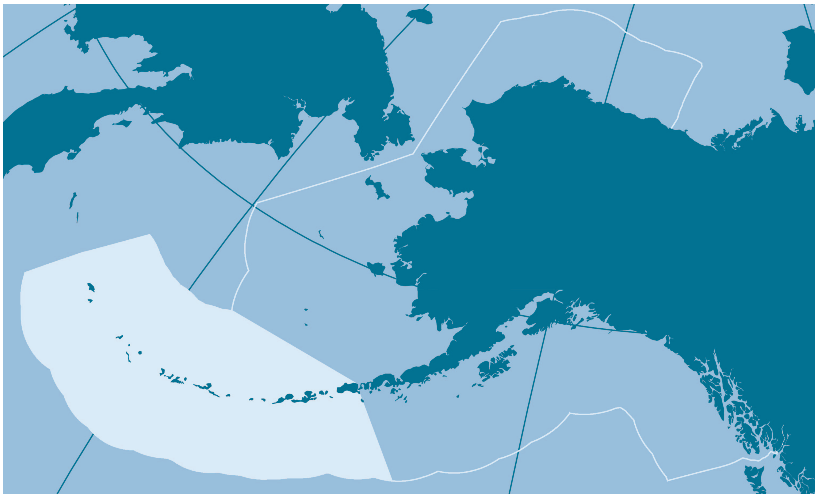
Ecosystem Status Report 2021

Aleutian Islands



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Purpose of the Ecosystem Status Reports

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

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

The SSC is the primary audience for this report, as the final ABCs are determined by the SSC, based on biological and environmental scientific information through the stock assessment and Tier process[1],[2]. TACs may be set lower than the ABCs due to biological and socioeconomic information. Thus, the ESRs are also presented to the AP and Council to provide ecosystem context to inform TAC and as well as other Council decisions. Additional background can be found in the Appendix (p. 115).

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

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

Aleutian Islands 2021 Report Card

For more information on individual Report Card Indicators, please see Description of Report Card indicators (p. 126). For more information on the methods for plotting the Report Card indicators, please see "Methods Description for Report Card Indicators" (p. 125).

* indicates Report Card information updated with 2021 data

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

Region-wide

- The North Pacific Index (NPI) effectively represents the state of the Aleutian Low. Above (below) average winter (November - March) NPI values imply a weak (strong) Aleutian Low and generally calmer (stormier) conditions. The NPI was above average during the winter of 2020-2021 before returning to near average again in summer 2021. The NPI has been above average for the last 5 winters. /sloppy
- The Aleutians Islands region experienced **suppressed storminess through fall and winter 2020/2021** across the region, potentially favoring foraging of plankton-eating seabirds (Bond et al., 2011).

Western Aleutian Islands

- The reproductive success of least and crested auklets, all planktivorous seabirds at Buldir Island was in above the long term average in 2021, indicating that **overall zooplankton availability was sufficient to support seabird reproductive success in 2021 and potentially other plankton eating commercial groundfish species**.
- Forage fish trends, as indicated by their percent in the composition of tufted puffin chick meals, have varied over the long term, with episodic peaks lasting 1–2 years. In general, Ammodytes (sand lance) have been absent starting 2010; age-0 gadids (pollock mostly), which had not been seen in great abundance since 2006, were above the long term average this year although not as abundant as in years past; and hexagrammids (primarily atka mackerel) were near average, improving from last year, thus signaling **potentially favorable conditions for fish foragers**. Not shown here, rockfish comprised 25% of tufted puffin chick meals. There were no seabird diets collected in 2020.
- Pelagic forager biomass, apex predator biomass and Steller sea lion (SSL) non-pup counts were not updated this year.
- The **amount of area trawled increased in 2020**, continuing its increasing trend since 2014, then last year a 4-year decline following measures aimed at increasing protection for Steller sea lions during 2012–2014. This increase is likely due to a rise in non-pelagic trawl effort. Commercial fishing patterns may reflect recent changes in economics, ownership, and fishing effort allocation. Trawled area has

remained within 1 to 3% through the time series. Note this indicator is updated annually with data for the previous year.

- There are no schools in the western Aleutian Islands.

Central Aleutian Islands

- Pelagic forager biomass, apex predator biomass and Steller sea lion (SSL) non-pup counts were not updated this year.
- The **amount of area trawled increased in 2020**, continuing its upward trend since 2015 and following a similar trend as in the western Aleutians. The increase, likely due to a rise in non-pelagic trawl effort, is the highest since 2015 when the percent area trawled was at its lowest following the 2012–2014 increasing protection measures for Steller sea lions. Changes in trawled area follows commercial fishing patterns, which may reflect recent changes in economics, ownership, and fishing effort allocation. Despite this year's increase, trawled area remains within 1 to 3% through the time series. Note this indicator is updated annually with data for the previous year.
- Both Adak and Atka **school enrollment has experienced a decline in the past 5 years**. This year's decrease keeps enrollment at Atka at the 10-student threshold that risks closure of the schools, while enrollment at Adak decreased from 18 last year (the highest since 2016) to 15 in October 2020. Decreasing enrollment trends impact the stability to families living in those communities. This indicator is updated anually with data for the previous year.

Eastern Aleutian Islands

- As indicated by their percent in the composition of tufted puffin chick meals **forage fish were not as abundant as in past years** with ammodytes (sand lance) at average levels, and both gadids (pollock) and hexamgrammids (atka mackerel) below average. Not shown, euphausiids made up 34% of the chick meals. This suggests puffins continue to respond to chnages in prey availability and that forage fish may not be as available as in other years for fish-eating commercial groundfish. Gadids were more common through the 1990s while hexagrammids are uncommon in this region. There were no seabird diets collected in 2020.
- Pelagic forager biomass, apex predator biomass and Steller sea lion (SSL) non-pup counts were not updated this year.
- The **amount of area trawled increased in 2020**, continuing its downward trend since 2018. Area trawled had been increasing following the 2012–2014 measures aimed at increasing protection for Steller sea lions. Changes in trawled area follows commercial fishing patterns, which may reflect recent changes in economics, ownership, and fishing effort allocation. Despite this year's increase, trawled area remains within 1 to 3% through the time series. Note this indicator is updated annually with data for the previous year.
- **School enrollment fell for the second year in a row, from its highest in 2019 at 443 students to 414 in October 2020**. This is the lowest since the recent enrollment in 2016–17 of 400 and 408 students. This primarily reflects trends in Unalaska, whereas the small communities have either closed schools (Nikolski, in 2009) or are at risk of closure if they fall under the 10 student threshold (False Pass, 10 students and Akutan with 17). As in the case in the central Aleutians, decreasing enrollment trends impact the stability to families living in those communities. This indicator is updated anually with data for the previous year.

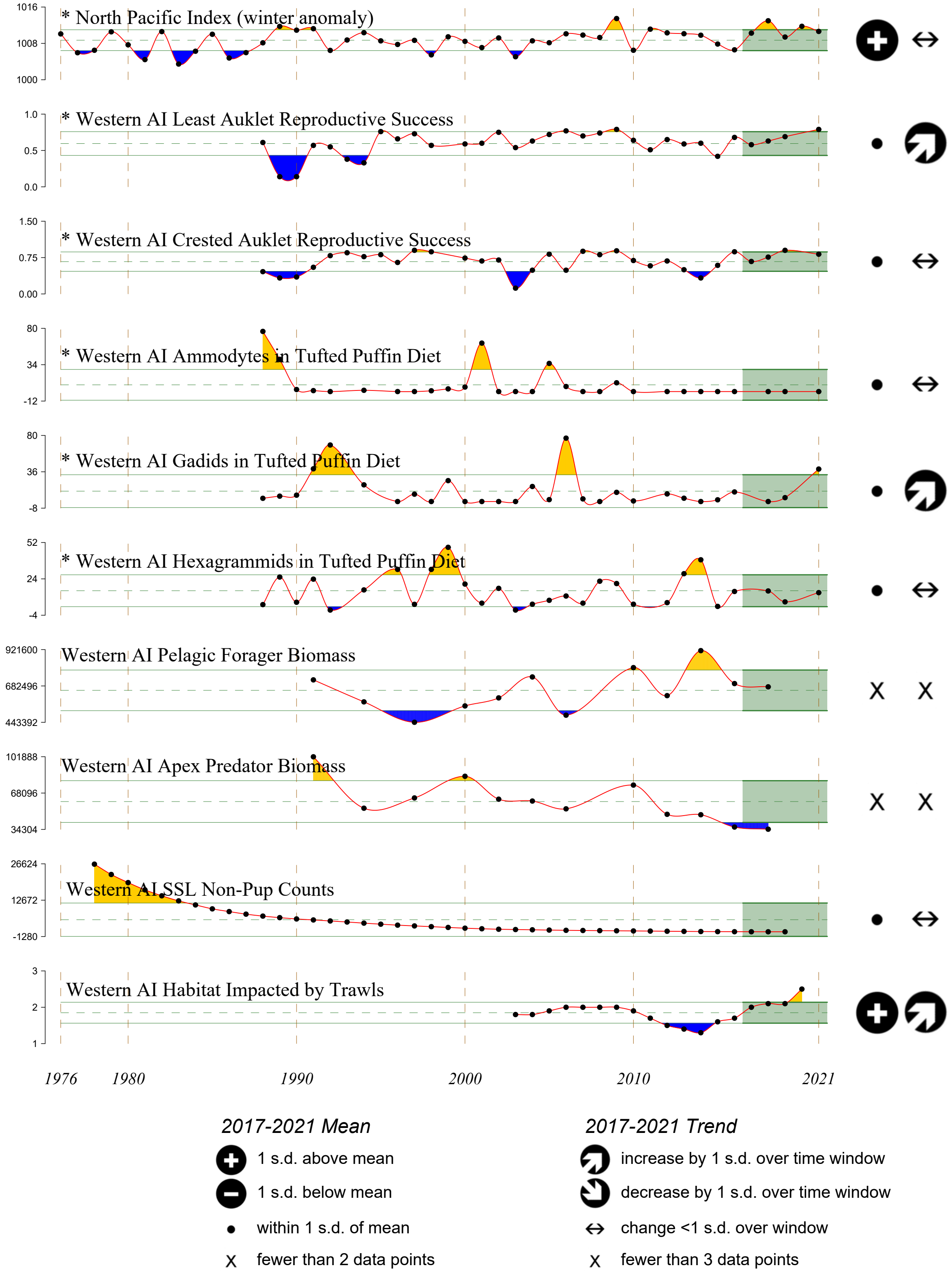

Figure 1: Region-wide and Western Aleutian Islands indicators. *indicates time series updated with 2021 data

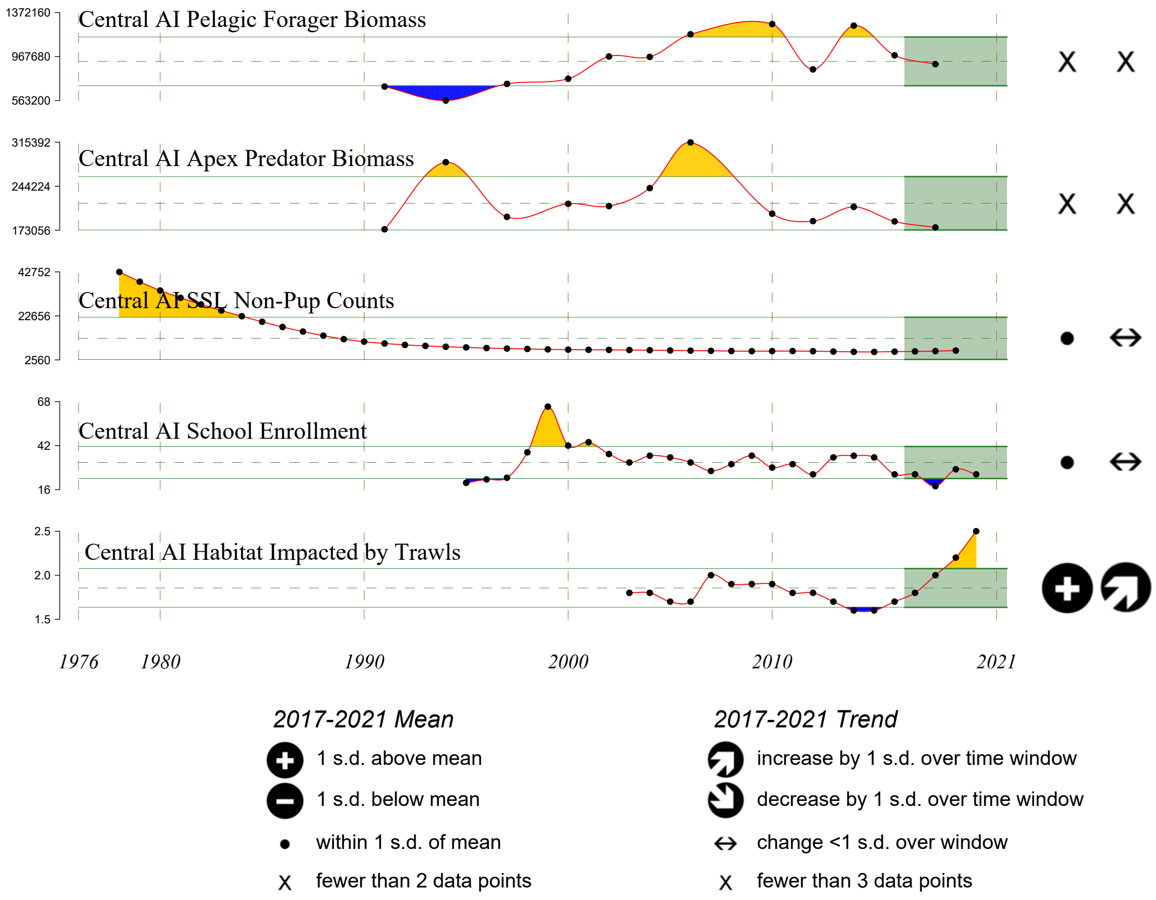

Figure 2: Central Aleutian Islands indicators. * indicates time series updated with 2021 data

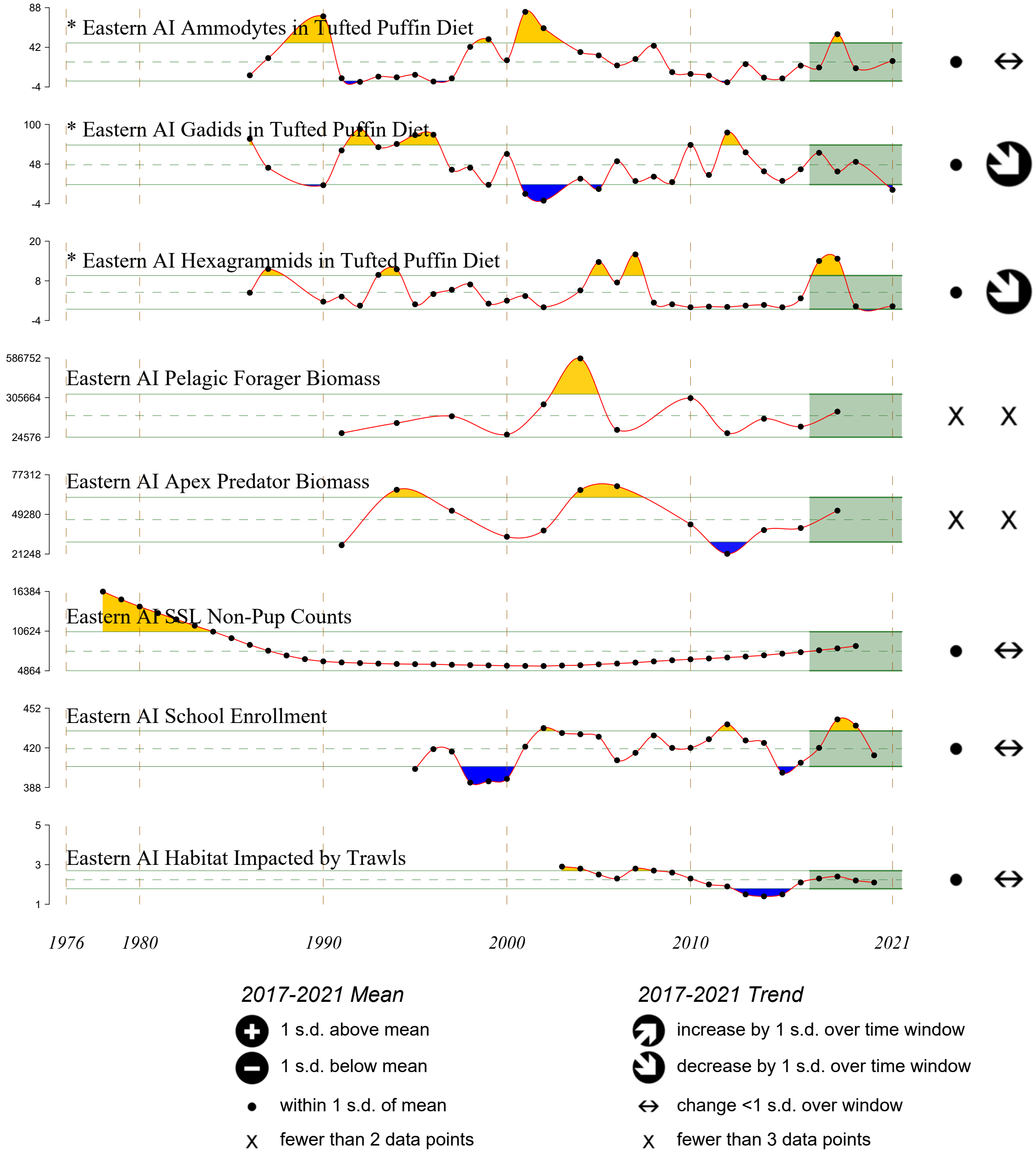

Figure 3: Eastern Aleutian Islands indicators. * indicates time series updated with 2021 data

Ecosystem Assessment

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The Aleutian Islands ecosystem assessment area

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

The three Aleutian Islands ecoregions are defined from west to east as follows (Figure 6). The western Aleutian Islands ecoregion spans 170° to 177°E. These are the same boundaries as the North Pacific Fishery Council fishery management area 543. This ecoregion was considered to be distinct from the neighboring region to the east by primarily northward flow of the Alaska Stream through wide and deep passes (Ladd, pers. comm.), with fewer islands relative to the other ecoregions.

The central Aleutian Islands ecoregion spans 177°E to 170°W. This area encompasses the North Pacific Fishery Council fishery management areas 542 and 541. There was consensus among the team that the eastern boundary of this ecoregion occurs at Samalga Pass, which is at 169.5°W, but for easier translation to fishery management area, it was agreed that 170°W was a close approximation. The geometry of the passes between islands differs to the east and west of Samalga Pass (at least until Amchitka Pass). In the central ecoregion the passes are wide, deep and short. The Alaska Stream, a shelf-break current, is the predominant source of water (Figure 5). There is more vertical mixing as well as bidirectional flow in the passes. This delineation also aligns with studies suggesting there is a biological boundary at this point based on differences in chlorophyll, zooplankton, fish, seabirds, and marine mammals (Hunt and Stabeno, 2005).

The eastern Aleutian Islands ecoregion spans 170°W to False Pass at 164°W. The passes in this ecoregion are characteristically narrow, shallow and long, with lateral mixing of water and northward flow. The prominent source is from the Alaska Coastal Current, with a strong freshwater component. This area encompasses the NPFMC fishery management areas 518, 517 (EBS) and the western half of 610 (GOA).

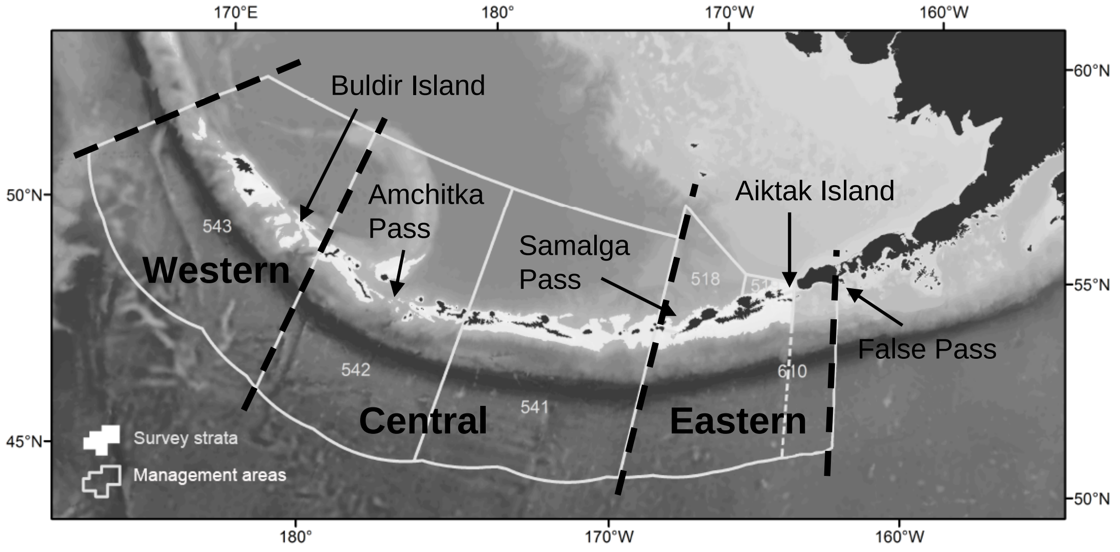

Figure 4: The three Aleutian Islands assessment ecoregions.

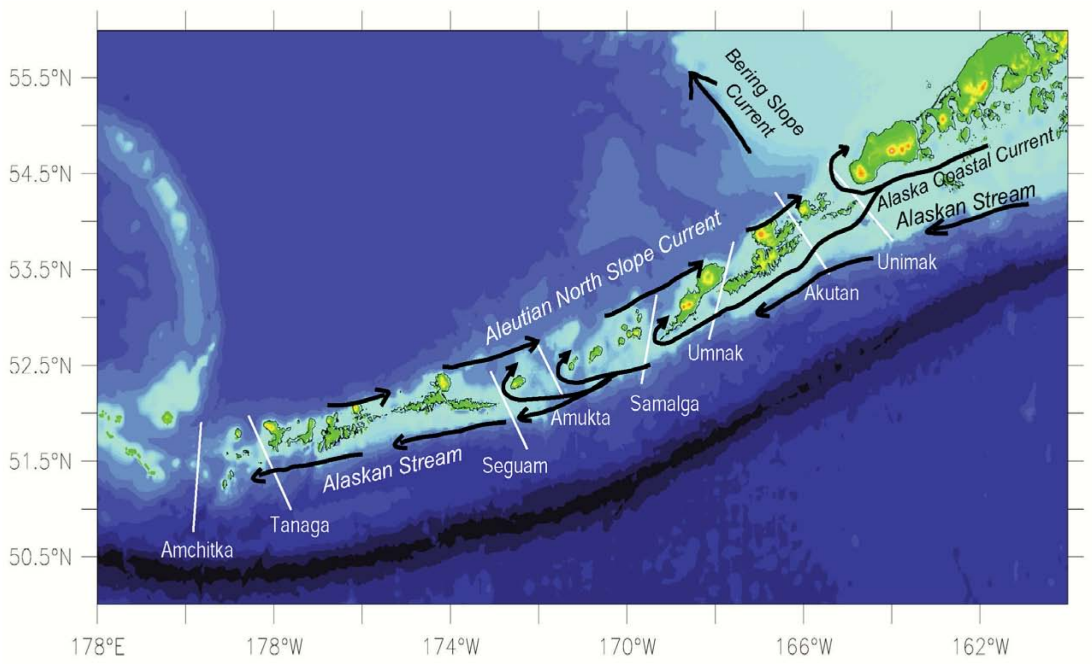

Figure 5: Ocean water circulation in the Aleutians. Currents are indicated with black lines. Selected passes are indicated with white lines. Image from Carol Ladd.

Aleutian Islands: Current Conditions 2021

In the Aleutian Islands as a whole, there are large gaps in knowledge about the local physical processes. These gaps are largely due to geographic reality. For example, persistent cloudiness and strong currents preclude obtaining comprehensive satellite-derived data, and strong currents preclude the use of various unmanned underwater vehicles. The long distances involved in surveying the island chain make comparing west-east trends in indicators difficult due to time lags during oceanographic surveys across the region. The archipelago is also influenced by different processes in the eastern than in the western Aleutians. Differences in survey timing and longitudinal gradients may also affect detection of biological patterns, as gradients are seldom monotonic in any direction. Integrative biological indicators such as fish or marine mammals abundances may be responding to physical indicators such as temperature, but are less sensitive to timing of when they are surveyed compared with direct measurements of temperature. Also, the extensive nearshore component of the ecosystem is a long, narrow shelf relative to the entire ecosystem, and strong oceanographic inputs mean that some metrics commonly used as ecosystem indicators in other systems may not be as informative in the Aleutians. Therefore, our synthesis of ecosystem indicators by necessity includes speculation. This year was a non-bottom trawl survey year, so all indicators stemming from the survey were last updated in 2018; there was no survey in 2020 due to COVID-19.

This year

This year is characterized by moderate La Niña conditions. Low sea level pressure caused a stormier winter (Figure 8) than the long term average which might have impacted planktivorous seabirds in Unalaska (Figure 28) as it was potentially harder to forage and they might have moved to more sheltered areas. In Spring, westerly winds prevailed, suppressing transport through eastern passes. Slightly stormier conditions than average returned in summer in the western and central Aleutians, which would have created potentially slightly less favorable environmental conditions for foraging (Bond et al., 2011) and thus potentially explaining the delayed hatching for piscivorous seabirds (Figure 25). Record high sea surface temperature in the western and central Aleutians drove a moderate marine heat wave in those areas; temperatures are now close to the long term average. Reproductive success was above the long term average across the chain for both planktivorous and piscivorous seabirds suggesting wide availability of prey (Figure 27). The abundance of Eastern Kamchatka pink salmon was the second highest on record; increased competition for prey and tropic cascades have been shown in years of high abundance of pink salmon (Springer and van Vliet, 2014; Batten et al., 2018; Springer et al., 2018). Lastly, paralytic shellfish toxins were reported to be 75x above the regulatory limit in Unalaska, which continues to pose a risk to human health and food webs in the region. More details on this year's trends are in the regional highlights section below.

Multi-year patterns

Overall, there seem to be three major drivers of the multi-year patterns observed across the chain:

Ecosystem-wide, several trends and conditions seem to have prevailed since 2013: The continued negative NPGO (Figure 7), sustained sea surface temperature above the mean across the Aleutians (Figure 11), with mid-depth waters also warming since 2013 (Figure 15). Low eddy kinetic energy in the eastern Aleutian Islands (Figure 18), and below average abundance of large diatoms and biomass of meso-zooplankton (Figure 22) have also persisted. Cumulatively, these conditions suggest a lower productivity level across the system with increased bioenergetic needs for fish and faster growth rates for zooplankton. Lower fish condition from 2012 to 2018 was reported in past assessments and, although these data have not been updated, the continued higher temperatures would suggest increased bioenergetic needs for fish and faster growth for zooplankton still persist. The warm temperatures can be attributed in part to slower at-depth processes, with several mechanisms contributing as well, such as weaker wind/mixing, warmer air temperature, and advection of warm water from the North Pacific Ocean, the relative importance of which is hard to assess without a detailed heat budget analysis. Overall, 2021 is a La Niña year with a negative PDO, few days under marine heatwave conditions, and (newly-estimated) near-average surface chlorophyll concentrations (Figures 7, 12, 19). The result has been near average conditions through much of the year, sustaining the more favorable conditions for the biota observed in 2020 relative to recent years. Overall, sea surface temperature is expected to decrease to average levels through winter 2021 and early spring 2022 (Figure 13).

The high abundance trend of Eastern Kamchatka pink salmon abundance in odd years continues (Figure 23) with this year being second to the record abundance in 2019. The biennial pattern of high abundance in odd years and low abundance in even years continues. However, since 2009, high abundances have doubled and even tripled (315 million adult fish) compared to prior levels of around 100 million fish. Low abundance [even] years have reached the 100 million fish mark in 2016 and 2018 (perhaps related to higher temperatures mentioned above). In 2020, pink salmon abundance decreased to pre-2014 levels, perhaps due to low availability of prey as the large meso-zooplankton negative anomaly would suggest (Figure 22). Several papers report that the pink salmon biennial pattern seems to be cascading through the system by consuming zooplankton which impacts fish growth (Atka mackerel, Matta et al. 2020), and food available for seabirds (Zador et al., 2013; Springer and van Vliet, 2014; Springer et al., 2018). In this assessment, bycatch of all seabirds combined increases in years of high pink salmon abundance and decreases during low pink salmon abundance (Figure 46). However, the impact of pink salmon can be offset by other factors, as in the case of hatch dates for tufted puffins at Buldir Island in the Western Aleutians (Figure 26). Prior to 2017, earlier (later) hatch dates coincided with high (low) abundance of pink salmon; since then the pattern seems to have been disrupted.

Rockfish have replace Atka mackerel and pollock as the main pelagic foragers: The increase of rockfish across the Aleutians has slowly changed the ratio of Atka mackerel/pollock to northern rockfish/Pacific ocean perch, with rockfish now contributing a higher percent of the local biomass across the archipielago and higher percentages in tufted puffin chick meals. Although no survey has been conducted since 2018, stock assessment estimates support rockfish becoming dominant and Atka mackerel declining. Jointly these conditions might lower the availability of Atka mackerel and pollock to other predators such as Pacific cod, whose diet shows little Atka mackerel consumed in NMFS areas 543 ad 542 in 2016 and 2018, but an increase in area 541. It is unclear whether this change in pelagic foragers has contributed to the decline of harbor seals (new this year, Figure 36) and Steller sea lions (reported in last year's assessment).

Regional Highlights

Western Aleutians

There was some enhanced storminess in the region during summer due to negative sea level anomalies (Figure 8), with record high temperatures in August and September within the satellite sea surface temperature record (Figure 10). These high temperatures lead to a two month long moderate heat wave with a short-lived strong heat wave during peak sea surface temperatures followed by temperatures quickly dropping and returning to near normal by October. This heatwave coincided with the start of the spawning season of Atka mackerel when they move to shallower areas and may have raised temperatures close to 10-11°C, the upper limit of the observed temperatures during and after Atka mackerel spawning. Atka mackerel nests are typically found between 32 - 144m depth (Lauth et al., 2008). Eddie kinetic energy was below average, suggesting low fluxes of nutrients, heat and salt trough the passes (Figure 18). Satellite-derived Chlorophyll concentration, often a proxy for phytoplankton biomass, was near average during early spring, and above average in June, particularly north of the western Aleutian islands (Figures 19, 20). It was an exceptionally successful season for fish-eating seabirds (tufted and horned puffins, thick-billed murres), improving from already favorable conditions in 2019, which had been preceded by poor reproductive success.

The reproductive success of fish-eating seabirds and zooplankton-eating seabirds at Buldir Island (Figure 27) suggests a wide variety of prey available. Their long-term average hatch dates fall between mid June to late July (Dragoo et al., 2019), along with average hatching periods of 30 to 42 days, suggest prey were available throughout the summer for chick rearing and potentially commercial groundfish as well. Zooplankton-eating seabirds (auklets) serve as indicators of zooplankton production; their reproductive success was above average during 2019 and again this year, 2021. These species feed their chicks mainly euphausiids and copepods. While the overall timing of breeding for fish-eating seabirds was average or later than average in 2021 (Figure 25), their reproductive success was also above average. Tufted puffins consumed Atka mackerel (14% of diet composition), as did horned puffins (56% diets composition). There was an increase in the proportion of gadids fed; rockfish have also increased in the diets of both tufted (25%) and horned puffins (8%) at Buldir. The increase of rockfish in seabird diets suggests they are more available to seabirds as prey, potentially because they have displaced Atka mackerel and pollock in some areas. (**?**) estimated the area occupied by Pacific ocean perch doubled from 1991 to 2018 based on survey data.

Central Aleutians

There was some enhanced storminess in the region during summer due to negative sea level anomalies (Figure 8), with record high temperatures in August and September within the satellite sea surface temperature record (Figure 10). As in the western Aleutians, there was a strong short-lived marine heatwave in September that quickly subsided and sea surface temperatures are currently at average or slightly below average levels. Eddy kinetic energy north of the islands is usually the lowest in magnitude compared to that in the western and eastern Aleutians. Events are characterized either by multiyear or continuous eddies of low intensity in the area, this year was average in the region, meaning there was likely an average flux of nutrients and and heat across the passes. Phytoplankton biomass, as represented by chlorophyll a concentration, was slightly above average offshore from the islands, but slightly below on the south side of the islands during June (Figures 19 and 20).

The area had the highest number of reports of beach-cast dead seabirds, particularly shearwaters in Atka (200 birds, Figure 29, which were just wings and bones, and no complete carcasses. Bycatch estimates of shearwaters seem to be low during low (even) pink salmon abundance years and higher in high (odd) pink salmon abundance years, suggesting increased competition between shearwaters and pink salmon (Figure 32). Weekly mussel collections for PST were taken at Adak, as well as a late-summer single collection of a suite of other species for the Knik Tribe's monitoring efforts. While results are not available yet, in the past, toxin levels have been within regulatory limits.

Eastern Aleutians

Sea surface temperatures in the eastern Aleutians in 2021 were not as high during August and September as they were in the western and central Aleutians. While they were higher than those observed last year in September, for the most part of the year they have been very similar to last year, and seem to be currently below average (Figure 11). There were only a few days under moderate marine heat wave conditions. Mid-water temperatures also seem to have cooled compared to 2019 and previous years, and are similar to those recorded last year by the longline survey at depths between between 100-300 m. (Figure 15). Winds blowing from the west to the east in the area low flows through Unimak Pass, and eddie kinetic energy - typically driven by intense pulse eddies remained at speeds below average, as has been the case since 2013. Spring phytoplankton biomass, as suggested by chlorophyll concentration was also below average (Figures 19 and 20). The Christmas Bird Count at Unalaska Island using an area and effort-standardized protocol reported unusually low numbers of cormorants, guillemots, murres and even gulls. Last winter was a low pink salmon abundance (Figure 23) year with slightly above average phytoplankton biomass in fall (Figures 19 and 20. The low numbers of wintering seabirds may be due to the increased storminess in the area during winter (Figure 8a).

Fish eating seabirds had mostly high reproductive success, this includes murres and puffins, with gulls having an average year. No auklets (primarily zooplankton eaters) were surveyed in the region. Storm-petrels which feed on a mix of invertebrates and zooplankton had mixed reproductive success; for fork-tailed storm-petrels hatching date was average and they had good reproductive success. In contrast, Leach's storm-petrels hatched later than average and they had below average reproductive success (Figures 25, 27). There were few reports of dead seabirds (20-50 birds) in Cold Bay and Unalaska (Figure 29). While indicators suggest good availability of forage fish to rear chicks and potentially for fish-eating groundfish, there was no data collected on planktivorous seabirds. It is therefore unclear whether the conditions were as favorable for zooplankton-eating seabirds as for fish eating seabirds. However, the euphausiids in tufted puffins chick meals (34%) suggest zooplankton was available, thus it would be available for planktivorous commercial groundfish.

Weekly shellfish samples are sent from several locations including King Cove, Little Priest Rock and Front Beach to test for toxins. Monitoring of harmful algal blooms indicate that peak toxin levels occurred during June. This year, as in 2020, blue mussels had toxins 75x above the regulatory level (Figure 40. This level is much lower than the one reported on the shellfish that caused a fatality last year (140x above the regulatory level). Public awareness efforts have increased in the area to minimize impacts on human health.

Recap of the Aleutian Islands 2020 Ecosystem State

In 2020, due to the COVID-19 pandemic, most survey and fieldwork was cancelled, so there are no biological indicators updated for 2020. The new information in 2020 is largely from remote-sensing, updated analysis of 2019 data, and local observations. Whenever possible we included data for 2019 as an update from the previous 2018 Aleutian Islands Ecosystem Status Report. Cancelled surveys and data streams include:

1. AFSC AI 2020 biennial bottom trawl survey, which provides data for:
    (a) Aleutian Islands Trawl Survey Water Temperature Analysis
    (b) Jellyfish in the Bottom Trawl Survey
    (c) Aleutian Islands Groundfish Condition
    (d) Distribution of Rockfish Species in the Aleutian Islands
    (e) Miscellaneous Species in the Aleutian Islands
    (f) Stability of Groundfish Biomass in the Aleutian Islands
    (g) Mean Length of the Fish Community in the Aleutian Islands
    (h) Mean Lifespan of the Fish Community in the Aleutian Islands
2. AMNWR seabird monitoring, which provides data for:
    (a) Hatching dates at Buldir and Aiktak
    (b) Reproductive success at Buldir and Aiktak
    (c) Seabird diets—tufted puffin chicks diets
    (d) Seabirds die-offs (contribute data to overall dataset)
3. AFSC Steller sea lion surveys, which provides data for:
    (a) Counts of non-pups at rookeries and haul-outs
    (b) Counts of pups at rookeries and haul-outs
4. COASST year-round citizen scientists surveys, which provide data for:
    (a) Seabird die-offs
    (b) Beached bird relative abundance
5. Fish and Wildlife Survey periodic sea otter survey that was planned this year.

