrowtooth females, and 0.45 yr^{-1} (SD = 0.02) for arrowtooth males. 2022 age-1 M across species is 6.55% to 34.18% lower than in peak years. Estimated age-1 natural mortality (M) peaked in 2005 for walleye pollock, in 2005 for Pacific cod, and in 1991 for arrowtooth flounder (Figure 57). Average age-1 M estimated by CEATTLE was greatest for pollock

(1.26 yr^{-1}) and lower for Pacific cod (0.84 yr^{-1}) and arrowtooth (0.36 yr^{-1} for females and 0.46 yr^{-1} for males).

On average 154,995 mt of age-1 pollock, 2,631 mt of age-1 Pacific cod, and 5,644 mt of age-1 arrowtooth flounder were consumed annually by species included in CEATTLE between 1977 and 2022. For 2022, we estimated 64,852 mt (SD = 84,348) of age-1 pollock, 632 mt (SD = 314) of age-1 Pacific cod, 3,800 mt (SD = 1,363) of age-1 arrowtooth females, and 632 mt (SD = 1,352) of age-1 arrowtooth males was consumed by species included in CEATTLE. Across all ages, 564,652 mt of pollock, 27,555 mt of arrowtooth flounder, 5,532 mt of Pacific cod was consumed annually, on average, by species included in CEATTLE. The total biomass consumed of pollock as prey across all ages increased in 2022 compared to 2021 (Figure 58). The total biomass consumed of arrowtooth flounder and Pacific cod has decreased in recent years. However, 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 59) and arrowtooth flounder biomass has declined in recent years. Increases in biomass consumed of walleye pollock in 2021 relative to 2020 reflect elevated recruitment of age-1 pollock in 2021 that was available to the modeled predators. Combined annual predation demand (annual ration) of age-4+ pollock, Pacific cod, and arrowtooth flounder in 2022 was 5.2 hundred thousand tons, down from the 6.73 hundred thousand ton annual average (Figure 60).

Implications: We find evidence of continued decline in predation mortality on age-1 walleye pollock, Pacific cod and arrowtooth flounder, due to the species modeled in CEATTLE. Previous ecosystem modeling efforts have estimated that mortality of pollock is primarily driven by P. cod (16%), Pacific halibut (23%) and arrowtooth flounder (33%) (Gaichas et al., 2015). Declines in total predator biomass are contributing to an overall decline in total consumption and therefore reduced 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. A strong recruitment of age-1 pollock in 2021 led to an increase in biomass of pollock being consumed by predators.

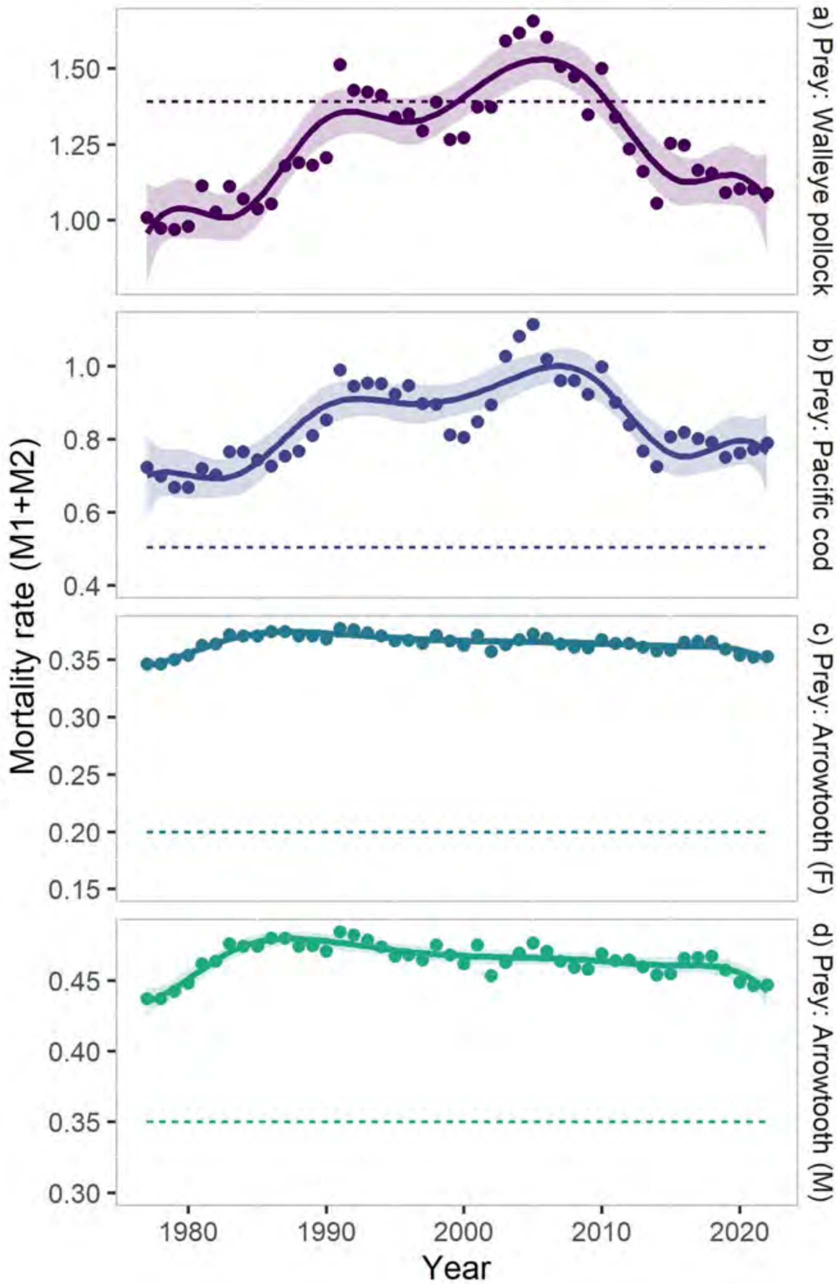

Figure 57: Annual variation in total mortality (M1 + M2) of age-1 walleye pollock, Pacific cod, and arrowtooth flounder (females and males) from the single-species models (dashed line), and the multi-species models with temperature (points; solid line is a loess polynomial smoother indicating trends over time).

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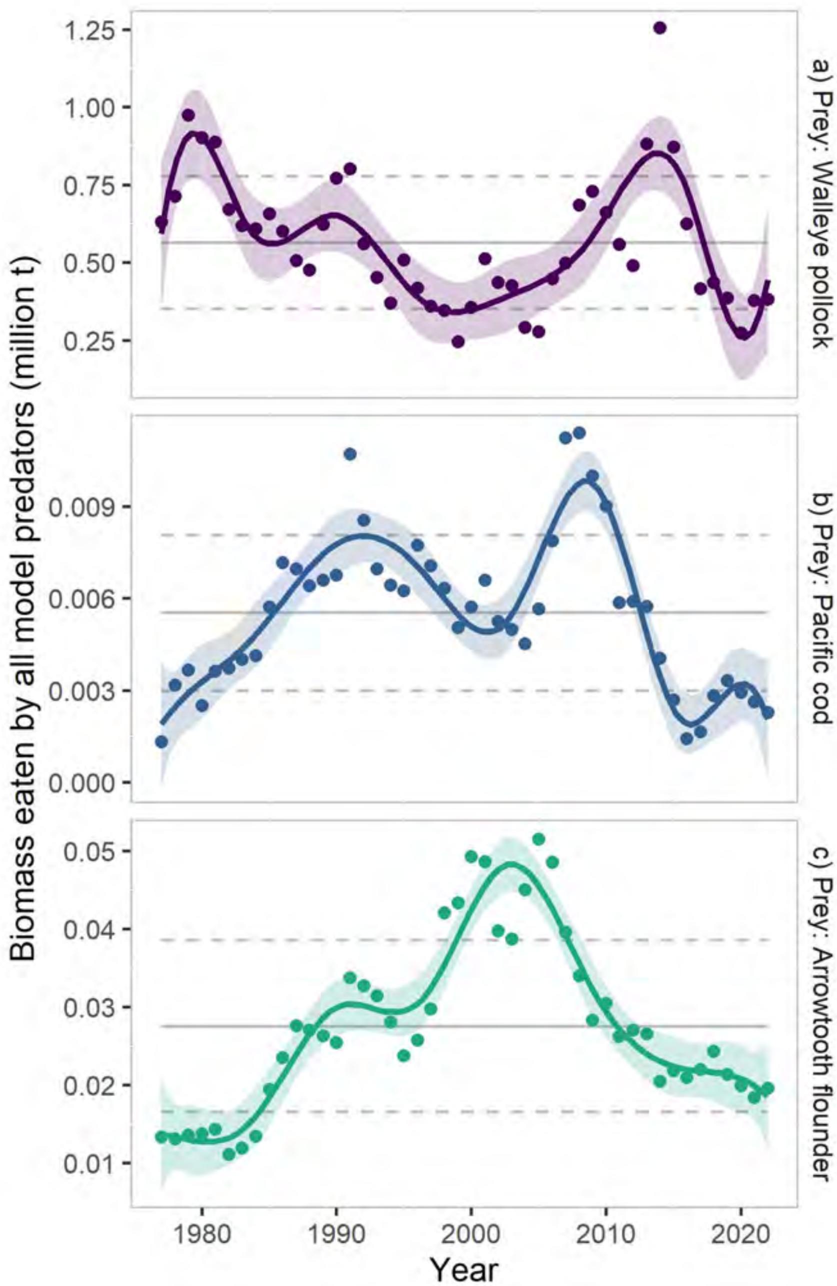

Figure 58: Multispecies estimates of biomass consumed as prey across all ages by all predators annually in the models for walleye pollock, Pacific cod, and arrowtooth flounder. Points represent annual estimates, gray lines indicate 1979–2022 mean estimates for each species, and the solid line is a 10 year (symmetric) loess polynomial smoother indicating trends over time.

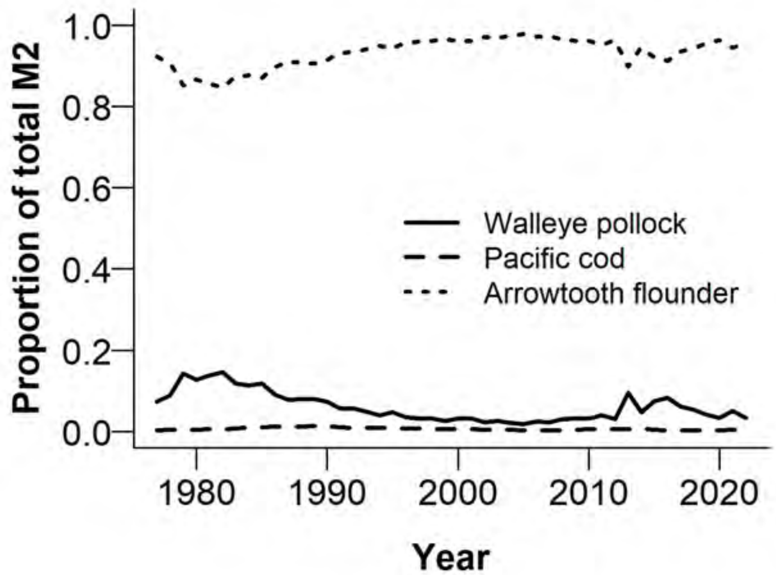

Figure 59: Proportion of total predation mortality for age-1 pollock from pollock (solid), Pacific cod (dashed), and arrowtooth flounder (dotted) predators across years. Updated from Adams et al. (2022)

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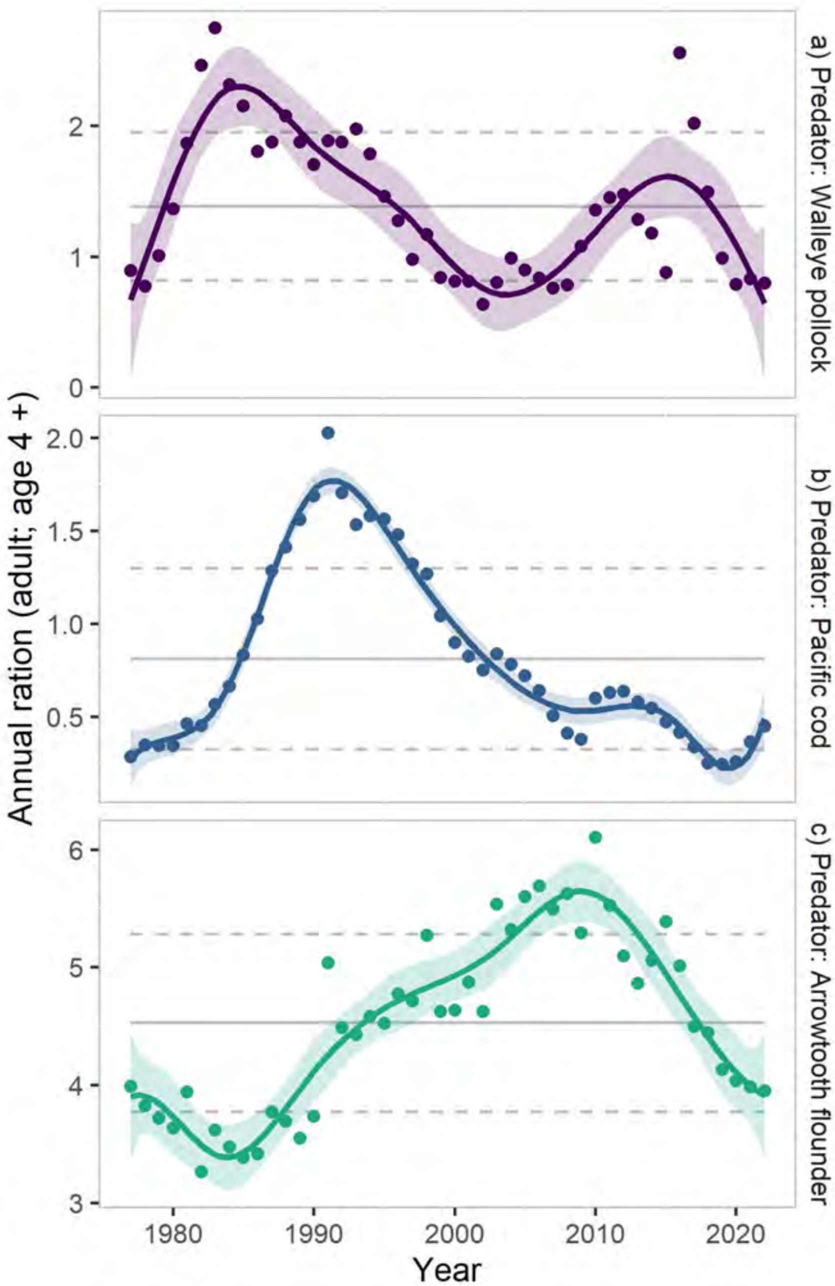

Figure 60: Multispecies estimates of annual ration (hundred thousand tons consumed per species per year) for adult (age 4 +) predators: a) walleye pollock, b) Pacific cod, and c) arrowtooth flounder. Gray lines indicate 1979–2022 mean estimates and 1 SD for each species; solid line is a 10 y (symmetric) loess polynomial smoother indicating trends in ration over time.

Benthic Communities and Non-target Fish Species

Miscellaneous Species—Gulf of Alaska Bottom Trawl Survey

NOAA Fisheries Gulf of Alaska Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Seabirds

Seabird Synthesis

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Last updated: October 2022

Summary Statement: Overall, the status of seabirds in the Gulf of Alaska in 2022 was above average (Figure 61). Across the GOA, all foraging guilds had above-average reproductive success in 2022, with the exception of planktivorous diving seabirds (parakeet auklets) in the western GOA. Piscivorous seabirds have still not returned to pre-marine heatwave densities in the middle and outer shelf domains of the central GOA, although some species are expanding their distribution in that direction. Colonies of piscivorous seabirds (surface and diving) had an early onset of breeding across the GOA, with the exception of parakeet auklets (Chowiet Isl., western GOA) and common murres (St. Lazaria Isl., eastern GOA), which had average timing. The reproductive successes and early phenology indicate that there was good availability of forage fish prey across the GOA, in alignment with other forage indicators (see Summary of Forage Conditions in this report, p.85), and good availability of zooplankton prey base in eastern GOA and the eastern edge of western GOA, in alignment with other positive trends in zooplankton indicators (Hopcroft in this report, p.70), Fergusson in this report, p.72). The below-average reproductive success of parakeet auklets on Chowiet Island (western GOA) is the exception to positive seabird trends in 2022, and may reflect local planktivorous foraging conditions around the island. There are no other zooplankton data available in 2022 in this region of western GOA to add context to this trend. There were no large-scale mortality events recorded via monthly beach surveys in the western GOA, but a small recurrence of localized botulism event that occurred on Middleton islands affected kittiwakes and gulls.

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 5 government,

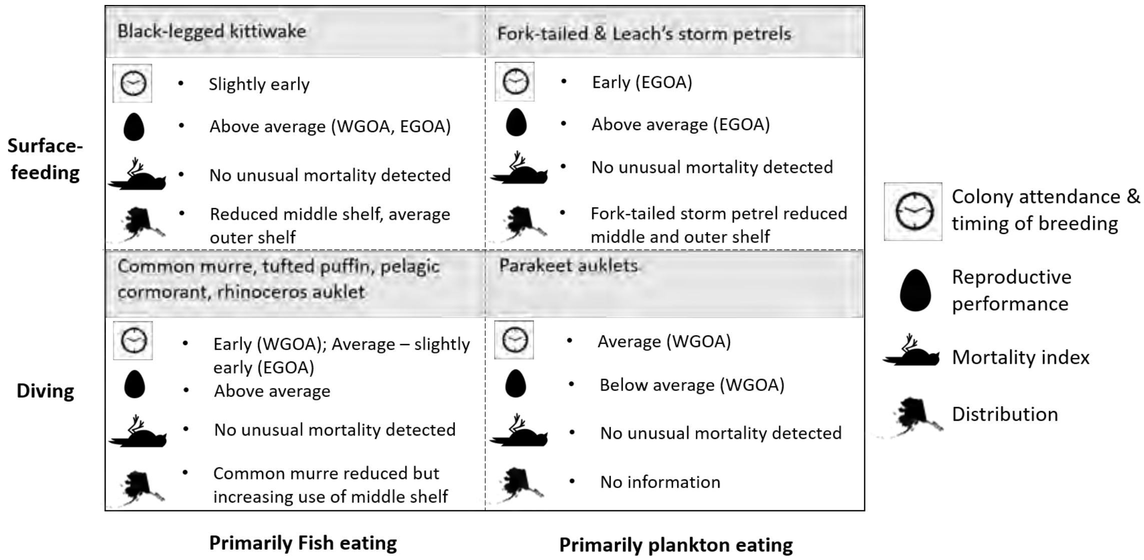

Figure 61: Summary of 2022 status for seabird feeding guilds (surface-feeding and diving, fish and plankton-eating) in the Gulf of Alaska.

university and non-profit partners, we provide a summary of the best available data on seabirds in the Gulf of Alaska in 2021. 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.
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.
3. **Mortality** which gives insight into environmental conditions and ecosystem impacts beyond breeding colonies and the breeding season. Unusual mortality events in the GOA 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:

Fish-eating, surface feeding seabirds: Fish-eating, surface feeding seabirds in the GOA 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, age-0 sablefish, capelin and herring), making them potential indicators of processes affecting juvenile groundfish that migrate to the surface to feed.

Breeding timing: *Breeding timing appeared slightly early 2022*. The timing of breeding by black-legged kittiwakes was three days early at Middleton Island (June 3) and four days early on Chowiet Island (time series begins in 1990), west of Kodiak. Birds that were part of an experimental, supplemental feeding program laid eggs, on average 3 days earlier (average = ±4 days, range = 0 to + 9). This result suggests that the early phenology seen in non-experimental birds was likely an indication of favorable foraging conditions during the pre-lay period (April through mid-May) in 2022, an improvement from 2021.

Reproductive success: *Reproductive success appeared above average in 2022*. All three glaucous-winged gull colonies had above-average years in the Gulf (Chowiet Isl., East Amatuli Isl., Saint Lazaria Isl.). Naturally foraging, unfed black-legged kittiwakes had above-average reproductive success in 2022 (baseline 1996–2021; Figure 63), despite warmer midsummer ocean conditions and continued low numbers of energy-rich capelin *Mallotus villosus*. Reproductive success of black-legged kittiwakes on Chowiet was the highest of the time series (baseline 1989–2021, Figure 62), reflective of good spring conditions for high egg lay rates and summer prey conditions for hatching success). This result in 2022 differed from the pattern in the previous 5 year (2016-2021) pattern, when there were high numbers of nests and high egg laying rates, but low hatching success and relatively high chick loss.

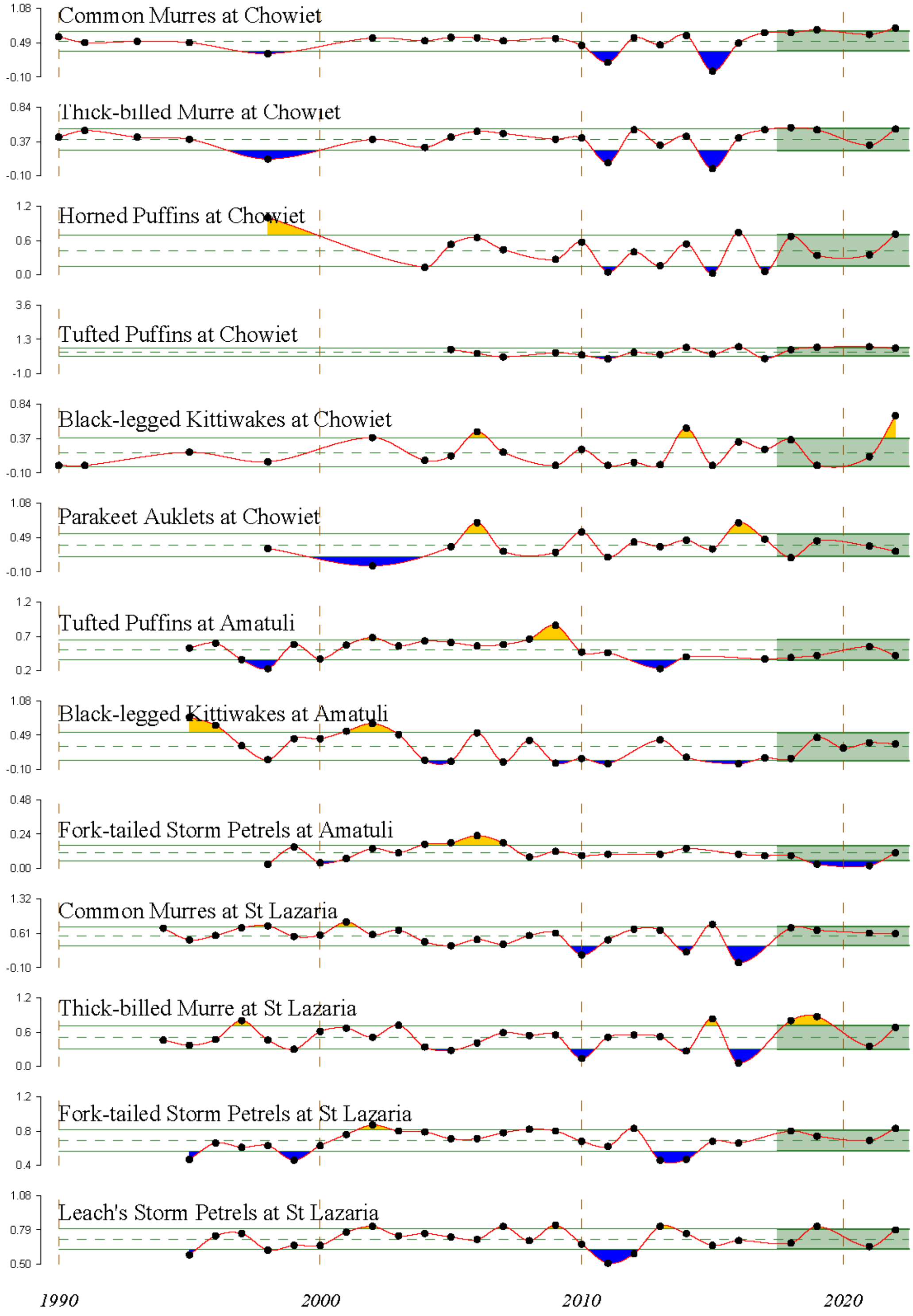

Figure 62: Reproductive success of piscivorous (common murre, thick-billed murre, horned puffin, tufted puffin, black-legged kittiwakes) and plantivorous (black-legged kittiwakes, parakeet auklets, fork-tailed storm petrels, Leach's storm petrel) GOA seabird species on Chowiet Island (western GOA), Amatuli Island (western GOA), and St. Lazaria Island (eastern GOA), as assessed by the Alaska Maritime National Wildlife Refuge. The dashed line is the long-term average and solid green lines are ± 1 SD. Yellow/blue shading indicates values greater than 1SD above/below the mean.Green shading highlights the previous 5 years. Data provided by the U.S. Fish and Wildlife Service, Alaska Maritime National Wildlife Refuge.

