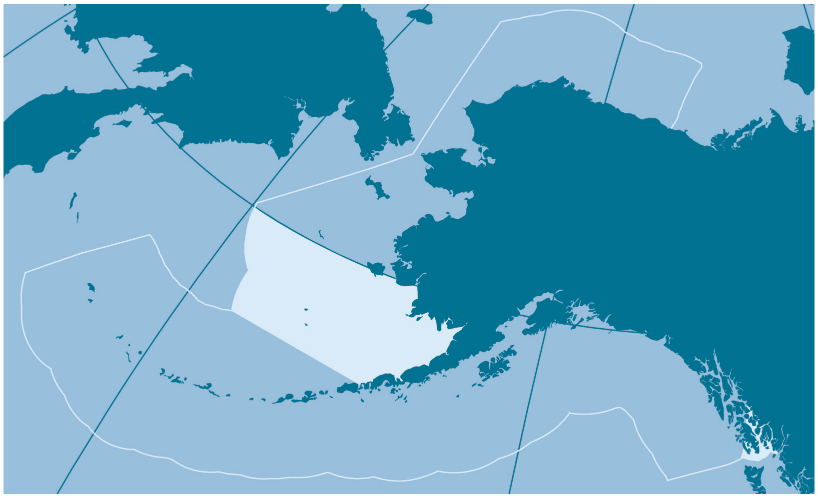
Ecosystem Considerations 2017

Status of the Eastern Bering Sea Marine Ecosystem



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Reviewed by:
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November 13, 2017
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Eastern Bering Sea 2017 Report Card

- The eastern Bering Sea was characterized by **moderately warm conditions** in 2017. The **PDO remained positive**, although the magnitude decreased. **Weak La Niña conditions** are predicted for the winter of 2017-2018.
- **Sea ice extended** over the southern shelf during the winter and spring and resulted in an **extensive, although narrow, cold pool** during summer 2017.
- Acoustic estimates of euphausiids from the 2016 summer trawl survey were **the lowest in the time series**. RZA assessments showed **comparable euphausiid abundances over the middle shelf between 2016 and 2017.**
- The biomass of motile epifauna remains **above the long-term mean**, with an increasing trend in the past 5 years. **Brittle star biomass remains above average**, with a slight (9%) decline from 2016–2017. **Urchins, sand dollars, and cucumbers are also above their long-term mean**, with a 12% increase from 2016–2017. **King and tanner crabs decreased (28% and 21%, respectively).**
- The biomass of benthic foragers dipped in 2015, but has **remained at a near-average level in 2016 and 2017**. The decline in 2015 was due to a 25% decline in Northern rock sole, which continued to decline in 2017 (by 7.5%). The overall return to an average level was due to a **112% increase in "miscellaneous flatfish"** (e.g., Bering flounder, Longhead dab, Slender sole, Starry flounder) and 24% increase in Flathead sole between 2016 and 2017.
- The biomass of pelagic foragers **remains at its 34-year mean** in 2017. A large **increase in Pacific herring was off-set by a decrease in Capelin.**
- The biomass of fish apex predators **declined, largely driven by a 35% reduction in Pacific cod** biomass and 11% reduction in Arrowtooth flounder biomass.
- **The multivariate seabird breeding index remains below the long term mean**, indicating that seabirds bred later and less successfully in 2017. Seabirds showed overall poor reproductive success at St. Paul and St. George Islands in 2017, with the exception of red-faced cormorants.
- Northern fur seal pup production for St. Paul Island in 2016 **remained low with a decrease of 12.1% from 2014.** Pup production on St. George Island increased 8.2% between 2014 and 2016.
- **Seafloor habitat disturbance** due to fishing gear (pelagic and non-pelagic trawl, longline, and pot) shows **interactions have remained below the long-term average** since 2011.

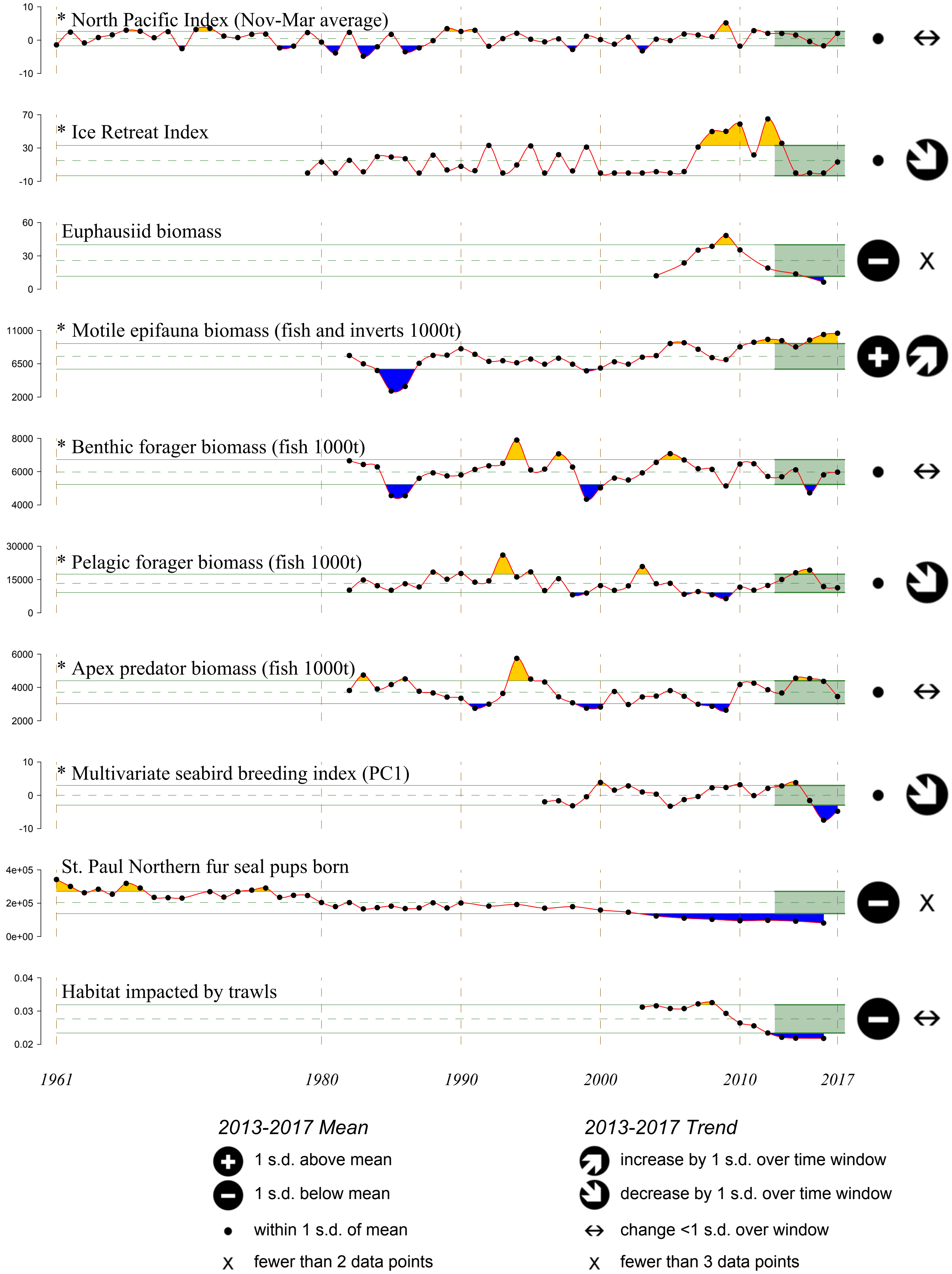

Figure 1: Eastern Bering Sea ecosystem assessment indicators; see text for descriptions.
* indicates time series updated in 2017.

Executive Summary of Recent Trends in the Eastern Bering Sea

This section contains links to all new and updated information contained in this report. The links are organized within three sections: Physical and Environmental Trends, Ecosystem Trends, and Fishing and Human Dimensions Trends.

Physical and Environmental Trends

North Pacific Trends

- The state of the North Pacific atmosphere-ocean system during 2016–2017 featured the moderation of sea surface temperatures following the marine heat wave of 2014–2016 (p. 63).
- Fall (Sept.–Nov.) 2016 SSTs were warmer than normal in the northern and eastern Bering Sea with strongly negative sea level pressure anomalies in the western Bering Sea (p. 64).
- Winter (Dec.–Feb.) 2016–2017 SSTs reflected cooling that was associated with winds out of the west across the Bering Sea (p. 64).
- A weak Aleutian Low implied suppressed storminess for the southeastern Bering Sea. Suppressed storminess continued in spring (Mar.– May) (p. 64).
- A transition from a strong El Niño to a weak La Niña occurred in 2016 (p. 68).
- A disproportionately large positive-magnitude NPI occurred in winter of 2016–2017, considering the weak amplitude of La Niña in late 2016 (p. 68).
- Fall through winter 2017–2018 is predicted to have a 40% chance of neutral conditions and a 55% chance of a weak La Niña (p. 69).
- Slight cooling of SSTs are predicted in the eastern Bering Sea based on 3-month forecasts for December 2017–February 2018 and February–April 2018 (p. 69).

Eastern Bering Sea Trends

- The Bering Sea experienced moderate climate conditions in 2017 (p. 71).
- Summer winds were very light from the south giving slightly positive air temperature anomalies over the Bering Sea (p. 71).
- Sea ice extended father south over the shelf (more similar to 2006) with an unusual boundary of sea ice retreating into the Gulf of Anadyr (p. 71).

- A narrow cold pool extended over the southern shelf middle domain (p. 71).
- The predictions for summer 2018 are for a smaller-than-average but near-average cold pool using the ≤0°C or ≤1°C definitions, but a larger-than-average ≤2°C cold pool.
- Surface and bottom temperature means for the 2017 eastern Bering Sea shelf decreased from 2016 estimates, but were still warmer than the long-term time series mean (p. 78).
- In 2016, temperatures above and below the MLD were warmer than average in all regions of the shelf (p. 80).
- The 2017 springtime drift pattern was mixed; initial unfavorable off-shore winds changed to northerly onshore winds. This may be more consistent with years of below-average recruitment for winter-spawning flatfish (p. 85).

Ecosystem Trends

- Catch rates for sponges and sea anemones remained lower than the previous 7 years; sea whips decreased significantly from 2016 (p. 87).
- Dissolved inorganic nitrogen (DIN) concentrations, indicative of nutrient availability, have decreased in the southern middle domain and could limit primary productivity in the system (p. 89).
- The ratio of large-size-fraction phytoplankton was below average in 2014–2016 and could indicate longer food webs and less efficient transfer of energy to fish, sea birds, and marine mammals (p. 91).
- September 2017 exhibited the lowest coccolithophore index of the record over the middle and inner shelves. This may result in improved foraging success for visual predators (p. 95).
- Large copepod abundances were low along the southeastern Bering Sea shelf in 2017. This suggests that juvenile pollock did not encounter large, lipid-rich copepods in fall (p. 99). However, euphausiid abundances were slightly higher than in recent years, therefore pollock may find adequate prey to provision for overwintering (p. 99).
- Relative CPUE of jellyfishes (primarily *Chrysaora melanaster*) during the 2017 bottom trawl survey increased by 18% from 2016, however, the 2016–17 estimates are among the lowest observed since 1989 (p. 105).
- The abundance of smaller-sized jellyfish (*Aequorea*, *Aurelia*, and *Cyanea*) increased during the 2016 BASIS survey while larger jellyfish (*Chrysaora*) decreased (p. 106).
- Increased abundance of *Chrysaora* is observed in cold years with a shift to multiple, smaller-sized species in warm years (p. 106).
- Estimated abundances of forage fish (e.g., Capelin, Pacific herring) decreased during late summer 2016 (p. 112).
- The 2017 preliminary estimate of Canadian-origin juvenile Chinook salmon in the northern Bering Sea is below average; this could lead to reduced bycatch caps three to four years in the future (p. 118).
- Estimated abundances of juvenile salmon in the eastern Bering Sea increased in 2016, typical of warm years (p. 120).
- Juvenile Chinook, chum, and pink salmon were distributed farther south in warm years, while juvenile sockeye salmon were distributed farther north and west in warm years (p. 120).
- Estimated abundances of juvenile groundfish species (e.g., pollock, Pacific cod) decreased in 2016 (p. 125).
- Age-0 pollock are distributed farther north during warm years and have an expanded range relative to cold years (p. 125).

- Fish condition (based on length-weight residuals) has been negative for Pacific cod since a peak value in 2003. Condition of age-1+ pollock in 2017 was the second lowest on record (p. 130).
- Length-weight residuals for all species (except Arrowtooth flounder) were less in 2017 than in 2016, indicating poorer condition and possibly poor overwinter survival (p. 130).
- Estimated age-1 natural mortality for pollock, Pacific cod, and Arrowtooth flounder remained elevated in 2017 (p. 134).
- Elevated rates of predation mortality may reflect higher energetic demands of predators under warm conditions and/or maturing large age-classes (e.g., 2012) of pollock and Pacific cod that have increased predator demand (p. 134).
- Recruitment predictions for the 2016 year class of pollock were mixed: the Temperature Change (TC) index predicted lower than average recruitment to age-3 (p. 140), surface silicic acid concentrations predicted above-average fish weight and therefore recruitment to age-1 (p. 143), and age-0 pollock energy density predicted intermediate survival to age-1 (p. 151).
- The 2017 relative CPUE for eelpouts decreased, but is still among the highest estimates over the last 11 years. The poacher group CPUE decreased and is the lowest estimate since 2001. Sea star CPUE increased and is the second highest estimate since 1982 (p. 154).
- Biomass of commercial crab stocks is highly variable with negative trends in 2017 (p. 156).
- Cliff-nesting seabirds showed overall poor reproductive success at the Pribilof Islands in 2017, with the exception of nearshore-feeding red-faced cormorants (p. 159).
- Fur seal pup production at St. Paul Island decreased 12.1% from 2014 to 2016 while it increased 8.2% on St. George Island (p. 161).
- The total biomass of demersal fish and invertebrates suggests that the prey base has remained stable over recent decades. Total biomass increased since the early 2000's due to several strong year classes of pollock (p. 164).
- Species richness and diversity on the EBS shelf increased significantly in 2016 and 2017. Richness was highest along the 100 m isobath, while diversity was highest on the middle shelf (p. 166).
- Cooler water temperatures in 2017 resulted in a substantial southeastward shift in species distributions (p. 168).
- The mean lifespan of demersal fish increased from 26.1 years in 2016 to 27.8 years in 2017. Mean lifespan has generally been stable over the 36 year time series with no indication of a long-term trend (p. 171).
- The mean length of groundfish in 2017 was 38.6 cm, a decrease of 0.5 cm from 2016, but above the long-term average. Mean length shows interannual variability, but has been generally stable with no indication of a long-term trend (p. 173).
- The stability of groundfish biomass showed a slight increase from 2016 to 2017. This indicator has remained generally stable since 1993 with no indication of a long-term trend (p. 174).

Fishing and Human Dimensions Trends

- Discard rates in the Bering Sea pollock trawl sector have remained at or below 1% since 1998. Rates in the non-pollock trawl sector have remained below 8% since 2011. Discard rates in the fixed gear sector have trended slightly upward since 2012. In 2016, higher discard rates corresponded to the highest annual discard weight of the time series (p. 176).

- The catch of jellyfish peaked in 2014 with sharp declines in 2015 and 2016; the catch of structural epifauna has been relatively steady; sea stars increased between 2011–2015 with a decrease in 2016 (p. 179).
- The number of seabirds caught incidentally in EBS fisheries in 2016 exceeded the 2007–2015 average by 78% and was the second highest in the time series. This was largely due to an increase in shearwater and northern fulmar bycatch (p. 182).
- Habitat impacts due to fishing gear (pelagic and non-pelagic trawl, longline, and pot) interactions has decreased steadily to the present level of about 2.3% (p. 186).
- As of June 30, 2017, no BSAI groundfish stock or stock complex is subjected to overfishing, is considered to be overfished, or to be approaching an overfished condition. Only the Pribilof Islands blue king crab stock is considered overfished and subject to overfishing; the stock is in year 3 of a rebuilding plan (p. 188).
- Pelagic foragers (i.e., pollock) represent the largest share of total landings between 2003–2016, while motile epifauna (i.e., crabs) represent the smallest share. Trends in landings by functional group may be driven by TAC levels for representative species (e.g., Pacific cod drive the apex predator group) (p. 193).
- Subsistence harvest of Pacific halibut represented only 2.3% of total harvests in 2014, with 9% of subsistence harvest occurring in the eastern Bering Sea (Area 4E). Subsistence salmon harvests have decreased state-wide, particularly for Chinook salmon. The Bristol Bay Management Area accounts for 41% of subsistence Chinook salmon harvests (p. 195).
- Trends in ex-vessel value are closely connected to landings (see p. 193). Flatfish revenues have declined recently due to decreased prices; crab value has increased with increased landings; salmon value has increased due to stable landings and strong prices (p. 198).
- First-wholesale value varies by landings and/or prices. Pollock prices have decreased since 2013, but this has been largely offset by increased landings; Pacific cod prices dropped in 2009, but rebounded and have been stable; flatfish value decreased between 2012–2015 with decreased prices and significant supply; salmon value decreased in 2012, but rebounded in 2013 and has remained stable at 2010 levels; crab value increased with increasing prices through 2012, but has decreased slightly with reduced landings (p. 198).
- A low level of saltwater sport fishing occurs in the region; the number of anglers fishing has declined since the mid-1990s and is currently at about 2,000 anglers (p. 202).
- The unemployment rate in EBS communities decreased from 3.29% in 2015 to 3.16% in 2016 (p. 205).
- The unemployment rate in NBS communities decreased from 12.77% in 2015 to 12.48% in 2016 (p. 207).
- The 2016 population estimate of all EBS communities was 10,150 and the population of small communities (excluding Dillingham) was 7,834. The EBS population has remained relatively stable overall, yet 41% of communities experienced population decline between 1990 and 2016 (p. 209).
- The 2016 population estimate of all NBS communities was 33,780 and the population of small communities (excluding Bethel and Nome) was 23,759. The NBS population has remained relatively stable with only 21% of communities experiencing population declines between 1990 and 2016 (p. 212).
- There has been a general trend toward decreasing school enrollment in most eastern Bering Sea boroughs; many areas have had school closures. The Aleutians West census area (Pribilof Islands and Nelson Lagoon) school enrollment has decreased substantially while the Bethel census area has increased slightly (p. 215).

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* indicates contribution updated in 2017
† indicates new contribution

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

December 2016 SSC Comments

This year, as in the past, the Ecosystem Considerations (Reports) are thoughtful, well done, and most helpful in providing a context within which to assess the stocks of commercially harvested fish in Federal waters off Alaska. The editors and authors have also been most responsive to the comments and suggestions provided by the SSC in 2015. The most striking change this year has been to split the Ecosystem Considerations (Report) into four Large Marine Ecosystem (LME) (reports), one each for the Arctic (not yet available), the eastern Bering Sea, the Aleutian Islands, and the Gulf of Alaska. Moreover, the chapter on the Aleutian Islands recognizes three distinct ecoregions, and the Gulf of Alaska report is split into two regions. The SSC strongly supports, and deeply appreciates the effort associated with, these changes. The high quality of the figures was noteworthy, as was the consistent inclusion of error bars, where appropriate.

Thank you. This year we provide an update to the eastern Bering Sea (Siddon & Zador) and Gulf of Alaska (Zador & Yasumiishi) Reports.

The SSC was also pleased to see the inclusion of human communities as ecosystem components, the new approach for assessing trawl impacts, and the various new forage fish indices in the chapters, among other changes. All of these additions represent important improvements to the document. The SSC further encourages the continued development of predictive capacity, and commends the efforts in this direction to date. Although more of the indicator reports mention the management implications of the findings than has been the case in the past, some of these discussions of implications are rather cursory, and the SSC recommends that authors continue to expand these sections.

In the 2017 reports, we have further expanded the human dimensions section to include social-cultural, recreation, and economic indicators. Additional new contributions include a standardized summary of the Rapid Zooplankton Assessments and historical time series across Large Marine Ecosystems as well as expanded analyses to estimate distribution and abundance shifts of fish and jellyfish from standard NOAA surveys. The Gulf of Alaska report also includes two new humpback whale contributions.

In the eastern Bering Sea report we've included a new section entitled "Groundfish Recruitment Predictions" that incorporates a new indicator for Pacific cod along with five indicators for Walleye pollock recruitment. We plan to do the same for the Gulf of Alaska report when we have more indicators that include recruitment predictions. Currently the report contains one for Sablefish.

We continue to encourage authors to discuss the management implications of their findings; we hope the SSC finds utility in each contribution. For 2018 Reports, we plan to revise the instructions for the Implications section to encourage more relevant responses that directly address whether there are potential management concerns, or not.

As we obtain more and better data for the Aleutian Islands and the Gulf of Alaska, it is likely that the Ecosystem Consideration documents will grow substantially. The annual production of the Ecosystem Considerations (reports) is a heroic accomplishment, but it also brings to mind a question: If the Ecosystem Considerations are as important as the SSC thinks they are, are there sufficient resources being devoted to their compilation and editing? Synthesis across the indicators is a critical component of this effort, but is somewhat limited, likely due to time constraints. The SSC suggests that it may be appropriate to provide additional staff resources to sustain the improvement of these documents.

Additional staff resources have been devoted to the production of the Reports (i.e., Editors), and many AFSC staff now have Performance Plan metrics dedicated to Ecosystem Considerations indicators. These steps have helped immensely; however, in 2017 we updated the eastern Bering Sea and Gulf of Alaska reports only. Increased production frequency for the Aleutian Islands report and development of the Arctic report will require additional staff time and/or resources.

Given the length and breadth of the 2016 Ecosystem Considerations (reports), it is not practical to review and evaluate all elements and issues that might be addressed. Thus, this SSC report deals only with some of the most critical issues. These include the new structure of the documents, major issues in the environment that may impact commercially important stocks, and issues pertaining to the need for additional information.

Splitting the Ecosystem Considerations Chapter into Large Marine Ecosystems *The SSC sees the new format of the Ecosystem Considerations (reports) as a very positive step toward integrating the various topics within a region. Particularly in the chapter on the eastern Bering Sea, there was improved coherence within topic areas (e.g., zooplankton), and improved cross-referencing between issues of relevance to each other. Cross-referencing between regions (GOA vs. EBS) still remains a challenge, but the loss of between-region comparisons is more than offset by improved integration within regions, including an increased awareness of potential data gaps. The SSC also appreciates the efforts of the authors to examine ecological issues at spatial scales below those of the regions, thereby reflecting differences in sub-regional ecosystems. The split of the three ecoregions of the Aleutian Islands and the split between the eastern and western Gulf of Alaska seem most appropriate. As suggested on page 45 of the eastern Bering Sea Chapter, it may be appropriate to examine selected indicators by the Inner, Middle, and Outer Shelf Domains in the Bering Sea.*

We appreciate the positive feedback on splitting the previously single report into separate reports based on Large Marine Ecosystems. We agree the new format encourages better synthesis within a region, an ability to identify (and fill) gaps, and a coherence across ecosystem levels that better enables an ecosystem approach to fisheries management. For the eastern Bering Sea report, we encouraged authors to examine individual indicators by domain (where appropriate) and are pleased to include 4 indicators by domain (and an additional indicator split by north/south) in this year's report. For the Gulf of Alaska report, we grouped indicators within sections by East or West

GOA, and encourage authors to split GOA-wide indicators by the East/West designation where appropriate.

Cross-cutting issues that may be of importance to management *Selection and/or development of Ecosystem Indicators included in the Report Cards: The SSC appreciates the authors efforts to identify regionally relevant ecosystem indicators to include in each of the report cards. As new indicators are identified and/or prior indicators replaced within each region, we request that the rationale behind indicator selection be provided.*

As part of the Bering Sea Fisheries Ecosystem Plan (FEP) Team, we will be convening a working group to re-evaluate and select Report Card indicators for the eastern Bering Sea. A similar workshop was held in early 2016 in conjunction with a GOA IERP PI meeting for the Gulf of Alaska report. Additionally, in April 2017, the Editors of these Reports (S. Zador, E. Yasumiishi, and E. Siddon) attended a national Ecosystem Status Report meeting in Washington, D.C. From that meeting, there are on-going efforts to standardize time series analyses and indicator presentation across Science Centers. We will aim to include justification and explanation each time there is a new indicator within a Report Card, as we did this year in the GOA Report Cards.

Continuation of aberrantly warm conditions *With the possible exception of the western Aleutian Islands, all regions managed by the NPFMC have experienced unusually warm conditions for the past three years. Forecasts suggest that these warm conditions may persist at least for the coming winter and spring. The last time we had four warm years in a row (2001–2005), there was a strong reduction in pollock recruitment in the eastern Bering Sea, among other impacts. The Ecosystem Considerations (reports) provide a useful heads-up that commercially valuable fish stocks may be adversely impacted by the continuing warm anomaly.*

The Ecosystem Considerations Reports provide an ecosystem context within which to discuss harvest recommendations, thus supporting the operationalizing of Ecosystem-Based Fisheries Management. We would encourage stock assessment authors, plan team members, and SSC members to formally acknowledge when consideration of ecosystem indicators is taken into account (whether it affects harvest recommendations or not) as a best-practice of EBFM.

Bottom-up impacts on commercially important stocks *There is accumulating evidence from the Bering Sea, the Aleutians, and the Gulf of Alaska that bottom-up issues may be affecting recruitment and fish weight-at-length or -age. Changes in the size composition of copepod zooplankton associated with warming waters have now been identified in the eastern Bering Sea and the Gulf of Alaska. In the eastern Bering Sea, changes in the timing of sea ice retreat appear to affect the recruitment of both large calanoid copepods and shelf species of euphausiids, with a demonstrated impact on the survival of age-0 pollock. We need to know what other species of commercially important fish are similarly affected. In the Aleutians, there is evidence of fish being underweight (negative length-weight residuals for most species in 2014 and 2016), but the direct mechanisms have not been identified. There are some old zooplankton data of Coyle and Hunt from the western Aleutians (Kiska and Buldir waters) that have not been published. Comparison of these historic (1990s) data with present-day conditions might be very valuable. In the Gulf of Alaska, shifts in copepod size distribution may be negatively affecting the availability of forage fish, which in turn affects predatory fish of all kinds.*

We appreciate the broader interests by the SSC for better mechanistic understanding of recruitment dynamics. The Recruitment Processes Alliance (RPA) continues to conduct process-oriented research on several target species within each of Alaskas Large Marine Ecosystems to better resolve mechanisms of ecosystem change, develop indices and metrics that quantify shifts, and construct models that forecast ecosystem effects on key fisheries species. In the eastern Bering Sea, the ecosystem assessment focuses on walleye pollock, Pacific cod, Arrowtooth flounder, juvenile salmonids, and forage fish; in the Gulf of Alaska the RPA focuses on pollock, Pacific cod, Arrowtooth flounder, juvenile salmonids, rockfishes, and Sablefish; in the northern Bering Sea and Arctic the RPA focuses on pollock, Pacific cod, Arctic cod, Saffron cod, and juvenile salmonids.

These data are crucial to the understanding of loss of sea ice in the eastern Bering Sea and the resultant trophic cascade that influences ecosystem function and fisheries recruitment dynamics for pollock. Research is ongoing to address the impact of loss of sea ice on lower trophic levels such as phytoplankton and zooplankton as well as important fishes including Pacific cod, Arrowtooth flounder, western Alaska salmon, and forage fish. In addition, modeling projects such as FEAST and ACLIM are studying impacts of future changes in lower trophic communities, fish recruitment, and resulting fisheries. Such analytical/modeling efforts synthesize data while incorporating the mechanistic understanding that stems from process-oriented research. There are peer reviewed publications that connect ecosystem function (zooplankton species composition) to fitness of Pacific cod and western Alaska salmon (Bristol Bay sockeye salmon, Yukon River Chinook salmon). In the Gulf of Alaska, current research includes understanding ecosystem impacts on target species' distribution, growth, fitness, and recruitment. In particular, AFSC scientists are working with stock assessment scientists to understand why Pacific cod abundance declined dramatically in recent years and to document ocean conditions that lead to high recruitment success of Sablefish.

The Rapid Assessments of Zooplankton are a valuable addition to the tools with which we assess environmental change, and the SSC appreciates the requested expansion of these data in all LMEs. It is hoped that the full work-ups of the samples will become the basis for future in-depth reports. In the meantime, it would be good if the authors could provide an indication of the abundance of large copepods as well as their relative abundance with respect to small copepods, as opposed to simply reporting on composition of zooplankton catches.

In this year's reports, a standardized summary of the Rapid Zooplankton Assessments are provided for both the eastern Bering Sea and Gulf of Alaska. In addition, the RZA estimates are shown in context of historical time series of abundance for large copepods, small copepods, and euphausiids. Another improvement to the RZA analysis is an estimation of abundance, as opposed to proportional catches. In the Western Gulf of Alaska Report Card, we include copepod community size composition from the Continuous Plankton Recorder. New this year for the Eastern Gulf of Alaska, we include the proportion of large calanoid copepod in relation to all calanoid copepods, from data in the Ferguson et al. contribution in the 2017 Gulf of Alaska Report, to represent changes in copepod community size.

There is a current lack of information on the lower trophic levels in the central and western Aleutian Islands, and to a lesser extent, in the Gulf of Alaska. These lower trophic-level-processes are potentially vulnerable to the impacts of climate warming and to ocean acidification. We lack sufficient information about the lower trophic levels in these region to be able to anticipate how warming, acidification, and harmful algal blooms might impact the lower trophic levels and, through them, the stocks of commercial interest. Obtaining the necessary information should be a high priority for research.

We agree that having high quality information on lower trophic processes is of particular importance for assessing ecosystem status. This year we include six indicator contributions on zooplankton in the Gulf of Alaska report, of which two are new. There remains a lack of information on primary production. The sole primary production-related time series we include is on diatom size as recorded by the Continuous Plankton Recorder.

Forage fish and groundfish trends across LMEs *There are some indications across LMEs that forage fishes and groundfishes may be impacted by aberrant environmental conditions, resulting in impacts to foraging behavior and efficiency. Drift patterns in the eastern Bering Sea in 2016 are consistent with below-average recruitment for winter-spawning flatfishes (northern rock sole, arrowtooth flounder, and flathead sole). There are several seabird-based indicators that suggest that foraging conditions were extremely poor in the EBS as well. In the GOA, the apparent recruitment failure of multiple groundfish stocks in 2015, including pollock, Pacific cod and several flatfishes, and the predicted below average recruitment for sablefish are additional potential examples. The SSC continues to strongly endorse investigations into the mechanisms behind these potential impacts across all LMEs.*

We agree that better scientific understanding of the impacts of the recent extreme warming event from 2014–2016 is a high priority. We have been tracking apparent impacts across ecosystem components in these reports and provide syntheses in the Ecosystem Assessments. The Gulf of Alaska Pacific cod stock in particular appears to have experienced adverse impacts such that commercial fisheries will be negatively affected.

The status and ecology of marine mammals *The chapters on the eastern Bering Sea and Aleutian Islands say relatively little about the status and ecology of Northern Fur Seals and Steller Sea Lions. There is a report that fur seals are declining steadily, particularly on St Paul Island, but there is little information on progress that may have been made in determining when and where in their life cycle threats to fur seal survival and successful reproduction are occurring. Likewise, we are told little about the status and ecology of sea lions in the Central and Western Aleutians. Declines in Steller Sea Lions have impacted fisheries in the Aleutian Islands, and on-going declines in Northern Fur Seals have the potential to impact the pollock fishery over a large portion of the eastern Bering Sea. If the Council and the National Marine Fisheries Service are to manage fisheries to protect these marine mammal species, then the Marine Mammal Laboratory will have to become more proactive in providing information and in collaborating with the Council in the management and protection of these marine mammal stocks. A useful starting place would be for the Marine Mammal Laboratory to contribute more fulsomely to the relevant annual Ecosystem Considerations chapters; for instance, by providing the biennial pup counts in time for inclusion in this document.*

The below information is provided from the Marine Mammal Laboratory:

The Marine Mammal Laboratory conducts biennial fur seal pup production surveys in the eastern Bering Sea, and has provided estimates in time to be included in the Ecosystem Considerations Report and presentation to the SSC for the past 2 surveys (2014 and 2016). The contributions include preliminary estimates from the Pribilof Islands in even years (immediately following the surveys) as well as finalized estimates in odd years.

The 2016 contribution from MML also incorporated information on the status of northern fur seals, the foraging ecology, and possible explanations for changes in abundance at the Pribilof Islands and Bogoslof Island. MML will continue to provide relevant information on northern fur seals in a timely manner to be included in the Ecosystems Considerations Report.

During 2017, the Marine Mammal Laboratory provided a comprehensive overview of the present state of the fur seal population and NMFS research plans at the April Council meetings, and assisted Council staff in their preparation of a synthesis paper entitled “Northern Fur Seals: Synthesis paper for the North Pacific Fishery Management Council”.

There is virtually no information presented on the impacts of increasing numbers of baleen whales in any of the regions. It would be useful to know something about the numbers of whales likely present in the various regions, their diets, and their potential prey consumption. There are data on whales in Prince William Sound that could be used as an example. Modeling of some what-if scenarios could be useful for understanding the potential for whales to impact fisheries through either consumption of young of commercially valuable species or their prey.

This year we are pleased to include two new indicator contributions on humpback whales in the Gulf of Alaska report. These will hopefully begin to fill an information gap in this area. Trends in numbers of whales and calf production indicate that the recent warm conditions have had an adverse impact on these large mammals that sample a broad swath of the NE Pacific during migration. Additionally, modeling efforts being developed within the REFM Division can address potential impacts to fisheries or their prey.

Humans as part of ecosystems *With reference to human communities, the SSC requests consistency across the documents in the use of key indicators. The use of school enrollment data in the AI document, for example, should be repeated for the other ecoregions as this is an established indicator of community health in areas where commercial fishing is a significant economic driver. The analyses of population changes reference decline and urban consolidation, among many trends; spatial data to accompany these population shifts would demonstrate sub-regional trends more effectively and is consistent with the ways non-human species are presented in the documents. The SSC recommends that the authors use their own subheading, Humans as a Part of Ecosystems, that is, humans are members of ecosystems as apex predators, as the framework for inclusion of future indicators and to discard the notion that humans are impacted by or impacting the ecosystem, as was presented to the SSC. The latter is a Western and Euro-American philosophy that places humans outside of nature, is in conflict with Alaskan Natives relationship with the environment, and does not capture the integral role and complexity of human communities and stakeholders in the AI, EBS, and GOA. Additional indices, such as use of subsistence food from the sea, would be welcome.*

Across both the eastern Bering Sea and Gulf of Alaska reports, we have standardized and broadened our inclusion of human indicators. We have restructured the “Fishing and Human Dimensions Indicators” section to include the following:

1. Discards and Non-Target Catch
2. Maintaining and Restoring Fish Habitats
3. Sustainability
4. Seafood Production
5. Profits

6. Recreation
7. Employment
8. Socio-Cultural Dimensions

We have added five new indicators as well as updated (i) Trends in Unemployment and (ii) Trends in Human Populations to address urban versus rural communities and patterns.

Eastern Bering Sea
BASIS Survey (p. 25) *The Editor acknowledges the importance of the BASIS survey, and notes that these surveys will now be biennial surveys in the future. The SSC continues to be concerned by this loss, and recommends a continued search for funding this as an annual survey.*

In 2017 (an "off year" for the BASIS survey), RPA scientists secured supplemental funding through NOAA's Office of Science & Technology to conduct nodal sampling in the eastern Bering Sea. While transiting from Nome to Dutch Harbor after the completion of an Arctic IERP survey, selected samples were collected from two stations located inside the cold pool (bottom temps $< 2^{o}$C). Activities included physical oceanographic sampling, phytoplankton and zooplankton analyses, trawling, age-0 pollock bioenergetics, and diets. A third station was occupied outside of the cold pool south of the Pribilof Islands over the outer shelf, where oceanographic and lower trophic sampling was accomplished. This nodal sampling was conducted to test the hypothesis that age-0 pollock opportunistically utilize ecosystem resources derived from the presence of arctic sea ice in spring and manifested in the cold pool in summer/autumn.

New index on herring in the eastern Bering Sea *The SSC appreciates the development of the new Bering Sea herring index based on the BASIS survey data. Both the abundance and the distribution of herring indicated by the index differ greatly from other studies of herring in the eastern Bering Sea, such as ADF&G surveys of mature herring during spawning and literature studies of the herring monthly distributions and migration based on herring bycatch (Barton and Wespestad, 1980) and Prohibited Species Catch (Tojo et al., 2007). As a result, background information to help interpret the results of the index and put it in context with other studies would be particularly valuable. For instance, to understand how and why this index differs from other Bering Sea herring studies, it would be helpful to include (1) what age classes are sampled, (2) what age classes, maturity classifications (mature fish, immature fish), and Bering Sea areas do the biomass estimates represent, and (3) how effective do authors expect the survey is for estimating population biomass and distribution of the age classes captured by the survey, including any suggestions the authors may have on what factors may have negatively affected the surveys or indexs effectiveness.*

The contributing authors appreciate the SSC's interest in efforts to produce biomass estimates of fish from the BASIS survey. The following response was provided by Ellen Yasumiishi (AFSC/EMA):

The BASIS survey differs in sample time, location, and gear from the ADF&G survey, Hood and Calder (1981), and Tojo et al. (2007). Tojo et al. (2007) analyzed herring bycatch data collected from 1977–2003 by NMFS observers aboard groundfish fishing vessels. The groundfish fishery occurred primarily in the middle domain, especially in spring and summer, and in the outer domain. The groundfish vessel samples are primarily taken from the mid-water in the middle and outer domain of the southeastern Bering Sea and outer domain in the northeastern Bering Sea. The BASIS survey samples are primarily collected from the top 20m of the water column during

September from the middle domain of the southeastern Bering Sea and inner and middle domains of the northeastern Bering Sea.

ADF&G age-structure models for herring include data on age compositions of the purse seine and gillnet catches, the age composition of the mature run, and aerial survey estimates of biomass for nearshore spawning aggregations in Norton Sound, Kuskokwim, and Bristol Bay. Unfortunately, our staff does not conduct genetics, age, and maturity analyses for herring catches. Staff are exploring the possibility of a herring age study in 2018.

According to the migration model in Figure 1 of Tojo et al. (2007), based on bycatch samples, the BASIS survey is sampling herring during their migrating from nearshore spring spawning areas to offshore winter feeding grounds. Our catches coincide with the proposed summer migration routes from nearshore, passed Nunivak Island, and to offshore winter grounds by western Alaska herring populations (see Figure 1 in Hood and Calder (1981)). Hood and Calder (1981) note that some Norton Sound stocks remain closer to their spawning areas during the winter.

In 2017, Yasumiishi et al. updated the herring (now forage fish) contribution (see p. 112). Specifically, the encounter probability presented in 2016 is now shown as the predicted field densities. This revised figure provides more detailed information on catch locations in the survey.