Most of what we can say about the Aleutians Islands ecosystem is based upon biological trends. There are large gaps in knowledge about the local physical processes and, as a result, their impact on biological processes. These gaps are largely due to geographic reality. For example, persistent cloudiness and strong currents preclude obtaining comprehensive satellite-derived data and the use of various unmanned underwater vehicles. In addition to the sheer distances involved in surveying the island chain that make comparing west-east trends in indicators such as bottom temperature difficult due to difference in timing of oceanographic surveys across the region, the archipelago is also influenced by different processes in the eastern than in the western Aleutians. Differences in survey timing and longitudinal gradients may also affect detection of biological patterns, as gradients are seldom monotonic in any direction. Integrative biological indicators such as fish or sea lion abundances may be responding to physical indicators such as bottom temperature, but are less sensitive to timing of when they are surveyed compared with direct measurements of temperature. Also, the extensive nearshore component of the ecosystem, narrow shelf relative to the entire ecosystem, and strong oceanographic input mean that some metrics commonly used as ecosystem indicators in other systems may not be as informative in the Aleutians. Therefore, our synthesis of ecosystem indicators by necessity includes speculation.

During 2019–2020, the state of the North Pacific atmosphere-ocean system featured the continuance of warm sea surface temperature anomalies in the Gulf of Alaska with an almost year-long marine heat wave in 2019 that decreased significantly towards the west, with subsurface warmer temperatures throughout the chain that reached the western Aleutians. Bottom trawl survey temperatures from 2019 support model results from the Global Ocean Data Assimilation System that show the persistence of subsurface warmer temperatures in the 100–250 m deep layer that have stayed statistically above the long-term mean. The warm temperatures can be attributed in part to slower at-depth processes. In 2020, the surface temperatures cooled, and climate indices were near average, potentially offering more favorable environmental conditions for biota relative to recent years.

Newly estimated indices show eddies have a distinctly different signature across the island chain, with discrete, strong events characterizing the east and multiple or multi-year but less intense events towards the west. The role of these eddies and how they are processed within the system are yet to be understood, as stocks and overall populations are subject to the dynamics in the east and the west throughout their life cycle. Eddy kinetic energy has remained low since 2013 in the east, and this coincides with the North Pacific Gyre Oscillation more than with the North Pacific Index, which is typically the more characteristic index of the region. Model results suggest moderate increases in the strength of the Alaskan Stream Current increases flow through the eastern passes such as Amukta, while stronger flows carry the current westward, decreasing flows through the eastern passes and increasing them through the wider and deeper passes prevalent in the central and western Aleutians.

With average or close to average climate conditions throughout, 2020 is expected to be a return to more favorable conditions for the biological components of the Aleutian Islands ecosystem.

Biological summary through 2019 In general, warmer temperatures increase bioenergetic costs for ectothermic fish, and all else being equal, prey consumption must increase to maintain fish condition. These increased bioenergetic costs and consumption demands may partly explain why the observed body condition of several commercial groundfish (adult pollock, Pacific cod, northern rockfish and Pacific ocean perch) has been lower than the survey mean since 2012, as last measured by length-weight residuals during the biennial summer bottom trawl survey during 2018. We note however, that for Pacific Ocean perch and northern rockfish, intraspecific competition might be a contributing factor, as their abundance increased and appears to have now stabilized at high biomasses (e.g. Pacific Ocean perch) that now surpass that of Atka mackerel and pollock combined. While Pacific Ocean perch condition has also been lower than the long term mean, it has decreased less than that of the rockfish. The poorer condition of fish, particularly of species such as Atka mackerel and pollock that when small serve as prey for piscivorous seabirds and apex fish predators like Pacific cod and arrowtooth flounder, also means that that their quality as prey has decreased, with potential cascading effects on their predators.

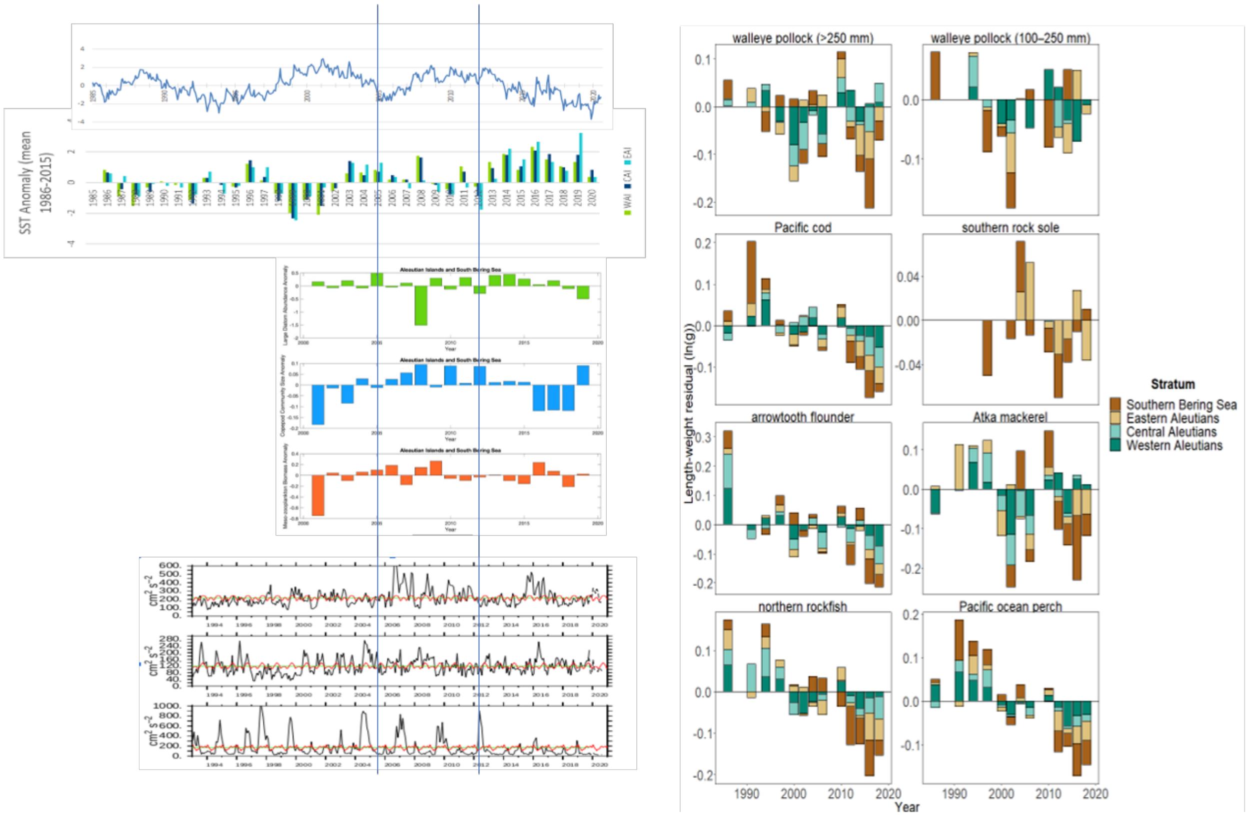

Figure 6: Compared indicators before and after 2012, from top to bottom left side: NPGO, summer SST by AI region, CPR, EKE (top WAI, middle CAI, bottom, EAI), right side, Fish Condition.

Warmer temperatures may also impact ontogenesis of Atka mackerel eggs (Lauth et al., 2007). Surface temperature was found to be the most important determinant of egg and larval stage distribution of commercial fish in Alaska based on the distribution models used to define EFH. For many of the commercial groundfish for which the youngest age in the stock assessment is 4 years old or older, effects of this sustained warmer temperature on recruitment will not be immediately apparent.

These generally unfavorable conditions seem to be improving, as seabirds—both plankton and fish-eating species—had earlier to average hatch dates and average to above-average reproductive success in 2019. This seems particularly true for surface-feeding seabirds which have been shown to respond more consistently with changes in their phenology as warmer temperatures bring earlier spring blooms. This flexibilty and higher response to fluctuations in the environment is also coherent with the lower response to variable environmental conditions that is observed in fish and seabirds used to generally more stable processes at depth throughout their lifespan.

In addition to physical drivers, Kamchatka pink salmon (a new indicator this year), with a marked biennial signal in their abundance that peaks in odd years, has been shown to be correlated with copepod abundance, otolith growth in Atka mackerel, planktivorous seabird reproductive success (Batten et al., 2018; Matta et al., 2020; Springer and van Vliet, 2014), and potentially, Pacific ocean perch young of the year. With record abundance in 2019 and an increasing trend over the past decade, their potential for competitive impacts on prey availability for other groundfish and cascading ecosystem effects warrants consideration. This competitive impacts may differ for fish feeding in shallow versus deeper waters as other biological processes may confound physical forcing driven by surface temperatures or may have a lagged effect in deeper waters. While, in general, Kamchatka pink salmon abundance correlates with a lower copepod abundance in off years, 2019 was an exception, as shown by the CPR timeseries which shows an increase in the mean size of the copepod community and its abundance - as supported by the decreased biomass of large diatoms which signals a potential increased predation pressure from copepods. With a potential cascading effect on plankton feeding species and young-of-year fish, this may partly explain the success of fish feeding seabirds in 2019. Understanding the interplay of vertical and horizontal spatial variability in food-web and oceanographic dynamics is particularly relevant given the higher reliance on plankton in the western Aleutians versus more piscivorous and invertivore feeding habits of fish and seabirds towards the eastern Aleutians.

The largest total biomass of both fish apex predators and pelagic foragers is located in the central Aleutians, the ecoregion with the largest shelf area under 500m. The lowest apex predator biomass is located in the western Aleutians whereas that of pelagic foragers is found in the eastern Aleutians. This pattern has been consistent since 1991, though individual species group fluctuations do not necessarily follow the same behavior. Finally, the increase of Pacific Ocean perch biomass and its stable high population, might be driving some spatial dynamics, where it may be encroaching onto other species' habitats, as seen by the estimated increase in the area occupied shown in the Pacific Ocean perch stock assessment. This increase in abundance and area occupied may be the cause of the increased bycatch of Pacific Ocean perch.

Western Ecoregion In the western ecoregion, the reproductive success of planktivorous auklets, serving as indicators of zooplankton production, was above average during 2019. Both least and crested auklets hatched chicks earlier than the long term average. These species feed their chicks mainly euphausiids and copepods, respectively. Parakeet, whiskered, and crested auklets all had high reproductive success in 2019, while that of least auklets was average. While the overall timing of breeding for fish-eating seabirds was average in 2019, their reproductive success varied. Glaucous-winged gulls and horned puffins had high reproductive success, tufted puffins and thick billed murres had average reproductive success, and common murres failed. There was an increase in the variety of fish brought back to feed tufted puffin chicks. Increased diversity in chick diets may indicate that more favored prey were less available. There was a slight increase in the proportion of gadids fed but lower proportions of hexagrammids (likely age-0) and *Ammodytes*. It is still unknown whether the high number of hexagrammids seen in 2013 and 2014 possibly indicated high recruitment in Atka mackerel, as their overall abundance has been in decline since 2006. Steller sea lion non-pup counts continue to decline with the lowest estimated numbers yet in 2019. The diet of Steller sea lions consists primarily of commercially fished species, many of which seem to have had poorer body condition in recent years. The declining Steller sea lion trends in both numbers and birth rates are topics of active research, and prey quality may play a role in their lack of recovery.

Central Ecoregion There was a slight increase in Steller sea lions non-pup estimates in 2019, which although small, have been consistent since 2015. School enrollment was slightly higher, pointing perhaps to more stable conditions for families in the area. The increase was driven by both students in Adak and Atka.

Eastern Ecoregion Pollock and Pacific Ocean perch commonly comprise more than half the pelagic foraging fish biomass observed in the bottom trawl survey, and 2019 was no exception. There are almost no northern rockfish in this area, but Pacific Ocean perch has been increasing their spatial extent, as seen by the estimated area occupied in the Pacific Ocean perch stock assessment. All the piscivorous seabirds species monitored for reproductive timing at Aiktak Island in Unimak Pass, hatched chicks early or on average in 2019, signaling favorable foraging conditions in the region. Reproductive success was high for red-faced cormorants, thick-billed murres, and puffins. This is despite the low forage fish availability of sandlance *Ammodytes*, gadiids and hexagrammids as suggested by the 2019 diets of tufted puffin chicks. Chick-provisioning patterns suggest puffins are responding to changes in forage fish availability. As in the west, the diversity of fish prey in puffin diets increased in 2019, possibly indicating that more favored prey were less available. Planktivorous auklets are not as numerous in the eastern ecoregion as in the central and western ecoregion and are not monitored in the Eastern ecoregion. School enrollment dropped slightly in 2019 compared to 2018, but is still above the long-term mean, possibly indicating more stable conditions for families.

Contents

* indicates contribution updated in 2021, † indicates new contribution

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Ecosystem Indicators

Noteworthy (formerly Hot Topics)

This section replaces the previously-named Hot Topics. We include information here that is deemed of relevance to ecosystem considerations of fisheries managers, but does not fit our typical indicator format. Information included here is often new, a one-time event, qualitative, or some other type of non-standard ecosystem indicator.

Mercury in Aleutian Islands food webs

Relatively high total mercury concentrations ([THg]) have been identified in over 25% of the Steller sea lion pups sampled to date in the western and central Aleutian Islands rookeries (Rea et al., 2013, 2020, 2021). These young rookery pups were exposed to mercury during *in utero* development, a particularly vulnerable time during fetal neurological development. Fetal exposure to mercury has been documented in harbor seals to cause abnormal neurological symptoms (Van Hoomissen et al., 2015), including decreased response to tactile stimuli and decreased movement (Lian et al., 2020). This indicates that adult female Steller sea lions ingested mercury tainted fish or cephalopod prey (Tollit et al., 2017; Scherer et al., 2015; Doll et al., 2018) during the mid- or late-gestation period that passed to pups across the placenta. Pups can be further exposed to additional low levels of mercury through ingestion of maternal milk. Unlike persistent organic pollutants which associate mostly with fats, mercury has a higher affinity with protein and thus fetal exposure is much higher than during the nursing period.

Mercury has been shown to negatively impact health, survival, and reproduction in other wildlife species (Wolfe et al., 1998; O'Hare and Hart, 2018). Recent research has shown evidence of adverse toxicological effect in SSL pups at the concentrations of mercury found in some pups in the Aleutian Islands. Pups with total mercury concentrations above 0.1 μg/g wet weight in whole blood showed decreased immune function (e.g., haptoglobin response Kennedy et al. 2019). Pups with elevated total mercury concentrations (and thus lower selenium to mercury molar ratios) also had poor antioxidant function (Lian et al., 2021) which could lead to tissue oxidative damage when free radicals are produced in peripheral muscles and internal organs (like liver, kidney and heart) during active breath-hold diving. Methylmercury exposure has also been shown to impact the immune system through impacting the proliferation of white blood cells both in vitro (e.g., exposure of blood cells in a controlled laboratory setting Levin et al. 2020) and in vivo (e.g., response of cells to natural exposure in rookery pups Keogh et al. In Review).

The concentrations of mercury and the proportion of pups with mercury concentrations above this lower toxicological level of concern have increased significantly over the past 10 years. Rea et al. (2021) found a broad range of [THg] (2.55–73.74 μg/g dw) was found in *lanugo* (natal hair) samples from pups sampled at Agattu Island in June of 2011, 2012, 2013, 2015, 2017, 2018, and 2019 (n=339).A significant increase in median [THg] in the *lanugo* of pups was identified over this brief period from 8.005 μg/g in 2011 to 17.275 μg/g in 2019 (Kruskal-Wallis H=41.24, $p<0.001$). The proportion of pups sampled on Agattu Island with *lanugo* [THg] above 20 μg/g THg (a published threshold of adverse effect of mercury in pinnipeds) increased more than twofold during this time period from 20.6% in 2011 to 46.4% in 2019. The proportion of pups at high risk for adverse effects increased at a rate of 3.7% per year. These biologically significant increases in [THg] accumulated through maternal diet are particularly concerning due to the short, intra-decadal scale of the escalation and the consistent rate of increase of proportion of pups at risk.

Higher median total mercury concentrations in *lanugo* of young pups have also been measured on rookeries that continue to decline in population and that show lower total selenium (TSe) to THg molar ratios in pup blood (Rea et al., 2020). As an essential antioxidant and modulator of Hg toxicosis it is important to interpret THg relative to TSe. This research on Steller sea lion mercury concentrations has been undertaken in collaboration with NOAA and colleagues at Texas A&M University, and we eagerly await the possibility to assess continuing trends once the pandemic abates and field sampling is once again possible.More limited sampling of harbor seals in the Aleutian Islands suggests that phocid seals foraging from the same island location as Steller sea lions can have a similar range of total mercury concentrations in their hair, and also be at risk for toxic effects (Rea et al., 2017).

Other studies are currently underway to understand movement of mercury through the food web to help identify potential sources and to understand whether these same trends of increasing mercury concentrations are apparent in fish prey species sampled in the Aleutian Islands. Ocean Peace Inc. have been an important research donor and collaborator since 2013, providing fish sampled from commercial trawls and supporting student research to measure mercury and stable isotopes in Aleutian fish and cephalopods. This research has shown that mercury concentrations in several fish species are significantly higher in the western Aleutian Islands compared to fish sampled to the east (Cyr et al., 2019). This concurs with prior research on seabirds which showed higher levels of mercury in towards the west in glaucous-winged gull and northern fulmars in Buldir Island (Ricca et al., 2008). More recent collections now enable analysis of whether there have been increases in mercury in these fish species over the past decade. A new collaboration with the US Fish and Wildlife Service has also provided a large set of invertebrate species from the central and western Aleutian Islands. This will allow measurement of mercury and selenium in more sessile, nearshore organisms. that will assist in determining if there are discrete regions within the Aleutian Islands that have higher mercury concentrations (and potential toxicologic risk) that should be the focus of future research.

Contributed by: Lorrie Rea
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Plastics in the Aleutian Islands

Plastics derived contaminants, phtalates, were detected in 115 seabirds tested with concentrations varying from 3.64–539.64 ng/g. While phthalates did not vary geographically, diving plankton-feeders showed significantly higher concentrations compared to diving fish, surface fish, and opportunistic feeders. Species sampled included: diving fish-feeders, common murre, horned and tuftedpPuffins, pelagic and red-faced cormorants and pigeon guillemots; two species of surface fish-feeders: black-legged kittiwakes and northern fulmars; one species of diving plankton-feeder: crested auklet; and one species of opportunistic feeder: glaucous-winged gulls. Plastic particles were detected in 36.5% of subsampled stomachs (n = 74), suggesting plastic ingestion as a potential route of phthalate exposure (Padula et al., 2020). While harmful levels of phtalates wre not assessed, Lavers et al. (2019) studied the sublethal effects of ingested plastic in flesh-footed shearwaters and found the presence of plastic had a significant adverse effects on seabird morphometrics, blood calcium levels, and were positively correlated with the concentration of uric acid, cholesterol, and amylase. These sublethal effects of ingesting plastic show seabirds may still experience adverse consequences despite being apparently healthy. While ingesting marine debris can lead to mortality it is not the leading cause (Roman et al., 2019). Out of 1733 seabirds examined, 557 (32.1%) had ingested marine debris, and 22 were determined to have died from debris ingestion. The study found ingesting one item has a 20.4% chance of lifetime mortality, while 93 items increase the chance to 100%. When mortality by plastic ingestion does occur, the leading cause of death was found to be obstruction of the gastro-intestinal tract, with balloons32 times more likely to result in death than ingesting hard plastic Roman et al. (2019). Regional variability in the amount of plastics ingested depends both on the foraging ecology of the species as well as the areas in which they are foraging.

Contributed by: Ivonne Ortiz
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Ecosystem Status Indicators

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

Biophysical Environment

Biophysical Synthesis

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Last updated: October 2021

Synthesis *At the beginning of 2021, low sea level pressure caused a stormier winter than the long term average which might have impacted planktivorous seabirds in Unalaska (Figure 28) as it was potentially harder to forage and they might have moved to more sheltered areas. The negative SLP in the Bering Sea is consistent with an intensification of the Aleutian low, which potentially moved the storm track towards a more westward position than normal. After a high SLP in spring, it dropped again in summer (Jun - Aug), when the negative SLP anomalies over the northern Bering Sea extended across the Chukchi Sea to north of Alaska and south to the central and western Aleutians implying enhanced storm activity for those regions (Figure 8. The resulting west to east winds suppressed northward flow through Unimak Pass. The winds are also consistent with a low eddy kinetic energy EKE) in the eastern Aleutians, although EKE was low across the region with potentially decreased fluxes of heat, salt and nutrients through the Aleutian passes which may have an impact on primary productivity (as measured by its proxy, satellite chlorophyll a). Some of the warmest sea surface temperatures on record were observed in the central and western Aleutians* *during late summer 2021- these high temperatures were short lived, quickly returning to near average values, but would have had a stronger impact in the shallower areas where Atka mackerel build their nests. Water temperatures during and after Atka mackerel spawning range from 4 to 11°C, thus the moderate heatwave in the western and central Aleutians would have brought sea surface temperature close or slightly above the upper limit (in contrast to average SST in 2020). Despite this localized effect, the total days under marine heatwave conditions remained below 100 so far this year, which is lower than the past two years in the Central and Eastern Aleutians.*

Overall Aleutian Islands surface chlorophyll concentrations measured from MODIS were near-average in spring 2021 and slightly above average during June, which may have favored zooplankton production, in contrast to below average concentrations in June of 2020, which also showed negative anomalies for large diatoms and mesozooplankton biomass. The higher temperatures also increase growth rates in zooplankton, which may change the timing and size spectrum of zooplankton prey available to seabirds and fish. The potential above average productivity in late spring may have contributed to enhanced foraging conditions in the latter portion of the seabird's breeding season, particularly in the western Aleutians, where piscivorous seabirds had above average reproductive success despite later than average hatching chronology. This higher primary production and potential cascade to zooplankton might have offset the increased competition for prey brought by increased bioenergetic needs of groundfish in shallow waters during the heatwave.

Long term context: Several indicators have remained similar since late 2013, reflecting sustained conditions for eight continuous years now. In terms of climate indices, the NPGO has remained negative which is generally accompanied by warmer waters south of Alaska. The expected warmer waters is supported by the above average sea surface temperatures across the Aleutian chain and the warmer mid-water temperatures at 100-300m from both the bottom survey (for years 2014-2018) and the longline survey. The low eddy kinetic energy, has been sustained in the eastern Aleutians, suggesting lower fluxes of heat, nutrients and salt thorugh the passes and going north feeding the Bering Sea Slope current or the flow north of the Alaska Peninsula. Jointly, higher temperatures for consecutive years may be changing the phenology of the size spectrum of zooplankton, shifting groundfish distribution both vertically and horizontally, as well as increasing bionergetic costs across the board for all groundfish, with potentially higher competition for prey. The decreasing trend in large diatom abundance also supports a lower productivity which would cascade down to large zooplankton. This might be exacerbated by an increase in eastern Kamchatka pink salmon abundance, which act as a predatory front feeding on copepods and competing with other predators. Pink salmon abundance alternates between years, with odd years showing high abundance and even years showing low abundance. However, since 2014 abundance of pink salmon has increased in both odd and even years (but note abundance in 2020 it decreased to pre-2014 levels). Decreasing fish condition supports that environmental conditions have been unfavorable for groundfish from 2014-2018, although lack of more current bottom trawl survey data precludes a more recent assessment of fish condition.

On a general note, smoke from the extensive Siberian wildfires has been reaching various parts of Alaska since 2019 (Wehrdahl 2020, Johnson 2021, NASA 2020, ADN 2021). Both aerosols and carbon dioxide increase with wildfires. Wildfire aerosol deposition has been linked to phytoplankton blooms. Smoke can also reduce the insolation enough to impact productivity rates. In the Aleutians, crew on board the R/V Tiglax (ADFG) only noticed smoke upon arrival to Homer, AK. Field crew from the Alaska Maritime National Wildlife Refuge in Buldir and Aiktak did not report any smoke.

Introduction

We provide an overview of the physical oceanographic conditions impacting the Aleutian Islands, the conditions observed during 2021, and place 2021 in the context of recent years. The physical environment has implications for ecosystem dynamics and productivity important to fisheries within the system and their management. The information has been merged across sources, from broad-scale to local-scale, and is presented as follows:

Sections:
1. North Pacific Climate Overview and Regional Highlights
2. Winds (North Pacific Sea Level Pressure)
3. Sea Surface Temperatures
4. Mid Water Temperature
5. Ocean Transport -Eddies in the Aleutian Islands—FOCI
6. Primary Production -Satellite Chla 7. Zooplankton - Continuous Plankton Recorder data

1. Climate Overview

Lead contributor Nick Bond, *nicholas.bond@noaa.gov*

Climate indices provide an alternative means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices, of which the first three are potentially the most relevant to the AI: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, the Pacific Decadal Oscillation index (PDO, the leading mode of North Pacific SST variability), the North Pacific Index (NPI, area-weighted sea level pressure over the region 30–65°N, 160°E–140°W), the North Pacific Gyre Oscillation (NPGO, the 2nd dominant mode of sea surface height variability in the Northeast Pacific), and the Arctic Oscillation (AO). The time series of these indices from 2011 into spring/summer 2021 are plotted in Figure 7. The dominant atmosphere-ocean relationship in the North Pacific is one where atmospheric changes lead changes in sea surface temperatures by one to two months. However, strong ties exist with events in the tropical Pacific, with changes in tropical Pacific SSTs leading SSTs in the north Pacific by three months). The NPGO is significantly correlated with previously unexplained fluctuations of salinity, nutrients and chlorophyll-a measured in long-term observations in the California Current (CalCOFI) and Gulf of Alaska (Line P). The AO is characterized by winds circulating counter-clockwise around the Arctic at around 55°N latitude; during a positive phase, colder air is confined across polar regions; in a negative phase, winds become weaker which allows an easier southward penetration of colder, arctic airmasses and increased storminess into the mid-latitudes. For each time series discussed below, the analysis is based on the monthly values that are normalized using a climatology based on the years of 1981–2010. These climatologies are considered to have been the long-term average or ”normal” conditions.

The NINO3.4 index was negative from spring 2020 through early summer 2021. This index bottomed out with a value of -1.42 in November 2020, implying that the equatorial Pacific was in a moderately strong La Niña state. Slow warming followed with near-neutral conditions developed by late spring/early summer 2021. Relatively cool water remains at depth in the tropical Pacific with more likely than not a weak-moderate La Niña forming by late fall 2021.

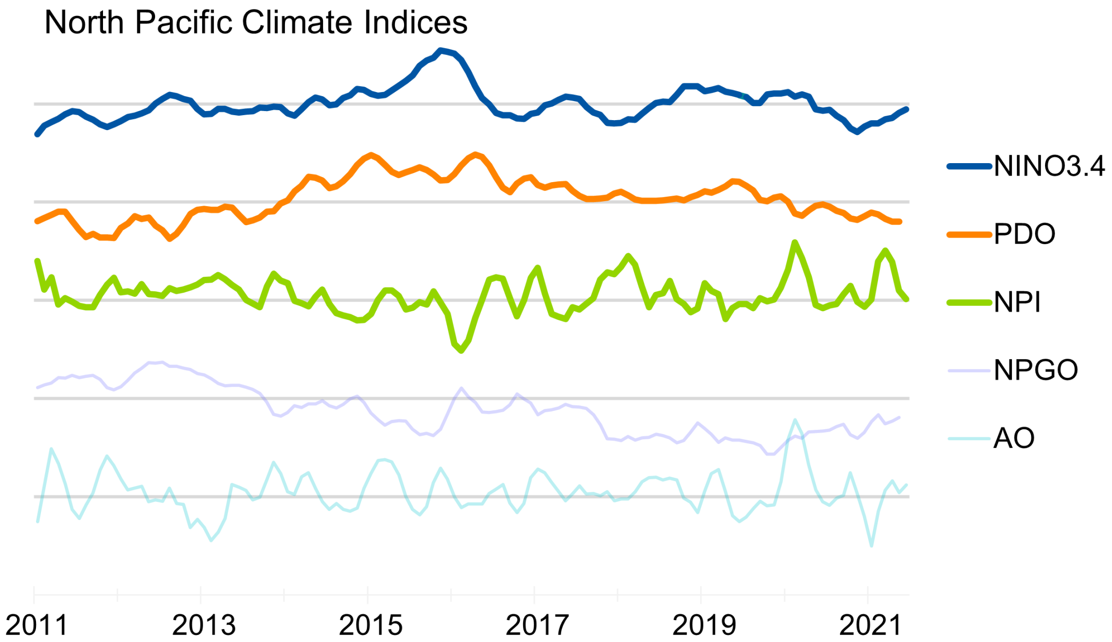

Figure 7: Time series of the NINO3.4, PDO, NPI, NPGO, and AO indices (ordered from top to bottom) for 2011–2021. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Physical Sciences Laboratory at `https://psl.noaa.gov/data/climateindices/`.

The PDO continued its mostly negative trend following a strongly positive state during the major Northeast Pacific marine heat wave of (MHW) of 2014-16. The PDO reached a value of about -1 during the spring of 2021 and remained near that value through the following summer. The moderately negative state of the PDO during spring and summer 2021 can be largely attributed to relatively cool temperatures in the eastern subtropics and warm temperatures in the western mid-latitudes of the North Pacific; a negligible contribution was represented by the SST anomalies in the Alaskan waters portion of the PDO spatial pattern.

The state of the Aleutian low is often summarized in terms of the NPI, with negative (positive) values signifying relatively low (high) SLP. Following a near neutral state in fall 2020, the NPI was strongly positive during the winter of 2020-21 before returning to an average of near neutral again in summer 2021. The NPI has been positive during 4 out of the last 5 winters; this aspect of the atmospheric forcing of the North Pacific helps account for the overall decline in the PDO over the interval.

The NPGO has been mostly negative since 2014; this sign of the NPGO is generally accompanied by warmer than normal upper ocean temperatures south of Alaska between 35 and 50°N and is associated with high SLP over the GOA and low SLP in the vicinity and northeast of the Hawaiian Islands. The NPGO did undergo a decrease in intensity from about -2 in early 2020 to -1 in early 2021 between 35 and 50°N.

The AO represents a measure of the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the North Pacific and North Atlantic at a latitude of roughly 45 °N. The AO switched from strongly positive early in 2020 to temporarily negative during the winter of 2020-21, followed by mostly positive values in spring and summer 2021 with considerable month-to-month variability.

NP Climate Summary The North Pacific atmosphere-ocean climate system during autumn 2020 through summer 2021 featured generally higher than normal sea level pressure (SLP) across a broad band between roughly 25° and 50°N and lower than normal SLP from eastern Siberia into the southern Chukchi Sea. The region of positive SLP anomalies in the middle latitudes of the North Pacific generally corresponded with positive sea surface temperature (SST) anomalies. This high pressure, particularly during the winter of 2020-21, meant that the Aleutian Low was weaker than normal, which is consistent with the moderate La Niña that was co-occurring in the tropical Pacific. The PDO was negative during the period of interest here, in large part to the persistent positive SST anomalies in the western and central North Pacific. Along the west coast of North America, there was a mixed bag of warm and cool SST anomalies varying in space and time. The climate models used for seasonal weather predictions are indicating elevated odds of La Niña conditions re-developing in the latter part of 2021. These models as a group are indicating SST distributions in early 2022 that include colder than normal temperatures for the Gulf of Alaska and near-normal temperatures for the Aleutian Islands and eastern Bering Sea. For the latter region, sea ice is expected to extend south over the shelf to at least 60°.

Aleutian Islands. The winter of 2020-21 was stormy for the Aleutian Islands with the mean wind anomalies of a sense associated with suppressed northward flow through Unimak Pass. A relatively calm period followed during the spring of 2021. Near normal values of SST prevailed in this region from late 2020 through the spring of 2021, with warming during the following summer, albeit some enhanced storminess in the central and western Aleutians due to negative SLP anomalies.

Gulf of Alaska. The coastal GOA experienced a relatively wet winter in 2020-21, with the coldest air temperatures occurring in February and March 2021. The weather was considerably drier in late spring and summer relative to seasonal norms. This period also included westerly wind anomalies, which are downwelling favorable in the coastal zone. One consequence was a pocket of SST anomalies of minor magnitude in the northern GOA in summer 2021 as opposed to the generally warm temperatures that were present across virtually the entire North Pacific Ocean north of 30°N.

Bering Sea deep basin. The western, deep portion of the Bering Sea transitioned from warmer than normal (0.5 to 1C) SSTs in the latter part of 2020 to near-normal temperatures during the first half of 2021. Warm anomalies developed in the western portion of this region in summer 2021. Similar to the Eastern Bering Sea shelf, its northern portion experienced a relatively stormy summer in 2021.

2. Wind

North Pacific Sea Level Pressure Anomalies. contributed by Nick Bond

The state of the North Pacific climate from autumn 2020 through summer 2021 is summarized in terms of sea level pressure (SLP) and seasonal mean sea surface temperature (SST) anomaly maps. The SLP anomalies are relative to mean conditions over the period of 1981-2010. The SLP data are from the NCEP/NCAR Reanalysis project. This data set is made available by NOAA's Physical Sciences Laboratory (PSL) at `https://www.psl.noaa.gov/cgi-bin/data/composites/printpage.pl`.

Status and Trends The SLP during autumn (Sep-Nov) 2020 (Figure 8a) included positive anomalies south of the Aleutians extending through the Gulf of Alaska (GOA), and negative anomalies over northeastern Siberia. This SLP distribution resulted in anomalous winds from the southwest for the Bering Sea and suppressed storminess for the southeast Bering Sea shelf and the GOA.

The winter (Dec-Feb) of 2020-21 featured a strongly negative SLP anomalies in the southwestern Bering Sea with relatively low pressure extending across Alaska into northwestern Canada, and positive SLP anomalies in the eastern part of the mid-latitude North Pacific, with a center located near 35°N, 140°W (Figure 8 b). The consequence was enhanced westerlies stretching from the Aleutians to the GOA. The high pressure off the coast of the lower 48 states was associated with a dearth of landfalling storms into California.

The positive SLP anomalies in the NE Pacific during the previous season persisted through spring (Mar-May) of 2021 (Figure 8 c), with their spatial extent expanding west of the dateline and northward into the Bering Sea and GOA. The highest pressures were at roughly 45°N, again resulting in westerly wind anomalies for the Bering Sea and GOA.

The distribution of SLP anomalies across the North Pacific during summer (Jun-Aug) of 2021 is shown in Figure 8 d. As is often the case during this time of year, the seasonal mean anomalies were generally of moderate amplitude. Lower than normal SLP over Alaska and northwestern Canada with relatively high SLP south of 50^o N led to anticyclonic wind anomalies for the northern and eastern GOA. The negative SLP anomalies over the northern Bering Sea extending across the Chukchi Sea to north of Alaska and south to the central and western Aleutians implies enhanced storm activity for those regions.