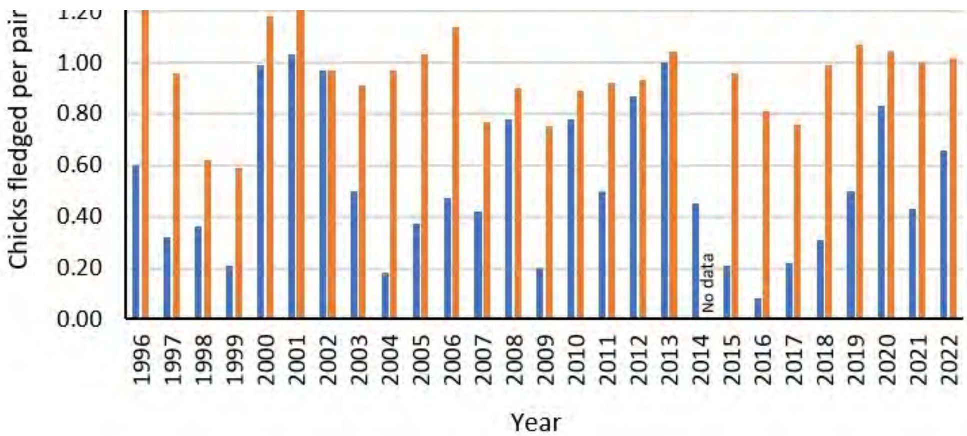

Figure 63: Annual reproductive output for black-legged kittiwakes on Middleton Island. Figure provided by the Institute for Seabird Research and Conservation.

Mortality: *Small recurrence of avian botulism type C Middleton Island in 2022.* Avian botulism type C is suspected to be the cause of a small mortality event of black legged kittiwakes and glaucouse winged gulls (17 birds as of Sept. 24) on Middleton Island from June 14 – July 17. Avian botulism type C is a pathogen often associated with a single, high-use fresh water source and low upland scavenging rates typical of islands (Work et al., 2010) and was the cause of a large mortality event on Middleton Island in 2021 (Schoen et al., 2021). Botulinum was detected in a pond on the Island in 2022, and a few black-legged kittiwakes and glaucous winged gulls are being analyzed for botulism type C as the cause of this mortality.

No large-scale mortality event of fish-eating surface-feeding birds was recorded in 2022 based on beach surveys (179 surveys on 34 beaches in 2022) in the western GOA (Figure 64). Methodology for beached bird surveys can be found in Jones et al. (2019). Like much of Alaska, beach surveys show a late summer, post-breeding mortality pattern, with 2013 reflecting an unusually good reproductive season in the Gulf (Figure 63, Figure 64). In 2011, a localized mortality event was observed in Prince William Sound (highlighted by red bars; Figure 4) associated with storm conditions, but recent years (2020–2022) have seen near baseline levels of recorded carcass abundance.

Distribution: *continued trends from post 2014–2016 marine heatwave years*. Black-legged kittiwake densities in early-May 2022 were below the 2007–2022 mean on the inner shelf and middle shelf, but close to the 2007–2022 mean on the outer shelf (Figure 65). This continues a pattern of decreased use of the middle shelf and outer shelf during and after the 2014–2016 marine heatwave compared to the preceding period 2007–2013 period during which cooler temperatures predominated.

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

Breeding timing: *In 2022, breeding timing was early (western GOA) and average to slightly early (eastern GOA).* Moving from west to east across the GOA, breeding timing of common murres and tufted puffins on Chowiet Island (southwest of Kodiak) were 8 days early and 6 days early, respectively (time series starts in 1990 or murres and 1998 for tufted puffins). Pelagic cormorants on Middleton

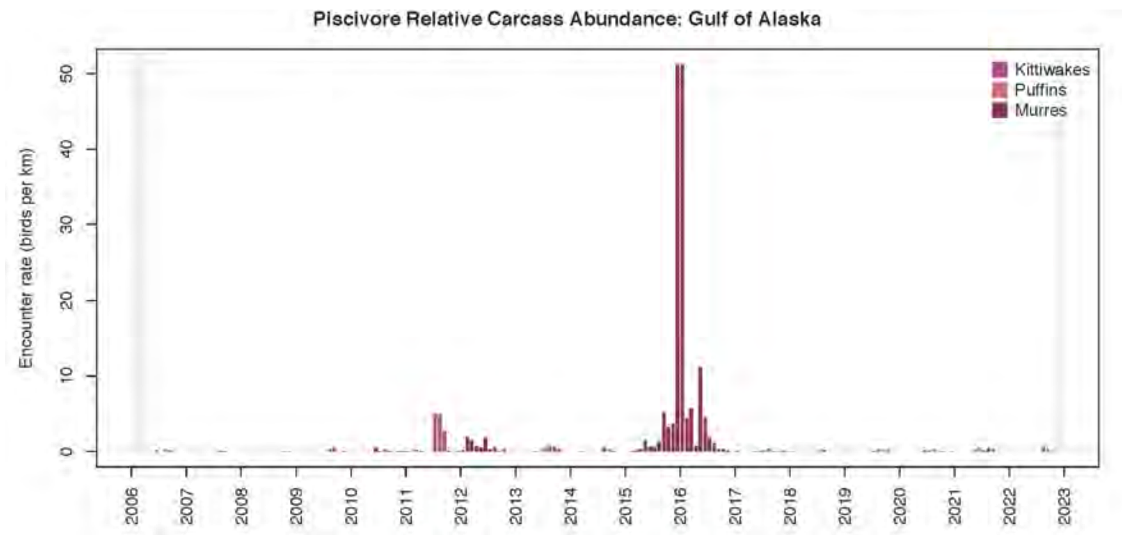

Figure 64: The number of fish-eating seabirds (kittiwakes, puffins, murres) encountered per km of beach surveyed by citizen scientists in the Gulf of Alaska. Data were insufficient to produce meaningful measures of long-term baseline variation. Data indicate regional trends, but are biased toward more 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 2022.

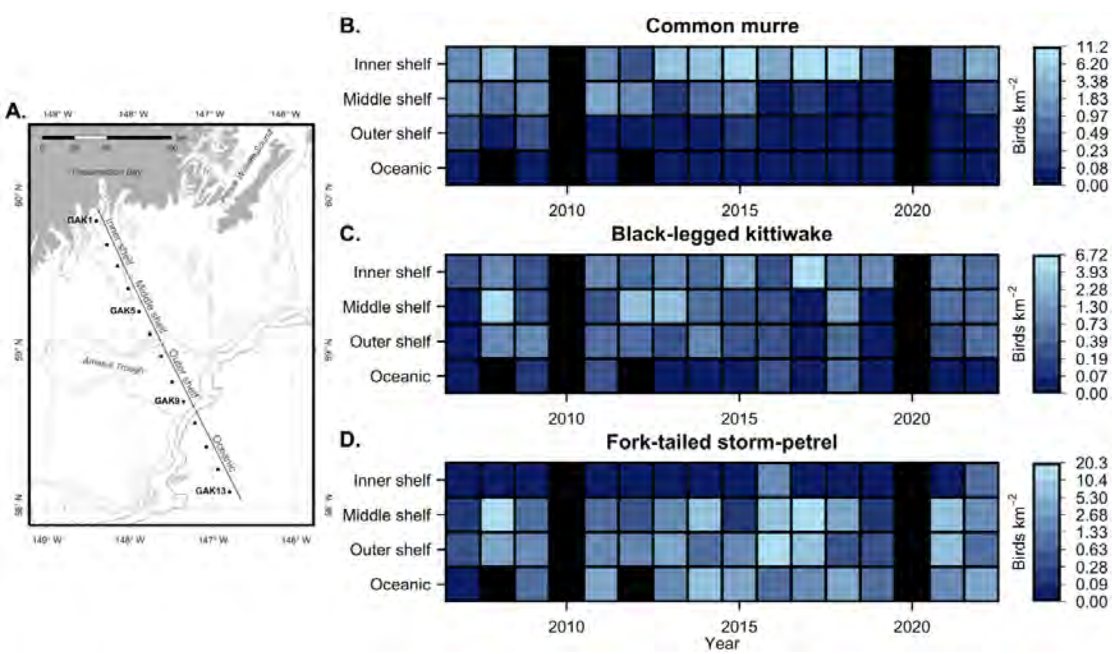

Figure 65: The spring Seward Line in the northern GOA, and four domains used for analysis (5a). Mean densities (birds km^{-2}) of major seabird taxonomic groups within domains during spring Seward Line cruises, 2007–2022 (5b-d). Black indicates no seabird surveys were conducted.Figure provided by Pole Star Ecological Research, and US Fish and Wildlife Service, Migratory Birds – Alaska.

Island (central GOA off Seward) were earlier than the long-term average (2002–2022), continuing a 10-year trend (no data in 2014) after progressive delays in breeding in 2002–2011 (Figure 66). Breeding timing of rhinoceros auklets and common murres on St. Lazaria Island (eastern GOA offshore of Sitka) were three days early and on the long-term average, respectively (time series starts in 1994).

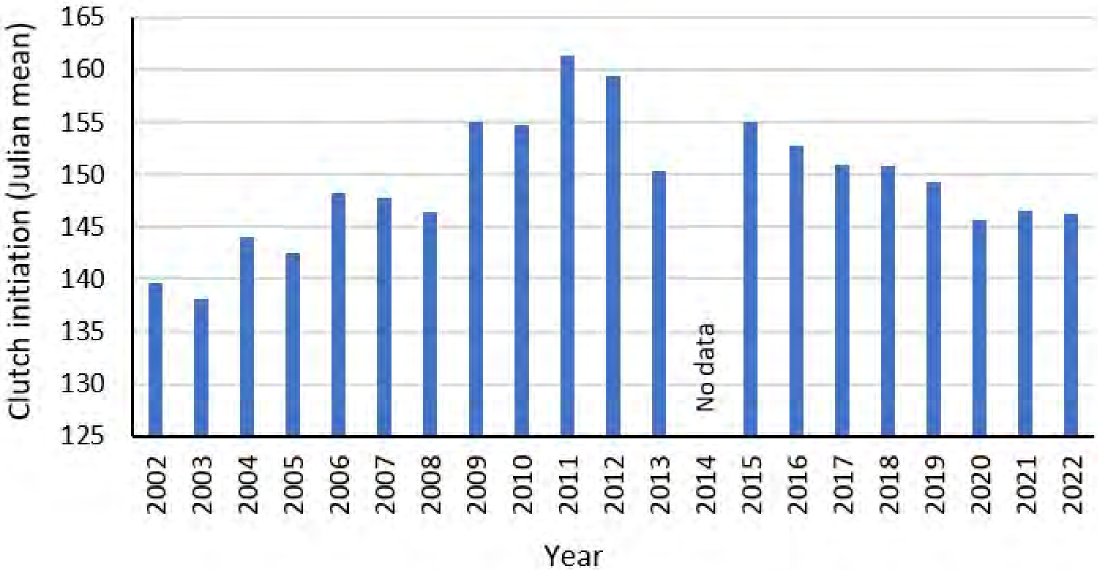

Figure 66: Breeding chronology of pelagic cormorants on Middleton Island (2002-2022). Figure provided by the Institute for Seabird Research and Conservation.

Reproductive success: Reproductive success was above average for fish-eating, diving seabirds in 2022. Pelagic cormorants breeding on Middleton Island continued a 3 year trend of elevated numbers of chicks fledged per laying pair (time series 2002–2022; Figure 67). Rhinoceros auklets also had above-average reproductive success on Middleton in 2022, but it was lower than in 2021 (time series 1997–2022; Figure 68). Common murres (St. Lazaria, Chowiet) and Tufted Puffins (Chowiet) continued 5–6 years of above-average success and thick-billed murres and horned puffins (both with smaller sample sizes) increased to above-average success in 2022 (baselines starting in 1998 on Chowiet Isl. (murres), 2005 on Chowiet Isl. (Tufted puffins), and 1994 on St. Lazaria Isl. (murres); Figure 62).

Mortality index: *No large-scale mortality event was recorded for fish-eating, diving seabirds* based on beach surveys in the Western GOA in 2022. This marks six years since the mass mortality event of common murres linked to the 2014–2016 marine heatwave (red bars - Figure 64).

Distribution:continued trends from post 2014–2016 marine heatwave years. Densities of common murres in early-May 2022 were below the 2007–2022 mean on the inner shelf and middle shelf, where they are historically most common during this time of year (Figure 65). This continued a trend of below-average use of the middle shelf following the 2004–2016 marine heatwave, when an influx of murres into coastal waters preceded an unprecedented mass-mortality event during the winter of 2015–2016. However, while below the long-term average, densities of murres were higher in 2022 than in 2019–2021, and murre densities on the middle shelf in 2022 were the highest observed since 2015.

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

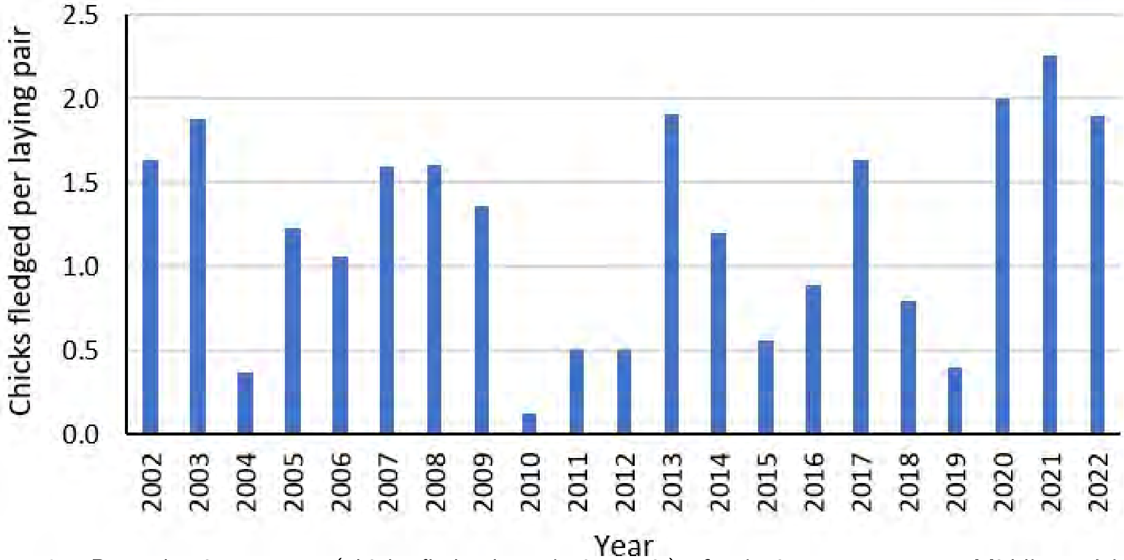

Figure 67: Reproductive success (chicks fledged per laying pair) of pelagic cormorants on Middleton Island (2002-2022). Figure provided by the Institute for Seabird Research and Conservation.

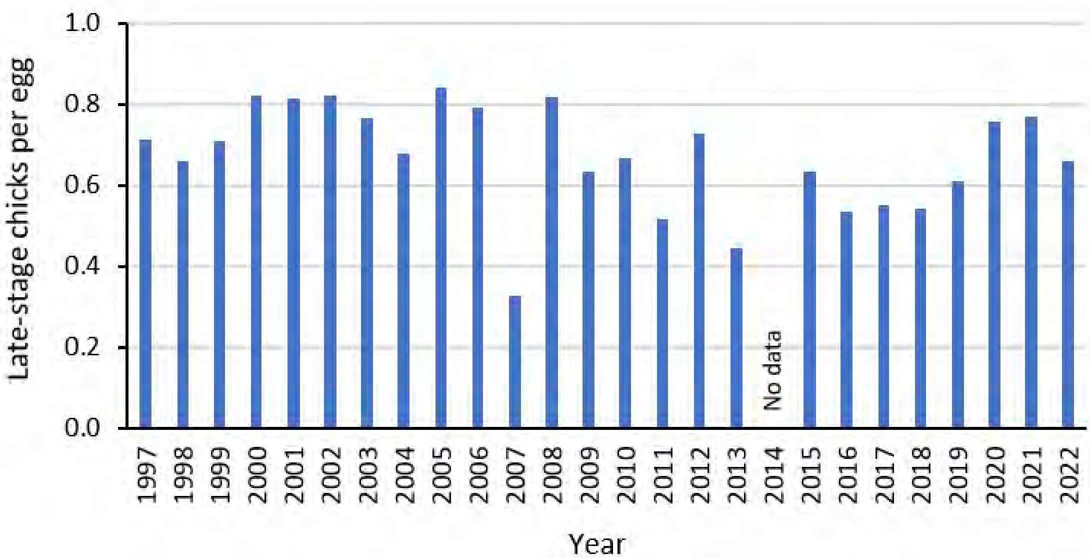

Figure 68: Reproductive success (late stage chicks per egg) of rhinoceros auklets breeding on Middleton Island (1997–2022). Figure provided by the Institute for Seabird Research and Conservation.

Breeding timing: *Breeding timing was average in western GOA and early in eastern GOA in 2022.* Parakeet auklets had average breeding timing on Chowiet Island (time series began in 1998), and fork-tailed and Leach's storm-petrels were 16 days and 3 days early on St. Lazaria Isl. (offshore of Sitka), respectively (time series began in 1995).

Reproductive success: *Reproductive success was average for plankton-eating seabirds in 2022.* Parakeet Auklets had below-average success on Chowiet Island, potentially reflective of local foraging conditions around the colony (Figure 62). Conversely in the eastern GOA, earlier breeding St. Lazaria fork-tailed and later breeding Leach's storm petrels had above-average reproductive success (1995–

2021) and above-average chick growths (increased from 2021 lowest in time series) reflecting consistent plankton prey availability (Figure 62). These values continue a 5 year trend of above-average reproductive success for fork-tailed petrels and show an increase from below-average 2021 values for Leach's storm petrels.

Mortality index: *No large-scale mortality event was recorded for plankton-eating seabirds based on beach surveys in the GOA in 2022* (Figure 69). The encounter rate of fork-tailed storm-petrels in the GOA was marginally higher than normal in 2021, but not indicative of a mortality event; Leach's storm-petrels are rare in this dataset. Similar to fork-tailed storm-petrels, encounter rates of crested auklets and other small alcids was also slightly elevated in 2021, but not indicative of a mortality event; no least auklets have been found in the GOA. In 2022, there was no indication of elevated mortality for either storm-petrels or small alcids.

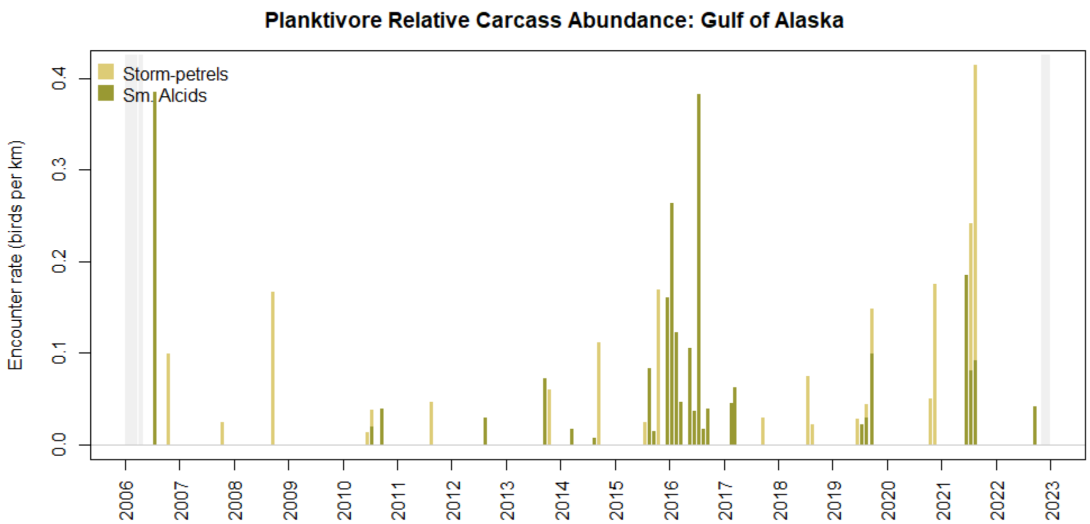

Figure 69: The number of dead storm-petrels (*Oceanodroma* spp.) and small alcids (*Aethia*, *Ptychoramphus*, *Synthliboramphus* spp.) encountered per km of beach surveyed by citizen scientists in the Gulf of Alaska. Data show regional trends, but are biased toward more accessible beaches in areas of higher human population density. Data were insufficient to produce meaningful measures of long-term baseline variation. Light gray shading indicates time-periods where surveys were not performed. Figure provided by the Coastal Observation and Seabird Survey Team (COASST).

Distribution: *Continued trends from post 2014–2016 marine heatwave years*. Densities of fork-tailed storm-petrels in early-May 2022 were below the 2007–2022 mean over the middle shelf and outer shelf, but near the 2007–2022 mean over the oceanic domain (Figure 65d). These results continue a trend of decreasing numbers over the middle and outer shelf regions after the heatwave, but contrasts with observations during the heatwave, when above-average densities of storm-petrels occurred in these habitats.

Factors influencing trends and implications for ecosystem productivity: The GOA shelf pelagic environment appears to have been relatively productive in 2022. A third continuous year of non-persistent marine heatwave conditions (but see eastern GOA fall temperatures in Ocean Synthesis in this report) and the cooler than average ocean temperatures in the winter and early spring appear to have supported productive lower trophic levels (zooplankton and forage fish) and seabird populations as a result. Strong breeding performances observed in geographically dispersed populations of many of the fish-eating seabird populations in geographically dispersed populations of Alaska (both surface-feeders and divers) reflect good availability of small schooling fish in the region. Diet contents of black-legged kittiwakes and rhinoceros auklet chicks on Middleton Island show the presence of sandlance, herring, hexagrammids, and a variety of other forage species (Hatch in this report, p.86), demonstrating a diverse forage base. Capelin remains reduced in their diets, a continued trend since the 2014–2016 marine heatwave. Herring population in southeast Alaska and Prince William Sound (Hebert in this report, p.91 and Pegau in this report, p.164) had continued elevated biomass in 2022, and abundance of calanoid copepods (Seward Line and southeast Alaska inside waters) and euphausiids (southeast Alaska inside waters) were average to above average (Hopcroft in this report,p.70 and Fergusson in this report, p.72). The GOA had below-average (winter and early spring) to above average (late spring, summer, fall) surface temperatures in 2022 (Ocean Temperature Synthesis in this report, p.36), but the warm summer did not appear to impact negatviely the foraging conditions and related reproductive success of these seabirds. Overall these data reflect above-average productivity at the lower trophic levels, relevant to juvenile and adult planktivorous and piscivorous groundfish found on the shelf.

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), 2007–2021, 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: October 2022

Description of indicator: 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 whales target the same lipid-rich prey (i.e., forage fish and euphausiids). From 1985–2022, biologists in Glacier Bay National Park and Preserve used consistent methods and levels of effort annually from June 1 – August 31 to document individually-identified humpback whales and their reproductive parameters in Glacier Bay and Icy Strait (Gabriele et al., 2017). Consistent methods and a high level of annual effort make this one of the world's most complete long-term datasets on a baleen whale population.

We photographically identified whales by matching the markings on the ventral tail flukes and dorsal fin of each whale to curated catalogs of identification photos. From these data we document 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); 4) within-season calf survival; 5) return rate of calves in subsequent years as juveniles and adults; and 6) indicators of health/body condition for mothers and calves. Throughout the study, we have maintained a shared Southeast Alaska fluke catalog and database with our collaborator Jan Straley (University of Alaska Southeast) so that we can track individual life histories throughout Southeast Alaska. In 2019, we joined the North Pacific Humpback Whale Collaboration, which uses an automated fluke-matching system known as HappyWhale.com and a large collection of fluke photographs taken by citizen science and research groups throughout the North Pacific. These data sources augment our knowledge of the movements, survival, and reproductive status of individual whales outside of our study area in Glacier Bay and Icy Strait. Individual sightings from other researchers are reported with their permission.

Status and trends: Humpback whale calf production in 2022, in Glacier Bay and Icy Strait, declined compared to 2021 and 2020, with only six cow/calf pairs in June–August 2022 (Table 1, Figure 70). The CBR in 2022 (3.6%) is far below the mean CBR prior to the 2014–2016 marine heat wave (9.3%; Table 1, Figure 70). Furthermore, none of the CBRs since 2019 (range 1.4%–7.4%) have reached the pre-2014 mean (9.3%) (time series starting in 1985). Although calf production increased in 2020 and 2021, the mean CBR in 2019–2022 (5.8%) remains lower than the mean CBR before 2014 (9.3%).

After a pulse of apparent mid-summer calf mortalities during and after the 2014–2016 heatwave period, we detected none in 2022. All of the 2022 calves were with their mothers on our final observations of the cow/calf pairs for the season.

Juvenile survival (i.e., resightings of juveniles) is increasing after an abrupt decline during and after the 2014–2016 marine heatwave. While none of the Glacier Bay/Icy Strait calves born from 2014–2018 have been documented as juveniles in Southeast Alaska or elsewhere (Table 1), several calves born since

Table 1: Humpback whale calf production and survival observations in Glacier Bay and 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 2022. *Not all calves show their flukes so they are much harder to re-identify in future years. Crude birth rate is calculated by dividing the number of calves by the total number of whales. **The median age at which juveniles tend to return to the study area is 3 years (Gabriele et al., 2017)

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 9.3 (range 2–21)	191 (range 3.3–18.2)	mean 9.3	8 (4%)	124 (65%)
2014	14*	5	8	5 (36%)	0
2015	5*	1	3	0	0
2016	0*	0	0.6	0	0
2017	2*	1	1.6	1 (50%)	0
2018	1*	0	1.0	1 (100%)	0
2019	2	1	1.3	0	0
2020	12	12	7.4	0	1(100%)
2021	11	8	6.6	1(9%)	3(35%)
2022	6		6.6	1(9%)	2(25%)

then have been re-sighted. Yearling #2695 (calf of #1832) returned to the study area in 2022. Citizen science data in Happywhale revealed that yearling #2696 (calf of #1846) was sighted in July 2022 by San Juan Excursions whale-watch in Washington State. Happywhale also allowed us to identify an unfamiliar small whale that we learned was a calf in British Columbia in 2021 (BCZ0421 calf 2021, nicknamed Harry Potter; Marine Education and Research Society, unpublished data). Two-year-olds #2659 and #2689 were sighted in 2021 but not in 2022. Two-year-old #2665 (calf of #2169) was sighted near Victoria, British Columbia by Prince of Whales Whale Watching in September 2022. Three-year-old (#2652, calf of #219) was sighted for the third year in a row. We documented a few small or medium-sized whales that may be juveniles, but we could not confirm their age.