Second, Yasumiishi et al. changed the model assumption of a normal distribution of the data to a more flexible gamma distribution. As a result, the annual biomass estimate for BASIS herring now ranges from 10,000 to 50,000 metric tonnes, lower than the 2016 model estimates. Commercially important predators of herring include Pacific cod, Walleye pollock, Arrowtooth flounder, and Greenland turbot (Livingston, 1993). Livingston (1993) reported that 448,000 tonnes of herring was consumed by bird, fish, and marine mammal predators in the eastern Bering Sea during 1985, therefore our survey likely samples a fraction of the population.

The revised herring abundance index includes additional warm and cold years than previously published studies. Abundance trends now show that herring biomass is higher during warm years than cold years, at a 1-2 year lag. We plan to add environmental covariates to the model in 2018 to try to better understand factors influencing changes in the distribution and abundance of this forage fish species.

Multivariate Index of Climate Forcing (p. 44) *For several years, the issue of the development of a multivariate index of climate forcing has been mentioned, but apparently little progress has been made. Is this index important? If so, it would be good to see it to completion.*

Index of Primary Production (p. 44) *What may be more important than an estimate of the amount of primary production is an index of the timing of the spring blooms and the availability of phytoplankton to herbivorous zooplankton in spring and early summer. Also, the composition of the phytoplankton is important in so far as diatoms are more nutritious than the smaller celled dinoflagellates.*

Index of cold pool species (p. 45) *The SSC supports the development of an index of species that particularly depend on the presence, location and/or timing of the cold pool. This information will be of particular importance if the cold pool shrinks and shifts northward in the future.*

Index of Fishery Performance (p. 45) *The SSC notes that development of a fishery performance index based on attainment of TAC may not be informative for fisheries that are more* *bycatch limited, and recommends consulting with industry or the Advisory Panel for appropriate performance indices for these fisheries.*

The four comments above refer to the "Gaps and Needs" section of the Introduction in reference to the selected Report Card indicators. As part of the Bering Sea Fisheries Ecosystem Plan (FEP) Team, we will be convening a working group to evaluate and select Report Card indicators for the eastern Bering Sea. Through this effort, we will take the above comments into consideration.

Structural Epifauna and Bottom temperatures (p. 74) *Bottom temperatures have been greatly elevated in the past year, particularly in the shallower portions of the Middle and Inner Shelf domains. What do we know about the potential impact of elevated temperatures on the survival of benthos, in particular the structural epifauna? Are there data on lethal temperatures?*

The structural epifauna reported in this contribution (sponges, sea whips, and sea anemones) seem to have differing responses to temperature variability over the time series reported. For example, while the abundance of sponges tracks thermal shifts (warm/cold stanzas), sea whip abundance is more variable. However, at this time, more research is needed on the Phyla Porifera and Cnidaria regarding taxonomic resolution (Stevenson and Hoff, 2009), survey trawl efficiency, and catch quantification (Stevenson et al., 2016) before such trends can be interpreted with confidence.

Spatial Distributions of fish (e.g., Fig. 54, 58, 59, 93) *The data on distribution shifts is most interesting and presages possible shifts with continued warming. It would of value to relate these shifts to variables such as bottom temperatures, ice cover, and depth. This might help stimulate examinations of mechanisms behind the observed shifts.*

Examining environmental variables as they relate to shifts in distribution and abundance is of utmost interest to the authors, as well, and is in progress. The inclusion of environmental covariates into these analyses is planned for the 2018 contributions.

Eastern Bering Sea Slope Surveys (p. 76) *For the shelf and upper slope surveys, catches of anemones were reported, but not for the slope surveys. It would be of interest to know if they also declined in this deeper habitat that is presumably more protected from rapid environmental change.*

The slope survey is biennial, but we will communicate this to the authors for their consideration in 2018.

Yukon Chinook Salmon (p.118) *It appears that there is good news concerning the abundance of Yukon River juvenile Chinook salmon of Canadian origin. If there is a substantial increase in the salmon in the Bering Sea, then there are likely to be an increase in salmon PSC in the eastern Bering Sea pollock fishery, for which there is a hard cap on the number of PSC salmon allowed.*

This year's preliminary estimate of Canadian-origin juvenile Chinook salmon in the northern Bering Sea in 2017 is 1.3 million juveniles, which is below the the overall average of 1.7 million. Low juvenile abundance will likely result in reduced bycatch caps three to four years in the future.

Condition of fish (139) *The author raises the question of whether it would be more useful to report the condition of juvenile fish separately from that of fish that have recruited to the fishery. This seems like a useful addition, as one may predict survival to recruitment, whereas the other provides an index for converting numbers of fish to biomass of fish.*

While this work has not yet been done for the 2017 bottom trawl survey data, the authors are preparing a manuscript describing the juvenile-adult condition correlation and further splitting of juvenile and adult fishes. They anticipate including it in the 2018 Ecosystem Considerations Report.

Aleutian Islands *The new organizational structure served to highlight the lack of information for the Aleutian Islands in particular and would like to encourage continued investigation into additional sources of data for this LME, particularly in the Western Aleutians, as patterns there appear to frequently diverge from that of the Central and Eastern subregions.*

We anticipate an update to the Aleutian Islands report in 2018 and will work to expand the indicators included.

Introduction

The goals of the Ecosystem Considerations report are to (1) provide stronger links between ecosystem research and fishery management and to (2) spur new understanding of the connections between ecosystem components by bringing together the results of diverse research efforts into one document. Beginning in 2016, we split the report into four separate documents, one for the Gulf of Alaska, Aleutian Islands, eastern Bering Sea, and the Arctic[1]. This year we present updated reports for the Gulf of Alaska and eastern Bering Sea. Each report contains four main sections:

- Report Card(s)
- Executive Summary
- Ecosystem Assessment
- Ecosystem Status Indicators and Fishing and Human Dimensions Indicators

The purpose of the first section, the Report Card(s), is to summarize the status of the top indicators selected by teams of ecosystem experts to best represent each ecosystem. Time series of indicators are presented in figures formatted similarly to enable comparisons across indicators. Recent trends in climate and the physical environment, ecosystems, and fishing and fisheries are highlighted in bulleted lists.

The purpose of the second section, the Executive Summary, is to provide a concise summary of the status of marine ecosystems in Alaska for stock assessment scientists, fishery managers, and the public. Page links to sections with more detail are provided.

The purpose of the third section, the Ecosystem Assessment, is to synthesize historical climate and fishing effects on Alaskan marine ecosystems using information from the Ecosystem Status and Management Indicators section and stock assessment reports. Notable items, called “Hot Topics”, that capture unique occurrences, changes in trend direction, or patterns across indicators are highlighted at the beginning. An ongoing goal is to produce ecosystem assessments utilizing a blend of data analysis and modeling to clearly communicate the current status and possible future directions of ecosystems. This year, we expanded the Fishing and Human Dimensions section to more broadly reflect aspects of our role in the ecosystem. In doing so, we organized this new section around a proposed set of ecosystem-scale objectives derived from U.S. legislation and current management practices (Table 1). We are considering reformatting the entire report by management objectives in future editions. *Note: In this year’s report, the Ecosystem Status indicators remain organized by trophic level.*

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[1] The Arctic report is under development

Table 1: This table represents the current indicators in this report organized by ecosystem-scale objectives derived from U.S. legislation and current management practices.

Objective	**Indicators**
Stability	• Species richness and diversity (p. 166) • Lifespan of the fish community (p. 171) • Length of the fish community (p. 173) • Stability of groundfish biomass (p. 174) • Fish stock sustainability index (p. 188)
Biomass	• Abundance and distribution of jellyfish (p. 105, p. 106) • Abundance and distribution of forage fish, salmon, and groundfish (p. 112, p. 120, p. 125) • Juvenile Chinook salmon abundance (Northern Bering Sea; p. 118) • Fish and invertebrate CPUE (p. 154, p. 164) • Commercial crab biomass (p. 156)
Productivity	• Dissolved Total Inorganic Nitrogen (p. 89) • Phytoplankton Biomass and Size Structure (p. 91) • Coccolithophore blooms (p. 95) • Rapid Zooplankton Assessment (p. 99) • Groundfish condition (p. 130) • Multispecies model estimates of natural mortality (p. 134) • Groundfish recruitment predictions (Pacific cod: p. 138; Walleye pollock: p. 140, p. 143, p. 145, p. 149, p. 151) • Seabird reproductive activity (p. 159) • Dead and dying seabirds (Hot Topic; p. 50) • Northern fur seal pup production (p. 161)
Trophic Structure	• See Report Card indicators 4–7 (Figure 1)
Habitat	• Structural epifauna (p. 87) • Spatial distribution of groundfish stocks (p. 168) • Area disturbed by trawl fishing gear (p. 186)
Climate & Oceanography	• North Pacific climate conditions (p. 63, p. 64, p. 71, p. 78, p. 80) • Climate indices (p. 68) • Projections (p. 69) • Wind forcing (OSCURS model; p. 85)
Bycatch Reduction	• Groundfish discards (p. 176) • Non-target species catch (p. 179) • Seabird bycatch (p. 182)
Seafood production	• Commercial landings (p. 193) • Subsistence trends (p. 195)
Profits	• Ex-vessel value, first-wholesale value, and unit ratio value (p. 198)
Recreation	• Number of recreational anglers and fishing days (p. 202)
Employment	• Unemployment estimates in the eastern and northern Bering Sea (p. 205, p. 207)

Social-Cultural	• LEO Network (Hot Topic; p. 48) • Trends in human population (p. 209, p. 212) • School enrollment (p. 215)

We initiated a regional approach to ecosystem assessments 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.

The eastern Bering Sea and Aleutian Islands assessments are 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 instead of an in-person workshop.

The purpose of the fourth section, Ecosystem Status Indicators and Fishing and Human Dimensions Indicators, is to provide detailed information and updates on the status and trends of ecosystem components. Additionally, this section may provide early warning signals of direct ecosystem impacts that could warrant management intervention or evidence of the efficacy of previous management actions. Ecosystem-based management indicators should also track performance in meeting the stated ecosystem-based management goals of the NPFMC, which are:

1. Maintain biodiversity consistent with natural evolutionary and ecological processes, including dynamic change and variability
2. Maintain and restore habitats essential for fish and their prey
3. Maintain system sustainability and sustainable yields for human consumption and non-extractive uses
4. Maintain the concept that humans are components of the ecosystem

Since 1995, the North Pacific Fishery Management Councils (NPFMC) Groundfish Plan Teams have prepared a separate Ecosystem Considerations report within the annual SAFE report. Each new Ecosystem Considerations 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 Considerations 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 then, the Ecosystem Considerations reports have included some 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.

Originally, contributors to the Ecosystem Considerations report were asked to provide a description of their contributed index/information, summarize the historical trends and current status of the index, and identify potential factors causing those trends. Beginning in 2009, contributors were also asked to describe why the index is important to groundfish fishery management and implications of index 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 are they 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.

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 2). The primary stakeholders in this case are the North Pacific Fishery Management Council. Research and development of risk analyses and management strategies is ongoing and will be referenced or included as possible.

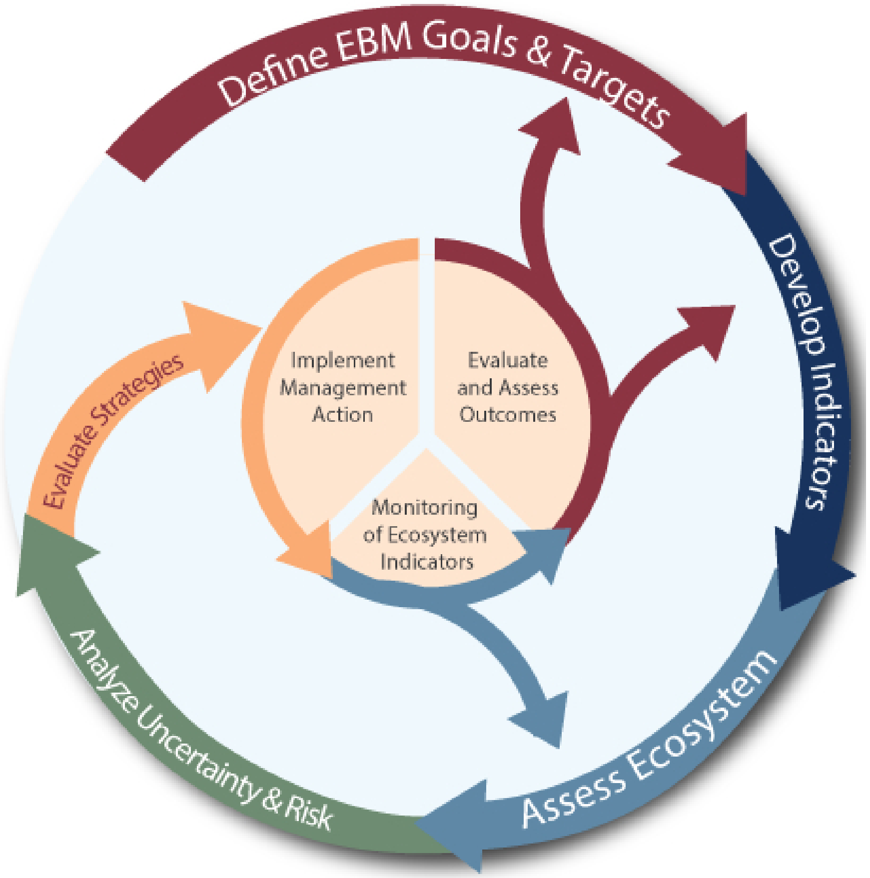

Figure 2: The IEA (integrated ecosystem assessment) process.

It was requested that contributors to the Ecosystem Considerations report provide actual time series data or make it available electronically. Many of the time series data for contributions are available on the web, with permission from the authors. We are in the process of improving online access to indicators and debuted a new webpage in early 2016.

The Ecosystem Considerations reports and data for many of the time series presented within are available online at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Past reports and all groundfish stock assessments are available at: `http://www.afsc.noaa.gov/refm/stocks/assessments.htm`

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

Ecosystem Assessment

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Introduction

The primary intent of this assessment is to summarize and synthesize historical climate and fishing effects on the shelf and slope regions of the eastern Bering Sea from an ecosystem perspective and to provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function. The Ecosystem Considerations section of the Groundfish Stock Assessment and Fishery Evaluation (SAFE) report provides the historical perspective of status and trends of ecosystem components and ecosystem-level attributes using an indicator approach. For the purposes of management this information must be synthesized to provide a coherent view of the ecosystem effects in order to clearly recommend precautionary thresholds, if any, required to protect ecosystem integrity. The eventual goal of the synthesis is to provide succinct indicators of current ecosystem conditions and a prognosis of how fish stocks are expected to fare, given concurrent information on ecosystem status. In order to perform this synthesis a blend of data analysis and modeling is required annually to assess current ecosystem status in the context of past and future climate conditions.

Hot Topics

We present items that are either new or otherwise noteworthy and of potential interest to fisheries managers as Hot Topics.

Thinking Outside the Survey Box

In 2017, the eastern Bering Sea (EBS) shelf bottom trawl survey was extended northward to include 144 additional stations in an area bounded by the Bering Strait, Norton Sound, and the U.S.–Russia Maritime Boundary (Figure 3). This "Northern Bering Sea" (NBS) extension of the survey is a fundamental part of the Alaska Fisheries Science Center Loss of Sea Ice (LOSI) Research Plan (Hollowed et al., 2007; Sigler et al., 2015), the primary purpose of which is to study the impacts of diminished sea ice on the marine ecosystem. The 2017 survey was the second snapshot in a formative time series that began in 2010. The intent of the LOSI Research Plan is to continue the time series by surveying the NBS biennially, contingent on agency funding. The scale and extent of fish and crab movements can vary from year to year in response to a variety of biological or environmental processes causing changes in distribution and abundance that extend beyond the standard EBS shelf survey area (the survey "box"). Continuation of the combined EBS and NBS bottom trawl survey will provide more comprehensive snapshots of the broader shelf for investigating how different demersal fish and invertebrate taxa respond to biological and environmental processes on larger temporal and spatial scales.

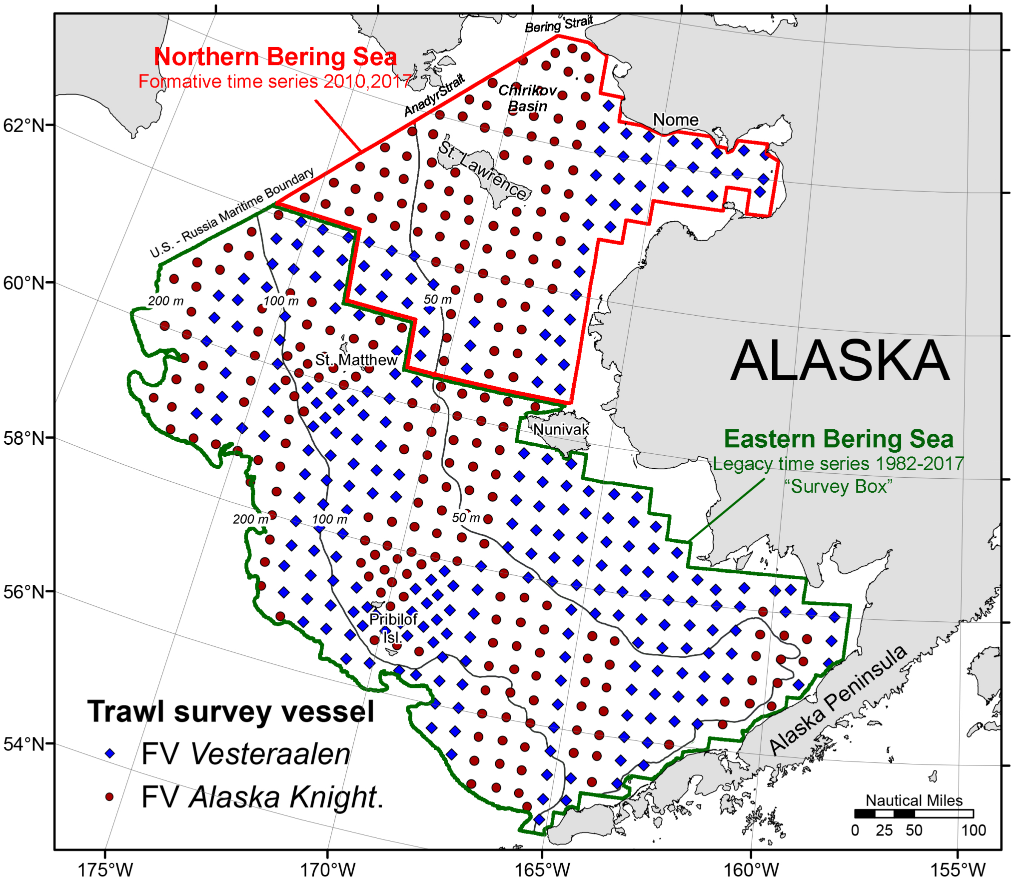


Figure 3: Sampled survey stations in 2017, by survey vessel and area. Enclosed within the green line are eastern Bering Sea shelf stations that have been sampled annually since 1982 (the survey "box"). Enclosed within the red line are the northern Bering Sea shelf stations that were sampled for only the second time since 2010.

Bottom temperature is a major environmental driver that can affect the distribution of demersal fishes and crabs on the shelf (Kotwicki and Lauth, 2013). Environmental conditions leading up to the summer of 2017 were much different from those leading up to the 2010 survey (Figure 4). Relative to the long-term survey mean for bottom temperature, years 2006–2013 were colder than average ("cold stanza") and years 2014–2017 were warmer than average ("warm stanza"). During the 36-year time series (1982–2017) of the annual EBS shelf bottom trawl survey, mean summer bottom temperatures were highly variable, ranging from 0.8°C to 4.5°C, with a grand mean for all years of 2.5°C (Figure 4A).

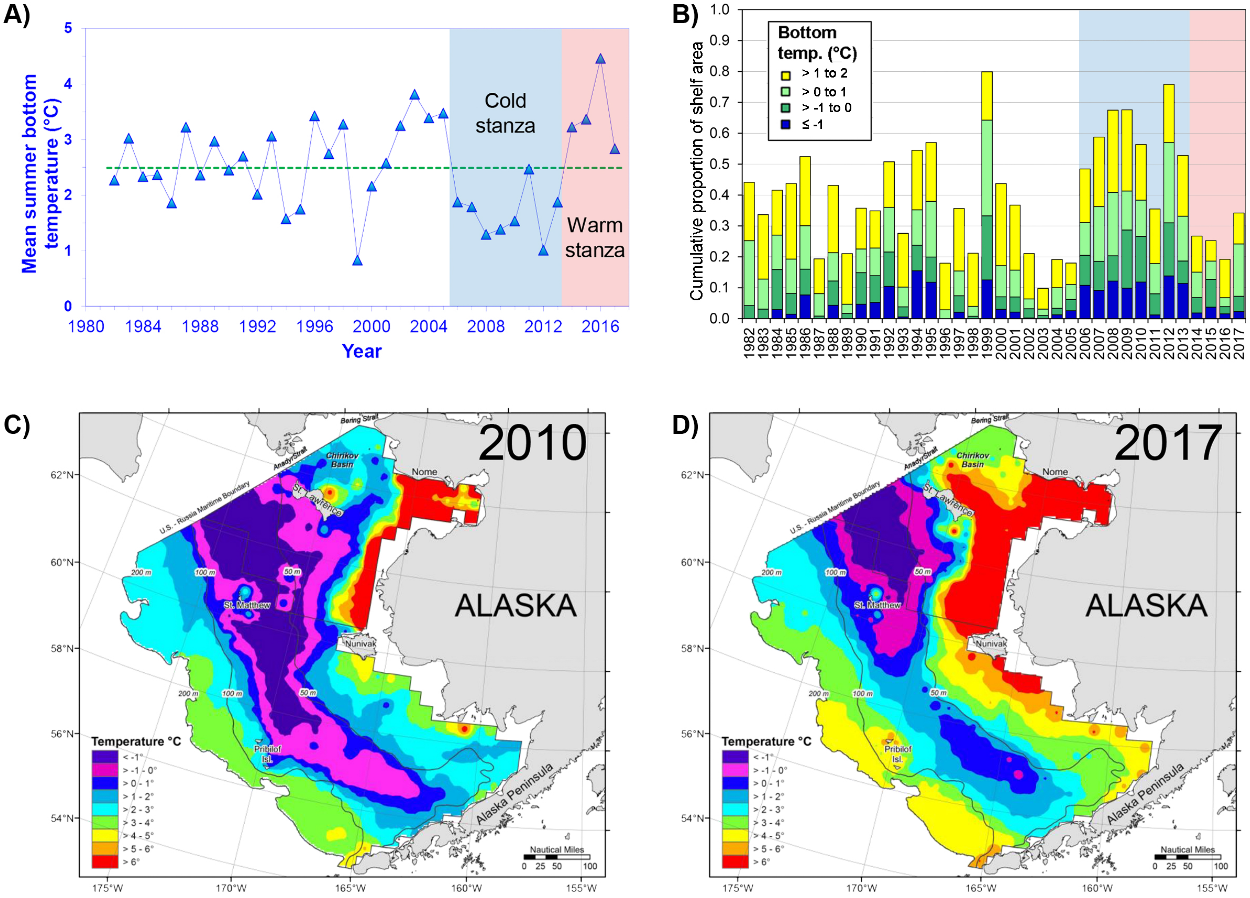


Figure 4: Mean summer bottom temperatures for the 36-year time series from the eastern Bering Sea shelf bottom trawl survey (A) and the cumulative proportion of EBS shelf area covered by each one-degree bottom isotherm range (B). Distribution of survey bottom temperatures for 2010 (C) and 2017 (D), the two years that the EBS survey was expanded to include the northern Bering Sea shelf.

The highly variable survey bottom temperatures are related to the variability of the summer cold pool (<2°C) which, when developed, can extend southward on the middle shelf from the northern edge of the survey box. The size of the cold pool each summer depends on sea ice coverage from the previous winter and the timing of its retreat during the spring and early summer. Over the period of the 36-year time series, the areal coverage of the summer survey cold pool has varied in size from 48,000 to 394,000 km^2, comprising 10% to 80% of EBS shelf area (Figure 4B).

The 2010 and 2017 NBS surveys provided a much broader view of the spatial pattern of bottom temperatures across the shelf and how they might affect distribution patterns or potential migration pathways available to fishes and crabs. The cold pool in 2010 was more extensive compared to 2017 and was composed of colder water that impinged on Chirikov Basin, Nunivak Island, and the Alaska Peninsula (Figures 4C and 4D), potentially restricting east-west and north-south movements of demersal fauna. The cold pool in 2017 extended to within 50 km of the Alaska Peninsula, but bottom temperatures along the entire length of the inner shelf from Bristol Bay up to Chirikov Basin were relatively warm (>3°C). Although east-west movement of demersal fauna over much of the shelf may have been limited by the 2017 cold pool, the inner shelf was certainly an open corridor for north-south movement, especially between Nunivak Island and Chirikov Basin where bottom temperatures exceeded 6°C. Regardless of the size of the cold pool or mean summer bottom temperatures, a portion of the cold pool persists year round in a transboundary basin extending from the Gulf of Anadyr on the middle shelf past the west side of St. Lawrence Island (Sigler et al., 2011). Given that some fish species appear to actively avoid areas of colder temperatures (Kotwicki and Lauth, 2013), the location of this year-round cold pool may hinder transboundary fish movement along the inner shelf through Anadyr Strait. Considering how water temperatures below freezing (<0°C) could slow down food digestion and body metabolism, such an environment would not be optimal during the summer when feeding and growth are vital. The outer shelf appears to be less of a hindrance because bottom temperatures are generally always warmer (>3°C) and the shelf is relatively broad where it crosses the transboundary towards Cape Navarin.

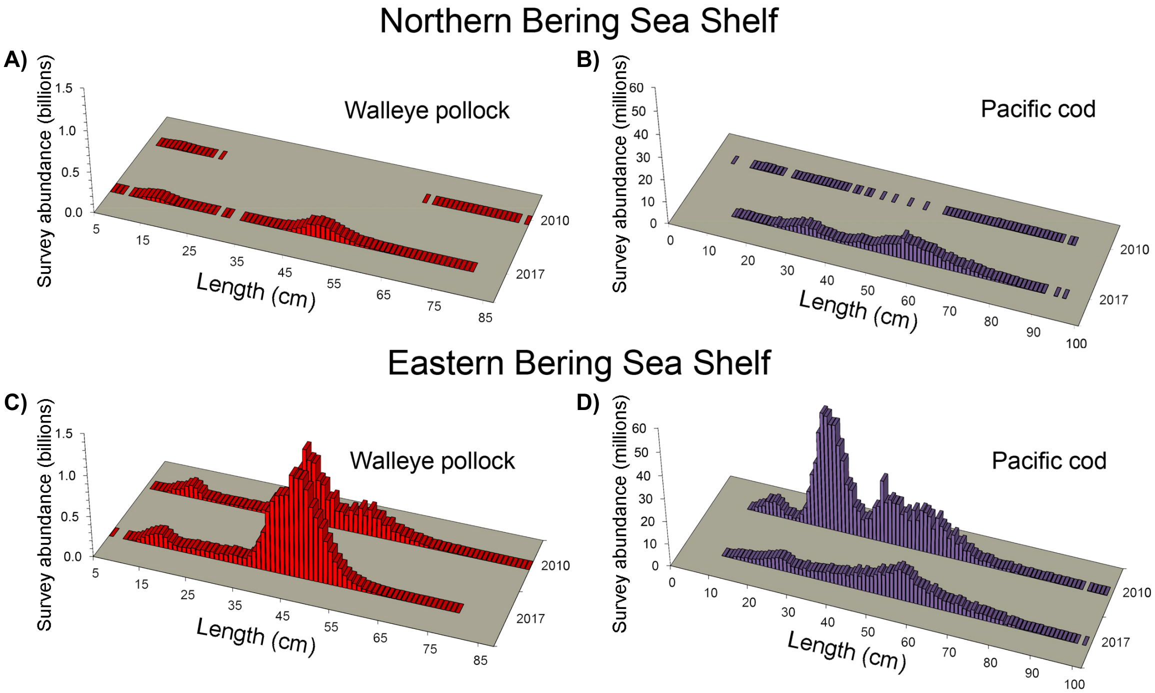


Figure 5: Survey abundance-at-length of Walleye pollock and Pacific cod comparing the size compositions between the northern Bering Sea shelf (A & B) and eastern Bering Sea shelf (C & D) during the 2010 and 2017 bottom trawl surveys.

Between 2010 and 2017, total survey biomass in the NBS shelf increased 59% from 2.9 to 4.6 million metric tons (mt). The percent change in biomass varied by fish and invertebrate taxon or taxonomic group (Table 2). There were increases in biomass for 27 taxa, decreases for 13 taxa, and no change for one taxon (Table 2). The two most dramatic increases were Walleye pollock (*Gadus chalcogrammus*) and Pacific cod (*G. macrocephalus*). The NBS survey biomass of pollock alone increased over six-thousand percent from 0.02 million mt in 2010 to 1.3 million mt in 2017, and for NBS Pacific cod, biomass increased by an order of magnitude from 28,425 mt to 286,310 mt. Plots of the NBS shelf abundance-at-length for pollock and Pacific cod from 2010 bore little resemblance to those from the 2010 EBS shelf. In 2010, there was generally low abundance of all sizes of pollock and Pacific cod in the NBS with a notable absence of intermediate sizes (Figure 5). Conversely, the 2017 NBS shelf abundance-at-length for pollock and Pacific cod was similar to that of the 2017 EBS shelf (Figure 5). In 2017 there was an abundance of one-year old pollock with a modal length of 15 cm in both areas, as well as a relatively high abundance of older pollock that were slightly larger in the NBS (mode 49 cm) than in the EBS (mode 44 cm). In 2017, Pacific cod had a much broader size range in the EBS compared to the NBS, but the two predominant size modes varied only slightly between regions. The first mode was larger in the NBS (32 cm) than the EBS (25 cm), and the second mode was only one cm greater in the NBS (45 cm) than the EBS (44 cm). The similar size distributions between areas for both species suggests they could be from the same populations.

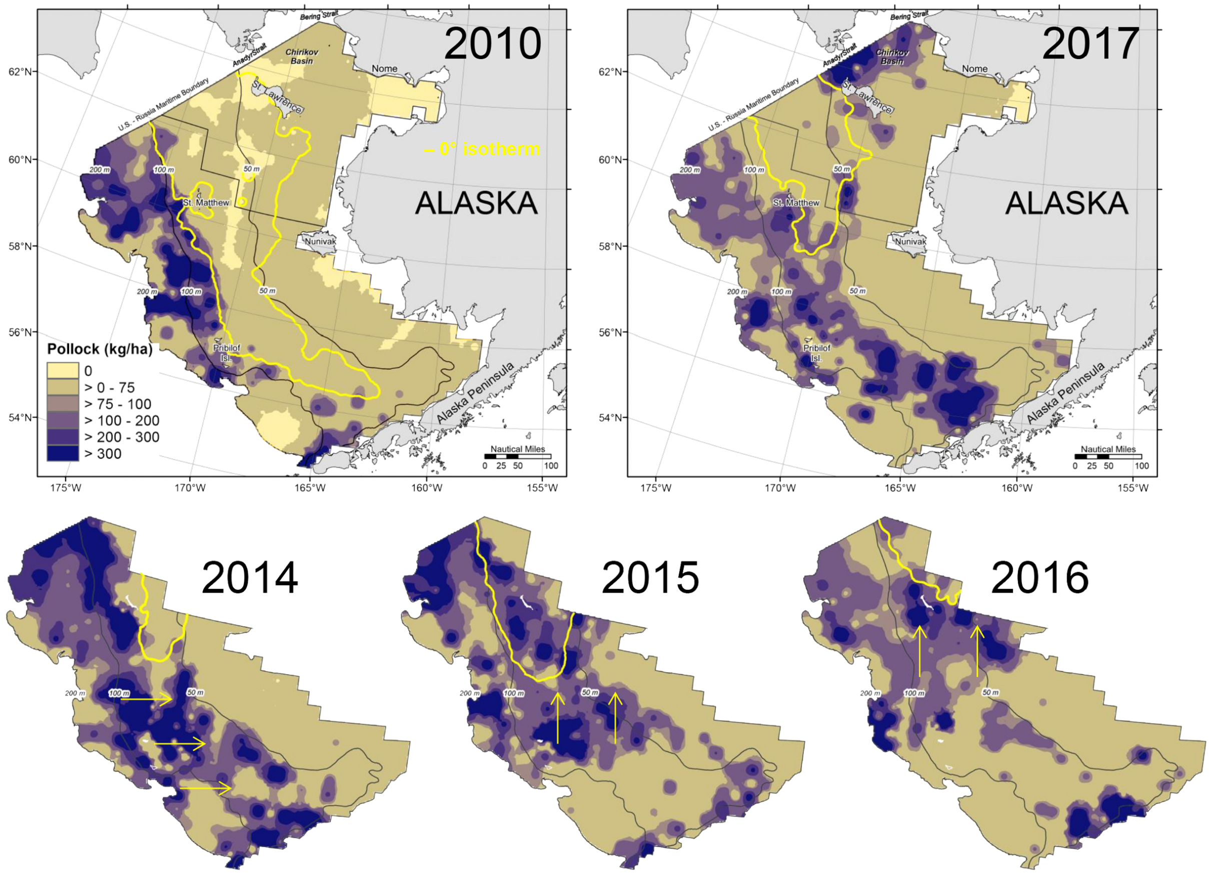


Figure 6: Distribution and abundance of Walleye pollock during the 2010 and 2017 eastern and northern Bering Sea shelf surveys (top) and during the warm stanza years 2014–2016 (bottom) relative to the 0°C bottom isotherm (yellow line). The yellow arrows in the bottom figures show the general eastern and northern movement of the eastern Bering Sea shelf population from 2014–2016.

Table 2: Biomass of fish and invertebrate taxa or taxonomic group in metric tons (mt) in 2010 and 2017. The percent change in biomass between survey years is shown.

		Biomass (mt)		
Common name	**Taxon**	**2010**	**2017**	**Change**
Walleye pollock	*Gadus chalcogrammus*	20,977	1,312,620	6,157%
Pacific cod	*Gadus macrocephalus*	28,425	286,310	907%
Jellfishes	Scyphozoa	13,112	66,166	405%
Poachers	Agonidae	422	2,040	384%
Green sea urchin	*Strongylocentrotus* sp.	49,263	164,277	233%
Blue king crab	*Paralithodes platypus*	1,940	5,795	199%
Shorthorn (=warty) sculpin	*Myoxocephalus scorpius*	38,172	108,753	185%
Bryozoans	Bryozoa	2,747	7,463	172%
Northern rock sole	*Lepidopsetta polyxystra*	21,379	56,093	162%
Other flatfishes	Pleuronectidae	3,549	8,715	146%
Pricklebacks	Stichaeidae	1,553	3,609	132%
Sea anenomes	Actinaria	9,381	21,330	127%
Clams	Bivalvia	2,531	5,374	112%
Starry flounder	*Platichthys stellatus*	15,319	31,103	103%
Other snails	Gastropoda	27,102	54,963	103%
Pacific herring	*Clupea pallasii*	22,289	35,365	59%
Bering flounder	*Hippoglossoides robustus*	12,661	20,022	58%
Neptune whelk	*Neptunea heros*	115,325	178,443	55%
Snailfishes	Liparidae	3,316	4,842	46%
Plain sculpin	*Myoxocephalus jaok*	28,338	36,819	30%
Hermit crabs	Paguridae	134,417	162,475	21%
Purple-orange sea star	*Asterias amurensis*	298,087	353,314	19%
All shrimps		3,777	4,462	18%
Alaska plaice	*Pleuronectes quadrituberculatus*	309,523	333,947	8%
Alaska skate	*Bathyraja parmifera*	78,972	84,267	7%
Segmented worms	Polychaetes	124	130	5%
Other sculpins	Cottidae	10,219	10,422	2%
Yellowfin sole	*Limanda aspera*	438,548	439,801	0%
Other sea stars	Asteridae	103,392	101,312	-2%
Red king crab	*Paralithodes camtschaticus*	2,453	2,254	-8%
Eel pouts	Zoarcidae	11,313	9,842	-13%
Saffron cod	*Eleginus gracilis*	91,593	76,455	-17%
Pacific halibut	*Hippoglossus stenolepis*	23,806	18,538	-22%
Snow crab	*Chionoecetes opilio*	324,549	227,948	-30%
Corals	Anthozoa	12,343	8,429	-32%
Brittle stars	Ophiuridae	69,653	40,697	-42%
Basket starfish	*Gorgonocephalus* sp.	68,662	39,878	-42%
Other crabs		60,972	33,575	-45%
Smelts	Osmeridae	16,745	5,273	-69%
Tunicates	Urochordata	358,440	101,083	-72%
Arctic cod	*Boreogadus saida*	37,981	3,963	-90%

In 2017, high densities of both pollock and Pacific cod were distributed in Chirikov Basin along the transboundary line and northeast of St. Lawrence Island (Figures 6 and 7) adjacent to the bottom 0°C isotherm. Also observed in the area during the survey were large aggregations of feeding seabirds and whales on the surface. There was probably plenty of prey in this area for both pollock and Pacific cod because Chirikov Basin is where the nutrient-rich Gulf of Anadyr water mixes with Bering Slope and Shelf currents resulting in high plankton productivity and benthic biomass (Highsmith and Coyle, 1990; Sigler et al., 2011). Small snow crab were in high abundance in the vicinity of St. Lawrence Island, especially inside the cold pool (Figure 8A), and survey scientists also noted that many Pacific cod stomachs in the area were full of snow crab.