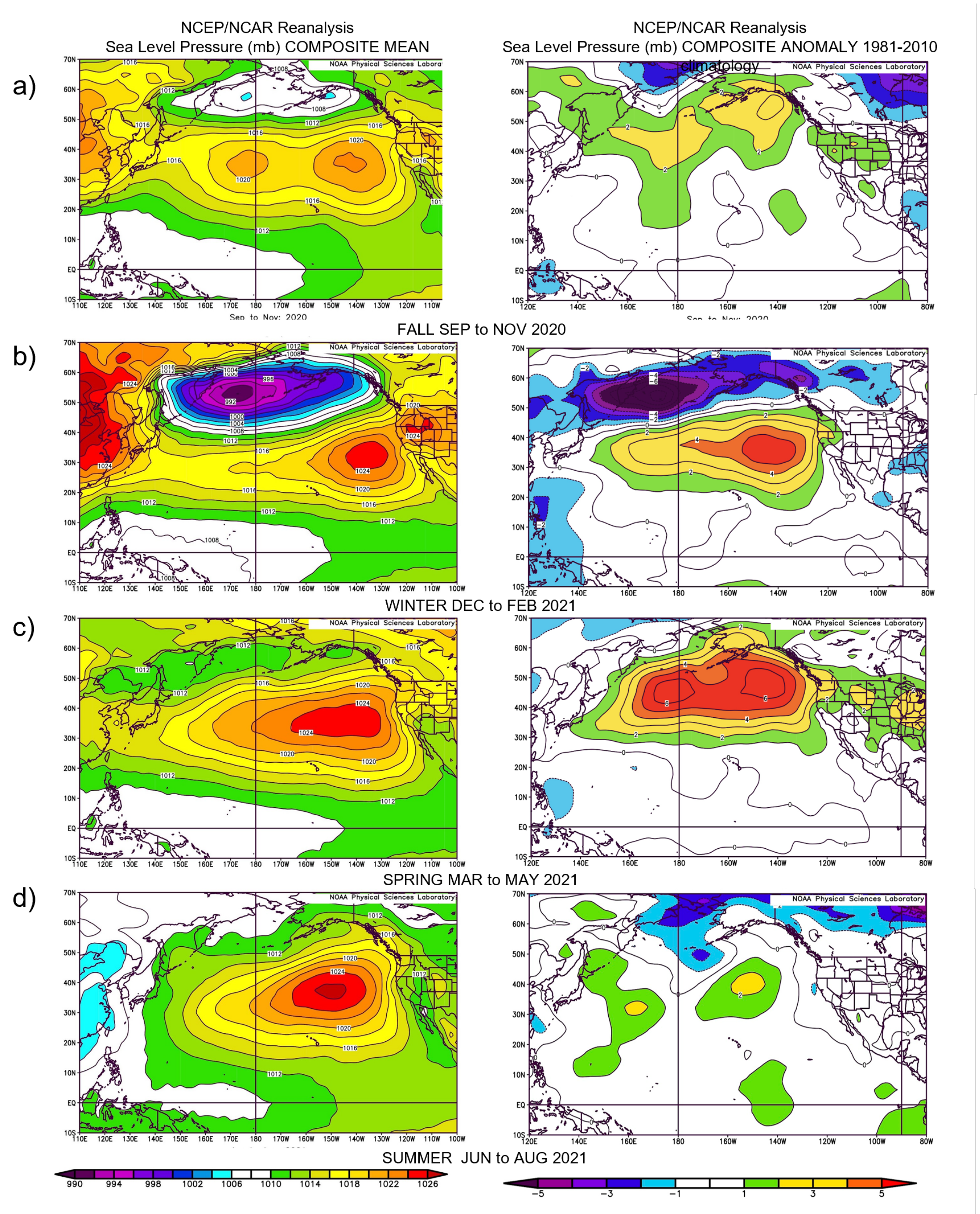

Figure 8: Left, right, Top to bottom: SLP mean and anomalies (hPa) for September-November 2020, December 2020-February 2021, March-May 2021, June-August 2021.

3. Sea Surface Temperature

North Pacific Sea Surface Temperature contributed by Nick Bond

The autumn of 2020 (Figure 9, Sep–Nov) included warmer than normal SSTs across virtually the entire North Pacific Ocean. Particularly warm waters with anomalies exceeding 2°C were present east of Hokkaido, in the northwestern Bering Sea near the Gulf of Anadyr, and in the eastern portion of the basin along 40°N from 160° to 130°W. The Pacific Ocean east of the dateline was cooler than normal in association with the development of moderate La Niña conditions. The magnitude of the positive SST anomalies in the North Pacific moderated late in 2020. For the winter (Dec-Feb) of 2020-21 as a whole, Figure 9 (Dec–Feb) shows that the region of relative warmth was largely confined to a basin-wide band between 15° and 45°N, with mostly minimal anomalies (<0.5°C magnitude) on the Bering Sea shelf and in the GOA. La Niña remained present, with the most prominent anomalies occurring in the central tropical Pacific.

The large-scale SST anomaly pattern in the North Pacific during spring (Mar–May) of 2021 (Figure 9) was similar to that of the previous winter. There were increases in the magnitudes of the warm anomalies in the western North Pacific from Japan to the dateline, and to a lesser extent for the southeastern Bering Sea. A minor cold SST anomaly emerged in the GOA between the Kenai Peninsula and Kodiak Island. The tropical Pacific returned to near-neutral ENSO conditions, with slightly cool SSTs east of the dateline.

During the summer (Jun–Aug) of 2021, the positive SST anomalies in the mid-latitudes of the North Pacific increased to the east of the dateline well off the coast of the US lower 48 states. Positive anomalies of about 1°C were present in the western Aleutian Islands. There were minor warm SST anomalies on the southeastern Bering Sea shelf; temperatures in the northern GOA were near normal. The tropical Pacific was in a near-neutral state.

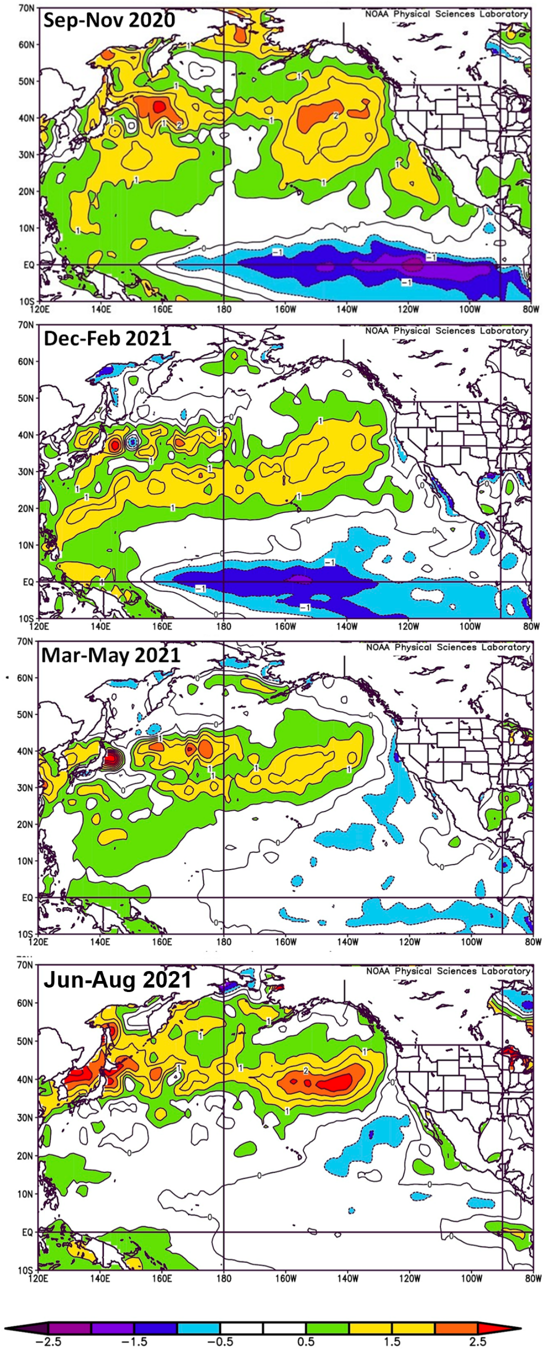

Figure 9: SST anomalies for autumn (September–November 2020), winter (December 2020–February 2021), spring (March–May 2021), and summer (June–August 2021).

Regional Sea Surface Temperature and Marine Heatwaves contributed by Jordan Watson and Matthew W. Callahan

Sea surface temperature is a foundational characteristic of the marine environment and temperature dynamics can impact many biological processes. Changes in temperatures can influence physiological processes of fish (e.g., metabolic rates and growth rates), fish distribution (e.g., (Yang et al., 2019), trophic interactions, availability of spawning habitat (e.g., (Laurel and Rogers, 2020)), and energetic value of prey (von Biela V. R. et al., 2019). Extended periods of elevated SST can lead to marine heat waves (MHWs), which can drastically influence ecosystem dynamics (Bond et al., 2015; Hobday et al., 2016). Trends in SST and MHWs are presented here throughout the Aleutian Islands ecosystem regions.

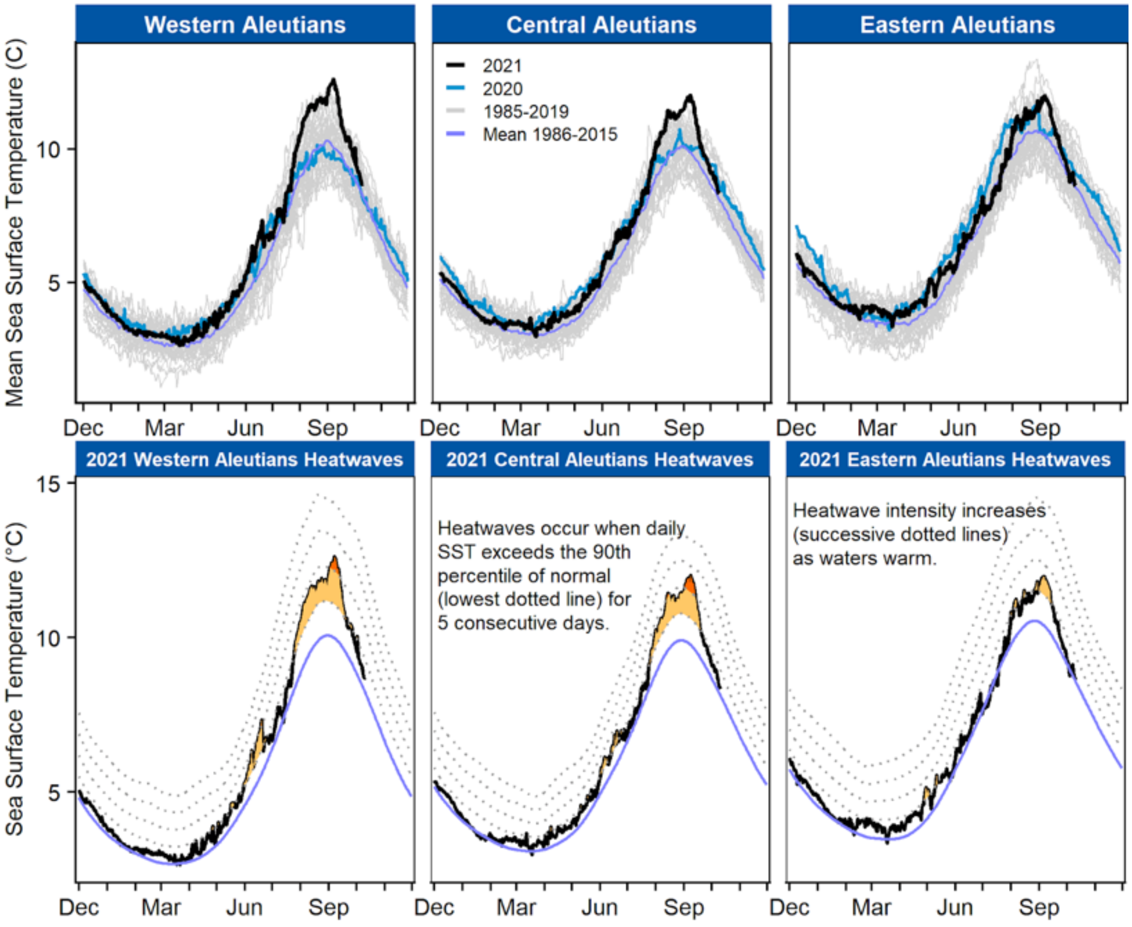

Figure 10: Annual sea surface temperatures and 2021 marine heatwave status for Aleutian Islands ecosystem regions. Data extends through September 17, 2021. Note that heatwave intensity is based on thresholds determined by the difference between the mean and the 90th percentile temperature (Hobday et al., 2018), thus while the September 2021 temperatures are the highest in the time series, the heatwave status is only “strong”.

Satellite SST data (source: NOAA Coral Reef Watch Program) were accessed via the NOAA CoastWatch West Coast Node ERDDAP server `https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW.html` for April 1985 - September 2021. Daily SST data were averaged within the western (west of 177°W), central (170°W–177°W), and eastern (165°W–170°W) Aleutian Islands. The earliest complete 30-year time series (1985 – 2014) was used as the baseline period for mean and standard deviation comparisons (see (Hobday et al., 2018; Schlegel et al., 2019) for discussions of baseline choices). Detailed methods are online, including maps of the spatial strata and querying satellite data with R (`github.com/jordanwatson/EcosystemStatusReports`). Annual SST time series are apportioned from December of the previous year through November so that the winter season (Dec–Feb) for each year can be consistently aggregated. A time series decomposition (i.e., seasonality and noise removed) is also provided to better illustrate the long term trends in SST data (Edullantes, 2019).

Warm water events have become so frequent in the world's oceans that a new method for describing them has been formalized and is widely used (Hobday et al., 2016). A marine heatwave occurs when SST exceeds a particular threshold for five or more days. That threshold is the 90th percentile of temperatures for a particular day of the year based on a 30-year baseline (Hobday et al., 2016). The intensity of a MHW can be further characterized by examining the difference between the 90th percentile threshold for a given day and the baseline ("normal") temperature for that day. When the threshold is exceeded, the event is considered moderate, strong (2 times the difference between then threshold and normal), severe (3 times the difference), or extreme (4 times the difference; (Hobday et al., 2018)). MHW indices were developed using the heatwaveR package (Schlegel and Smit, 2018).

Status and Trends

During the winter (Dec – Feb) and spring (Mar – Jun) of 2021, SST in all three regions was generally cooler than 2020 but still above average (Figure X4). Peak summer temperatures however, have been among the highest of the time series for all three regions and the warmest recorded SST occurred in September for the western and central AI.

Generally, all three regions have trended towards anomalously warm (>1 SD from the long term mean) conditions over the last few years, especially in the eastern Aleutians where the SSTs have been the highest in this time series. (Figure 10). The trend for each of the Aleutian regions continues for temperatures to be at least one standard deviation above the long term average. Note that (Figure 11 plots the time series trend, which smooths the data. Thus, the ends of the time series are truncated so the current marine heatwave events are not included in this figure.

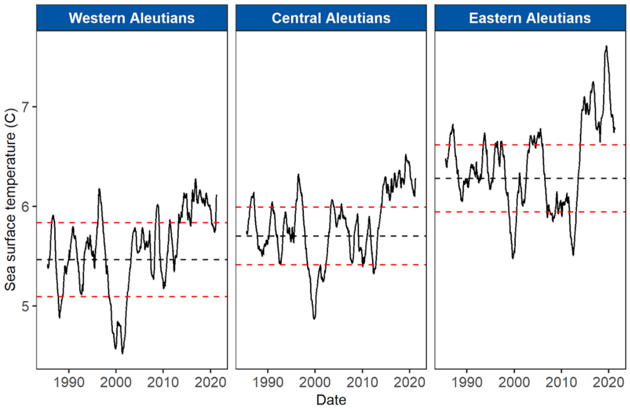

Figure 11: Time series trend (i.e., seasonality and noise removed) of sea surface temperatures. Horizontal dashed lines represent the mean (black) and standard deviation from the mean (red) during the earliest complete 30-yr baseline period (1985-2014). The trend is an annual moving average, with the latest date in March 2021, thus the current marine heatwave is not detected in this plot

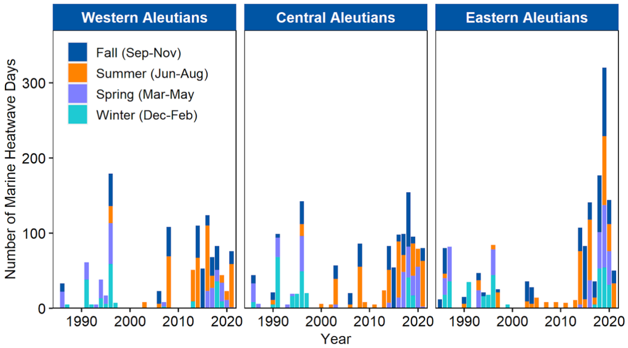

Figure 12: Number of days during which marine heatwave conditions persisted in a given year. Seasons are summer (Jun - Aug), fall (Sept – Nov), winter (Dec – Feb), spring (Mar – Jun). Years are shifted to include complete seasons so December of a calendar year is grouped with the following year to aggregate winter data (e.g., Dec 2020 occurs with winter of 2021). Data extends through September 17, 2021.

MHWs have occurred periodically throughout the SST time series but with greater frequency during the last few years. In 2021, heatwave duration and intensity was low during winter and spring, though all three regions experienced notable MHWs in the summer of 2021. In each of the most recent 8 years, at least one MHW event has occurred in each of the three Aleutian Islands regions, with the greatest duration of events occurring in the eastern region (Figure 12).

Implications

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

SST Projections from the National Multi-Model Ensemble contributed by Nick Bond

Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 13a–c. An ensemble approach incorporating different models is appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the National Weather Service Climate Prediction Center[3].

First, the model projections from a year ago are reviewed. In general, the model forecasts from September 2020 for the following fall and winter indicated a continuation of positive SST anomalies across the North Pacific south of 50N and in the northern Bering Sea. For the spring of 2021, these forecasts included moderation in the magnitude of the warmer than normal temperatures in the Bering Sea and the development of slightly cooler than normal temperatures in the northern GOA. The model performance as a group was very good for the first period considered (Oct-Dec 2020). In particular these forecasts showed near-normal temperatures in the vicinity of the Aleutian Islands separating relatively warm SSTs to the south and to the north, as observed. The predictions for the later period of December 2020 through February 2021 were largely correct in a basin-scale sense,

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

specifically relating to La Niña in the tropical Pacific and positive SST anomalies in the mid-latitude North Pacific, particularly in a localized region just east of Japan. From an Alaskan perspective, the models failed to predict the observed development of relatively cold conditions observed along the west coast of Alaska north of Nunivak Island into Norton Sound. The locations and nature of the better and worse model forecasts persisted into the longest time horizon considered, i.e., the predictions for Feb-Apr 2021. The model predictions were quite good for the tropics and mid-latitude North Pacific, but failed with respect to a regional detail in terms of the presence of cool (warm) temperatures for the northern (southern) portion of the eastern Bering Sea shelf.

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 2021; Figure 13a). Positive anomalies are also predicted for the southeast Bering Sea shelf. Cold anomalies are projected north of Bering Strait, and to a lesser extent, for the GOA. The forecast of cool conditions in the northern waters of Alaska may seem curious given the long-term decline in summer sea ice in the Arctic. The model predictions here may in part be attributable to the location of the ice edge during late summer 2021, which is not far displaced from its climatological position for the period of 1981-2010. The models also are indicating relatively high pressure centered south of the Aleutians near the dateline, which results in fewer storms of mid-latitude origin for the northern Bering and Chukchi Seas, and hence fewer incursions of mild, maritime air masses. It will be interesting to see if this scenario actually comes to pass.

The ensemble of model predictions for December 2021 through February 2022 includes anomalously high sea level pressure centered over the western Bering Sea resulting in a decrease in the positive temperature anomalies on the southeast Bering Sea shelf and continued cooling of the GOA (Figure 13b) as compared with climatological norms. These changes are consistent with what has occurred in past La Niña winters; the models as a group are predicting tropical Pacific temperatures commensurate with a moderate La Niña. The distribution of SST anomalies predicted for February through April of 2022 (Figure 13c) shows that the trends of the previous 3-month period considered here are liable to be continued. If the models as a group are correct, the late winter and early spring of 2022 will bring near-normal temperatures to most of the Bering Sea and Aleutian Islands, and quite cold temperatures to the central GOA. The models also show a winding down of La Niña in the tropical Pacific.

There is a fair amount of spread in the forecasts among the models. More specifically, 2 out of the 6 models forming the NMME are showing that the southeast Bering Sea shelf will remain warmer than normal into spring 2022, and 3 out of the 6 models are emphatic about the cool temperatures in the GOA with the others showing a more muted response. This variability/uncertainty also applies to the sea ice extent over the shelf in the eastern Bering Sea. Most, but not all, of the models suggest conditions that would result in ice extending south of 60 N perhaps all the way to M2, and as far south as Bristol Bay along the west coast of Alaska.

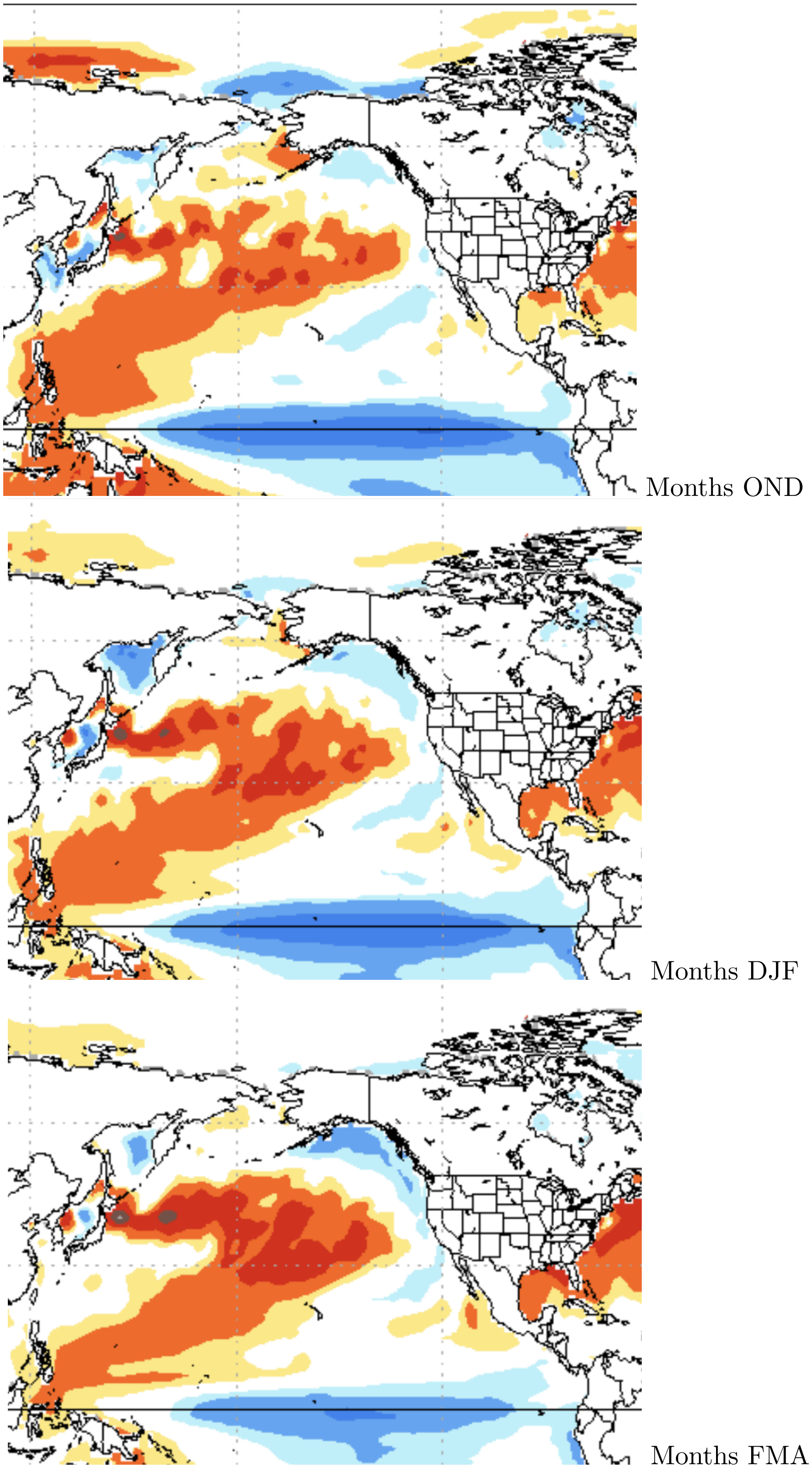

Figure 13: Predicted SST anomalies from the NMME model for OND (1-month lead), DJF (3-month lead), and JFM (4-month lead) for the 2019–2020 season.

4. Mid-Water Temperature

Longline Survey Mid-depth Temperature and Trawl Survey Water Temerature Analysis

Contributors Kevin Siwicke, Ned Laman

Longline survey

Description of indicator: Subsurface temperature can be a useful indicator for tracking long term ecosystem trends (i.e., static, cooling, or warming). The Alaska Fisheries Science Center (AFSC) has been conducting a longline survey since 1987 to sample groundfish from the upper continental slope annually in the Gulf of Alaska, during odd years in the Bering Sea, and during even years in the Aleutians. More details related to this survey can be found in (Siwicke et al., 2021). Beginning in 2005, a temperature (depth) recorder (TDR SBE 39 (Seabird Electronics) has been attached directly to the middle of the longline, with a second TDR being attached deeper starting in 2019. The TDR records water temperature and depth every 10 seconds, and the downcast is processed to 1-m increments via the double parabolic method used by the World Ocean Atlas 2018 ((Reiniger and Ross, 1968; Locarnini et al., 2019).

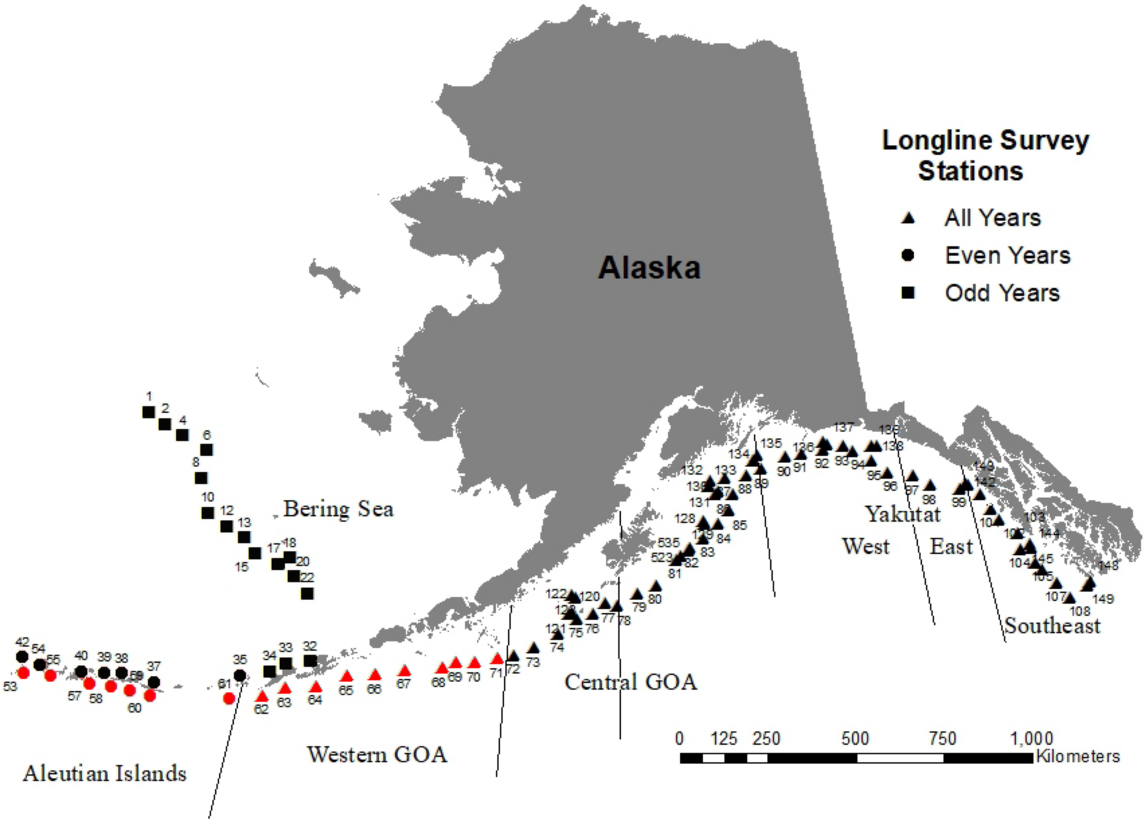

Figure 14: Longline survey in the Bering Sea (squares, odd years), the Aleutians (circles, even years) and GOA (triangles, every year). Stations shown in red are the ones used for the longitudinal comparison of mid-depth temperature from 180°W to 154°W

There are 21 stations sampled by the AFSC longline survey located within the Aleutians ESR region (14 in the central Aleutians and 7 in the eastern Aleutians). In even years, sampling begins from east to west on the north of the central Aleutian Islands, then west to east on the south of the central Aleutian Islands. In every year, four stations are sampled on the south of the eastern Aleutians Islands and continue to the Gulf of Alaska. Here we include the stations sampled south of Aleutians through the western GOA from 180°W to 154°W (Figure 14) for a longitudinal comparison of mid-water temperature along the continental slope (Figure 15).

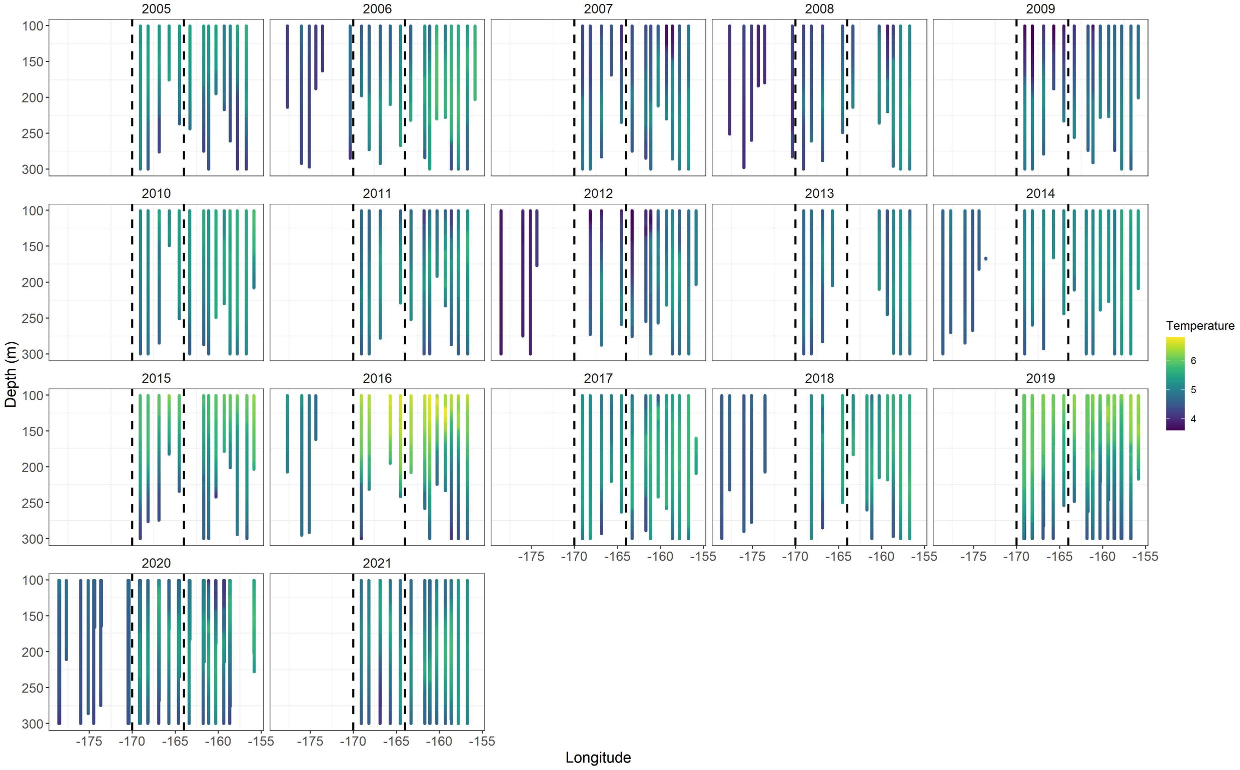

Figure 15: Temperature depth profiles (101–300 m) longitudinally along the continental slope for stations sampled during the first two legs of the longline survey and south of the Aleutian Chain. Vertical dashed lines at 170°W (-170) denote the boundary between the central and eastern Aleutians and 164°°W (-164) denotes the boundary between the eastern Aleutians and western Gulf of Alaska.

Status and trends: Longitudinal cross sections of temperature from 101-300 meters along the continental slope south of the Aleutians show how water masses interact in this region (Figure 15). These temperature profiles are a snapshot from the month of June, and do not capture many of the dynamics of this region; however, they are representative of the thermal conditions that the survey experienced. As expected, there is a temperature gradient from east to west with colder temperatures towards the west. Although temperatures warmer than 6°C reached deeper than 100 m in the GOA during the 2024-2016 heatwave, this does not seem to be the case for water west of 170-172°W coinciding with Samalga and Amukta passes (the easternmost deep wide pass) which are believed to be a biogeographical boundary (particularly the first one). This is most evident in 2020 when temperatures around 5°C were recorded east but not west of 172°W. However, waters west of 170-172°W seem to have remained warmer than temperatures seen in 2012 and earlier.

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

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

Trawl survey Water Temperature Analysis

Description of indicator: Since 1994, water temperature data have routinely been collected during the Aleutian Islands Bottom Trawl Survey conducted by the Alaska Fisheries Science Center Resource Assessment and Conservation Engineering Division Groundfish Assessment Program (von Szalay et al., 2017). There were three triennial AI bottom trawl surveys between 1994 and 2000; since 2000 the surveys have been conducted biennially (except in 2008 when there was no AI bottom trawl survey).

Microbathythermographs (MBTs) attached to the headrope of the net measure and record water temperature and depth during each trawl haul. In 2004, the SeaBird (SBE-39) MBT (Sea-Bird Electronics, Inc., Bellevue, WA) that is in use today replaced the Brancker XL200 data logger (Richard Brancker Research, Ltd., Kanata, Ontario, Canada) which had been in use since 1993. The analyses presented here utilize bathythermic data collected on AI bottom trawl surveys since 1994.

The bottom trawl survey has historically begun in late spring (late May to early June) and proceeds west from around Unimak Pass to Stalemate Bank over the course of the summer sampling in the Bering Sea and Pacific Ocean north and south of the archipelago (von Szalay et al., 2017). In 2002 and 2006, our typical sampling progression was partially reversed with the later season survey sweeping from west to east. We anticipate that water temperatures will increase with advancing collection date and increasing day length as the survey progresses westward over the summer which could lead to spatially and temporally confounded data complicating inter-annual comparisons.

To account for the influence of changing day length on water temperatures over the course of the summer and to make inter-annual comparisons more meaningful, an attempt was made to remove the effect of collection date on water temperature by standardizing all bottom trawl collection dates to a median survey date. This was achieved using generalized additive modeling (GAM) to estimate the effects of collection date on temperature at depth across survey areas and years. The resulting model was used to predict temperature at depth at the historic median survey day for all survey trawl hauls of July 10. Residuals from this GAM were added to the predicted median day temperature-at-depth to produce estimates of thermal anomaly from the model prediction at each station in all survey years. To facilitate visualization, these temperature estimates were averaged over systematic depth bins in ½ degree longitude increments. Depth gradations were set finer in shallower depths and broader in deeper depths (e.g., 0–3 m bin, 3–5 m bin, 5 m bins between 5 and 100 m and 25 m bins between 300 and 450 m) to capture the rapid changes anticipated in surface waters of temperature with depth. To further stretch the color ramp and enhance the visual separation of the near-surface temperature anomalies (between about 4 and 10°C and < 100 m), predicted temperature anomalies ≥7.5°C and ≤3.5°C were fixed at 7.5 and 3.5°C (e.g., a 12.5°C temperature anomaly was recoded as 9.5°C for the graphic representation).

Status and trends: The warmest anomalies across the AI typically occurred near the surface (less than 50m) and their depth of penetration beyond the surface varied between years (Figure 16). During the warmest years in the record (2014 and 2016), the warmer anomalies penetrated to 100 m or deeper. There were also some temporally persistent and spatially consistent features in these anomaly plots. Warm, near-surface temperature anomalies were commonly found around the Island of Four Mountains, between Seguam Pass (173°W), Amchitka Pass (179°W), and west of Buldir Pass (175°E). Cooler temperatures were consistently observed at depths greater than 100 m near Seguam Island (172.5°W), which is a particularly striking feature during colder years (e.g., 2010, 2012). Warmer years were dominated not only by warmer surface anomalies, but by deeper penetration of warmer waters across the breadth of the archipelago. The last three survey years in the AI have generally been warmer than previous years with the exception of 1997 which was comparable with the thermal anomalies observed in 2014 and 2016. The 2018 AI profile suggests a return to slightly cooler conditions relative to 2016, but is still amongst the warmer years from our record with warm anomalies penetrating deeper and distributed more extensively across the Aleutian archipelago than in 2014. The marked differences amongst survey years and the warm and cold year patterns help to illustrate the highly variable and dynamic oceanographic environment found in the Aleutian archipelago.

Factors influencing observed trends: These observations, and the thermal anomalies modeled from them, represent a brief spatial and temporal snapshot of water temperatures collected during bottom trawl surveys in the AI. Each temperature bin represents data collected over a relatively short time as the vessels moved through an area. Thus, it is difficult to draw general conclusions since short term events such as storms, tidal exchange, or freshwater runoff greatly affect local water temperatures.