Preliminary results show that at least three of the six mothers in 2022 were in sub-optimal body condition based on physical indicators such as visible scapulae, an overall "angular" appearance, the presence of a post-cranial depression, or rough skin. Female #250 and her calf both appeared to be in poor body condition in late June (Figure 71). Females #1480 (on July 8) and #1906 (on August 1) also appeared to be skinny, however they were not as severely emaciated as #250. The other five calves in 2022 appeared to be in relatively good physical condition.

Factors influencing observed trends: Humpback whale productivity and juvenile survival in Glacier Bay and Icy Strait declined sharply beginning in 2014 (Neilson et al., 2017; Gabriele and Nielson, 2018, 2019; Gabriele et al., 2022) after many years of steady reproductive success (Gabriele et al., 2017), likely due to ecological disruptions brought on by warm ocean conditions including the 2014–2016 marine heatwave (Piatt et al., 2020; Arimitsu et al., 2021; Suryan et al., 2021).

Humpback whales in southeastern Alaska are in the process of recovering from a major ecological disruption. After many years of population growth and steady reproductive success (Gabriele et al., 2017), humpback whale abundance, productivity, and juvenile survival in Glacier Bay and Icy Strait declined sharply in 2014, following the onset of the 2014–2016 marine heatwave (Gabriele et al., 2022).

Recent studies suggest that the root cause behind reduced whale abundance, survival and reproduction during and after the marine heatwave period was a decline in the quantity and quality of forage fish and

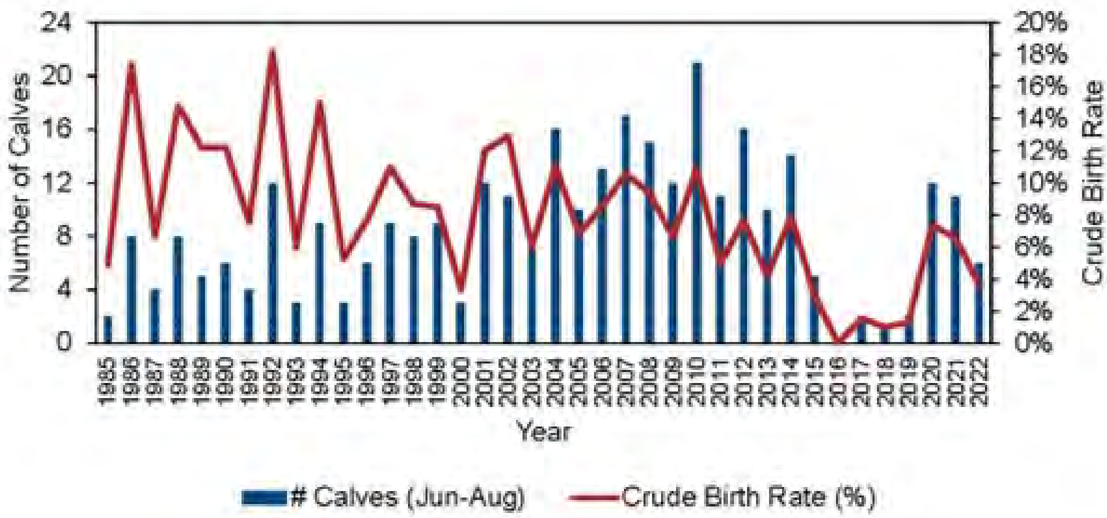

Figure 70: Annual number of calves (blue bars) and crude birth rate (CBR, red line) in Glacier Bay-Icy Strait, 1985–2022. CBR is calculated by dividing the number of calves by the total number of whales identified in June-August each year. The preliminary CBR for 2022 is 3.6% based on a preliminary whale count of 166 individually identified whales for June-August.

Figure 71: Health assessment photographs of mother #250 (A) and her calf (B) on June 23, 2022, showing an overall angular appearance, a lack of fat behind the blowholes, and moderate whale lice infestations, all of which characterize poor body condition. This female and calf were documented in Glacier Bay through early August.

zooplankton prey available (Von Biela et al., 2019; Piatt et al., 2020; Arimitsu et al., 2021; Suryan et al., 2021). Based on Glacier Bay/Icy Strait data from 1985–2020, we determined that the heatwave had profound population-level effects on humpback whales in southeastern Alaska and that the effects on the whales lasted years longer than the heatwave itself (Gabriele et al., 2022). Notably, we documented: 1) Whale abundance declined by 56% between 2013 and 2018, followed by increases in 2019–2020; 2)

Calf survival dropped by a factor of ten (from 39% to 3%) during and after the PMH; 3) Far fewer calves were born during and after the heatwave, but in 2020 and 2021 calf production (Table 1) and juvenile return rates trended toward more typical pre-2014 levels.

The 2022 crude birth rate (3.6%) is lower than the long-term mean CBR prior to 2014 (9.3%; Table 1, Figure 70), suggesting that prey availability and/or quality for humpback whales in 2020 and/or 2021 may have been insufficient to support typical rates of conception and/or full-term pregnancy. Other potential reasons for the decline that would not be detectable with our methods include diseases, toxins affecting mothers or calves, and/or an increase in neonatal mortality before or during the migration to Alaska.

The relatively low number of calves in 2022 was not due to the absence of adult females in the study area. In 2022, we documented at least 39 adult females in the study area (6 mothers, 33 non-mothers) along with 37 adult males, resulting in a fairly typical female to male ratio (0.51) for this population (compare to Fig A4 in Gabriele et al., 2022).

The CBRs in 2020 and 2021 were not exceptionally high, thus the low CBR in 2022 does not appear to be a consequence of increased reproduction in recent years. Rather, our observations indicate that some adult females may be calving less often since the PMH. Seventeen of this year's non-mothers (52%) were sighted with a calf in the past three years (2019, 2020 or 2021), within the typical 2–3 year calving interval for this population (Baker et al., 1987; Gabriele et al., 2017). The calving histories of several non-mothers are obscure because they have incomplete sighting histories during and after the marine heatwave. However, two non-mothers (#1088 and #1486) have not been documented with a calf since 2013 and 2014, respectively, although we have sighted them every year since. Similarly, female #1246 was last documented with a calf in 2014, although she was not sighted in 2016–2018 and may have been one of the few females to have a calf at that point during 2014–2016 (Table 1, Figure 70). These females, and possibly others, may be having a calf less often in response to physiological stress (Kraus et al., 2007; Kershaw et al., 2021) or they may have given birth to one or more calves since 2013 that died prior to reaching Alaska.

An additional factor in the low 2022 CBR could be the absence of females born in 2011–2016 that died as juveniles during the PMH (Figure 4 in Gabriele et al., 2022) who would have been having their first calves around age 10–12 (Gabriele et al., 2017). In fact, all six mothers in 2022 have previously had a calf and range in age from 21 to 45+ years old.

The upward trend in juvenile return seems to indicate that calves born in 2019 or later are surviving at a higher rate than was true in 2014–2018 (Gabriele et al., 2022). The North Pacific Humpback Whale Collaboration, using Happywhale automated fluke matching, contributes enormously to our ability to track juvenile survival beyond our study area.

The poor condition of #250 and her calf may be related to the mother's age, insufficient prey resources, and/or unidentified factors such as disease or injury. Mother #250 was first sighted in 1978 (Kewalo Basin Marine Mammal Laboratory, unpublished data), making her minimum age 45 years and her minimum reproductive span 27 years (first documented with a calf in 1996, Gabriele et al., 2017). She had been noted as skinny in 2016 and 2017. She was most recently identified with a calf in 2014, but she was not sighted in 2018 so her history is incomplete. Mother #219 is of similar minimum age (first sighted in 1982, first documented with a calf in 1988) but appeared to be in good body condition in 2022. Notably, whale #219's 35-year reproductive span now surpasses any previously documented for a female humpback whale in southeastern Alaska (Gabriele et al., 2017).

Implications: Humpback whales in southeastern Alaska are in the process of recovering from a major ecological disruption. We noted indirect indicators of favorable foraging conditions, including 2020–2022 visual observations of plentiful forage fish, particularly sand lance (*Ammodytes personatus*) in 2022, and the presence of pairs, trios and larger groups of whales that were conspicuously absent in 2014–2018. The observed variability in humpback whale productivity and apparent feeding conditions may indicate that groundfish also experienced variable prey availability and/or quality.

Marine Mammal Strandings in the Gulf of Alaska

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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.

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 (Figure 72). 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 a vessel strike. These responses are conducted under the Marine Mammal Protection Act authorization either under a 112c 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 fall under the Marine Mammal Health and Stranding Program Permit #18786.

Status and trends: The number of confirmed strandings in Alaska has increased over time (time series starting in 2016). As of August 31, 2022, 190 confirmed stranded marine mammals have been reported for the year within Alaska; 99 occurred in the GOA (Table 2). The majority of reports were from populated areas where AMMSN members and NMFS Office of Law Enforcement members are located. Further, increased outreach and dedicated surveys (e.g., Cook Inlet and Kodiak Island) associated with high priority species or events (e.g., Cook Inlet beluga, 2019 gray whale Unusual Mortality Event) also contributed to reported strandings in some area and years. Reported strandings in the GOA since 2017 varied between years without an overall pattern or consistent increase in reports (Table 2). The 2022 stranding data include confirmed strandings reported between January 1, 2022 and August 31, 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 a large influence on variability between years in this area (Table 2). 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 include changing populations of some species and increased public awareness through outreach such as

Figure 72: Examples of stranded marine mammals within the Gulf of Alaska Region in 2022. A. 2022070, *Eschrichtius robustus* B. 2022148, *Phoca vitulina*; C. 2022033, *Megaptera novaeangliae*; D 2022027, alive *Mirounga angustirostris*; E. 2022032, *Eumetopias jubatus*; F. 2022146, alive, entangled *Eumetopias jubatus*.

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 such as increased whale entanglements in fishing gear. An additional change this year was the use of the revised Examiners

Guide[14] which requires completion of level A and human interaction forms for entangled large whales that are free-swimming and a response deemed necessary (whether or not a response is conducted). Under previous examiner guides, national stranding forms were completed for entangled whales only if a response was conducted. The evaluation of reports of entangled, free-swimming large whales has not been completed and therefore no entangled, live whale reports are included in this summary.

Implications: Across Alaska, reported marine mammal strandings have varied by year and location. In 2019, the increase in gray whale strandings along the migration route between Mexico and Alaska led to the declaration of an UME which may signal changes in the environment. In 2022, three northern elephant seal yearlings stranded in Alaska, two of which required relocation to more remote beach. The third seal died (Figure 72). An additional two northern elephant seals were reported hauled out and molting in Alaska but did not require a response. It is important to track and have a sense of the regular number of strandings in an area to provide a context to mass strandings or UMEs. Marine mammal stranding data can be paired with other datasets and may give clues to ecosystem-wide changes.

[14] https://media.fisheries.noaa.gov/2021-07/EXAMINERS%20GUIDE_2024%20FINAL.pdf?

Table 2: Reported stranded NMFS marine mammal species from 2016-2022 in the Gulf of Alaska by species and year.* 2022 stranding data includes confirmed strandings reported between January 1, 2022 and August 31, 2022.

Species	2016	2017	2018	2019	2020	2021	2022*
Blue whale	-	-	-	1	-	-	
Cook Inlet beluga	8	13	7	13	13	10	3
Dall's porpoise	3	3	2	1	2	-	1
False killer whale	-	-	1	-	-	1	-
Fin whale	2	1	1	-	2	2	-
Gray whale	6	4	4	22	26	14	10
Harbor porpoise	12	6	5	5	4	5	5
Humpback whale	14	13	9	14	22	4	-
Killer whale	3	1	-	-	3	4	1
Sperm whale	1	2	2	1	-	1	-
Cuvier's beaked whale	-	-	-	-	2	-	-
Unidentified beaked whale	-	-	-	-	1	1	2
Minke whale	-	-	1	-	-	1	1
Pacific white-sided dolphin	-	-	-	-	-	2	-
Unidentified whale	4	8	5	-	11	-	3
Unidentified cetacean	6	2	2	13	2	1	2
Total cetaceans	70	54	43	65	80	63	45
California sea lion	1	-	1	-	-	-	-
Harbor seal	25	31	27	28	23	28	22
Northern fur seal	-	-	-	-	1	3	-
Northern elephant seal	-	-	-	-	-	-	3
Steller sea lion	35	30	28	46	35	26	29
Unidentified pinniped	1	1	2	2	-	2	-
Unidentified marine mammal	-	-	1	1	-	-	-
Total pinnipeds	63	62	59	77	58	59	54
Total Cetaceans and Pinnipeds	113	116	102	142	139	122	99

Steller Sea Lions in the Gulf of Alaska

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Last updated: September 2022

Description of indicator: As a large apex, piscivorous predator that ranges across a broad geographic range, the Steller sea lion serves as an indicator species. Depending on the area, a large portion of the Steller sea lion diet is typically one comprised of one or more of these three commercially fished groundfish species: Atka mackerel, Pacific cod, and walleye pollock (Sinclair et al., 2013).

During the non-breeding season, sea lions disperse and can move widely throughout the North Pacific Ocean, especially juveniles and males. During the summer breeding season, sea lions aggregate on land, usually at their natal rookery site, to breed and birth pups. The Marine Mammal lab (MML) conducts annual population surveys during the peak of the breeding season to collect counts throughout the Steller sea lion's range in Alaska (Muto et al., 2021) 73. Challenging survey conditions usually mean there are data gaps for sites that cannot be surveyed. MML uses the R package, agTrend (Johnson and Fritz, 2014; Gaos et al., 2021) to interpolate counts for the missed sites and to estimate modeled counts (an index of population abundance) and trends for defined geographic areas.

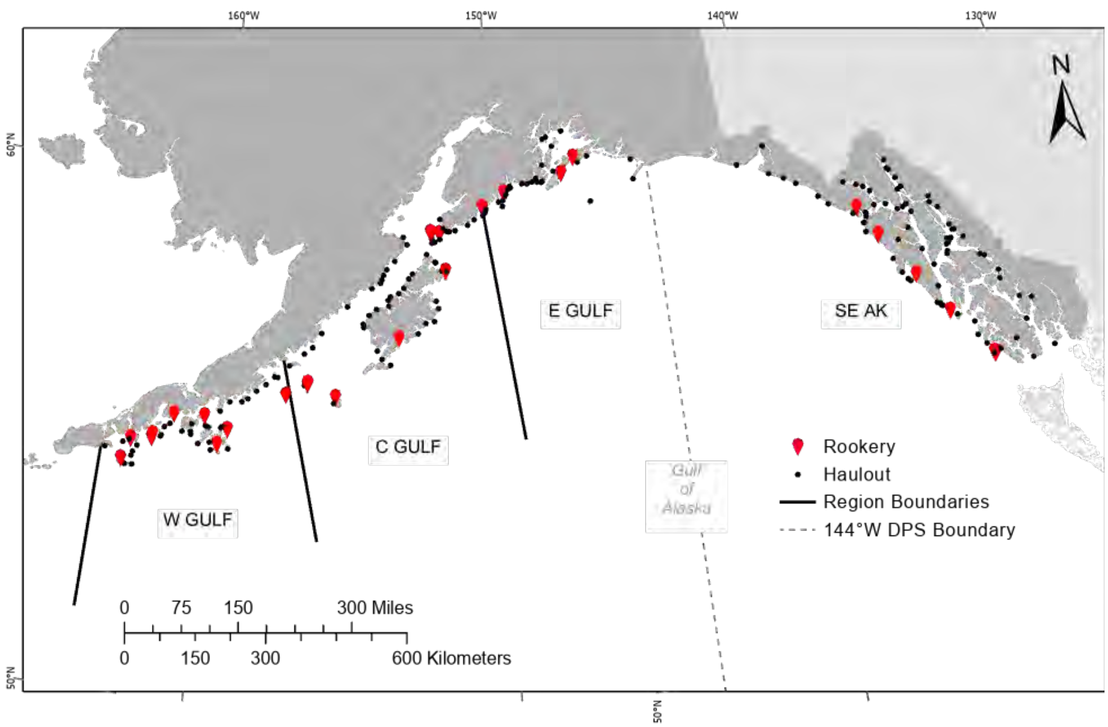


Figure 73: Steller sea lion regions in the GOA.

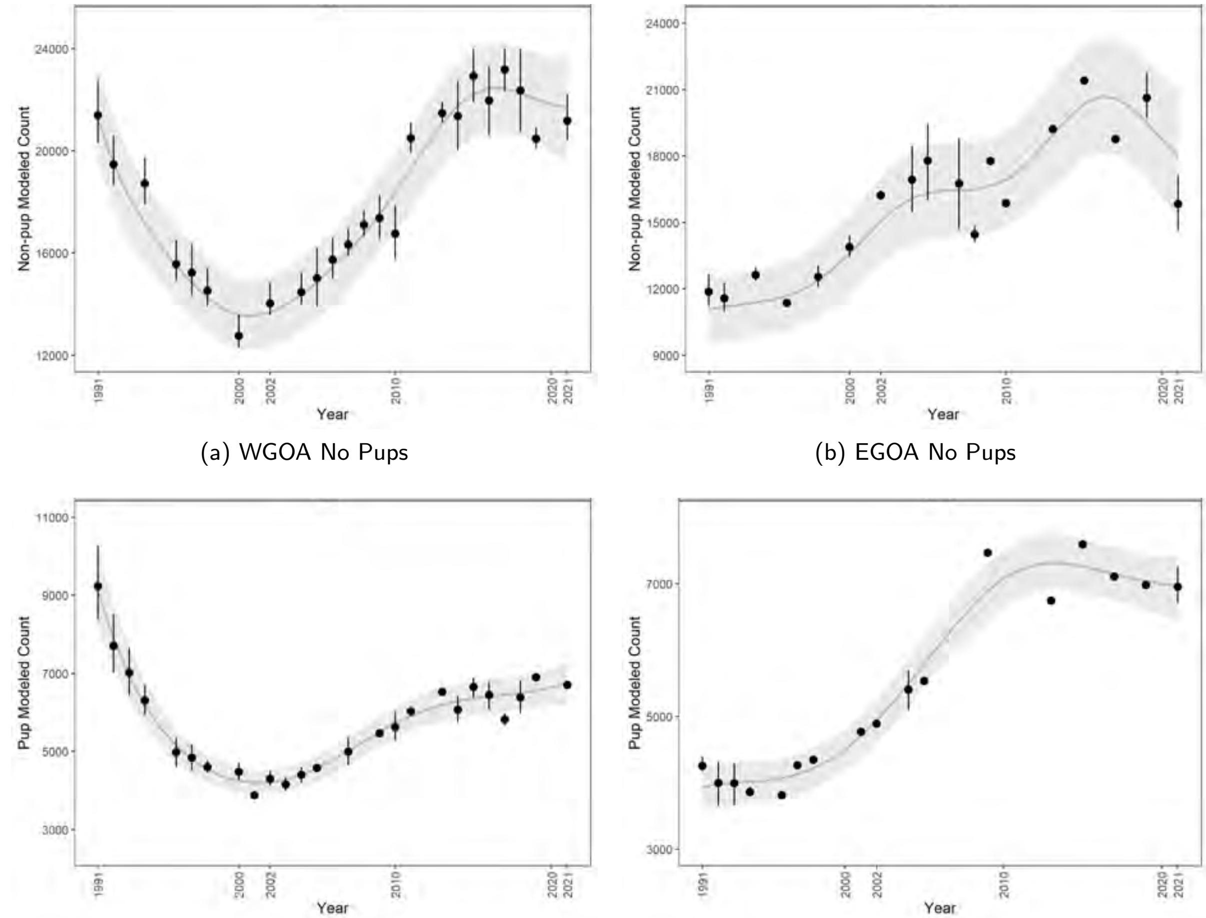
In Alaska, Steller sea lions range throughout the southern coastline from southeast Alaska to the western Aleutian Island chain. The species is divided into two populations at the 144ºW longitudinal line (near Cape Suckling): the eastern and the western Distinct Population Segments (DPSs). The GOA geographic area is comprised of four Steller sea lion regions: eastern, central and western GOA regions (western DPS), and southeast Alaska region (eastern DPS) 73. The range of eastern DPS Steller sea lions extends from southeast Alaska and down along the west coast of Canada and the U. S. (Muto et al., 2021).

A note about agTrend & SSL outputs— The MML does not report abundance estimates but rather agTrend derived modeled counts (an index of population abundance) and trends. The model outputs do not account for animals at sea during the survey. The Steller sea lion agTrend model was updated (Gaos et al., 2021) to increase precision and the data outputs shared in this report (note: the 2021 aerial survey memo to the record reports agTrend counts from the original model). Modeled counts are used to represent the minimum population estimate (Nmin) (Muto et al., 2021). As pups do not take to the water until they are older ($\sim$ 1 month), pup counts are considered a census, but the pup counts do not account for pups born before the survey or that died after. Two types of count estimates are generated with agTrend:

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

Status and trends: In the western DPS in Alaska between 2006 and 2021, non-pup (adults and juveniles) and pup counts increased 1.68% y^{-1} (95% CI 0.99-2.4% y^{-1}) and 1.00% y^{-1} (95% CI 0.45-1.57% y^{-1}), respectively (Figure 74). For the same period, the combined eastern, central, and western GOA regions' non-pup and pup sea lion counts increased 2.48 and 2.14% y^{-1}, respectively. Between 1991–2021, non-pup and pup counts in southeast Alaska (eDPS) increased 2.12 and 2.69% y^{-1}, respectively. Non-pup and pup counts in this region appear to have been plateauing since 2013 (non-pup counts oscillating $\pm$10% around 80,000 sea lions), but non-pups declined 23% in 2021 (from 2019).

Declines in Steller sea lion populations were first observed in the 1970s, with the steepest declines occurring in the mid-1980s. The western DPS as a whole began to rebound in 2002. However, regional trends tell a different story in the Aleutian Islands and since 2017, in the GOA. Beginning in 2017, MML began to observe anomalous declines in pup and non-pup counts in the GOA regions likely largely associated with the warming events in the GOA.



(a) WGOA No Pups

(b) EGOA No Pups

(c) WGOA Pups

(d) EGOA Pups

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

MML began to observe anomalous counts in the upward trend of GOA regions in the wDPS in 2017, likely due to the GOA warming events which began in 2014. The eastern GOA non-pup realized count declined ∼1,000 sea lions with an increase in the central GOA, since the 2015 survey (combined region counts remained stable between 2015 and 2017). This indicated atypical movement west to the central GOA of mostly adult females and juveniles (and likely not into the western GOA). Despite this movement of adult females (and stability in non-pup counts), pup counts declined 33 and 17% in the eastern and central GOA (respectively). In 2019, the counts in the western GOA didn't appear to be impacted except for a slight increase in 2019. Pup counts in the eastern and central GOA regions rebounded to around 2015 levels, while non-pups have declined 19% since 2017. Non-pups in the combined eastern and central GOA regions increased approximately 11% in these regions in 2021. Overall, counts in the wDPS GOA appear to be plateauing and counts have not been this low since 2011.

Factors influencing observed trends: MML has observed anomalous changes in in non-pup and pup counts since 2017, following the first significant warming event in the GOA from 2014–2016. Steller sea lions are a long-lived species. Therefore, it is expected that evidence of impacts from an event or stressor will be delayed. Studies have shown that the anomalous warming in the GOA has resulted in a cascade of negative impacts upon many species and trophic levels, including species that compose Steller sea lion diets.

Low pup counts could indicate reduced fecundity in adult females (not breeding/pupping, or aborted pups, or pups died after birth) and/or reduced survival. Pup declines will typically cause lower juvenile recruitment in the following years; however, non-pup declines in survey years following pup declines appeared to be at a higher magnitude than can be explained by declines in pups, which could mean juvenile survival could have also been impacted. From count data, there appeared to be evidence of movement of adult females and juveniles from the eastern to the central GOA regions in 2017, though this was not as apparent in other years (with any age/sex class or region). Movement could be a factor that is also impacting counts, though to show this would require brand sighting data; however, re-sighting effort has been low in the GOA in recent years.

Implications: The wDPS GOA regions began to show signs of recovery since the early 2000s, and southeast Alaska (eDPS) was removed from the threatened listing under the Endangered Species Act in 2013, after 30 years of recovery. The eastern and central GOA regions (since 2017) and southeast Alaska (since 2019) have experienced anomalous declines in pups and non-pups, likely impacted by the anomalous warming in the GOA.

The recent decline in pup counts and stabilizing of non-pup counts indicate that this protected species is still susceptible to threats and the trends towards recovery seem to have slowed or plateaued. The GOA is host to walleye pollock and Pacific cod groundfish fisheries. Previous work using the frequency of occurrence (FO) from hard parts in sea lion stomachs indicated that Steller sea lions in the GOA largely rely on these species, especially in the winter (Sinclair et al., 2013). Between 1999 and 2009 in the western GOA region, Steller sea lions consumed predominantly walleye pollock and Pacific cod during the summer (34.3–64.2% and 2.9–37.7% FO, respectively) and winter (46.4–90.0% and 45.9–57.5% FO, respectively) (Sinclair et al., 2013). Samples from the eastern GOA region (scat collected between 1997–1999), indicated that sea lions consumed predominantly walleye pollock (56.4–96.5% FO) (Trites et al., 2007). Thus, along with the anomalous warming events, GOA groundfish fisheries have the potential to influence the ability of SSL to obtain prey. It's important to understand that diet analysis from hard parts in scat can underrepresent the importance (quantity and size) of certain prey species, and further research using DNA techniques in scat analysis is needed to improve the understanding of diet in this region. This would require having resight and scat collection efforts in the GOA in both the summer and winter.