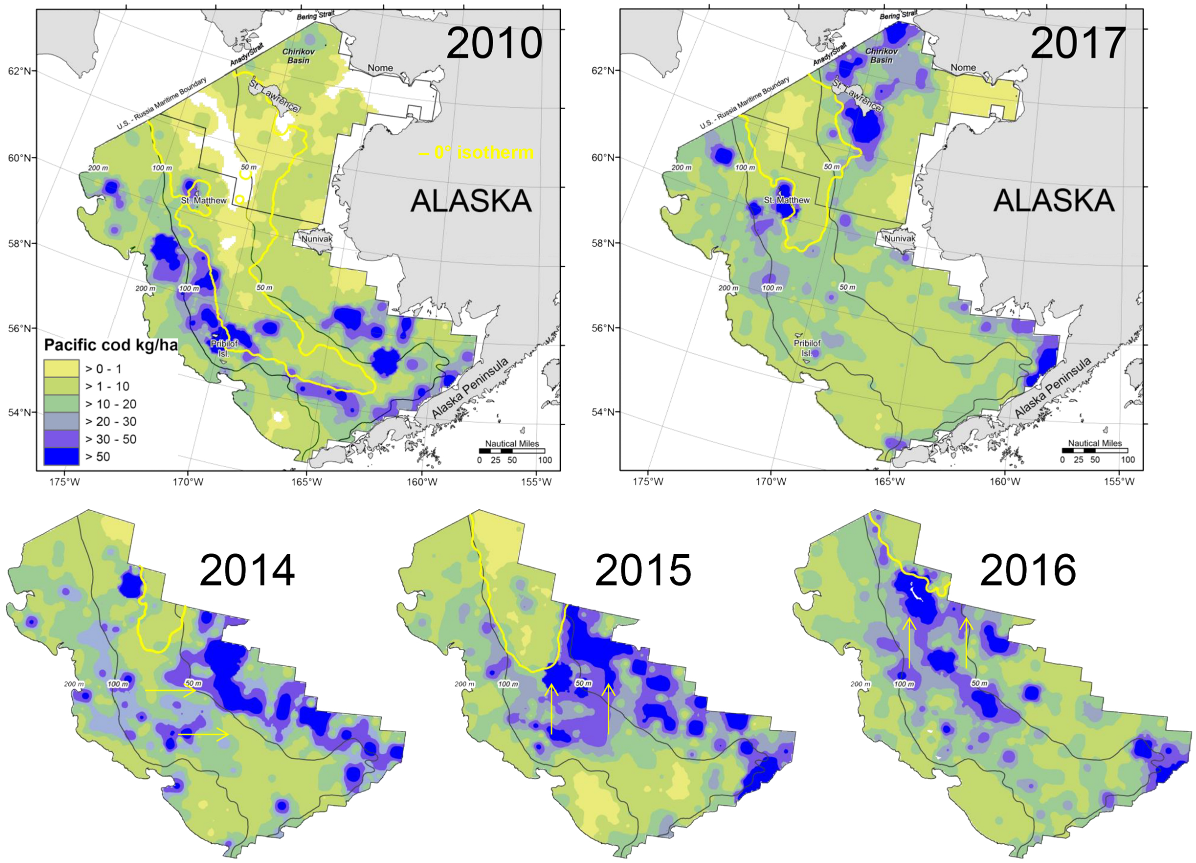


Figure 7: Distribution and abundance of Pacific cod during the 2010 and 2017 eastern and northern Bering Sea shelf surveys (top) and during the warm stanza years 2014–2016 (bottom) relative to the 0°C bottom isotherm (yellow line). The yellow arrows in the bottom figures show the general eastern and northern movement of the eastern Bering Sea shelf population from 2014–2016.

The distribution, abundance, and size composition of other fish and invertebrate taxa also changed. The NBS Arctic cod (*Boreogadus saida*) biomass decreased 90% from 37,981 mt in 2010 to 3,963 mt in 2017. High catch rates of Arctic cod in 2017 were confined to the heart of the cold pool near the transboundary line (Figure 9) versus 2010 when high densities were found in Norton Sound, south of St. Lawrence Island, and along the transboundary line south of latitude 63.5°N (Figure 9A). NBS Saffron cod (*Eleginus gracilis*) biomass dropped 17% from 91,593 mt to 76,455 mt with a similar distribution for both survey years (Figure 9B). Sizes of Arctic cod in 2010 had a broader range and a much higher abundance of juveniles (<15 cm) compared to 2017 (Figure 9C, left). Larger sizes of Saffron cod were more prevalent in 2010, and there was a higher abundance of juveniles in the latter survey year (Figure 9C, right). More seasonal ice and cooler temperatures during the cold stanza leading up to 2010 may have been more favorable to the introduction and survival of juveniles for the cryophilic Arctic cod, and less shore-fast ice during the warm stanza leading up to 2017 may have been more favorable to the demersal, eulittoral-sublittoral Saffron cod.

Changes in survey abundance and distribution were also observed for NBS shelf crab populations. The NBS survey abundance of snow crab (*Chionoecetes opilio*) increased 6% from 811 to 864 million, and red king crab (*Paralithodes camtschatica*) increased 25% from 2.1 to 2.8 million, however, survey biomass for both crabs decreased because of lower mean sizes in both populations (Figure 10A and 10B). The highest catch rates of NBS snow crab in 2010 were along the transboundary line (Figure 8A), and in 2017, the distribution shifted farther south where the highest densities in the NBS were along the 50 m isobath and at the southwest corner of St. Lawrence Island (Figure 8A) in the same location where NBS Pacific cod were in high abundance (see Figure 7). NBS red king crab distribution was similar for both years (Figure 8B). In 2017, NBS blue king crab (*P. platypus*) increased in survey abundance (69%) from 1.8 to 5.9 million and biomass increased from 1,904 mt to 5,795 mt with the largest concentrations in the NBS for both years between St. Lawrence Island and the transboundary line (Figure 8C). Similar to the other two crab taxa, there was a decrease in the mean size of blue king crab (Figure 10C).

Species showing little change in NBS biomass or distribution between the two survey years included Yellowfin sole (*Limanda aspera*), with a biomass of 0.44 million mt (0% change), and Alaska plaice (*Pleuronectes quadrituberculatus*), with a biomass of 0.33 million mt (8% increase). Yellowfin sole and Alaska plaice distributions in the NBS were generally restricted to the inner shelf during both survey years (Figure 11A and 11B); however their distributions in the EBS shifted more towards the middle shelf in 2017 (Figure 11A and 11B). Variable distributions of Yellowfin sole in the EBS might be due to temperature effects on the annual spring and summer spawning migration to nearshore waters (Nichol, 1998), and Alaska plaice is a cold tolerant species having an antifreeze glycoprotein so it may have been avoiding the warm temperatures along the lower inner shelf. The size compositions of NBS Yellowfin sole were similar for both years (Figure 11A, bottom) and NBS Alaska plaice were slightly larger in 2017 (Figure 11B, bottom).

There are a host of research questions arising from the comparison of results from the 2010 and 2017 NBS surveys, especially for understanding the effects that such large scale changes in distribution and abundance have on reorganizing the community structure of the ecosystem and on the subsistence harvest of Alaska coastal communities in the NBS. We also need to know more about the population structure and distribution patterns for taxa straddling the survey box boundary, and how biological and environmental processes affect along-shelf, cross-shelf, and transboundary movements. We also question how climate and variability in the interannual cold pool may be driving these large scale changes. The 2017 NBS survey was only the second data point in a formative time series, and with only two data points from the NBS shelf, we are only getting initial glimpses of multiple alternative possibilities yet to come. We will require more snapshots of the NBS and more focused research to understand the dynamic processes at work in the Bering Sea in their entirety.

Contributed by Bob Lauth and Lyle Britt

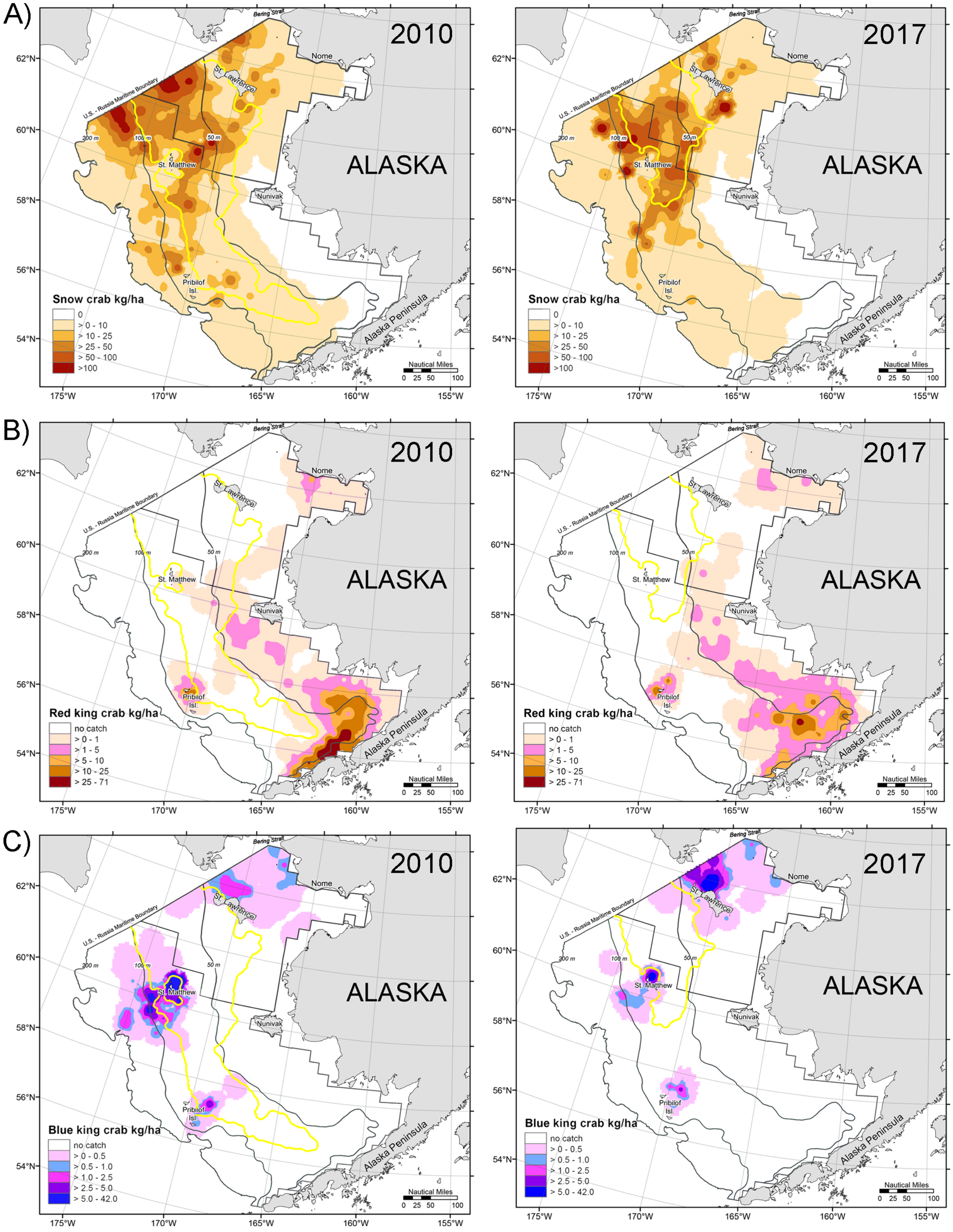


Figure 8: Distribution and abundance of snow crab (A), red king crab (B), and blue king crab (C) during the 2010 (left) and 2017 (right) eastern and northern Bering Sea shelf surveys relative to the 0°C bottom isotherm (yellow line).

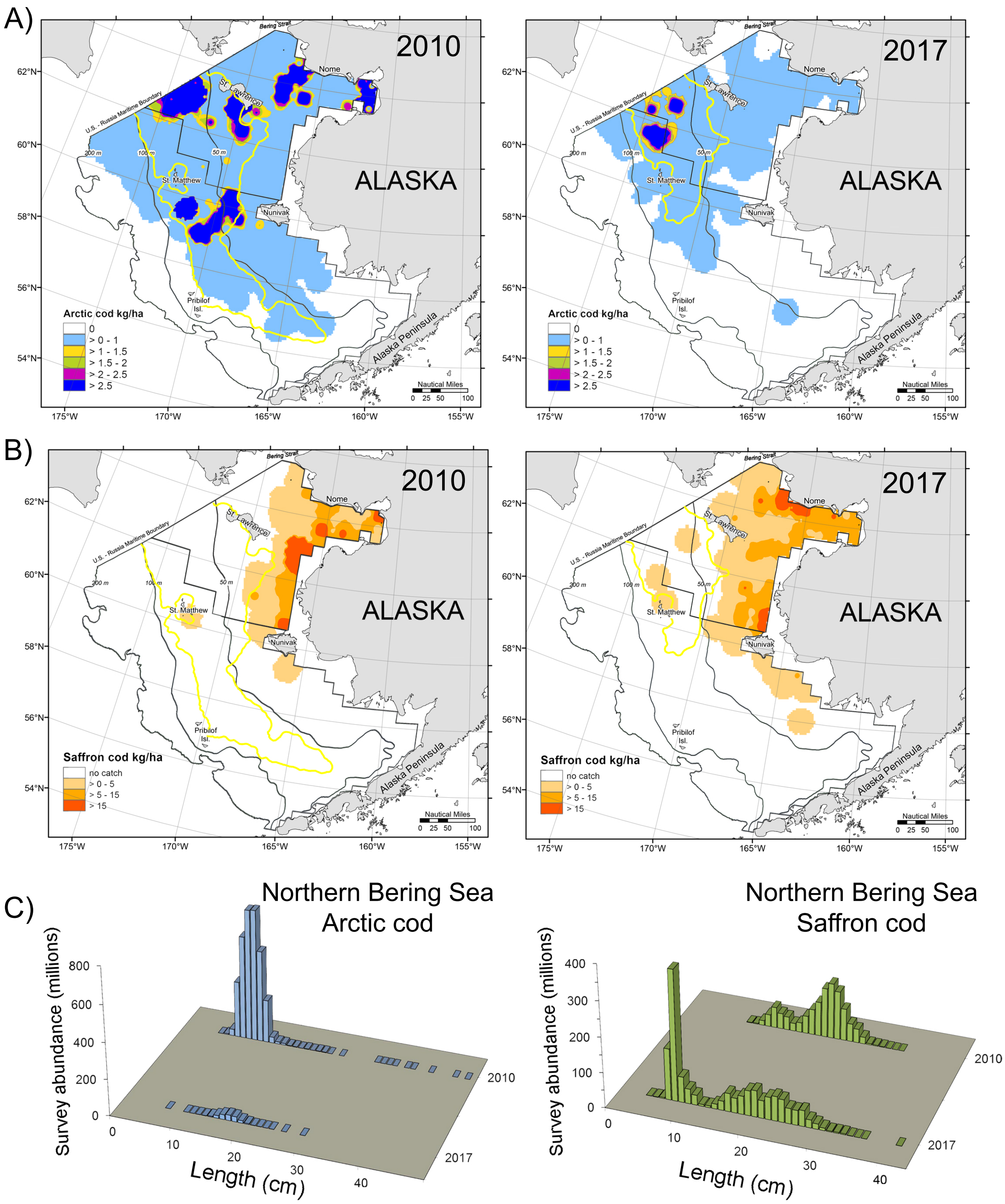


Figure 9: Distribution and abundance of Arctic cod (A) and Saffron cod (B) from the 2010 (left) and 2017 (right) eastern and northern Bering Sea shelf surveys relative to the 0°C bottom isotherm (yellow line). At bottom are the survey abundance-at-length for Arctic and Saffron cods (C) from the northern Bering Sea shelf in 2010 and 2017.

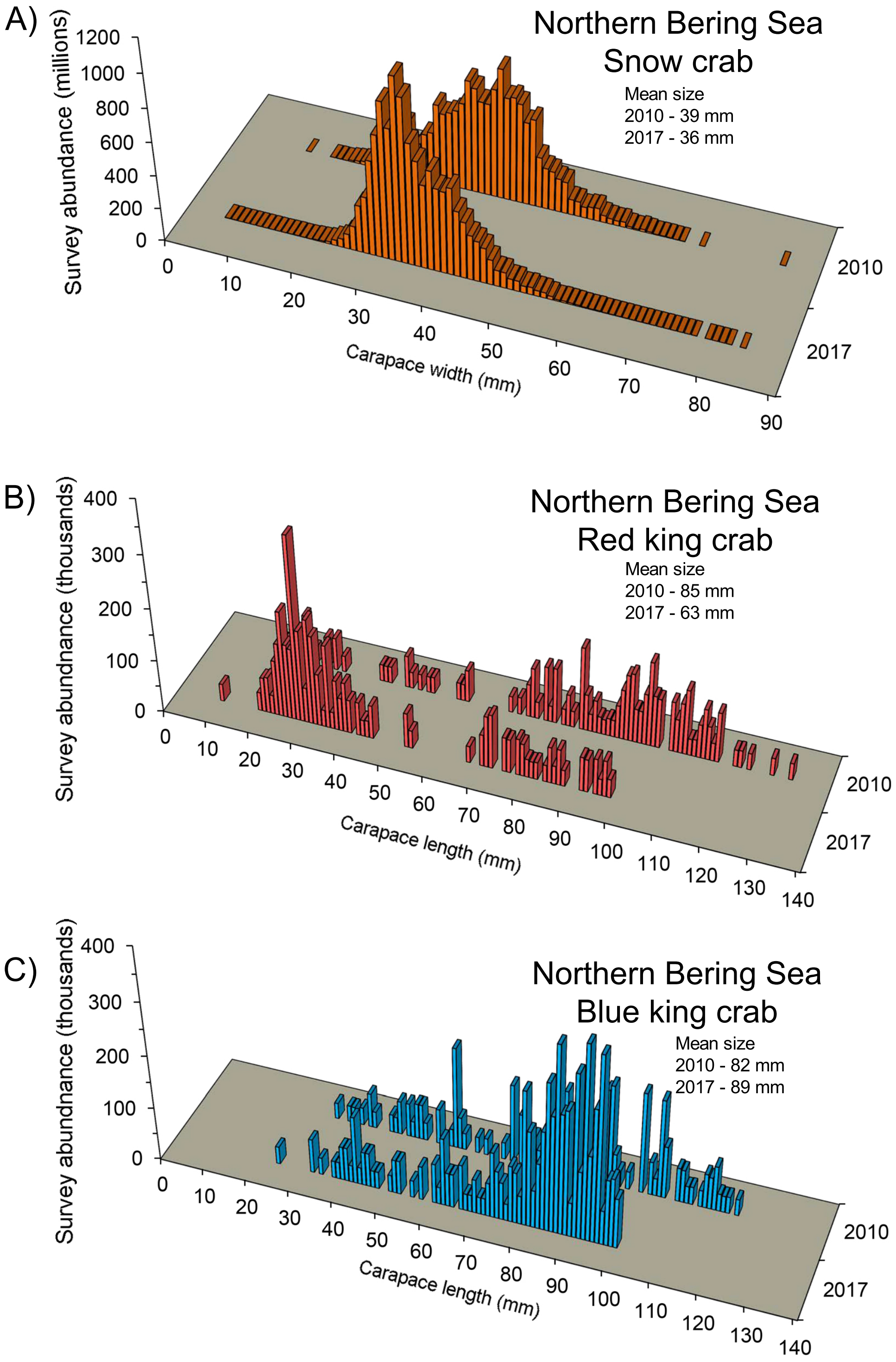


Figure 10: Survey abundance-at-size for snow crab (A), red king crab (B), and blue king crab (C) from the 2010 and 2017 northern Bering Sea shelf bottom trawl surveys.

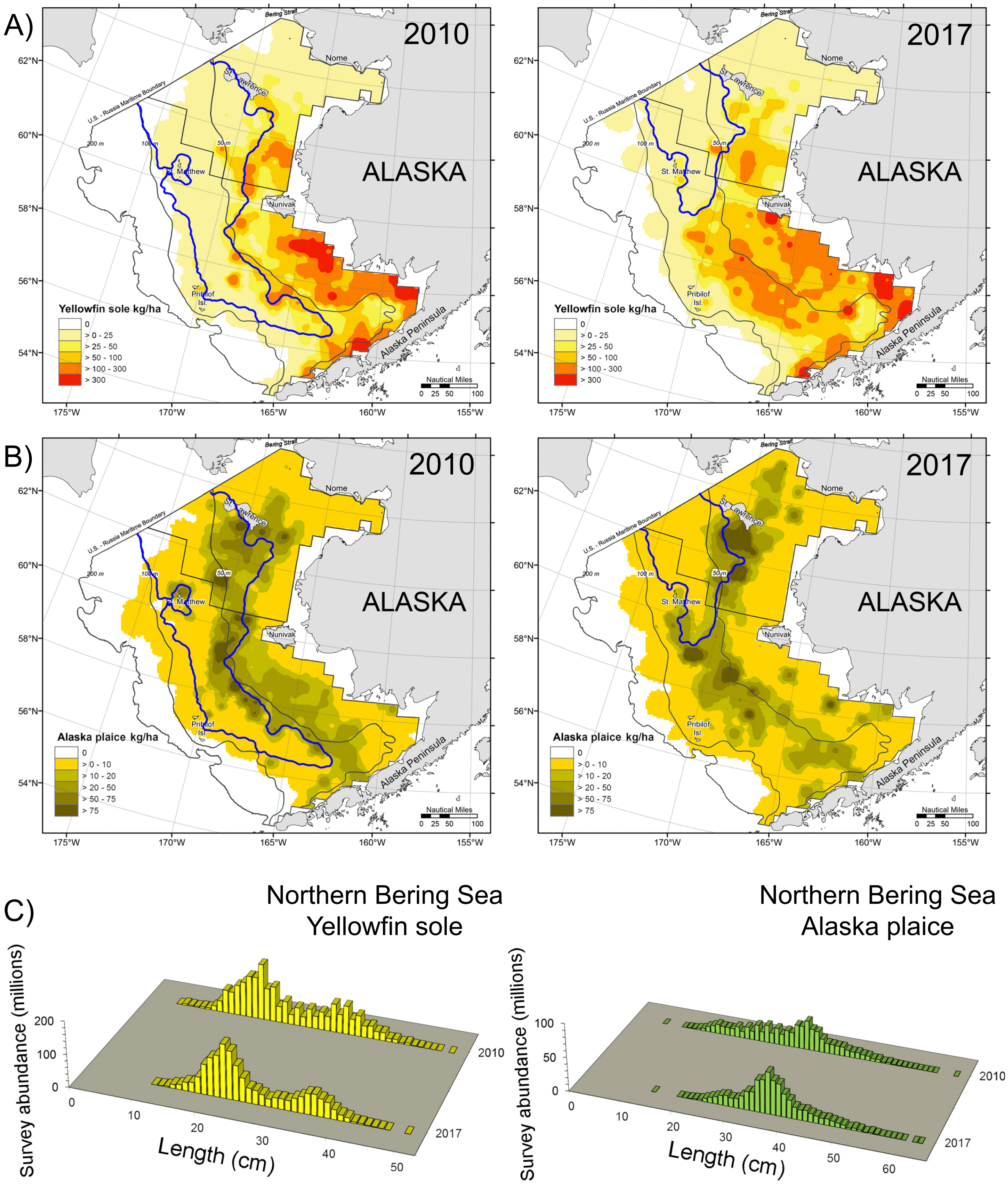
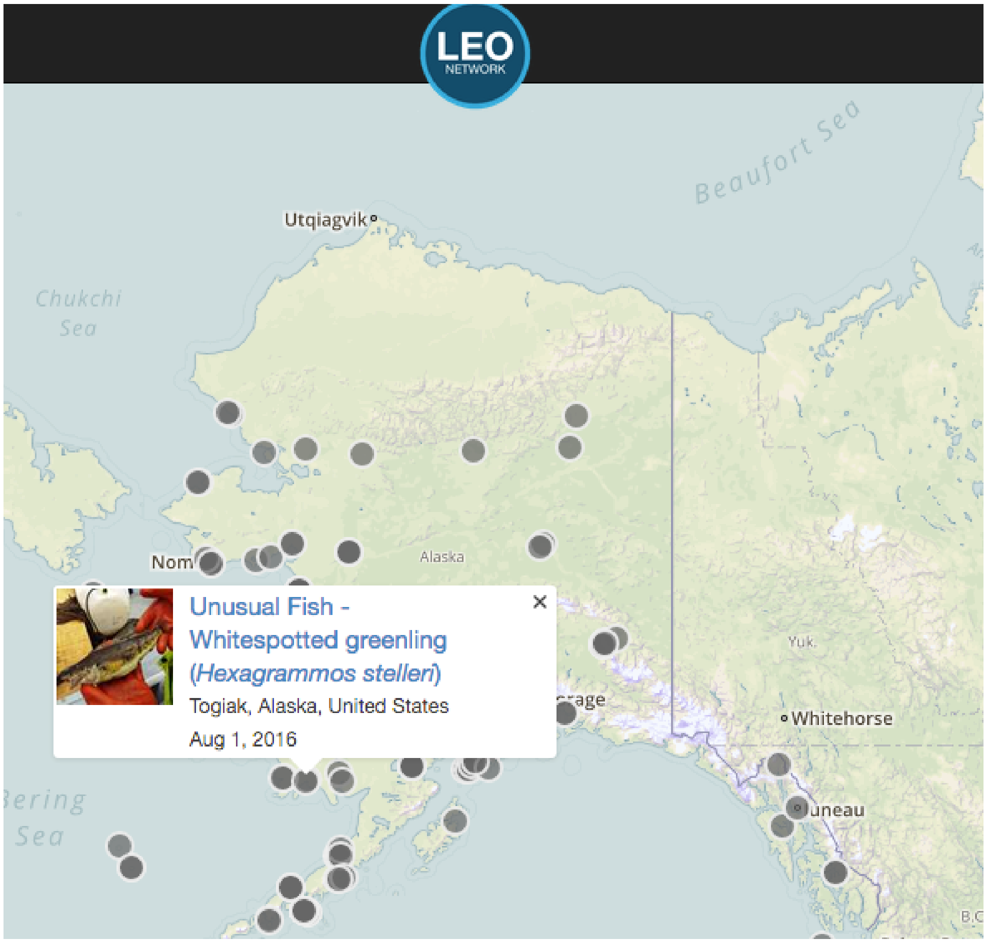


Figure 11: Distribution and abundance of Yellowfin sole (A) and Alaska plaice (B) from the 2010 (left) and 2017 (right) eastern and northern Bering Sea shelf surveys relative to the 0°C bottom isotherm (blue line). At bottom are the survey abundance-at-length for Yellowfin sole and Alaska plaice from the northern Bering Sea shelf in 2010 and 2017.

Local Environmental Observer (LEO) Network

The NMFS AFSC is interested in documenting and learning from citizen science observations that may be incorporated into future Ecosystem Status Reports (ESRs). We have identified the LEO Network as a potential platform for tracking these observations. We are seeking Council input on the utilization of this network to gather citizen science observations on marine environment changes for future ESRs. Other citizen science efforts exist in Alaska, but to our knowledge these efforts are mostly project-specific (e.g., bird spotting and identification) or community-specific.

The LEO Network was launched in 2012 by the Alaska Native Tribal Health Consortium (ANTHC) as a tool for local observers in the Arctic to share information about climate and other drivers of environmental change (see: `https://www.leonetwork.org/en/docs/about/about`). Anyone may join the network and provide observations, and the network now spans the globe. Consultants with relevant expertise often, but not always, review the observations and provide feedback. The observations are of unusual environmental events or notable environmental changes, reported by geographic location and date, and classified by relevant category (or multiple relevant categories) such as Weather, Land, Fish, Sea Mammals, and Ocean/Sea (Figure 12).



Unusual Fish - Whitespotted greenling (*Hexagrammos stelleri*)

Togiak, Alaska, United States

Aug 1, 2016

Figure 12: LEO Network observations in Alaska for 2016 with an example observation and description. Source: `https://www.leonetwork.org`.

A preliminary analysis of 2016 LEO Network observations in the eastern Bering Sea indicates the following frequency of observations by category (Figure 13). These categories are based on initial analysis of the 17 total observations in 2016 and are not limited to the marine environment. This figure is being included as an example of the types of observations that are made; future utilization of LEO Network observations for ESRs would be highly refined. The observations in Figure 13 were made in 12 total communities.

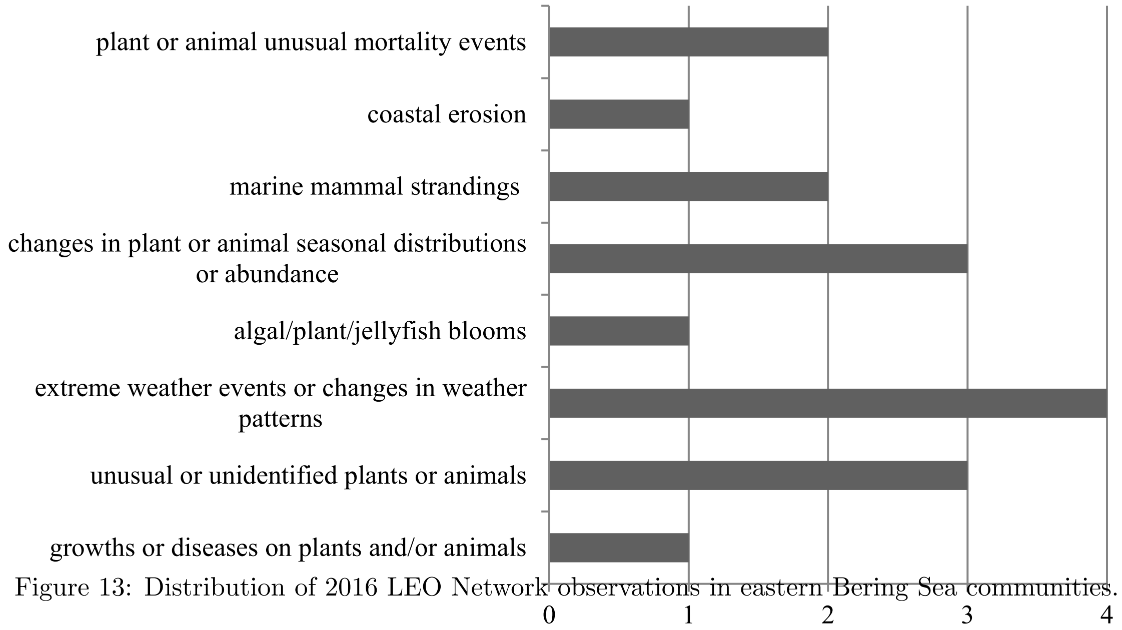


Figure 13: Distribution of 2016 LEO Network observations in eastern Bering Sea communities.

With the permission of the ANTHC, future reports could utilize qualitative content analysis techniques to systematically categorize observations by ecosystem. These categories would be mutually exclusive and exhaustive and would pertain to the marine environment. An alternative to this approach would be the development of LEO Network "projects" specific to Alaska's Large Marine Ecosystems under which LEO Network participants could categorize their observations and NMFS staff could track relevant observations. Alaska state agencies, non-profit organizations, universities, and U.S. federal agencies have developed projects on the network to track observations specific to their area of interest (e.g., weather events, fish pathology, subsistence harvests). Similarly, the National Weather Service (NWS) has developed an extreme weather-tracking program called "Storm Spotters" for citizens to report severe weather, and such events identified on the LEO Network are forwarded to the NWS Program.

ent analysis

Utilization of the LEO Network for citizen science input on observed environmental changes may provide an important avenue for NMFS to engage with communities that are not usually represented in the fisheries management process If the LEO Network is identified as an appropriate venue for citizen science observations for future ESRs, NMFS researchers will work with the ANTHC to reach out to communities and popularize the utilization of this network for ESR-specific information.

Contributed by Marysia Szymkowiak

Dead and Dying Seabirds: Seward Peninsula to Pribilof Islands

In 2017, dead and dying seabirds were reported from Shishmaref south to the Pribilof Islands (Figure 14). First responders in coastal communities, with the U.S. Fish and Wildlife Service (USFWS), Aleut Community of St. Paul Island Ecosystem Conservation Office (ACSPI ECO), Kawerak, Inc., Alaska Sea Grant program in Nome, and others have counted over 1,250 beached seabird carcasses since early August 2017. The main species found have been northern fulmars and short-tailed shearwaters, but a variety of species including murres, kittiwakes, puffins, and auklets have also been reported. USFWS and University of Washington (UW) biologists at sea also reported observations of ~70 dead birds in the northern Bering and eastern Chukchi Seas during surveys from June through early September (Figure 15). In previous years of at-sea seabird surveys only a few dead birds have been observed in this region. The USFWS is coordinating with the Coastal Observation and Seabird Survey Team (COASST) to monitor selected beaches near communities. ACSPI ECO and Alaska Sea Grant have collected carcasses for examination by the U.S. Geological Survey National Wildlife Health Center (NWHC). Necropsies on 20 carcasses from Shishmaref, Gambell, and St. Paul Island indicate drowning and severe emaciation (empty stomachs and intestinal tracts, little body fat). To date there is no microscopic or laboratory culture evidence of infectious disease. While examined birds ultimately died of starvation, underlying factors (disease,

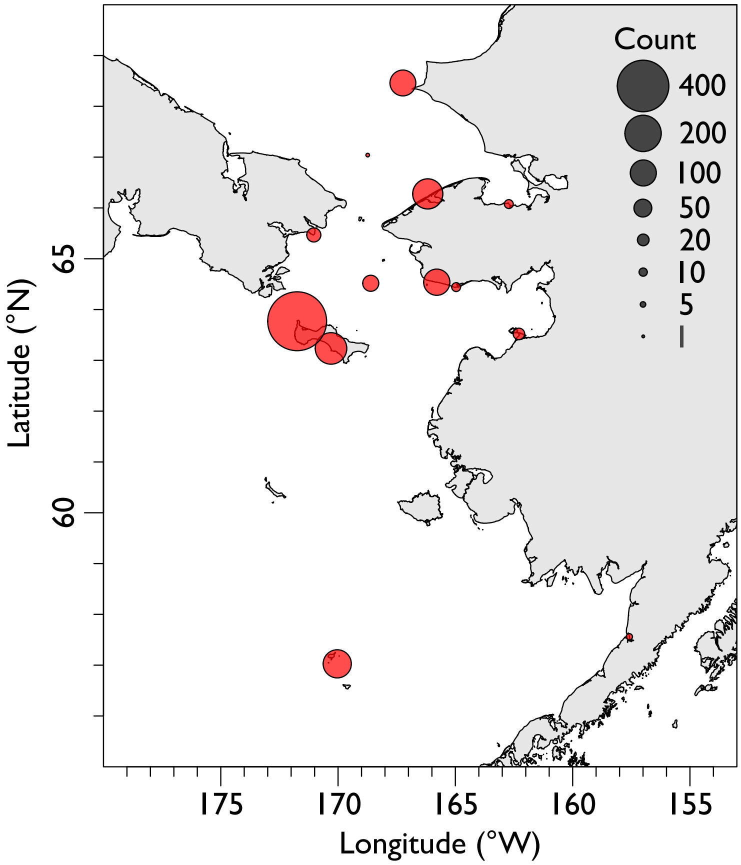


Figure 14: Dead birds counted on shore in 2017.

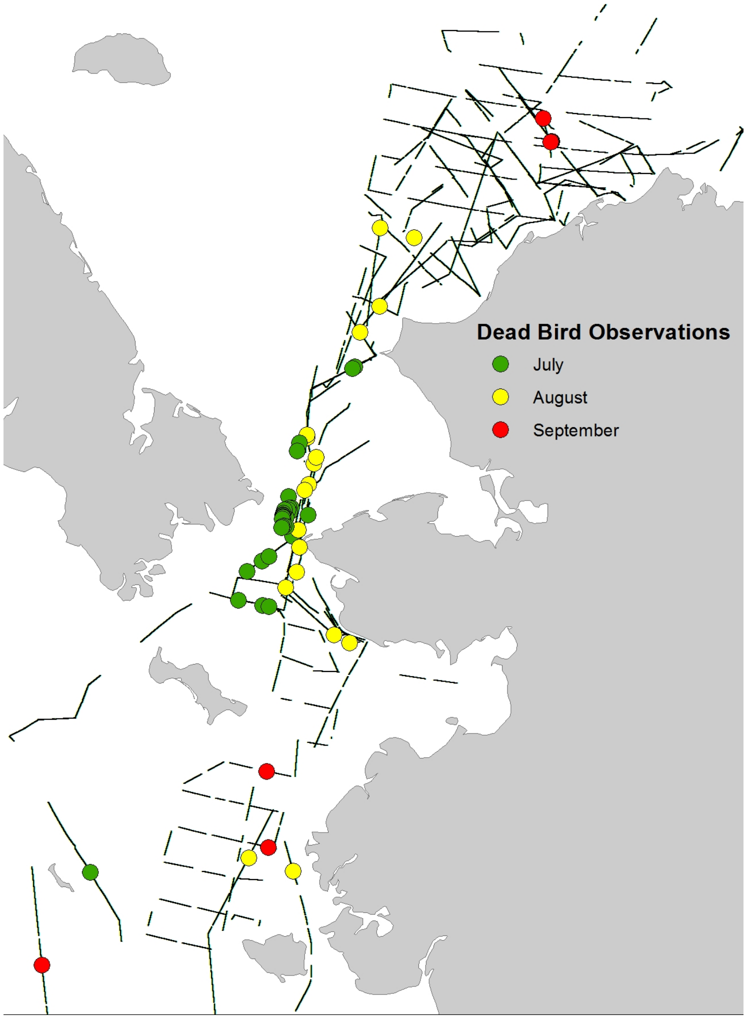


Figure 15: Dead birds counted at sea in 2017.

toxins, lack of food) have yet to be identified. Testing of carcass tissues is ongoing and results will be shared as soon as available.

A 1-page information sheet on this recent die off is available at: `https://www.fws.gov/alaska/pdf/BeringSea_DieOff_Info_September2017Update.pdf`.

Contributed by Kathy Kuletz, Liz Labunski, Robb Kaler, Julia Parish, Timothy Jones, Hillary Burgess, and Kate Stafford

Recap of the 2016 ecosystem state

Some ecosystem indicators are updated to the current year (2017), while others can only be updated to the previous year (or earlier) due to the nature of the data collected, sample processing, or modeling efforts. Therefore, some of the "new" updates in each Ecosystem Considerations Report reflect information from the previous year. Below is a complete summary of 2016 that includes information from both previous and current indicators. The next section (Current Conditions: 2017) provides a summary of the 2017 ecosystem state based on indicators updated this year.

In 2016, the eastern Bering Sea experienced record warm conditions that continued the 3rd year of above-average temperatures (see Figure 27). Warmer winds from the south contributed to the 2014 and 2016 warm summer conditions. However, in 2015, the marine heat wave (termed the "warm blob") in the Gulf of Alaska (Bond et al., 2015) may have prevented the advance of sea ice that would have been expected based on predominantly northwesterly winds (Duffy-Anderson et al., 2017). Thus, overall warm conditions occurred in 2015 although the physical processes supporting the warm conditions differed from those in 2014 and 2016. As expected, predominantly small, lipid-poor zooplankton were observed during these three warm years, however the retracted cold pool areas continued to harbor larger zooplankton (Duffy-Anderson et al., 2017).

The Pacific Decadal Oscillation (PDO) remained positive, and the state of the North Pacific atmosphere-ocean system continued to be warm. Spring 2016 had the lowest sea ice cover over the Bering Sea shelf in the time series and the cold pool was reduced (cold "puddle") and retracted over the northern shelf. Both surface and bottom temperatures over the shelf were the highest on record in the 35-year bottom trawl survey time series; 2016 saw sea surface temperatures reaching 14°C with a >3°C positive anomaly over the entire shelf.

In 2016, the zooplankton composition reflected taxa that typify warm thermal stanzas. In spring, large copepods occurred near the outer shelf and at some inner domain stations, but were spatially mismatched from larval Walleye pollock (*Gadus chalcogrammus*). By fall, small copepods comprised 99% of the community. In addition, the overall volume of zooplankton samples was qualitatively low, suggesting both poor quality and quantity prey available for foragers such as age-0 pollock. Low abundances of large copepods are less critical in the spring, but very important later in the year (Hunt et al., 2011) for age-0 pollock to provision for overwinter survival (Heintz et al., 2013).