More recent and larger scale phenomena may have longer-lasting implications on water temperatures in the region. The thermal signal caused by the “Ridiculously Resilient Ridge” of atmospheric high pressure that helped to establish the persistent warm water “Blob” in the Northeast Pacific during 2014 and 2015 (Bond et al., 2015; Di Lorenzo and Mantua, 2016), and which likely intensified the El Niño Southern Oscillation (ENSO) event of 2015–2016 (Levine and McPhaden, 2016), probably influenced the temperatures observed on our 2016 survey. Daily plots of sea surface temperature anomalies (SST) show warmer surface waters extending from east to west during the summer of 2016 (`http://www.ospo.noaa.gov/Products/ocean/sst/anomaly/index.html`). Due to these and other sources of variation not accounted for in the temperature model presented here, caution should be exercised when interpreting these results.

Implications: The strength and persistence of various oceanographic features in the AI are anticipated to influence ecological processes there. The depth and horizontal dispersion of the mixed layer affect primary production in this region (Mordy et al., 2005). Water temperatures influence ontogenesis of Atka mackerel eggs and larvae (Lauth et al., 2007) and have been shown to impact pollock abundance in the eastern Bering Sea (Stevenson and Lauth, 2012). Work on habitat-based delineation of essential fish habitat (EFH) in the AI and eastern Bering Sea have demonstrated that water temperature can be an important determinant of EFH for many groundfish species (Laman et al., 2017, 2018; Turner et al., 2017). Eddies are also believed to play a major role in the transport of both heat and nutrients into the Bering Sea through the Aleutian passes (Maslowski et al., 2008). Phenomena such as these must influence both AI and Bering Sea ecosystems and fish populations. By considering inter-annual differences in water temperatures and their implications, we can better utilize our survey data to understand the state of fish populations in the AI.

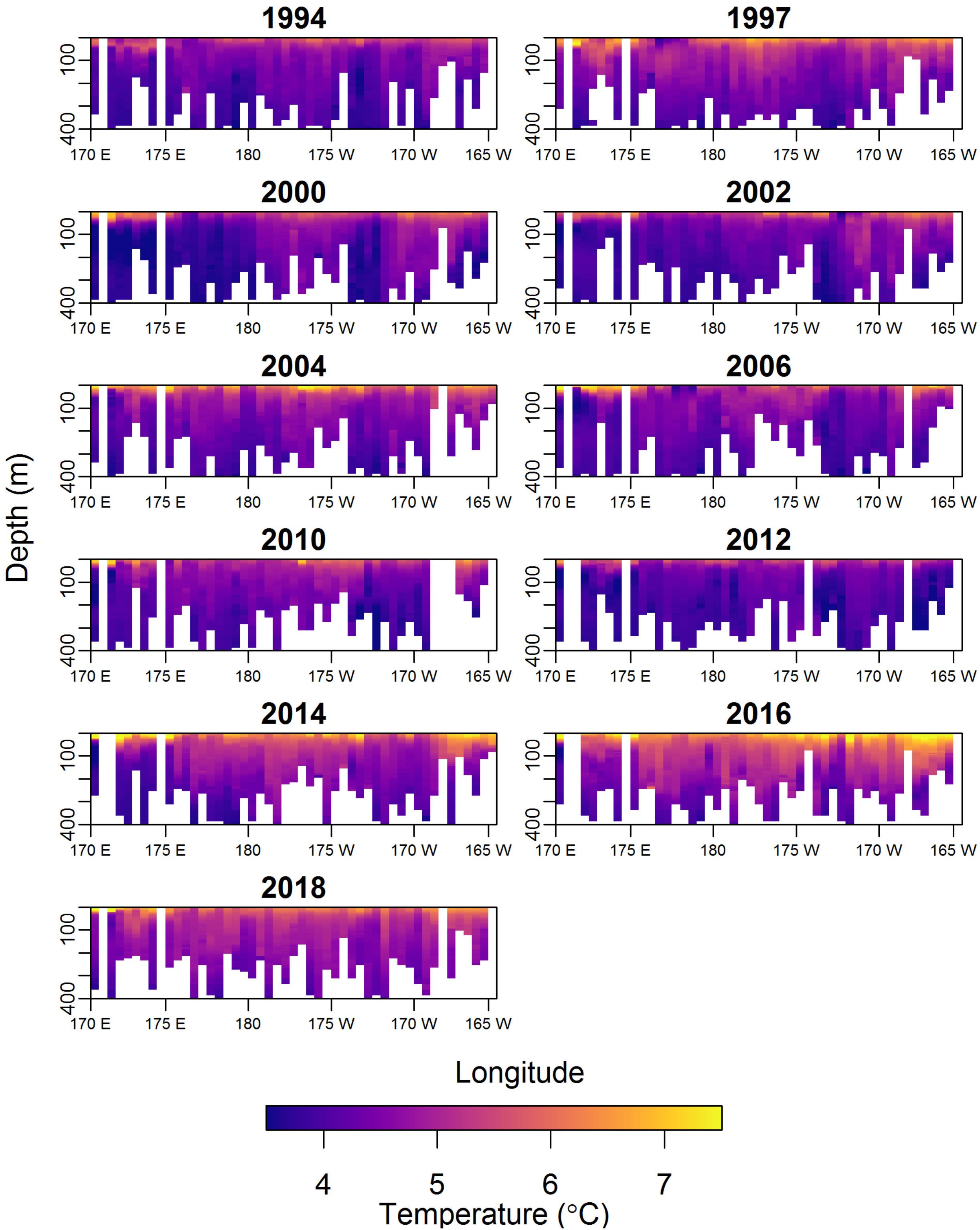

Figure 16: Median-survey-date-standardized, generalized additive model (GAM) predicted thermal (°C) anomaly profiles from water temperature measurements collected on Aleutian Islands [mostly biennial] bottom trawl surveys (1994–2018); to visually enhance near-surface temperature changes, values ≤3.5°C or ≥7.5°C were fixed at 3.5 or 7.5°C and the y-axis (depth) was truncated at 400 m though maximum collection depth was ca. 500 m.

5. Ocean Transport –Eddies in the Aleutian Islands

Contributed by Wei Cheng, Carol Ladd,

Description of indicator: Eddy kinetic energy can be used as an index of strength and frequency of eddies. Three regions of high eddy kinetic energy are highlighted in Figure 17. Eddies in the Alaskan Stream south of the Aleutian Islands and east of ∼180° (easternmost box in map figure) have been shown to influence flow into the Bering Sea through the Aleutian Passes (Okkonen, 1996; Stabeno and Hristova, 2014). Numerical models have suggested that eddies passing near Amukta Pass may result in increased flow from the Pacific to the Bering Sea (Maslowski et al., 2008). By influencing flow through the passes, eddies could impact flow in the Aleutian North Slope Current (Stabeno et al., 2009) and Bering Slope Current (Ladd, 2014) as well as influencing the transports of heat, salt and nutrients (Mordy et al., 2005; Stabeno et al., 2005) into the Bering Sea. Eddies north of the Aleutian Islands (middle box in map, Figure 17) typically form in the Bering Slope Current near Pribilof Canyon and propagate southwestward toward Amchitka Pass (Ladd et al., 2012). They are typically weaker than those in the Alaskan Stream but may play a role in modulating flow through Amchitka Pass. Eddies formed west of 180° are called Aleutian Eddies (westernmost box in Figure 17). They typically form near the Aleutian Islands and then move southwestward away from the Aleutians (Saito et al., 2016) potentially influencing the distribution of phytoplankton and zooplankton (Saito et al., 2013) during their propagation.

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

Status and trends: In the western Aleutian Islands, (Figure 18, top panel), EKE continues on its last year's status, both are below the long-term average. EKE was low until 2006 when it abruptly increased and remained relatively high until 2012. This region experienced another period of high EKE in 2015–2016 but has been low since 2017.

EKE north of the Aleutian Islands near Amchitka Pass (Figure 18, middle panel) is much lower than the two highlighted regions south of the islands (note differing vertical axes between plots). Eddy energy was higher than average in this region during 2000–2008 and again in 2016 but has been relatively low since then.

Particularly strong eddies were observed south of Amukta Pass (Figure 18, bottom panel) in 1997, 1999, 2004, 2006/2007, 2009/2010, and summer 2012. Eddy energy in the region has been low from the fall 2012 through 2021.

Factors causing trends: Eddies in the eastern AI are related to the strength of the Alaska Stream (AS) which in turn is forced by large scale atmospheric forcing and the North Pacific gyre. Local wind can push AS against or away from the coast and changes transport in Unimak Pass. Transport and eddies in the western AI passes are less studied/measured. Presumably transport

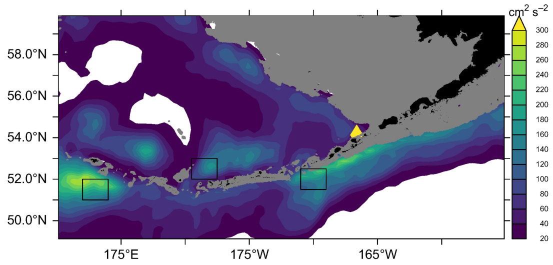

Figure 17: Eddy kinetic energy averaged over January 1993–December 2020, calculated from satellite altimetry. Squares denote regions over which EKE was averaged for Figure 18

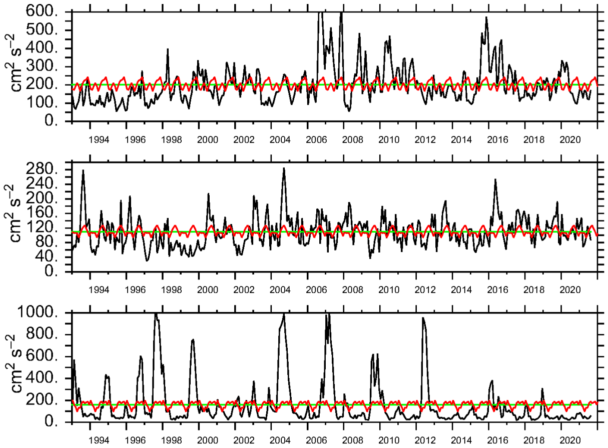

Figure 18: Time series of eddy kinetic energy averaged over regions shown in Figure 17 from west (top) to east (bottom). Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product). Red: seasonal cycle. Green (straight line) : mean over entire time series.

in the western region is highly correlated with AS. Causes of variability in EKE in this region are currently unclear and a subject of ongoing research. For example, it is unclear whether changes in the time series reflect a long-term trend in the large scale forcing (e.g., wind, NPGO, the latter shows a decline trend since 2011), and it is unknown whether the relationship between mean flow and eddy strength reinforce or counteract each other.

Implications: These trends indicate that higher than average volume, heat, salt, and nutrient fluxes to the Bering Sea through Amukta Pass may have occurred in 1997/1998, 1999, 2004, 2006/2007, 2009, and summer 2012. EKE is near or below its long-term average in 2021 in all regions along the AI chain even though the anomalies are not particularly strong, thus these fluxes likely have been smaller since fall 2012.

6. Primary Production – Satellite derived Chl-a

Contributed by Noel Pelland and Jordan Watson,

Description of Indicator: Surface chlorophyll concentrations, often interpreted as a proxy of phytoplankton biomass or abundance in the surface ocean, can be an important indicator for bottom-up ecosystem processes and resources available at the base of the marine food web (e.g., Ware and Thomson (2005)). We present estimates of the average satellite-sensed surface chlorophyll in non-coastal areas of the AI ecosystem, along with spatial patterns of recent chlorophyll anomalies. These estimates are constructed from 8-day composite MODIS Aqua 4km chlorophyll-a images obtained from the NOAA CoastWatch West Coast Regional Node from 2003 to 2021. Analysis focuses on the two periods of the most consistent data availability: spring (April–June) and late summer/early fall (August–October).

Previous ESRs for the Aleutian Islands (AI) have highlighted a need to better understand variability in surface chlorophyll concentrations, relationships to large-scale physical changes, and potential significance to the distribution, abundance, and reproductive success of higher trophic level organisms. Recently, a new project was initiated to assess satellite chlorophyll data availability, modes of variability, and the role of previously-identified physical mechanisms (e.g., Mordy et al., 2005) in forcing interannual changes in the AI. The indicator described here is an outgrowth of this work.

The 2020 physical environmental synthesis noted that satellite chlorophyll data coverage in the AI was significantly lower than the Bering Sea and Gulf of Alaska regions, and featured interannual and geographic variability within the ecosystem. The impact of these processes on chlorophyll signals was unclear and therefore results beyond data coverage were not presented. For this year's update, the methodology has been refined with the goal of addressing these uncertainties and quantifying the reliability of chlorophyll information obtained in this ecosystem. Specifically, to address or reduce uncertainty we: (a) first average the data from 8-day composites within Alaska Department of Fish and Game Groundfish Statistical Areas – `https://www.adfg.alaska.gov/index.cfm?adfg=fishingCommercialByFishery.statmaps`. This reduces spatial bias in data availability and isolates larger-scale signals; (b) quantify the impact of missing data on sampling error both within these areas and the overall AI (and on bias error in the latter); and (c) consider, for now, chlorophyll signals averaged across the entire AI ecosystem rather than sub-regions, which reduces random sampling error.

At present, chlorophyll data within statistical areas with a surface area >2500 km2 are retained for this analysis to ensure a greater likelihood of data availability. This criterion excludes data collected in some shallow near-coastal areas in the central and eastern Aleutians. Data averaged within statistical areas are then used to compute spatial averages across the AI in each 8-day image and a composite seasonal cycle across years. Confidence bounds for averages within statistical areas or the ecosystem overall are based on bootstrap sampling of 8-day images that are fully resolved or nearly so. Bias effects due to missing data on the average across the AI were assessed by filling missing statistical areas in an 8-day image using the mean spatial structure appropriate for that day of year. The mean spatial structure was estimated from the composite cycle across years and scaled to the resolved portion of the given 8-day image. The time series of the AI-average of this gap-filled dataset was not substantially different in interpretation from that with gaps.

Status and Trends: Overall Aleutian Islands surface chlorophyll concentrations measured from MODIS were near-average in spring 2021 (Figure 19 a). This follows two years of similarly near-average concentrations in spring 2019-2020, with the exception of a period in late May and June 2020 when concentrations were below normal (Figure 19 b). Peak AI-wide concentrations were observed in late May and early June 2021, as opposed to the typical mid-May peak in the composite seasonal cycle, suggestive of a slightly later than normal bloom in spring of this year. Fall 2020 values were above average, which followed below average values in fall of 2019 (Figure 19 c, d).

In spring 2021, anomalies were modest or spatially intermittent in April, but larger and more coherent anomalies were observed in May and June (Figure 20 top row). In May, positive anomalies were observed in the western Bering Sea and central North Pacific portions of the AI domain, with negative anomalies centered on the Alaska Stream and farther offshore. In June, positive anomalies strengthened in the western Bering and were more widespread south of the Aleutian chain, with weaker negative anomalies in the eastern portion of the domain. Fall 2020 anomalies (Figure 20, bottom row) had lower peak magnitudes than those observed in spring 2021 but were less spatially heterogeneous. Consistent positive anomalies were observed in the Bering Sea in September 2020 and across much of the domain in October 2020.

Factors causing observed trends: Light availability, nutrient concentrations, temperature, grazing pressure, turbulence intensity, and stratification are all significant factors that may affect phytoplankton growth, biomass, and chlorophyll concentrations. During spring, the largest interannual variability in spatial-average concentrations is observed in May. In fall, the range of interannual variability is more similar between months, and there tends to be a somewhat more consistent offset between years. Seasonal, spatial-average spring anomalies are not correlated with those in either the following ($r = -0.41$, $p = 0.09$) or preceding ($r = 0.23$, $p = 0.36$) fall season. Years in which low spring chlorophyll concentrations were observed (e.g., 2016, 2018, Figure 19 b) have relatively spatially uniform negative anomalies (not shown), suggesting processes operating at an ecosystem-wide scale, but further work is needed to explore these results. Research is ongoing to explore climate indices or other physical indicators related to interannual variability and spatial patterns. Candidates include the strength of the large-scale oceanic circulation including the Alaska Stream, mixing in the Aleutian passes (Mordy et al., 2005), and atmospheric forcing of upper-ocean mixing and stratification.

Implications: The region shows evidence for significant interannual variability in chlorophyll concentrations, which may differ between the spring and fall blooms. In years with near average region-wide concentrations, anomalies can still be spatially heterogeneous, as observed in spring of 2021. The consequences of these variations to other components of the marine ecosystem in the AI are not well understood at present, but initial assessment is an important first step that can provide the foundation for future work.

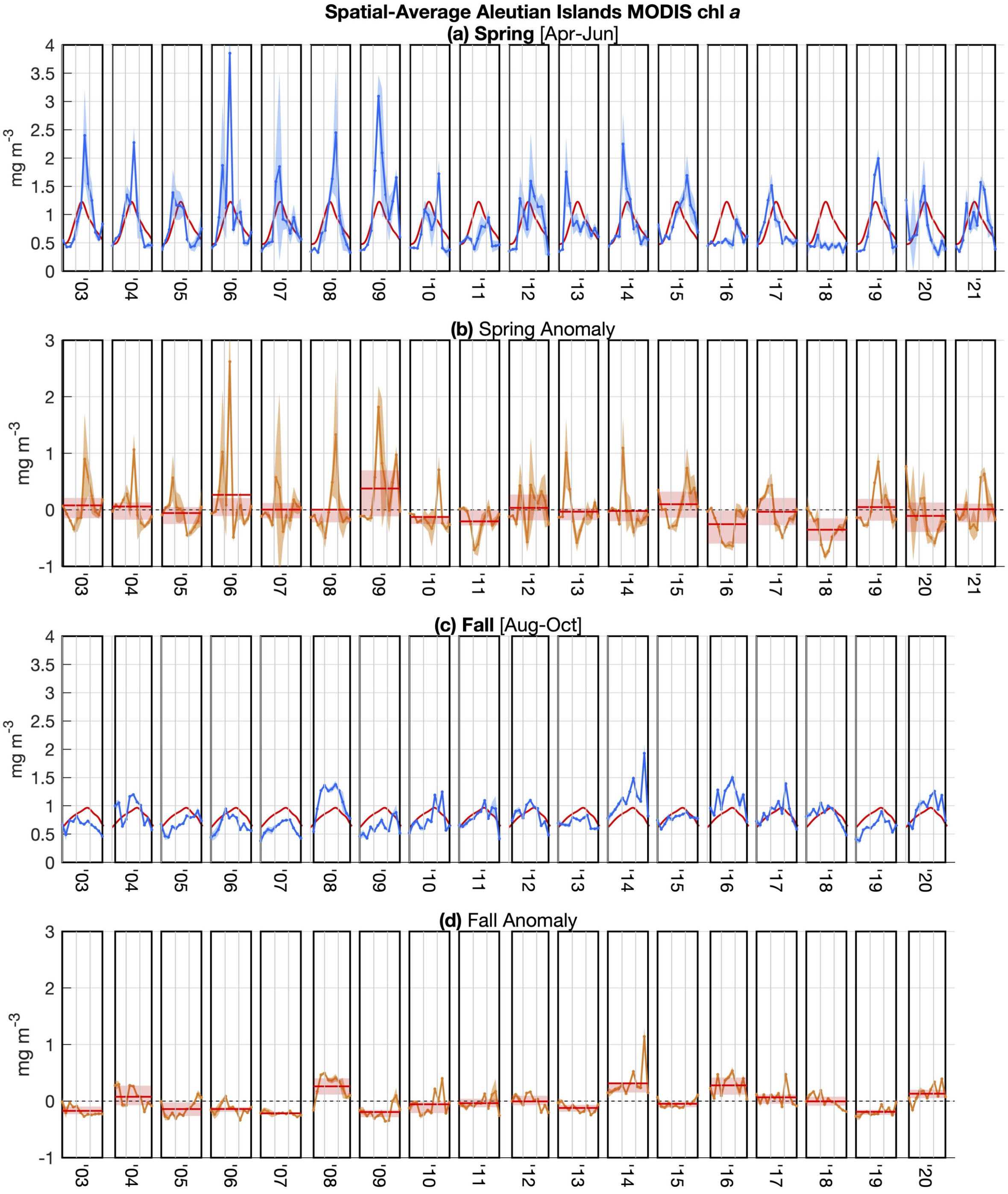

Figure 19: Time series of spatial-average Aleutian Islands chlorophyll a in MODIS 8-day composites, for the months of (a)-(b) April to June, and (c)-(d) August to October. Panels (a) and (c) show the full time series, while (b) and (d) show anomalies from a composite seasonal cycle (red line in (a)/(c)). In (b) and (d), red line and shading respectively indicate the mean and interquartile range of anomalies in each year. Gray shading indicates (preliminary) 95% confidence bounds. Light gray lines delineate boundaries between months in each year.

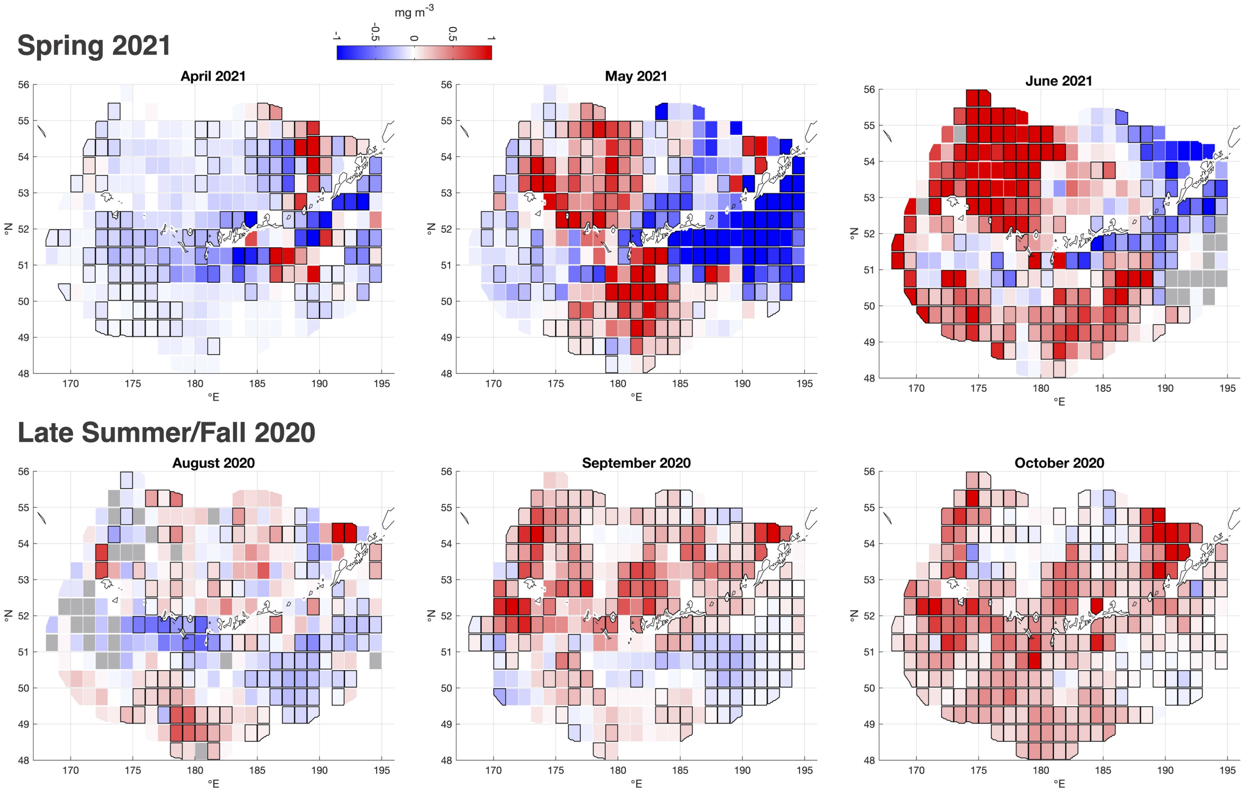

Figure 20: Spatial patterns in monthly-average anomalies from the seasonal cycle, April-June 2021 (top row) and August-October 2020 (bottom row). Anomalies are composed from data averaged with Alaska Department of Fish and Game Statistical Areas, restricted to areas of size ¿2500 square kilometers. Areas with a black boundary have an average anomaly exceeding the 95% confidence bounds. Color scale is at upper right in each panel. Gray shading indicates areas not sampled within a given month.

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

Contributed by Clare Ostle and Sonia Batten

Description of indicator: Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. Two transects are sampled seasonally, both originating in the Strait of Juan de Fuca, one sampled monthly (∼Apr–Sept) which terminates in Cook Inlet, the second sampled 3 times per year (in spring, summer and autumn) which follows a great circle route across the Pacific terminating in Asia. Several indicators are now routinely derived from the CPR data and updated annually. In this report we update three indices for the region around the Aleutian islands, including deep waters of the southern Bering Sea (Figure 21): large diatoms (the CPR only retains large, hard-shelled phytoplankton so while a large proportion of the community is not sampled, the data are internally consistent and may reveal trends), mesozooplankton biomass (estimated from taxon-specific weights and abundance data), and mean Copepod Community Size (Richardson et al., 2006) as an indicator of community composition. Anomaly time series of each index have been calculated as follows: a monthly mean value (geometric mean) is first calculated. Each sampled month is then compared to the mean of that month and an anomaly calculated (Log_{10}). The mean anomaly of all sampled months in each year is calculated to give an annual anomaly.

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

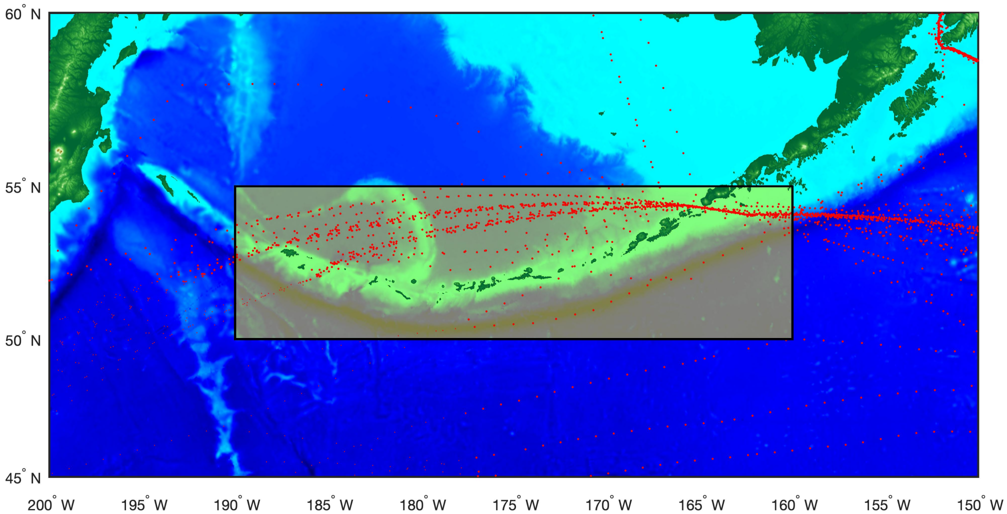

Figure 21: Location of the samples collected for the CPR analysis. Dots indicate actual sample positions and may overlay each other.

Status and trends: Figure 22 shows that the copepod community size and mesozooplankton biomass anomalies for 2020 were negative, where they had been positive in 2019. The mean diatom abundance anomaly was also negative in 2020.

Factors influencing observed trends: Analysis of summer CPR data in this region has revealed a general alternating (and opposing) pattern of high and low abundance of diatoms and large copepods between 2000 and 2012, believed to be the result of a trophic cascade caused by maturing Pink Salmon present in the region (Batten et al., 2018). Although the upper panel (diatoms) in Figure 22 contains data from spring and autumn as well as summer the alternating pattern is clear. The zooplankton data in Figure 22 consist of more taxa than just large copepods but it is likely that there is some top-down influence of the Pink Salmon also present in these data. In 2013 the east Kamchatka Pink Salmon run was much lower than expected and in 2014 it was much higher. CPR data were not collected in this region in the summers of 2015 to 2017 so we are not certain if their influence on the plankton continues, nor how to tease out the simultaneous influence of ocean climate. However, the copepod community size anomaly has been negative in each season sampled since summer 2016 (apart from 2019) which suggests a real increase in the relative abundance of smaller species, potentially because of warmer than normal conditions.

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

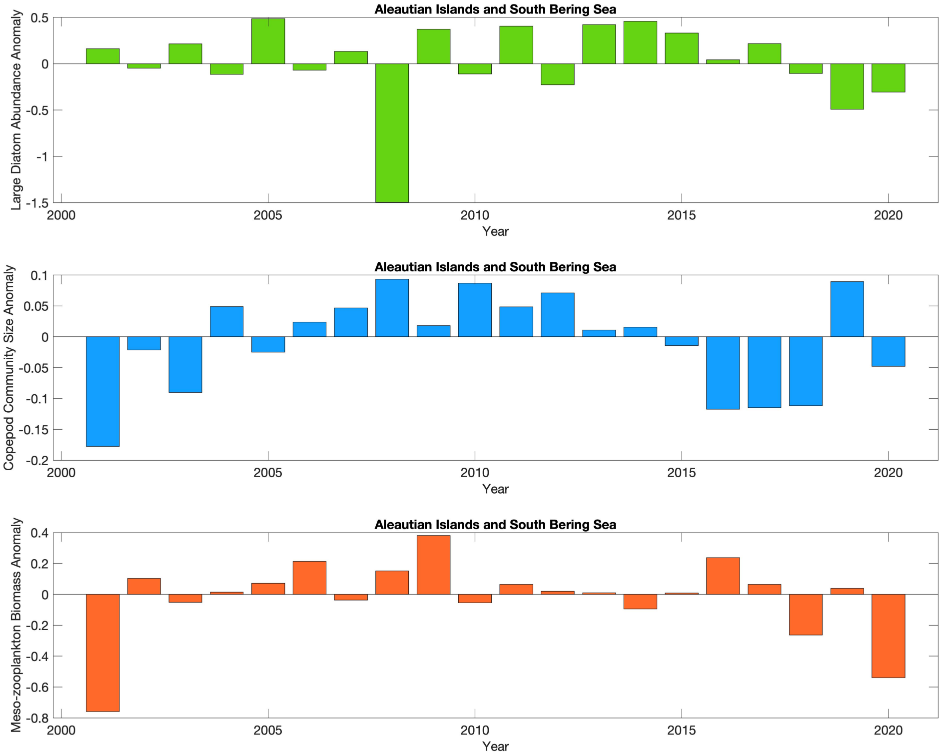

Figure 22: Annual anomalies of three indices of lower trophic levels from CPR data (from top to bottom): Large diatom abundance, copepod comunity size and meso-zooplankton biomass (see text for description and derivation) for region shown in Figure 21.

Salmon

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

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Last updated: 21 October 2021

Description of indicator: Eastern Kamchatka pink salmon (Russia) are the primary pink salmon population occupying the Aleutian Islands Ecosystem and adjacent areas, based on historical tag and recovery studies (Takagi et al., 1981). Other pink salmon populations from Russia, Japan, and Alaska may occur here to a lesser extent. However, stock-specific analyses of pink salmon in this region have not been conducted in several decades and it is unknown whether the increasing abundances of all pink salmon populations has led to a broader distribution at sea. Eastern Kamchatka pink salmon emerge from spawning grounds in coastal rivers during early spring, migrate to sea with little rearing in freshwater, then migrate southward in epipelagic waters of the East Kamchatka Current and eastward with the Subarctic Current along the southern side of the Aleutian Islands up to about 155°W. Little sampling of age-0 pink salmon has occurred in the Aleutian Islands Ecosystem owing to their small size, but some have been captured in this region during August and September. Pink salmon spend only one winter at sea (south of the Aleutian Islands). During spring (primarily June and July), maturing pink salmon migrate north and west through the Aleutian Island passages (including the eastern area) and into the Bering Sea where they are exceptionally abundant in spring and summer of odd-numbered years prior to migrating back to their natal rivers in summer. Sampling at sea indicates abundance in odd years is approximately 40 times greater than that in even years (Batten et al., 2018), owing to their fixed two-year life history.

Status and trends: The eastern Kamchatka pink salmon is an exceptionally abundant population of wild pink salmon, especially in odd-numbered years (Figure 23). No hatchery production of pink salmon occurs in this region. Pink salmon abundance was relatively stable over time from 1952 through the mid-1970s, then odd year runs began to increase over time. Even year abundances began to increase in 2014, corresponding with the unexpected decline in the 2013 return (33 million adults). From 2011 to 2021, abundance averaged 200 million salmon in odd-numbered years and 67 million salmon in even-numbered years. The largest run on record occurred in 2019 (∼315 million adults), followed by the small run in 2020 (∼29 million adult fish) that was less than recent even-year runs. In 2021, preliminary harvest data indicate exceptional harvestss of pink salmon, which were only exceeded by the record harvest and abundance in 2019. During off years (2015, 2017, and 2019), Eastern Kamchatka pink salmon represented ∼40% of total pink salmon returning from the North Pacific compared with 18% during even years (2016, 2018, and 2020).

As a species, pink salmon represent nearly 70% of all Pacific salmon (Ruggerone and Irvine, 2018). In 2018 and 2019, record numbers of Pacific salmon returned from the North Pacific (950 and 854 million, respectively), of which approximately 75% were pink salmon (Ruggerone et al., 2021). Preliminary harvest data from Alaska and Russia (e.g. both eastern and western Kamchatka) suggest pink salmon abundance returning from the North Pacific in 2021 may have exceeded abundances in all previous years since detailed record keeping began in 1925.

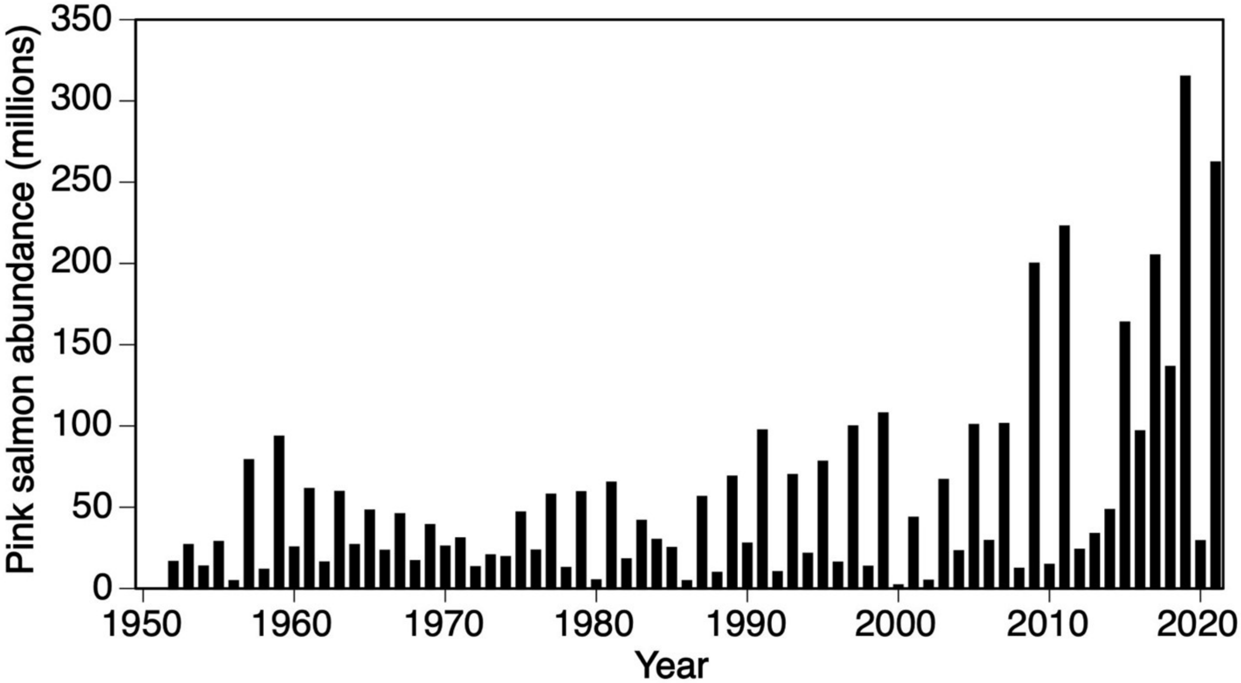

Figure 23: Time series of Eastern Kamchatka pink salmon abundance, 1952–2021. Values include catch and spawner abundances. Sources: (Ruggerone and Irvine, 2018), (Ruggerone et al., 2021). The 2021 value is based on preliminary harvest data (S. Zolotukhin, VNIRO, pers. communication).

Factors influencing observed trends: Abundances of pink salmon in Eastern Kamchatka and other regions increased after the 1977 ocean regime shift that was generally associated with warmer sea surface temperatures and greater zooplankton production (e.g., Brodeur and Ware 1992). However, in 2013 the abundance of Eastern Kamchatka pink salmon declined sharply for unknown reasons, potentially supporting an increase in even-year abundances of pink salmon in 2014, 2016 and 2018 followed by a return to typical even-year abundance in 2020 (Figure 23). Odd-year abundances quickly recovered after 2013 to record numbers in 2019 and high numbers in 2021, based on preliminary harvest values.