Ecosystem or Community Indicators

Foraging Guild Biomass—Gulf of Alaska

NOAA Fisheries Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Stability of Groundfish Biomass in the Gulf of Alaska

NOAA Fisheries Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Mean Length of the Fish Community in the Gulf of Alaska

NOAA Fisheries Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Mean Lifespan of the Fish Community in the Gulf of Alaska

NOAA Fisheries Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys in the Gulf of Alaska, 1993–2021

NOAA Fisheries Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Species Richness and Diversity of the Gulf of Alaska Groundfish Community

NOAA Fisheries Bottom Trawl Surveys are conducted every other year. Please refer to the archives for past reports.

Disease & Toxins Indicators

Harmful Algal Blooms in the Gulf of Alaska

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[13] Knik Tribe of Alaska, Palmer, AK
[14] Norton Sound Health Corporation, Nome, AK
[15] USGS Alaska Science Center, Anchorage, AK
[16] NOAA NOS Beaufort Lab,Beaufort, NC
[17] AK Sea Grant, Kodiak, AK
[18] Aleut Community of St. Paul, St. Paul Island, AK
[19] Little Diomede, AK
[20] AK Department of Health and Social Services, Anchorage, AK

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Last updated: September 2022
Sampling Partners:

Alaska Ocean Observing System
Alaska Sea Grant
Alaska Veterinary Pathologists
Aleut Community of St. Paul Aleutian Pribilof Island Association
Central Council of Tlingit and Haida*
Chilkoot Indian Association*
Craig Tribal Association*
Hoonah Indian Association*
Hydaburg Cooperative Association*
Kachemak Bay NERR
Ketchikan Indian Association*
Klawock Cooperative Association*
Knik Tribe of Alaska
Kodiak Area Native Association
Metlakatla Indian Community*
NOAA Kasitsna Bay Lab
NOAA WRRN-West

North Slope Borough
Norton Sound Health Corporation
Organized Village of Kake*
Organized Village of Kasaan*
Petersburg Indian Association*
Qawalangin Tribe of Unalaska
Sitka Tribe of Alaska*
Skagway Traditional Council*
Southeast Alaska Tribal Ocean Research
Sun'aq Tribe of Kodiak*
University of Alaska Fairbanks
USGS Alaska Science Center
Woods Hole Oceanographic Institution
Wrangell Cooperative Association*
Yakutat Tlingit Tribe*

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

Description of indicator: Alaska's most well-known and toxic harmful algal blooms (HABs) are caused by *Alexandrium* spp. and *Pseudo-nitzschia* spp. *Alexandrium* produces saxitoxin (STX) 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.

Pseudo-nitzschia produces domoic acid which can cause amnesic shellfish poisoning and inflict permanent brain damage. Domoic acid (DA) 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.

The State of Alaska tests all commercial shellfish harvest. However, there is no state-run shellfish testing program for recreational and subsistence shellfish harvest. Regional programs, run by Tribal, agency, and university entities, have expanded over the past five years to provide test results to inform harvesters and researchers, and to reduce human health risk (Figure 75). All of these entities are partners in the Alaska Harmful Algal Bloom Network which was formed in 2017 to provide a statewide approach to HAB awareness, research, monitoring, and response in Alaska. More information on methods can be found on the Alaska HAB Network website[15] or through the sampling partners listed above.

Status and trends:

Alaska Region: Results from shellfish and phytoplankton monitoring showed an overall lower presence of harmful algal blooms (HABs) throughout all regions of Alaska in 2022 compared to 2021, 2020 and 2019. However, bivalve shellfish from areas that are well known for having PSP levels above the regulatory limit, including Southeast Alaska and Unalaska, continued to have samples that tested above the regulatory limit (particularly from March to September) albeit less frequently than since 2019. Over the last few years, the dinoflagellate *Dinophysis* (which may cause Diarrhetic Shellfish Poisoning, DSP) has become more common and abundant in water samples, and 2022 continued that trend.

We are seeing a geographic expansion of the areas that are being sampled for phytoplankton species, so the decrease in the number of HABs detected may be more related to sampling generally cooler water temperatures, especially in the GOA. A detailed survey of HABs from the northern Bering Sea to the western Beaufort Sea was conducted. This is the first-ever extensive survey of HABs in this region.

[15] `http://ahab.aoos.org`

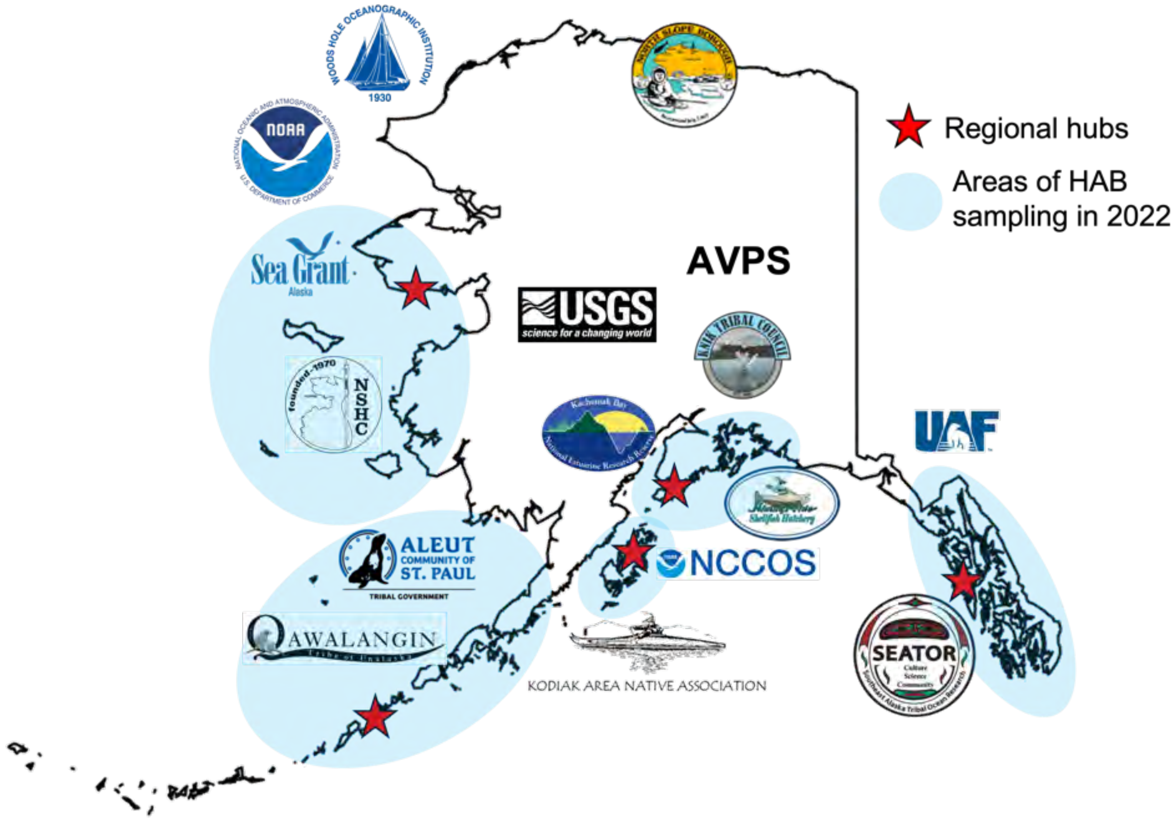

Figure 75: Map of 2022 sampling areas and partners conducted by partners of the Alaska Harmful Algal Bloom Network (AHAB). Opportunistic sampling of marine mammal tissue and other marine species occurs statewide and is not shown here.

The Alaska Department of Environmental Conservation tests bivalve shellfish harvested from classified shellfish growing areas meant for the commercial market for marine biotoxins including paralytic shellfish toxin (PST, tested by mouse bioassay and post-column oxidation) in all bivalve shellfish and domoic acid specifically in razor clams. The Environmental Health Laboratory (EHL) also does testing for research, tribal, and subsistence use. The EHL is the sole laboratory in the state of Alaska certified by the FDA to conduct regulatory tests for commercial bivalve shellfish. As of September, 2022, the EHL has analyzed 371 commercial samples (DA: 0, PST: 371) and 723 non-commercial samples (DA: 537, PST: 186).

The sole commercial razor clam fishery in Alaska did not operate in 2022 as a result of the Covid-19 pandemic, and no regulatory tests for DA in razor clams were conducted.

The 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). In April 2022, an Epidemiology Bulletin describing cases was released[16]. More information about PSP and other shellfish

[16] http://www.epi.alaska.gov/bulletins/docs/b2022_05.pdf

poisoning can be found on the SOE website[17].

Eastern GOA:
Southeast Alaska & Kodiak — HABs species (particularly *Alexandrium* spp.) and environmental parameters have been monitored at an oyster farm in SE Alaska since 2018 by researchers from Alaska Sea Grant and NOAA Alaska Fisheries Science Center (Lead PI: J. Hollarsmith). Overall, the phytoplankton community composition varies seasonally, which may impact seasonal trends in HAB development and oyster health. In 2022 (as of September), there were no *Alexandrium* blooms that led to high PSP levels or closure of the oyster farm, but some *Alexandrium* cells were observed in water samples. High Alexandrium densities are more frequent in summer months, although no statistically significant relationships have been observed between environmental parameters and *Alexandrium* cell densities. Higher lipid content was marginally significantly related to higher water temperatures ($p = 0.076$, $R^2 = 0.38$) and lower salinities ($p = 0.048$, $R^2 = 0.45$) (Figure 76).

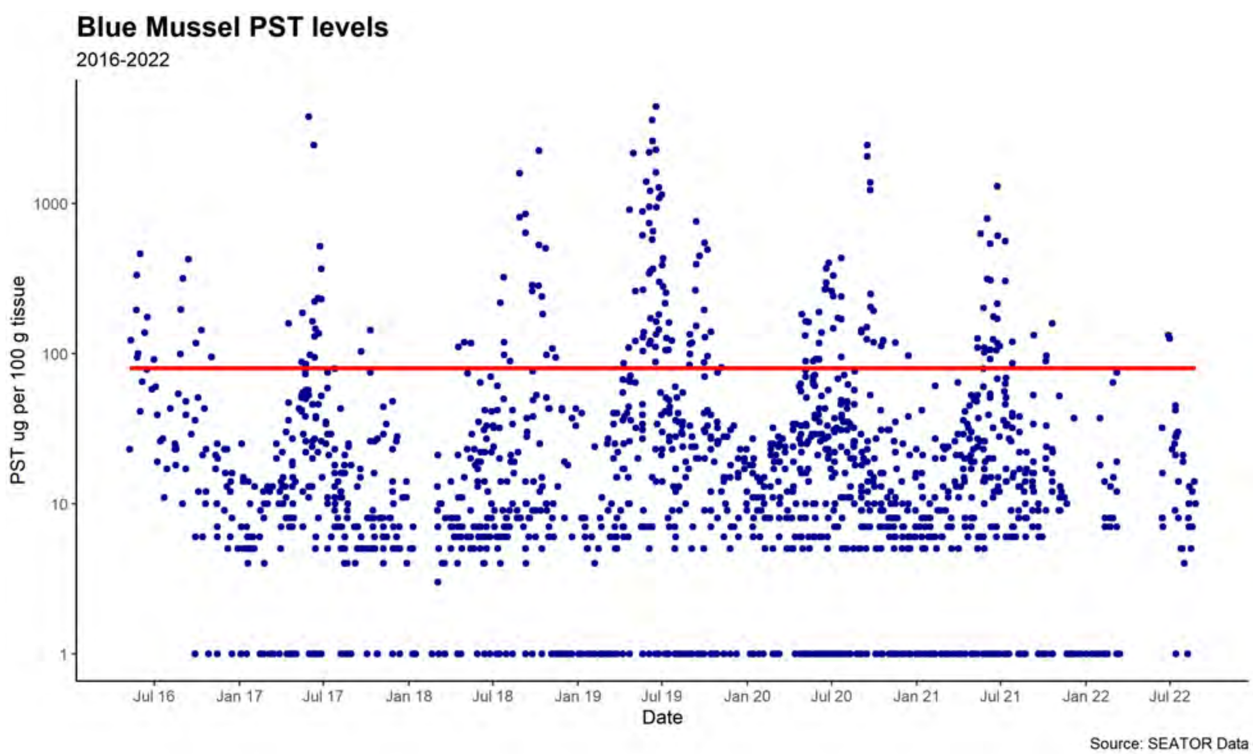

Figure 76: Paralytic shellfish toxicity (PST) results from blue mussel samples collected from 2016 through September 2022 in Southeast Alaska and Kodiak communities. The red line is the regulatory limit (80 µg of toxin/100 g of tissue. Data provided by SEATOR.

The Southeast Alaska Tribal Ocean Research (SEATOR) network is composed of Tribes throughout the GOA that collect shellfish and phytoplankton samples to improve understanding of the risk that shellfish toxins pose to Tribal communities. Most non-butter clam samples collected in August and September, 2022, were below the regulatory limit of 80 μg of toxins per 100g of shellfish tissue. However, 3 of 68 blue mussel samples were over the limit (Figure 76). The high-toxicity blue mussels were all found in July. Butter clam samples in many communities were above the regulatory limit, with 12 out of 28 samples coming over the regulatory limit from January to August. Samples analyzed by the Sitka Tribe of Alaska Environmental Research Lab were limited due to supply chain issues in 2021 and 2022.

[17] `https://health.alaska.gov/dph/Epi/id/Pages/dod/psp/default.aspx`

In August, a case of possible PSP was reported to DOH Section of Epidemiology near Ketchikan. The DOH worked with area AHAB members to check water samples and toxin levels, as well as made the communities and other stakeholders aware of the concern. Monitoring, collaboration, and communication between partners is a way to ensure safety of Alaska coastal communities. There was one farm closure in southeast Alaska in 2022 due to oyster PST levels at 370 μg/100 g of tissue. This area remained closed to harvesting for a couple of weeks until the reopening criteria were met (three consecutive PST tests taken at least four days apart spanning at least 14 days must be below 80 μg/100. (Patryce McKinney/Kim Stryker/Carol Brady, ADEC)).

Western GOA:
Kachemak Bay — Kachemak Bay National Estuarine Research Reserve's (KBNERR) Community Monitoring Program collected over 130 phytoplankton samples in 2022 from over 11 sites within Kachemak Bay Alaska. In contrast to the past three years, *Dinophysis* has not been as abundant at inner bay sites this year. There was a peak in *Alexandrium* cells in community samples in August. (Jasmine Maurer, KBNERR)

Shelikof Strait — Opportunistic samples were collected along the coast of the Katmai National Park (coast of Shelikof Strait) and Preserve in July 2022 by the National Park Service. No samples had domoic acid levels above 1.2 ppm, and the highest PST level was.13.9 μg/100g. These results suggest that there wasn't an algal bloom in that area in mid-July. (Thomas Farrugia, AOOS)

Kasitsna Bay — For this year, so far, NCCOS in Kasitsna Bay collected 40 phytoplankton samples for visual counts paired with another 40 for qPCR analysis of *Alexandrium* abundance. Overall it was a fairly typical year with an early summer peak around June for phytoplankton dominated by diatoms. We did see a lot of pteropods all around the bay in late August/ early September. Around the same time, there were also a lot of krill or similar zooplankton in Kasitsna Bay. From our monthly oceanography surveys, we know that the pteropods seen all along Kachemak Bay in late August/early September coincided with an intrusion of Alaska Coastal Current waters at depth into the bay. While these are ocean waters, the incoming late summer waters are actually a bit fresher than what we see for most of the year below the seasonal surface layer in the Kachemak Bay. And this year was the freshest we've ever seen - but not surprising, given the amount of rain along the GOA coast for the past few months.

Lower Cook Inlet and Prince William Sound — Alutiiq Pride Marine Institute conducted phytoplankton and shellfish monitoring at six locations between Lower Cook Inlet and Prince William Sound. Phytoplankton monitoring observed an *Alexandrium* and *Dinophysis* blooms in Qutekcak (Seward) and an *Alexandrium* bloom in Chenega in early August. Qutekcak (Seward) also saw a *Pseudo-nitzschia* bloom in mid-August. Additionally, bivalves were collected on a weekly basis in Qutekcak. The process to test this tissue for saxitoxin and domoic acid concentrations has begun and will continue through the winter months. Currently, there have been no significantly elevated levels of toxins present in shellfish samples from Quekcak.

Middleton Island — The USGS Alaska Science Center responded to a die-off event involving multiple seabird species on Middleton Island in June-July 2022 that raised concerns of possible STX involvement. Tissues from six black-legged kittiwakes were tested and all returned values below detectable levels for STX. As of September, we have not received additional samples from die-off events in 2022.

Kodiak Island — The Kodiak Area Native Association Environmental Department have been sampling for HAB species at two locations around Kodiak (Mission Beach and South Trident Basin) in 2022. Samplers have identified over a dozen phytoplankton species in their samples, including HAB species such as *Alexandrium* spp., *Dinophysis* spp., *Pseudo-nitzschia* spp. and *Chaetoceros* spp. *Chaetoceros* was found in all 13 samples so far this year, and was elevated in two samples. *Alexandrium* was only found in two samples and *Pseudo-nitzschia* in eight samples.

GOA-wide — NPRB project 1801 (conducted by S. Kibler and J. Matweyou), a 4-year effort with the Prince William Sound Science Center, Oregon State University, the University of Alaska, the Knik Tribe of Alaska and other partners to investigate the occurrence of paralytic shellfish poisoning toxins (PSTs) produced during blooms of *Alexandrium* in plankton, invertebrates, and forage fishes in southern Alaska was recently completed. One of the project findings was that PSTs are pervasive, occurring in trace-low levels in nearly all species examined (22 forage fish species, 9 commercial fish species, 20 invertebrate taxa) throughout the marine food web, with moderate to high toxin levels in many specimens. The project provided a basis for more focused work on trophic transfer pathways for PSTs in areas with regular *Alexandrium* blooms.

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

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

"Mushy" Halibut Syndrome Occurrence

Contributed by Stephani Zador
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Last updated: September 2022

Description of indicator: Mushy Halibut Syndrome was first detected in GOA halibut in 1998. Increased prevalence occurred in 2005, 2011, 2012, 2015, and 2016. It was apparently absent in 2013, 2014, 2019, and 2020, and there were relatively few occurrences in 2017, 2018, and 2021. It is most often observed in smaller halibut of 15–20 lbs in the Cook Inlet area, but has also been noted in Kodiak, Seward, and Yakutat. Alaska Department of Fish and Game (ADF&G) describes the typical condition consisting of fish having large areas of body muscle that are abnormally opaque and flaccid or jelly-like. The overall body condition of these fish is usually poor, and often they are released because of the potential inferior meat quality. Data are collected through searches of ADF&G fishing reports and queries to IPHC 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: There was an anecdotal report of a "couple sightings" during 2022 by port samplers (pers.comm. Martin Schuster, ADF&G), otherwise there were no other reports of mushy halibut in 2022. This was similar to the year before, when a port sampler in Seward noted mushy halibut on a couple of occasions during the 2021 sport fishing season (pers. comm. Corey Litwiniak, ADF&G); otherwise none were reported. There were no reports of mushy halibut during the 2019–2020 sport fishing seasons in central Alaska[18]. However there was one anecdotal report of mushy halibut in a tribal fishery off Washington in 2020 (pers. comm. Josep Planas, IPHC).

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

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

Prince William Sound

Contributed by Rob Suryan, NOAA Fisheries, Auke Bay Laboratory, Alaska Fisheries Science Center, Juneau, AK
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Last Updated: October 2022

Prince William Sound (PWS) is finally showing return to pre-heatwave (2014-2016) levels for some physical and biological metrics. In 2022, temperature anomalies showed mixed conditions, some strongly positive (e.g., central PWS surface and deep water) and others negative (central mid-water and western intertidal) (Campbell in this Report, p.156). Although the intertidal community metric for primary producers (rock weed) remained below pre-heatwave densities, predators (sea stars) and consumers (mussels) returned to pre-heatwave levels (Coletti in this Report, p.159). Likewise, herring spawning and population size estimates returned to pre-heatwave levels (Pegau in this Report, p.164). However, humpback whale abundance is still well below pre-heatwave levels (Moran in this Report, p.167). It is uncertain why humpback whales are not returning to PWS when prey availability no longer appears to be a limiting factor and populations in other GOA regions have shown some positive signs of recovery, though generally still also below pre-heatwave levels.

Temperature Trends in Prince William Sound

Contributed by Rob Campbell, Prince William Sound Science Center, Cordova, AK
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Last updated: September 2022

Description of indicator: A 46-year time series of sea surface temperature (SST) was compiled in Prince William Sound (PWS), western GOA region for the period, 1974–2022. Sea surface temperature anomalies were calculated as the residual of the 2nd order cosine fit to daily temperature data, to remove seasonality (Campbell, 2018). Data were collected from the World Ocean Database (NOAA), and an unpublished database of casts done by the University of Alaska Fairbanks (UAF) and ongoing surveys (2009-present). The data represent an exhaustive collation of historical data from prior projects, and were collected with a variety of instruments from numerous platforms. Recent data (>2010) are from ongoing Gulf Watch Alaska[19] projects conducted by the PWS Science Center, UAF, and NOAA.

Status and trends: In 2022 near surface temperature anomalies continue the temperature trend of 2021, and are near the climatological average (1974–2022). Temperature anomalies deeper in the water column (25 m), have been similar to the pattern at the surface, but are smaller and with a higher preponderance of negative anomalies. Temperature anomalies at depth (200 m) remain warmer than average, continue a long-term warming trend, and have been positive since 2013.

SST has been increasing in central PWS for the last four decades, at approximately 0.1°C per decade (Figure 77), although there is substantial year-to-year variability. In 2013, anomalies shifted towards strongly positive, and have for the most part stayed that way into 2020 except for a brief dip in 2018,

[19] http://gulfwatchalaska.org

which reflected basin scale marine heatwaves that have been noted throughout the GOA in 2013–2015 (Bond et al., 2015) and 2019 (Amaya et al., 2020). Temperatures in PWS remained elevated for about 1 year longer than was observed offshore, which is typical– PWS generally lags the GOA by about 12 months (Campbell, 2018).

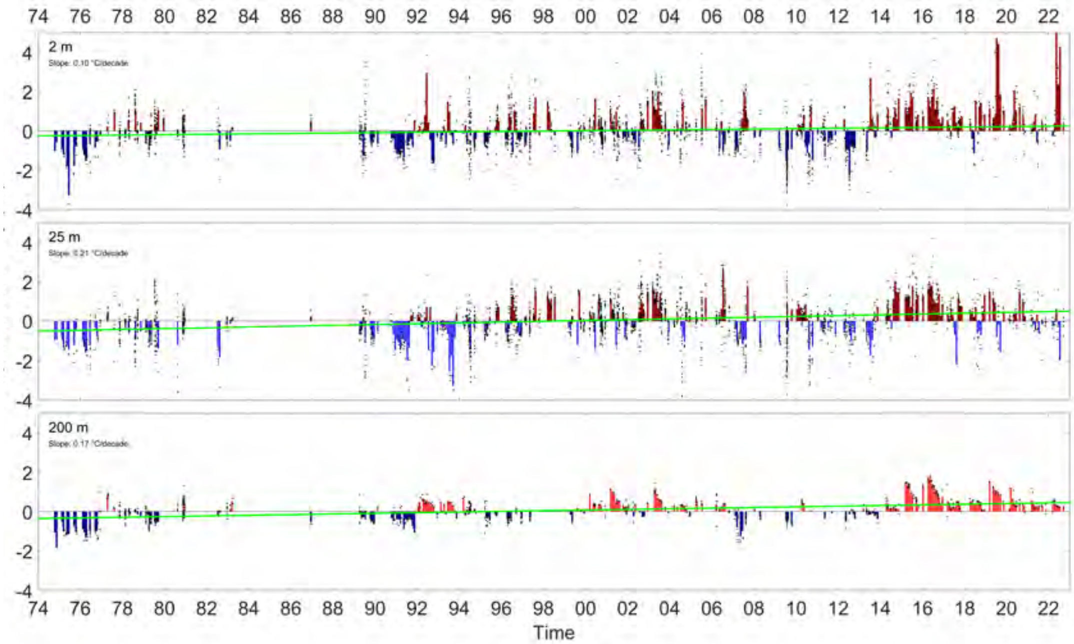

Figure 77: Temperature anomalies at three depths (2 m, 25 m, and 200 m) in central Prince William Sound, 1974–2022. Black dots indicate observations, and bars are monthly averages; the green line is the long-term trend. Anomalies were calculated as the residuals of a second order cosine curve fit to all years' data (to remove seasonality).

Factors influencing observed trends: Temperatures in PWS generally track those of the GOA with a lag of about 12 months, which is driven by circulation within the region (Campbell, 2018). The onset of the marine heatwaves in PWS was concurrent with the increase in temperatures basin-wide, because the driver of the onset of the heatwave was atmospheric. In 2013–2014 a prolonged period of calm winter weather occurred where heat was not mixed out of the surface layer in winter (Bond et al., 2015). In 2019 a period of calm weather allowed greater heat fluxes into the surface layer (Amaya et al., 2020). The long-term trend towards warming also matches a long-term warming trend observed in the GOA (Royer and Grosch, 2006; Janout et al., 2010). The negative anomalies observed at mid-depths (25 m) may reflect an overall shallowing of the seasonal mixed layer. High frequency observations of the surface layer at a profiler site in central PWS (Campbell, unpubl.) also support this idea. The deep waters of PWS are renewed annually (Halverson, 2014), and above-average temperatures at depth (200 m) are likely a manifestation of warmer than average shelf and slope waters being mixed and advected onto the continental shelf (Janout et al., 2010).