The abundance of *Chrysaora melanaster* jellyfish continued to decline in 2016 with a 79% decrease from 2015 to one of the lowest observed values since 1989. The abundance of jellyfish (principally *Chrysaora*) from the EBS bottom trawl survey showed two gradual increases followed by more abrupt declines over the time series. Concurrent with the recent decline of *Chrysaora*, the abundance of smaller-sized jellyfish (*Aequorea*, *Aurelia*, and *Cyanea*) increased in 2016 during the BASIS survey. Starting in 2014 (the first warm year in the current warm stanza) and continuing through 2016, notable increases in abundance were observed for all taxa except *Chrysaora*. In 2016, the abundance of *Aurelia* exceeded that of *Chrysaora* during the BASIS survey.

The 2016 springtime drift patterns on the southern shelf were consistent with years of below-average recruitment for winter-spawning flatfish (Northern rock sole, *Lepidopsetta polyxystra*; Arrowtooth flounder, *Atheresthes stomias*; Flathead sole, *Hippoglossoides elassodon*) following a year with drift patterns consistent with above-average recruitment (2015). The abundance of adult-stage benthic foragers sampled on the EBS bottom trawl survey changed trend from declining in 2015 (due to a 25% in Northern rock sole) to neutral in 2016 (due to 50% increase in Yellowfin sole, *Limanda* *aspera*). Groundfish condition, inferred from length-weight residuals, increased for all groundfish species (except Arrowtooth flounder) in 2016 indicating greater weight at length than average. Of particular note is the anomalously positive length-weight residual for Pacific cod (*Gadus macrocephalus*), which has shown a generally declining or negative trend since the peak value in 2003. These positive length-weight residuals suggest good foraging conditions in 2016.

Pelagic forager biomass, which is mainly driven by fluctuations in pollock, changed from a recent 5-year increasing trend in 2015 to neutral in 2016. This likely reflects the growth of the strong 2012 year class and subsequent years with intermediate year-class strength. Conversely, the recent trend in apex predator biomass changed from neutral in 2015 to increasing in 2016, due to increases in Pacific cod. Estimated age-1 natural mortality (based on the CEATTLE model) for pollock, Pacific cod, and Arrowtooth flounder was high in 2016 (highest in the time series since 1979). The record warm summer temperatures in 2016 may have caused increased metabolic rates for apex fish predators. Given that the zooplankton prey were of lower quality, such increases in metabolic demand may have resulted in increased predation pressure and a notable impact on age-1 natural mortality.

The biomass of motile epifauna remained above the long-term mean in 2016, and brittle stars continued to increase, showing a 34% increase from 2015 to 2016. The success of brittle stars may be due, in part, to long-term declines in the biomass of commercial crab stocks, which are major predators of brittle stars. Additionally, habitat impacts due to fishing gear interactions have decreased from a high of 3.5% between 2003–2008 to the present level of about 2.3% in 2016, presumably improving habitat for stationary taxa. While coral had its highest abundance in 2016 and sea whip abundance was stable on the shelf, sea whip abundance decreased on the slope and sponges and sea anemones declined on the shelf. The overall decrease in stationary taxa abundance, despite reduced habitat disturbance, may indicate stronger influence of poor environmental conditions (e.g., warm water) and/or increased predation pressures (note increased motile epifauna [i.e., brittle stars] and above-average apex predator biomass in 2016).

The total estimated number of Northern fur seal (*Callorhinus ursinus*) pups born on St. Paul Island in 2016 was 12.1% less than in 2014, which was 5.3% less than in 2012. On St. George Island there was an 8.2% increase between 2014 and 2016, following a 17.0% increase between 2012 and 2014. This disparity suggests fur seals may be experiencing more favorable conditions near St George, assuming overlap between the two rookeries in their non-breeding season distribution. The seabird breeding index continued to decline in 2016, reflecting poor productivity and later hatch dates for cliff-nesting piscivorous seabirds. Additionally, the number of seabirds estimated to be caught incidentally in eastern Bering Sea fisheries in 2016 increased from 2015, and exceeded the 2007–2015 average by 78%. In fact, 2016 experienced the second highest number of birds estimated to be caught incidentally in the time series, 2007–2016. Increased interactions with fishing vessels suggests that “natural” prey for species that forage at both fishing vessels for offal and at sea may have been limiting. Visual predators, such as seabirds, were also likely negatively impacted by the extensive coccolithophore bloom over the southern EBS shelf in 2016.

In 2016, many ecosystem indicators showed a decrease in productivity, consistent with hypothesized ecosystem-level responses to continued above-average thermal conditions. This was particularly evident in the Rapid Zooplankton Assessment, acoustic euphausiid estimates, jellyfish abundance, and seabird indices. Exceptions include motile epifauna (e.g., brittle stars) and apex predator biomass (e.g., Arrowtooth flounder). Additionally, in the third consecutive warm year, increased diversity of fish and invertebrates combined with significant northward shifts in species’ distributions may indicate new niche availability in the ecosystem.

The eastern Bering Sea has experienced shifts between multi-year stanzas of warm and cold conditions (i.e., typified by small or large cold pools, respectively). Ecosystem-level responses, in terms of productivity, may be influenced by bottom-up and top-down drivers differentially. The ecosystem response to the recent warm stanza (2014–2016) differed from the previous (2002–2005) warm stanza, potentially due to the marine heat wave centered in the Gulf of Alaska and warm water advected through Unimak Pass onto the southern Bering Sea shelf (i.e., increased rate of change). The ecosystem responded differently to the return of warm conditions over the shelf, including the timing of sea-ice retreat and of the spring phytoplankton bloom (Stabeno et al., 2017). Previous warm conditions (2002–2005) resulted in a trophic cascade including lipid-poor zooplankton communities, low age-0 pollock energy densities, and poor overwinter survival and recruitment of pollock. A 40% reduction in the pollock population was observed. During this recent warm stanza, however, pollock appear to have buffered against such declines. Possible mechanisms include utilizing high productivity waters associated with the strong, northerly cold pool as a refuge, or by exploiting alternative prey over the southern shelf (Duffy-Anderson et al., 2017). Research into cold pool dynamics (e.g., thermal gradients) and spatially-explicit bioenergetic modeling will help resolve whether these mechanisms were available, but not exploited, during the previous warm stanza.

New human dimensions indicators added in the 2017 Report provide information on the 2016 status of human economic and social well-being aspects. Landings reflect commercial economic production in the region; salmon landings have been stable, while crab landings decreased from 2015–2016. The resultant value of these fisheries has been increasing for salmon (due stable landings and strong prices) and crab. The population in eastern Bering Sea communities increased 8.7% between 1990–2016, with a slight decrease from 2015–2016. School enrollment has generally decreased and small rural communities have experienced school closures. Meanwhile, unemployment is second lowest (central Aleutian Islands is lowest) across the state. Taken as a whole, these indicators suggest stability in these aspects of human dimensions within the eastern Bering Sea. Future refinement of, and research into, this suite of indicators may inform more subtle yet important trends.

Current Conditions: 2017

In 2017, sea ice extended over the shelf and created an extensive, although narrow, cold pool over the middle domain (see p. 71). Interestingly, sea level pressure patterns set up persistent winds from the south that prevented sea ice formation in the Gulf of Anadyr creating an unusual retraction of ice extent over the northwestern shelf. As a result, the northwestern Bering Sea responded more similarly to a "warm year", whereas ice coverage over the southern middle domain lead to more moderate conditions in the southeast. Over the southeastern shelf, latent heat from the previous warm stanza (2014–2016) was off-set by the narrow, but extensive cold pool that resulted in average water column temperatures at mooring M2 at the southern end of the eastern Bering Sea shelf.

Indications of a "warm year" response in the north include observations of crab as well as adult pollock and Pacific cod in the northern Bering Sea (see p. 37). While these populations might typically move south during winter, the environmental cues (i.e., sea ice, cold pool) did not occur during winter 2016–2017. Zooplankton distributions reflect increased productivity in the north with significantly higher small and large copepod abundances near St. Matthews Island. Over the southeastern shelf, surface and bottom temperatures were moderately warm. The 2017 estimate of small and large copepod abundances were below that of 2016, while euphausiid abundances were comparable.

Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) abundance in the northern Bering Sea was below the long-term average; this has important implications for abundance-based bycatch caps for Chinook in the pollock fishery because low juvenile abundance leads to reduced bycatch caps 3–4 years in the future. Groundfish condition declined from 2016–2017 for all species (except Arrowtooth flounder) and may be a leading indicator of poor overwinter survival and potential for smaller stocks in 2018. Additionally, estimated age-1 natural mortality for pollock, Pacific cod, and Arrowtooth flounder (based on the CEATTLE model, p. 134) remained at elevated levels in 2017. Commercial crab biomass decreased in 2017, as did abundances of eelpouts and poachers.

Declines in forage fish quality and quantity have cascading effects for piscivorous-feeding seabirds and marine mammals. The reproductive success of cliff-nesting seabirds at both St. Paul and St. George Islands was poor in 2017, with the exception of nearshore-feeding red-faced cormorants (*Phalacrocorax urile*). Despite the moderation of environmental conditions in 2017, seabird foraging conditions do not appear to have recovered.

Maintaining adequate prey has important implications for upper trophic level species and other ecosystem components. Maintaining species diversity increases ecosystem stability as species have differential responses to environmental variability. Total CPUE from the bottom trawl survey peaked in 2014 due to increased pollock catches, but has declined slightly in 2015–2017. Species richness remains high along the 100m isobath while diversity is highest over the middle domain. Cooler water temperatures in 2017 resulted in a substantial southeastward shift, in contrast to a more moderate response to similar cooling in 2006. Several new indicators (see p. 171, 173, and 174) demonstrate that the mean lifespan, overall length, and biomass of the groundfish community have remained relatively stable over the time series. However, these indicators are very sensitive, and small changes in mean length or mean age can be quite significant and indicative of ecosystem shifts. For example, mean length increased in 2002–2005 and again in 2014–2016. The fish community is dependent on previous year-classes that are maturing, and low recruitment during these warm stanzas results in an increase in mean length. This trend could have important consequences for the fishery.

Forecasts and Predictions

Climate projections for the eastern Bering Sea indicate significant warming of both surface and bottom summer temperatures, especially over the southern shelf, as well as declines in sea ice extent in the winter, the areal extent and intensity of the cold pool, and concomitant shifts in productivity. Projected declines of large zooplankton biomass in fall may impact the survival of groundfish species including pollock (Hermann et al., 2016; Ortiz et al., 2016). Multiple ecosystem modeling efforts based on climate projections predict overall declines in pollock biomass in the eastern Bering Sea under warming conditions (Ianelli et al., 2016; Seung and Ianelli, 2016; Spencer et al., 2016). Importantly, changes in harvest policies may influence how strongly climate impacts future eastern Bering Sea fisheries. Harvest rates of pollock can either amplify or slightly attenuate climate-driven declines (Holsman et al., 2016; Ianelli et al., 2016). Economically, a declining pollock supply may be buffered somewhat by increased whitefish prices, which could reduce the impact on the fishery (Seung and Ianelli, 2016). Recent modeling also suggests that fish distributions may shift northward to follow cold refugia (Pinsky et al., 2013; Cheung et al., 2015), while their associated fisheries may or may not be able to follow the northward shift (Haynie and Pfeiffer, 2013).

Preliminary 9-month ecosystem forecast for the eastern Bering Sea: AFSC and PMEL have produced 9-month forecasts of ocean conditions in the eastern Bering Sea as part of the Alaska region's Integrated Ecosystem Assessment (IEA) program since 2013. Forecasts made in October of each year run through July of the following year using the Bering10k ocean and plankton model, including predictions covering the majority of the annual eastern Bering Sea bottom trawl survey (BTS). Large-scale atmospheric and oceanic forecasts from the NOAA/NCEP Climate Forecast System (CFS) are applied as atmospheric surface forcing and oceanic boundary conditions to a finite-scale oceanic model of the region.

The CFS is a global, coupled atmosphere-ocean-land model, which uses a 3DVAR technique to assimilate both in-situ and satellite-based ocean and atmospheric data (Saha et al., 2010). The CFS resolves the global atmosphere at 200km resolution and the global ocean at 50km resolution. Monthly and daily averages of CFS output are available online and include both hindcasts, from 1979–present, and forecasts out to 9 months beyond present time. The CFS is currently being run operationally by NOAA/NCEP/CPC for seasonal weather predictions. Skill metrics for this system have been reported in Wen et al. (2012).

The Bering10k regional model is based on the Regional Ocean Modeling System (ROMS) implemented at 10km resolution (Hermann et al., 2013) and includes an embedded Nutrient Phytoplankton Zooplankton (NPZ) model with euphausiids (Gibson and Spitz, 2011). The regional models were calibrated using repeated hindcasts of the region covering the period 1972-2012.

A particular metric of interest is the summer cold pool, the proportion of the summer BTS survey area under a particular temperature. Figure 16 shows the cold pool with limits of ≤0°C, ≤1°C, and ≤2°C. Shown are BTS survey data, Bering10k hindcast results 1982-2012, and Bering10k 9–month ahead predictions. The most recent prediction, made in October 2017, is shown for summer (July) 2018.

The Bering10K model successfully predicted a transition from cold to warm conditions between 2013 and 2014, and continued warm conditions were predicted successfully for three further years, through summer 2016. The prediction made in 2016 for 2017 was for warm conditions and an extremely small cold pool; the 2017 BTS data indicate more cooling than predicted, though the cold pool size was still below its long-term averages for the ≤0°C, ≤1°C, and ≤2°C definitions. The predictions for summer 2018 are for a **smaller-than-average but near-average cold pool using the ≤0°C or ≤1°C definitions, but a larger-than-average ≤2°C cold pool.**

Pollock Recruitment Predictions: The EBS Ecosystem Considerations Report includes several leading indicators of pollock recruitment that give, in some cases, contradictory results. In this section, we have summarized these predictions so that we can more easily track how they compare and how well they hold up over time. Additional research is underway to assess these indicators over longer time periods.

Survival and recruitment success of juvenile pollock are driven, in part, by bottom-up processes. The abundance, species composition, and quality of zooplankton prey resources are governed by

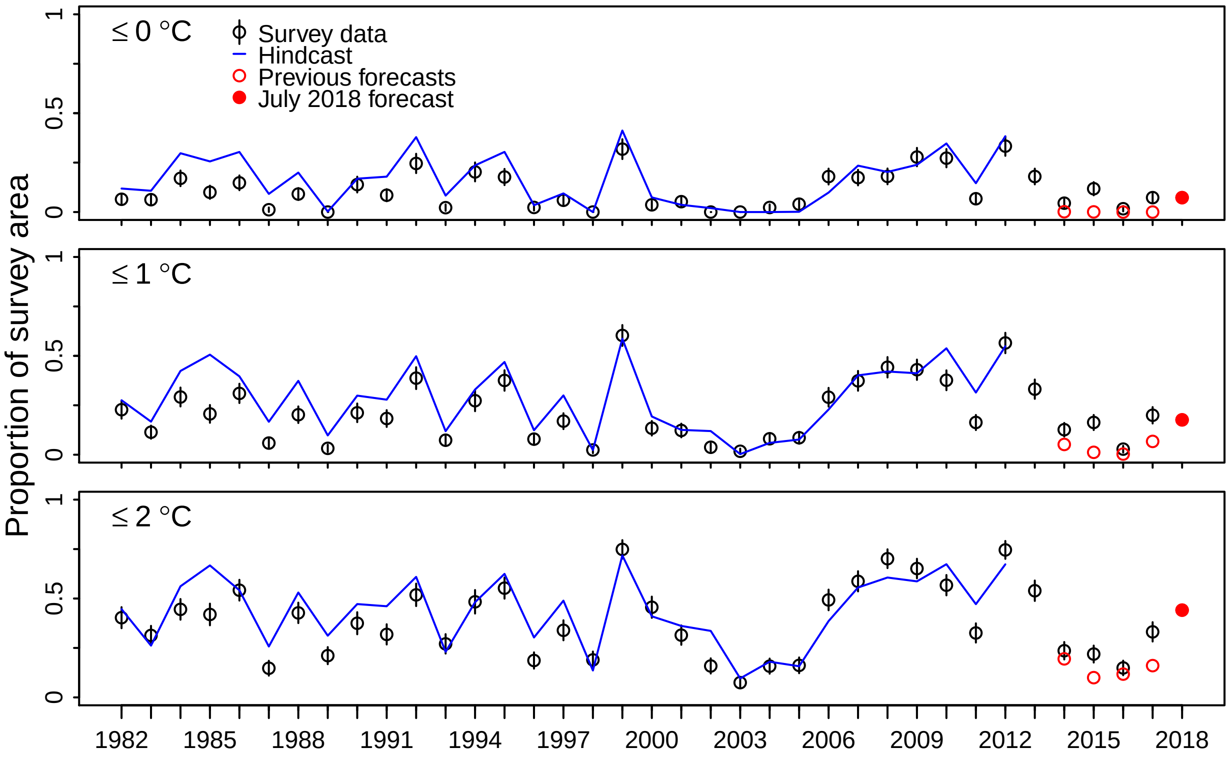


Figure 16: The eastern Bering Sea cold pool with limits of ≤0°C, ≤1°C, and ≤2°C. Shown are BTS survey data, ROMS hindcast results 1982-2012, and ROMS 9-month ahead predictions. The most recent prediction, made in October 2017, is shown for summer (July) 2018.

large-scale oceanographic processes and vary between warm and cold climate stanzas. The abundance of large zooplankton (e.g., *Calanus marshallae*) is greater in cold years when above-average pollock recruitment has been observed. A new indicator (p. 89) presents total dissolved inorganic nitrogen (DIN) as an indicator of nutrient availability for lower trophic levels. A significant decreasing trend was observed in surface DIN concentrations within the southern middle domain over time. This could imply that summertime wind mixing events are occurring less frequently and with less intensity in recent years. This trend could limit the amount of primary production available as the base of the food web with cascading impacts to age-0 pollock.

Below we track available predictions for several recent year classes of pollock. We include 2012 because estimates of the 2012 pollock year class suggest that it may be one of the largest in the past three decades. This year class now dominates estimates of spawning biomass, which is currently at an overall high level and supports a large fishery quota (Ianelli et al., 2016). The explanation for the somewhat surprisingly strong 2012 year class remains uncertain.

2012 year class: The 2012 pollock year class may be one of the **largest in the past three decades.** Indicators that supported this include:

- The Temperature Change Index predicted **above-average recruitment**
- Large zooplankton abundance was high, therefore **above-average recruitment** was predicted

- Spatial overlap between prey availability and age-0 pollock predicted **above-average recruitment**

In contrast, the following indicators predicted below-average recruitment:

- Surface silicic acid concentrations indicated low nutrient availability; combined with a very low mean weight of age-0 fish, below-average recruitment was predicted.
- Average energy content (product of energy density and average mass) predicted below-average recruitment.

In 2012, the eastern Bering Sea experienced the coldest average bottom temperatures and largest extent of the cold pool since 1999. Despite favorable prey conditions, temperatures were considered too cold for the pollock to grow well. However, predictions that accounted for their very small size incorrectly predicted below-average recruitment. The spatial overlap model indicates that under cold conditions (i.e., 2012), bottom-up processes are important, however top-down processes that delineate the spatial overlap with predators may also contribute. Perhaps the additive effects of favorable prey conditions combined with low overlap with predators resulted in the strong 2012 year class.

2015 year class: The 2015 pollock year class appears **slightly below-average** (Ianelli et al., 2016). Indicators that support below-average or intermediate recruitment include:

- Large zooplankton abundance was low, therefore **below-average recruitment** was predicted
- Biophysical indices (chum salmon growth, temperature, predator abundance) predicted **below-average recruitment**
- Age-0 pollock diet energy density predicted **intermediate recruitment**
- Average energy content predicted **intermediate recruitment**

In contrast, the following indicators predicted above-average recruitment:

- The Temperature Change Index predicted above-average recruitment
- Surface silicic acid concentrations predicted above-average recruitment

The EBS had warm conditions in 2015, although age-0 pollock may have utilized the cold pool as a refuge which may act as a buffer against recruitment declines for this year class (Duffy-Anderson et al., 2017).

2016 year class: No assessment estimate available for the 2016 pollock year class.

- Surface silicic acid concentrations predicted **above-average recruitment**
- Average energy content predicted **intermediate recruitment**
- The Temperature Change Index predicted **below-average recruitment**

2016 was record warm over the eastern Bering Sea shelf and zooplankton communities appeared qualitatively and quantitatively low. However, pollock appear to have mitigated against dramatic recruitment declines. Possible mechanisms include utilizing high productivity waters associated with the strong, northerly Cold Pool, as a refuge, or by exploiting alternative prey over the southern shelf (Duffy-Anderson et al., 2017).

2017 year class: No assessment estimate available for the 2017 pollock year class.

- The Temperature Change Index predicts **below-average recruitment**

Description of the Report Card indicators

1. The North Pacific Index (NPI) (Nov. - Mar. average): The NPI 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° to 65°N, 160°E to 140°W (Trenberth and Hurrell, 1994). It is relevant to the Bering Sea because 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.

The advantageous aspects of the NPI include its systematic relationship to the primary causes of climate variability in the Northern Hemisphere, especially the El Niño-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 such as the Bering Sea shelf.

2. Eastern Bering Sea ice retreat index: Sea ice over the southern Bering Sea (south of ∼60°N) varies greatly on all time scales (daily, annual, decadal), while the variability over the northern Bering Sea shelf is much less. We use an index of the number of days during March and April in which there was at least 20% ice cover in a 100 km box around the M2 mooring located in the southeastern portion of the shelf at 57°N and 164°W (Stabeno et al., 2012). We chose spring, because it is spring sea ice that influences the timing of the spring phytoplankton bloom, determines the extent of the cold pool, and strongly influences sea surface temperatures during summer.

3. Euphausiid biomass: Macrozooplankton are intermediaries in the transfer of carbon from primary production to living marine resources (commercial fisheries and protected species). Understanding the mechanisms that control secondary production is an obvious goal toward building better ecosystem syntheses. In the absence of direct measurements of secondary production in the eastern Bering Sea, we rely on estimates of biomass. We use an estimate of euphausiid biomass as determined by acoustic trawls.

4., 5., 6., 7. Description of the fish and invertebrate biomass indices: We present four guilds to indicate the status and trends for fish and invertebrates in the EBS: motile epifauna, benthic foragers, pelagic foragers, and apex predators. Each is described in detail below. The full guild analysis involved aggregating all EBS species included in a food web model (Aydin and Mueter, 2007) into 18 guilds by trophic role, habitat, and physiological status (Table 3). For each guild, time trends of biomass are presented for 1977–2017. EBS biomass trends are summed stock assessment model estimates or scaled survey data, where available, for each species within the guild. If neither time series are available, the species is assumed to have a constant biomass equal to the mid-1990s mass balance level estimated in Aydin and Mueter (2007). Catch data were directly taken from the Catch Accounting System and/or stock assessments for historical reconstructions.

4. Motile epifauna (fish and benthic invertebrates): This guild includes both commercial

Table 3: Composition of foraging guilds in the eastern Bering Sea.

Motile epifauna	**Benthic foragers**	**Pelagic foragers**	**Fish apex predators**
Eelpouts	P. cod (juv)	W. pollock (juv)	P. cod
Octopuses	Arrowtooth (juv)	W. pollock	Arrowtooth
Tanner crab	P. halibut (juv)	P. herring (juv)	Kamchatka fl. (juv)
King crabs	Yellowfin sole (juv)	P. herring	Kamchatka fl.
Snow crab	Yellowfin sole	Gr. turbot (juv)	P. halibut
Sea stars	Flathead sole (juv)	Sablefish (juv)	Alaska skate
Brittle stars	Flathead sole	P. ocean perch	Large sculpins
Other echinoderms	N. rock sole (juv)	Sharpchin rockfish	
Snails	N. rock sole	Northern rockfish	
Hermit crabs	AK plaice	Dusky rockfish	
Misc. crabs	Dover sole	Other Sebastes	
	Rex sole	Atka mackerel (juv)	
	Misc. flatfish	Atka mackerel	
	Shortraker rockfish	Misc. fish shallow	
	Thornyhead rockfish	Squids	
	Greenlings	Salmon returning	
	Other sculpins	Salmon outgoing	
		Bathylagidae	
		Myctophidae	
		Capelin	
		Eulachon	
		Sandlance	
		Other pelagic smelts	
		Other managed forage	
		Scyphozoid jellies	

and non-commercial crabs, sea stars, snails, octopuses, and other mobile benthic invertebrates. Information is based on bottom trawl survey data (for more information, see p.154 and 156). There are ten commercial crab stocks in the current Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs; we include seven on the EBS shelf: two red king crab *Paralithodes camtschaticus* (Bristol Bay, Pribilof Islands), two blue king crab *Paralithodes platypus* (Pribilof District and St. Matthew Island), one golden king crab *Lithodes aequispinus* (Pribilof Islands), and two Tanner crab stocks (southern Tanner crab *Chionoecetes bairdi* and snow crab *C. opilio*). The three dominant species comprising the eelpout group are marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*), and shortfin eelpout (*L. brevipes*). The composition of sea stars in shelf trawl catches are dominated by the purple-orange sea star (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. Stock assessments for crabs have not been included to date, but could be in the future.

5. Benthic foragers (fish only): The species which comprise the benthic foragers group are the Bering Sea shelf flatfish species, juvenile Arrowtooth flounder (*Atheresthes stomias*), and the sculpins. The major species of this group are surveyed annually and have abundances estimated by statistical models, therefore our confidence in their time-trend of abundance is high.

6. Pelagic foragers (fish and squid only): This guild includes adult and juvenile Walleye pollock (*Gadus chalcogrammus*), other forage fish such as Pacific herring (*Clupea pallasi*), Capelin (*Mallotus villosus*), Eulachon (*Thaleichthys pacificus*), and Sand lance, pelagic rockfish, salmon, and squid. Information quality ranges from a sophisticated highly quantitative stock assessment for pollock (the biomass dominant in the guild) through relatively high variance EBS shelf survey data for forage fish, to no time series data for salmon and squid.

7. Apex predators (shelf fish only): This guild includes Pacific cod (*Gadus macrocephalus*), Arrowtooth flounder, Kamchatka flounder (*Atheresthes evermanni*), Pacific halibut (*Hippoglossus stenolepis*), Alaska skate, and large sculpins. Pacific cod and Arrowtooth flounder time series are from stock assessments, and the remaining time series are from the annual EBS shelf bottom trawl survey.

8. Multivariate seabird breeding index: This index represents the dominant trend among 17 reproductive seabird data sets from the Pribilof Islands that include diving and surface-foraging seabirds. The trend of the leading principal component (PC1) represents all seabird hatch timing and the reproductive success of murres and cormorants.

9. St. Paul Northern fur seal pup production: Pup production on St. Paul was chosen as an index for pinnipeds on the eastern Bering Sea shelf because the foraging ranges of females that breed on this island are largely on the shelf, as opposed to St. George which, to a greater extent, overlap with deep waters of the Basin and slope. Bogoslof Island females forage almost exclusively in pelagic habitats of the Basin and Bering Canyon and, as such, would not reflect foraging conditions on the shelf.

10. Habitat impacted by trawls: Fishing gear can affect habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. An estimate of the area of seafloor disturbed by trawl gear may provide an index of habitat disturbance. This new 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 indicator more accurately reflects an estimate of time that gear is in contact with the substrate. Further detail on this index is reported on p. 186.

Gaps and needs for future EBS assessments

As part of the Bering Sea Fisheries Ecosystem Plan (FEP) Team, we will be convening a working group to evaluate and select Report Card indicators for the eastern Bering Sea. A similar workshop was held in early 2016 in conjunction with a GOA IERP PI meeting for the Gulf of Alaska report. This working group will assess current Report Card indicators, evaluate new/available time series as potential new indicators, and develop a research plan for identified gaps in ecosystem indicators.

Ecosystem Indicators

Ecosystem Status Indicators

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

Physical Environment

North Pacific Climate Overview

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Last updated: August 2017

Summary: *The state of the North Pacific atmosphere-ocean system during 2016–2017 featured the moderation of warm sea surface temperature (SST) anomalies associated with the extreme marine heat wave of 2014–2016. The sea level pressure (SLP) anomaly patterns varied from season to season, with the most prominent perturbation occurring in winter 2016–2017 when the Aleutian Low was much weaker than normal. This kind of anomaly has often been associated with the remote forcing by La Niña; the magnitude of the response was large relative to that of the tropical Pacific signal. The Pacific Decadal Oscillation (PDO) was positive during the past year, with an overall decline in amplitude. The climate models used for seasonal weather predictions are indicating that near-neutral ENSO conditions or a weak La Niña are most likely for the winter of 2017–2018, while maintaining North Pacific SST anomalies in a weakly PDO-positive sense.*

Regional Highlights:

Alaska Peninsula and Aleutian Islands. The weather of this region featured enhanced storminess in the fall of 2016, especially in the west, and suppressed storminess during the following winter. Easterly wind anomalies and mild temperatures occurred during spring 2017. Based on synthetic data from NOAA's Global Ocean Data Assimilation System (GODAS), the westward flow associated with the Alaskan Stream decreased from relatively high values late in 2016 to lower than normal values in the summer of 2017. The GODAS product suggests there were pulses in the strength of the eastward flow associated with the Aleutian North Slope Current.

Bering Sea. The weather on the Bering Sea shelf was generally warmer than normal, for the 4th year in a row. An exception was early 2017, which included the usual intermittent outbreaks of Arctic air. The fall of 2016 was stormier than normal; winter and spring were relatively calm. During the winter of 2016–2017, sea ice was present mostly between the coast and the 70-meter isobath. While ice reached the M2 mooring site on the southeast Bering Sea shelf, the water column did not fully mix. The result was moderate bottom temperatures (∼0°C) for the summer cold pool in the middle domain of the southern Bering Sea shelf. In this region the thermal stratification was greater than usual in summer 2017, but the vertically integrated heat content was more typical, at least as compared with 2015 and 2016.

Arctic. The fall of 2016 featured particularly low sea ice extents in the Chukchi and Beaufort Seas. For the Arctic as a whole, the maximum sea ice extent at the end of winter was the lowest on record. In addition, Barrow, Alaska experienced a record warm winter. The sea ice melted rapidly in Chukchi Sea beginning in May 2017, presumably due to a combination of the weather and relatively thin ice associated with the unusually short period of ice cover. The ice edge was farther north than usual during summer 2017 for the Chukchi Sea and much of the Beaufort Sea. For the Arctic as a whole, the area of sea ice cover during the middle of August 2017 was the 5th lowest value in the observational record, despite a weather pattern unfavorable to ice melt.

Sea Surface Temperature and Sea Level Pressure Anomalies

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Description of indices: The state of the North Pacific climate from autumn 2016 through summer 2017 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981–2010. The SST data are from NOAA's Optimum Interpolation Sea Surface Temperature (OISST) analysis; the SLP data are from the NCEP/NCAR Reanalysis project. Both data sets are made available by NOAA's Earth System Research Laboratory (ESRL) at `http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl`.

Status and trends: The eastern portion of the North Pacific ocean experienced during 2014–2016 one of the most extreme marine heat waves in the observational record (Scannell et al., 2016); the interval summarized here can be considered a transition period between that event and a more climatologically normal SST distribution on the basin-scale. More detail on the evolution of the SST and SLP from a seasonal perspective is provided directly below.

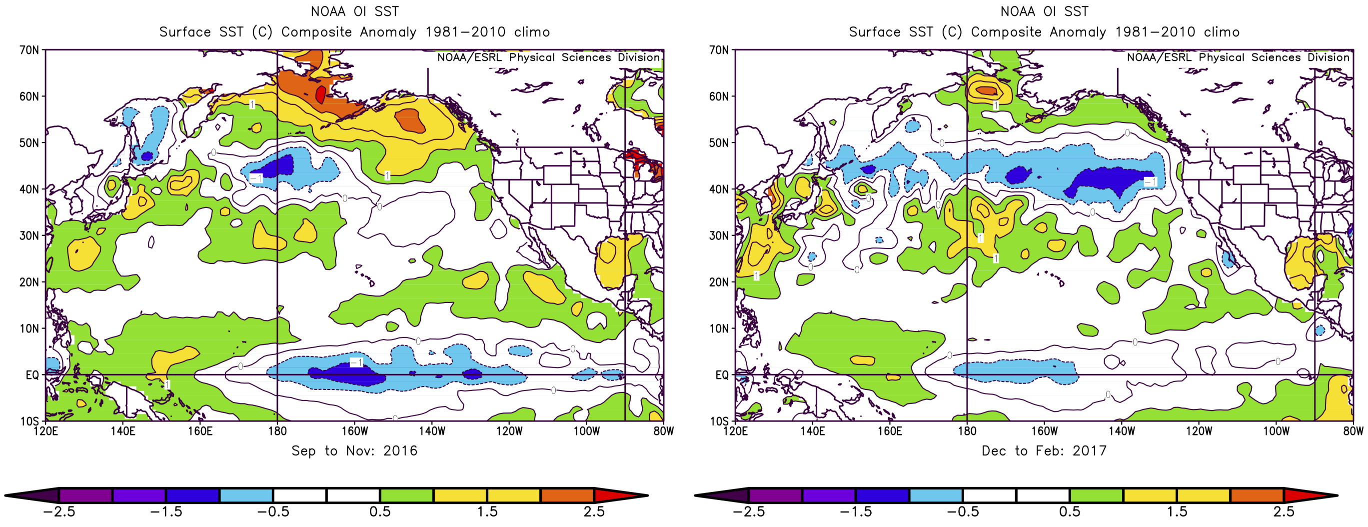
The SST in the North Pacific during the autumn (Sep–Nov) of 2016 (Figure 17a) was warmer than normal in the Gulf of Alaska (GOA) and much warmer than normal (> 2°C) in the northern and eastern Bering Sea. Most of the remainder of the North Pacific Ocean had SSTs that were near to slightly above normal, with the exception of a cold patch at the dateline between 40° and 50° N.

The SST anomalies in the tropical Pacific were positive in the west, and negative in the east, with the latter implying weak La Niña conditions. The pattern of anomalous SLP during autumn 2016 featured a pole of strongly negative anomalies over the western Bering Sea, and lower than normal SLP extending eastward to a secondary negative pole off the coast of the Pacific Northwest (Figure 18a). This SLP pattern implies wind anomalies from the west across the North Pacific between roughly 40° and 50° N, causing enhanced cooling.

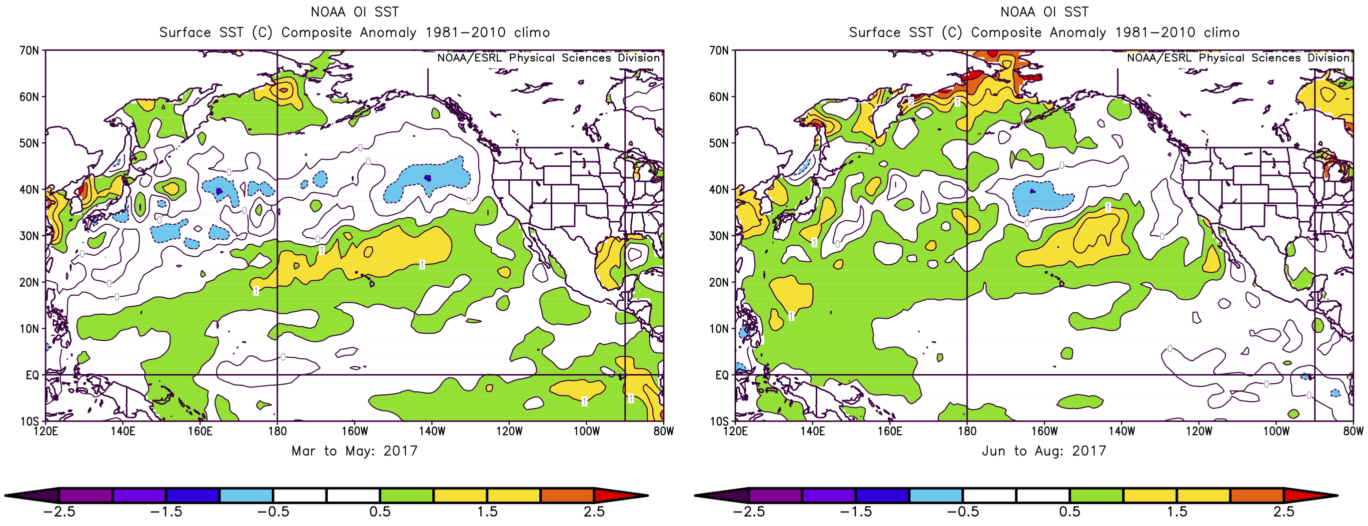
The pattern of North Pacific SST during winter (Dec–Feb) of 2016–2017 relative to the seasonal mean (Figure 17b) reflected cooling north of about 40°N relative to the previous fall season. This cooling was associated with anomalous winds out of the west across the middle latitudes of the North Pacific in fall, followed by anomalous winds during winter out of the west across the Bering Sea and out of the northwest in the GOA. The latter wind anomalies were due to a distribution of anomalous SLP during winter 2016–2017 that featured much higher pressures than normal over a large portion of the eastern North Pacific, with a peak magnitude greater than 12 mb located south of the Alaska Peninsula (Figure 18b). This is the signature of a particularly weak Aleutian Low, and implies suppressed storminess for the southeastern Bering Sea and GOA. A weak Aleutian Low commonly occurs during La Niña, but as shown in Figure 17b, the SST anomalies in the central and eastern tropical Pacific were not much cooler than normal. It is not known why there appears to have been such a disproportionate response in the atmospheric circulation over the North Pacific. The anomalous northerly flow on the east side of the positive SLP anomaly south of Alaska resulted in the coldest winter for the Pacific Northwest since 1992–1993; the region of lower than normal pressure along the west coast of the US was also accompanied by higher than normal precipitation.

The distribution of anomalous SST in the North Pacific during spring (Mar–May) of 2017 (Figure 17c) was similar to that during the previous winter season, with moderation in the magnitude of the anomalies north of 30°N and modest warming in the sub-tropical North Pacific. Moderate cooling occurred in the central North Pacific in the vicinity of 40°N, 170°W. The overall pattern projected on the positive phase of the Pacific Decadal Oscillation (PDO), but not as strongly as during the past two years. The SST anomalies in the tropical Pacific were of minor amplitude. The SLP anomaly pattern (Figure 18c) for spring 2017 featured a band of lower than normal pressure from eastern Siberia to a negative center south of the Aleutian Islands, with an eastward extension to British Columbia. Above-normal SLP resulted in suppressed storminess for the eastern Bering Sea. The atmospheric circulation in the northeast Pacific promoted relatively downwelling-favorable winds in the coastal GOA and wet weather in the Pacific Northwest.

The SST anomaly pattern in the North Pacific during summer (Jun–Aug) 2017 is shown in Figure 17d. It was warmer than normal north of 50°N, with the greatest positive anomalies of +2°C near Bering Strait into the southern Chukchi Sea. Warm SSTs were also present in a band between about 30° and 15°N across the entire North Pacific Ocean with the greatest anomalies located northeast of the Hawaiian Islands. Upper ocean temperatures in the tropical Pacific were quite close to their climatological norms. The distribution of anomalous SLP (Figure 18d) during summer 2017 included negative centers in the northwestern portion of the North Pacific basin and south of mainland Alaska straddling a region of slightly higher than normal SLP centered near 40°N and the dateline.