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

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

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

Seabirds

Integrated Seabird Information

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Last updated: October 2021

Synthesis: *Both plankton and fish-eating species had good reproductive success in 2021. It was an exceptionally successful reproductive season for fish-eating seabirds at both Buldir in the western Aleutians and Aiktak in the eastern Aleutians, presumably indicating uniformly high prey availability for both nearshore and offshore foragers, surface feeders and divers. This success is despite possible lagged effects from the northeast Pacific marine heatwave of 2014–2016 (Piatt JF, 2020), especially in the eastern Aleutians, and good returns of Kamchatka pink salmon in 2021, which compete with seabirds and other fish for copepods (Zador et al., 2013; Springer and van Vliet, 2014).*

In 2021, the timing of breeding was average or earlier for most seabird species at both Buldir and Aiktak. The exceptions were fish-eating divers on Buldir (thick-billed murres, puffins) and tufted puffins at Aiktak, which arrived later than average (Figure 25). Earlier hatch dates were coincident with higher-than-average chlorophyll a concentration in June (Figure 19) and were more common for surface-feeders that are dependent on sea surface productivity (Descamps et al., 2019).

No large or unusual seabird die-offs were documented via standardized beach-based surveys. Opportunistic reports of beached birds included few that were resident species. Most were migrant short-tailed shearwaters that possibly left the Bering Sea in search of food farther south.

Description of indicator: Seabirds are considered to be useful ecosystem indicators, as their breeding performance and diet composition reflect conditions in the marine environment. Here we provide an overview of environmental impacts to seabirds and what those may indicate for ecosystem productivity as it pertains to fisheries management. We synthesize data and field observations collected by government, university and non-profit partners to provide an assessment of the status of seabirds in the Aleutian Islands during 2020 and 2021.

We present information in three main sections as indicators of processes at different spatio-temporal scales: i) timing of breeding, which reflects ecosystem conditions prior to breeding, ii) reproductive success, which reflects feeding conditions during the breeding season and/or system phenology, and iii) population information, including mortality, which encompasses environmental and ecosystem effects during spring/summer, and winter abundance, which reflects fall/winter conditions and possible summer carry-over effects.

Each type of information is presented for seabirds based on their feeding strategy and main prey—surface or diving seabirds feeding on fish or plankton (see Figure 24). Seabirds discussed here feed offshore, as well to nearshore (∼3 km from land, Byrd et al. (2005)), regardless of their feeding strategy or prey. However, because nearshore feeders generally forage in shallow water, their prey is less likely to be affected by currents and fronts (Byrd et al., 2005). The western Aleutians are dominated numerically by planktivorous seabirds, while the eastern Aleutians are dominated by piscivorous seabirds.

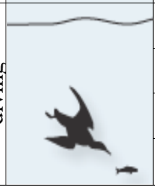
strategy	prey	habitat	common name
surface 	plankton	offshore	fork-tailed and Leach's storm-petrels
	fish	nearshore	glaucous-winged gull
	fish	offshore	red/black-legged kittiwakes and northern fulmars
diving 	plankton	nearshore	parakeet auklets, whiskered auklet
	plankton	offshore	ancient murrelets, least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

Figure 24: Feeding strategy, prey and habitat of the main seabird species monitored annually by AMNWR in the Aleutian Islands, based on Byrd et al. (2005)

Status and Trends

Timing of breeding and reproductive success (Buldir and Aiktak)

Hatch dates for most auklet species (which are near-obligate planktivores) were within the long-term mean, while those for several diving fish-eating seabirds (thick-billed murres at Buldir, horned puffins at Buldir and tufted puffins at both sites) were later than the long-term mean (Figure 25).

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

Figure 25: Seabird relative breeding chronology in 2021 compared to long-term averages for past years at Aiktak and Buldir islands. White clock indicates hatching chronology was >3 days earlier than average. Gray clock within 3 days of average. Black clock <3 days later than average. Dashes indicate species not monitored at a site or for which sample size too small for comparison.

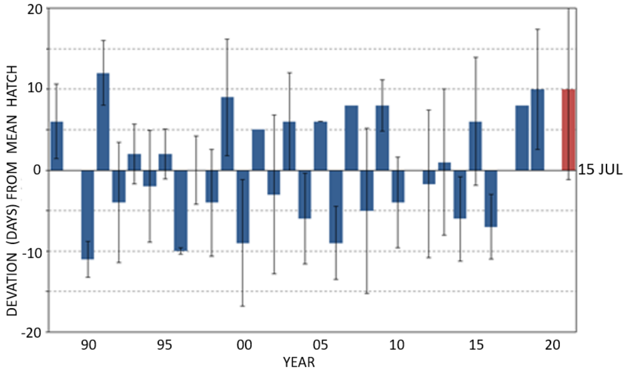


Figure 26: Yearly hatch date deviation (from the 1988-2020 average of 15 July) for tufted puffins at Buldir Island, Alaska. Negative values indicate earlier than mean hatch date, positive values indicate later than mean hatch date. Error bars represent standard deviation around each year's mean hatch date (years without error bars have sample size of one); red highlights the current year. No data were collected in 2020; no hatch dates were recorded with the appropriate egg to chick interval (≤7 days) in 1989 or 2017 and no eggs hatched in plots in 2011.

The breeding timing of tufted puffins at Buldir has been shown to vary with the high/low biennial runs of Kamchatka pink salmon (Springer and van Vliet, 2014), where high pink salmon numbers correlated with later hatch dates. The biennial pattern continued in 2021, with a high pink salmon year occurring with later than average hatch dates (Figure 26). The deviation from this pattern that occurred in 2018, when the few birds that returned to breed failed, was likely due to lagged effects due to the widespread, prolonged marine heatwave from 2014–2016 (Piatt JF, 2020).

Seabird reproductive success was average to above average for most species at both colonies during 2021. However, storm-petrels had mixed success. At Aiktak, fork-tailed storm petrels had above average success, while that of Leach's storm petrel was below average. The reverse was true for Buldir (Figure 27). Diving, fish-eating seabirds (common and thick-billed murres, tufted and horned puffins) all had above average reproductive success in 2021, except for common murres at Buldir, which had a small sample size. Black-legged kittiwakes and storm-petrels (which consume a mix of fish and invertebrates) and auklets (which are near-obligate planktivores) showed average to above average success rates, except for fork-tailed storm-petrels at Buldir and Leach's storm-petrels at Aiktak.

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

Figure 27: Seabird reproductive success in 2021 compared to long-term means for past years at Aiktak and Buldir islands. Big smiley face indicates reproductive success >1 SD above the long term mean, smiley indicates within 1 SD of long term mean, frowny face indicates >1 SD below long term mean, and broken faces indicate failure, which is considered values at or near zero. Dashes indicate species not present or monitored at a site or for which sample size too small for comparison.

Population information – winter abundance

In early winter each year, citizen science volunteers monitor seabird abundance on Unalaska Island using the Christmas Bird Count (CBC) area and effort-standardized protocol. The CBC from December 19, 2020 provides the best index of abundance for overwintering birds in the eastern Aleutians, including many species groups of interest with conservation concerns, such as declining populations, bycatch and/or die-offs.

Counts from December 2020 were significantly below the 10-year long-term average (Figure 28), suggesting that seabirds might have moved to more sheltered areas due to the stormier than average winter or that there might have been lower prey availability which resulted in fewer birds overwintering in the area and/or feeding very nearshore in the eastern Aleutians. This was in contrast to the winter of 2015, a strong El Niño winter with record-high water temperatures (Figure 7), when 931 crested auklets were documented during the 24-hour survey period (9-year average = 1.5 birds).

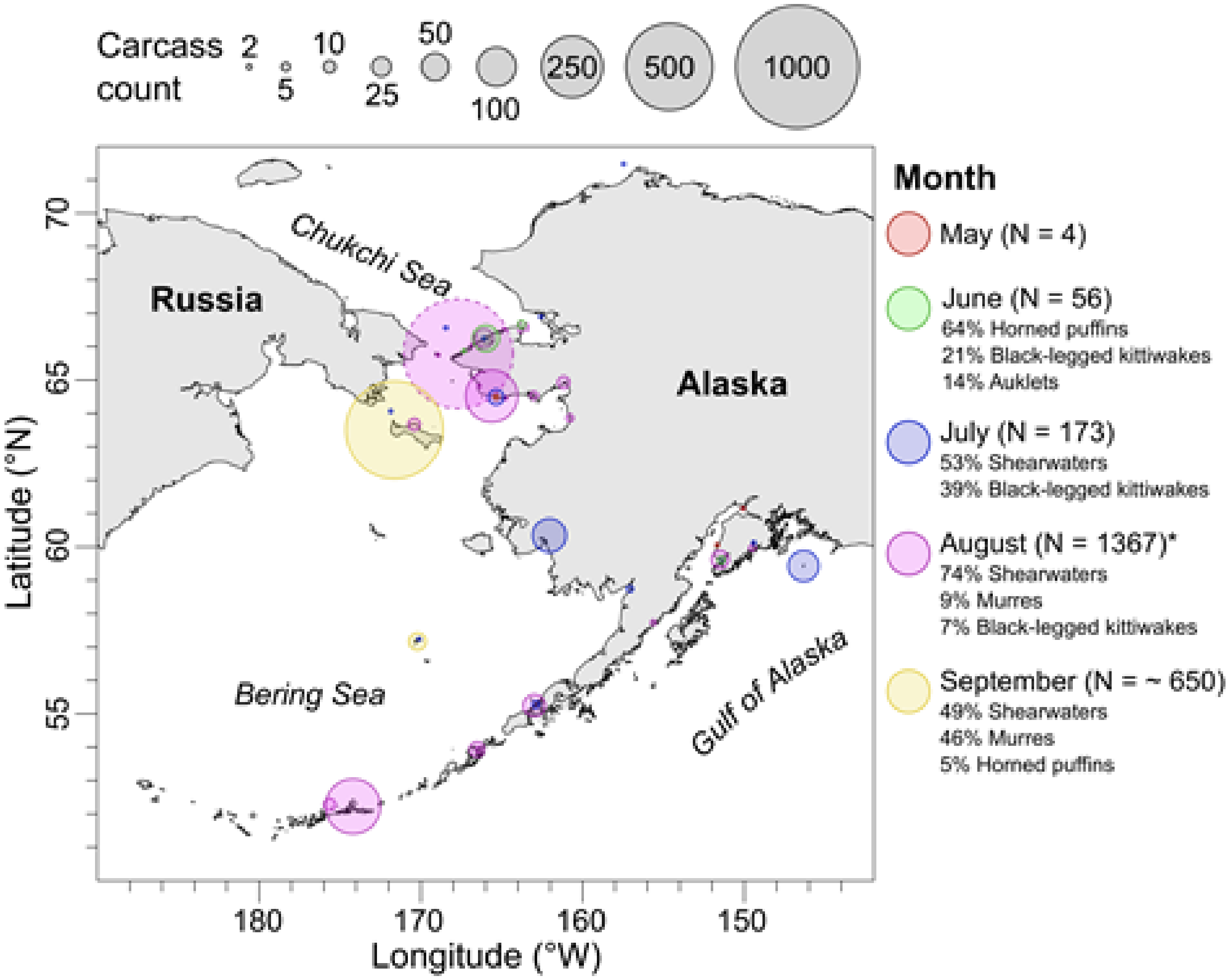
Figure 28: Marine bird groups consistently found during the Unalaska Christmas Bird Count. Grey bars indicate long-term average (Dec 2010–Dec 2020), black error bars are standard error. Dots are Dec 2020 count data.

Population information – mortality

Historically, seabird die-offs are not uncommon in Alaska (Bailey and Davenport 1972), but are seldomly reported from the Aleutian Islands, likely due to its remoteness, where die-offs may go unobserved (Alaska Report 2006). Opportunistic reports of beached birds were submitted to COASST and regional partners during the summer of 2021. These reports (mapped in Figure 29) layer contributions by community members in remote coastal locations on top of reports by citizen scientists.

Between May and September 2021, opportunistic reports of at least 2,250 seabird carcasses were received (Figure 29), which is an order of magnitude higher than in 2020 (∼638) and an order of magnitude lower than reports in 2019 (∼11,548). For comparison, a recent large die-off that occurred during spring 2015 to spring of 2016 was composed of about 47,000 common murres that were reported dying or dead on beaches and lakes across Alaska. Shearwaters made up the vast majority of reports from in August 2021, with small (20-50 birds) peaks in Cold Bay and Unalaska and ∼200 in Atka.

In 2021, COASST's standardized, monthly beached-bird surveys were conducted by the Alaska Maritime National Wildlife Refuge staff at five islands: three sites on Buldir, two on Chowiet, and one on Hall Island, Aiktak and Adak. Month-averaged encounter rates (birds/km) were similar to recent years (excluding 2020, when there was limited survey effort), see Figure 30.



* : species composition is of birds identified to species/group. However, in August a large proportion (60%) of birds were unidentified

Note: Circles represent reports of seabird carcass abundance and are not standardized for variable observer effort among locations. The absence of reports in certain locations may indicate gaps in current knowledge OR an actual absence of bird carcasses. Reports from aerial surveys (dashed circles) are distinguished from other beach-based reports (solid circles) due to major differences in area observed.

Figure 29: Opportunistic reports of seabird carcass show the extent and magnitude of seabird die-off events in Alaska in 2021. Map provided by Coastal Observation Seabird Survey Team (COASST) (`www.coasst.org`), with data from COASST participants, NPS staff, and coastal community members reporting to ADF$G, USFWS, UAF-Alaska Sea Grant, and Kawerak, Inc.

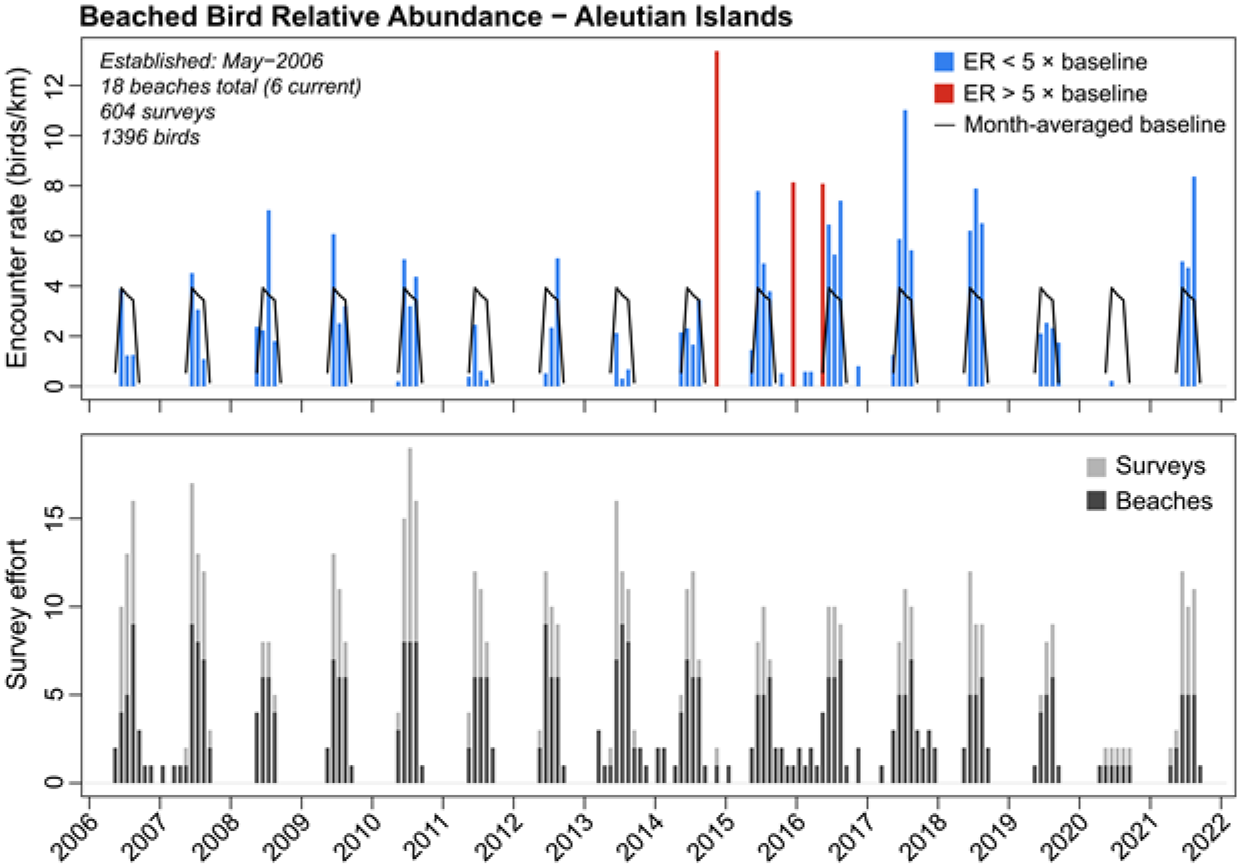
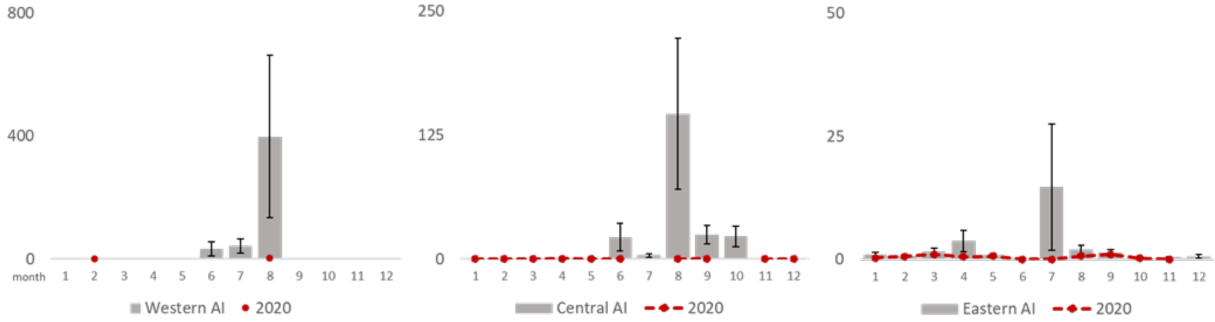


Figure 30: Month-averaged beached bird abundance, standardized per km of survey effort, for the Aleutian Islands. The top panel shows the month-averaged encounter rate (ER: birds per km). Months where the encounter rate was unusually high (¿ 5x the baseline rate) are highlighted in red and excluded from the calculation of the month-averaged baseline; these months likely contained surveys conducted during an unusual mortality event. The bottom panel shows survey effort at the monthly scale, indicated by number of surveys conducted and number of beaches surveyed.

Bycatch rates have been shown to be related to environmental conditions and bird abundance (Bi et al. 2020). The most recent bycatch data available are from 2020. Bycatch of two common species groups, shearwaters and fulmars was generally much lower than average in 2020, especially compared to peaks in 2019 associated with the marine heatwave (see seabird bycatch estimates, Table 1). Non-zero estimates of bycatch in February 2020 were higher for fulmars in the central and Eastern Aleutians (Figure 31), which may be related to an increase in winter marine heatwave days in both these regions (Figure 12).

Short-tailed shearwater reproductive success at summer breeding colonies in Southeastern Australia is negatively correlated with high runs of Kamchatka pink salmon in the preceding austral winter (Springer et al. 2018). Bycatch estimates of shearwaters show similar trends, low bycatch occurs in low pink salmon abundance “even” years and higher bycatch occurs during “odd” years of higher seabird-pink salmon competition, which is especially evident in the central Aleutians (Figure 32).

(a) Shearwaters, 2020 vs 2011-2020



(b) Fulmars, 2020 vs 2011-2020

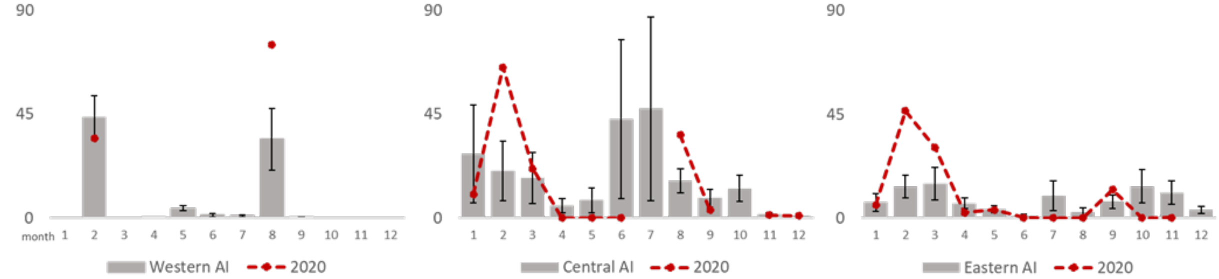


Figure 31: Monthly, non-zero, average bycatch estimates from the Catch Accounting System, 2011-2020, for the Western, Central, and Eastern Aleutians ecoregions. Confidentiality filete applied for when x the number of vessels in mo/year by ecoregion is less than 3. (a) 10-year average for shearwater (gray bars) compared to 2020 (black points) (b) 10-year average for fulmars (gray bars) compared to 2020 (black points).

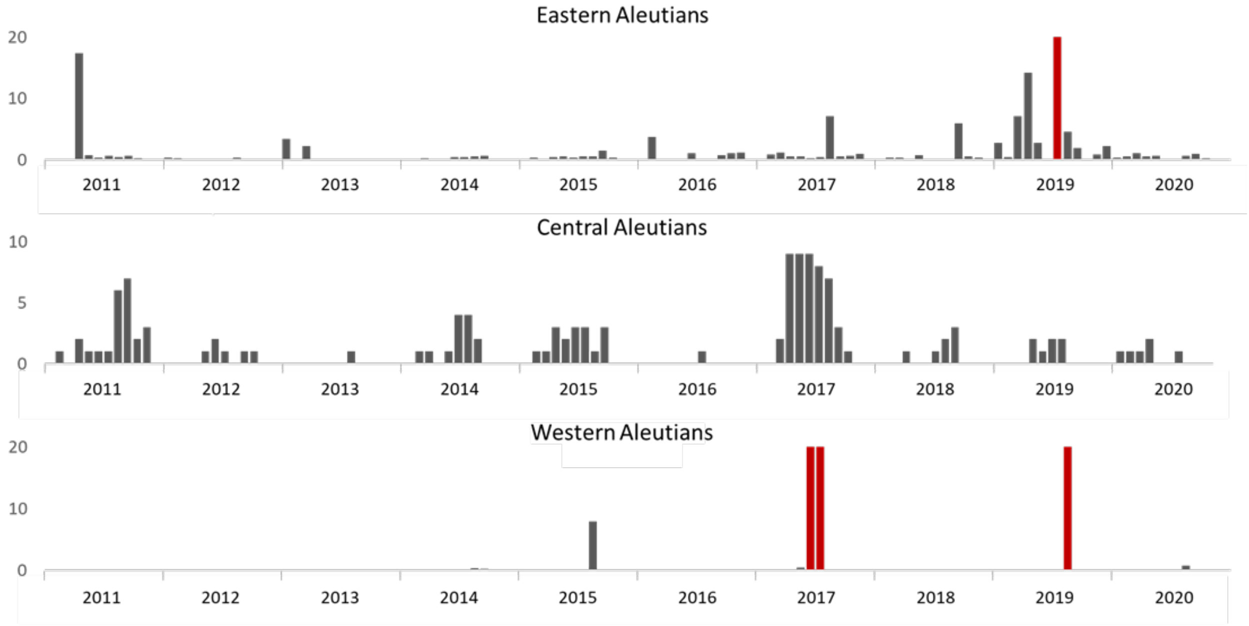


Figure 32: Monthly non-zero average bycatch estimates of shearwaters for 2011-2020 for the Eastern, Central and Western Aleutians. Y axis is truncated to show pattern; red bars indicate peaks that exceed 20 estimated birds/month

Factors influencing observed trends: Many fish-eating seabirds did poorly or had mixed success in recent years, while planktivorous seabirds have remained generally within normal range. In 2021, fish-eating seabirds had very high reproductive success, relative to recent years. This may reflect changes in environmental conditions, particularly the overall near average winter and spring temperatures (Figure 10 which may have favored higher prey availability. Planktivorous seabirds likely benefited from the unusually high productivity during early summer, especially in the western Aleutians (Biophysical Environment Synthesis: Satellite derived Chla). The early-to-average breeding timing and strong reproductive success suggest widespread zooplankton and small fish abundance during spring and summer 2021 throughout the Aleutians.

Implications: Reproductive activity of central-place foraging seabirds can reflect ecosystem conditions at multiple spatial and temporal scales. For example, because of their generalist diets, tufted puffins can adapt their foraging to what is available. After complete reproductive failure in 2018 at Buldir, tufted puffins reproductive success returned to average in 2019 and above-average in 2021, which suggests that prey (that includes forage fish and squid) were available in the western Aleutians for chick rearing. In 2021, as in 2019, ecosystem conditions appeared to be favorable for the majority of breeding seabirds in both the western and eastern Aleutians. This suggests that foraging conditions for both plankton and fish-eating commercial groundfish may also have been favorable in 2021.

Methods

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

   Timing of breeding is based on mean hatch date at a site. The deviation of the current year mean hatch dates from the mean of all prior years is used to determine whether the timing in the current season is earlier, average,or later than the long-term mean. Early hatch is defined as >3 days earlier than mean hatch, average as within 3 days of the mean, and late as >3 days later than the mean. Reproductive success is defined as the proportion of nest sites with eggs (or just eggs for murres, which do not build nests) that fledged a chick. For the summary presented in Figure 27 of seabird productivity at these sites, success categories (depicted with egg icons) were determined using parametric SD estimates for most species, and nonparametric bootstrap SD estimates (based on 1000 resamples) for those species with the possibility of more than one egg/chick. For each species and location, using all previous years' data, success was delineated as follows:

   (a) Way above average: current year's values above the quantity (mean + 1 SD) received big smiley faces;

   (b) current year's values between (mean - 1 SD) and (mean + 1 SD) received smiley faces; III.

    (c) Below average: current year's values below (mean - 1 SD) received frowny faces;
    (d) Complete failure: current year's values at or near zero received cracked frowny faces.

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

Marine Mammals

Sea Otters in the Aleutian Islands

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Last updated: September 2021

Description of indicator: Sea otter (*Enhydra lutris*) counts were selected as representative of the nearshore Aleutian environment. The >300 islands which make up the Aleutian chain provide extensive nearshore habitat. Sea otters are an integral component of the coastal ecosystems in which they occur. Sea otter predation limits the distribution and abundance of their benthic invertebrate prey, in particular herbivorous sea urchins (*Strongylocentrotus polyacanthus*). Otter-induced urchin declines increase the distribution and abundance of kelp in Alaska (Estes and Duggins, 1995) and in other areas of their range (Breen et al., 1982; Kvitek et al., 1998). This trophic cascade initiated by sea otters has indirect effects on other species and processes. Kelp forests are more productive than habitat without kelp (a.k.a. sea urchin barrens), fixing 3–4 times more organic carbon through photosynthesis (Duggins et al., 1989). This increased primary production results in increased growth and population size of consumers such as mussels and barnacles (Duggins et al., 1989; Gregr et al., 2020).

The southwest (SW) northern sea otter (NSO) distinct population segment (DPS) is divided into 5 management units (MU), two of which are within the geographic region of this report: Western Aleutian Islands and Eastern Aleutian Islands (Figure 33).

Status and trends:

Western Aleutians MU In 1992 and 2000, select islands were surveyed with twin engine aircraft (Doroff et al., 2003). Aerial survey data indicated a decline of 17.66% (±2.98%) in sea otter densities from 1992-2000 for the islands of Adak, Amchitka, Attu, Kagalaska, Little Kiska, and the Semichi Islands (Doroff et al., 2003). Due to logistical constraints, population trends are monitored using skiff surveys at five of the more remote islands (index sites) in the Western Aleutians MU. A Bayesian state-space trend analysis (Clark and Bjørnstad, 2004) based on those skiff surveys from 1993 to 2003 indicated that population trends were strongly negative, with an average rate of decline of approximately 20% per year (USFWS, 2013). Since then, the Service has conducted skiff-based trend surveys in the Western Aleutians in 2011 and 2015. The most recent survey in 2015 counted a total of 620 independent SW NSO at seven islands. The corresponding population estimate for 2015 from an extrapolation of growth rates (λ) from the seven islands from 2000 to 2015 applied to all 37 islands was 1,852 sea otters with a 95 percent Bayesian credible interval (CI) of 1,368—2,514 (Tinker 2020, pers. comm.; USFWS, 2020, Appendix A).

In 2020, the Service finalized a species status assessment and found the population of NSO in this MU is stable, but at a very low abundance following the decline in the 1990's.

The Service was planning on conducting boat-based sea otter surveys and an ecological function survey in the Western Aleutians MU in 2021.

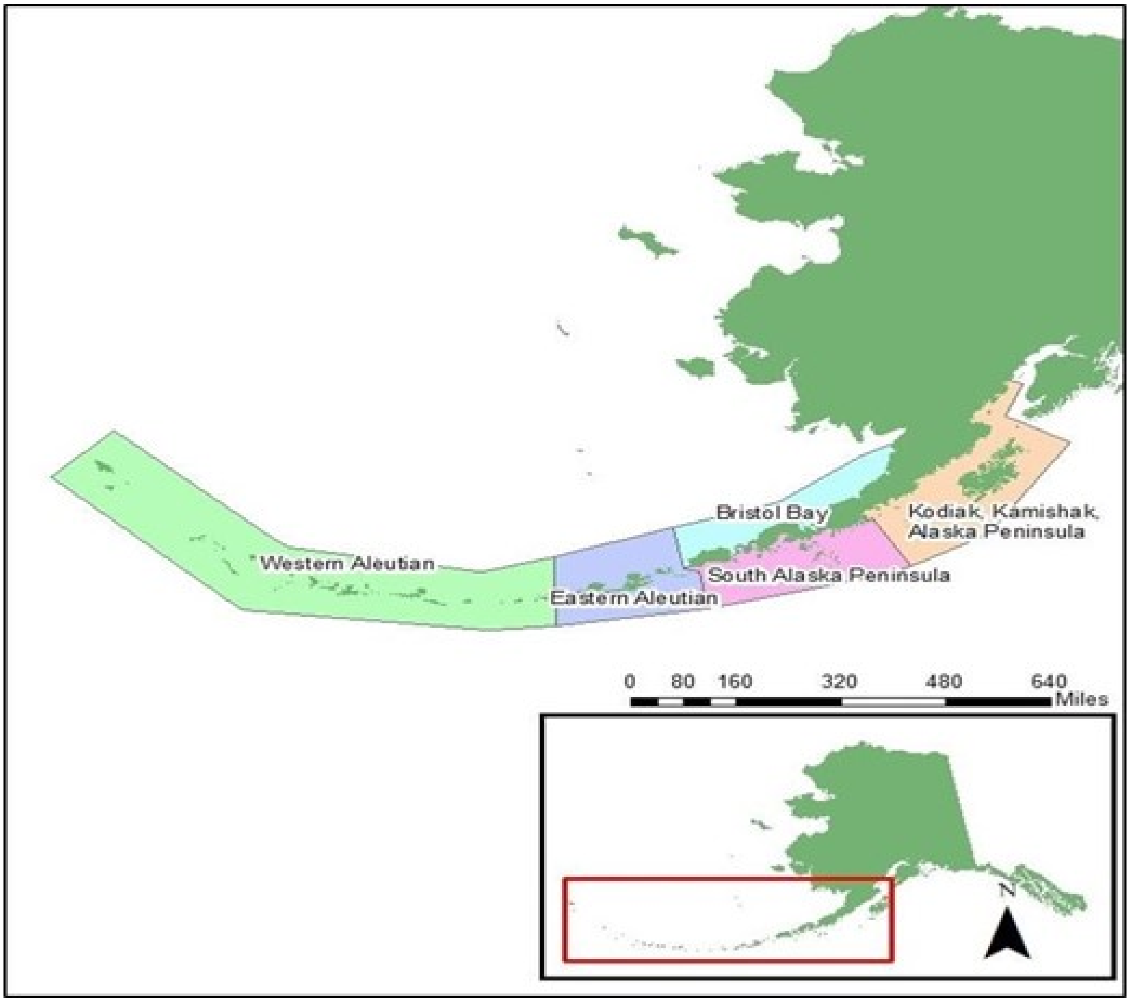

Figure 33: The Southwest sea otter distinct population segment (DPS) broken up into 5 different management units

Eastern Aleutians MU The Eastern Aleutians MU was surveyed from 1957 to 1965 (Kenyon, 1969). There were two small populations totaling 41 otters observed in 1962 in the Fox and Krenitzen Islands (Kenyon, 1969). By the time of the next aerial survey in 1992, SW Northern Sea Otters (NSO) were present throughout Fox and Krenitzen (Evans et al., 1997). A similar survey was conducted in 2000, and SW NSO abundance had declined from 1992 by an estimated 55 % in the MU (Doroff et al., 2003). In 2017, the Service conducted a sea otter survey using both boat and aerial based platforms. A population estimate was developed using a spatially explicit hierarchical distance sampling model (Wilson et al., 2021). The population size was estimated to be 8,593 individual sea otters (95% CI: 7450–9984), and the model explicitly accounted for factors that affect the ability to detect sea otters during surveys (i.e., group size, ocean conditions). This estimate is higher than previous estimates by Doroff et al. (2003), however the estimates should not be directly compared because Doroff et al. (2003) provide only a minimal estimate of abundance..

In 2020, the Service finalized a species status assessment and found the population of NSO in this MU is stable and exhibited high to moderate resiliency to current and projected future conditions.

Factors influencing observed trends: SW NSOs have been surveyed with a variety of methods over the years and the specific survey method used in the field constrains subsequent statistical modeling and inferences on population trends. The Service cautions comparing abundance and density estimates across years due to the different survey methodologies and statistical approaches applied to estimate these metrics. For instance, the Wilson et al. (2021) population estimate developed for the Eastern Aleutians is considerably higher than the previous population estimate. Direct comparison on these two population estimates are difficult given the divergent methodologies. Specifically, Doroff et al. (2003) did not account for the perceptibility, availability, or sampling effort in different study area strata. In contrast, Wilson et al. (2021) accounted for these processes. Given these factors, it is unknown whether the population increased in size since previous surveys, or if the population has remained stable but appears larger given the analytical methods employed by Wilson et al. (2021) (USFWS, 2020).

Implications: The lack of sea otters as an apex predator in some areas of the Western Aleutians suggest there will continue to be an ecosystem driven by species such as the herbivorous sea urchins which will continue to degrade the structural habitat required by many fishes and invertebrates (Bodkin et al., 2002). As noted by (Rasher et al., 2020), recovery of the sea otters in the Aleutians is important as they ”effectively buffer their system against a climate-induced decline of its structural foundation”.

Harbor Seals in the Aleutian Islands

Contributed by Josh M. London[1], Peter Boveng[1], Shawn Dahle[1], Heather Ziel[1], Cynthia Chirstman[2] and Jay Ver Hoef[1]

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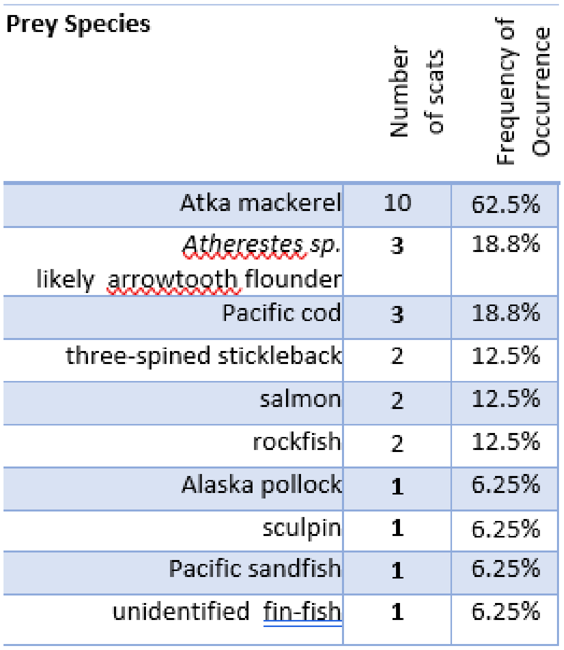
Last updated: September 2021

Description of indicator: Harbor seals (*Phoca vitulina richardii*) are distributed throughout the Aleutian Islands where they compose one of twelve harbor seal management stocks in Alaska. The current population estimate based on aerial surveys through 2018 is 5,588 (SE: 274) (Muto et al., 2020), see Figure 36. The harbor seal population experienced a significant decline (67%) over an approximate 20-year period from the late 1970s to the late 1990s (Small et al., 2008). Since then, estimates of population abundance and trend have fluctuated. In 2018, the probability the stock was decreasing over the previous 8 years was estimated to be 93.2% (Muto et al., 2020). Diet of harbor seals in the Aleutian Islands, while poorly studied, appear to be mostly composed of Akta mackerel followed by an assortment of species such as arrowtooth flounder, Pacific cod, three-spined stickleback, salmon, and rockfishes (*Sebastes* sp.) (see Figure 34). Stomach contents from 34 harbor seals collected in the central and eastern Aleutian Islands between 1954 and 1981 contained Atka mackerel, Pacific cod, octopus, Alaska pollock, fringed greenling, Pacific halibut, pandalid and crangonid shrimps, mysids, and unidentified cods, sculpins, rockfishes, other fishes, and crab (Wilke, 1957; Kenyon, 1965; Lowry et al., 1982).