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

Intertidal Ecosystem Indicators in the Northern Gulf of Alaska

Contributed by Heather Coletti[1], James Bodkin, Thomas Dean, Daniel Esler, Katrin Iken, Brenda Ballachey, Kim Kloecker, Brenda Konar, Mandy Lindeberg, Daniel Monson, Brian Robinson, Robert Suryan, Sarah Traiger, Benjamin Weitzman
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Last updated: September 2022

Description of indicator: Nearshore monitoring in the Gulf of Alaska (GOA) provides ongoing evaluation of status and trends of more than 200 species associated with intertidal and shallow subtidal habitats. The spatial extent of sampling includes 21 sites distributed across the northern GOA from western Prince William Sound (WPWS), Kenai Fjords National Park (KEFJ), Kachemak Bay (KBAY), and Katmai National Park and Preserve (KATM). Since 2018, we have reported one physical indicator (intertidal water temperature) and three biological indicators that represent key nearshore ecosystem components of primary production (algal cover), prey abundance (mussel density), and predator abundance (sea star density), with data collection beginning in 2005–2007. Our algal cover indicator is percent cover of rockweed (*Fucus distichus*) sampled in quadrats 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 star species, estimated along a 50 m x 4 m transect at each rocky intertidal site in the GOA. 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 in the first half of 2022 continued a cooler than average trend in all four intertidal zones from Prince William Sound to the Alaska Peninsula (time series starting in 2006 (KATM), 2008 (KEFJ), 2011 (WPWS), and 2013 (KBAY) respectively). Nearshore water temperature in all four intertidal zones from Prince William Sound to the Alaska Peninsula showed a warming trend beginning in 2014, persisting across all regions through 2016 and into 2017 in WPWS and KEFJ (Figure 78). These results confirm that the 2014-2016 marine heatwave in the GOA affected intertidal zones. While temperatures had appeared to cool and return to normal across all regions later in 2017 and into 2018, 2019 had warmer than average intertidal water temperatures in the intertidal zone across all four study regions, and cooling during the early part of 2020, particularly in the western blocks of KBAY and KATM. Temperatures appeared to return to the long-term mean across all regions early in 2021, followed by cooling across all regions into the summer months of 2021.

Algal cover in 2022 continued a negative anomaly in KATM, while KBAY continues to have roughly average *Fucus* cover without a noticeable response in percent cover of *Fucus* to the heatwave. *Fucus* cover in WPWS was average in 2022 while in KEFJ it was slightly positive. Despite considerable variability in percent cover among sites and generally positive anomalies through 2014, KATM and KEFJ sites showed consistently negative values during the recent marine heatwave and continuing through 2021, with WPWS also indicating strongly negative values in 2021 (Figure 79).

Large mussel densities ($\geq$ 20 mm) in 2022 had negative anomalies in KATM and WPWS, with average values in KBAY and positive values in KEFJ. As oceanographic conditions return to cooler temperatures, 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 are important drivers of mussel

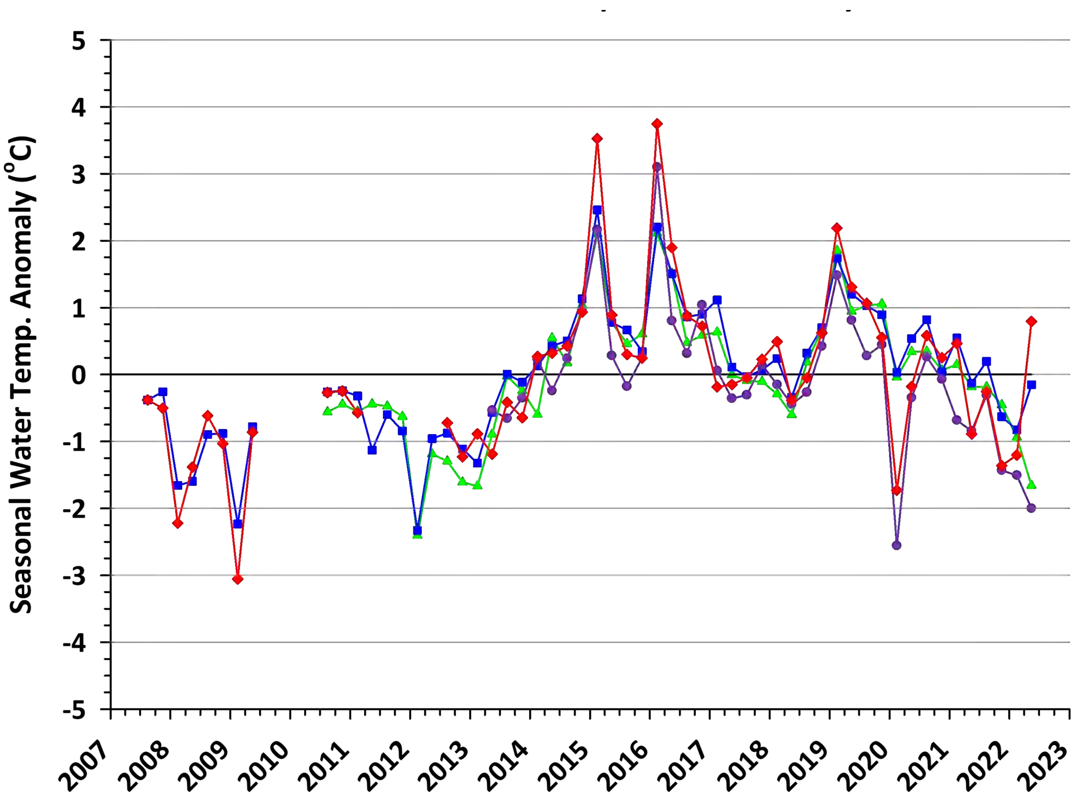

Figure 78: Seasonal intertidal water temperature anomalies at the 0.5 m tide level in four regions of the western Gulf of Alaska, western Prince William Sound (WPWS; 2011–2022), Kenai Fjords National Park (KEFJ; 2008–2022), Kachemak Bay (KBAY; 2013–2022), and Katmai National Park adjacent to Shelikof Strait (KATM; 2006–2021). Long tick marks indicate the start of the calendar year (January) while short tick marks are quarterly divisions within the year (April, July, October).

abundance (Bodkin et al., 2018; Traiger et al., 2022). Large mussel densities ($\geq$ 20 mm) showed an overall positive trend across sites consistent with timing of the marine heatwave through 2019, in this case switching from generally negative to positive anomalies after 2014 — an opposite response compared to algal cover and sea stars (Figures 80 and 81). In 2021, it appeared that large mussel density had returned to the long-term mean across all regions

Sea star 2022 abundance in KEFJ and WPWS had strong positive anomalies dominated by *Pisaster* (54%) and *Evasterias* (31%) in KEFJ and *Dermasterias* (41%) and *Pycnopodia* (35%) in WPWS (Figure 81). The star species documented in KATM that accounted for the positive anomaly in 2022 were primarily *Evasterias* (45%) and *Pisaster* (48%). Sea star densities in KBAY have not yet recovered to 2016 and earlier values; however, it was also one of the last regions to succumb to sea star wasting. The variability in the sea star community (both by density and species composition) among 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.

Variability in density, diversity and dominance of individual sea star species varied greatly among regions through 2015 (Figure 81). Between 2015 and 2017, abundance declined and remained strongly negative across all regions through 2019, likely due to sea star wasting (Konar et al., 2019). In 2019, there

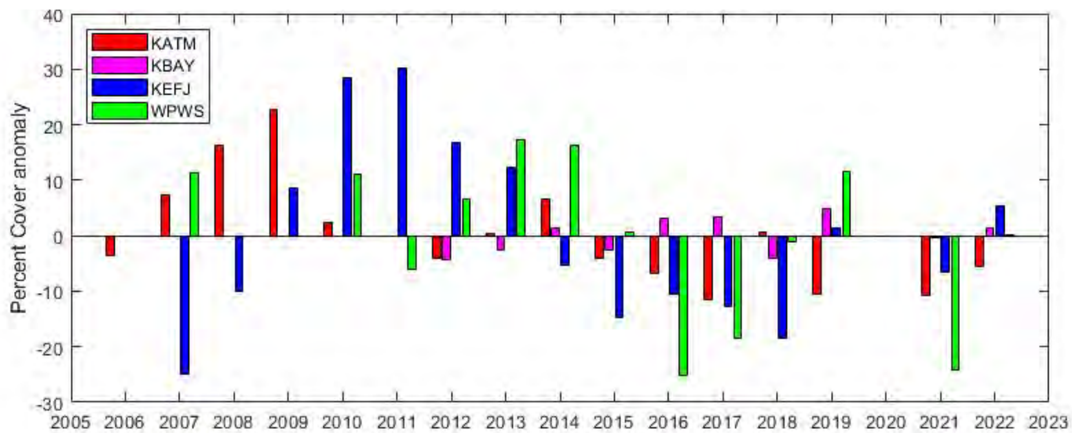

Figure 79: Percent cover anomalies for rockweed (*Fucus distichus*) in four regions of the western Gulf of Alaska, WPWS (2007, 2010-2019, 2021-2022), KEFJ (2008-2019, 2021-2022), KBAY (2012-2022), and KATM (2006-2010, 2012-2019, 2021-2022). Note: KBAY anomaly in 2021 was close to 0 (-0.381), hence the lack of visible bar for KBAY in 2020 and 2021.

was some recruitment and recovery in WPWS, which persisted through 2020. However, the sea star species thought to be least affected by sea star wasting in the northern GOA (primarily *Henricia* and *Dermasterias*) continued to be present and accounted for the positive anomalies. By 2021, sea star abundance in all regions except KATM was again negative, indicating a possible shift in the sea star community (Figure 81).

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

Implications: Collectively, these indicators demonstrate consistent, broad-scale perturbations of nearshore ecosystems coincident with the Pacific marine heatwave 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, 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 suspected the loss of sea stars allowed for the increase in mussel density due to a decline in predation pressure. However, preliminary analyses indicate that the decline in sea stars and increased temperatures only explain 33% of the variation in large mussel density, suggesting that other factors such as predation pressure from nearshore vertebrates to shifts in primary productivity to changes in environmental variables (salinity) may also influence mussel density (Traiger et al., 2022).

Intertidal and nearshore ecosystems provide valuable habitat for early life stages of various commercially important species in the GOA, including Dungeness crab, Pacific cod, salmonids and several species of rockfish. Our indicators suggest that some nearshore biological responses to the heatwave appear to continue into 2021 and could possibly affect future recruitment and survival of species whose life stages rely on nearshore habitat. Evidence of return to more average conditions in nearshore habitats suggests

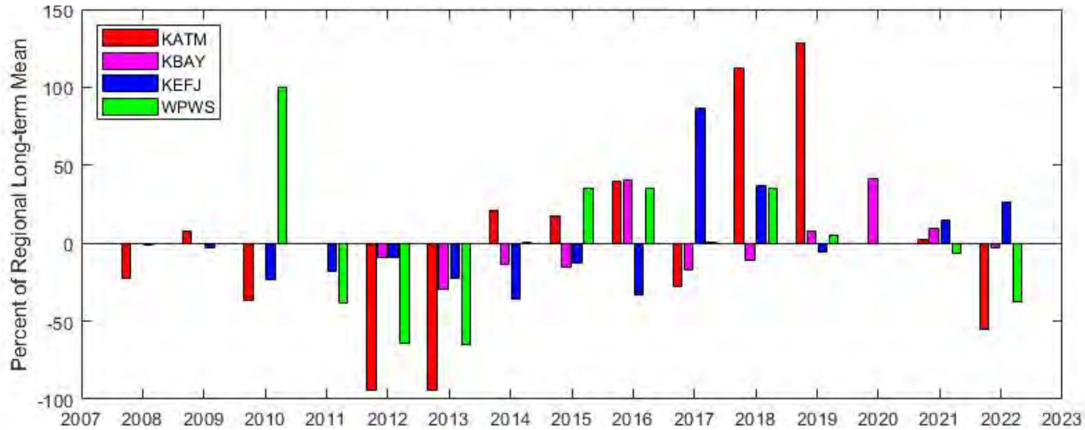

Figure 80: Percent of density anomalies for large mussels (> 20 mm) in four study regions spanning the northern Gulf of Alaska. WPWS (2010–2019, 2021-2022), KEFJ (2008–2019, 2021-2022), KBAY (2012–2022), and KATM (2008–2010, 2012–2019, 2021-2022).

that heatwave effects, both positive and negative, are dissipating. Further, we hypothesize that 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.

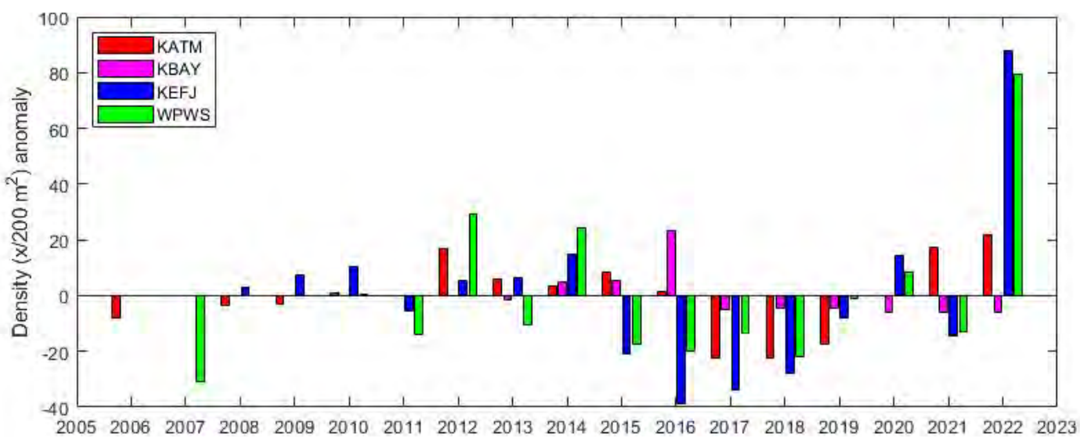

Figure 81: Density of sea stars (primarily *Dermasterias imbricata*, *Evasterias troschelii*, *Pisaster ochraceus*, and *Pycnopodia helianthoides*) in four study areas spanning the northern Gulf of Alaska. WPWS (2007, 2010–2022), KEFJ (2008–2022), KBAY (2005, 2009, 2011–2022), and KATM (2006, 2008–2010, 2012–2019, 2021-2022).

Prince William Sound Herring

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Last updated: August 2022

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 milt surveys collected by ADF&G extend back to the early 1970s, but the approach used became more consistent beginning in 1980. While the mile-days of milt survey is a relative index of abundance, it is the longest abundance time series used in the model. It is the sum of miles of spawn observed each day during the spawning season. Acoustic surveys collected by the Prince William Sound Science Center were conducted from the mid-1990s–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: Estimated herring pre-fishery biomass and the observed mile-days of milt continued an increasing trend in 2021 and 2022 (preliminary results), respectively (baseline 1980–2021). Relatively large numbers of age-1 herring schools were observed in Prince William Sound in 2021 and 2022. A rapid rise in the estimated prefishery biomass occurred in the 1980s and a subsequent decline in the 1990s (Figure 82). There is no 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, which continued through 2021 (Figure 82). The decline in the observed mile-days of milt is more rapid that the model decline (Figure 83) but also shows a rapid increase starting in 2019. The rapid increase was 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. The mile-days of milt has continued to increase due to other recruit classes or increased fecundity as the herring grow older. A similar increase in mile-days of milt was observed at Kayak Island between 2021 and 2022.

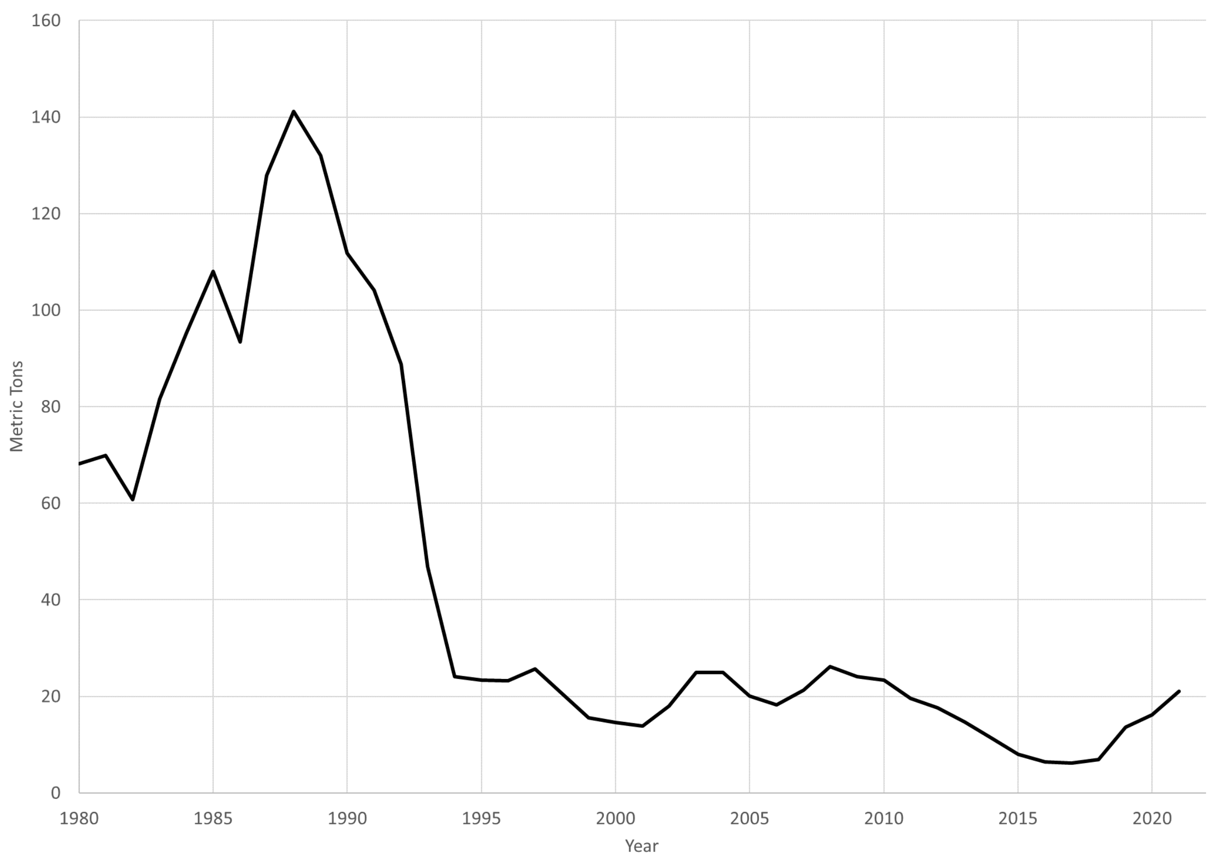

Figure 82: The Bayesian age-structured assessment model median estimate of the pre-fishery biomass.

The last two years (2021, 2022) there have been large numbers of age-1 herring schools observed (Figure 84). 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.

Factors influencing observed trends: The building trend in herring biomass has been associated with the recruitment of the 2016 year class. The 2016 year class may have been a successful year class for herring throughout the GOA with recruit to spawner metrics across the region being nearly four times greater than the next most successful year class since 1980. It is not possible to determine if the continued increasing mile-days of milt is caused by the recruitment of new recruit classes or is a result of increased milt production as the fish from the 2016 year class grow in size.

Implications: The herring population is beginning to increase but will need additional large year classes to join the spawning biomass to reach the levels where a fisheries might occur. The age-1 survey results provide optimism that there will be another large recruitment event. Large recruitment events have occurred on a four-year cycle in the past and a large 2020 year class would be consistent with that previous pattern. The two consecutive years of high age-1 school abundance was unexpected.

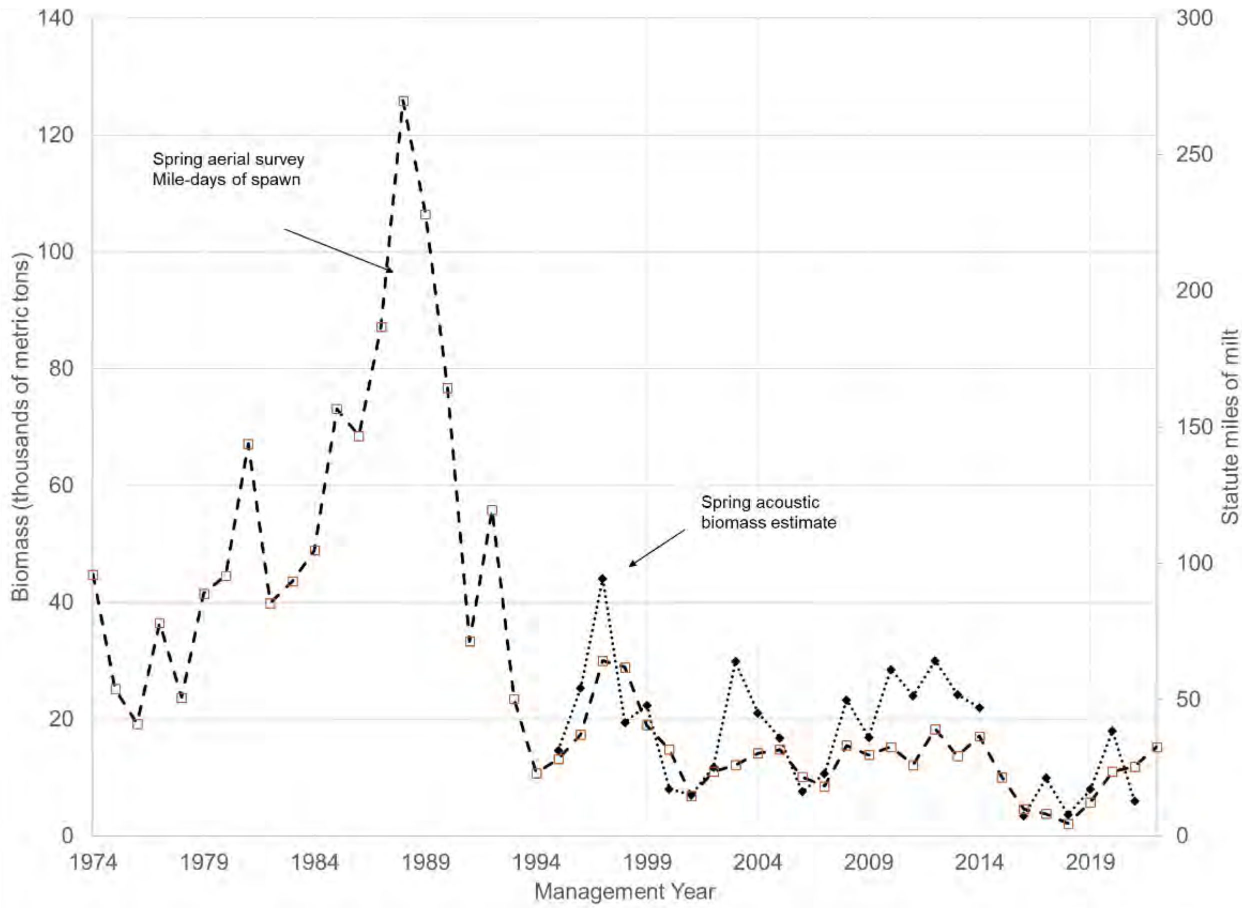

Figure 83: Mile-days of milt in Prince William Sound based on aerial surveys, and biomass estimates from acoustic surveys. Includes preliminary results of the 2022 survey from Alaska Department of Fish and Game.

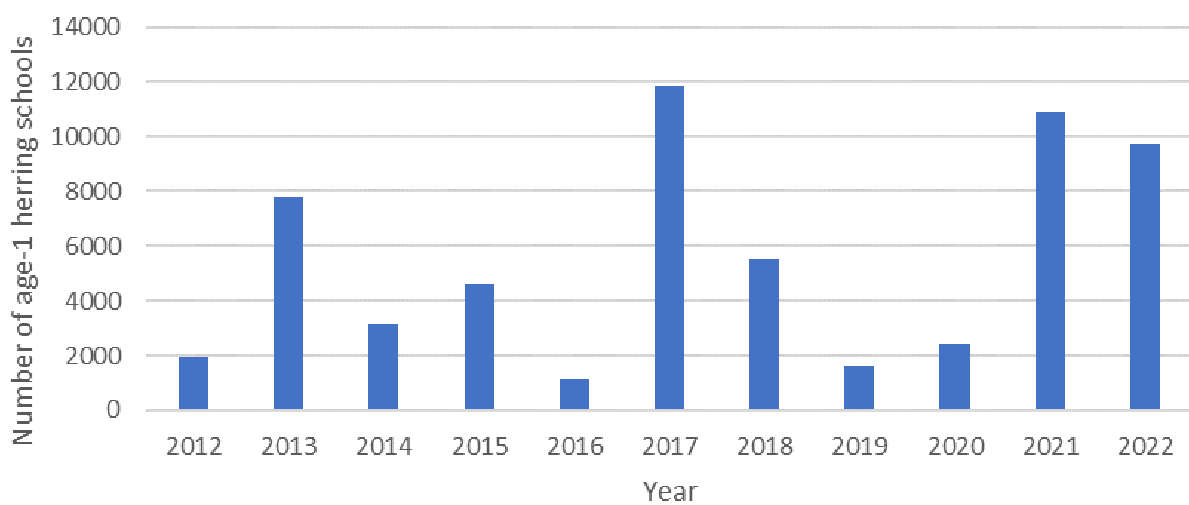

Figure 84: The school-size weighted number of age-1 herring schools in Prince William Sound.