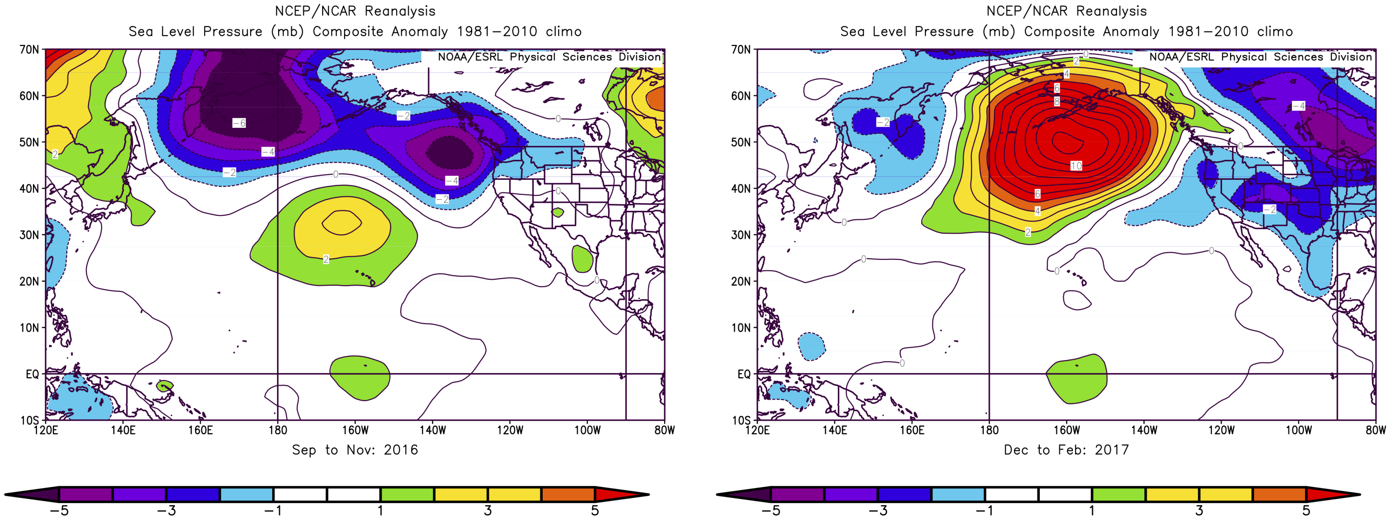


(a) Autumn (b) Winter



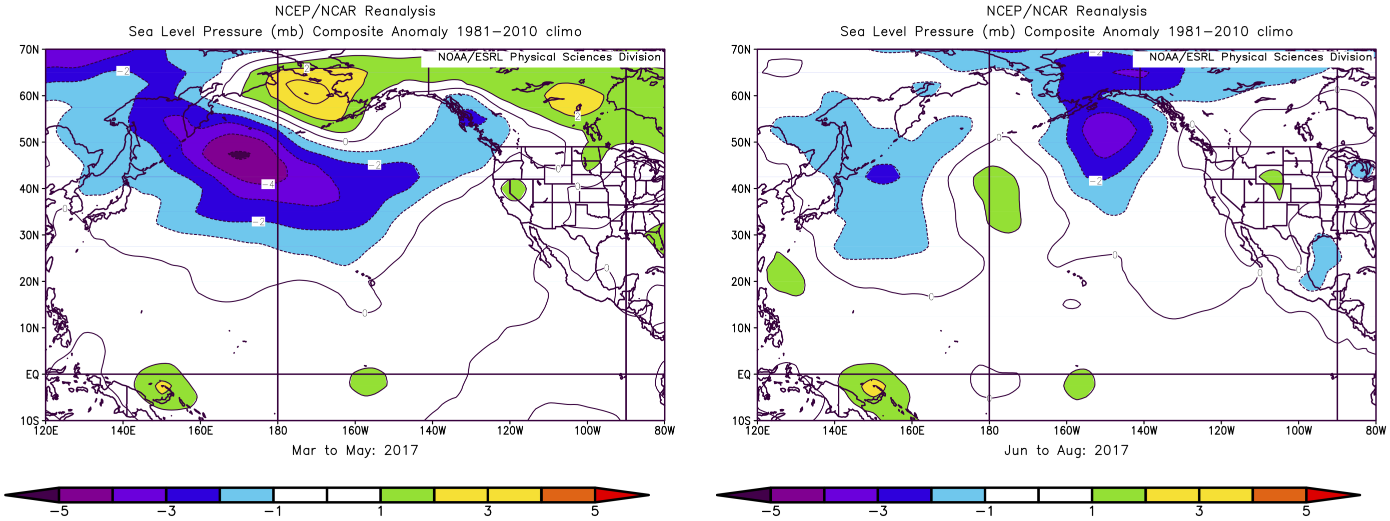
(c) Spring (d) Summer

Figure 17: SST anomolies for autumn (September–November 2016), winter (December 2015–February 2017), spring (March–May 2017), and summer (June–August 2017).


NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Anomaly 1981–2010 climo
Sep to Nov: 2016

NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Anomaly 1981–2010 climo
Dec to Feb: 2017

(a) Autumn (b) Winter


NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Anomaly 1981–2010 climo
Mar to May: 2017

NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Anomaly 1981–2010 climo
Jun to Aug: 2017

(c) Spring (d) Summer

Figure 18: SLP anomolies for autumn (September–November 2016), winter (December 2016–February 2017), spring (March–May 2017), and summer (June–August 2017).

Climate Indices

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Description of indices: Climate indices provide an alternative means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, Pacific Decadal Oscillation (PDO) index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO) and Arctic Oscillation (AO). The time series of these indices from 2007 into summer 2017 are plotted in Figure 19.

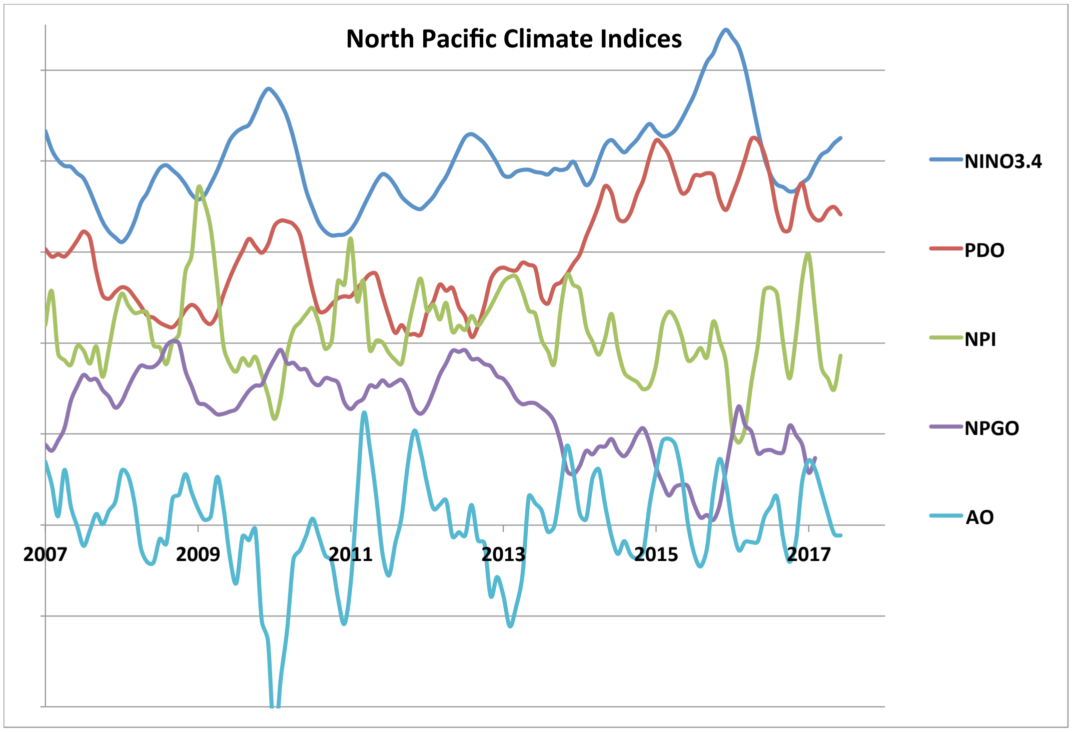

Figure 19: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Earth Systems Laboratory at `http://www.esrl.noaa.gov/psd/data/climateindices`.

Status and trends: The North Pacific atmosphere-ocean climate system, in an overall sense, was in a more moderate state during 2016–2017 than during the previous two years. The NINO3.4 index ranged from slightly negative during late 2016 to slightly positive during spring of 2017, with little trend over the course of summer 2017 (Figure 19). This rather quiet state for the tropical Pacific is in contrast with the large swings that occurred in 2015–2016. The PDO has been positive (indicating warmer than normal SST along the west coast of North America and cooler than normal in the central and western North Pacific) since early 2014. The magnitude of the PDO has generally decreased since early 2016. Much of this decline can probably be attributed to ENSO, and in particular the transition from a strong El Niño to a weak La Niña in 2016. The NPI was negative during the past fall and spring, implying a deeper than normal Aleutian Low, as indicated in Figures 18a and 18b. In contrast, the winter of 2016–2017 included a large positive value for the NPI. While this sign of the NPI represents a typical atmospheric response to La Niña, its magnitude is disproportionately large considering the weak amplitude of La Niña in late 2016.

The NPGO mostly declined from a small positive value in early 2016 to a small negative value in early 2017. This index has been shown to be positively correlated with nitrate concentrations on Line P extending from Vancouver Island to Station P at 50°N, 145°W. 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 Pacific and Atlantic Ocean at a latitude of roughly 45°N. It has a weakly positive correlation with sea ice extent in the Bering Sea. The AO was positive during the winter of 2016–2017, perhaps contributing to the anomalously weak Aleutian Low (Figure 18b), and otherwise in a mostly neutral state on seasonal time scales since early 2016.

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

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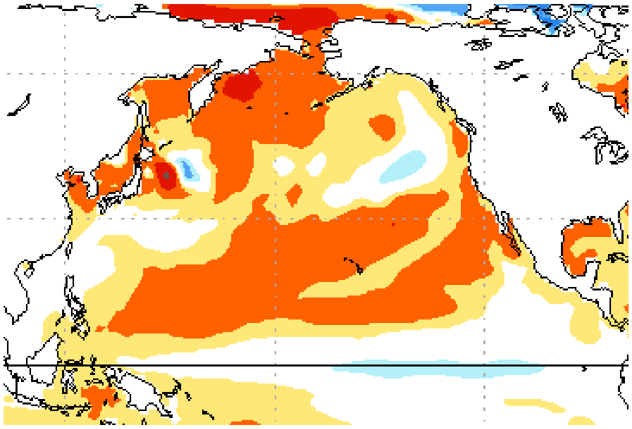
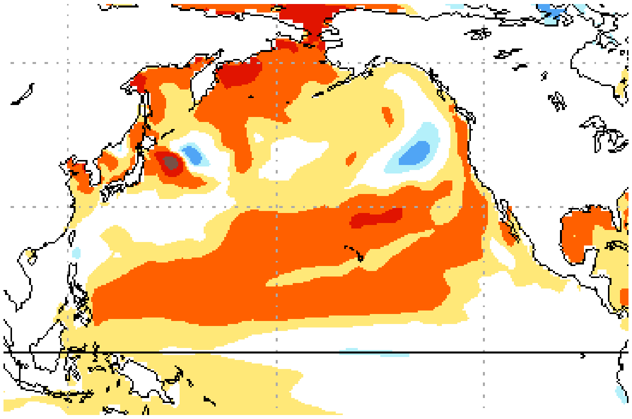
Last updated: September 2017

Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 20. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.

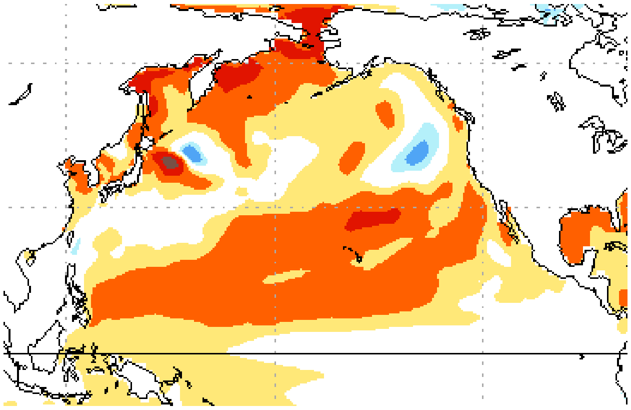
Status and trends: First, the projections from a year ago are reviewed qualitatively. The one-month lead forecast for Oct–Dec 2016 was quite accurate, which is not surprising in that the upper ocean has a great deal of thermal inertia, i.e., persistence, with the initial state being a primary determinant of near-term future conditions. This influence lessens with time and indeed for the period considered here, the longer-range (3-month and 5-month) forecasts were not as skillful. The models as a group, as reflected in the ensemble averages, correctly predicted the signs and the magnitudes of the SST anomalies in the sub-tropical and tropical Pacific, with only minor discrepancies. The NMME forecasts at the 3-month and 5-month forecast horizons did not validate as well north of about 30°N, where the modeled SSTs were generally warmer than observed. The models simulated too-little moderation of the pre-existing warm anomalies in the GOA and Bering Sea, and also under-predicted the amount of cooling in the waters offshore of the Pacific Northwest. Nevertheless, the models did reproduce the overall patterns in anomalous SST that were observed, even in the longer-range projections; the positive skill in these forecasts discussed here (and found in other studies) suggest that the NMME SST output merits consideration.



(a) Months OND



(b) Months DJF



(c) Months FMA

Figure 20: Predicted SST anomalies from the NMME model for OND (1 month lead), DJF (3 month lead), and JFM (4 month lead) for the 2017–2018 season.

These NMME forecasts of three-month average SST anomalies indicate a continuation of warm conditions across most of the North Pacific through the end of the year (Oct–Dec 2017) with a reduction in the longitudinal extent of cooler than normal temperatures offshore of the Pacific Northwest (Figure 20a). The magnitude of the positive anomalies is projected to be greatest (exceeding 1°C) in the western Bering Sea. Negative SST anomalies are projected in the central and eastern equatorial Pacific. It is uncertain whether they will remain weak enough to constitute neutral conditions or become strong enough to constitute La Niña. As of early September 2017, the probabilistic forecast provided by NOAA's Climate Prediction Center (CPC) in collaboration with the International Research Institute for Climate and Society (IRI) for the upcoming fall through winter indicates about a 40% chance of neutral conditions and a 55% chance of a weak La Niña. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2017–February 2018 (Figure 20b) and February–April 2018 (Figure 20c) with some slight cooling in the eastern Bering Sea, GOA, and nearshore waters of the Pacific Northwest.

Implications: The distribution of forecast SST anomalies projects on the positive phase of the PDO, but also exhibits some substantial differences with the characteristic pattern of the PDO. In particular, the positive phase of the PDO generally includes significantly warmer than normal water in the GOA, and only modest anomalies in the western Bering Sea, while just the reverse is shown in the forecasts. This discrepancy appears to be related to some of the individual NMME models forecasts of a relatively weak Aleutian low (not shown).

Eastern Bering Sea Climate - FOCI

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Last updated: October 2017

Summary. After 3 consecutive warm years (2014–2016), the Bering Sea experienced moderate climate conditions in 2017. Sea level pressures over the Bering Sea were moderate and summer winds were very light from the south giving slightly positive air temperature anomalies ($\sim$+1°C) over all of the Bering Sea. While residual heat maintained above-average water temperatures (both surface and bottom) over the shelf, sea ice extended over much of the southern shelf. This resulted in a larger, although narrow, cold pool over the shelf with weaker thermal gradients at the boundaries. The PDO pattern suggests a possible continuation of moderate conditions into 2018.

Air temperatures Slightly positive near-surface air temperature anomalies for summer (May–July) in southwest Alaska and the southeastern Bering Sea were +1–1.5°C above those of the eastern regions (Figure 21). Alaska conditions were driven by a moderation of the Pacific Decadal Oscillation (PDO) and a generally western location for the Aleutian Low pressure feature. The moderation of the PDO has resulted in milder, positive SSTs along the coastal Gulf of Alaska with associated low level warm air temperature anomalies. Winds follow the contours of geopotential heights, with east-west gradients associated with the warm temperature regions and the coastal mountains (Figure 22) to the east and the Aleutian Low to the west, giving southerly winds that advect warm temperatures into Alaska. Summer winds were very light from the south giving slightly positive air temperature anomalies over the Bering Sea (Figure 22). Long-term surface air temperatures measured on St. Paul Island (Figure 23) also reflect a moderation of recent warm conditions.

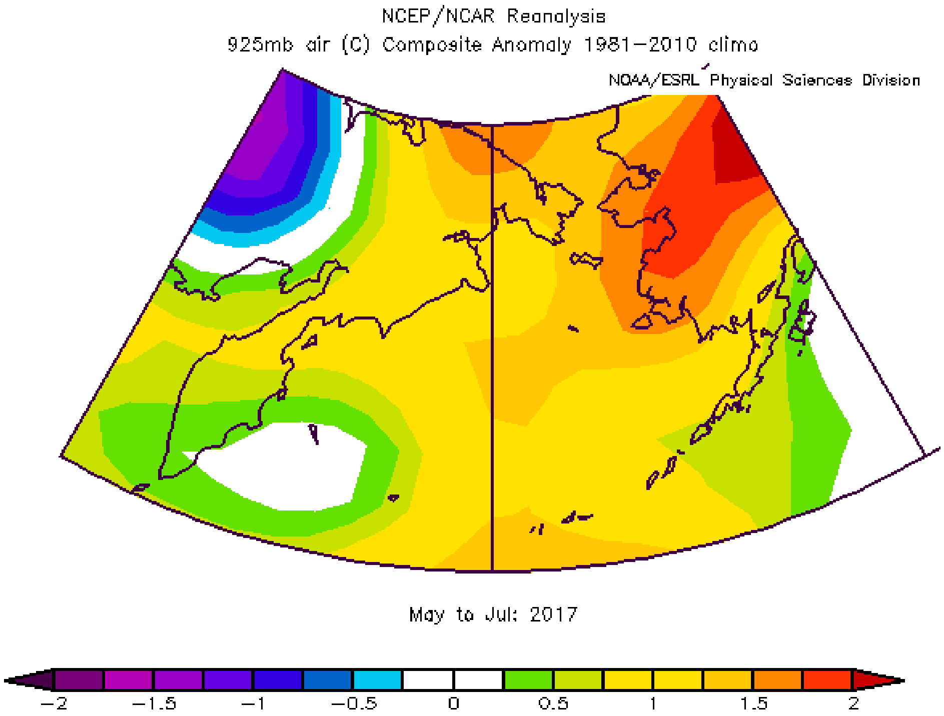

Figure 21: Near surface positive air temperature anomaly over the southeastern Bering Sea for May–July 2017.

Sea ice. Seasonal sea ice is a defining characteristic of the Bering Sea shelf. The presence of sea ice influences the timing of the spring bloom and bottom temperatures throughout the year. Over the time series, years with less sea ice coverage occurred in 2001–2005 and years with more extensive sea ice coverage occurred in 2007–2010, 2012, and 2013 (Figure 24). Conditions in 2017 resulted in a more southerly extent of sea ice over the Bering Sea shelf (more similar to 2006). Note the unusual feature of the 2017 sea ice boundary retreating into the Gulf of Anadyr.

Ocean temperatures. The cold pool (Figure 25), defined by bottom temperatures $<2^{\circ}$C, influences not only near-bottom biological habitat, but also the overall thermal stratification and ultimately the mixing of nutrient-rich water from depth into the euphotic zone during summer. The cold pool extent for summer 2017 was more extensive over the shelf, although more narrowly confined to the middle domain (50–100 m).

Depth-averaged temperatures. Figure 26 shows the depth-averaged temperatures at mooring M2 located over the southern shelf. The cold years of 2009, 2010, and 2012 cluster together with cooler temperatures; intermediate years of 2006, 2011, and 2017 group together; warm years of 2014–2016, with 2016 being especially warm, cluster together.

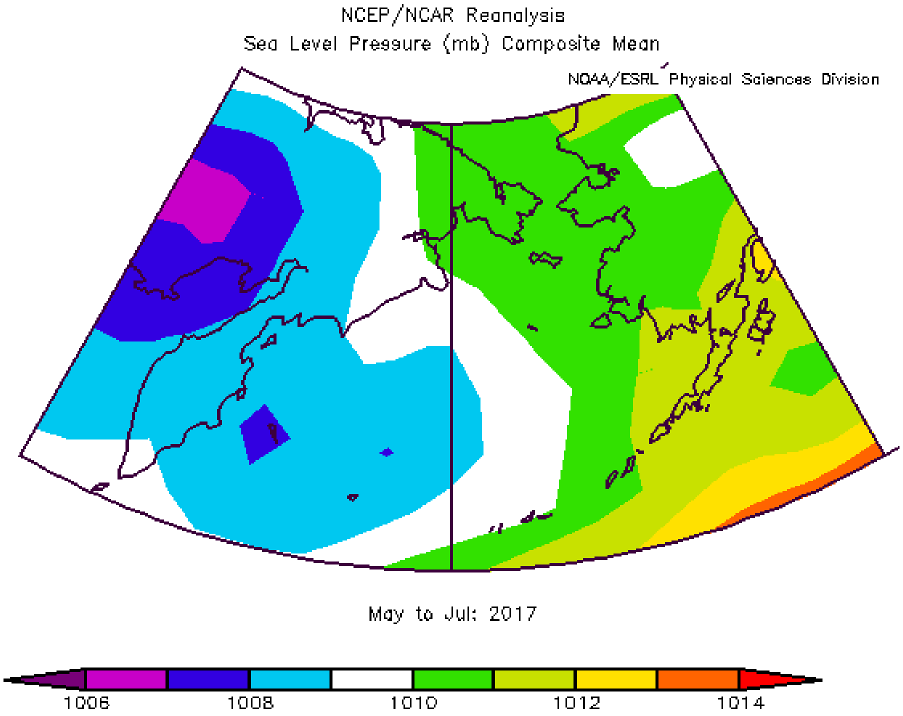

Figure 22: Near surface positive air temperature anomaly over the southeastern Bering Sea for May–July 2017.

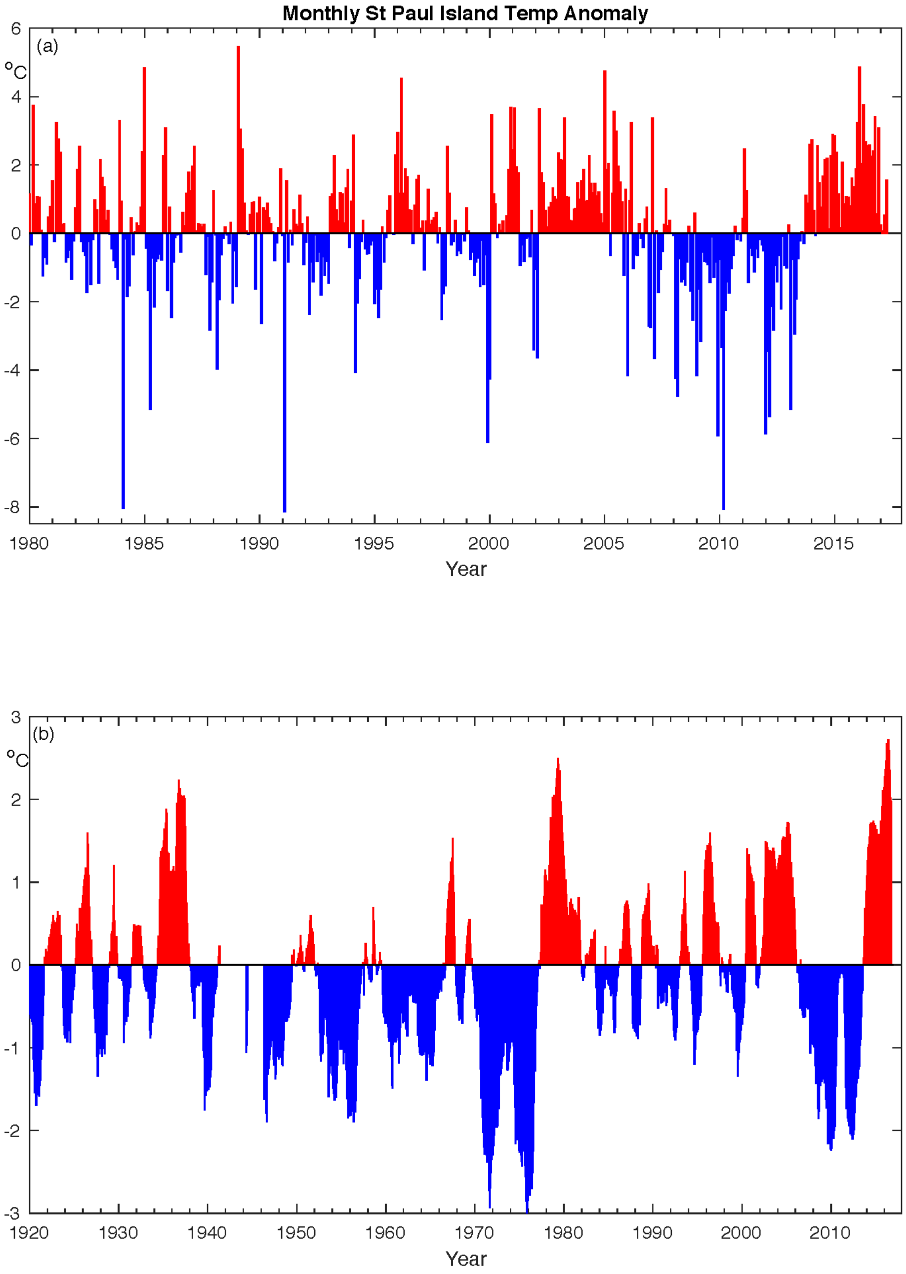

Figure 23: Mean monthly surface air temperatures anomalies at St. Paul (Pribilof Islands). Top panel: unsmoothed 1980–2017. Bottom panel: smoothed by 13-month running averages, January 1920 through March 2017. The base period for calculating anomalies is 1981–2010.

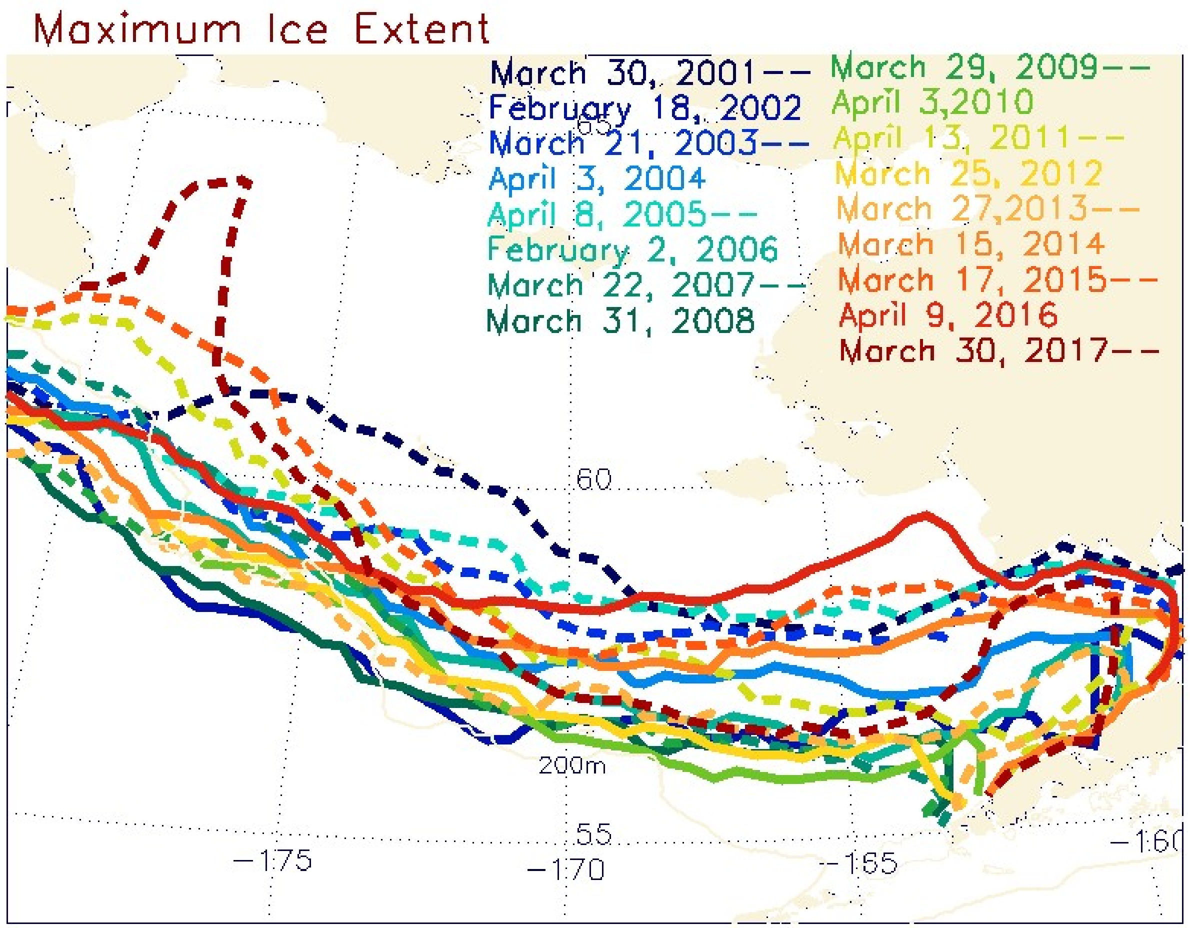

Figure 24: Springtime maximum ice extent in the southeastern Bering Sea for 2001–2017.

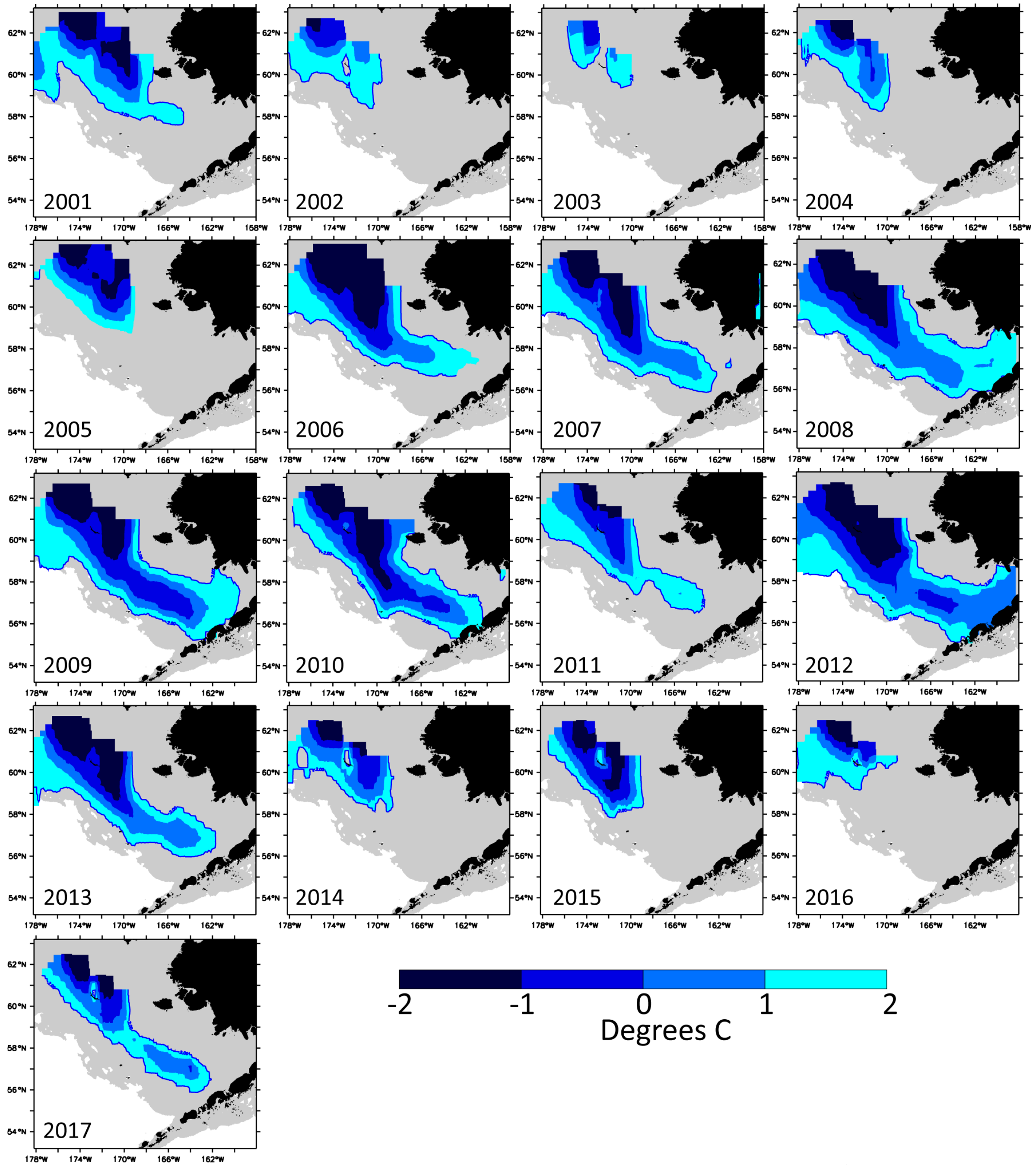

Figure 25: Cold Pool extent in the southeastern Bering Sea from 2001 to 2017. After a sequence of warm years from 2014–2016, a more extensive cold pool occurred in 2017.

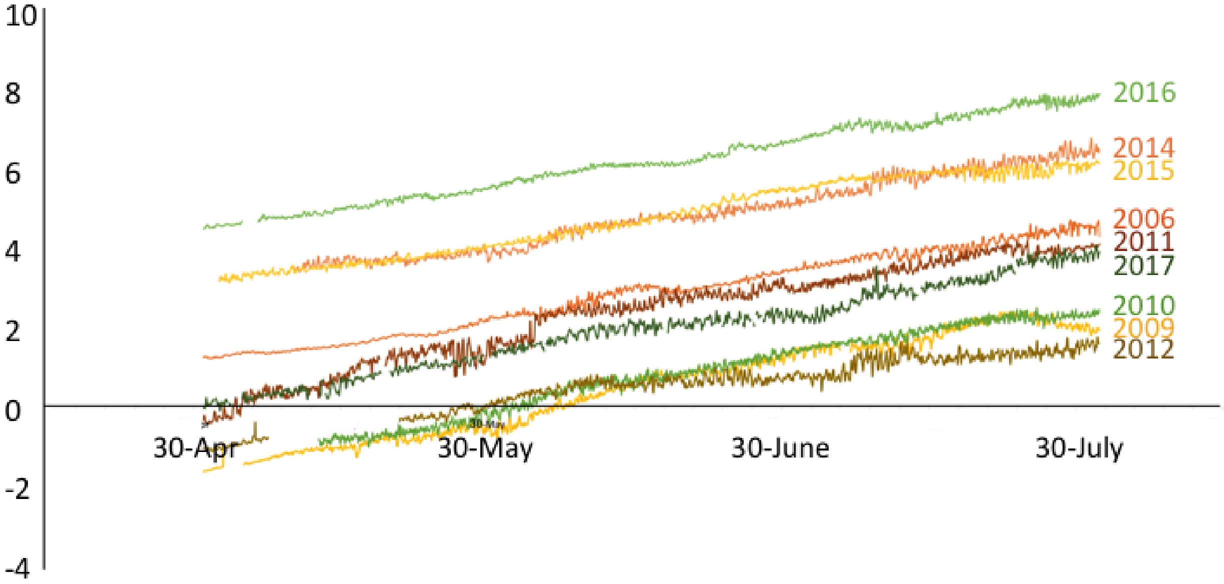

Figure 26: Depth-averaged temperature at M2 mooring.

Summer Bottom and Surface Temperatures - Eastern Bering Sea Shelf

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Last updated: October 2017

Description of indicator: Survey operations for the annual AFSC eastern Bering Sea shelf bottom trawl survey in 2017 started on 31 May and ended on 31 July.

Status and trends: Surface and bottom temperature means for the 2017 eastern Bering Sea shelf decreased from 2016 estimates, but both were still warmer than the long-term time series mean (Figure 27). The 2017 mean surface temperature was 7.8°C, which was 1.7°C lower than 2016 and 1.4°C above the time series mean (6.5°C). The mean bottom temperature was 2.8°C, which was 1.7°C lower than 2016, but 0.4°C above the time series mean (2.5°C). The 'cold pool', defined as the area where temperatures <2°C, extended from the northern-most port of the survey (latitude 62°N) south-east to latitude 54°N between 50 and 100 m bottom depth (Figure 28). This extent was significantly more developed than in 2016, when the cold pool was confined to the upper middle shelf, but was generally less extensive compared to 2007–2013 when overall temperatures were colder.

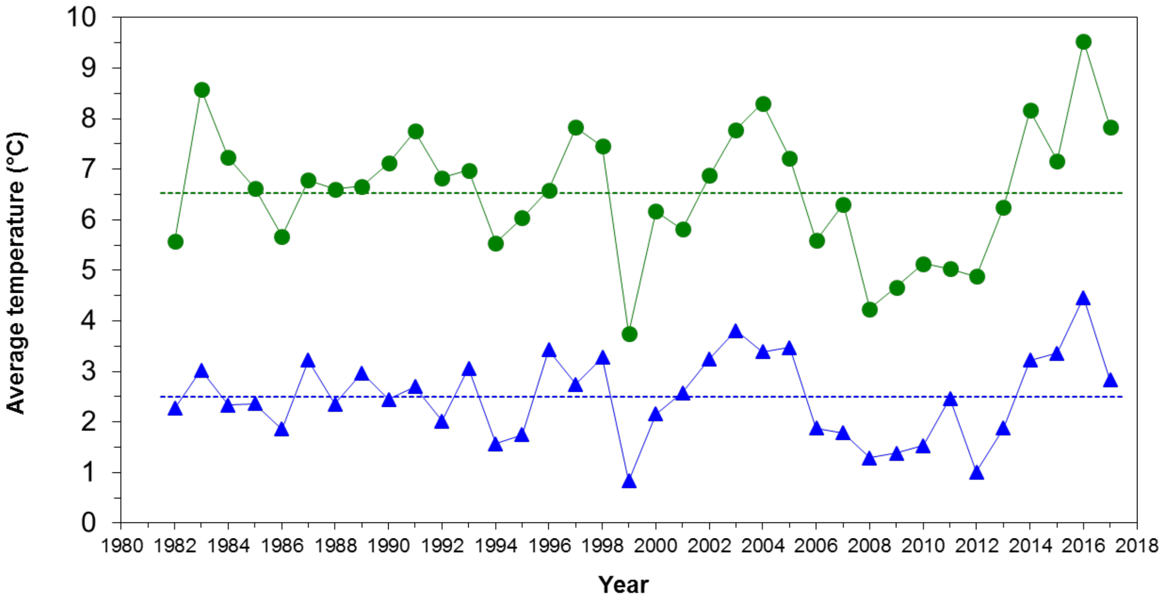

Figure 27: Average summer surface (green dots) and bottom (blue triangles) temperatures (°C) of the eastern Bering Sea shelf collected during the standard bottom trawl surveys from 1982–2017. Water temperature samples from each station were weighted by the proportion of their assigned stratum area. Dotted line represents the time series mean for 1982–2017.