Prey Species	Number of scats	Frequency of Occurrence
Atka mackerel	10	62.5%
Atherestes sp. likely arrowtooth flounder	3	18.8%
Pacific cod	3	18.8%
three-spined stickleback	2	12.5%
salmon	2	12.5%
rockfish	2	12.5%
Alaska pollock	1	6.25%
sculpin	1	6.25%
Pacific sandfish	1	6.25%
unidentified fin-fish	1	6.25%

Figure 34: Harbor seal diet presented as frequency of occurrence from scats (n=22) collected at haul-out locations in the Aleutian Islands between 2014-2016. All identifiable prey hard parts found in the scat were used to determine species presence (NOAA, unpublished data).

Between 2014 and 2016, the Alaska Fisheries Science Center deployed satellite telemetry devices on 80 harbor seals at 11 locations distributed throughout the Aleutian Islands archipelago (NOAA AFSC, *unpublished data*. Preliminary analyses of telemetry data showed that most seals remained within about 25 kilometers of the haul-out site where they were captured, and many made use of a small network of nearby haul-out sites. A few seals, mostly sub-adults, undertook longer trips off the Aleutian shelf or to haul-out locations 50 or more kilometers away from their release site. Dive behavior records indicate harbor seals are targeting the bottom of the water column as their dive depths often match the shelf bathymetry.

Given the common prey items found in harbor seal scats and the spatial overlap with commercial fisheries, the abundance, trend, and ecology of harbor seals in the Aleutian Islands are important considerations for groundfish fishery management

Status and trends: Recent survey efforts have improved the dataset for this population and current abundance estimates are based on aerial survey data through 2018. Stock abundance is estimated at 5,588 (SE: 274). The estimated 8-year population trend is -131 seals per year (Figure 35), with a 93.2% probability that the stock is decreasing (Muto et al., 2020). Figure 35 shows the temporal changes in annual estimates of stock abundance and trend since 1996. The Aleutian Islands harbor seal stock is not listed as threatened or endangered and is not classified as a strategic stock under the Marine Mammal Protection Act. Because of limited funds and aircraft hours, survey effort and study design are focused on stock-level estimates of abundance and trend. There is limited data available for evaluation of any regional trends.

A partial estimate of harbor seal abundance in the Aleutian Islands was determined from skiff-based surveys conducted at 106 islands from 1977 to 1982 (Small et al., 2008). When researchers compared this estimate (8,601 seals) to counts at the same islands from aerial surveys conducted in 1999 (2,859 seals), the number of harbor seals had declined by 67 percent. Regionally, the strongest declines occurred in the western Aleutians (Near Islands, 86%) with progressively lower declines in the central (Rat and Andreanof Islands, 66%) and eastern (Fox Islands, 45%) Aleutians. The magnitude and geographic pattern of the harbor seal declines was similar to that of Steller sea lions in the Aleutian Islands from 1985 to 2000 (Small et al., 2008). The factors responsible for these declines remain unknown.

The Aleutian stock covers the largest geographic range of any harbor seal stock in Alaska (over 1,600 km long) and is challenging to adequately survey due to frequent and extensive fog cover, turbulent winds, and access to only three viable airports (located on the islands of Unalaska, Adak, and Shemya). Limited funds and availability of suitable aircraft have also prevented greater survey coverage. Aerial surveys (Figure 36) are conducted from fixed-wing aircraft flown at a target altitude of 750 feet. High-resolution photographs (taken with handheld DSLR cameras) and GPS coordinates are recorded at each location that harbor seals are spotted hauled out along the shoreline. Seals are later counted from survey photos.

Factors influencing observed trends: The overall paucity of data regarding abundance, trend, and ecology of harbor seals in the Aleutian Islands limits our ability to evaluate ecosystem factors that could be influencing the observed trends. That harbor seals appear to share similar patterns in trend with Steller sea lions (dramatic decline followed by limited recovery; larger declines in the western portion of the stock) and that they overlap in their spatial range and diet suggests many of the factors influencing Steller sea lions are also influencing harbor seals. Atka mackerel, arrowtooth flounder, and Pacific cod are all commercially harvested prey species and are likely to exhibit spatial distributions that are less predictable, altered demographics, and lower overall abundance in fished versus unfished regions (Hsieh et al., 2006; Barbeaux et al., 2013; Fritz et al., 2019). While there have been no studies linking sea lion population trends with fisheries and prey availability in the Aleutian Islands, realized counts of sea lions indicated a period of stability from 2014 to 2016 following closure of the Pacific cod and Atka mackerel fisheries from 2011 to 2014. Given the overlap between commercial fisheries and common prey items found in harbor seal scats, it is plausible these activities exert influence on the abundance, trend, and ecology of harbor seals

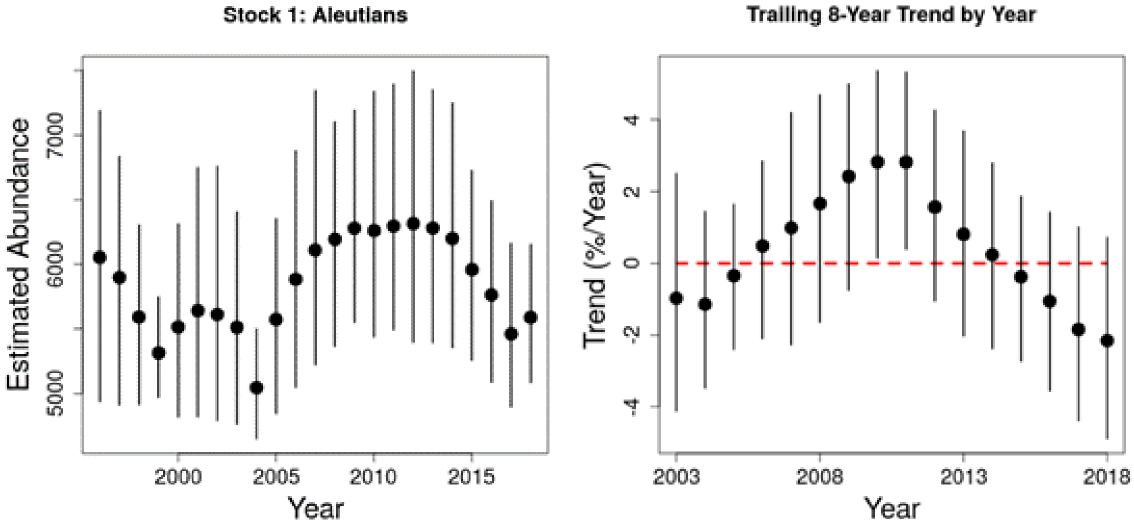


Figure 35: Estimated abundance and trailing 8-year trend by year for the Aleutian Islands harbor seal stock. Estimates are determined from counts of aerial surveys conducted in August or September and a haul-out availability model derived from telemetry deployments. Surveys were conducted in 1999, 2004, 2008-2011, 2014-2015, and 2017-2018.

in the Aleutian Islands.

In addition to fisheries, natural and climate-driven variation in annual conditions may impact harbor seals in the Aleutians. Bov (2020) found that body condition of all sex and age classes of Aleutian harbor seals declined in samples measured from 2014-2016, a period corresponding to a North Pacific marine heatwave that caused widespread ecological effects from bottom to top trophic levels (e.g., Duffy-Anderson et al. 2019; Huntington et al. 2020; Piatt JF 2020).

The nature of our data collection and the key challenges associated with conducting harbor seal research in the Aleutian Islands may also influence our observed trends in abundance. Aerial survey effort is generally limited to the months of August and September to coincide with the annual molt when seals are more likely to be hauled out and available for counting. The spatial distribution of harbor seals at haul-out sites during the winter and spring months has not been documented. Outside of our molting-season surveys, only limited flights have been conducted during the pupping period of June and July.

In addition to the logistical challenges associated with flying surveys in the Aleutian Islands, detection of seals from the aircraft can also be a challenge. Harbor seals in the Aleutian Islands are inconspicuous as they have dark pelage that matches the intertidal reefs they haul out on and they tend to be spread out in smaller groups than are typical in other parts of Alaska. In 2019, a forward-looking infrared system was used to test in flight detectability of harbor seals and, under common survey conditions, significantly more seals were detected with the thermal system than with the typical visual detection by human observers (Christman et al., 2022). As such, counts of harbor seals may be smaller than the actual number of seals hauled out, and our current understanding of absolute abundance is likely to be biased low. It is important, though, to keep in mind that inferences from harbor seal monitoring in the Aleutian Islands are drawn largely with respect to trends in abundance rather than absolute abundance. As long as detection probabilities remain constant (an untestable assumption in this case), trends are indicative of the overall pattern even if absolute abundance is underestimated, especially when environmental and detection factors are controlled for in the analysis (Eberhardt, 1978).

Implications:Trends in species abundance can provide an indication of the overall health of an ecosystem. In this case, the decline of harbor seals that inhabit the Aleutian Islands may be reflective of suboptimal conditions to forage, reproduce, or survive in the region. Because of this, AFSC has identified the Aleutian Islands stock of harbor seals as an 'at-risk' population and a high priority for monitoring. While the underlying mechanisms that are driving this decline for harbor seals may not be fully understood, they are likely to impact other species in the region.

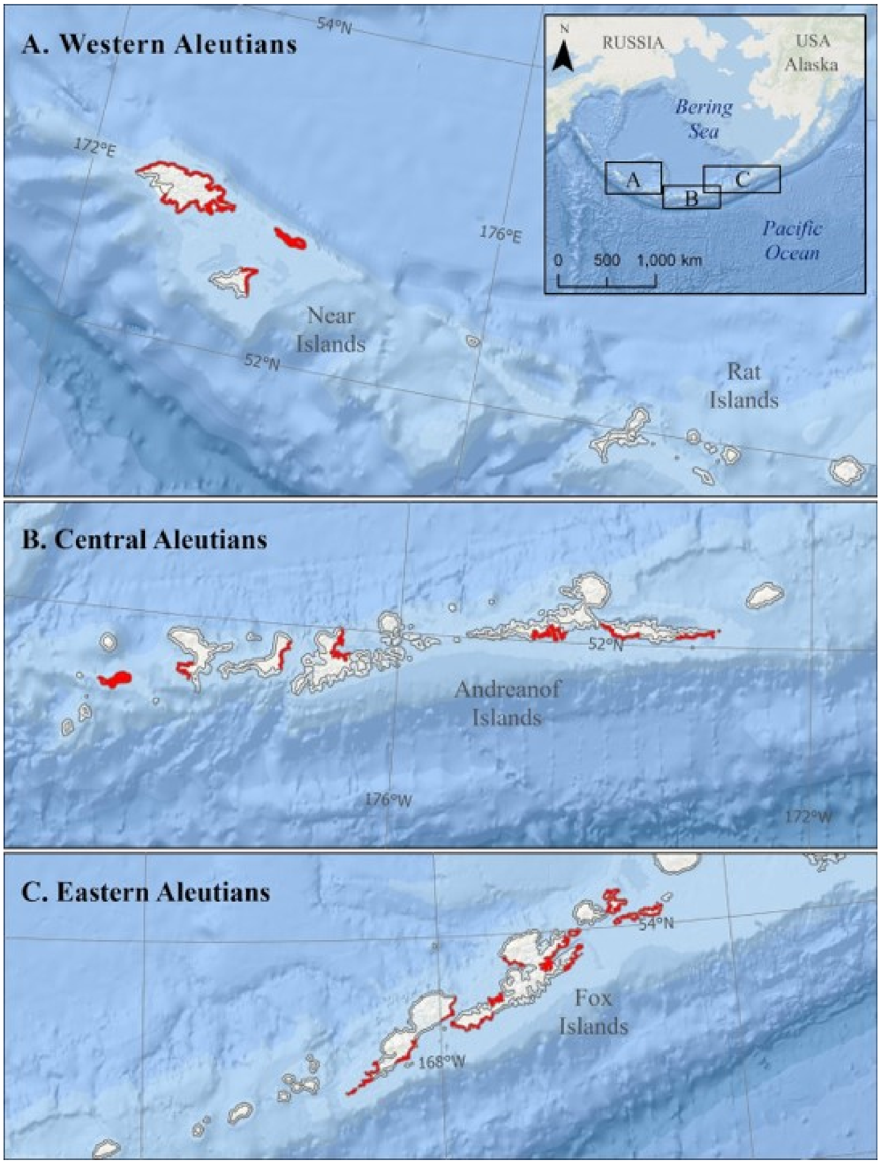


Figure 36: Map of coastal survey units within the %Aleutian Islands stock of harbor seals. Units shown in red were %surveyed in 2019.

Marine Mammal Strandings in the Aleutian Islands

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Last updated: September 2021

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 the state. 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. Over the last five years, the AMMSN has received over 1,600 reports of stranded marine mammals within Alaska. The causes of marine mammal strandings is often unknown but some causes are disease, exposure to contaminants or harmful algal blooms, ship strikes, entanglement in fishing gear, or ingestion of marine debris.

When a stranded marine mammal is reported information is collected including species, location, and age or size. In some cases, the initial photos and observations reported to AMMSN may be the only opportunity to collect information on the event. When possible, trained and authorized members respond and collect life history data and samples as part of a partial or full necropsy. Photos and carcasses are evaluated for potential human interactions such as vessel strikes. 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.

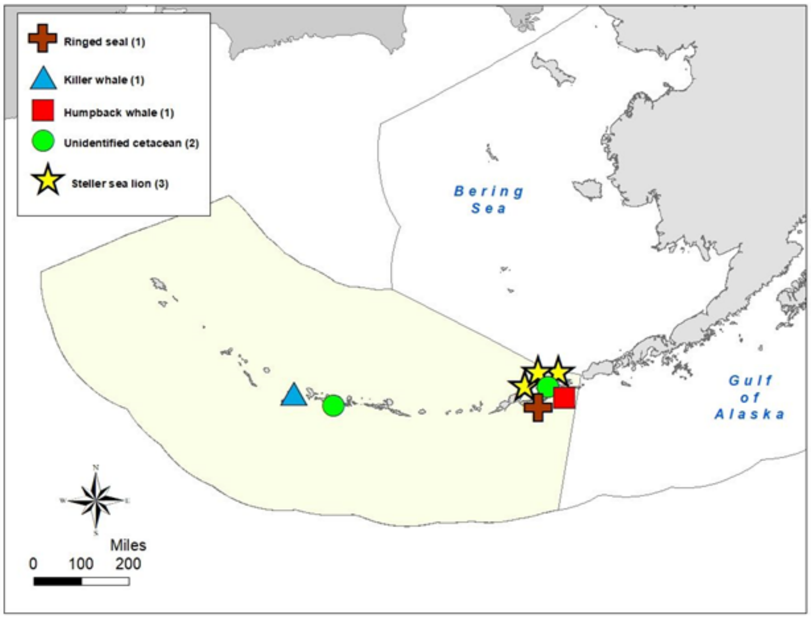
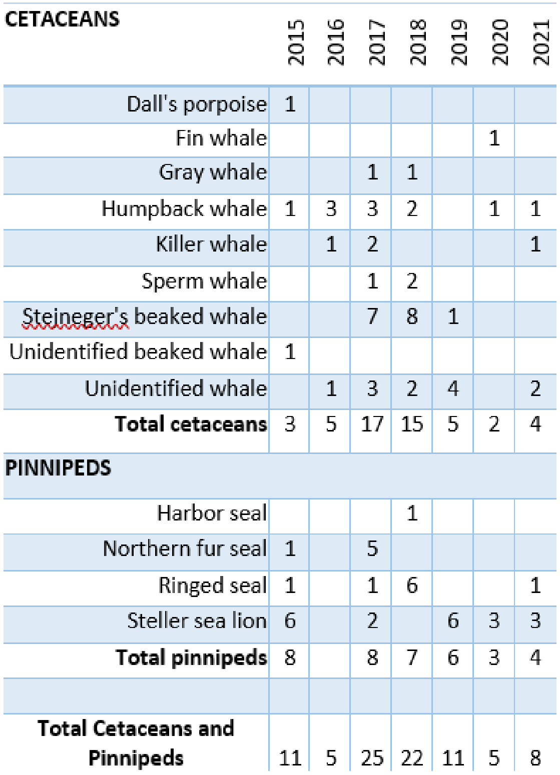


Figure 37: Reported stranded marine mammals in 2021, largely found near Dutch Harbor.

Status and trends: The number of reported strandings in Alaska has increased over time. So far in 2021, eight stranded marine mammals have been reported in the Aleutian Island region, the majority of reports being from the Dutch Harbor area where AMMSN members and NMFS Office of Law Enforcement members are located (Figure 37). Reported strandings in the Aleutian Islands since 2015 have varied between years without an overall pattern or consistent increase in reports (Figure 38). The 2021 stranding data includes confirmed strandings reported between January 1, 2021 and September 18, 2021.

Factors influencing observed trends: It is important to recognize that stranding reports represent effort that has varied substantially over time and location and overall has increased over time and with areas with higher human population densities. There have been relatively few reported stranded marine mammals in the Aleutian Islands (Figure 38), likely due to the remoteness of the area and the low and sporadic human population throughout the Aleutian Islands. The number of stranded marine mammals are likely grossly underestimated as observations are opportunistic and without consistent effort. Further, unusual events such as the mass strandings of Stejenegers beaked whales in 2017 and 2018 (Savage et al., 2021) or the 2018 ice seal Unusual Mortality Event (`http://www.north-slope.org/assets/images/uploads/NOAA_NMFS_ringed-seals-health-eval-2017-2018.pdf`) can have a large influence on variability between years in this area (Figure 38). 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.”



CETACEANS	2015	2016	2017	2018	2019	2020	2021
Dall's porpoise	1						
Fin whale						1	
Gray whale			1	1			
Humpback whale	1	3	3	2		1	1
Killer whale		1	2				1
Sperm whale			1	2			
Steineger's beaked whale			7	8	1		
Unidentified beaked whale	1						
Unidentified whale		1	3	2	4		2
Total cetaceans	3	5	17	15	5	2	4
PINNIPEDS							
Harbor seal				1			
Northern fur seal	1		5				
Ringed seal	1		1	6			1
Steller sea lion	6		2		6	3	3
Total pinnipeds	8		8	7	6	3	4
Total Cetaceans and Pinnipeds	11	5	25	22	11	5	8

Figure 38: Reported stranded NMFS marine mammal species for the last five years in the Aleutian Islands by species and year.

Other factors that may influence the number and species of marine mammals being reported include changing populations of some species including the increase in northern fur seals using Bogoslof Island for breeding and the declining western Distinct Population Segment of Steller sea lions. Further, the number of stranded marine mammals in an area can vary due to potential conflict with fishery resources either indirectly through prey competition or directly through interactions with fishing gear such as increased whale entanglements in cod pot gear.

Implications: Marine mammal strandings have been increasing in later years, often signaling changes in the environment. It is important to keep track of and have a sense of the regular number of strandings in the area to provide a context for massive mortality events and to identify whether some suite of species is more vulnerable than another, and what they have in common. Cumulatively these commonalities may give clues to ecosystem-wide changes.

Disease Ecology Indicators

Harmful Algal Blooms in the Aleutian Islands

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Last updated: October 2021

Sampling Partners:

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

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

Description of indicator: Alaska's most well-known and toxic harmful algal blooms (HABs) are caused by *Alexandrium spp.* and *Pseudo-nitzschia spp. Alexandrium* produces saxitoxin which can cause paralytic shellfish poisoning (PSP) and has been responsible for five deaths and over 100 cases of PSP in Alaska since (Ostasz, 2001) (see DHSS fatality report: `https://aoos.org/wp-content/uploads/2019/06/DHSS_PressRelease_PSPFatality_20200715.pdf`)). Analyses of paralytic shellfish toxins are commonly reported as µg of toxin/100 g of tissue, where the US Food and Drug Administration (FDA) limit for paralytic shellfish poinsoning is 80µg/100g. Toxin levels between 80µg–1000µg/100 g are considered to potentially cause non-fatal symptoms in humans, whereas levels above 1000µg/100g ($\sim$ 12x) are considered potentially fatal.

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

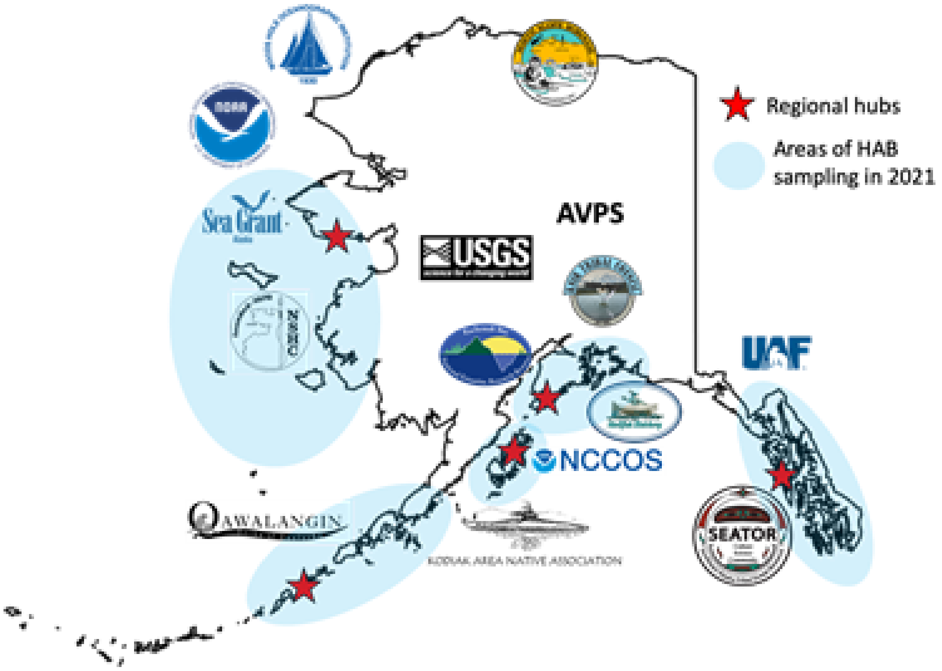


Figure 39: Map of sampling areas and sampling partners in 2021

The State of Alaska tests all commercial shellfish harvests, however there is no state-run shellfish testing program for recreational and subsistence shellfish harvest. Regional programs, run by Tribal, agency and university entities, have expanded over the past five years to provide test results to inform harvesters and researchers and to reduce human health risk (top map, Figure 39). All of these entities are partners in the Alaska Harmful Algal Bloom Network which was formed in 2017 to provide a statewide approach to HAB awareness, research, monitoring, and response in Alaska. More information on methods can be found on the Alaska HAB Network website (`https://aoos.org/alaska-hab-network/`) or through the sampling partners listed above.

Status and trends: Alaska Region: Results from shellfish and phytoplankton monitoring showed a consistent presence of harmful algal blooms (HABs) throughout all regions of Alaska in 2021. Bivalve shellfish from areas that are well known for having PSP levels above the regulatory limit, including Southeast Alaska and Kodiak, continued to test above the regulatory limit. Shellfish in other areas, which have seen high levels only in recent years (e.g. the Aleutian Islands), continued to show high levels in 2021. Overall, 2021 seems to have been slightly less active for blooms and toxin levels than 2020 and 2019, but many areas continue to have HAB organisms in the water, and shellfish testing well above the regulatory limit, especially between March and September. Over the last few years, the dinoflagellate *Dinophysis* has become more common and abundant in water samples, and 2021 continued that trend.

Aleutian Islands: Shellfish collection and testing in the Aleutians by the Qawalangin Tribe of Unalaska during spring and summer indicates continued high levels of PST well above regulatory limits for multiple species. The highest result reported was in June, when blue mussels from Unalaska were over 6.000 µg/100g. PST levels of blue mussels in Unalaska were consistently above regulatory limits beginning in March (Figure 40). Results are not yet available for August or September. Staff from USGS also collected samples of a variety of species in July for further analysis. Sampling from outside of Unalaska (King Cove and Sand Point) did not materialize as much as had been hoped, but results from May and June also show an increase in PST levels in blue mussels and consistent high PST levels in butter clams. (Chandra Poe, Qawalangin Tribe of Unalaska). West of Unalaska samples were taken in Yunaska and Atka Islands during 2018 and 2019 to measure saxotoxin levels, where PSP levels remained within the regulatory level (Wright, 2020). In 2021 Coastal community members have been sending in weekly shellfish samples from a dozen locations along the Gulf of Alaska and Aleutian Islands, including Adak, King Cove, Little Priest Rock and Front Beach within the Aleutians. Knik Tribe will pay for the shipping and lab analyses and send the results to the collectors. The samples are just now arriving at the Alaska Department of Environmental Conservation lab for analysis. (Bruce Wright, Knik Tribe).

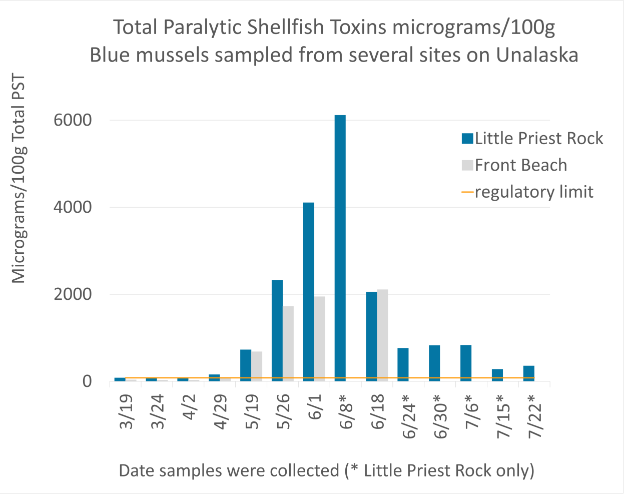


Figure 40: Paralytic shellfish toxins detected in blue mussels samples collected at three locations on Unalas. Data and figure from Qawalangin Tibe of Unalaska

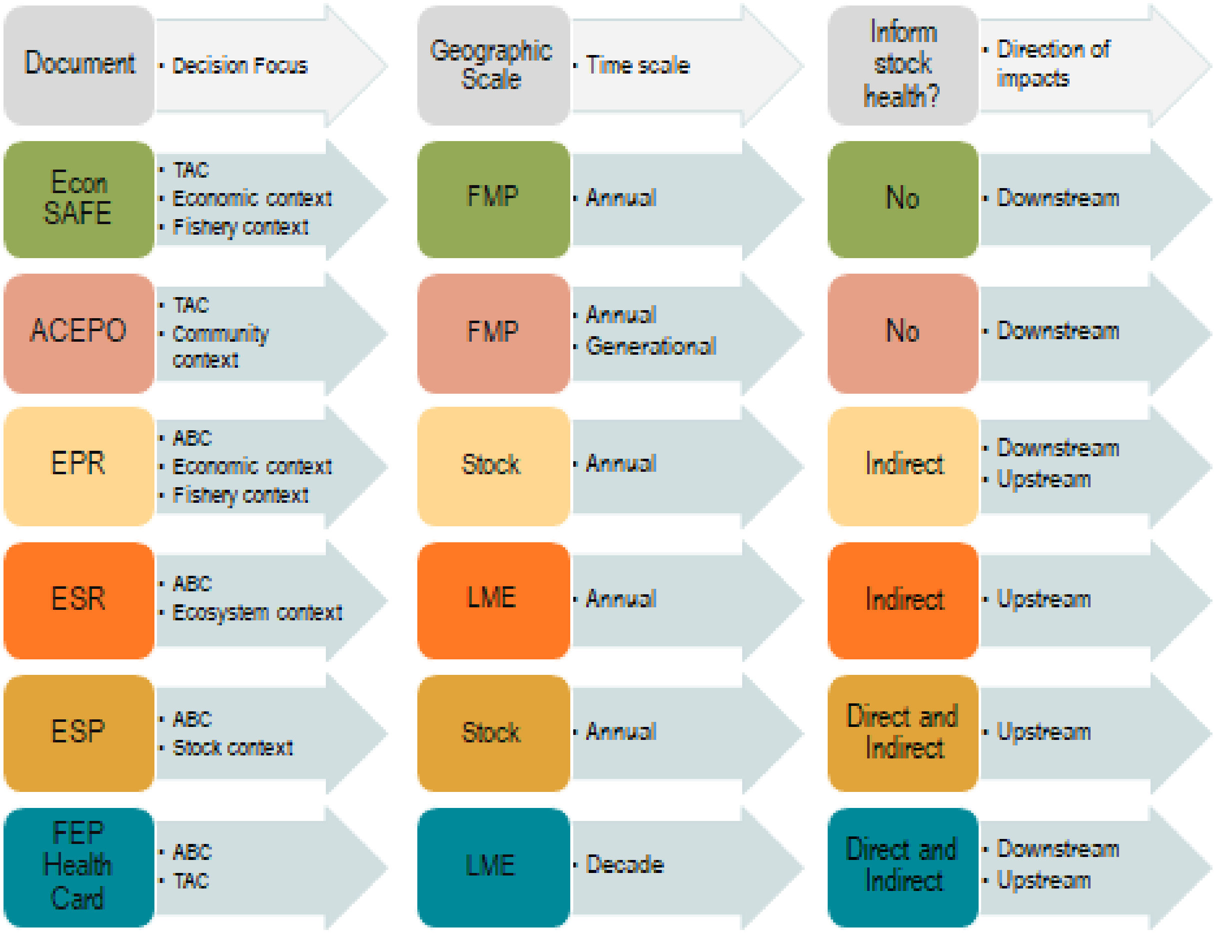
Factors influencing observed trends: HABs are likely to increase in intensity and geographic distribution in Alaska waters with warming water temperatures. Observations in Southeast and Southcentral Alaska suggest *Alexandrium* blooms occur at temperatures above 10°C and salinities above 20 (Vandersea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

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

Fishing and Human Dimensions Indicators

The Ecosystem Status Report (ESR) team places high value on including human dimensions information in our analysis of the status of the ecosystem, to inform the North Pacific Fisheries Management Council's harvest specification process. This year, AFSC is reexamining what economic and social science information is most useful to the Council in the context of these ESRs and other Council documents. As a result, we have not updated previous contributions in this section for 2021. Following the NPFMC's Science and Statistical Committee's October 2021 meeting discussion, the ESRs will be part of a holistic review of how economic and social science information is communicated and applied to the Council's harvest specification process.

NOAA's Alaska Fisheries Science Center's Economic and Social Science Research department has stated the following — *Previous human dimensions indicators (landings by functional group, fishery value and unit value (price) by functional group, trends in groundfish discards, trends in unemployment, and trends in human population) are being cut back for 2021 to better align the focus of the ESR specifically on informing next year's Allowable Biological Catch (ABC) determination. Going forward, we intend to focus on human dimensions contributions to the ESR which can provide near-term information on the health of a particular stock or region, primarily those currently considered fishing performance metrics (those effects that are upstream from fishing). Many of the removed indicators that speak to general ecosystem health (landings, volume, and unit value by functional group) appear to be more appropriate for the other products such as the Eastern Bering Sea FEP's upcoming Fisheries Ecosystem Health Card. This then properly aligns the human dimensions contributions across Council productions and allows the focus of the Ecosystem and Socioeconomic Profiles (ESPs) to be solely on single species stock health related ecosystem, economic, and social indicators. However, downstream impacts of the fishery on human well-being is outside the scope of the focus of the ESR and is treated more comprehensively in the Groundfish Economic SAFE, Crab Economic SAFE, and the Annual Community Engagement and Participation Overview (ACEPO). Figure 41 shows the AFSC's conceptualization of where human dimensions information is included in various NPFMC documents, including the Economic Performance Reports (EPRs) which are included within the stock assessment (or as an appendix), as well as the ESR and ESPs, and the upcoming FEP health card. Additional information on human dimensions indicators can be found at the following website:* `https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities`*.*



Document	Decision Focus	Geographic Scale	Time scale	Inform stock health?	Direction of impacts
Econ SAFE	TAC Economic context Fishery context	FMP	Annual	No	Downstream
ACEPO	TAC Community context	FMP	Annual Generational	No	Downstream
EPR	ABC Economic context Fishery context	Stock	Annual	Indirect	Downstream Upstream
ESR	ABC Ecosystem context	LME	Annual	Indirect	Upstream
ESP	ABC Stock context	Stock	Annual	Direct and Indirect	Upstream
FEP Health Card	ABC TAC	LME	Decade	Direct and Indirect	Downstream Upstream

Figure 41: NOAA Alaska Fisheries Science Center's human dimensions indicators mapping

Indicators presented in this section are intended to provide a summary of the status of several ecosystem-scale indicators related to fishing and human economic and social well-being. These indicators are organized around objective categories derived from U.S. legislation and current management practices:

begin

- Maintaining diversity
- Maintaining and restoring fish habitat
- Sustainability (for consumptive and non consumptive uses)

  not included this year: seafood production, profits, recreation, employment and socio-cultutral

Maintaining Diversity: Discards and Non-Target Catch

Time Trends in Groundfish Discards

Contributed by Jean Lee, Resource Ecology and Fisheries Management Division, AFSC, NMFS, NOAA, and Alaska Fisheries Information Network, Pacific States Marine Fisheries Commission
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Last updated: September 2021

Description of indicator: Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Regions blend data, while estimates for 2003 and later come from the Alaska Regions Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards in the North Pacific. Discard rates as shown in Figure 42 below are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area-gear-target sector. Where rates are described below for species or species groups, they represent the total discarded weight of the species/species group divided by the total catch weight of the species/species group for the relevant area-gear-target sector. *These estimates include only catch of FMP-managed groundfish species within the FMP groundfish fisheries.* Discards of groundfish in the halibut fishery and discards of forage fish and species managed under prohibited species catch limits, such as halibut, are not included.

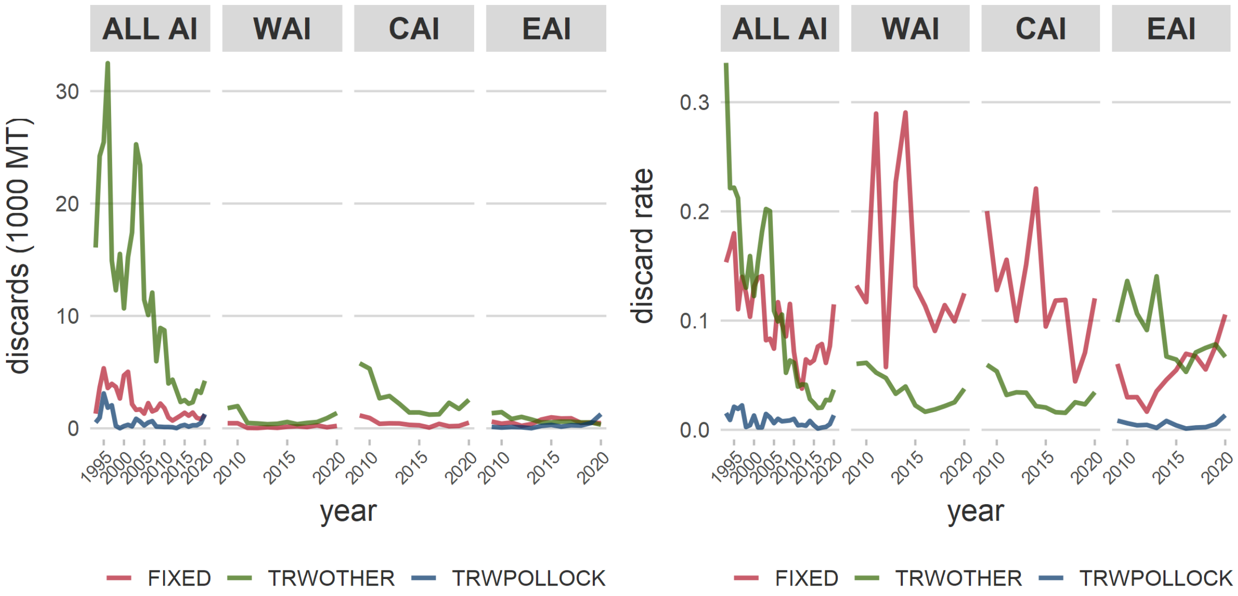

Figure 42: Total biomass and percent of total catch biomass of FMP groundfish discarded in the fixed gear (FIXED), pollock trawl (TRWPOLLOCK), and non-pollock trawl sectors (TRWOTHER) for the Aleutian Islands (ALL AI) region, 1993-2020; and for central (CAI), eastern (EAI), and western (WAI) subregions, 2009-2020. 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)

.