Fall Surveys of Humpback Whales in Prince William Sound

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Last updated: Ocotber 2022

Description of indicator: The humpback whale population in the North Pacific rebounded from near extinction in the late 1960s to over 22,000 individuals in 2006 (Barlow et al., 2011). This rapid recovery has coincided with major natural and anthropogenic perturbations in the marine ecosystem. Over much of the same period, in Prince William Sound, the dominant forage fish, Pacific herring, shifted from an abundant state to a diminished state. The lack of a commercial fishery has not restored the herring population to its former abundance. Humpback whale abundance and calf production within Prince William Sound often tracks herring abundance and indicates the ability of the ecosystem to support populations of large vertebrate predators.

Status and trends: Foraging observations seen prior to the 2014–2016 marine heatwave (beginning 2008), consisted of groups of whales (up to 80 individuals) typically targeting shoals of energy rich adult herring in predictable locations as they moved into the Sound. Our September 2022 survey yielded similar results to our 2017–2021, post-heatwave efforts. One mother calf pair was seen in September. The encounter rate for humpback whales (number of whales/nm traveled) was similar to 2019–2021 (Table 3). Acoustic surveys for prey in 2022 have yet to be quantified, however, euphausiids (likely *Thysanoessa spinifera*) were abundant in the western Sound. A large school of adult herring was located near Glacier Island while juvenile herring were scattered across the Sound. We documented humpback whales feeding on euphausiids, as well as adult and juvenile herring.

Whale sightings were up from recent years during our April 2022 survey, but have still not reached pre-heatwave abundance. Prey was abundant with herring being the main target, followed by euphausiids.

Table 3: 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	17	412	0.17
Oct-11	62	2	441	0.14
Sep-12	81	5	444	0.18
Sep-13	113	6	355	0.32
Sep-14	181	1	427	0.42
Sep-17	12	0	543	0.02
Sep-18	17	1	541	0.03
Sep-19	35	0	573	0.06
Sep-20	14	2	331	0.04
Sep-21	23	0	525	0.04
Sep-22	20	1	504	0.04

Factors influencing observed trends: The abundance of suitable whale prey in Prince William Sound seems to be increasing post-heatwave, but the abundance of humpback whales is not. The factors limiting the return of humpback whales to the Sound remains uncertain, however, prey availability seems to be less of an issue.

Implications: The trend in whale numbers and calf production within Prince William Sound continues to differ with observations from Southeast Alaska and Hawaii where both the sightings of adults and calves are showing signs of recovery towards pre-heatwave levels. The Prince William Sound prey field appears to be recovering, although whale numbers remain low. During our prey sampling efforts we encountered unusually high numbers of kelp greenling, black rockfish and copper rockfish associated with schools of juvenile herring, suggesting a shift in herring predators from marine mammals to fish.

Fishing and Human Dimensions 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 2022

Description of indicator: Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Region's blend data, while estimates for 2003 and later come from the Alaska Region's Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards in the North Pacific. Discard rates, as shown in Figure 85, are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area gear-target sector. Where rates are described for species or species groups, they represent the total discarded weight of the species/species group divided by the total catch weight of the species/species group for the relevant area-gear-target sector. These estimates include only catch of FMP-managed groundfish species within the FMP groundfish fisheries. Discards of groundfish in the halibut fishery and discards of forage fish and species managed under prohibited species catch limits, such as halibut, are not included.

Status and trends: In 2022, through week 35, discard biomass in the fixed gear and non-pollock trawl sectors is trending lower relative to the previous 5 years, whereas trawl pollock discard biomass is trending in line with previous years (Figure 85). Since 1993 discard rates of groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in both pollock and non-pollock trawl fisheries in the Gulf of Alaska (Figure 85). In the non-pollock trawl sector, discard rates dropped from 40% in 1994 to 21% in 1998, trended upwards from 1998 to 2003, and generally declined to a low of 8% in 2015 and 2016 before increasing slightly to 11% in 2017. The 2021 discard biomass for non-pollock trawl is at its lowest at 3445 mT and rate of 8%. Discard rates in the GOA pollock trawl sectors declined from over 10% in 1993 to about 1% in 1998 and have since fluctuated between 1% and 3%. Discard biomass in the fixed gear (hook-and-line and pot) sector has generally declined from 2013 onward, though discard rates for fixed gear across the GOA as a whole increased to over 17% in 2018 and 2019 after remaining at 11% or lower from 2013 to 2017.

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

Figure 85: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear (FIXED), pollock trawl , and non-pollock trawl sectors for the Gulf of Alaska (ALL GOA) region, 1993–2022; and for and eastern and western GOA subregions, 2009–2022. Discard rates are calculated as total discard weight of FMP groundfish divided by total retained and discarded weight of FMP groundfish for the sector (includes only catch counted against federal TACs).

- Limited access privilege programs (LAPPs), which allocate catch quotas and may reduce economic discards by slowing down the pace of fishing
- In-season closure of fisheries once target or bycatch species quotas are attained
- Minimum retention and utilization standards for certain fisheries
- Maximum retainable amounts (MRAs), which allow for limited retention of species harvested incidentally in directed fisheries.

In the GOA, management and conservation measures aimed at reducing bycatch have contributed to an overall decline in groundfish discards since the early 1990s (NPFMC, 2016). Pollock roe stripping, wherein harvesters discard all but the highest value pollock product, was prohibited in 1991 (56 Federal Register 492). In 1997 arrowtooth flounder was added as a basis species for retention of pollock and Pacific cod (62 Federal Register 11109), and in 1998 full retention requirements for pollock and cod were implemented for federally-permitted vessels fishing for groundish, leading to overall declines in pollock and cod discards in the GOA (62 Federal Register 65379). Additional retention requirements went into effect in 2003 for shallow-water flatfish species across the entire GOA (62 Federal Register 65379) and in 2004 for demersal shelf rockfish in the Southeast Outside district of the Eastern Gulf (69 Federal Register 68095). In 2009, NMFS revised the MRA for groundfish caught in the GOA arrowtooth flounder fishery, including an increase from 0 to 20 percent for flatfish species (74 Federal Register 13348). Under

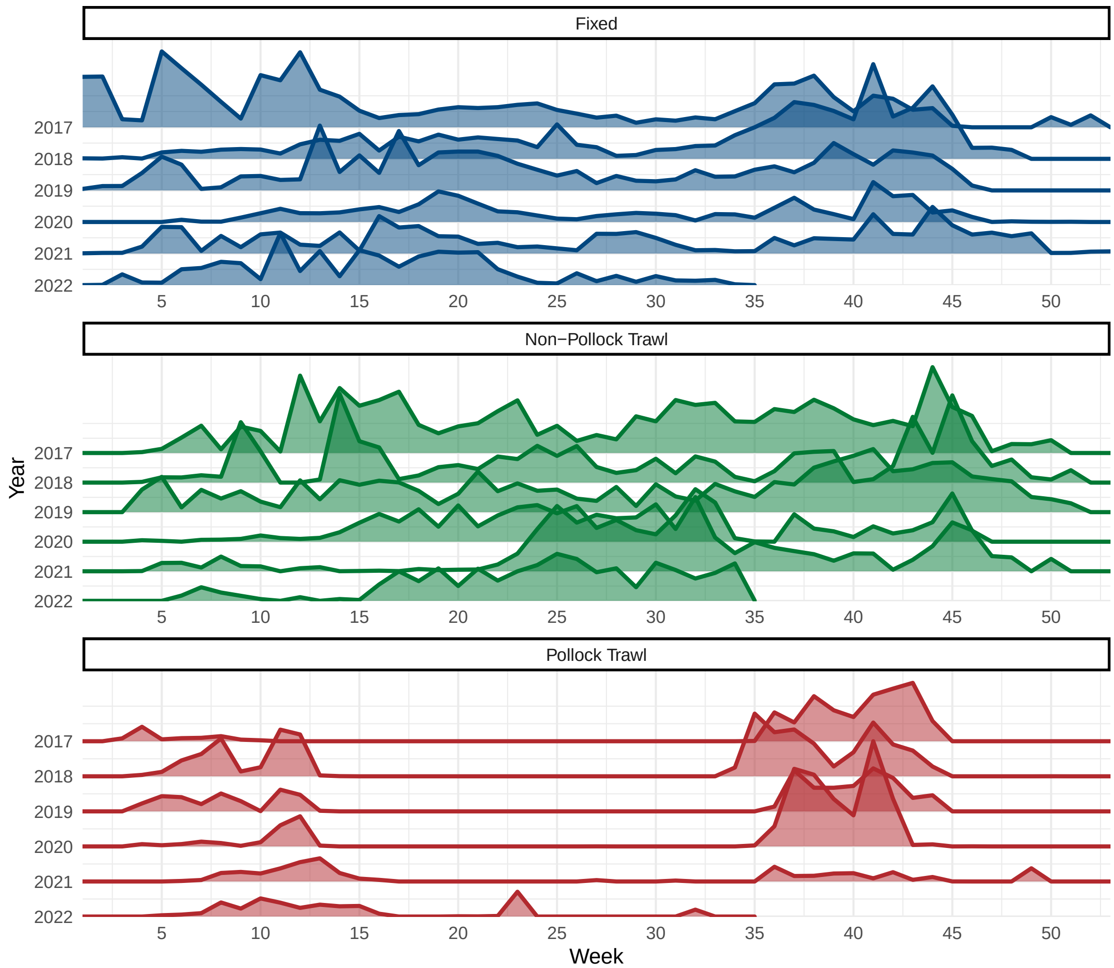

Figure 86: Total biomass of FMP groundfish discarded in the Gulf of Alaska by sector and week of the fishing season, 2014–2022 (data for 2022 is shown through week 35). Plotted heights are not comparable across fisheries.

the GOA groundfish FMP, fisheries with discard rates over 5% for shallow-water flatfish are subject to annual review by the North Pacific Council. Reductions in flatfish discards account for most of the general decline in discards and discard rates for the non-pollock trawl sector. As of March 2020, the regulations 50 CFR 679.20(j) and 50 CFR 679.7(a)(5) were implemented to require operators of catcher vessels using hook-and-line, pot, or jig gear (fixed gear) to fully retain rockfish landings in the BSAI or GOA. These regulations also limit the amount of rockfish that can enter into the market with the overall purpose of limiting total catch of rockfish.

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

In recent years the species historically comprising the "other groundfish" assemblage (skate, sculpin, shark, squid, and octopus) have overtaken flatfish as the largest source of discards in the GOA. Most discards of these species currently occur in the longline fishery, although expanded observer coverage of smaller hook and line vessels beginning in 2013 may account for some of the recent increase in fixed gear sector discards. Retention rates for skate and octopus have fluctuated over time, in part due to changing market conditions for these species (Conners and Conrath, 2017; Ormseth, 2017). Interest in retention of skates and directed fishing for skates, despite management under bycatch-only status beginning in 2005, resulted in annual overages of longnose and big skate TACs from 2007 to 2013. Discards and discard rates of skate increased between 2013 and 2016 as NMFS took action to prevent such overages, including regulatory discard requirements for big skate in the Central GOA, imposed at progressively earlier dates during the year from 2013 to 2015, and, in 2016, a reduction in the MRA for GOA skates from 20% to 5% (Ormseth, 2017).

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

Time Trends in Non-Target Species Catch

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Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the Gulf of Alaska. In previous years we included the catch of "other" species, "non-specified" species, and forage fish in this contribution. However, stock assessments have now been developed or are under development for all groups in the "other species" category (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), some of the species in the "non-specified" group (giant grenadier, other grenadiers), and forage fish (e.g., capelin, eulachon, Pacific sand lance, etc.), and therefore we no longer include trends for these species/groups here (see AFSC stock assessment website at [20]). Invertebrate species associated with Habitat Areas of Particular Concern, previously known as

[20]https://www.fisheries.noaa.gov/alaska/population-assessments/north-pacific-groundfish-stock-assessments-and-fishery-evaluation

HAPC biota (seapens/whips, sponges, anemones, corals, and tunicates) are now referred to as structural epifauna. Starting with the 2013 Ecosystem Considerations Report, the three categories of non-target species we continue to track here are:

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

Total catch of non-target species is estimated from observer species composition samples taken at sea during fishing operations, scaled up to reflect the total catch by both observed and unobserved hauls and vessels operating in all Fishery Management Plan areas. Catch since 2003 has been estimated using the Alaska Region's Catch Accounting System (Cahalan et al., 2014). This sampling and estimation process results in uncertainty in catches, which is greater when observer coverage is lower, and for species encountered rarely in the catch.

The catch of non-target species/groups from the GOA includes the reporting areas 610, 620, 630, 640, 649, 650, and 659[21]. Within reporting area 610, the GOA and Aleutian Islands (AI) Large Marine Ecosystems (LME) are divided at 164°W. Non-target species caught east of 164°W are within the GOA LME and the catch west of 164°W is within the AI LME.

Status and trends: The catch of Scyphozoan jellies in the GOA has been variable from 2011–2021, with peaks in 2012, 2015, 2016, and 2019 (baseline 2011–2021; Figure 87). The catch of jellies in 2021 was the third lowest over 2011–2021. 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 2021 where it is at its second lowest level since 2011. Sea anemones comprised the majority of the structural epifauna catch from 2011–2019, and were co-dominant with unidentified corals and bryozoans in 2020 and 2021. Structural epifauna was primarily caught in flatfish, Pacific cod, and sablefish fisheries. The catch of assorted invertebrates increased from 2012 to a peak in 2015 and has decreased each year since to a low in 2021. 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 the Pacific cod and halibut 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. The reductions in Pacific cod TAC since 2018 may have contributed to declines in the catch of structural epifauna and assorted invertebrates.

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.

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

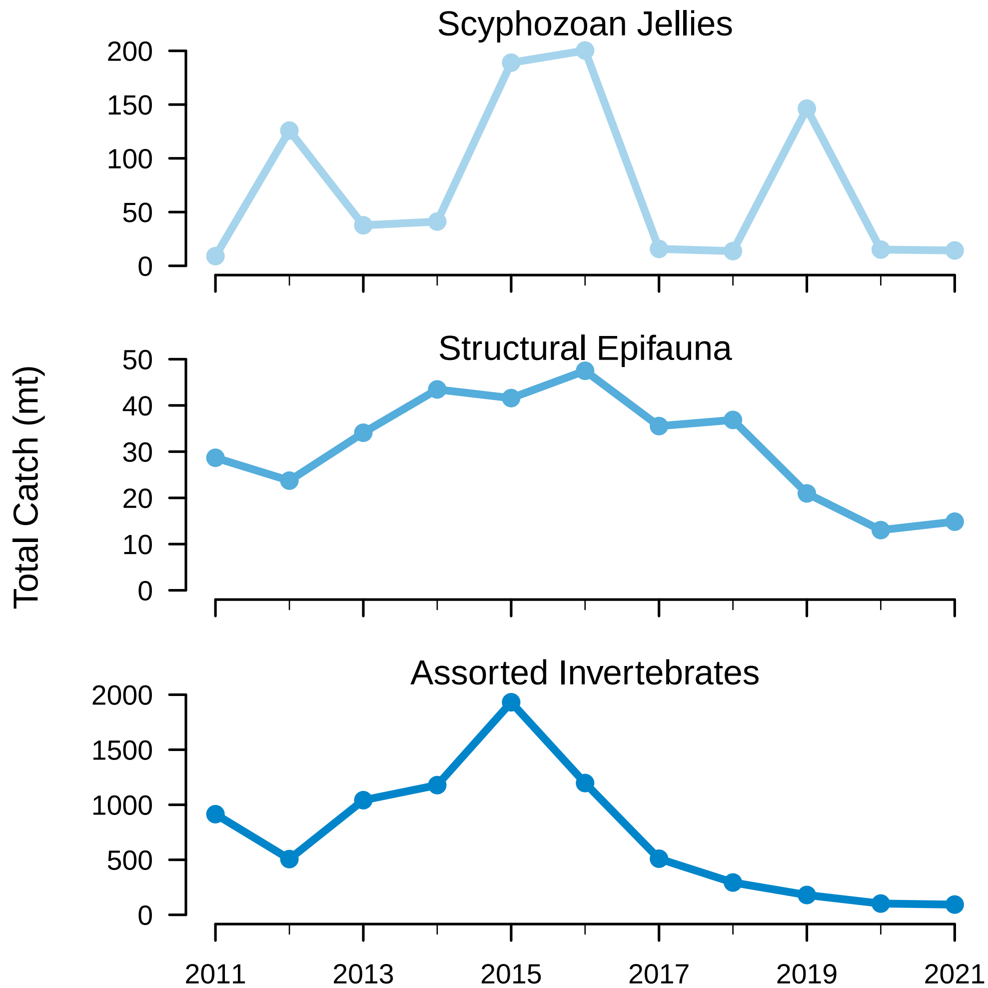

Figure 87: Total catch of non-target species (tons) in the GOA groundfish fisheries (2011–2021). Note the different y-axis scales between species groups.

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 additionally, jellyfish may prey upon the early life history stages (eggs and larvae) of fishes (Purcell and Arai, 2001; Robinson et al., 2014).

Seabird Bycatch Estimates for Groundfish Fisheries in the Gulf of Alaska

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Last updated: August 2022

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.

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. Observer deployment plans are reviewed and updated annually in the Annual Deployment Plan (the 2021 plan is available at: `https://www.fisheries.noaa.gov/resource/document/north-pacific-observer-sampling-manual`). The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2014, 2010). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. CAS also estimates non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. The CAS produces estimates based on these three current data sets, which may have changed over time.

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 GOA include reporting areas 650, 659, 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)[22].

Status and trends: The number of seabirds estimated to be caught incidentally in eastern GOA fisheries in 2021 (300 birds) was more than twice as many as in 2020 (128 birds), and was above the 2012–2020 average of 233 birds by 29% (Table 4, Figure 88). Black-footed albatross and gulls were the most common species caught incidentally in eastern GOA fisheries. In 2021, the number of black-footed albatross (254 birds) was 243% more than that in 2020 (74 birds), and 131% above the 2012—2020 average of 110 birds. In 2021, the estimated number of gulls (29 birds) was 53% more than in 2020 (19 birds) but was below the 2012-–2020 average of 78 birds by 63%.

The number of seabirds estimated to be caught incidentally in western GOA fisheries in 2021 (216 birds) increased from that in 2020 (29 birds) by 645%, but was below the 2012–2020 average of 473 birds by 54% (Table 5, Figure 88). Black-footed albatross and northern fulmar were the most common species caught incidentally in western GOA fisheries. In 2021, the number of black-footed albatross (86 birds) was 975% more than that in 2020 (8 birds), but 52% below the 2012–2020 average of 180 birds. In 2021, the estimated number of northern fulmar (81 birds) far exceeded the estimate in 2020 (5 birds) but was below the 2012–2020 average of 120 birds by 33%.

Focusing solely on the bycatch of albatross (unidentified, short-tailed, Laysan, and black-footed) in the GOA, an average of 350 albatross per year were taken from 2011 through 2021 (Tide and Eich, 2022) (Figure 89).

The sablefish IFQ fishery using demersal longline is responsible for the majority of seabird bycatch in the Gulf of Alaska—the average annual seabird bycatch for 2011–2021 is 527 birds per year (Table 13 in

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

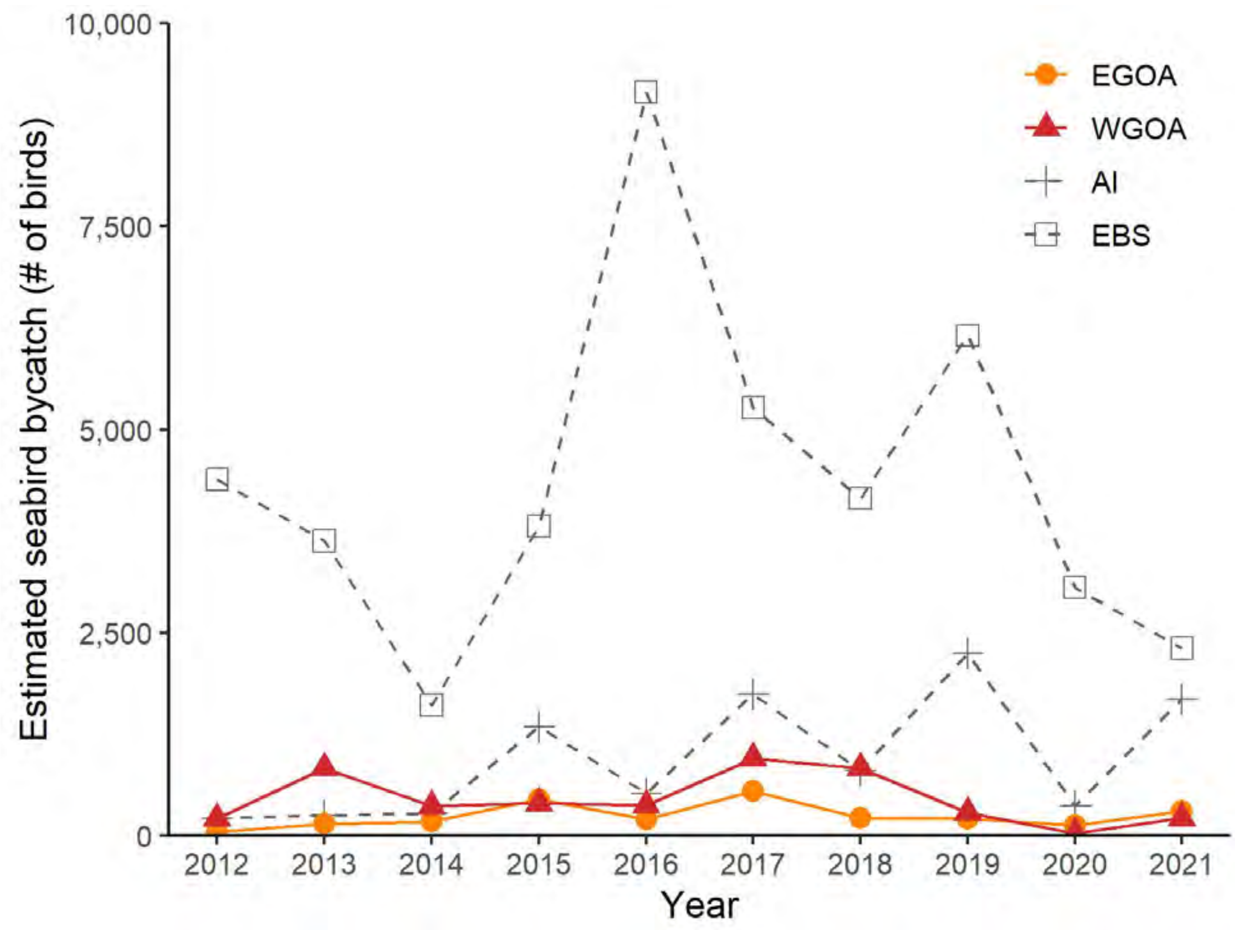

Figure 88: Total estimated seabird bycatch in eastern Bering Sea (EBS), eastern Gulf of Alaska (EGOA), western Gulf of Alaska (WGOA), and Aleutian Islands (AI), groundfish and halibut fisheries, all gear types combined, 2012 through 2021.

Tide and Eich, 2022). In 2021, the estimated seabird bycatch (273 birds) was 51% less than the 2011-2020 average (553 birds; Table 13 in Tide and Eich, 2022). Figure 90 shows the spatial distribution of observed seabird bycatch from 2016-2021 from the sablefish IFQ fishery from vessels fishing with hook and line overlaid onto heat maps depicting fishing effort for the fishery.

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

While an increase in seabird bycatch in the groundfish and halibut fisheries in the GOA occurred in 2021 compared to 2020, several events occurred during the 2020 fishing seasons which may partially explain this difference. As with many other things in 2020, the COVID-19 pandemic disrupted normal fishing operations throughout Federal fisheries. In Alaska, such disruptions included lost fishing days due to closures and stand-downs (primarily at the beginning of the pandemic) and reduced market prices for fish as restaurants and other buyers were not operating at normal levels and thus were not purchasing as much fish product. The number of fishing trips in 2020 (13,493 trips) was the lowest over the 2012 to 2020 time-period and down from a high of 19,246 trips in 2016 (NMFS Alaska Region, unpublished

Table 4: Estimated seabird bycatch in the eastern Gulf of Alaska groundfish and halibut fisheries for all gear types, 2012 through 2021 (halibut fisheries 2013 through 2021). Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Unidentified Albatross	0	26	0	0	0	0	42	1	0	0
Laysan Albatross	4	9	3	6	4	2	3	37	13	5
Black-footed Albatross	19	39	76	221	93	225	96	99	74	254
Northern Fulmars	0	13	4	19	6	31	18	41	2	12
Shearwaters	0	0	0	1	2	23	2	2	6	0
Gulls	5	47	77	116	66	220	31	16	19	29
Auklets	0	0	0	1	0	0	0	0	0	0
Cormorants	0	0	0	24	0	0	0	0	0	0
Unidentified Birds	1	0	0	17	2	1	0	0	14	<1
Grand Total	29	134	160	405	174	501	192	196	128	300

Table 5: Estimated seabird bycatch in the western Gulf of Alaska groundfish and halibut fisheries for all gear types, 2012 through 2021 (halibut fisheries 2013 through 2021). Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Unidentified Albatross	0	2	0	0	0	0	8	18	0	0
Laysan Albatross	6	57	23	29	39	23	19	2	9	15
Black-footed Albatross	109	384	177	115	75	441	202	112	8	86
Northern Fulmars	18	239	46	57	173	230	224	85	5	81
Shearwaters	0	51	0	4	17	12	38	30	2	0
Gulls	46	88	74	126	55	231	199	35	3	23
Auklets	0	0	1	45	0	0	0	0	0	0
Other Alcids	0	0	37	0	0	0	0	0	0	0
Cormorants	0	0	0	2	0	0	0	0	0	0
Unidentified Birds	31	7	0	17	16	13	140	0	3	10
Grand Total	210	828	360	394	375	951	831	283	29	216

data). Less fishing effort would reduce the opportunities for interactions with seabirds and less seabird bycatch. The COVID-19 pandemic continued to disrupt normal fishing operations in 2021. Even fewer trips (12,873) were taken in 2021 (NMFS Alaska Region, unpublished data). Aside from disruptions associated with the COVID-19 pandemic, there was also a major shift in gear usage in the sablefish IFQ fishery that could partially explain the relatively low seabird bycatch estimates in 2020. Many vessels in this fishery shifted from using hook-and-line gear to using pot gear. This was primarily done in an attempt to avoid whale depredation on sablefish catch. The number of fishing trips utilizing pot gear in the sablefish fishery increased from 274 in 2019 to 654 in 2020, and to 1,123 in 2021 (16.8%, 40.8%, and 64.8% of all sablefish trips, respectively; NMFS Alaska Region, unpublished data)[23]. The proportion of sablefish trips fished using pot gear in 2021 is the highest between 2012 and 2021. Take of seabirds by pot gear is relatively rare compared to take of seabird by hook-and-line gear. If the sablefish IFQ fishery

[23]The trip counts provided here are based on the NMFS Alaska Region Catch Accounting System (CAS) and the regulatory definition of a fishing trip (50 CFR part 679.2). These counts may differ from trip counts previously published in the North Pacific Observer Program Annual Reports, because they include state managed fisheries, are not based on Observer deployments, and reflect current data rather than a previous snapshot in time.