Factors influencing observed trends: Warm and cold years are the result of interannual variability in the extent, duration, and timing of sea ice retreat on the eastern Bering Sea shelf. During

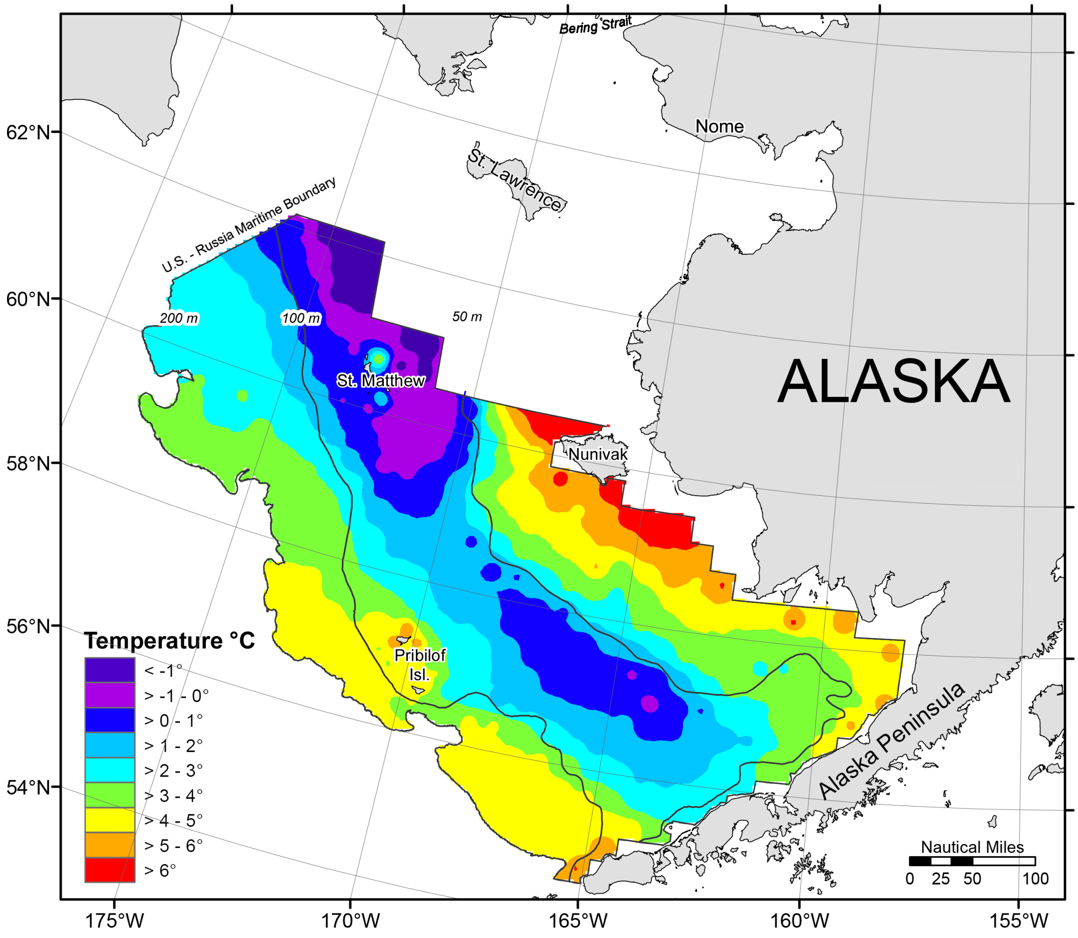

Figure 28: Contour map of the near-bottom temperatures from the 2017 eastern Bering Sea shelf bottom trawl survey.

warm years, sea ice generally does not extend as far down the shelf and retreats sooner.

Implications: The relatively large interannual fluctuations in bottom temperature on the eastern Bering Sea shelf can influence the spatial and temporal distribution of groundfishes and the structure and ecology of the marine community (Kotwicki and Lauth, 2013; Mueter and Litzow, 2008; Spencer, 2008). The timing of phytoplankton and subsequent zooplankton blooms are also affected by the extent of sea ice and timing of its retreat which in turn can affect survival and recruitment in larval and juvenile fishes as well as the energy flow in the system (Hunt et al., 2002; Coyle et al., 2011; Coyle and Gibson, 2017).

Variations in Temperature and Salinity During Late Summer/Early Fall 2002–2016 in the Eastern Bering Sea - BASIS

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Last updated: August 2017

Description of indicator: Oceanographic and fisheries data were collected over the eastern Bering Sea (EBS) shelf during fall 2002–2016 for a multiyear fisheries oceanography research program, Bering-Arctic-SubArctic Integrated Survey (BASIS). Stations were located between 54.5°N and 65°N, at ∼60 km resolution. Bristol Bay stations were sampled from mid-August to early September, while stations in the central and northern EBS were generally sampled from mid-September to early October. Physical oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles. Mean temperature and salinity above and below the mixed layer depth (MLD) were estimated for each station following methods in Danielson et al. (2011). Normalized anomalies (mean yearly value minus average value over 2002–2016 normalized by standard deviation) of temperature and salinity were separately computed for each Bering Sea Project region (Ortiz et al., 2012) (Figures 29–33). Normalized anomalies of MLD were similarly estimated for middle and outer domain regions (Figure 34). Only station locations sampled 5+ years were included in the analyses (Figure 29).

Status and trends: Temperatures above and below the MLD (Tabove, Tbelow) were roughly warmer than average in 2002–2005, average in 2006, and cooler than average in 2007–2012 (Figures 30 and 31). In 2014 and 2016, Tabove was high for all regions (with the exception of St. Matthew Island in 2014), whereas in 2015 it was above average in only two regions, likely due to the early onset of fall mixing which deepened the MLD in 2015 (Figure 34). Tbelow was above average primarily in southern regions in 2014 and 2015. In contrast, in 2016 Tbelow was high in both southern and northern regions, similar to the earlier warm periods of 2003–2005. Salinities above and below the MLD (Sabove, Sbelow) for the south middle shelf (regions 3 and 6) were generally higher in warm years (2002–2005, 2014–2016) than in cold years (2006–2012) (Figures 32 and 33). With the exception of 2015, the average MLD varied ∼10 m in the south middle domain (regions 3, 6), 6–7 m in the north middle domain (regions 9, 10), and 13 m in the south outer domain (region 4); variations did not appear to co-vary with warm or cold year periods (Figure 34).

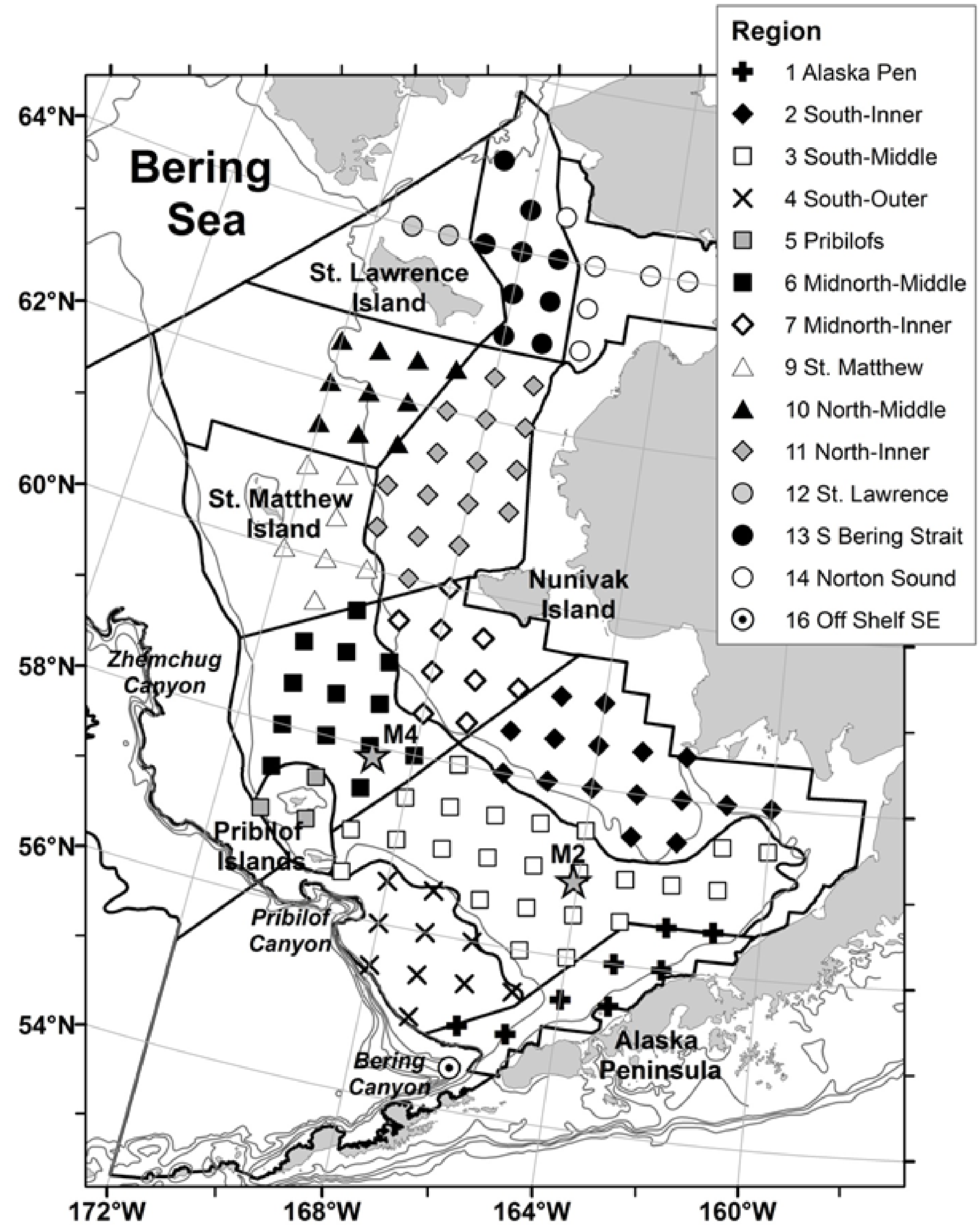


Figure 29: Stations within each Bering Sea Project region (Ortiz et al., 2012) sampled a minimum of 5 years between 2002 and 2016. We sampled three inner shelf regions (regions 2, 7, 11), six middle shelf regions (regions 1, 3, 5, 6, 9, 10), one outer shelf region (region 4), and three regions north and east of St. Lawrence Island (regions 12, 13, and 14).

Table 1. Mean Tabove (°C) color coded with anaomaly normalized by standard deviation for each region. Red indicates above average (> 0.5) no shading indicates average (-0.5 to 0.5) and blue indicates belo

Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Inner	South	2	11.7	11.4	12.5	12.7	9.4	10.1	8.9	9.8	8.4	8.8	8.0		13.4	11.0	13.7
	Mid-north	7	10.1	9.9	11.1	8.9	8.2	9.4	7.6	8.2	7.8	7.2	7.2		11.5	9.0	12.1
	North	11	8.7	7.8	10.0	7.1	7.9	8.4		8.2	8.5	7.6	7.2	8.6	9.9		11.4
Middle	AK Penn	1	11.3	11.1	10.5	11.7	10.1	10.3	9.6	9.1	8.9	9.0	9.4		12.4	11.1	12.2
	South	3	11.5	11.7	12.2	11.2	9.8	10.9	8.9	7.8	8.5	8.6	8.6		13.4	10.9	13.6
	Pribilofs	5	9.2		10.6	9.7	8.9	8.0		6.9		8.9	6.5		10.0		11.1
	Mid-north	6		9.7	11.3	8.1	9.5	7.5	7.4	7.5	7.9	7.8	6.1		11.5	8.2	11.0
	St Matthew	9	8.8	7.4	8.9	6.7	7.5	6.8		7.5	7.1	7.4	3.8		7.7		9.9
	North	10	7.9		9.4	7.1	8.1	7.8		7.6	7.6	6.3		6.6	10.0		9.8
Outer	South	4	10.2	10.4	10.5	10.0	10.0	10.5		8.0	9.6	8.9	8.9		12.2	10.6	13.0
> 63°N	St Lawrenc	12	6.4	8.7	9.1		8.4	8.9		6.7	5.4	5.1	6.1	5.7			
	S Bering Str	13	6.2	7.3	10.3	7.9	7.2	8.8		6.9	7.5	5.9	5.0	6.4	9.9		8.4
	Norton Sou	14	7.4	10.5	12.0		10.4	10.4		9.7	9.0	8.3	7.5	9.5	10.7		11.8
Offshore	southeast	16	9.0	9.7	8.2	8.8	8.3				8.2	8.8			9.2		

Table 2. Mean Tbelow(°C) color coded by normalized anaomaly as described in Table 1.

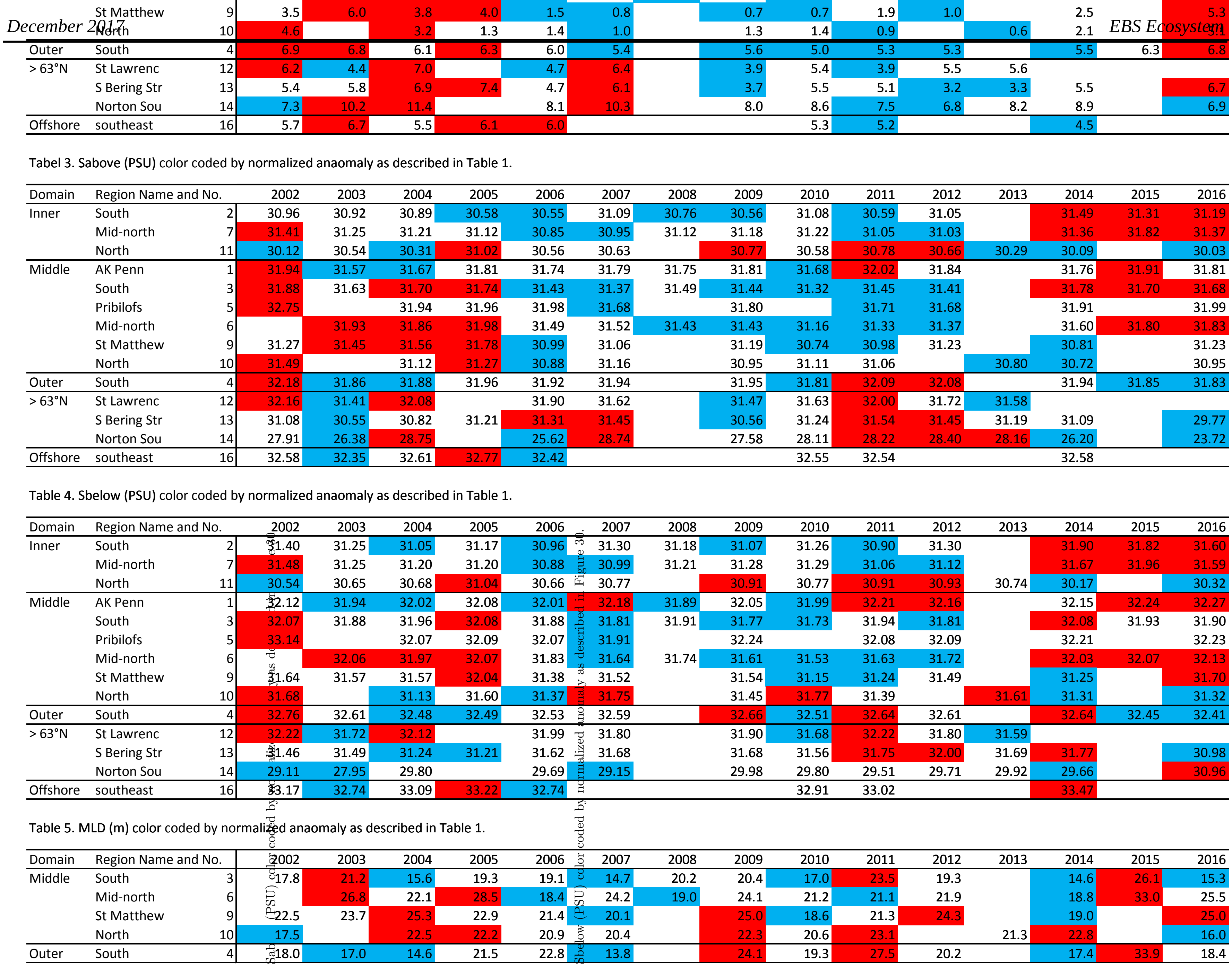
Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Inner	South	2	8.7	9.3	9.5	9.2	7.9	6.3	6.5	7.3	7.1	7.0	6.5		6.3	7.3	9.0
	Mid-north	7	9.5	9.9	9.9	8.4	7.6	7.9	6.1	7.6	7.3	7.2	6.5		6.1	7.2	8.8
	North	11	7.3	7.7	9.0	7.0	6.7	7.1		6.4	6.1	6.8	6.3	5.2	8.8		9.3
Middle	AK Penn	1	7.7	7.8	7.8	7.8	7.9	5.3	6.8	7.0	6.0	6.9	5.4		7.2	7.9	7.1
	South	3	4.9	5.2	5.2	5.9	4.1	2.9	2.9	2.6	2.2	3.9	2.0		4.8	5.3	6.8
	Pribilofs	5	4.1		7.6	7.5	5.5	4.2		4.2		5.0	3.6		5.9		7.5
	Mid-north	6		5.7	4.3	5.5	2.2	2.9	1.9	3.4	1.9	3.5	2.2		3.4	3.9	5.2
	St Matthew	9	3.5	6.0	3.8	4.0	1.5	0.8		0.7	0.7	1.9	1.0		2.5		5.3
	North	10	4.6		3.2	1.3	1.4	1.0		1.3	1.4	0.9		0.6	2.1		5.1
Outer	South	4	6.9	6.8	6.1	6.3	6.0	5.4		5.6	5.0	5.3	5.3		5.5	6.3	6.8
> 63°N	St Lawrenc	12	6.2	4.4	7.0		4.7	6.4		3.9	5.4	3.9	5.5	5.6			
	S Bering Str	13	5.4	5.8	6.9	7.4	4.7	6.1		3.7	5.5	5.1	3.2	3.3	5.5		6.7
	Norton Sou	14	7.3	10.2	11.4		8.1	10.3		8.0	8.6	7.5	6.8	8.2	8.9		6.9
Offshore	southeast	16	5.7	6.7	5.5	6.1	6.0				5.3	5.2			4.5		

Tabel 3. Sabove (PSU) color coded by normalized anaomaly as described in Table 1.

Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Inner	South	2	30.96	30.92	30.89	30.58	30.55	31.09	30.76	30.56	31.08	30.59	31.05		31.49	31.31	31.19
	Mid-north	7	31.41	31.25	31.21	31.12	30.85	30.95	31.12	31.18	31.22	31.05	31.03		31.36	31.82	31.37
	North	11	30.12	30.54	30.31	31.02	30.56	30.63		30.77	30.58	30.78	30.66	30.29	30.09		30.03
Middle	AK Penn	1	31.94	31.57	31.67	31.81	31.74	31.79	31.75	31.81	31.68	32.02	31.84		31.76	31.91	31.81
	South	3	31.88	31.63	31.70	31.74	31.43	31.37	31.49	31.44	31.32	31.45	31.41		31.78	31.70	31.68
	Pribilofs	5	32.75		31.94	31.96	31.98	31.68		31.80		31.71	31.68		31.91		31.99
	Mid-north	6		31.93	31.86	31.98	31.49	31.52	31.43	31.43	31.16	31.33	31.37		31.60	31.80	31.83
	St Matthew	9	31.27	31.45	31.56	31.78	30.99	31.06		31.19	30.74	30.98	31.23		30.81		31.23
	North	10	31.49		31.12	31.27	30.88	31.16		30.95	31.11	31.06		30.80	30.72		30.95
Outer	South	4	32.18	31.86	31.88	31.96	31.92	31.94		31.95	31.81	32.09	32.08		31.94	31.85	31.83
> 63°N	St Lawrenc	12	32.16	31.41	32.08		31.90	31.62		31.47	31.63	32.00	31.72	31.58			
	S Bering Str	13	31.08	30.55	30.82	31.21	31.31	31.45		30.56	31.24	31.54	31.45	31.19	31.09		29.77
	Norton Sou	14	27.91	26.38	28.75		25.62	28.74		27.58	28.11	28.22	28.40	28.16	26.20		23.72
Offshore	southeast	16	32.58	32.35	32.61	32.77	32.42				32.55	32.54			32.58		

es above average (

Table 4. Sbelow (PSU) y normalized anaomaly as described in Table 1.



Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	St Matthew	9	3.5	6.0	3.8	4.0	1.5	0.8		0.7	0.7	1.9	1.0		2.5		5.3
	North	10	4.6		3.2	1.3	1.4	1.0		1.3	1.4	0.9		0.6	2.1		3.1
Outer	South	4	6.9	6.8	6.1	6.3	6.0	5.4		5.6	5.0	5.3	5.3		5.5	6.3	6.8
> 63°N	St Lawrenc	12	6.2	4.4	7.0		4.7	6.4		3.9	5.4	3.9	5.5	5.6			
	S Bering Str	13	5.4	5.8	6.9	7.4	4.7	6.1		3.7	5.5	5.1	3.2	3.3	5.5		6.7
	Norton Sou	14	7.3	10.2	11.4		8.1	10.3		8.0	8.6	7.5	6.8	8.2	8.9		6.9
Offshore	southeast	16	5.7	6.7	5.5	6.1	6.0				5.3	5.2			4.5		

Tabel 3. Sabove (PSU) color coded by normalized anaomaly as described in Table 1.

Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Inner	South	2	30.96	30.92	30.89	30.58	30.55	31.09	30.76	30.56	31.08	30.59	31.05		31.49	31.31	31.19
	Mid-north	7	31.41	31.25	31.21	31.12	30.85	30.95	31.12	31.18	31.22	31.05	31.03		31.36	31.82	31.37
	North	11	30.12	30.54	30.31	31.02	30.56	30.63		30.77	30.58	30.78	30.66	30.29	30.09		30.03
Middle	AK Penn	1	31.94	31.57	31.67	31.81	31.74	31.79	31.75	31.81	31.68	32.02	31.84		31.76	31.91	31.81
	South	3	31.88	31.63	31.70	31.74	31.43	31.37	31.49	31.44	31.32	31.45	31.41		31.78	31.70	31.68
	Pribilofs	5	32.75		31.94	31.96	31.98	31.68		31.80		31.71	31.68		31.91		31.99
	Mid-north	6		31.93	31.86	31.98	31.49	31.52	31.43	31.43	31.16	31.33	31.37		31.60	31.80	31.83
	St Matthew	9	31.27	31.45	31.56	31.78	30.99	31.06		31.19	30.74	30.98	31.23		30.81		31.23
	North	10	31.49		31.12	31.27	30.88	31.16		30.95	31.11	31.06		30.80	30.72		30.95
Outer	South	4	32.18	31.86	31.88	31.96	31.92	31.94		31.95	31.81	32.09	32.08		31.94	31.85	31.83
> 63°N	St Lawrenc	12	32.16	31.41	32.08		31.90	31.62		31.47	31.63	32.00	31.72	31.58			
	S Bering Str	13	31.08	30.55	30.82	31.21	31.31	31.45		30.56	31.24	31.54	31.45	31.19	31.09		29.77
	Norton Sou	14	27.91	26.38	28.75		25.62	28.74		27.58	28.11	28.22	28.40	28.16	26.20		23.72
Offshore	southeast	16	32.58	32.35	32.61	32.77	32.42				32.55	32.54			32.58		

Table 4. Sbelow (PSU) color coded by normalized anaomaly as described in Table 1.

Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Inner	South	2	31.40	31.25	31.05	31.17	30.96	31.30	31.18	31.07	31.26	30.90	31.30		31.90	31.82	31.60
	Mid-north	7	31.48	31.25	31.20	31.20	30.88	30.99	31.21	31.28	31.29	31.06	31.12		31.67	31.96	31.59
	North	11	30.54	30.65	30.68	31.04	30.66	30.77		30.91	30.77	30.91	30.93	30.74	30.17		30.32
Middle	AK Penn	1	32.12	31.94	32.02	32.08	32.01	32.18	31.89	32.05	31.99	32.21	32.16		32.15	32.24	32.27
	South	3	32.07	31.88	31.96	32.08	31.88	31.81	31.91	31.77	31.73	31.94	31.81		32.08	31.93	31.90
	Pribilofs	5	33.14		32.07	32.09	32.07	31.91		32.24		32.08	32.09		32.21		32.23
	Mid-north	6		32.06	31.97	32.07	31.83	31.64	31.74	31.61	31.53	31.63	31.72		32.03	32.07	32.13
	St Matthew	9	31.64	31.57	31.57	32.04	31.38	31.52		31.54	31.15	31.24	31.49		31.25		31.70
	North	10	31.68		31.13	31.60	31.37	31.75		31.45	31.77	31.39		31.61	31.31		31.32
Outer	South	4	32.76	32.61	32.48	32.49	32.53	32.59		32.66	32.51	32.64	32.61		32.64	32.45	32.41
> 63°N	St Lawrenc	12	32.22	31.72	32.12		31.99	31.80		31.90	31.68	32.22	31.80	31.59			
	S Bering Str	13	31.46	31.49	31.24	31.21	31.62	31.68		31.68	31.56	31.75	32.00	31.69	31.77		30.98
	Norton Sou	14	29.11	27.95	29.80		29.69	29.15		29.98	29.80	29.51	29.71	29.92	29.66		30.96
Offshore	southeast	16	33.17	32.74	33.09	33.22	32.74				32.91	33.02			33.47		

Table 5. MLD (m) color coded by normalized anaomaly as described in Table 1.

Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Middle	South	3	17.8	21.2	15.6	19.3	19.1	14.7	20.2	20.4	17.0	23.5	19.3		14.6	26.1	15.3
	Mid-north	6		26.8	22.1	28.5	18.4	24.2	19.0	24.1	21.2	21.1	21.9		18.8	33.0	25.5
	St Matthew	9	22.5	23.7	25.3	22.9	21.4	20.1		25.0	18.6	21.3	24.3		19.0		25.0
	North	10	17.5		22.5	22.2	20.9	20.4		22.3	20.6	23.1		21.3	22.8		16.0
Outer	South	4	18.0	17.0	14.6	21.5	22.8	13.8		24.1	19.3	27.5	20.2		17.4	33.9	18.4

Figure 32: Sabove (PSU) color coded by normalized anomaly as described in Figure 30.

Figure 33: Sbelow (PSU) color coded by normalized anomaly as described in Figure 30.

	North	10	31.49		31.12	31.27	30.88	31.16		30.95	31.11	31.06		30.80	30.72		30.95
Outer	South	4	32.18	31.86	31.88	31.96	31.92	31.94		31.95	31.81	32.09	32.08		31.94	31.85	31.83
> 63°N	St Lawrenc	12	32.16	31.41	32.08		31.90	31.62		31.47	31.63	32.00	31.72	31.58			
	S Bering Str	13	31.08	30.55	30.82	31.21	31.31	31.45		30.56	31.24	31.54	31.45	31.19	31.09		29.77
	Norton Sou	14	27.91	26.38	28.75		25.62	28.74		27.58	28.11	28.22	28.40	28.16	26.20		23.72
Offshore	southeast	16	32.58	32.35	32.61	32.77	32.42				32.55	32.54			32.58		

Table 4. Sbelow (PSU) color coded by normalized anaomaly as described in Table 1.

Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Inner	South	2	31.40	31.25	31.05	31.17	30.96	31.30	31.18	31.07	31.26	30.90	31.30		31.90	31.82	31.60
	Mid-north	7	31.48	31.25	31.20	31.20	30.88	30.99	31.21	31.28	31.29	31.06	31.12		31.67	31.96	31.59
	North	11	30.54	30.65	30.68	31.04	30.66	30.77		30.91	30.77	30.91	30.93	30.74	30.17		30.32
Middle	AK Penn	1	32.12	31.94	32.02	32.08	32.01	32.18	31.89	32.05	31.99	32.21	32.16		32.15	32.24	32.27
	South	3	32.07	31.88	31.96	32.08	31.88	31.81	31.91	31.77	31.73	31.94	31.81		32.08	31.93	31.90
	Pribilofs	5	33.14		32.07	32.09	32.07	31.91		32.24		32.08	32.09		32.21		32.23
	Mid-north	6		32.06	31.97	32.07	31.83	31.64	31.74	31.61	31.53	31.63	31.72		32.03	32.07	32.13
	St Matthew	9	31.64	31.57	31.57	32.04	31.38	31.52		31.54	31.15	31.24	31.49		31.25		31.70
	North	10	31.68		31.13	31.60	31.37	31.75		31.45	31.77	31.39		31.61	31.31		31.32
Outer	South	4	32.76	32.61	32.48	32.49	32.53	32.59		32.66	32.51	32.64	32.61		32.64	32.45	32.41
> 63°N	St Lawrenc	12	32.22	31.72	32.12		31.99	31.80		31.90	31.68	32.22	31.80	31.59			
	S Bering Str	13	31.46	31.49	31.24	31.21	31.62	31.68		31.68	31.56	31.75	32.00	31.69	31.77		30.98
	Norton Sou	14	29.11	27.95	29.80		29.69	29.15		29.98	29.80	29.51	29.71	29.92	29.66		30.96
Offshore	southeast	16	33.17	32.74	33.09	33.22	32.74				32.91	33.02			33.47		

Table 5. MLD (m) color coded by normalized anaomaly as described in Table 1.

Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Middle	South	3	17.8	21.2	15.6	19.3	19.1	14.7	20.2	20.4	17.0	23.5	19.3		14.6	26.1	15.3
	Mid-north	6		26.8	22.1	28.5	18.4	24.2	19.0	24.1	21.2	21.1	21.9		18.8	33.0	25.5
	St Matthew	9	22.5	23.7	25.3	22.9	21.4	20.1		25.0	18.6	21.3	24.3		19.0		25.0
	North	10	17.5		22.5	22.2	20.9	20.4		22.3	20.6	23.1		21.3	22.8		16.0
Outer	South	4	18.0	17.0	14.6	21.5	22.8	13.8		24.1	19.3	27.5	20.2		17.4	33.9	18.4

Figure 34: MLD (m) color coded by normalized anomaly as described in Figure 31.

Factors influencing observed trends: Sea ice during winter and spring extended farther to the south as the climate cooled. The cold pool is related to sea ice and thus extends farther south in years with higher sea ice coverage in the southern Bering Sea. The cold pool (located below the MLD) is always present in the northern Bering Sea since ice covers this region each year (Stabeno et al., 2012). The lower bottom salinities near the coast (e.g., inner domain regions and Norton Sound) indicate major freshwater input from the Yukon and Kuskoquim rivers (Figures 29, 32, and 33). Variations in salinity on the middle and outer shelf may be partially related to wind direction, with southeasterly winds producing enhanced on-shelf flows of oceanic water in warm years (Danielson et al., 2012). Therefore, the lower salinity in cold years on the south middle shelf may be due to ice melt and possibly reduced onshore flow of higher salinity waters. Tabove and Sabove are influenced by temporal mixing events relating to episodic wind mixing/storm events, while Tbelow and Sbelow may better reflect longer term climatic shifts. For example, in 2005 (a warm year), Tbelow was warmer than average in the middle domain regions 3, 6, and 9 reflecting the lack of sea ice during spring (Figure 31). In contrast, Tabove was average in these regions (Figure 30), due to high wind mixing in August prior to and during the survey (Eisner et al., 2015).

Implications: The variations of temperature and salinity between Bering Sea Project regions indicate that water mass properties vary considerably both spatially (horizontally across regions and vertically above and below the MLD) and interannually, and will impact ecosystem dynamics and distributions of zooplankton, fish, and other higher trophic levels. For example, larger more lipid rich zooplankton generally show increases in abundance in both the water column and in forage fish diets in cold compared to warm years (Coyle et al., 2011; Eisner et al., 2014).

Eastern Bering Sea Winter Spawning Flatfish Recruitment and Wind Forcing

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Description of indicator: Wilderbuer et al. (2002, 2013) summarized the recruitment of winter-spawning flatfish in relation to decadal atmospheric forcing, linking favorable recruitment to the direction of wind forcing during spring. OSCURS model time series runs indicated in-shore advection to favorable nursery grounds in Bristol Bay during the 1980s. The pattern change to off-shore in the 1990–97 time series coincided with below-average recruitment for Northern rock sole (*Lepidopsetta polyxystra*), Arrowtooth flounder (*Atheresthes stomias*), and Flathead sole (*Hippoglossoides elassodon*) relative to the 1980s. Favorable springtime winds were present again in the early 2000s which also corresponded with improved recruitment. The time series is updated through 2017 and shown for 2009 through 2017 in Figure 35.

Status and trends: The 2017 springtime drift pattern was mixed, with winds during the first 60 days of the 90 day drift index being unfavorable off-shore winds that changed to a northerly on-shore direction in the last 30 days of the index. This causes some difficulty in interpretation of drift patterns, but they may be more consistent with years of below-average recruitment for winter-

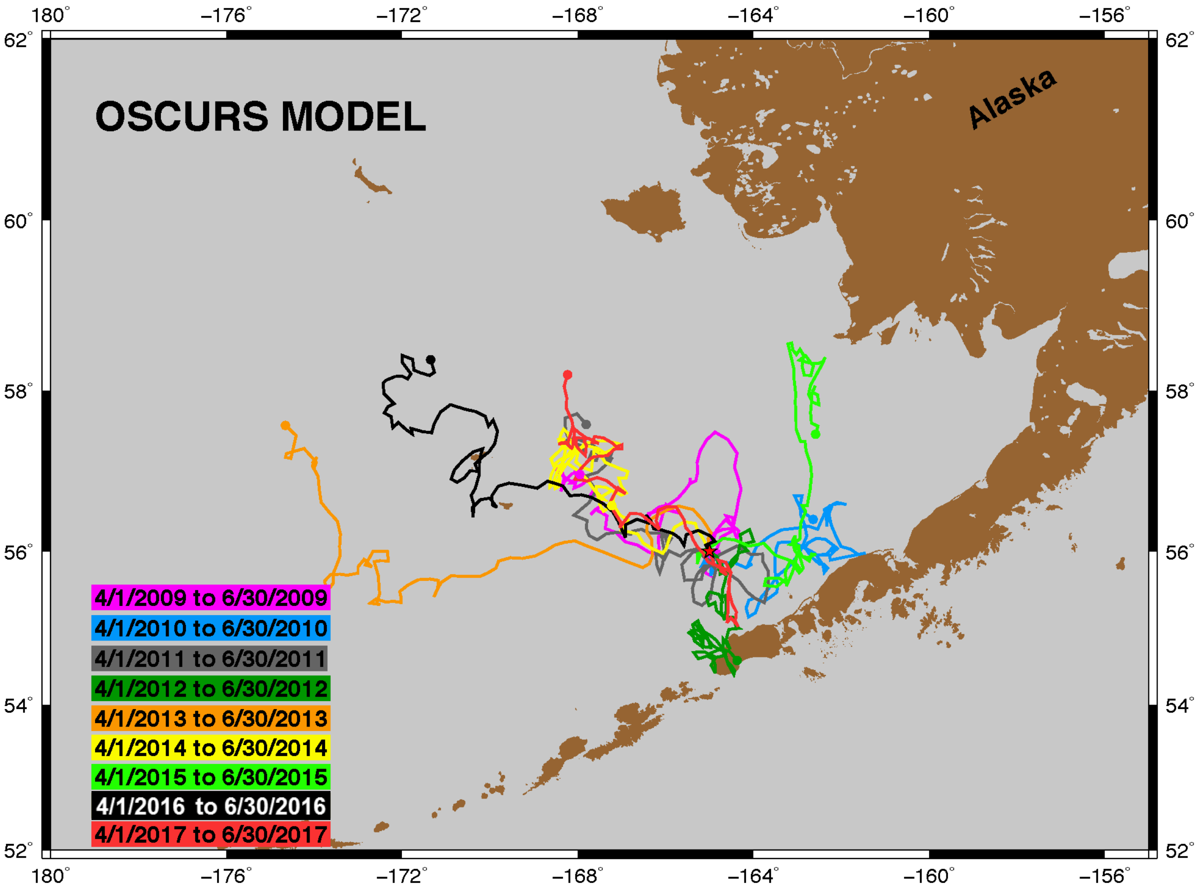

Figure 35: OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56°N, 164°W from April 1–June 30 for 2009–2017.

spawning flatfish. Only two years out of the past ten have OSCURS runs that are consistent with those which produced above-average recruitment in the original analysis (2008, 2015). The north-northeast drift pattern suggests that larvae may have been advected to favorable, near-shore areas of Bristol Bay by the time of their metamorphosis to a benthic form of juvenile flatfish. Preliminary estimates of Northern rock sole recruitment in recent years are consistent with this larval drift hypothesis. For Arrowtooth flounder and Flathead sole, the correspondence between the springtime drift pattern from OSCURS and estimates of year class strength have weakened since the 1990s. Arrowtooth flounder produced year classes of average strength during some off-shore drift years, suggesting that this species may have different timing for spawning, larval occurrence, and settlement preferences than Northern rock sole. In the case of Flathead sole, the 2001 and 2003 year-classes appear stronger than the weak recruitment that has persisted since the 1990s.

Implications: The 2017 springtime drift pattern appears to be consistent with years when below-average recruitment occurred for Northern rock sole, Arrowtooth flounder, and Flathead sole. Wind patterns in 2008 and 2015 may promote average to above-average recruitment. 2010 featured a mixture of wind direction as there were strong northerly winds for part of the spring but also southerly winds that would suggest increased larval dispersal to Unimak Island and the Alaska Peninsula.

Habitat

Structural Epifauna - Eastern Bering Sea Shelf

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Description of indicator: Groups considered to be structural epifauna include: sea whips, corals, anemones, and sponges. Corals are rarely encountered on the eastern Bering Sea shelf so they were not included here. Relative CPUE by weight was calculated and plotted for each species group by year for 1982–2017. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: Relative catch rates for both sponges and sea anemones remained similar to estimates from 2016, which were lower than the previous 7 years, and sea whip estimates decreased significantly from 2016. These trends should be viewed with caution, however, because the quality and specificity of field identifications and their enumeration have varied over the time series (Stevenson and Hoff, 2009; Stevenson et al., 2016). Moreover, the identification of trends is uncertain given the large variability in relative CPUE (Figure 36).

Factors influencing observed trends: Further research in several areas would benefit the interpretation of structural epifauna trends including systematics and taxonomy of Bering Sea shelf invertebrates; survey gear selectivity; and the life history characteristics of the epibenthic organisms captured by the survey trawl.

Implications: Understanding the trends as well as the distribution patterns of structural epifauna is important for modeling habitat to develop spatial management plans for protecting habitat, understanding fishing gear impacts and predicting responses to future climate change (Rooper et al., 2016); however, more research on the eastern Bering Sea shelf will be needed to determine if there are definitive links.