Status and trends: Since 1993 discards and discard rates of groundfish in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock and non-pollock trawl sectors in the Aleutian Islands (AI), (see Figure 42). Discard biomass in the trawl pollock sector was highest from 1995 to 1997, averaging 2,330 mT annually during this period, before falling in 1998 to 215 mT and averaging 320 mT annually from 1998 to 2020. The 2020 discard biomass in this sector (1265 mT) was the highest since 2007. The non-pollock trawl sector has seen the steepest declines in discard biomass and rates since 1993. Discards in this sector peaked at 32500mT in 1996 (21% discard rate); annual discard biomass and rates averaged 15,300 mT and 15% annually from 1997 to 2007 and 4,261 mT and 4% annually from 2008 to 2020.

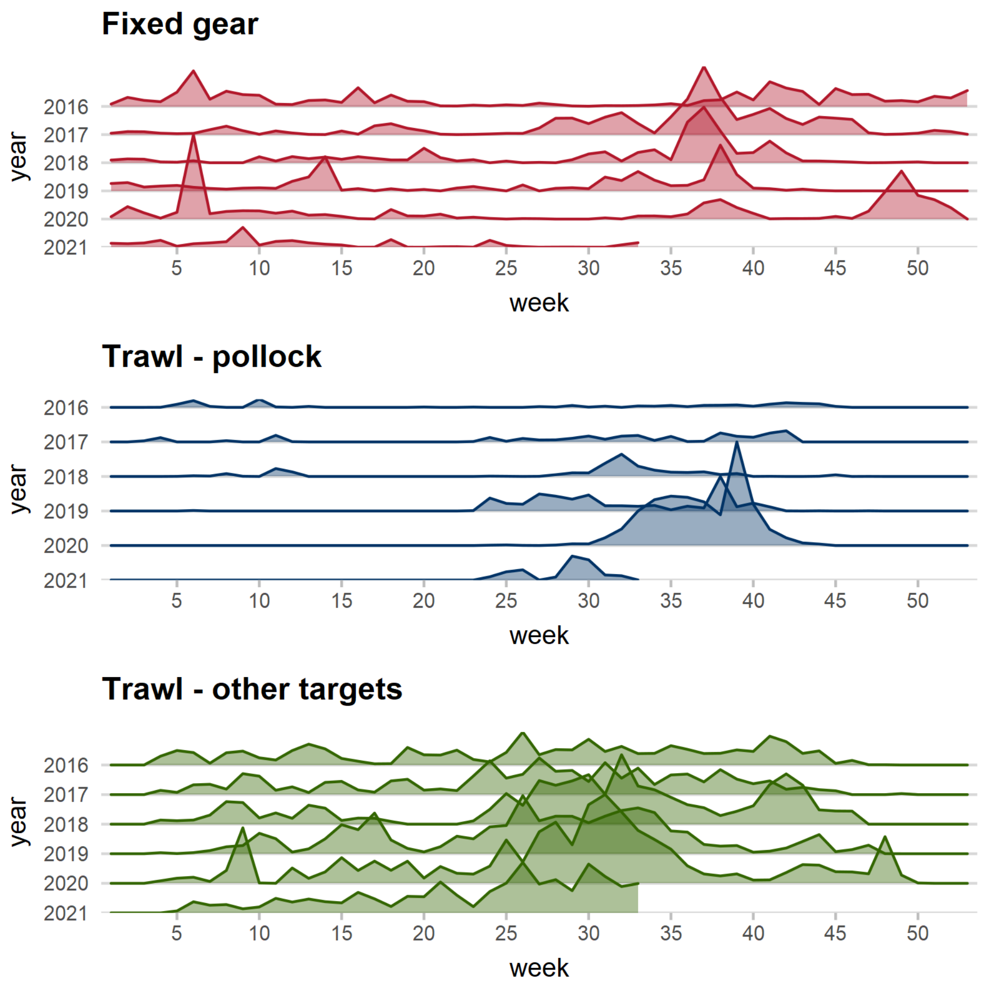

Figure 43: Total biomass of FMP groundfish discarded in the Aleutian Islands region by sector and week, 2015 - 2021 (data for 2021 is shown through week 33). Plotted heights are not comparable across sectors).

In the fixed-gear sector, the discard volume and discard rate have also declined across the AI area in general since 1993. Over the most recent 5-year period (2016–2020), the annual discard biomass and discard rate in the AI fixed gear sector have averaged 1,093 mT and 8%, respectively, compared to 2,166 mT and 10% averaged over the longer 1993–2020 period. When disaggregated by subarea, fixed gear discard rates in the Western (WAI) and Central AI (CAI) subareas show large interannual variation over the 10 most recent years. Discard rates in the non-pollock trawl sector have generally declined across all three subareas since 2010. To date in 2021, discard biomass through week 33 is higher in the trawl non-pollock and fixed gear sectors relative to the preceding 5-year (2016–2020) period, whereas discards in the fixed gear sector are lower (Figure 43).

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

Implications: Discards add to the total human impact on the biomass without providing a benefit to the nation.

Time Trends in Non-Target Species Catch

Contributed by George A. Whitehouse[1], Sarah Gaichas[2]
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[2]Ecosystem Assessment Program, Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, Woods Hole MA,
Contact: andy.whitehouse@noaa.gov
Last updated: July 2021

Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the Aleutian Islands (AI). 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), some of the species in the "non-specified" group (giant grenadier, other grenadiers), and forage fish (e.g., capelin, eulachon, Pacific sand lance, etc.), therefore we no longer include trends for these species/groups here (see AFSC stock assessment website at `https://www.fisheries.noaa.gov/alaska/population-assessments/north-pacific-groundfish-stock-assessments-and-fishery-evaluation`). Invertebrate species associated with habitat areas of particular concern, previously known as HAPC biota (seapens/whips, sponges, anemones, corals, and tunicates) are now referred to as structural epifauna. Starting with the 2013 Ecosystem Considerations Report, the three categories of non-target species we continue to track here are:

1. Scyphozoan jellyfish
2. Structural epifauna (seapens/whips, sponges, anemones, corals, tunicates)
3. Assorted invertebrates (bivalves, brittle stars, hermit crabs, miscellaneous crabs, sea stars,

marine worms, snails, sea urchins, sand dollars, sea cucumbers, and other miscellaneous invertebrates).

Total catch of non-target species is estimated from observer species composition samples taken at sea during fishing operations, scaled up to reflect the total catch by both observed and unobserved hauls and vessels operating in all FMP areas. Catch since 2003 has been estimated using the Alaska Regions Catch Accounting System (Cahalan et al., 2014). This sampling and estimation process results in some 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 AI includes the reporting areas 518, 519, 541, 542, 543, and 610 (`https://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones`). Within reporting area 610, the GOA and Aleutian Islands (AI) Large Marine Ecosystems (LMEs) are divided at 164°W. Non-target species caught east of 164°W are within the GOA LME and the catch west of 164°W is within the AI LME.

Status and trends: The catch of Scyphozoan jellies in the AI gradually decreased from 2011 to 2015, then increased from 2015 to 2020 with peaks in 2017 and 2020 (Figure 44). Scyphozoan jellies are primarily caught in the pollock fishery. The catch of structural epifauna in the AI has been variable from 2011-2020, with a peak catch in 2015. Sponge comprise the majority of the structural epifauna catch, followed by corals and bryozoans. These species are primarily caught in the Atka mackerel and rockfish fisheries. The catch of assorted invertebrates in the AI increased from 2011 to 2013 then dropped sharply in 2014. The catch remained relatively constant from 2015 to 2019 before decreasing in 2020 to the second lowest catch over the period 2011–2020. Sea stars dominate the catch of assorted invertebrates and are primarily caught 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. Alternatively, changes in allowable catch for target species, external market forces, fishing effort, or fishing gear restrictions can affect the catch of non-target species. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, wind-mixing, ocean currents, and prey abundance (Purcell, 2005; Brodeur et al., 2008)

Implications: The catch of structural epifauna species and assorted invertebrates is very low compared with the catch of target species. The higher catches of scyphozoan jellies in 2017–2020 may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries. Abundant jellyfish may have a negative impact on fishes as they compete with planktivorous fishes for prey resources (Purcell and Sturdevant, 2001), and additionally, jellyfish may prey upon the early life history stages (eggs and larvae) of fishes (Purcell and Arai, 2001; Robinson et al., 2014).

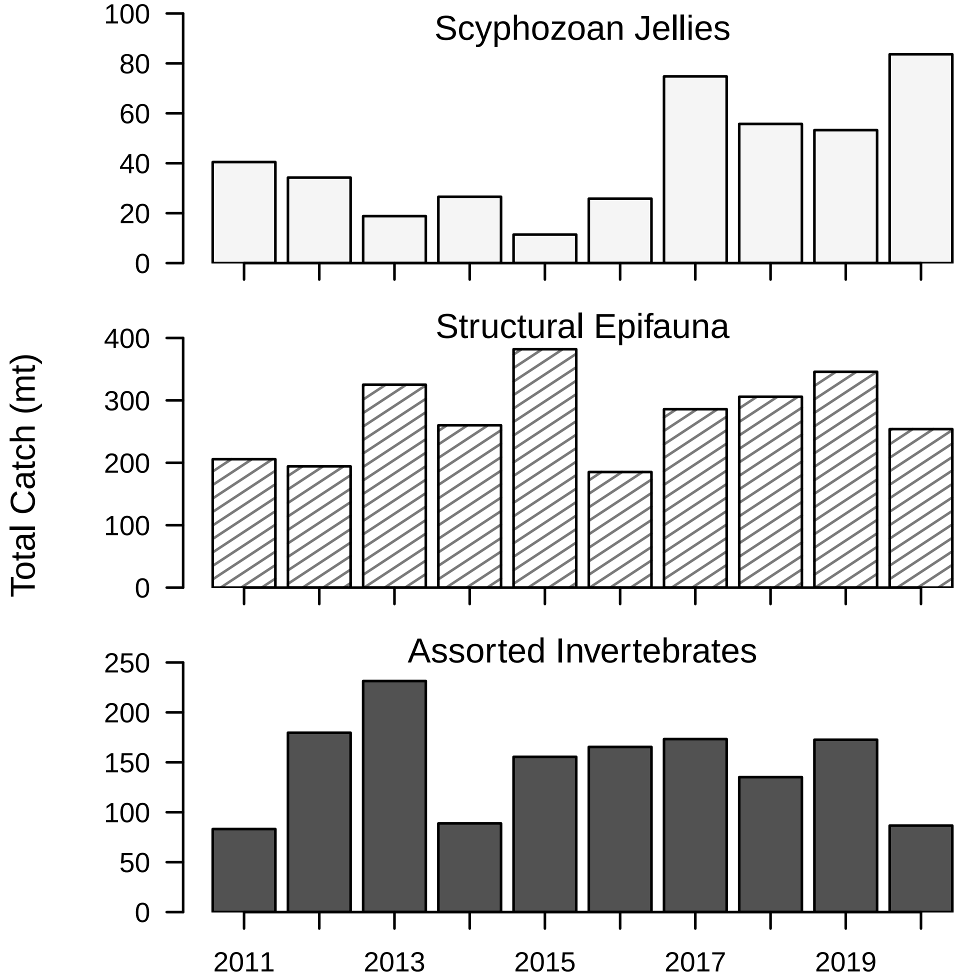

Figure 44: Total catch of non-target species (tons) in AI groundfish fisheries (2011–2020). Please note the different y-axis scales between regions and species groups.

Seabird Bycatch Estimates for Groundfish Fisheries in the Aleutian Islands, 2011–2020

Contributed by Joseph Krieger and Anne Marie Eich' Sustainable Fisheries Division, Alaska Regional Office, National Marine Fisheries Service, NOAA
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Last updated: August 2021

Description of indicator: This report provides estimates of the numbers of seabirds caught as bycatch in commercial groundfish fisheries operating in the federal waters of the U.S. Exclusive Economic Zone of the Aleutian Islands (AI) for the years 2010 through 2020. Estimates of seabird bycatch from earlier years using different methods are not included here. Fishing gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic trawl. These numbers do not apply to gillnet, seine, or troll fisheries. Data collection on the Pacific halibut longline fishery began in 2013 with the restructured North Pacific Observer Program.

Estimates are based on two sources of information: (1) data provided by NMFS-certified fishery observers deployed to vessels and floating or shoreside processing plants (AFSC, 2011), and (2) 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/2020-annual-deployment-plan-observers-groundfish-and-halibut-fisheries-alaska`). The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2014, 2010). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. CAS also estimates non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. The CAS produces estimates based on these two current data sets, which may have changed over time.

Estimates of seabird bycatch from the AI include the reporting areas 610 west of 164 split, 518, 519, 541, 542, and 543, (`https://www.fisheries.noaa.gov/alaska/commercial-fishing/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones`).

Status and trends: The number of seabirds estimated to be caught incidentally in the AI fisheries in 2020 (364) was 84% lower than estimates from 2019 (2,242 birds), and were 57 lower than the 2011-2019 average of 855 birds (Table 1; Figure 45). This dramatic decline in the estimated seabird takes is primarily due to the high number of shearwaters taken in 2019 in the western AI (management area 543; 1,588 birds). In 2019, the number of shearwaters was almost 15 times higher than was estimated in 2018, and was almost 11 times above the 2010–2018 average of 192 birds. Aside from shearwater bycatch, seabird takes in the AI fisheries in 2020 were relatively similar to takes in 2019. The exception was northern fulmar where the estimated bycatch was approximately 2.2 times higher compared to 2019, and was above the 2011-2019 average of 279 birds by 26%. No short-tailed albatross, black-footed albatross, or Laysan albatross were reported as taken in the AI(Figure 46).

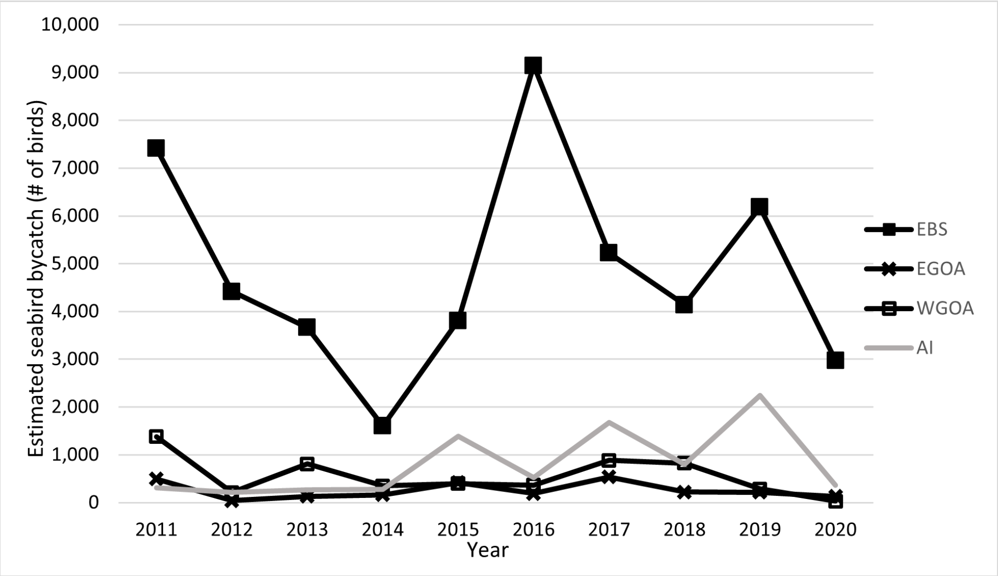

Figure 45: Total estimated seabird bycatch in eastern Bering Sea (EBS), Eastern Gulf of Alaska (EGOA), Western Gulf of Alaska (WGOA), and Aleutian Islands (AI), groundfish fisheries, all gear types combined, 2011 through 2020.

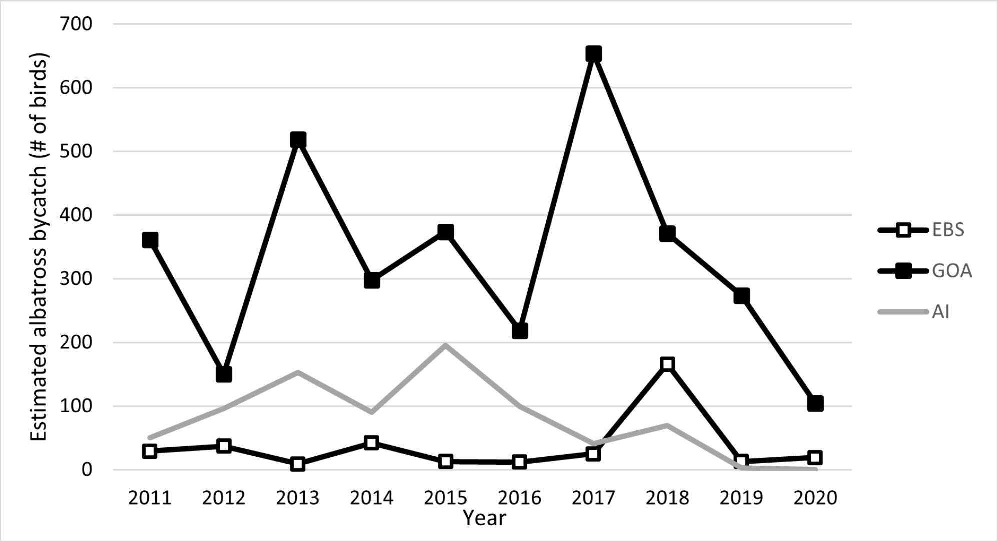

Figure 46: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2011 through 2020.

Table 1: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2011 through 2020.

Species Group	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Unidentified Albatrosses	0	0	0	23	0	0	0	0	0	0
Laysan Albatross	43	92	133	56	171	74	15	67	0	0
Black-footed Albatross	6	3	20	11	24	25	26	1	3	0
Northern Fulmar	83	25	61	69	1,105	180	531	292	161	350
Shearwaters	63	60	6	71	28	192	1,076	141	2069	6
Storm Petrels	0	23	0	0	0	0	0	177	0	0
Gulls	110	0	40	11	58	19	8	9	7	6
Murres	0	0	0	0	0	5	0	0	0	0
Auklets	0	0	0	38	5	28	11	102	0	0
Other Alcid	0	0	0	1	0	0	0	0	0	0
Unidentified Birds	7	6	13	1	1	1	12	5	2	3
Grand Total	312	209	273	281	1,392	524	1,670	795	2,242	365

BSAI Pacific cod using demersal longline, and Atka mackerel trawl fisheries are responsible for the majority of seabird bycatch in the AI—the average annual seabird bycatch for 2011 through 2019 was 4,741 and 280 birds per year, respectively (Table 13 in Krieger and Eich 2021).In 2020, the estimated seabird bycatch in the Atka mackerel fisheries was 30% lower than the 2011-2019 average (195 birds (1,575 birds; Table 13 in Krieger and Eich 2021). Estimated seabird bycatch in the Pacific cod fishery was below the 2011-2019 average by 48% (2,487 birds; Table 13 in Krieger and Eich 2021). Figure 47 shows the spatial distribution of observed seabird bycatch from 2015 – 2020 from the Pacific cod hook and line fisheries (responsible for the greatest overall takes of seabirds in the AI) overlaid onto heat maps depicting fishing effort for the fishery.

Focusing solely on the bycatch of albatross (unidentified, short-tailed, Laysan, and black-footed) in the AI, an estimated 61 albatross were taken per year from 2011 through 2020 (Krieger and Eich, 2021).

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 a reduction in seabird bycatch in the Federal fisheries off Alaska is positive, several events occurred during the 2020 fishing seasons which may partially explain this reduction. 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. Less fishing effort would reduce the opportunities for interactions with seabirds and less seabird bycatch. 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

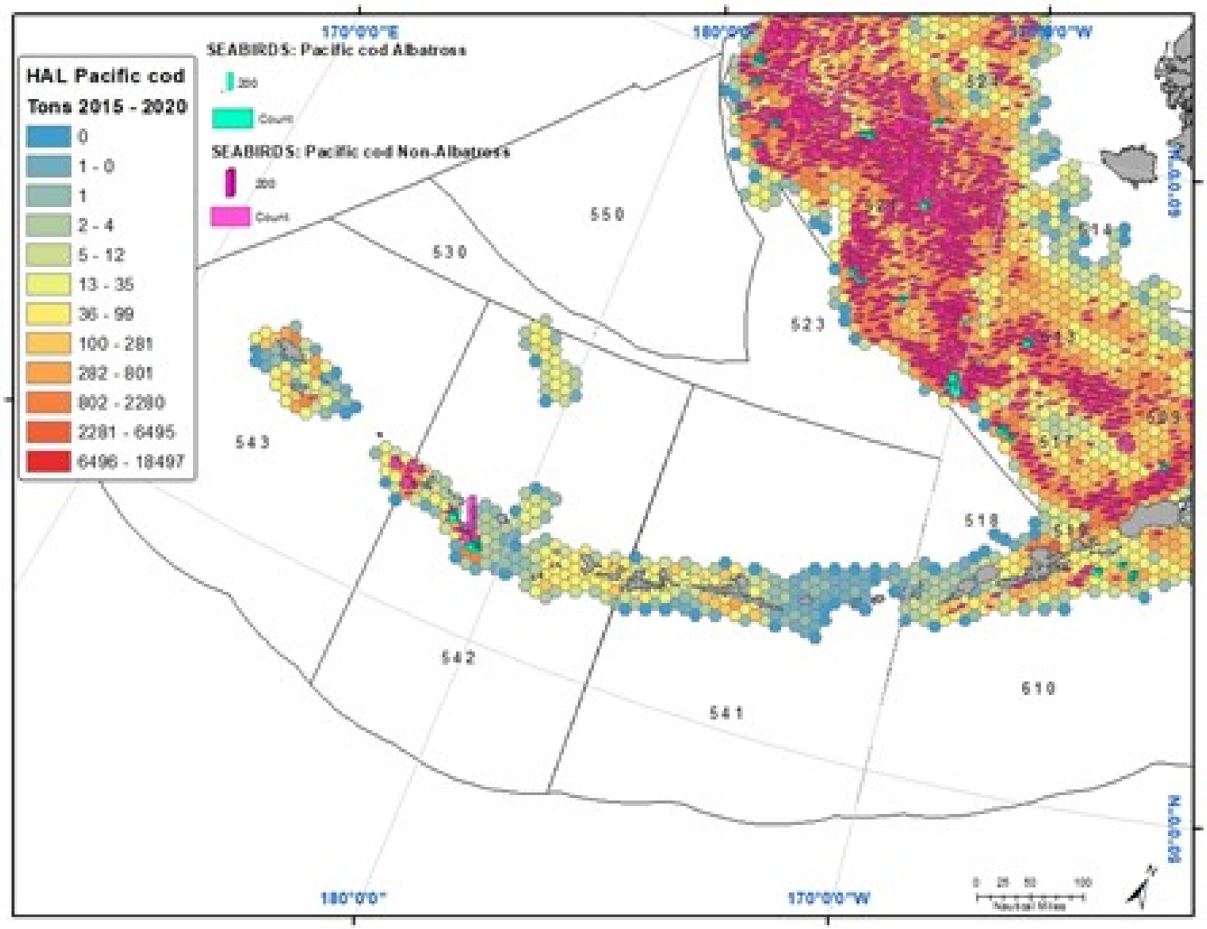

Figure 47: Spatial distribution of observed seabird bycatch from 2015–2020 from the Pacific cod hook and line fisheries. Colored vertical bars indicate the sum of incidental takes at a location grouped within 1/10 of a degree of latitude and longitude. Incidental takes are separated between takes of albatross and takes of non-albatross seabirds. Images include locations of incidental takes of seabirds overlaid on to heat maps depicting fishing effort for each relevant fishery. Note the difference of scale of observed takes of seabirds.

on sablefish catch. Take of seabirds by pot gear is relatively rare compared to take of seabirds by hook-and-line gear. If the sablefish IFQ fishery continues to increase its use of pot gear over hook-and-line gear, we would continue to 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 1,000s, given the vast size of the fishery, actual takes of seabirds remains relatively uncommon (Krieger and Eich, 2021).

Implications: Estimated seabird bycatch in the Federal fisheries off of Alaska in 2020 decreased dramatically from 2019, and was among the lowest estimate in the 10 year time series. While several unique situations presented themselves in 2020 that may have affected seabird bycatch, they themselves likely do not fully explain the reason for the observed trend.

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

Area Disturbed by Trawl Fishing Gear in Alaska

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Last updated: October 2021

Description of indicator: Fishing gear can impact habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. This indicator uses output from the Fishing Effects (FE) model (Smeltz et al., 2019) to estimate the area of geological and biological features disturbed in the Aleutian Islands, utilizing spatially-explicit Vessel Monitoring System (VMS) data summarized to 25km^2 grid cells in fishable depths (<1000m). The time series for this indicator is available since 2003, when widespread VMS data became available. In 2021, methods developed by the Alaska Regional Office of NMFS were used to incorporate unobserved fishing events over the entire time series (2003 – 2021) into FE analysis. Unobserved fishing events typically account for 7 - 12% of total effort in the VMS data set. For this analysis, NMFS statistical area 543 is in the western Aleutians, areas 542 and 541 are in the central Aleutians while the eastern Aleutians fall in statistical areas associated with the Bering Sea in the north and the western Gulf of Alaska in the south

Status and trends: The percent of area disturbed due to commercial fishing (pelagic and non-pelagic trawl, longline, and pot) across the Aleutian Islands has varied between 1–3% since 2003, with a slightly increasing trajectory across the three AI regions since 2015. This increase is likely due to a rise in non-pelagic trawl effort that has been higher than the 10-year average. (Figure 48). Figure 49 shows the location of the areas with the highest impact.

Factors influencing observed trends: A seasonal component can be observed where percent area disturbed increases slightly during late summer – early fall months. The percent area disturbed in all Alaska regions combined is driven by the southern Bering Sea where percent habitat disturbance used to be around 10% at the beginning of the time series and is currently around 8%. In 2010, trawl sweep gear modifications were implemented on non-pelagic trawls in the Bering Sea, resulting in less gear contacting the seafloor and less habitat impact. Trawl sweep modifications were implemented in the Gulf of Alaska in 2014. The increase in 2007 n the eastern Aleutians is presumably an increase in yearly percent swept area in the Bering Sea but not in the Gulf of Alaska (Smeltz et al., 2019). In 2008, Amendment 80 was implemented, which allocated BSAI yellowfin sole, flathead sole, rock sole, Atka mackerel, and Aleutian Islands Pacific ocean perch to the head and gut trawl catcher processor sector, and allowed qualified vessels to form cooperatives. The formation of cooperatives reduced overall effort in the fleet while maintaining catch levels.

Trends in seafloor area disturbed can be affected by numerous variables, such as fish abundance and distribution, management actions (e.g., closed areas), changes in the structure of the fisheries due to rationalization, improved technology (e.g., increased ability to find fish, acoustics to fish near the bottom without contact), markets for fish products, and changes in vessel horsepower and

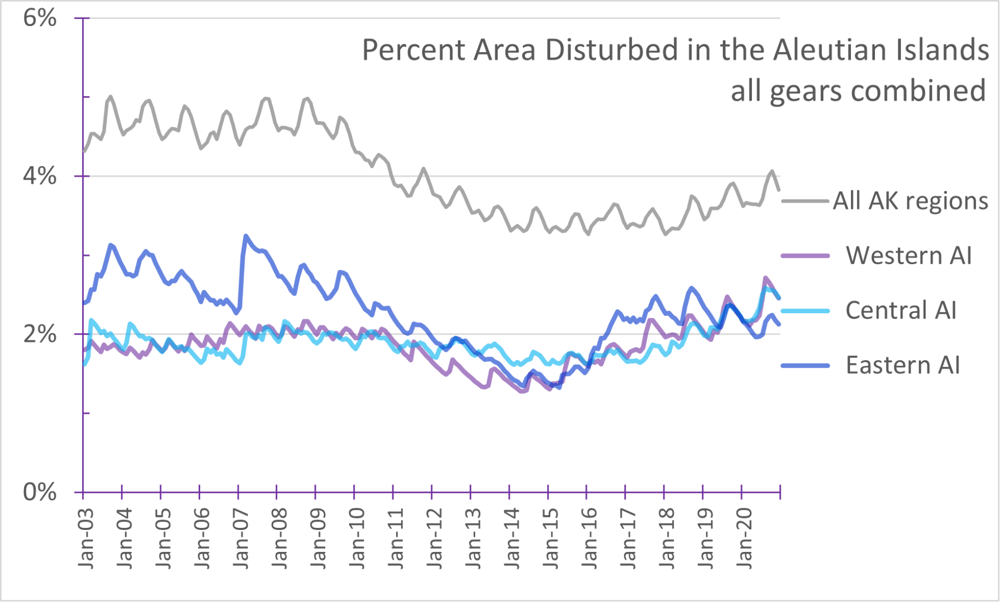

Figure 48: Percent habitat disturbance, all gear types combined, from 2003 through 2020.

fishing gear. Intensive fishing in an area can result in a change in species diversity by attracting opportunistic fish species which feed on animals that have been disturbed by fishing activity, or by reducing the suitability of habitat used by some species. It is possible that increased effort in fisheries that interact with both living and non-living bottom substrates could result in increased habitat loss/degradation due to fishing gear effects. The footprint of habitat damage varies with gear (type, weight, towing speed, depth of penetration), the physical and biological characteristics of the areas fished, recovery rates of living substrates in the areas fished, and management or economic changes that result in spatial redistribution of fishing effort.

Implications: The effects of changes in fishing effort on habitat are largely unknown, although our ability to quantify those effects has increased greatly with the development of a Fishing Effects model as a part of the 2015 Essential Fish Habitat (EFH) Review (`ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/TM_NMFS_AFKR/TM_NMFS_FAKR_15.pdf`). The 2005 EFH FEIS and 2010 EFH 5-year Review concluded that commercial fisheries can have long-term effects on habitat; however, those impacts were determined to be minimal and not detrimental to fish populations or their habitats. These previous EFH analyses indicated the need for an improved fishing effects assessment methodology. With the development and implementation of the FE model, many of the shortcomings of previous fishing effects methods were addressed. Vessel Monitoring System data provide a much more detailed treatment of fishing intensity, allowing better assessments of the effects of overlapping effort and distribution of effort between and within grid cells. The development of a literature-derived fishing effects database has increased our ability to estimate gear-specific susceptibility and recovery parameters. The distribution of habitat types, derived from increased sediment data availability, has improved. The combination of these parameters has greatly enhanced our ability to estimate fishing impacts.

New methods and criteria were developed to evaluate whether the effects of fishing on EFH are more than minimal and not temporary on managed fish stocks in Alaska. These criteria were developed and reviewed by the Council and its advisory committees in 2016, and stock assessment authors in 2017. In April 2017, the Council concurred with the Plan Team consensus that the effects of fishing on EFH do not currently meet the threshold of more than minimal and not temporary, and mitigation action is not needed at this time.

Although the impacts of fishing across the domain are very low, it is possible that localized impacts may be occurring.

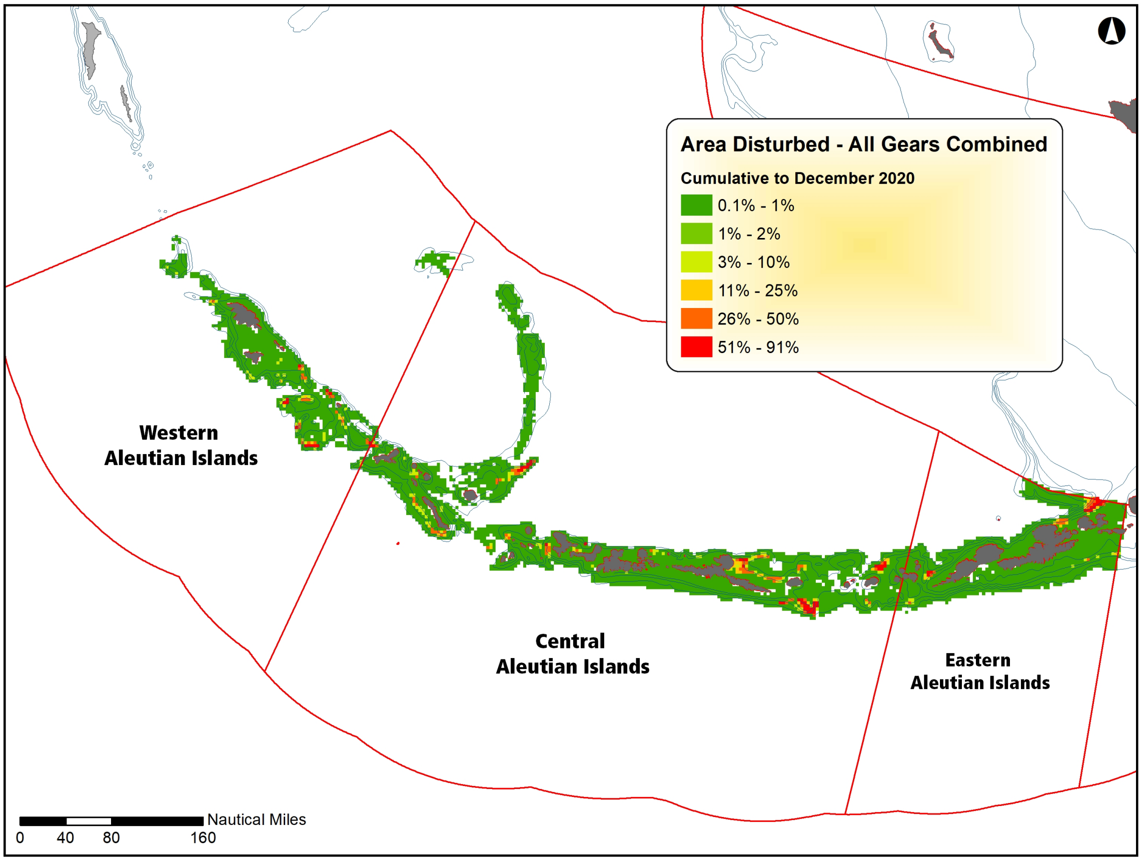

Figure 49: Map of percentage area disturbed per grid cell for all gear types. Effects are cumulative and consider impacts and recovery of features from 2003 to 2020.

Areas Closed to Bottom Trawling in the Aleutian Islands

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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 50, Table 2). Some of the trawl closures are in effect year-round while others are seasonal. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high.

Status and trends: Closures to scallop dredge were initially developed in 1981, and have been updated, most recently in 2018. 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 (Figure 51. In 2001, over 90,000 nm^2 of the Exclusive Economic Zone (EEZ) of Alaska was closed to trawling year-round as measures to protect the prey of Steller sea lions. 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. In 2006, a suite of measures were implemented by the NPFMC to freeze the footprint of non-pelagic trawling, resulting in over 280,000nm^2 of trawl closures.

Implications: With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling. The Steller Sea Lions Trawl Exclusion Zones limit access to Atka mackerel and Pacific cod in the Aleutian Islands. These closures may concentrate fishing effort to some localized areas for mackerel and cod; however, trawling for other species in those closed areas is allowed. In many cases, SSL and other closures are overlapping. Due to these closures and concentrated fishing effort, Aleutian Island habitat disturbance in the Aleutian Islands remain low (<4%).