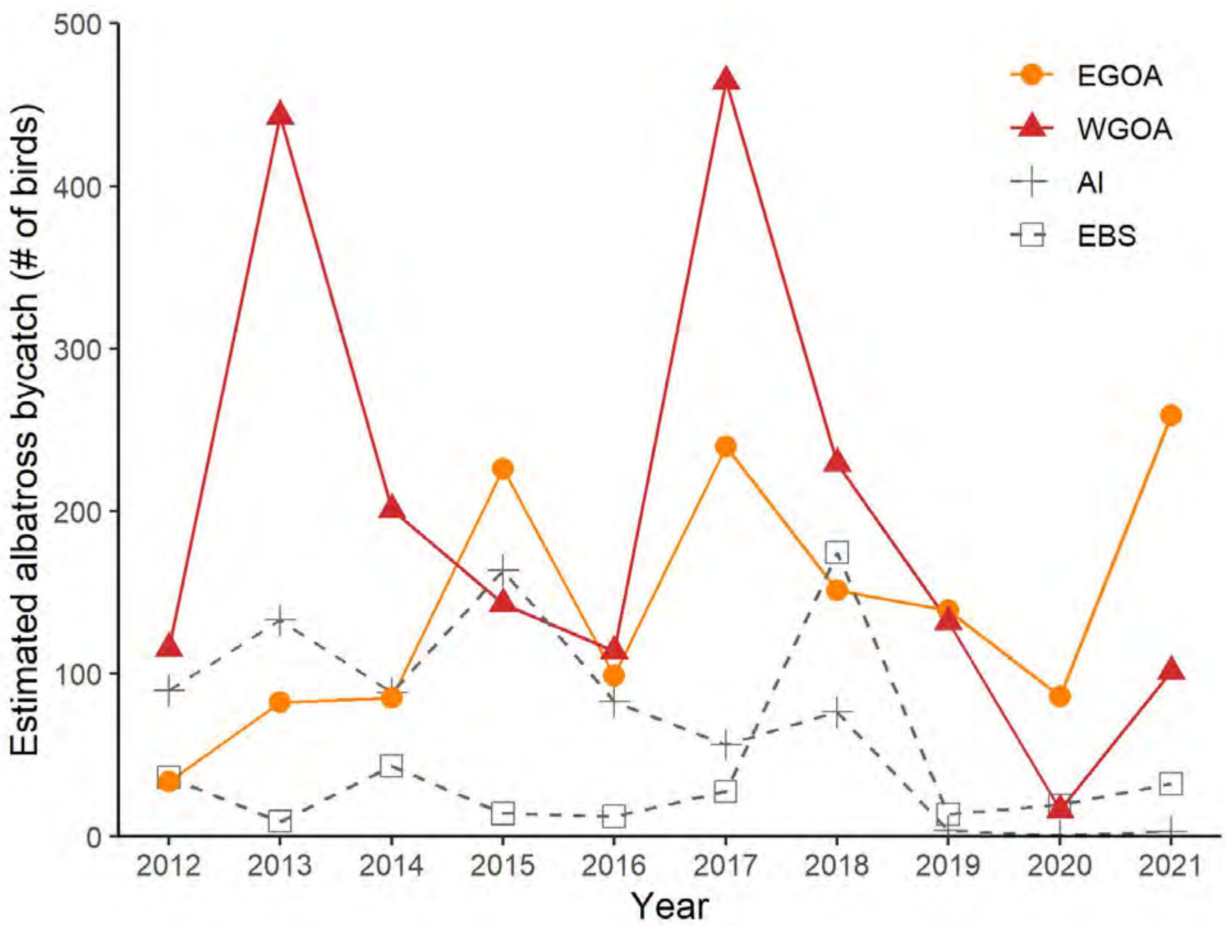

Figure 89: Total estimated albatross bycatch in eastern Gulf of Alaska (EGOA), western Gulf of Alaska (WGOA), Aleutian Islands (AI), and eastern Bering Sea (EBS) groundfish and halibut fisheries, all gear types combined, 2012 through 2021 (halibut fisheries 2013 through 2021).

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.

Further, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates may be downward biased.

Dietrich and Fitzgerald (2010) found in an analysis of 35,270 longline sets from 2004 to 2007 that the most predominant species, northern fulmar, only occurred in 2.5% of all sets. Albatross, a focal species for conservation efforts, occurred in less than 0.1% of sets. Thus, while annual seabird bycatch estimates number in the 1,000's, given the vast size of the fishery, actual takes of seabird remains relatively uncommon (Krieger and Eich, 2021).

Implications: Estimated seabird bycatch in the GOA fisheries in 2021 increased compared to 2020, but remained below the 2012 through 2020 average. No takes of ESA-listed seabirds occurred in any groundfish or halibut fisheries off Alaska in 2021.

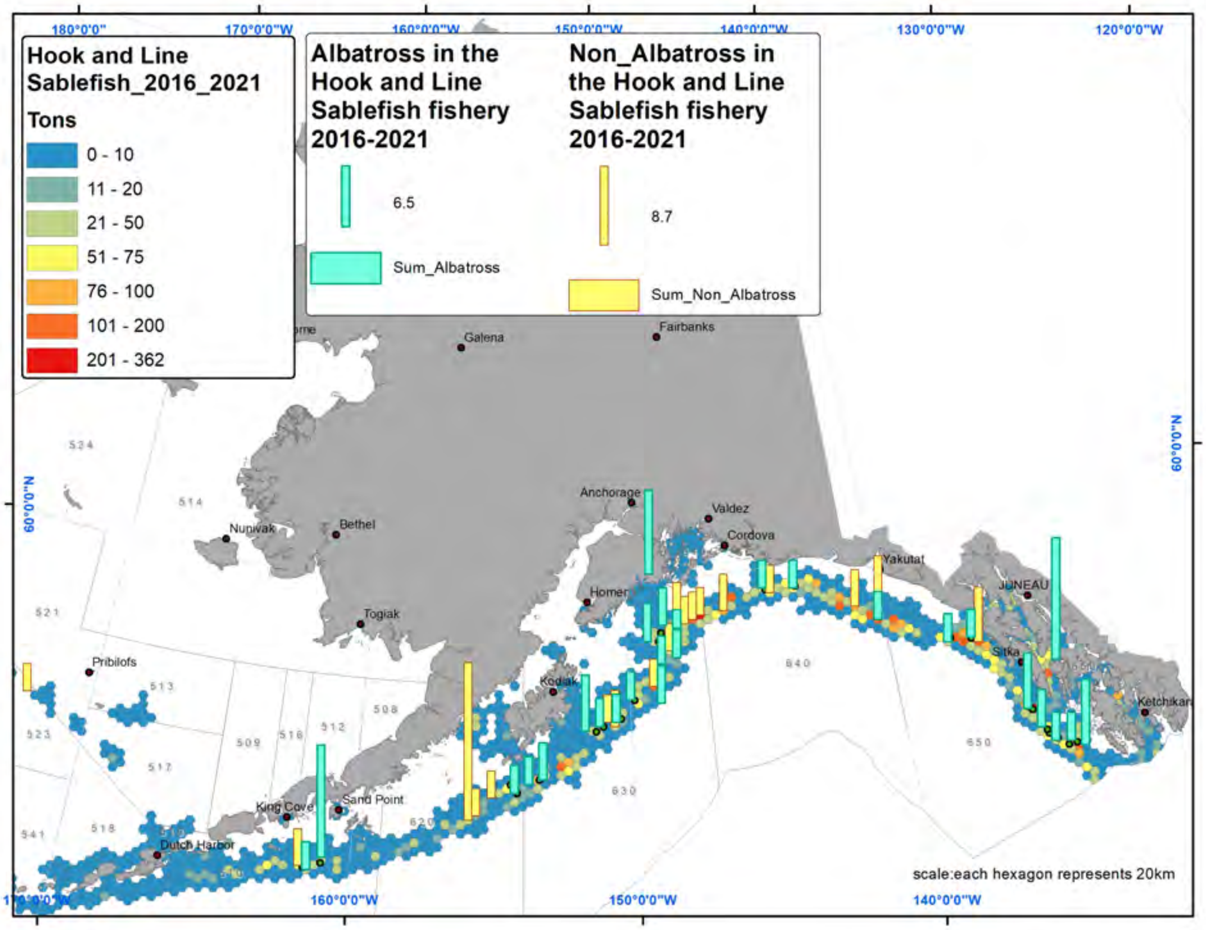

Figure 90: Spatial distribution of observed seabird bycatch from 2016 – 2021 from the sablefish IFQ fishery from vessels using hook and line gear. Colored vertical bars indicate the sum of incidental takes at a location grouped at 20 km resolution. Incidental takes are separated between takes of albatross and takes of non-albatross seabirds. Incidental takes of seabirds are overlaid on to heat maps depicting fishing effort for the sablefish IFQ fishery.

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

Maintaining and Restoring Fish Habitats

Fishing Effects to Essential Fish Habitat

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Last updated: August 2022

Description of indicator: Fishing gear can impact essential fish habitat (EFH) used by a fish or crab species for the processes of spawning, breeding, feeding, or growth to maturity. This indicator uses output from the Fishing Effects (FE) model to estimate the area of geological and biological features disturbed in the Aleutian Islands, Bering Sea, and Gulf of Alaska, utilizing spatially-explicit VMS data. A time series for this indicator began in 2003 when widespread VMS data became available.

Status and trends: The species and species complex time series data and FE maps are currently under review by stock authors and experts as part of EFH component 2, "Fishing activities that may adversely affect EFH", for the 2022 EFH 5-Year Review. The review process is part of an MSA requirement for Fishery Management Councils to describe and identify EFH for FMP species. It began with the 2005 EFH EIS (National Marine Fisheries Service, 2005) and then the first 5-Year Review was in 2010. The last FE model review was during the 2017 EFH 5-Year Review. For the 2022 Review, an updated model was published in 2019 (Smeltz et al., 2019) and model updates were presented to the SSC during the February 2022 NPFMC meeting. Stock author review of species or species complex results will be presented to the Crab Plan Team and Joint Groundfish Plan Teams meeting in September 2022, and the SSC during the October 2022 NPFMC meeting. During this review and analysis process, the most recent FE model output data is from December 2020 and was provided for the 2021 Ecosystem Status Reports (Ferriss and Zador, 2021). Once the 2022 EFH 5-Year Review process is completed, updated information will be available.

Areas Closed to Bottom Trawling in the BSAI and GOA

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Last updated: September 2021

Description of indicator: Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Figure 91, Table 6). Some of the trawl closures are in effect year-round while others are seasonal. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat or vulnerable species' life stages. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high.

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

Implications: With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling. For additional background on fishery closures in the U.S. EEZ off Alaska, see Witherell and Woodby (2005). Steller Sea Lion closure maps are available here at the website `https://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones`

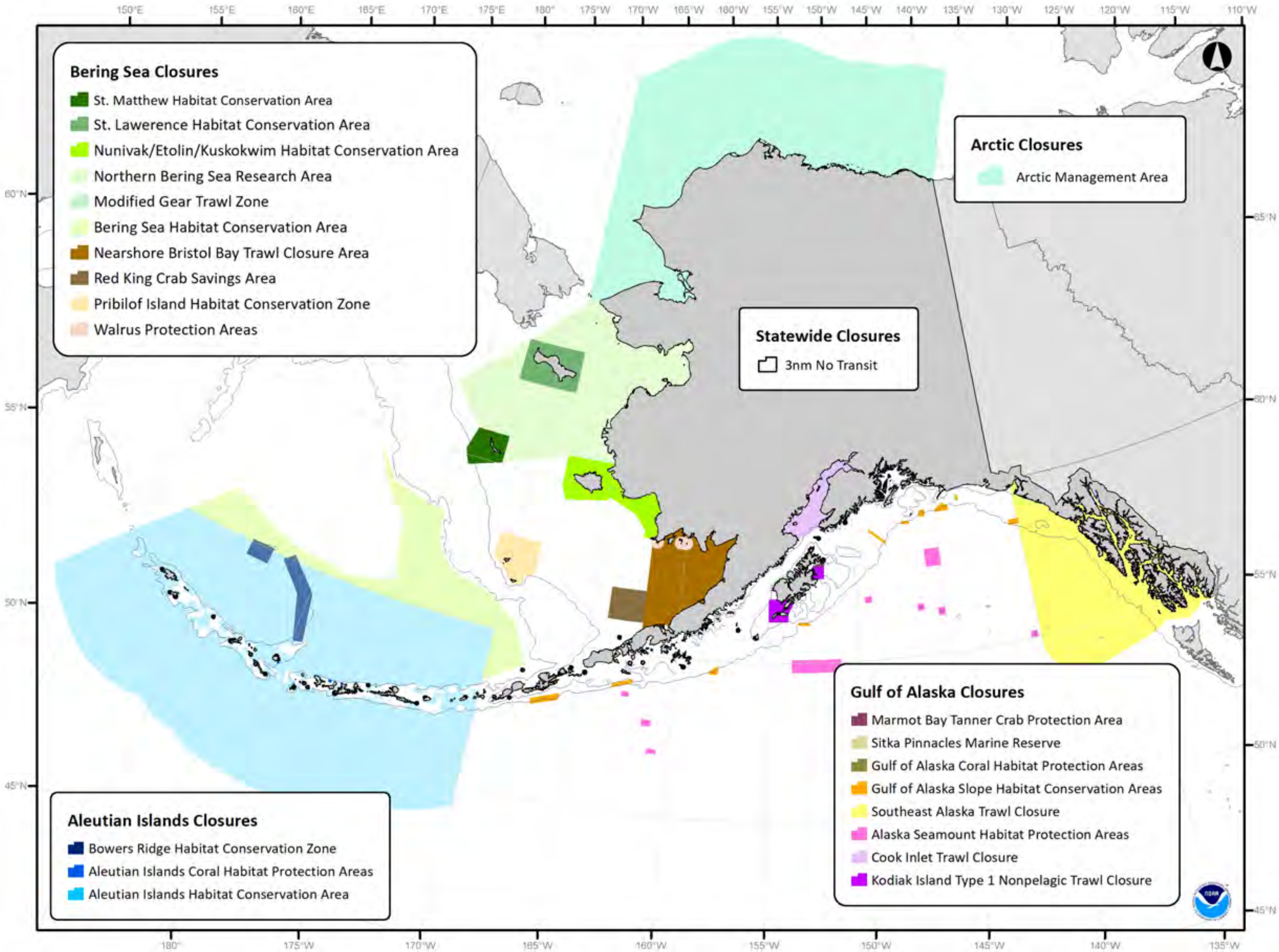

Figure 91: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Table 6: Time series of groundfish trawl closure areas in the BSAI and GOA, 1995–2020. LLP= License Limitation Program; HCA = Habitat Conservation Area; HCZ = Habitat Conservation Zone.

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

Sustainability (for consumptive and non-consumptive uses)

Fish Stock Sustainability Index—Gulf of Alaska

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Last updated: August 2022

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[24]. The FSSI will increase as overfishing is ended and stocks rebuild to the level that provides maximum sustainable yield. The FSSI is calculated by awarding points for each fish stock based on the following rules:

1. Stock has known status determinations:
   (a) overfishing level is defined = 0.5
   (b) overfished biomass level is defined = 0.5
2. Fishing mortality rate is below the "overfishing" level defined for the stock = 1.0
3. Biomass is above the "overfished" level defined for the stock = 1.0
4. Biomass is at or above 80% of the biomass that produces maximum sustainable yield (B_{MSY}) = 1.0 (this point is in addition to the point awarded for being above the "overfished" level)

The maximum score for each stock is 4.

In the Alaska Region, there are 35 FSSI stocks and an overall FSSI of 140 would be achieved if every stock scored the maximum value, 4. Over time, the number of stocks included in the FSSI has changed as stocks have been added and removed from Fishery Management Plans (FMPs). To keep FSSI scores for Alaska comparable across years we report the FSSI as a percentage of the maximum possible score (i.e., 100%).

The list of stocks included in the FSSI was revised in 2020 to focus on stocks of heightened commercial and recreational importance. In the GOA, this meant that the deepwater flatfish complex was removed from the FSSI and Shortraker rockfish were added. In the GOA region there are 14 FSSI stocks including sablefish. The assessment for sablefish is based on aggregated data from the GOA and BSAI regions[25].

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

[24] https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates
[25] https://www.fisheries.noaa.gov/national/population-assessments/status-us-fisheries#fish-stock-sustainability-index

Table 7: Summary of status for GOA FSSI stocks managed under federal fishery management plans, updated through June 2022.

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

stocks in the BSAI region are overfished but are not subject to overfishing. None of the other non-FSSI stocks are known to be subject to overfishing, are overfished, or are approaching an overfished condition. For more information on non-FSSI stocks see the Status of U.S. Fisheries webpage[26].

Status and trends: The GOA FSSI in 2022 is unchanged from 84.8% in 2021 (baseline 2006–2021; Figure 92). As of June 30, 2022, 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 7).

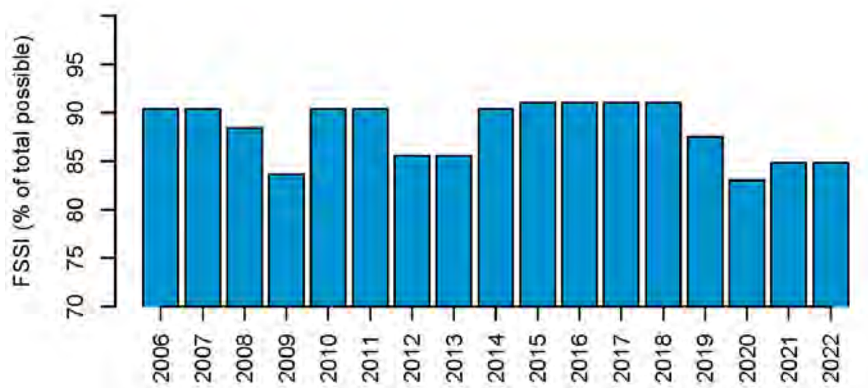

Figure 92: The trend in FSSI from 2006 through 2022 for the GOA region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: [27].

The overall Alaska FSSI generally trended upwards from 80% in 2006 to a high of 94% in 2018 (Figure 92) and has since trended downward to 88.2% in 2022. The biomass of GOA Pacific cod continues to be below 80% of BMSY (Table 2). 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 $B/_{MSY}$.

[26]https://www.fisheries.noaa.gov/national/population-assessments/status-us-fisheries

Table 8: GOA FSSI stocks under NPFMC jurisdiction updated June 2022 adapted from the Status of U.S. Fisheries website[28]. See FSSI and Non-FSSI Stock Status Table on the Fishery Stock Status Updates webpage for definition of stocks and stock complexes.

Stock	Overfishing	Overfished	Approaching	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	2.60	4
GOA Shallow Water Flatfish Complex[a]	No	No	No	N/A	2.32	4
GOA Rex sole	No	No	No	N/A	2.36	4
GOA Blackspotted and Rougheye Rockfish complex[b]	No	No	No	N/A	1.77	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	1.51	4
GOA Pacific Ocean perch	No	No	No	N/A	1.91	4
GOA Pacific cod	No	No	No	N/A	0.55	3
Walleye pollock-Western / Central GOA	No	No	No	N/A	1.31	4
GOA BSAI Sablefish[e]	No	No	No	N/A	1.04	4

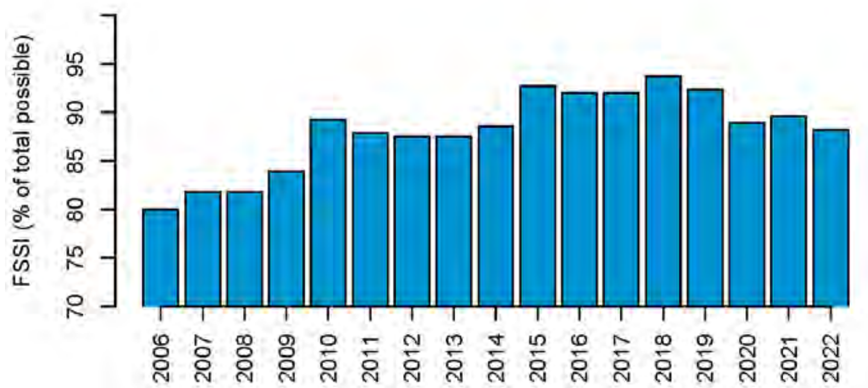

Figure 93: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2022. The maximum possible FSSI is 140 for 2006 to 2014, 144 from 2015 to 2019, and 140 in 2020–2022. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website[29].

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 93). 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% $_{MSY}$ for Pacific cod and sablefish.

Implications: The majority of Alaska groundfish fisheries appear to be sustainably managed, including GOA groundfish fisheries. However, the biomass of GOA Pacific cod remains below 80% of B_{MSY}. 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, Gulf of Alaska

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Last updated: August 2022

Description of indices: Total annual surplus production (ASP) of the groundfish complex in the Gulf of Alaska from 1978–2019 was estimated by summing annual production across 14 commercial groundfish stocks of 12 species (Table 9). Annual surplus production in year *t* was estimated as the change in total adult (mature) groundfish biomass across species from year *t* was estimated as the change in total adult (mature) groundfish biomass across species from year *t* (B_t) to year *t*+1 (B_{t+1}), plus total catches in year t (C_t):

$$ASP_t = \Delta B_t + C_t = B_{t+1} - B_t + C_t$$

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

$$u_t = C_t/B_t$$

Table 9: Species included in computing annual surplus production in the GOA management area.

Stocks
Walleye pollock (*Gadus chalcogrammus*)
Pacific cod (*Gadus macrocephalus*)
Arrowtooth flounder (*Atheresthes stomias*)
Flathead sole (*Hippoglossoides spp.*)
Northern rock sole (*Lepidopsetta polyxystra*) (2 stocks)
Southern rock sole (*L.bilineata*) (2 stocks)
Pacific Ocean perch (*Sebastes alutus*)
Northern rockfish (*S. polyspinus*)
Dusky rockfish (*Sebastes ciliatus*)
Rougheye / blackspotted rockfish (*S. aleutianus, S. melanostictus*)
Dover sole (*Microstomus pacificus*)
Sablefish (*Anoplopoma fimbria*)

Status and trends: The resulting indices suggest high interannual variability in groundfish production in the Gulf of Alaska (Figure 94), with low surplus production in recent years (time-series 1978–2019). ASP was very high in 1981/1982 associated with a number of strong recruitment events for multiple groundfish species after the 1976/77 oceanographic regime shift. The highest value was observed in 2013, due to a sharp increase in walleye pollock biomass resulting from a strong 2012 year class. ASP sharply declined after 2013 to its lowest values in 2014 and in particular 2016, and has remained relatively low since then. Total exploitation rates for the groundfish complex were generally low, ranging from 2.5–6% (Figure 94), with an increasing trend since the early 2000s. Trends in annual surplus production are dominated by variability in walleye pollock (Figure 96). Therefore, ASP for the GOA was also computed after excluding walleye pollock (Figure 95), suggesting a sharp decrease in non-pollock ASP during the heatwave in 2016, followed by a rapid recovery to relatively high levels. Non-pollock ASP shows an overall decreasing trend over time (-1,863 tons yr^{-1} $p = 0.056$), but the trend is strongly influenced by the low 2016 value.