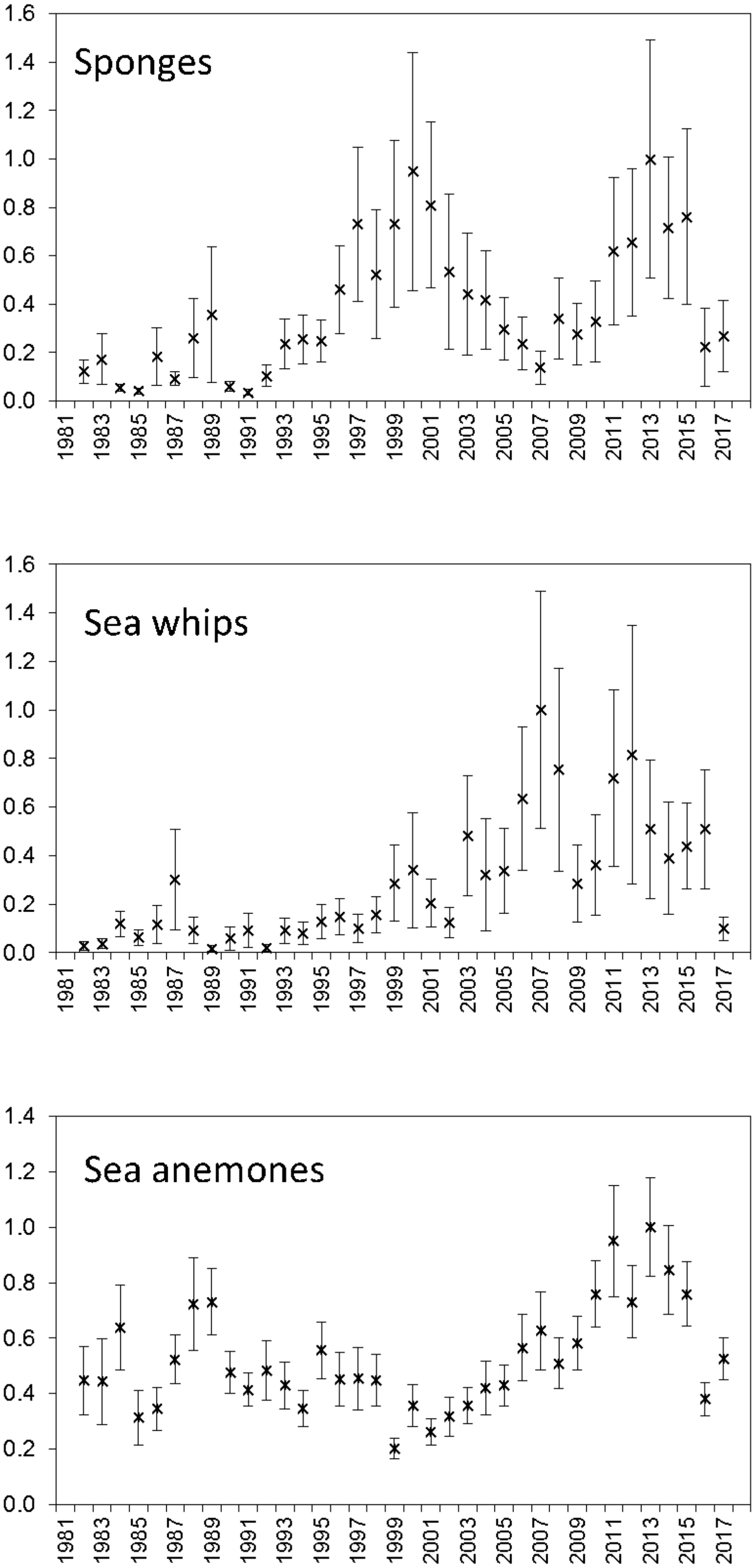

Figure 36: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for benthic epifauna during the May to August time period from 1982–2017.

Primary Production

Dissolved Total Inorganic Nitrogen Concentrations Above and Below the Pycnocline in the Eastern Bering Sea

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Description of indicator: We present total dissolved inorganic nitrogen (DIN) concentrations (μm) above and below the pycnocline during late summer/early fall 2003–2016 in the eastern Bering Sea. Data are divided by oceanographic domain (inner [0–50 m] and middle [51–100 m]) and further split between the northern and southern shelf at 60°N. The outer domain is left out due to inconsistent sampling. DIN (nitrate, nitrite, and ammonia) above the pycnocline at the surface mixed layer represents what is currently available for primary production at the end of summer (storm activity/wind mixing of deep nutrients to the surface tend to be lower during the summer, and surface nutrient stores are often depleted). Nutrients below the pycnocline represent what is potentially available should wind mixing become strong enough to break down the pycnocline and mix deeper layers to the surface. Sometime during autumn when wind storms increase in frequency and intensity, there is usually a second significant bloom of phytoplankton (though smaller than the spring bloom) after the summer pycnocline breaks down. During this time the deep nutrient stores are brought to the surface. This process is important for sending a new round of energy through the food web just prior to the onset of winter.

Status and trends: DIN above and below the pycnocline varies from year to year over the eastern Bering Sea shelf in all domains. As expected, the inner domain, which is often more thoroughly mixed, is more highly correlated between the surface and deep waters (with significant correlation in the north, $P = 0.002$), while in the middle domain there is considerably less correlation (Figure 37). Also as expected, deeper stores of nutrients are more often found at higher concentrations than their surface counterparts. In addition, a significant decreasing trend is seen in surface DIN concentrations within the southern middle domain over time ($P < 0.05$, Figure 38).

Factors influencing observed trends: During summer, the strength and frequency of summer storm events and water column stratification influence the amount of nutrients brought to surface waters from depth. Late summer concentrations of DIN at the surface may serve as an indicator of nutrient availability, with higher concentrations seen during windy years and lower stratification, and lower concentrations seen when storm activity is minimal and stratification is high (Gann et al., 2016; Eisner et al., 2016). Accordingly, years with higher water column chlorophyll a concentrations (a proxy for phytoplankton biomass) are associated with higher wind mixing (see p. 91).

Implications: A decreasing trend over time in surface DIN concentrations could imply that summertime wind mixing events are occurring less frequently and with less intensity in recent years. This trend could limit the amount of primary production available as food for lower trophic levels that may ultimately be adversely affected. Diminished nutrient stores leading to lower production in the upper water column may directly affect food stores for higher trophic levels and lead to slowed growth of age-0 pollock during summer months.

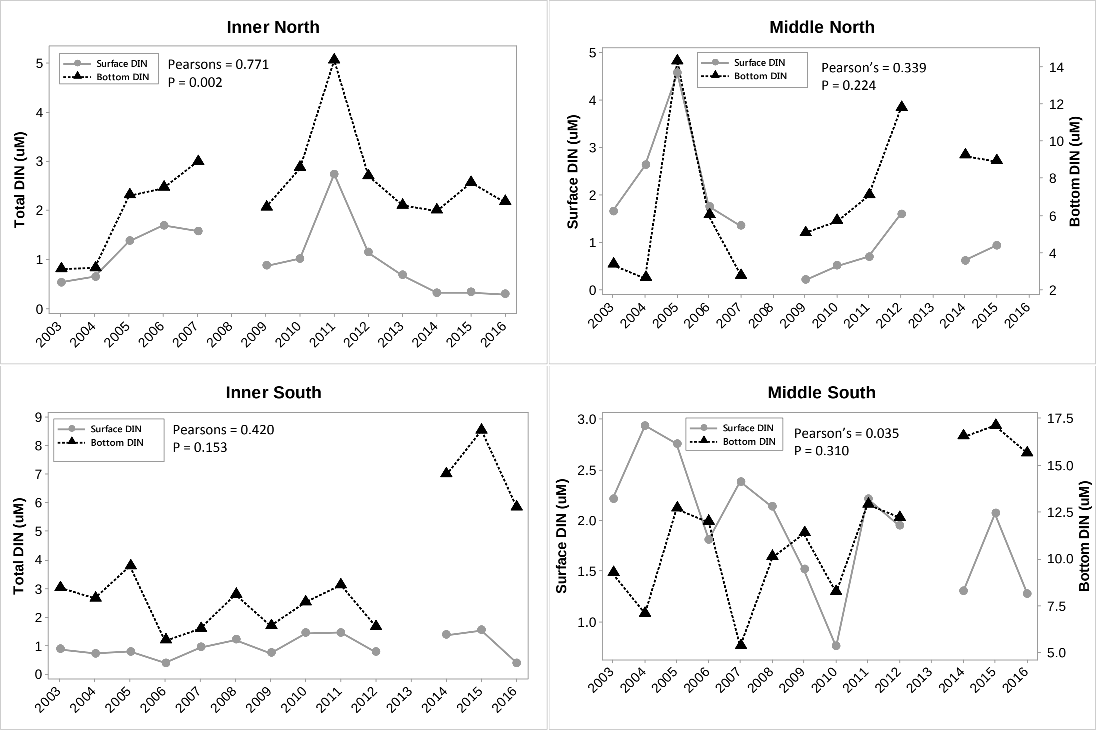

Figure 37: Mean total dissolved inorganic nitrogen concentrations (μm) above and below the pycnocline with Pearson's correlation coefficient (surface DIN vs. bottom DIN) and P-values shown (2003–2016). Note: the middle domain was not surveyed in the northern Bering Sea during 2016.

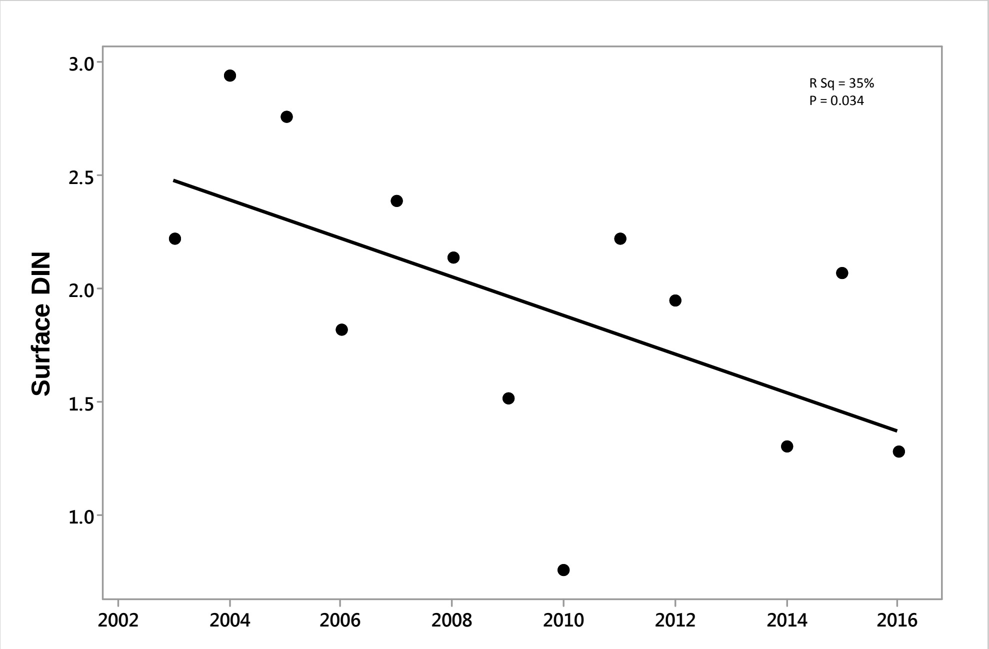

Figure 38: Surface dissolved inorganic nitrogen (DIN, μm) in the middle south domain versus year with an R^2 value of 35% and $P < 0.05$.

Phytoplankton Biomass and Size Structure During Late Summer to Early Fall in the Eastern Bering Sea

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Last updated: August 2017

Description of indicator: BASIS fisheries oceanography surveys were conducted in the eastern Bering Sea mid-August to late September for six warm (2003–2005, 2014–2016), one average (2006), and six cold (2007–2012) years. Variations in chlorophyll a (chla) were used to evaluate spatial and interannual differences in total phytoplankton biomass and size structure (an indication of phytoplankton species). The ratio of large (>10 μm) phytoplankton biomass to total biomass (>10 μm chla / total chla) were estimated from discrete water samples filtered through GFF and 10 μm filters and analyzed with standard fluorometric methods (Parsons et al., 1984). Integrated chla values were estimated from CTD fluorescence profiles, calibrated with discrete chla (GFF) samples. Chla data were averaged over the top 50 m of the water column or to the bottom for shallower stations. Water column stability was estimated over the top 70 m (Simpson et al., 1978). Similarly, a stratification index was estimated at PMEL Mooring 2 (M2) (Ladd and Stabeno, 2012; Eisner et al., 2015). Friction velocity cubed (u), a proxy for wind mixing, was obtained from NCEP reanalysis at M2 (courtesy of Nick Bond). Normalized anomalies of temperature, u , stratification index, integrated chla, and large size fraction chla are shown for the southeastern Bering Sea middle

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
T above	0.7	1.1	0.4	-0.1	-0.2	-0.8	-1.3	-0.9	-0.9	-1.2	NA	1.5	0.3	1.6
T below	0.4	0.3	0.6	-0.2	-0.3	-0.4	-0.3	-0.6	-0.1	-0.6	NA	0.1	0.3	0.7
u*	-0.5	0.6	2.7	-0.2	-0.3	-1.3	0.5	-0.1	0.0	0.1	NA	-1.1	0.4	-0.7
Stratification Index	0.3	1.6	0.6	-0.6	1.5	-1.1	-0.8	-0.1	0.0	-1.3				
Int chla	1.0	0.5	2.4	-0.6	-1.1	-1.2	0.0	-0.8	0.6	0.4	NA	-0.5	-0.2	-0.5
Large chla ratio	0.9	1.4	2.3	-0.2	-0.8	-0.6	0.2	-0.4	-0.1	-0.1	NA	-1.4	-0.6	-0.6

Figure 39: Normalized anomalies (mean yearly value minus average value over 2002–2016 normalized by standard deviation) shown for 2003 to 2016 (or to 2012 for stratification index) for the south Bering Sea middle shelf (Bering Project Regions 3 and 6, Ortiz et al. (2012)). Anomalies were calculated for temperature (T) above and below the pycnocline, integrated chla and ratio of large (>10 μm) to total chla over the top 50 m for August–September from BASIS data, and August stratification index and friction velocity cubed (u^{*3}) at PMEL mooring M2. Year is colored as red for warm, black for average, and blue for cold. Shading indicates if anomaly is positive (dark gray, >0.5), small (no shading, -0.5 to 0.5), or negative (light gray, <-0.5).

Status and trends: Highest phytoplankton biomass was observed in the south outer shelf (100–

200 m) with highest values inshore of Bering Canyon, near the Pribilof Islands, along the Aleutian Islands, north of St. Lawrence Island, and on the south inner shelf (<50 m) (Figure 40). Larger phytoplankton were observed on the inner shelf and near the Pribilof Islands, and smaller phytoplankton on the south middle and outer shelf. Integrated chla varied 3-fold among all years, with the highest values seen in 2005 in the south and 2003 in the north (Figure 41). Typically years with higher integrated chla had a greater fraction of large phytoplankton. The mean size of phytoplankton assemblages were higher in early warm (2003–2005) than in cold (2006–2012) years in the south. In contrast, in more recent warm years (2014–2016) integrated chla was average, whereas large size fraction ratios were below average (Figure 39) especially in 2014 which had the lowest percent large (highest % small) phytoplankton for our time series (Figure 41). This 2014 anomaly was due to an extensive coccolithophore bloom over the north and south middle shelf (see p. 95). Coccolithophores are small phytoplankton cells (2–5 μm) with calcium carbonate plates that give the water a milky aqua appearance. Coccolithophores were also observed in 2015 and 2016 in the south Bering Sea.

Factors influencing observed trends: Water column stability (or stratification), wind, and temperature can influence interannual and spatial variations in phytoplankton biomass. For the south middle shelf, a positive association was observed between August u^{*3} (wind mixing 2–3 weeks prior to chla sampling) and integrated chla in the top 50 m (Figure 42). Deep, nutrient-rich waters may be mixed to the surface to fuel production of assemblages of large phytoplankton (e.g., diatoms) during periods of high winds and low water column stability. Phytoplankton growth may be enhanced at higher temperatures, depending on species. For example, the highest chla and largest size fractions were seen in 2005, a period with high August wind mixing, average stability and high water column temperature (Figure 39). The lowest chla and smallest size fractions were observed in 2008, a period with low wind mixing, high stability, and low water column temperature. The low wind mixing in 2014 could also have favored formation of the coccolithophore bloom; these blooms are thought to be associated with low nutrient conditions. Spatially, low chla and small phytoplankton assemblages were seen in the area of highest stability, in the southeastern middle shelf near M2 (Figure 40).

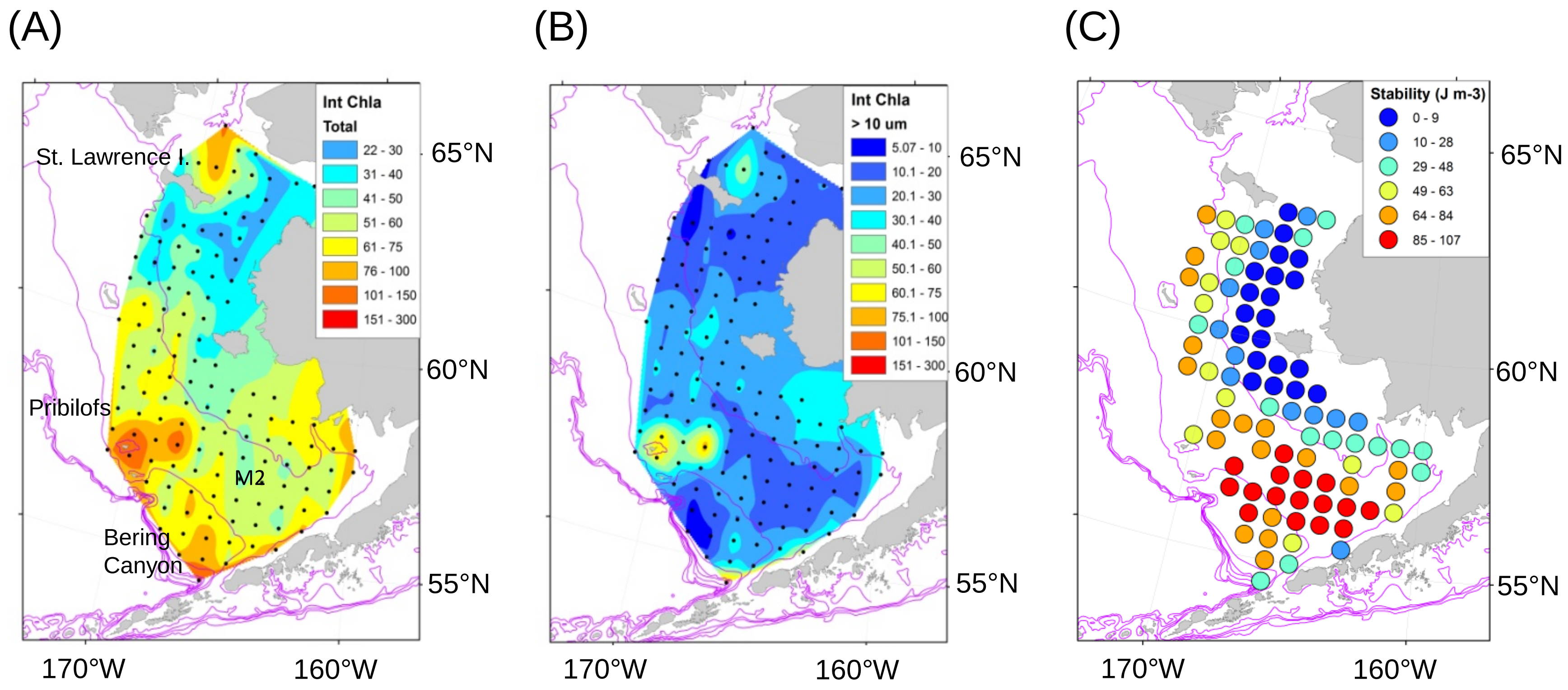

Figure 40: Contours of integrated total chla (mg m^{-2}) (A) and integrated >10 μm chla (B) averaged over 2003–2012, and stability (C) averaged over 2003–2009 for August and September. Bathymetry contours are shown for 50 m, 100 m, and 200 m (shelf break).

Figure 1. Contours of integrated total chla (mg m^{-2}) (A) and integrated > 10 µm chla (B) averaged over 2003-2012, and stability (C) averaged over 2003-2009. Bathymetry contours are shown for 50 m, 100 m and 200 m (shelf break).

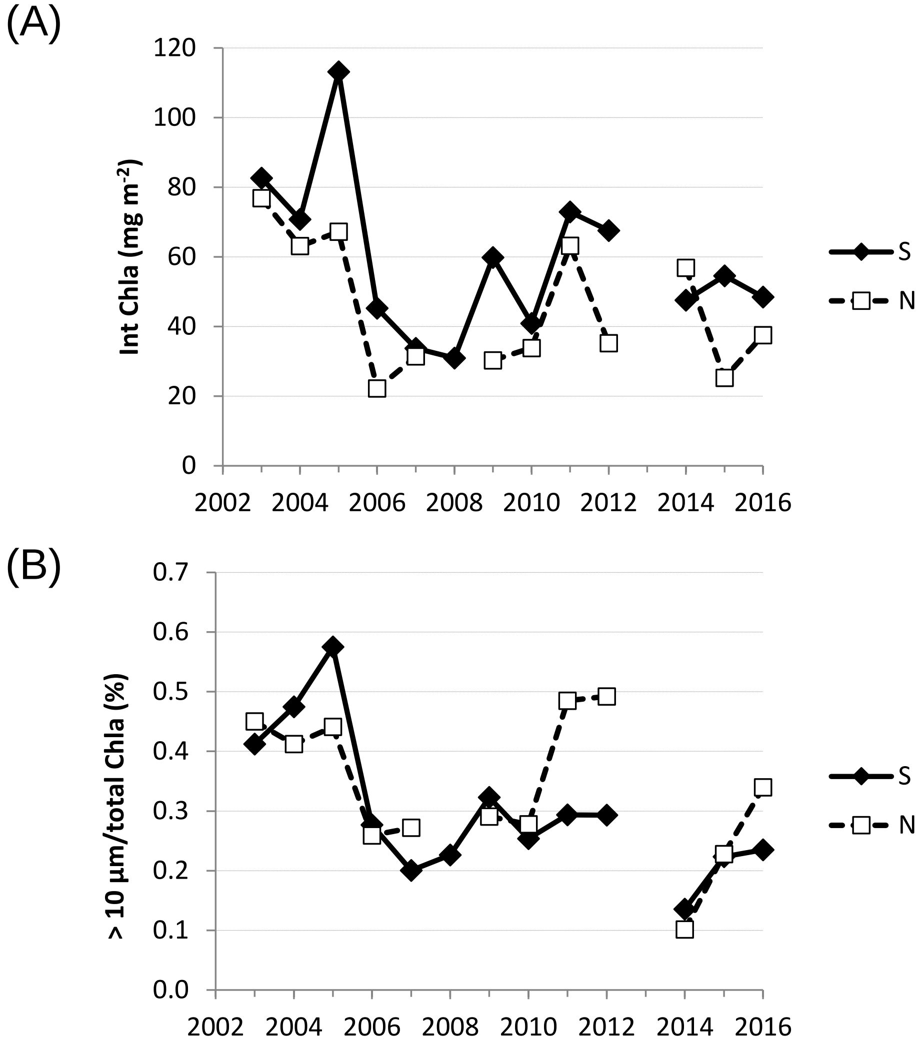

Figure 41: Integrated total chla (A) and ratio of large assemblages to total (>10 μm /total chla) (B) in the middle shelf in the south (S, 54.5 59.5 °N, Bering Sea Project Regions 3 and 6) and north (N, 60 63 °N, Bering Sea Project Regions 9 and 10) for 2003–2016. No survey in 2013. Note that north middle shelf data in 2016 were sparse (5 stations total).

Implications: Phytoplankton dynamics determine the amount and quality of food available to zooplankton and higher trophic levels, and are thus important to ecosystem function. For example, larger phytoplankton assemblages may lead to shorter food webs and a more efficient transfer of energy to seabirds, fish, and marine mammals. The cloudy water associated with coccolithophore blooms may also limit feeding by visual predators (e.g. surface feeding fish and seabirds). Our data help to characterize ecosystem processes during the critical late summer period prior to the over-wintering of key forage fish (e.g., juvenile Walleye pollock, *Gadus chalcogrammus*; Pacific cod, *Gadus macrocephalus*; salmonids) (Eisner et al., 2015).

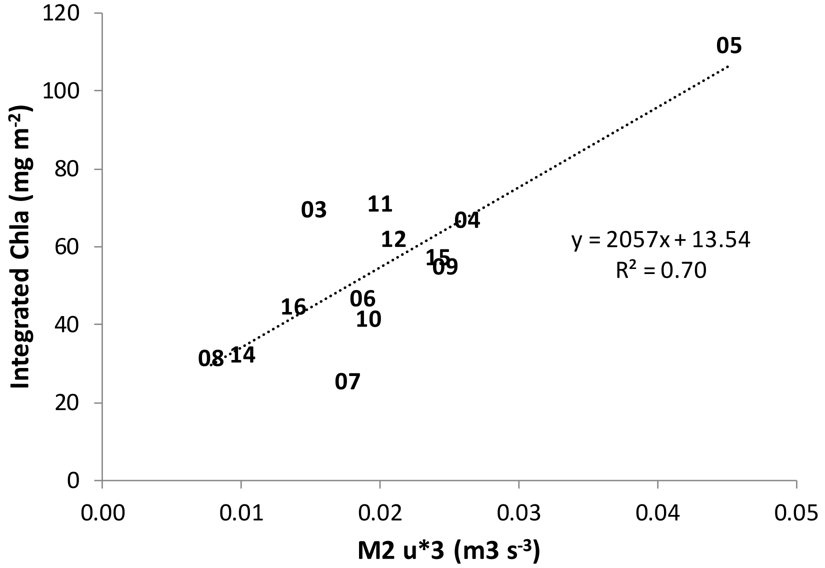

Figure 42: Linear regression between mean August u^{*3}, an indicator of wind mixing, at mooring M2 and integrated chla for the southeastern Bering Sea middle shelf in Bering Sea Project Region 3 (region around M2) for 2003–2016 (no 2013 data).

Figure 3. Linear regression between mean August u* , an indicator of wind mixing, at mooring M2 and integrated chla for the southeastern Bering Sea middle shelf in Bering Sea Project Region 3 (region around M2) for 2003-2016 (no 2013 data).

Coccolithophores in the Bering Sea

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Last updated: October 2017

Description of indicator: Blooms of coccolithophores, a unicellular calcium carbonate-producing phytoplanktonic organism, are easily observed by satellite ocean color instruments due to their high reflectivity (Figure 43). However, in situ measurements in the Bering Sea suggest that the algorithm used by NASA to identify coccolithophores from ocean color is not adequate in the Bering Sea (Iida et al., 2002, 2012). Using methodology developed by Iida et al. (2002, 2012), we identify the number of satellite ocean color pixels associated with coccolithophores. Highly reflective waters in shallow water near the coast can be due to re-suspended diatom frustules rather than coccolithophores (Broerse et al., 2003). Thus, the index is calculated from the region south of 60°N and deeper than 30m depth to avoid contamination by shallow regions around St. Matthew and St. Lawrence Islands, along the Alaskan coast, as well as sediment associated with the Yukon River. Because blooms are often largely confined to either the middle shelf or the inner shelf, two indices are calculated, one for the middle shelf (50–100m depth) and one for the inner shelf (30–50m depth). Using only days that are more than 50% cloud-free, coccolithophore indices were calculated as an average area (km^2) covered by coccolithophores during the month of September of each year. Blooms are most commonly observed and cloud cover is typically lower during September than other months, thus allowing for better quantification.

Note that the methodology for calculating the index has changed since the 2016 contribution. In 2016, the period from 1 August to 30 September was used (instead of September only) in calculating the index. This prior estimate eliminated the 1997 data point since SeaWiFS satellite data were not available in August 1997. In addition, we currently use only data from days that are more than 50% cloud free. The 2016 index used a cut-off of 10% cloud free. These two changes do not substantially change interpretation of the index.

Before 1997, coccolithophore blooms in the eastern Bering Sea were rare. A large bloom (primarily *Emiliania huxleyi*) occurred in 1997 (Napp and Hunt, 2001; Stockwell et al., 2001) and for several years thereafter. During the 1997 bloom, the bloom was associated with a die-off of short-tailed shearwaters (*Puffinus tenuirostris*), a seabird commonly seen in these waters (Baduini et al., 2001). It was thought that the bloom may have made it difficult for the shearwaters to see their zooplankton prey from the air (Lovvorn et al., 2001). Since then, coccolithophore blooms in the eastern Bering Sea have become more common. Satellite ocean color data suggest that blooms are only found where water depths are between 20 and 100 m. Blooms typically peak in September and appear to be related to strong stratification (Iida et al., 2012).

Status and trends: Annual images (Figure 43) show the spatial and temporal variability of coccolithophore blooms in September. Annual indices are obtained from these satellite data by averaging spatially over the inner and middle shelf (Figure 44). Coccolithophore abundance was particularly high during the early part of the record (1997–2000), with an index (averaged over the 3 years) of 120,075 km^2 for the middle and inner shelf combined. In 2001, the index dropped to 21,044 km^2 and remained low (<50,000 km^2) through 2006. In 2007, the index rose above 75,000 km^2. A higher index ($>$ 50,000 km^2) was observed in 2007, 2009, 2011, 2014, and 2016 for the middle shelf and in 2011 and 2014 ($>$ 20,000 km^2) for the inner shelf. September 2017 exhibited the lowest index of the record with 9 km^2 over the middle shelf and 431 km^2 over the inner shelf for a total of 440 km^2.

Factors influencing observed trends: It has been suggested that the strength of density stratification is the key parameter controlling variability of coccolithophore blooms in the eastern Bering Sea (Iida et al., 2012). Stratification influences nutrient supply to the surface layer. Stratification in this region is determined by the relative properties (both temperature and salinity) of two water masses formed in different seasons, the warm surface layer formed in summer and the cold bottom water influenced by ice distributions the previous winter. Thus, the strength of stratification is not solely determined by summer temperatures and warm years can have weak stratification and vice versa (Ladd and Stabeno, 2012).

Implications: Coccolithophore blooms can have important biogeochemical implications. The Bering Sea can be either a source or a sink of atmospheric CO$_2$, with the magnitude of coccolithophore blooms and the associated calcification playing a role (Iida et al., 2012). In addition, variability in the dominant phytoplankton (diatoms vs. coccolithophores) is likely to influence trophic connections with the smaller coccolithophores resulting in longer trophic chains. Coccolithophores may be a less desirable food source for microzooplankton in this region (Olson and Strom, 2002). As noted previously, the striking milky aquamarine color of the water during a coccolithophore bloom can also reduce foraging success for visual predators.

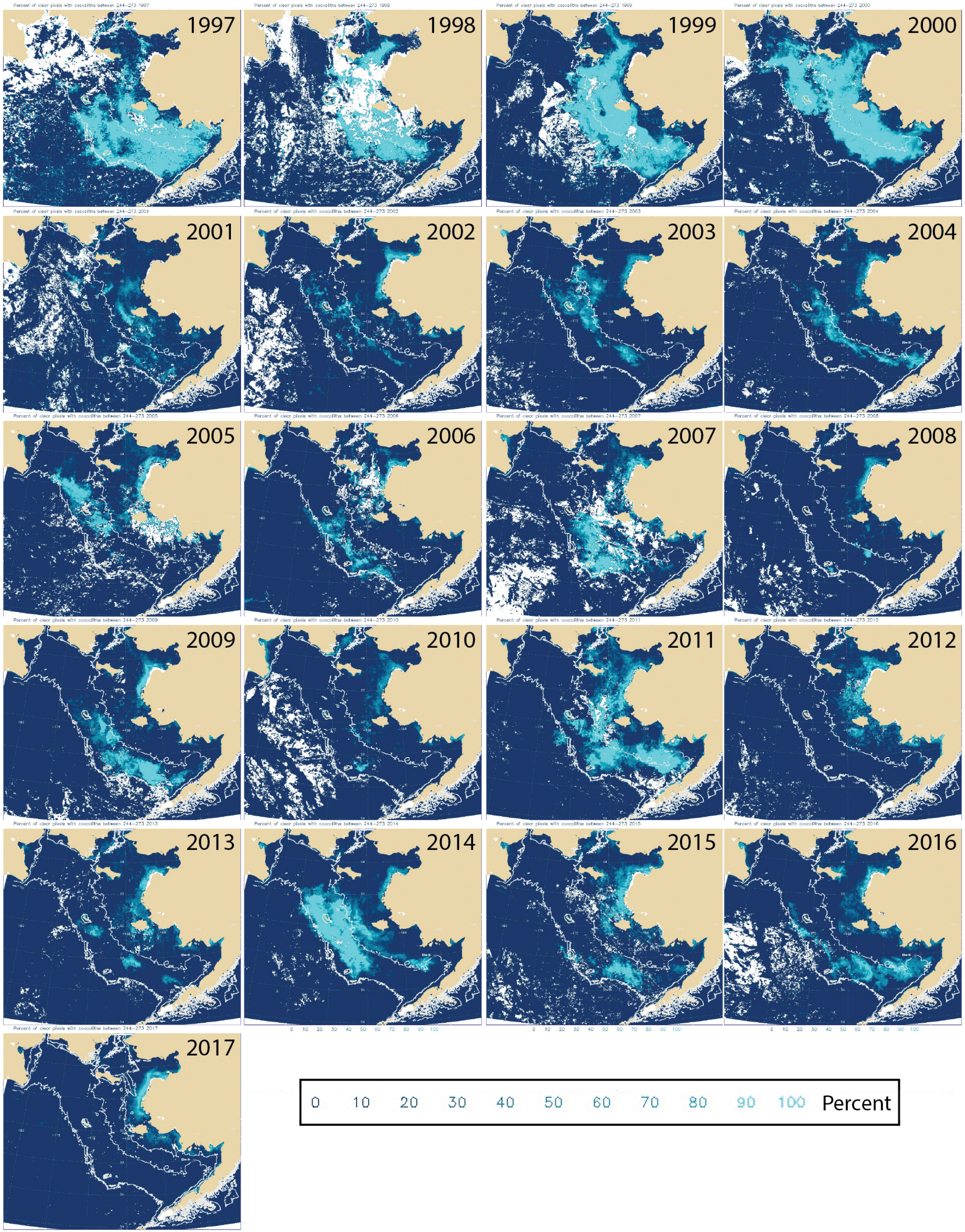

Figure 43: Maps illustrating the location and extent of coccolithophore blooms in September of each year. Color indicates the percent of cloud-free days in September for which each satellite ocean color pixel indicates coccolithophores. These data are used to calculate the areal index in Figure 44.

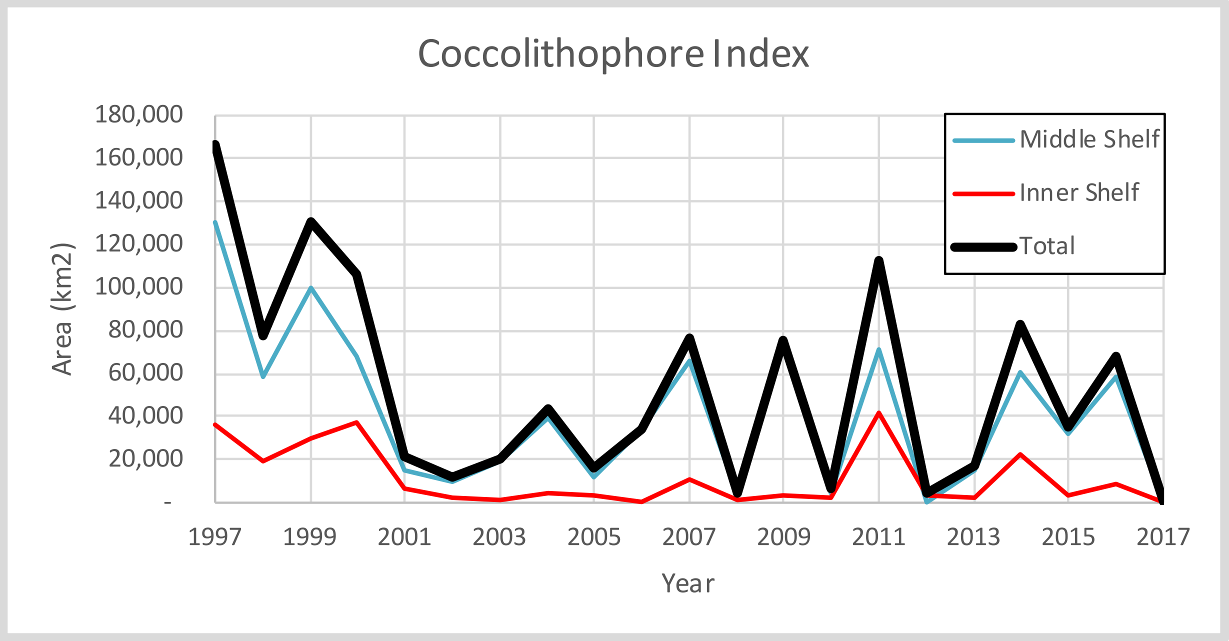

Figure 44: Coccolithophore Index for the southeastern Bering Sea shelf (south of 60°N). Blue: average over the inner shelf (30-50 m depth), Red: average over the middle shelf (50-100 m depth), Black: total

Zooplankton

Leading Zooplankton Indicator for the Bering Sea: Spring and Fall 2017 Rapid Zooplankton Assessment and Long-Term Time Series

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Last updated: October 2017

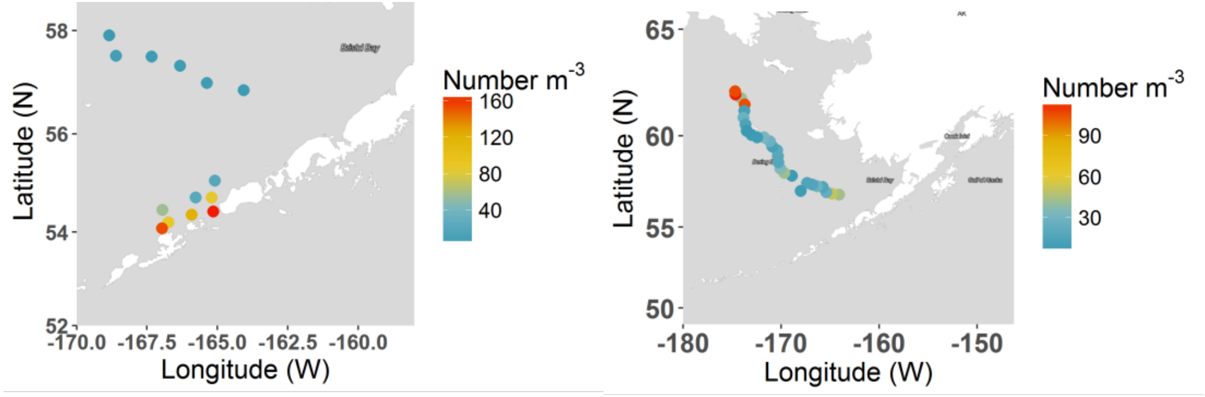
Description of indicator: In 2015, EcoFOCI implemented an at sea Rapid Zooplankton Assessment (RZA) to provide a leading indicator of zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20 and 60-cm oblique bongo tows from 10 m from bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories are small copepods ($<$ 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp., and *Oithona* spp.), large copepods ($>$ 2 mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids ($<$ 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 μm mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 μm mesh, 60 cm bongo net. In 2016, the method was refined and personnel counted a minimum of 100 organisms per sample at sea to improve zooplankton estimates. Other, rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1+ years post survey). The 70m isobath transect and Unimak Box were sampled April 28–May 8 2017 and sampling halted around mooring M4 due to the presence of ice. In order to provide comparison to yearly RZA data, long-term time series for the inner, middle, and outer domains were developed from archived data. The mean, annual abundance of each RZA category was plotted for the southern inner, middle, and outer shelf of the Bering Sea (Ortiz et al., 2012), and represented primarily April, May, and September as the months with the greatest sampling frequency. No RZA data were available along the inner and outer shelf in 2017 as only the 70 m isobath was sampled. Plotted on the time series were the RZA estimates from the corresponding location and year, presented as an annual mean.