For additional background on fishery closures in the U.S. EEZ off Alaska, see Witherell and Woodby (2005). Salmon savings areas are discussed within the context of salmon byctach by (Witherell et al., 2002). Steller Sea Lion closure maps are available in the link below:
`https://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-fisheries-figures-maps-boundaries-regulatory-areas-and-zones`

Steller Sea Lion closure maps are also available here:

`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/atka_pollock.pdf`

`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/pcod_nontrawl.pdf`

`http://www.fakr.noaa.gov/sustainablefisheries/sslpm/cod_trawl.pdf`

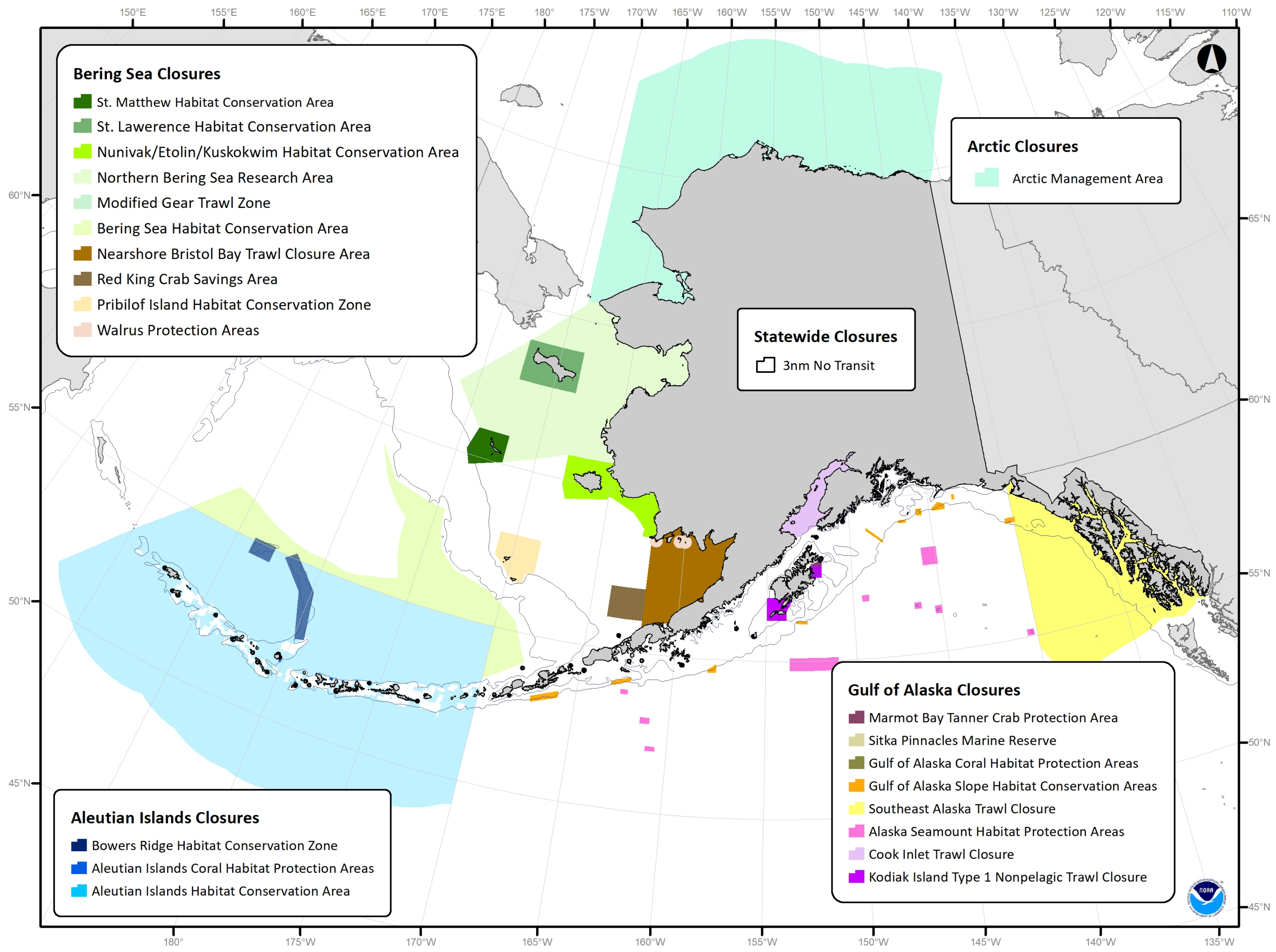

Figure 50: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

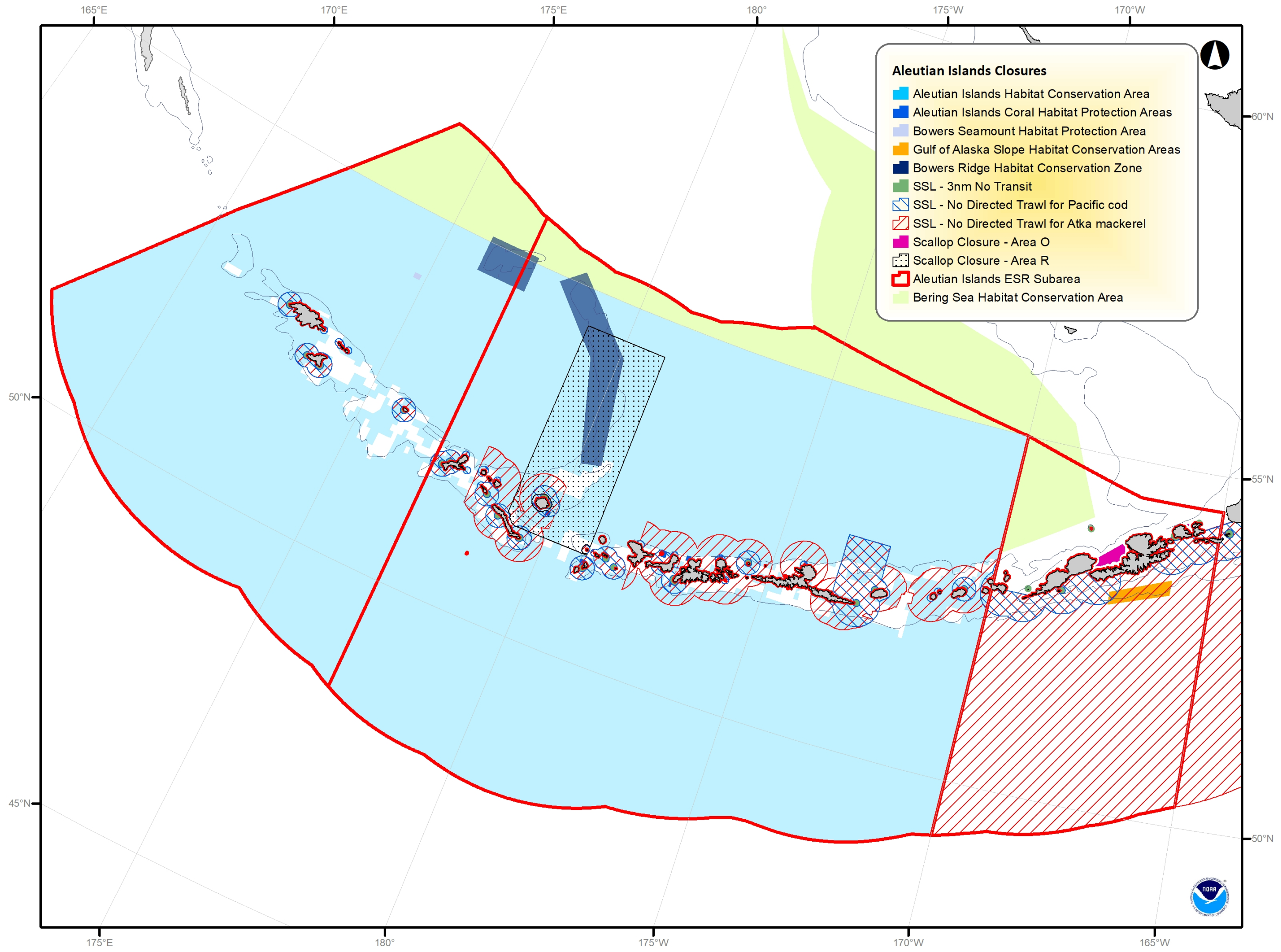

Figure 51: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, showing most SSL closures.

Table 2: Time series of groundfish trawl closure areas in the BSAI and GOA, that fall within the Aleutian Islands ecosystem 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
		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
		SSL Rookeries	seasonal ext.	5,100 nm^2	20 mile extensions at 8 rookeries
	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	
		Scallop Closure - Area R	No scallop dredge	295	initially 1981
GOA		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
	2000	Pollock haulout trawl exclusion zones for GOA* areas include EBS, AI	No trawl all year	11,900 nm^2*	
		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	

Sustainability (for consumptive and non-consumptive uses)

*Fish Stock Sustainability Index – Bering Sea/ Aleutian Islands

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Last updated: July 2021

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[4]. 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 Bering Sea and Aleutian Islands (BSAI), the Pribilof Islands blue king crab, Saint Matthew Island blue king crab, Pribilof Islands red king crab, and the black-spotted/rougheye rockfish stocks were removed from the FSSI and added to the group of non-FSSI stocks. The BSAI stock of Kamchatka flounder, the Aleutian Islands Pacific cod stock, and the Bogoslof stock of walleye pollock were added to the BSAI FSSI. These changes resulted in a net reduction from 22 to 21 FSSI stocks in the BSAI (See FSSI Endnotes for stock definitions). With few exceptions, groundfish species (or species complex) in the BSAI are managed as single stocks and not separately for the Bering Sea and Aleutian Islands. As such, the FSSI scores are reported for the BSAI as a whole.

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

Table 3: Summary of status for the 21 FSSI stocks in the BSAI, updated through June 2021.

BSAI FSSI (21 stocks)	Yes	No	*Unknown*	*Undefined*	N/A
Overfishing	0	21	0	0	0
Overfished	0	19	2	0	0
Approaching Overfished Condition	0	19	2	0	0

Additionally, there are 28 non-FSSI stocks in Alaska, three ecosystem component species complexes, and Pacific halibut, which are managed under an international agreement. Two of the non-FSSI crab stocks are overfished but are not subject to overfishing. The Pribilof Islands blue king crab stock is in year six of a rebuilding plan, and the North Pacific Fishery Management Council was notified that the Saint Matthew Island blue king crab stock is overfished on October 22, 2018 and have two years from this date to implement a rebuilding plan for this stock. 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[5].

Status and trends: The overall Alaska FSSI generally trended upwards from 80% in 2006 to a high of 94% in 2018 (Figure 52). The FSSI decreased in 2019 and 2020 to 88.9% but increased in 2021 to 89.6%..

As of June 30, 2021, no BSAI groundfish stock or stock complex is subject to overfishing, is known to be overfished, or known to be approaching an overfished condition (Table 3). The BSAI groundfish FSSI score is 59 out of a maximum possible 64. The AI Pacific cod stock and the walleye pollock Bogoslof stock both have FSSI scores of 1.5 due to not having known overfished status or known biomass relative to their overfished levels or to BMSY. All other BSAI groundfish FSSI stocks received the maximum possible score of four points.

The BSAI king and Tanner crab FSSI is 19 out of a possible 20. One point was deducted for the Norton Sound red king crab stock's biomass decreasing to below the B/B_{MSY} threshold.

The overall BSAI score is 78 out of a maximum possible score of 84 (Table 4). The overall FSSI has generally trended upward from 74% in 2006 to 93% in 2021 (Figure 53).

Factors influencing observed trends: The overall trend in Alaska FSSI has been positive over the duration examined here (2006-2021). The one point increase in the overall score from 2020 to 2021 was due to an increase in the biomass of sablefish above 80% of B_{MSY}. One point was lost for the Bristol Bay red king crab stock biomass dropping to below 80% of B_{MSY}. However, one point was gained for the biomass of the Norton Sound red king crab stock increasing to above 80% of B_{MSY}.

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

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

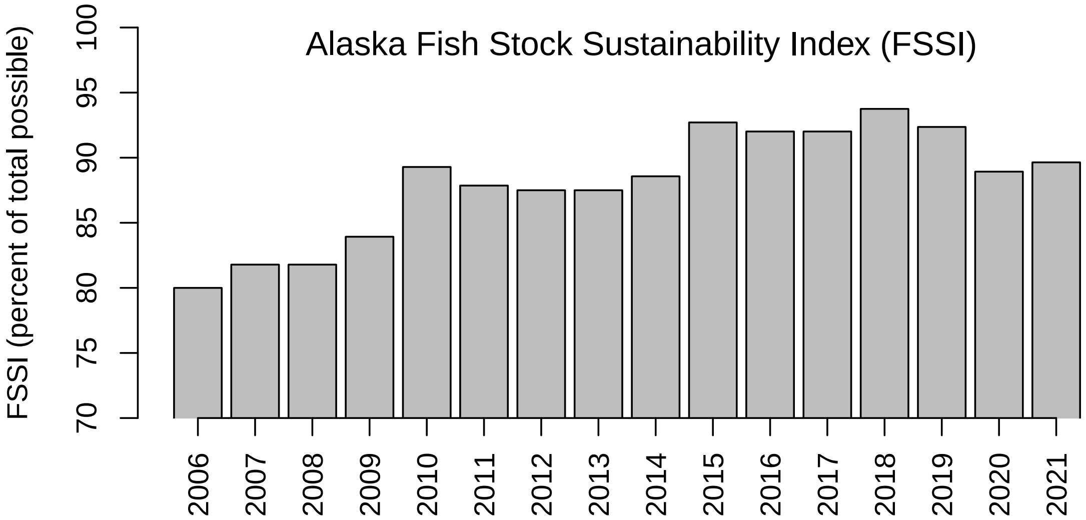

Figure 52: The trend in overall Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2021. The maximum possible FSSI was 140 from 2006 to 2014, 144 from 2015 to 2019, and is 140 in 2020 and 2021. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website.`https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`.

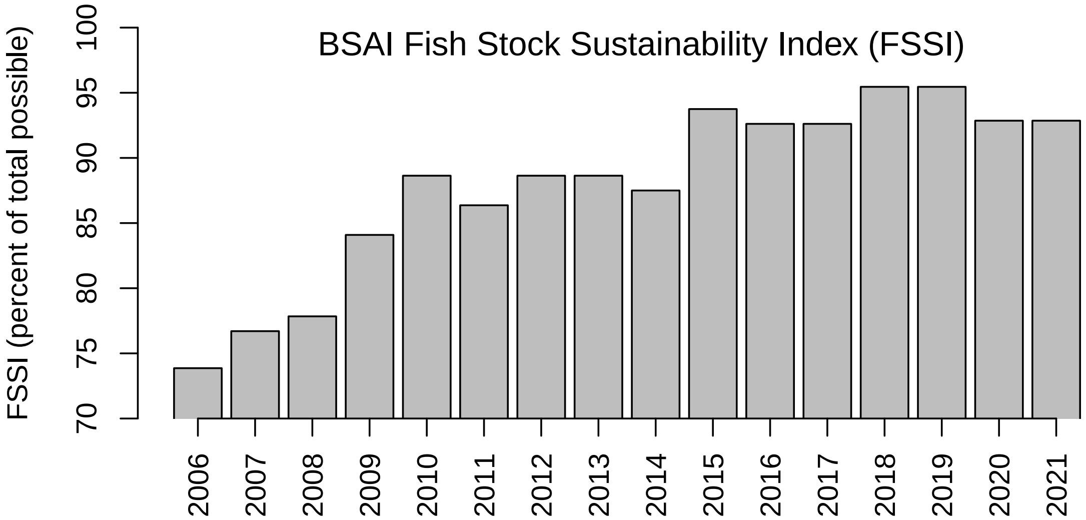

Figure 53: The trend in FSSI for the BSAI region from 2006 through 2021 as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: urlhttps://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates

Table 4: Table 2. BSAI FSSI stocks under NPFMC jurisdiction updated through June 2021 adapted from the NOAA Fishery Stock Status Updates webpage: `https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates`. *See FSSI and Non-FSSI Stock Status Table on the Fishery Stock Status Updates webpage for definition of stocks and stock complexes.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B_{MSY}	FSSI Score
Golden king crab - Aleutian Islands[a]	No	No	No	N/A	N/A	1.55/1.11	4
Red king crab - Bristol Bay	No	No	No	N/A	N/A	0.76	3
Red king crab - Norton Sound	No	No	No	N/A	N/A	0.80	4
Snow crab - Bering Sea	No	No	No	N/A	N/A	1.33	4
Southern Tanner crab - Bering Sea	No	No	No	N/A	N/A	0.96	4
BSAI Alaska plaice	No	No	No	N/A	N/A	1.84	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.24	4
BSAI arrowtooth Flounder	No	No	No	N/A	N/A	2.35	4
BSAI Kamchatka flounder	No	No	No	N/A	N/A	1.4	4
BSAI flathead Sole Complex[b]	No	No	No	N/A	N/A	2.09	4
BSAI rock sole complex[c]	No	No	No	N/A	N/A	2.47	4
BSAI skate complex[d]	No	No	No	N/A	N/A	1.7	4
BSAI Greenland halibut	No	No	No	N/A	N/A	1.59	4
BSAI Northern rockfish	No	No	No	N/A	N/A	1.89	4
BS Pacific cod	No	No	No	N/A	N/A	1.32	4
AI Pacific cod	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.81	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	1.26	4
Walleye pollock - Bogoslof	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.56	4
BSAI yellowfin sole	No	No	No	N/A	N/A	1.86	4

Box A. Endnotes and stock complex definitions for FSSI stocks listed in Table 4, adapted from the Status of U.S. Fisheries website.

(a) The status of this stock is based on the assessment of two stocks: the Eastern and Western Aleutian Islands golden king crab stocks.

(b) Flathead sole complex consists of Flathead sole and Bering flounder. Flathead sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the Overfishing Limit (OFL), which is computed from the combined abundance estimates for the two species.

(c) Rock sole complex consists of Northern rock sole and Southern rock sole (NOTE: These are two distinct species, not two separate stocks of the same species). Northern rock sole accounts for the overwhelming majority of the biomass and is regarded as the indicator species for the complex. The overfished determination is based on the combined abundance estimates for the two species; the overfishing determination is based on the OFL, which is computed from the combined abundance estimates for the two species.

(d) The skate complex consists of Alaska skate, Aleutian skate, Bering skate, Big skate, Butterfly skate, Commander skate, Deepsea skate, Mud skate, Okhotsk skate, Roughshoulder skate, Roughtail skate, Whiteblotched skate, and Whitebrow skate. Alaska skate is assessed and is the indicator species for this complex.

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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[6].

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

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

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

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[6] The Arctic report is under development

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

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

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

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

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 54). The primary stakeholders in this case are the North Pacific Fishery Management Council. Research and development of risk analyses and management strategies is ongoing and will be referenced or included as possible.

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

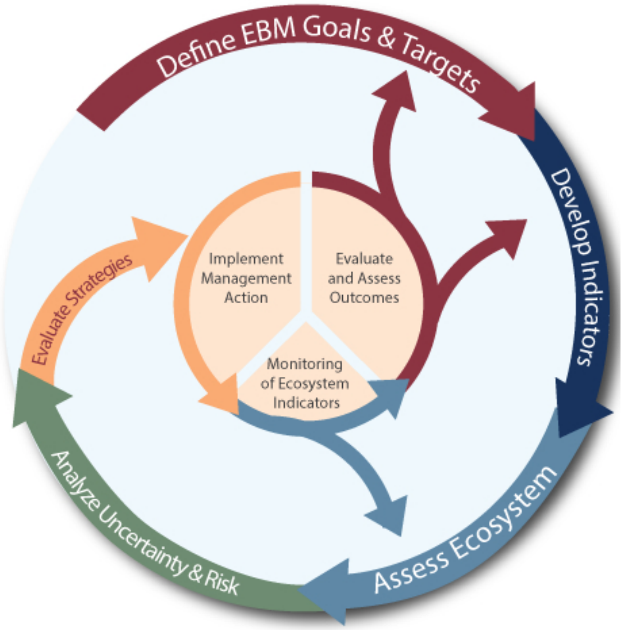

Figure 54: The IEA (integrated ecosystem assessment) process.

`reem/ecoweb/index.php`. These reports and data are also available through the NOAA-wide IEA website at: `https://www.integratedecosystemassessment.noaa.gov/regions/alaska`.

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

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

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

December 2020 SSC Comments

SSC appreciates the efforts made to standardize and stabilize the formats and methods applied to the ESRs. The ESRs for the EBS and GOA are already well aligned, and it would be good to put the AI ESR into a similar format, where possible. Standardized methodologies across ESRs would not have to be re-reviewed annually and changes to methods could be introduced in such a way that they could be quickly identified as new and then be evaluated. The SSC also continues to encourage the editors of the ESRs to work to reduce redundancy.

We have updated the format of the AI ESR this year to have a more cohesive format across all ESRs. Some formatting differences between ESRs will remain as we try to portray the information in a way that it highlights particular features of an ecosystem (e.g. regional report cards in the AI). With regards to standardized methodologies, contributors follow the same methodology (and text) for indicators sent to all three ESRs. However, sometimes using the same methodology is not possible or suitable- even when using the same kind of data. For example, satellite chla coverage has more gaps in the AI as opposed to the EBS, and hence the methodologies and indicators differ between both ESRs, despite the similarity in data sources. To help track changes in the ESR, any contribution that is either new or has updated methodology is marked by a dagger in the table of contents; updated contributions (new information, same methodology) are marked with an asterisk. Lastly, in an effort to reduce redundancy, we are removing the executive summary in the front matter of the ESR. Instead, we will focus on the ecosystem assessment and include links to the contributions as they are mentioned. The report card will continue to be included.

It would be useful to determine which of the sections of the ESRs are of greatest use to the intended audience.

The ecosystem information in this report is integrated into the annual harvest recommendations through inclusion in stock assessment-specific risk tables, 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. However, 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".

The Ecosystem Assessment sections of the ESRs are likely to be of greatest use to the SSC in this regard. The assessments are based on a synthesis of the myriad data in the reports, but are not necessarily reflective of all the information available. Instead, the authors strive to pull together "the story" for the ecosystem in the current and previous year based on apparent connections and mechanisms supported by recent trends. Some indicators may be more influential than others in any particular year due to changing environmental conditions or food web interactions. These are highlighted here, as well as common trends that may inform unobserved parts of the ecosystem.

Within each standard contribution, the last section is intended to highlight any implications of the indicator trends that could be informative for fisheries managers.

The SSC recommends that the ESR authors pursue the systematic and consistent incorporation of LK and TK as relevant to ESR. As noted before, we recognize that the systematic, methodologically sound, and culturally appropriate collection of all forms of LK and TK is beyond the purview of the ESR authors, but see the benefits of the ESRs incorporating these types of data when available. As demonstrated in the EBS ESR, in light of recent disruptions to surveys due to the pandemic, established protocols for incorporation of LK and TK can be useful for avoiding data gaps.

The ESR authors agree wholeheartedly in continuing to explore partnerships with the fishing industry, coastal communities, and regional entities, including tribal entities. Such partners have pertinent and relevant knowledge to inform the ESRs, both to help identify "red flags" and provide perspective and context to ecosystem trends. We continue to explore and invite partners to contribute to the ESRs while also awaiting advice on the systematic and consistent incorporation of local knowledge (LK) and traditional knowledge (TK) through the Bering Sea LK/TK/Subsistence Task Force.

Response from AFSC Economic and Social Science Research Program: The social science contributors to the ESR agree that it is important to include LK and TK in the ESRs when this information is available, but caution against its inclusion when there are recognized limitations in the methodological approaches (at present they are neither systematic nor consistent) as well as their limits on representativeness across regions, species, and communities. We recommend continuing additional efforts focused on incorporating LK and TK into the ESR to be done in coordination with the LKTKS Task Force.

In addition to the ESR Chapters, the SSC is pleased to see the continued development of the "In Brief" for the EBS and GOA, the addition of a new "In Brief" for the Aleutian Islands, and updated storymaps. We also look forward to seeing the new videos being developed. These resources are essential for efficiently and clearly communicating the main ecosystem patterns to stakeholders and the public, and the SSC supports their continued development.

In 2020 we produced "In Briefs" 4 page summaries for the EBS, GOA, and AI. We also produced an outreach video for the first time, summarizing the GOA 2020 ESR. In 2021 we plan to produce "In Briefs" for the EBS, GOA, and AI and a second outreach video summarizing the ESR products and process.

We have been examining the effort and resources required to produce these various outreach products (In Brief, storymap, video) with the AFSC communications team and have settled on a strategy that includes the annual production of "In Briefs", intermittent production of storymaps focussed on specific ecosystem stories, and no additional videos at this time.

The SSC suggests that the use of terms like "normal" is somewhat problematic given that what is "normal" seems to be changing rapidly. Some extremes are becoming normal. Regarding climate issues in particular, and perhaps for other areas in general, it might be better to use "average" and to indicate the years for which the average is calculated. It could also be appropriate to give departures from "average" in terms of standard deviations.

The ESR team agrees with the SSC and is working with our contributors to shift away from the term “normal” and to the term “average”, with specified years and standard deviations, where appropriate. In certain contributions that are qualitative or a synthesis of multiple datasets and observations, we are exploring the appropriate terminology that describes the concept of average conditions without using the quantitative term. This is an evolving conversation that reaches beyond the ESRs, particularly in the context of social science and local and traditional knowledge.

The MHW index provides a relative value for each season in each year in comparison to a long-term mean. However, it is likely the absolute value that drives ecosystem responses to heat waves via metabolic rates. In this regard, it would be useful if the authors can provide an index that captures the relative metabolic stress.

Metabolic stress, especially when talking about ”absolute” temperature values, is highly dependent on species. Bioenergetics indices, incorporating temperature-specific respiration, foraging rates, and varying prey quality, are being or have been incorporated into several stock-specific ESPs as requested by each stock’s ESP development team. However, on an ecosystem scale, it would be difficult to develop an absolute stress measure that is meaningful across a wide range of species; rather, a relative index provides a view of how unusual current conditions are compared to past observation, thus indicating greater potential for broad species shifts that may include less stress for warmer-water preferring species alongside decreases in colder-water species. As ESPs expand to include more per-species bioenergetics rates, we are considering future reporting of a ”meta-index” to indicate which/how many stocks are experiencing metabolic stress in any given year.

Additionally, the MHW does not seem to be reflected in the stability index. Is this because the index is averaged over 10 years? If so, this index may not be very sensitive to major perturbations of the ecosystem.

The lead contributor has provided a response to this comment: There is a certain amount of inertia built into these indicators. While they are responsive to and reflect change, they are not designed to show immediate and highly sensitive responses to small amounts of change, or change that is acutely felt by a single species. These community level indicators are intended to show when there is community-wide systemic change occuring, that integrate across species-specific responses. The changes in community indicator values during the heatwave may not have been as pronounced as one might have expected, perhaps due to variation in the magnitude and timing of the species-specific responses. While they may all ultimately end up having a similar trajectory in response to the heatwave (e.g., what may be happening with mean length and mean lifespan), it takes some time for the entire community to integrate those environmental changes. In summary, the inertia in these community indicators is intentional and they are designed to indicate systemic community-wide change.

Detailed response reflecting the 2014-2016 marine heatwave: The 10 year average dampens the effect of the survey index dip in 2017 (not 2016). While the survey biomass index dropped in 2017, the drop in the 10-year mean of the survey index was not remarkable. However, this indicator integrates information on both the mean and the variation in the index. In 2017, the survey biomass index was the second lowest over the time series (1999 was the lowest), the 10-year mean was the lowest over the time series, and the SD was the highest over the time-series. What’s important to note about the indicator in 2017 is that the 10 [survey] year window included the two lowest survey index values (1999 and 2017) and the four highest index values, over the survey index time series. This led to the high SD in 2017 and thus the low indicator value.

How meaningful is the index of mean lifespan of the community if so many species, and especially long-lived species such as rockfish, are excluded?

The lead contributor has provided a response to this comment: The mean lifespan indicator is specific to the portion of the groundfish community that is consistently sampled by the bottom-trawl survey gear. Rockfish are long-lived and would have an impact on the indicator value, particularly if they have high biomass in the survey area. Rockfish have previously been excluded from the bottom-trawl survey index, and thus the mean lifespan indicator, because the bottom-trawl surveys may not adequately sample the habitat or depths where rockfish are frequently found in order to represent their trends in abundance. The eastern Bering Sea shelf bottom-trawl survey is limited to depths less than 200 m and rockfish are routinely caught at only a small number of the standard stations, and in some years, some rockfish species are entirely absent from the survey catch. Furthermore, the topography of the eastern Bering Sea, with a very large shelf area compared to slope, means that the rockfish contribution would have a minimal effect on the lifespan indicator, even when weighted by age. Therefore, we continue to exclude rockfish from the eastern Bering Sea shelf survey index and related indicators, while noting the need to develop indicators specifically targeted towards the eastern Bering Sea slope region using slope survey data. The Gulf of Alaska bottom-trawl survey samples to much greater depths than in the eastern Bering Sea as part of the standard survey design, the slope represents a larger proportion of the overall Gulf of Alaska survey area, and rockfish species are consistently encountered across all years in the time series. We have reviewed the catch of rockfish in the GOA bottom-trawl survey time series and the relevant stock assessment documents and now include several rockfish species in the Gulf of Alaska bottom-trawl survey index and related indicators.

The absolute takes of seabirds in some years, and for some species, are of conservation concern. While a standardized index, such as birds caught per line or net set may be useful for some management purposes, the number of dead birds are more useful from a conservation and ecosystem perspective

The lead contributor has provided a response to this comment: In general, yes, providing only extrapolated numbers does generate a biased downward depiction of the take of seabirds. For example, the sablefish IFQ fishery has about 15% observer coverage. If we only provided observed takes of seabirds we would theoretically underestimate the seabird bycatch by 85%. We provide observed takes of ESA-listed seabirds (short-tailed albatross, Steller's eider, and spectacled eider) but I think it is less useful for something like northern fulmars whose populations number in the hundreds of thousands. In addition, we provide extrapolated and not extrapolated takes to the SSC when we present our annual bycatch report.

There have been suggestions that fluctuations in seabird bycatch possibly reflect prey availability; however, patterns differ among species or species groups. This may be an interesting area to investigate as the time series get longer and the methods of bycatch reduction stabilize. It may also be possible to relate seabird bycatch to die-off events, which also likely reflect a lack of available prey.

We agree with the SSC. We are hoping to include diet data of seabird bycatch in future ESRs to inform seabird bycatch trends and potentially prey availability. Currently, these food habits data exist but are in the process of being centralized into a searchable AFSC database. At that point, they will be available for further analyses to better understand these relationships of interest. We look forward to discussing these data in future ESRs.

In the description of fishing and human dimension indicators, it would seem useful to separate landings and price. Ex-vessel value may be what is of concern to economists or the industry, but when the two are multiplied together, the underlying driver behind the final number - whether the amount of fish has gone up or if the price has gone up - is unknown.

The AFSC Economic and Social Science Research Director has provided a response to this comment: The authors are unsure exactly to which area this comment applies. There are ESR contributions both for landings and value by functional group, as well as unit value (price) to make the distinction as suggested by the SSC.

Regarding the human dimension indicator of population and population change by community, the SSC recommends that the analysts consider flagging those communities that are currently directly engaged in the harvesting and/or processing sectors of federally managed fisheries.

The AFSC Economic and Social Science Research Director has provided a response to this comment: The social and economic conditions surrounding community participation in federal managed groundfish and crab species are more appropriately covered in the Annual Community Engagement and Participation Overview (ACEPO), which is its primary focus.

The addition of new data on HABs is excellent. Should there also be an effort to report on other pollutants and heavy metals?

Unfortunately, there are no yearly or periodic surveys for pollutants and heavy metals. We have included mercury in the food webs in the Aleutian Islands as a Noteworthy contribution as that is an ongoing project and also because levels of concern have been identified for mercury in several species. Threshold levels are not available for a lot of other pollutants (e.g., PCBs) but we will try to incorporate them as Noteworthy contributions as they become available.

The SSC reiterates that authors who wish to include figures make certain that these figures are readable when reduced to page or half-page size. This has been an issue of concern for a number of years. Perhaps the editors can scan contributions from authors when they are first submitted and return them to the authors if the included figures are unreadable. Fonts within figures are a particular problem; and figures that show long-term trends might benefit from zooming in on more recent years to show current trends

The ESR authors continue to work with contributors to improve the readability and utility of submitted figures.

Aleutian Islands

Multi-year Trends through 2019/2020 Several biological indicators were updated through 2019 and were discussed in terms of multi-year trends. Extended periods of above average SST corresponded with a decreasing trend in large diatom abundance and copepod size, increased bioenergetics costs, and declining groundfish condition over the period from 2010-2019. With average, or close-to-average, climate conditions throughout 2020 (e.g., cooler to moderate sea surface temperatures, fewer marine heatwave days), there was a return to more favorable conditions for the biological components of the Aleutian Islands ecosystem. However, groundfish condition continues to decline, particularly in the western Aleutians. Increases in the biomass of Kamchatka pink salmon, POP, and other rockfish may have created greater competition for available prey. The continued decline in a variety of components of the Western Aleutians marine ecosystem is cause for concern. Steller sea lions, some seabird species, and some groundfish species have experienced population declines, reproductive failures, and diminished body condition (mass/length). ***The SSC suggests a holistic approach may be needed to understand and manage this region given its remoteness.***

We agree with the SSC that a holistic approach would be beneficial and yield interesting and useful results. There are not many surveys in the Aleutian Islands and annual or region-wide information is scarce. There has been no Integrated ecosystem research program, synthesis program, or Regional Action Plan specific to the Aleutian Islands. The review of the FEP for the Aleutian Islands has also been delayed for several years now. Laboratory samples take lnger to process given priority processing for samples of commercial species in the EBS or GOA.

To make up for the lack of large scale studies in the area, we have supported/ encouraged targeted projects. The new contribution on satellite chla is an example, and we hope to continue developing indicators based on satellite data. We have also reached out to marine mammal groups working in the area and have now a new contribution on harbor seals, which along with Steller sea lions, sea otters and strandings, offer a more cohesive picture of marine mammals in the area. Likewise, we are using other sources of information in new ways including seabird bycatch information, seabird hatch dates, and the Christmas Bird Count to address changes in productivity and the food web. Two major objectives are trying to better understand longer term trends and their implications (such as the sustained SST above average) as well as the role of pink salmon in AI food-webs. This is in addition to the seabird and biophysical environment syntheses.

We will strive to expand these multidisciplinary collaborations to address ongoing and emerging issues.

Methods for the Report Card Indicators

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

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

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

Report Card Indicator Descriptions

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

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

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

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

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

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

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

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

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Proportions of hexagrammids, gadids, and *Ammodytes* in tufted puffin chick diets Tufted puffins (*Fratercula cirrhata*) are medium-sized seabirds that nest in varying densities throughout the Aleutians. The USFWS stations field biologists to monitor puffin chick diets annually at Buldir and Aiktak Islands (Figure 6) and less frequently at other Aleutian islands on which they occur. Puffins carry multiple prey items in their bills when they return to their colonies to feed their chicks. Forage fish and squid comprise most of puffin chick diets. In the absence of direct measures of forage fish abundance, time series of percent biomass of hexagrammids, gadids, and *Ammodytes* in puffin chick meals were selected as indicators of forage fish recruitment and system-wide productivity. Surveys are conducted on an annual basis.

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Apex predator and pelagic forager fish biomass indices We present two foraging guilds to indicate the status and trends for fish in the Aleutian Islands: apex predators and pelagic foragers. Each is described in detail below. This guild analysis was based on the time series available as part of the NOAA summer bottom trawl survey for the Aleutian Islands (Western and Central ecoregions) and the Aleutian Islands and Gulf of Alaska combined (Eastern ecoregion). These two guilds are based on the aggregation of Aleutian species by trophic role, habitat and physiological status. The species included in each guild are listed in Table 5.

Table 5: Species included in foraging guild-based fish biomass indices for the Aleutian Islands

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

Time series for the Western and Central ecoregions are based on data collected from the AI bottom trawl survey, which is conducted every other year during even years. The Eastern ecoregion time series is a composite of the Aleutian Islands survey, which samples the northern portion of the islands, and the Gulf of Alaska survey, which samples the southern portion. Since surveys in these two areas are conducted in different years, the biomass estimates represent the closest pair of years pooled together to get a total biomass estimate for the shelf region (0-500m). This time series excludes deep-water species such as sablefish and grenadiers, as most are found deeper than the trawl survey samples. The Team acknowledges that these would be good to include, but that the trawl survey does not sample them well.

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Steller sea lion non pup counts Counts of adult and juvenile Steller sea lions (*Eumetopias jubatus*) are used in the Aleutian Island ecosystem assessment to represent the status of an apex piscivorous predator whose diet consists primarily of commercially-fished species. The Steller sea lion inhabits coastal regions of the North Pacific Ocean, breeding in summer on terrestrial rookeries located from California north throughout the Gulf of Alaska, the eastern Bering Sea, the Aleutian Islands, Kamchatka Peninsula, Sea of Okhotsk, and the Kuril Islands (NMFS, 2010). The Steller sea lion is the world's largest member of the Otariidae family of pinnipeds. On average, Steller sea lions consume 6-10% of their body weight per day, but during lactation, energy intake by adult females may increase by as much as 3-fold (Keyes, 1968; Winship et al., 2002; Williams, 2005). Steller sea lions are generalist predators and consume a wide variety of fish and cephalopods in habitats ranging from nearshore demersal to offshore epi-pelagic, with local diets reflecting the species composition of the local fish community (Pitcher and Fay, 1982; Riemer and Brown, 1997;

Sinclair and Zeppelin, 2002; Waite and Burkanov, 2006; Trites et al., 2007; McKenzie and Wynne, 2008; Fritz and Stinchcomb, 2005). In the Aleutian Islands, the diet consists largely of Atka mackerel, followed by salmon, cephalopods, Pacific cod, sculpins and walleye pollock (Sinclair and Zeppelin, 2002). Unlike phocid pinnipeds, otariids do not have large blubber (energy) stores, and as a consequence, require reliable access to predictable, local prey aggregations to thrive (Williams, 2005; Sigler et al., 2009).

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

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

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

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

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

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