Factors causing trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e., mortality from all non-fishery sources) during a given year. It is highest during periods of increasing total biomass and lowest during periods of decreasing biomass such as during the marine heatwave. In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Theory suggests that surplus production of a population will decrease as biomass increases much above B_{MSY}, which is the case for many species in the GOA management area. Surplus production has been at or near its lowest levels in recent years, reflecting a decreasing trend in total groundfish biomass, while total catches have remained relatively high. The observed declines were associated with decreasing biomass trends in walleye pollock, Pacific cod, arrowtooth flounder and northern rockfish. Declining trends were likely associated with the

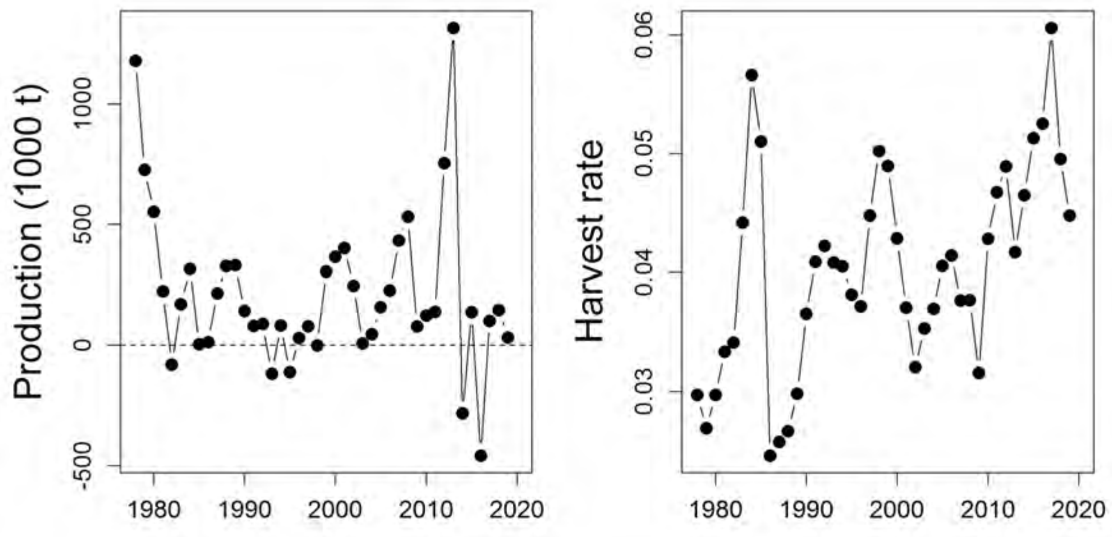

Figure 94: Total annual surplus production (change in biomass plus catch) across major groundfish species in the Gulf of Alaska and total harvest rate (total catch / beginning-of-year biomass, each summed across all major groundfish species).

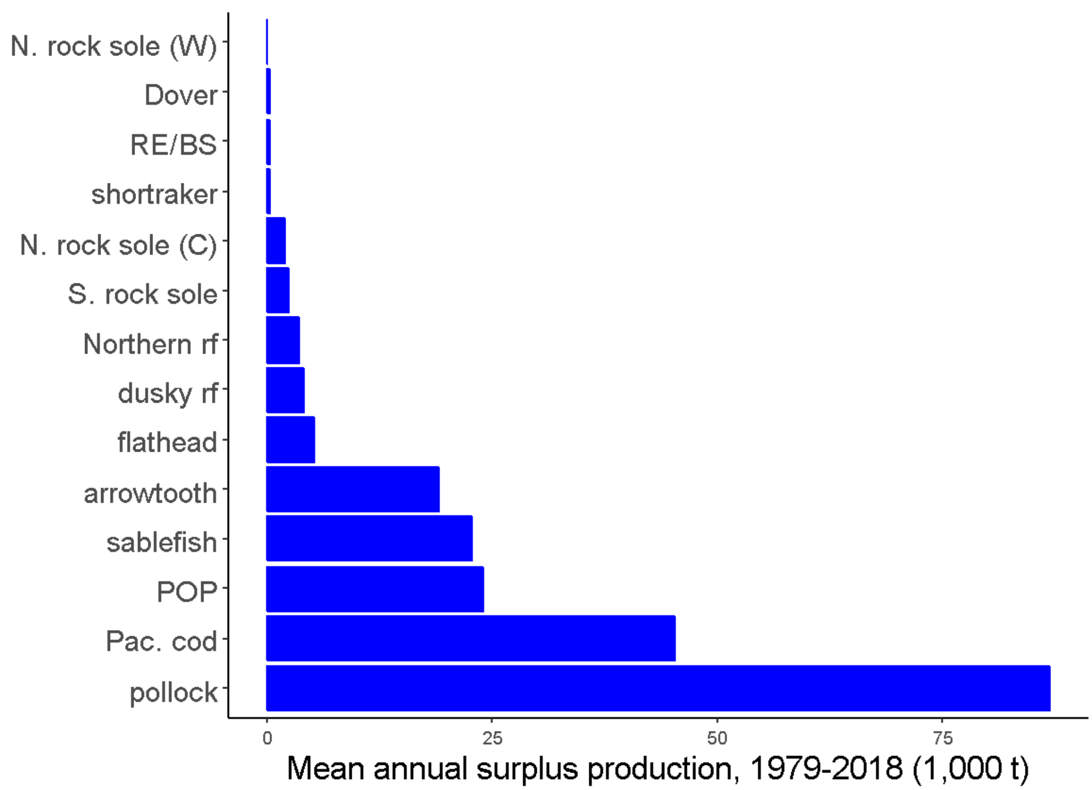

Figure 95: Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and total harvest rate (total catch / beginning-of-year biomass, each summed across all major groundfish species, **excluding walleye pollock).**

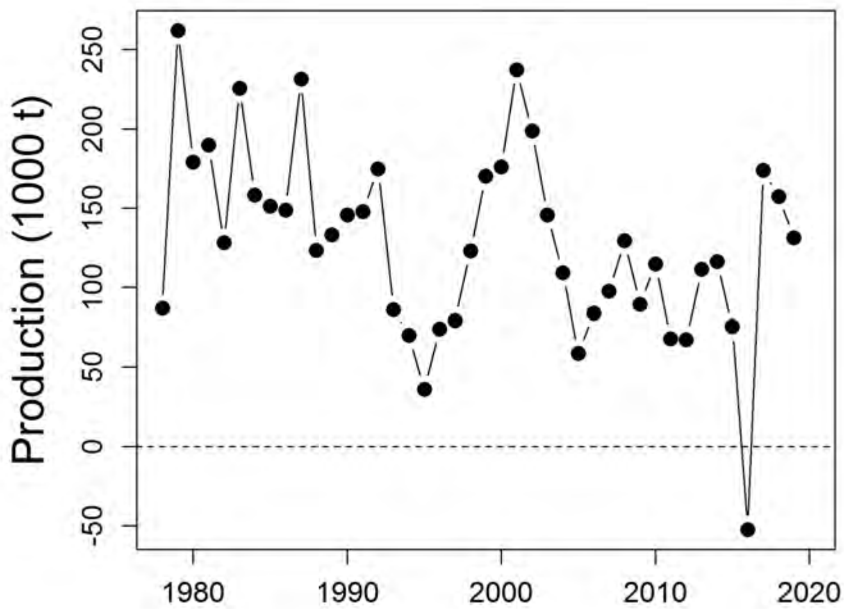

Figure 96: Contributions of each stock to mean annual surplus production

marine heatwave and surplus production has remained low through 2019, the last year for which it can be computed. Exploitation rates are primarily determined by management, reflecting a relatively precautionary management with rates that have averaged 4% of the total combined biomass of the species in Table 9. The exploitation rate increased from 2013 to 2017 as the biomass of a number of stocks declined, but has decreased since then due to a decrease in exploitable biomass.

Implications: Under certain assumptions, aggregate surplus production can provide an estimate of the long-term maximum sustainable yield of these groundfish complexes (Mueter and Megrey, 2006, Figure 96). However, there was relatively little contrast in total biomass over time in the GOA and there is only weak evidence of production peaking at an intermediate level of biomass. Monitoring surplus production provides insights into the overall productivity of the system and a decreasing trend or prolonged periods of low or negative surplus production in an exploited system can indicate reduced system productivity.

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Appendices

History of the ESRs

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

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

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

Each year since 1999, the Ecosystem Status Reports have included new contributions and will continue to evolve as new information becomes available. Evaluation of the meaning of observed changes should be in the context of how each indicator relates to a particular ecosystem component. For example, particular oceanographic conditions, such as bottom temperature increases, might be favorable to some species but not for others. Evaluations should follow an analysis framework such as that provided in the draft Programmatic Groundfish Fishery Environmental Impact Statement that links indicators to particular effects on ecosystem components.

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

We initiated a regional approach to the ESR in 2010 and presented a new ecosystem assessment for the eastern Bering Sea. In 2011, we followed the same approach and presented a new assessment for the Aleutian Islands based on a similar format to that of the eastern Bering Sea. In 2012, we provided a preliminary ecosystem assessment on the Arctic. Our intent was to provide an overview of general Arctic ecosystem information that may form the basis for more comprehensive future Arctic ecosystem assessments. In 2015, we presented a new Gulf of Alaska report card and assessment, which was further divided into Western and Eastern Gulf of Alaska report cards beginning in 2016. This was also the year that the previous Alaska-wide ESR was split into four separate reports, one for the Gulf of Alaska, Aleutian Islands, eastern Bering Sea, and the Arctic[30].

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

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

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

[30]The Arctic report is under development

reviews. With the risk table, formal consideration of concerns—including ecosystem—are documented and ranked, and the stock assessment author presents a recommendation for the maximum ABC or a value lower. Five risk tables were completed in 2018 as a test case. After review, the Council requested risk tables to be included in all stock assessments in 2019.

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

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

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

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 97). The primary stakeholders in this case are the North Pacific Fishery Management Council. Research and development of risk analyses and management strategies is ongoing and will be referenced or included as possible.

Figure 97: The IEA (integrated ecosystem assessment) process.

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

Past reports and all groundfish stock assessments are available at `https://www.fisheries.noaa.gov/`

alaska/population-assessments/north-pacific-groundfish-stock-assessment-and-fishery-evaluation

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

Responses to Comments from the North Pacific Fishery Management Council's Science and Statistical Committee (December 2021 and October 2022 meetings)

December 2021 SSC Final Report to the NPFMC
C-3 BSAI and C-4 GOA Ecosystem Status Reports
The SSC received presentations by Elizabeth Siddon (NOAA-AFSC), Bridget Ferriss (NOAA-AFSC), and Ivonne Ortiz (UW-CICOES) on the Ecosystem Status Reports (ESRs) for the eastern Bering Sea, Gulf of Alaska, and the Aleutian Islands. The presentations were informative and highlighted the great strides that the authors and editors of the ESRs have made in producing documents that are insightful and of benefit to the management of federal fisheries off Alaska. The SSC appreciates the consistent high quality of the ESRs and their presentations. There was no public testimony.

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

General Comments applicable to all three ESRs
The general summaries and integrated sections on the physical environment and seabirds (GOA, EBS, AI), and Regional Highlights (AI) were information-dense and provided excellent syntheses of the individual reports. The SSC appreciates the efforts that went into these components of the reports. The Noteworthy Topics sections continue to highlight observations and issues that demand attention. The excision of the Executive Summary reduced redundancy and streamlined the summary portion of the ESR. The Report Card remains very useful.

Thank you. We appreciate the SSC's feedback. We will continue to revise how information is presented through the ESRs in response to your feedback and to optimize the utility and effectively of the ESRs

The SSC supports a holistic review of how economic and social science information is communicated and applied to Council decision-informing analytic products in 2022 (see Economic SAFE Section of this SSC report, and October 2021 SSC Minutes). The SSC requests that the review be transparent and inclusive, consistent with its suggestion for such a review during the October 2021 meeting. The SSC looks forward to the planned synthesis products for the Fishing and Human Dimensions section. In anticipation of this holistic review, some human dimensions indicators were not included in the 2021 report to better align the focus of the ESRs on informing next year's ABC determinations.

The response below was provided by NOAA's Alaska Fisheries Science Center Economics and Social Science Research Program.
"The AFSC Economics and Social Science Research Program (ESSRP) devised a framework[31] to help explain the economic and social information it provides in various annual reports to the NPFMC (Figure 98). This framework has guided ESSRP's annual provision of social and economic information into NPFMC harvest specifications processes since 2021. There are several socio-economic documents produced annually by ESSRP and the placement of future social and economic indicators across these outlets will be guided by the decision the document is intended to inform (e.g., ABC/TAC/general management), the geographic and time scales of the indicator, and whether the indicator is intended to

[31] https://meetings.npfmc.org/CommentReview/DownloadFile?p=7a902abf-29ba-4c62-8b7e-4930eb80800b.pdf&fileName=PRESENTATION_ESSRP_GPT20210921.pdf

inform stock health. A SocioEconomic Aspects in Stock Assessments Workshop (SEASAW), specifically for the North Pacific, as suggested by the SSC in October 2021 is likely of interest to many, but the goals of that type of workshop are confounded by the NPFMC motion from October 2018[32], which states that socio-economic factors are to be considered during TAC setting but should not be incorporated into ABC recommendations. In light of this, ESSRP will not produce synthesized products for a "Fishing and Human Dimensions" section of the ESR, but will continue to provide syntheses and analyses of the economic condition of groundfish and crab fisheries in their respective economic SAFE reports as well as social conditions for communities highly engaged in FMP groundfish and FMP crab fisheries in the Annual Community Engagement and Participation Overview (ACEPO). These documents offer the appropriate length and context to address these critical socio-economic issues. ESSRP seeks to avoid duplicative effort by recreating this information in the ESR or potentially providing unusable information at the Large Marine Ecosystem (LME) scale. Stock-specific economic indicators are currently provided for economic context within the stock assessment itself via the Economic Performance Report (EPR) for several stocks (including EBS pollock), or are included as an appendix. Economic and social metrics that have a direct impact on stock health (and thus ABC recommendation) could potentially be included in an ESP, except for the prohibition on doing so according to the NPFMC October 2018 motion. Therefore, relatively few social and economic metrics are included in the ESR and ESPs. However, extensive social and economic information are provided at appropriate scales in the Economic SAFE and ACEPO reports as well as available on the web via AKFIN's Human Dimensions of Fisheries Data Explorer[33]."

The "Purpose of the ESR" section (p.4) in each report indicates that the SSC is the primary audience (for setting ABCs/OFLs) but also the AP and Council. The SSC has frequently discussed the numerous ecosystem-related documents that are produced through the Council process and some excellent infographics have been developed to indicate how and when they are used and how they differ (e.g., through the Climate Change Task Force, BS FEP). While the SSC/AP/Council are the main audiences for the report, many industry and community stakeholders use the ESRs as well as the "In Briefs". **The SSC suggests including such a flow chart/infographic in this section of the ESR to visualize the process.**

An infographic has been added to the "Purpose of the Ecosystem Status Reports" section (see p. 2, Figure 1). This figure depicts the current flow of ecosystem information in the ESRs that supports Ecosystem-Based Fisheries Management through Alaska's annual harvest specification process. The 'honeycomb' on the right shows examples of ecosystem indicators that are provided to Ecosystem Status Reports (ESRs) at the Large Marine Ecosystem (LME) scale and/or to Ecosystem and Socio-economic Profiles (ESPs) at the species-based level.

"In Briefs" are planned for the EBS, GOA, and AI and a second outreach video is being developed - summarizing the ESR products and process. The authors have settled on a strategy that includes the annual production of "In Briefs". The authors noted there will be intermittent production of storymaps focused on specific ecosystem stories and no additional videos at this time. **The SSC is supportive of these continued efforts to disseminate ESR information to stakeholders and communities and appreciates the efforts to provide hard-copy products to remote communities where digital media may be difficult to download or otherwise access.** *The SSC looks forward to hearing any feedback from end-users on how these products are used and valued. The SSC notes the ESR author participation at the recent Coastal Communities Forum in Unalaska/Dutch Harbor hosted by the*

[32] https://meetings.npfmc.org/CommentReview/DownloadFile?p=c93128f5-9fb8-42be-92bf-9b4c5daec17e.pdf&fileName=C2%20COUNCIL%20MOTION%20SocioEconomic.pdf

[33] https://reports.psmfc.org/akfin/f?p=501:2000

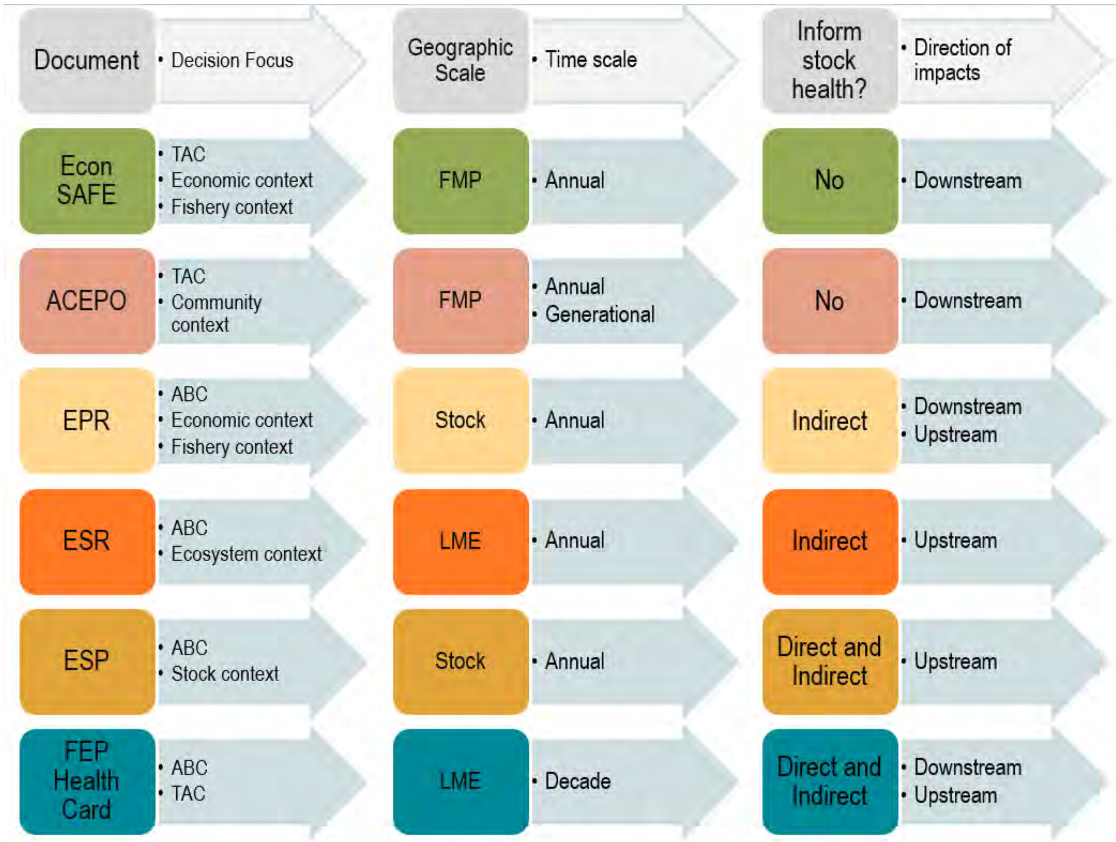

Figure 98: NOAA Alaska Fisheries Science Center's human dimensions indicators mapping. Impacts are assessed with respect to the health of a given stock(s) and are considered 'upstream' of the stocks when impacting environmental conditions and 'downstream' of the stocks when impacting social-economic outcomes of the fishery.

Qawalangin Tribe as a potentially rich context for the two-way flow of information on ESR topics of relevance to local communities and is supportive of similar future outreach efforts whenever practicable.

In December 2021, NOAA AFSC released a short video[34] describing how ecosystem scientists work collaboratively to develop Alaska's Ecosystem Status Reports.

The ESR authors greatly appreciate the support of the AFSC Communications team to help produce the "In Briefs". At this time, StoryMaps are not planned for the 2022 ESRs.

GOA Ecosystem Status Reports

Noteworthy topics

As discussed in the minutes of the October 2021 SSC meeting, there were two noteworthy occurrences in the GOA in 2021, both in the western Gulf of Alaska. First, there was a mid-July die-off of kittiwakes

[34] The video can be found here: `https://videos.fisheries.noaa.gov/detail/videos/alaska/video/6287018070001/alaska%E2%80%99s-ecosystem-status-report:-a-collaborative-approach?autoStart=true`

and gulls on Middleton Island. Tests for avian influenza and products of harmful algal blooms (saxitoxin and domoic acid) were negative, but tests for Clostridia botulinum and botulism toxin type C were positive. It is likely, but not yet confirmed, that these birds ingested Clostridia organisms while bathing in a small freshwater pond on Middleton Island. It is very unlikely that this problem will migrate to commercially important fish species, though the bacteria may reappear on Middleton Island or on the mainland where the birds may roost while foraging.

The second issue was the observation of four unique North Pacific right whales along the shelf southeast of Kodiak Island (Albatross Bank, with two near Barnabas Trough, and two near the Trinity Islands). This is extremely positive news from a conservation point of view, as there are believed to be only 30 individuals of this species in the eastern North Pacific. On the east coast of the United States, right whales are subject to entanglement in fishing gear (particularly the lines between lobster buoys and the traps on the bottom) and ship strikes. **At the very least, the SSC recommends that the GOA fishing fleets be made aware of where these whales were sighted and are requested to do their best to avoid harming them.**

NOAA's Alaska Regional Office (Sustainable Fisheries Branch) circulated an outreach flier (Figure 99) in January 2022 to industry and other relevant groups, produced in response to recent increases in sightings of right whales in Alaska. The flier contains information regarding areas where they were sighted and contact information to report additional sightings.

Key metrics of stability in the groundfish community, including high total biomass, low average biomass, variability over time, high species richness and diversity, and stable (eastern GOA) or slightly increasing (western GOA) mean length and lifespan of groundfish, point to overall high stability and resilience in the GOA (represented by species regularly caught by the AFSC bottom trawl survey). The SSC notes that is a promising key message of stability for groundfish (in bottom trawls) to perturbations. **The SSC encourages consideration of observed groundfish responses within the context of the overall responses across multiple trophic levels and species within the Gulf of Alaska large marine ecosystem (e.g., Suryan et al. 2021).**

The editor agrees with this comment and will include a broader marine context when presenting NOAA bottom trawl (or other survey) data in the future.

Prince William Sound Synthesis
The addition of a summary of findings in Prince William Sound was a welcome addition to the GOA ESR.

Thank you for noting this new addition. Given the SSC's feedback, we will continue to include this Prince William Sound summary in the future.

BSAI Forage Fish (pp32) **The SSC concurs with the BSAI GPT recommendation for a forage species workshop to discuss** *(1) surveying and population estimation of forage species, (2) importance of forage to different managed species (e.g., evaluate the suite of current food web models), (3) questions about how climate change may impact forage biomass and exploitation rates, (4) how best to report on changing populations, scientific knowledge about forage species, and the dependence of other species on them; including timing, frequency, and scope of the report, and (5) potential resulting management measures from shift in bycatch or spatial distribution of the forage base.* **The SSC also recommends that in light of the recent substantial increases in squid catch levels, this workshop focuses on identifying the threshold for placing squid back in the fishery.**

The BSAI GPT recommended coordination between editors of the ESR and the forage report to reduce redundancy. While the SSC supports efforts to reduce redundancy, there was hesitancy to support the initial suggestion of considering a combined forage species report for Alaska due to the significant differences in stock structure, ecosystem role, and dynamics across the GOA, BS and AI. **The SSC recommends that this topic would be a good discussion topic for the proposed workshop.**

The ESR editors, the Forage Report editor, and others at NOAA's Alaska Fisheries Science Center convened a virtual "Forage Congress" with two half-day meetings on March 30 and April 6, 2022. This Forage Congress had four major objectives: (1) identify major forage taxa for each Large Marine Ecosystem; (2) inventory major research including surveys, process research, fishery-dependent collections, and analytic methods; (3) identify major scientific goals and knowledge gaps; and (4) provide specific recommendations to AFSC leadership regarding future research priorities (NOAA tech memo is in development). This workshop helped to develop an understanding of AFSC's internal engagement in forage research and monitoring, to be able to better engage in the broader discussions described by the SSC in these comments.

October 2022 SSC Draft Report to the NPFMC
C-1 BSAI Crab
Ecosystem Status Report Preview
The SSC received remote presentations from Elizabeth Siddon (NOAA-AFSC), Ivonne Ortiz (NOAA-AFSC), and Bridget Ferriss (NOAA-AFSC). There was no public testimony. The SSC thanks the presenters for their efforts in providing excellent, targeted information related to crab stock assessments. In particular, the SSC greatly appreciates the presentation of slides with the "big picture" summary at the top, and then supporting information provided below in highly condensed form. The new format resulted in a smooth, clear, efficient presentation.

Thank you. We appreciate the SSC's feedback. We will continue to strive to provide 'smooth, clear, efficient' presentations.

In general, there were no new major environmental concerns reported to date in 2022. *The major climate indices were in the normal range, with indications that the marine heatwaves were of less concern in the GOA and EBS but continued in the Aleutian Islands (AI).*

The GOA editor agrees with this statement but would add "no new major environmental concerns reported to date in 2022, relevant to groundfish in the GOA."

Figure 99: The outreach flier circulated by NOAA's Alaska Regional Office regarding North Pacific Right Whales in Alaska.

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 Bond, p.27)

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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 western GOA (147°W–163°W). (See Watson, p.36)

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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.70)

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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.70)

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Motile epifauna biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community of the western GOA. In the 2016 report, this indicator included the entire survey area. (See Whitehouse, p.147)

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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 Hatch, p 86).

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Apex predator biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The apex predator foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. Fish in this guild include: Pacific cod, arrowtooth flounder, halibut, sablefish, large sculpins, and skates. Marine mammals, seabirds, and some other fishes such as sharks are included as constant ecopath-estimated biomasses. (See Whitehouse contribution, p.147)

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Black-legged kittiwake reproductive success

Black-legged kittiwakes are common surface-foraging, piscivorous seabirds that nest in the GOA. Reproductive success is defined as the proportion of nest sites with fledged chicks from the total nest sites that 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 124)

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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 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 Bond, p.27)

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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 Watson, p.36)

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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.72)

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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.72)

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Motile epifauna biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000 (in the odd years). The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community of the GOA. These values are summarized for the eastern region, where survey efforts vary among years. (See Whitehouse, p.147)

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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.91)

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Apex predator biomass

The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000 (in the odd years). The apex predator foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. Fish in this guild include: Pacific cod, arrowtooth flounder, halibut, sablefish, large sculpins, and skates. Marine mammals, seabirds, and some other fishes such as sharks are included as constant ecopath-estimated biomasses. These values are summarized for the eastern region, where survey efforts vary among years. (See Whitehouse, p.147)

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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.124)

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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 ± 1 SD from the mean within 5 years or less) for further consideration, rather than serving as a full statistical analysis of recent patterns.