Status and trends: Each RZA category had similar abundances along the 70 m isobath and had greater abundances in the Unimak Pass area during spring 2017 (Figure 45). Only the small copepods were found in high abundances along the 70 m isobath in spring (Figure 45c). Note that sampling did not proceed further north due to the presence of ice. Large copepods were abundant in the Unimak Pass area during spring and higher abundances were measured in the northernmost stations of the 70 m isobath (Figure 45b). Small copepod abundances were significantly higher in fall of 2017, with a hotspot near St. Matthew Island (Figure 45d). Euphausiids were more prevalent in the Unimak Pass area in spring and near St. Matthew Island in fall (Figures 45e and 45f).

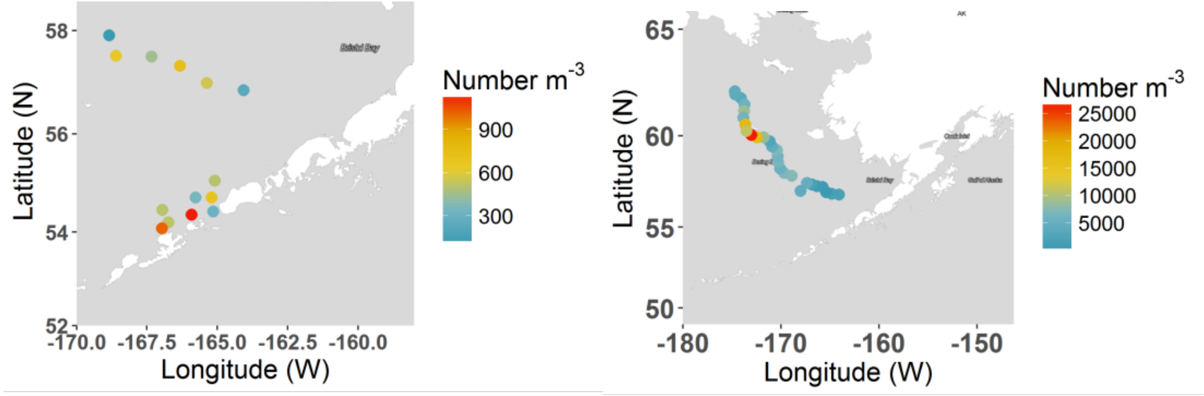
Large copepod abundances were higher during 2015 and 2016 in the inner shelf when compared to long-term averages, similar to estimates during the 2002–2006 warm period in the middle shelf, and similar to the long-term averages in the outer shelf (Figure 46). Small copepod abundance showed little variability over time, regardless of region (Figure 47). Euphausiid abundance was higher than recent estimates in the inner shelf, similar in the middle shelf, and higher in the outer shelf (Figure 48).

Factors influencing observed trends: Warm and cold year 'stanzas' influence zooplankton population dynamics in the Bering Sea (Eisner et al., 2014). Large copepod abundances were notably lower in 2017 along the middle shelf during spring (Figures 45a and 46) and this was typical of a cold year and similar to abundances observed during the cold years of 2005–2009 (Figure 46). Estimates of larger zooplankton abundance in the fall survey remained low, with the exception of the northern portion of the 70 m isobaths (Figure 45b). The slight decline observed in smaller copepod abundance during spring (Figure 45c) may also be due to cooler spring temperatures reducing smaller copepod abundances compared to more recent years (Figure 47); however, abundances were very high during the fall survey (Figure 45d). The low euphausiid abundances observed in the middle shelf (Figures 45e and 45f) appear to be typical of this region during the spring and fall (Figure 48).

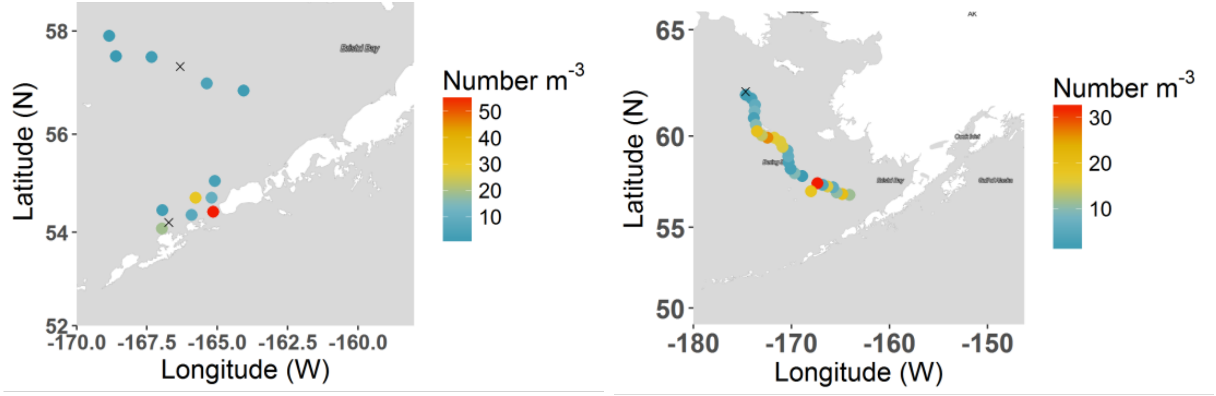
Implications: Smaller copepods form the prey base for late-larval to early juvenile Walleye pollock (*Gadus chalcogrammus*) during spring (Figure 45c). However, reduced abundances of smaller copepods are not necessarily detrimental as estimated production rates for smaller copepods are similar across warm and cold periods (Kimmel et al., In press). Low abundances of large copepods are less critical in the spring, but very important later in the year (Hunt et al., 2011) (see p. 145). Large copepod abundances were low along the southeastern Bering Sea shelf throughout 2017 (Figures 45a and 45b). This suggests that juvenile pollock did not encounter larger, lipid-rich copepods in the fall of 2017. It has been suggested that euphausiids may compensate for a lack of copepods during fall (Duffy-Anderson et al., 2017) and 2017 data indicate evidence of euphausiid presence on the shelf (Figure 45f) and abundances slightly higher than in recent years (Figure 48). Therefore, pollock may again find adequate prey in order to provision for overwintering.



(a) Large Copepods (>2mm) Spring (b) Large Copepods (>2mm) Fall



(c) Small Copepods (<2mm) Spring (d) Small Copepods (<2mm) Fall



(e) Euphausiids (<15mm) Spring (f) Euphausiids (<15mm) Fall

Figure 45: Maps show the abundance of large copepods, small copepods, and euphausiid larvae / juveniles as estimated by the Rapid Zooplankton Assessment in spring (left) and fall (right). Note all maps have different abundance scales (No. m^{-3}). X indicates a sample with abundance of zero individuals m^{-3}.

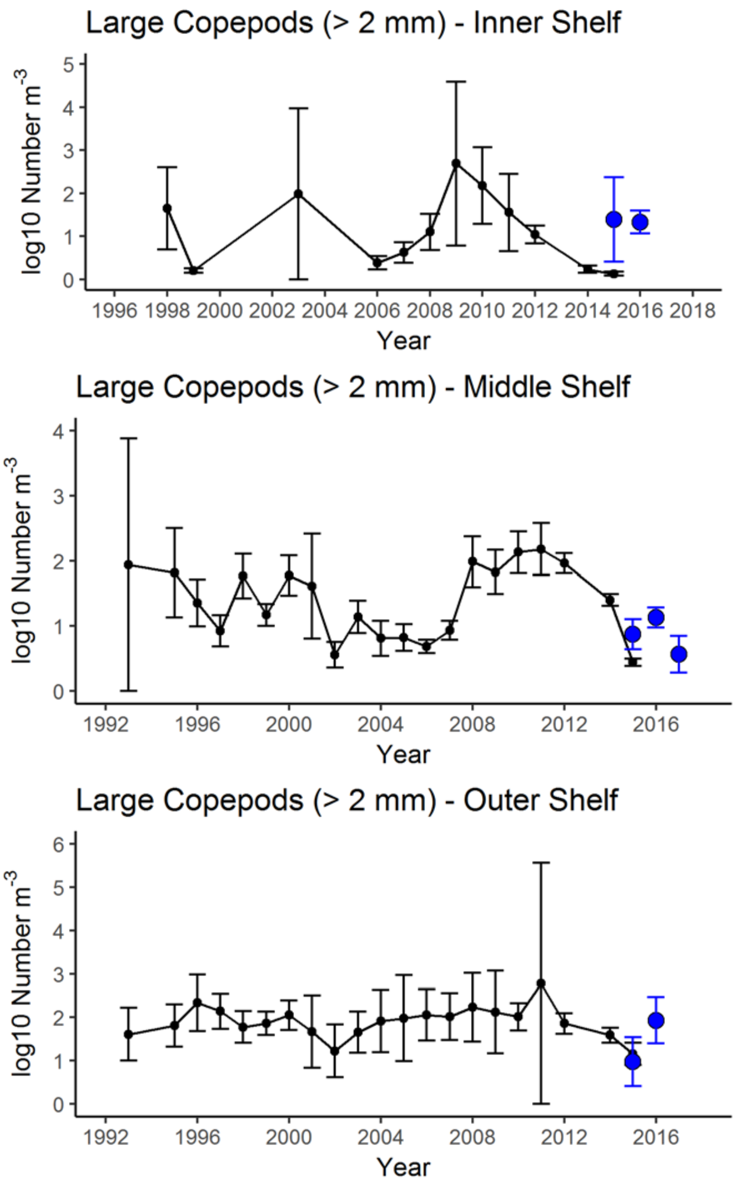


Figure 46: Annual mean abundance of large (>2 mm) copepods in the southeastern region of the Bering Sea (Ortiz et al. 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.

Figure 2. Annual, mean abundance of large copepods (> 2 mm) in the southeastern region of the Bering Sea (Ortiz et al. 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.

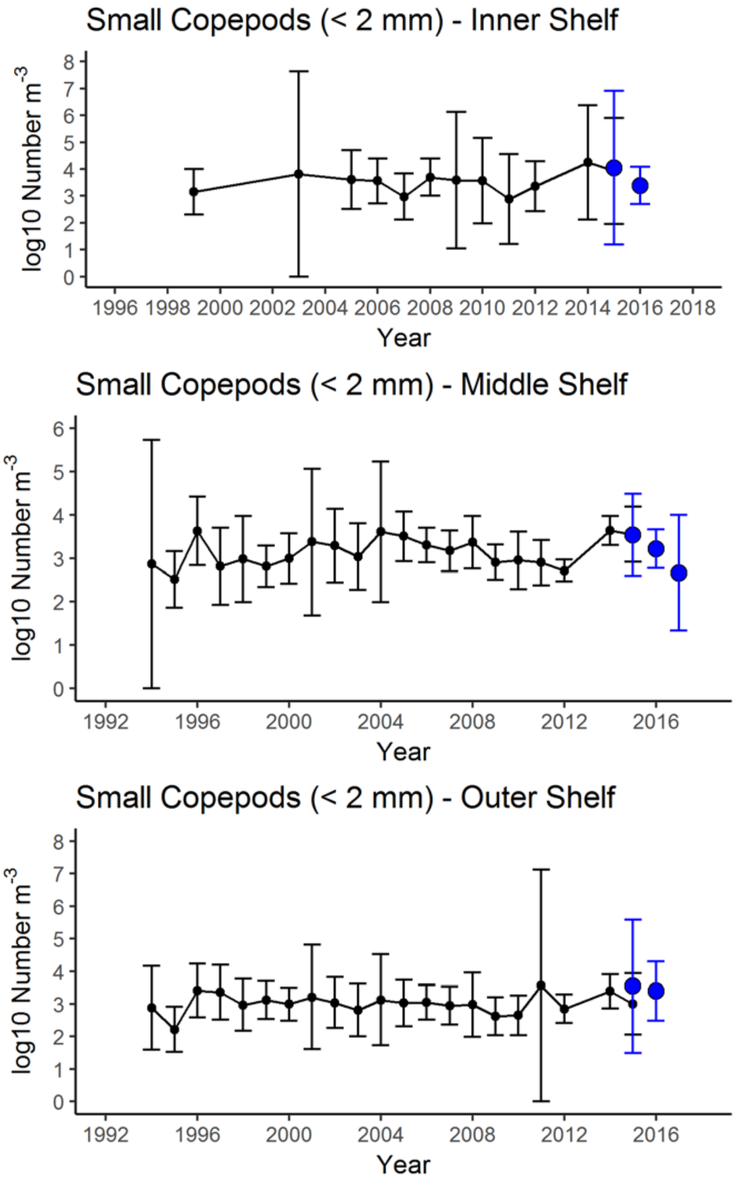
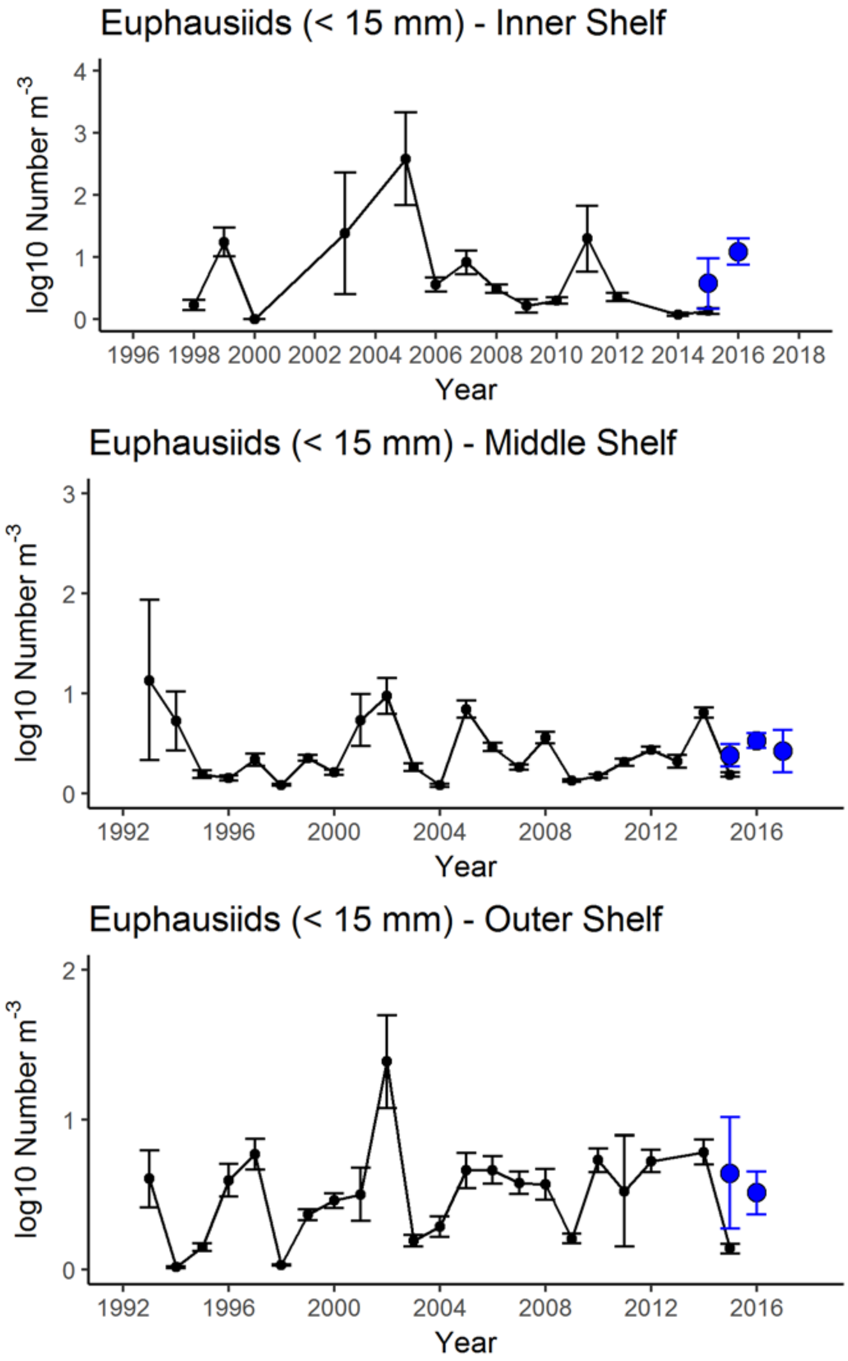


Figure 47: Annual mean abundance of small (<2 mm) copepods in the southeastern region of the Bering Sea (Ortiz et al., 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.


Euphausiids (< 15 mm) - Inner Shelf

Euphausiids (< 15 mm) - Middle Shelf

Euphausiids (< 15 mm) - Outer Shelf

Figure 48: Annual mean abundance of euphausiids in the southeastern region of the Bering Sea (Ortiz et al., 2012). Black points and lines represent FOCI archived data, blue points represent RZA data. Error bars represent standard error of the mean. Note differences in scale.

Jellyfish

Jellyfishes - Eastern Bering Sea Shelf

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Last updated: October 2017

Description of indicator: The time series for jellyfishes (primarily *Chrysaora melanaster*) relative CPUE by weight was updated for 2017 (Figure 49). Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

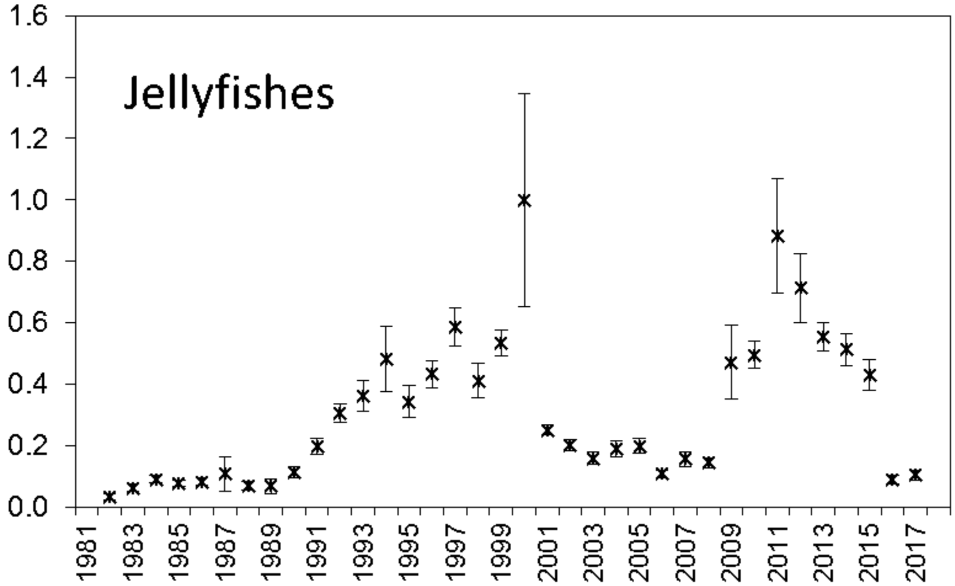

Figure 49: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for jellyfish during the May to August time period from 1982–2017.

Status and trends: The relative CPUE for jellyfishes in 2017 increased by 18% from 2016; however, the 2016–17 estimates remain among the lowest observed since 1989. These low CPUE values were within the range of those observed during the first nine years of the time series (1982–91). There was a period of increasing biomass of jellyfishes throughout the 1990's (Brodeur et al., 1999) followed by a second period of relatively low CPUEs from 2001 to 2008 and then a second period with relatively higher CPUE values from 2009 to 2015.

Factors influencing observed trends: The fluctuations in jellyfish biomass and their impacts on forage fish, juvenile Walleye pollock (*Gadus chalcogrammus*), and salmon in relation to other biophysical indices were investigated by Cieciel et al. (2009) and Brodeur et al. (2002, 2008). Ice cover, sea-surface temperatures in the spring and summer, and wind mixing all have been shown to influence jellyfish biomass and affect jellyfish sensitivity to prey availability (Brodeur et al., 2008).

Implications: Jellyfish are an important predator and prey. Large jellyfish blooms can impact survival of juvenile and forage fishes. Monitoring fluctuations in jellyfish abundance is important for understanding ecological impacts to juvenile and forage fishes and higher trophic levels.

Spatial and Temporal Trends in the Abundance and Distribution of Jellyfish in the Eastern Bering Sea During Late Summer, 2004–2016

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Last updated: August 2017

Description of indicator: Pelagic jellyfish were sampled using a trawl net towed in the upper 20 m of the eastern Bering Sea during the Alaska Fisheries Science Center's Bering Arctic Subarctic Integrated Surveys (BASIS) during late summer, 2004–2016. Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes. Area swept was estimated from horizontal net opening and distance towed.

Jellyfish catch was estimated in kilograms. Surveys were not conducted in the south (<60°N) during 2013 and 2015 and north (≥60°N) during 2008; jellyfish densities in these areas were estimated using geostatistical modeling methods (Thorson et al., 2015). All jellyfish medusae caught in the surface trawl (top 18–20 m of the water column) were sorted by species and subsampled for bell diameter and wet weight. Six species are commonly caught with the surface trawl: *Aequorea* sp., *Chrysaora melanaster*, *Cyanea capillata*, *Aurelia labiata*, *Phacellocephora camtschatica*, and *Staurophora mertensi*. Biomass is calculated for each species and compared across species and oceanographic domains on the Bering Sea shelf.

Abundance and distribution (center of gravity and area occupied) were estimated for each jellyfish species using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 1.0.136 and R software version 3.3.0 (R Development Core Team, 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015); Thorson and Kristensen (2016); Thorson et al. (2016*a*,*b*) to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components.

Status and trends: Temporal trends in the estimated abundance of jellyfish indicated an increase of smaller sized jellyfish (*Aequorea*, *Aurelia*, and *Cyanea*) and a decrease in the larger jellyfish (*Chrysaora*) in the eastern Bering Sea during 2016 (Table 4). Starting in 2014, notable increases in jellyfish species composition were observed for all taxa except *Chrysaora* and continued through 2016. The larger jellyfish was typically more abundant during the 2007–2013 cold stanza, while the smaller sized species were more abundant during the 2004–2006 and 2014–2016 warm stanzas, with the exception of the 2014 warm year. In 2016, *Aurelia* exceeded the typically most abundant

Chrysaora (Table 4).

The distribution of jellyfish varied among species and years. Yearly distributions throughout the sample grid for all species have been patchy and highly variable (example plots shown for *Aequorea* [Figure 50] and *Aurelia* [Figure 51]). Despite uneven distributions throughout oceanographic domains, highest concentrations of all species were found to occur in the middle domain. Center of gravity plots indicate no warm and cold year trend in the distribution of jellyfish (plots not shown). Area occupied was higher for all species during 2016 than the long-term average (Figure 52), except for *Aurelia*. *Aequorea* and *Aurelia* were the only species with a trend of an expanded distribution during warm years and contracted distribution during cold years, with the exception of 2016 for *Aurelia* (Figures 50, 51, and 52).

Factors causing observed trends: Shifts in abundance of single large sized jellyfish in cold years to multiple smaller sized species in warm years indicate that there could possibly be a shift to multiple taxa present in the future during warm stanzas. The cause for the shifts in biomass and distribution do not seem to rely solely on physical ocean factors (temperature and salinity). These shifts could also be a result of environmental forcing earlier in the growing season or during an earlier life history stage (polyp), which may influence large medusae biomasses and abundances (Purcell et al., 2009).

Implications: Significant increases in jellyfish biomass may redirect energy pathways in the eastern Bering Sea food web through jellyfish predation on zooplankton and larval fish, and could result in limited carbon transfer to higher trophic levels (Condon et al., 2011).

Table 4: Index of abundance (metric tonnes) ± 1 standard deviation (SD), and the coefficient of variation (CV; %) for jellyfish in the eastern Bering Sea during late summer, 2004–2016.

	Aeuqorea			*Aurelia*			*Chrysaora*		
Year	Estimate	SD	CV	Estimate	SD	CV	Estimate	SD	CV
2004	62,684	15,206	24%	2,939	1,147	39%	119,427	17,451	15%
2005	41,561	8,688	21%	1,236	406	33%	114,544	18,979	17%
2006	16,373	2,374	15%	517	171	33%	46,557	11,196	24%
2007	4,387	805	18%	354	117	33%	57,088	7,944	14%
2008	2,241	1,549	69%	3,391	5,782	170%	133,737	50,695	38%
2009	2,206	567	26%	1,084	288	27%	203,984	40,504	20%
2010	2,725	606	22%	2,833	791	28%	418,871	59,378	14%
2011	1,145	340	30%	2,929	666	23%	206,857	41,559	20%
2012	1,874	564	30%	55	40	72%	457,877	93,824	20%
2013	2,633	2,203	84%	60	63	104%	519,766	241,167	46%
2014	11,017	2,057	19%	1,163	345	30%	903,598	214,856	24%
2015	47,656	31,052	65%	1,395	1,058	76%	197,977	86,248	44%
2016	206,354	62,113	30%	27,396	23,571	86%	104,211	22,378	21%
Mean	30,989	9,856	35%	3,489	2,650	58%	268,038	69,706	24%

	Cyanea			*Phacellophora*			*Staurophora*		
Year	Estimate	SD	CV	Estimate	SD	CV	Estimate	SD	CV
2004	10,703	2,363	22%	563	411	73%	5,919	5,272	89%
2005	16,155	3,752	23%	0.2	0.3	165%	3,077	779	25%
2006	4,778	819	17%	928	367	40%	2,334	835	36%
2007	5,310	1,161	22%	71	35	50%	114	59	51%
2008	4,840	3,769	78%	3.1	6.1	194%	641	913	142%
2009	2,627	635	24%	178	69	39%	1,601	430	27%
2010	5,870	1,134	19%	273	148	54%	919	403	44%
2011	2,573	575	22%	201	60	30%	28	18	66%
2012	2,525	521	21%	31	19	62%	308	260	84%
2013	1,488	686	46%	2	4.3	222%	155	221	142%
2014	8,663	1,767	20%	139	51	37%	18	16	89%
2015	8,893	3,315	37%	2,524	1,452	58%	0.6	1.3	209%
2016	49,806	15,516	31%	798	494	62%	5,775	2,781	48%
Mean	9,556	2,770	30%	439	240	83%	1,607	922	81%

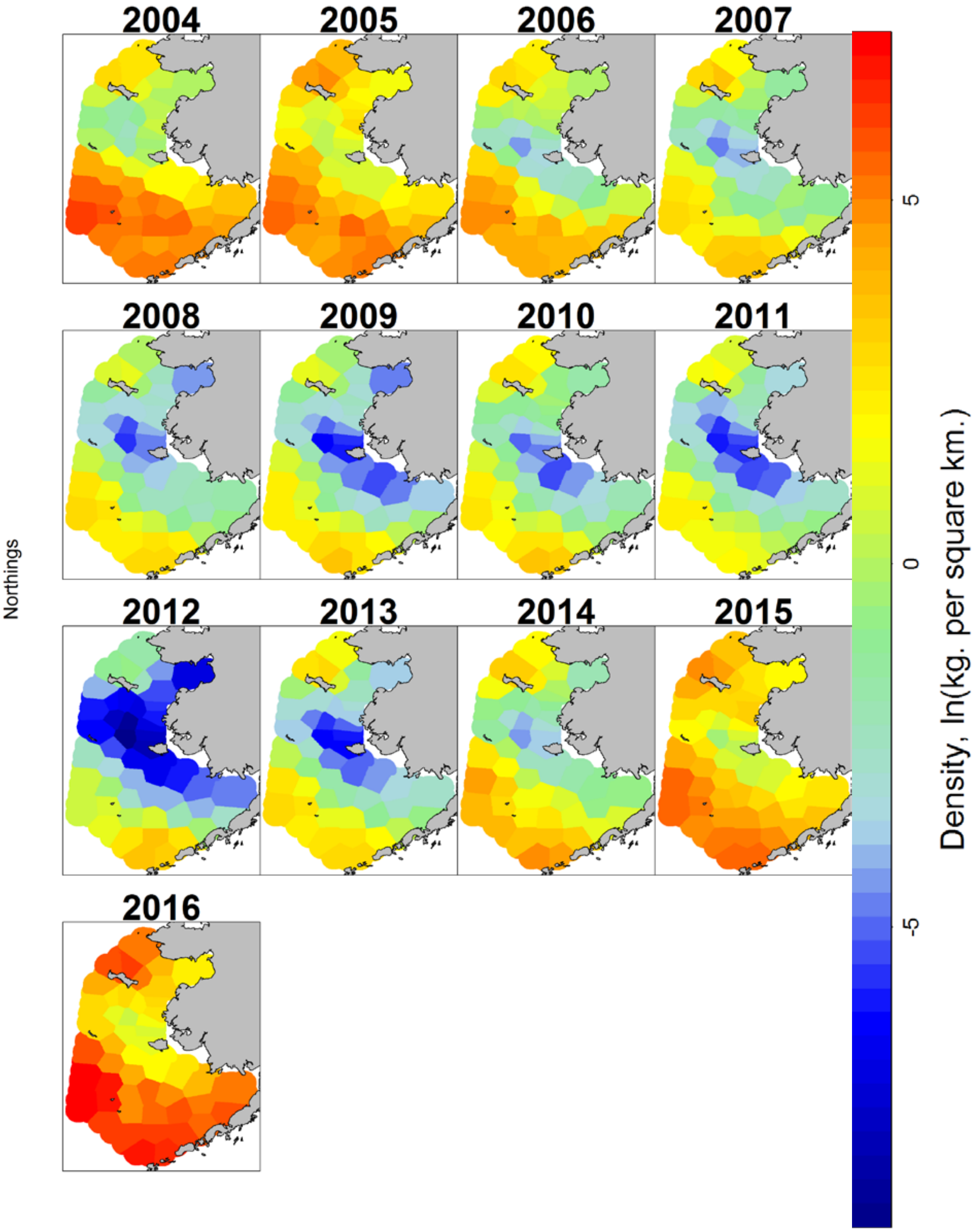

Figure 50: Predicted field densities of *Aequorea* in the eastern Bering Sea during late summer, 2004–2016.

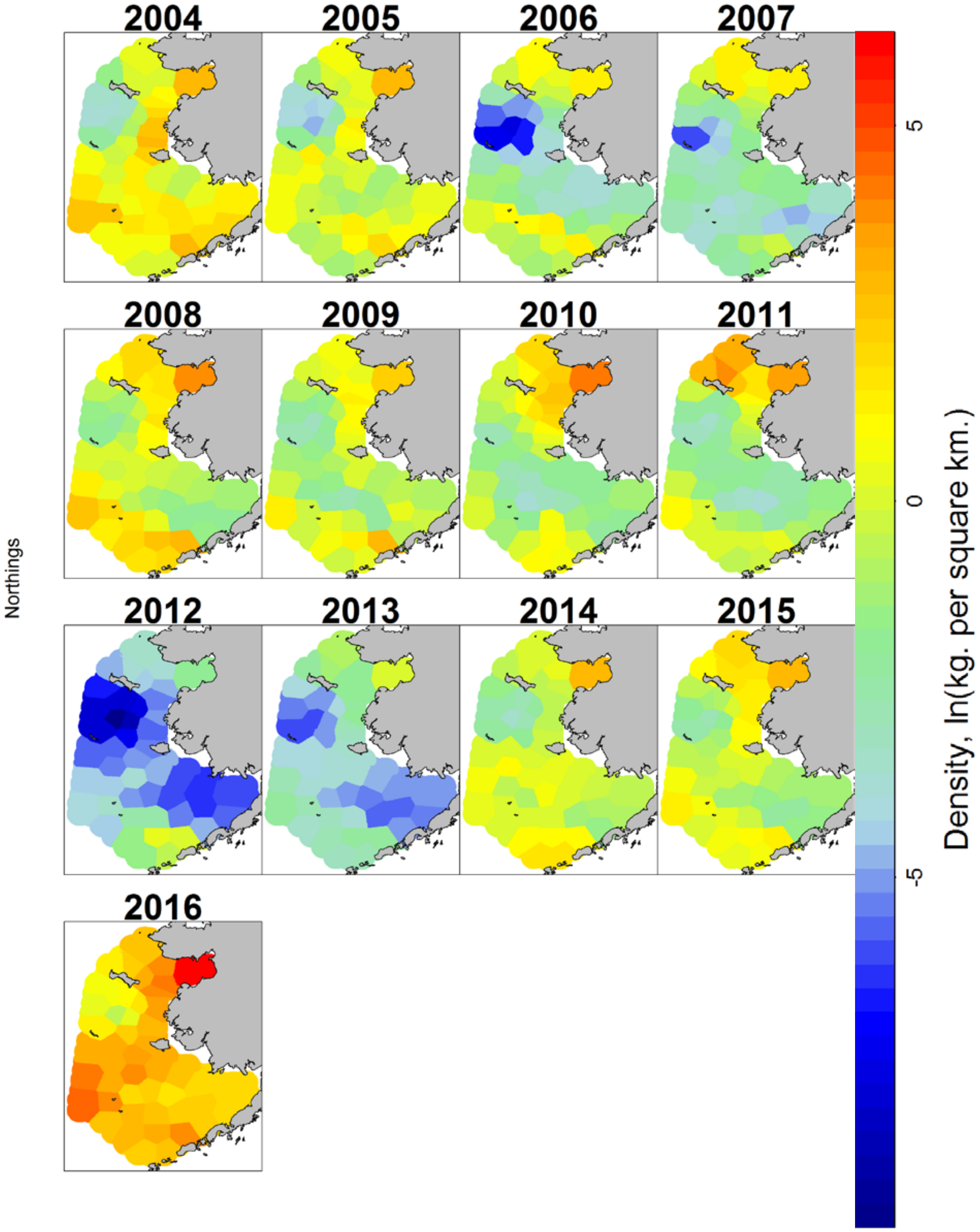

Figure 51: Predicted field densities of *Aurelia* in the eastern Bering Sea during late summer, 2004–2016.

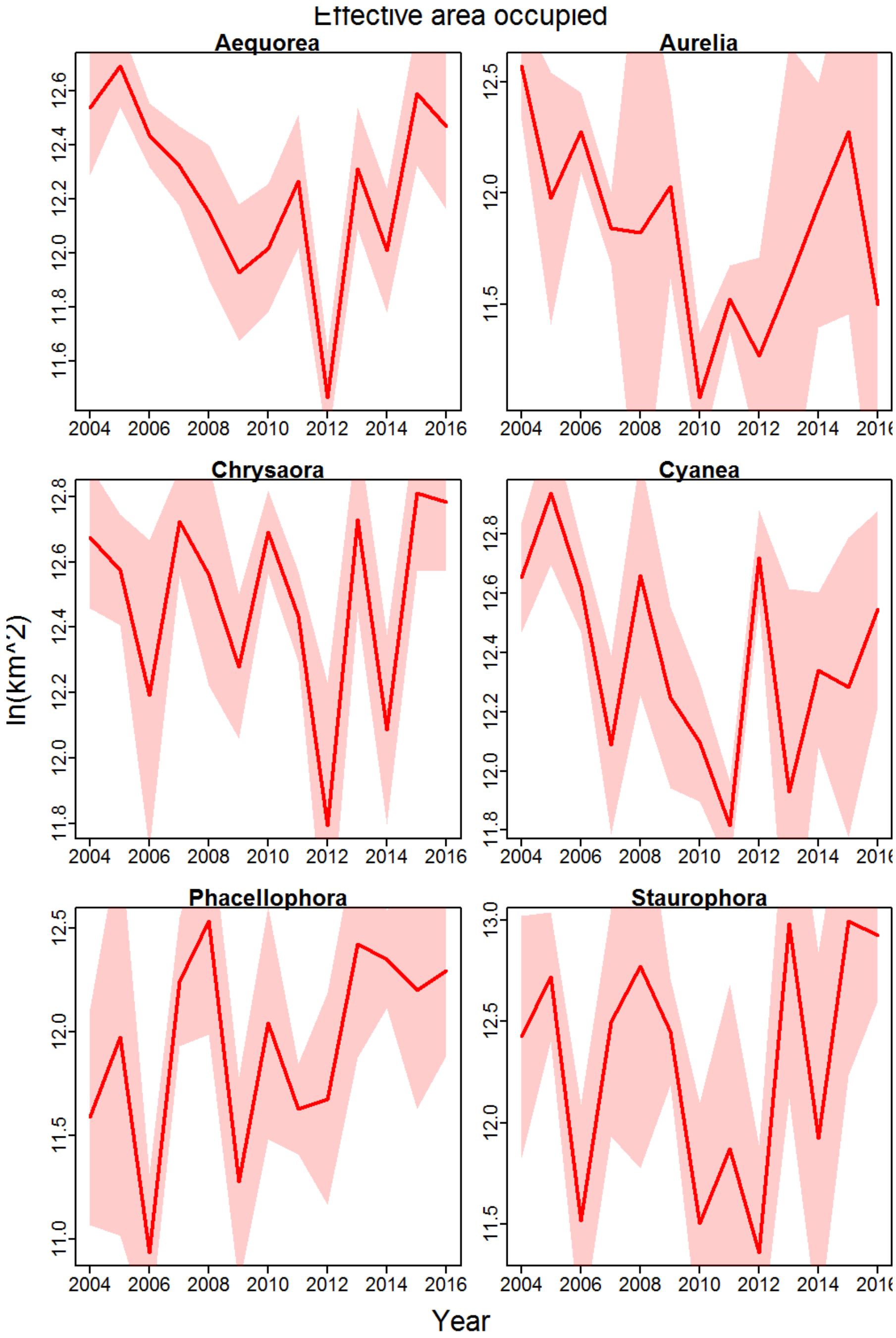

Figure 52: Effective area occupied ($\ln(\mathrm{km}^2)$) indicating range expansion/contraction ± 1 standard error for jellyfish in the eastern Bering Sea during late summer, 2004–2016.

Ichthyoplankton

There are no updates to Ichthyoplankton indicators in this year's report. See the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Forage Fish

Spatial and Temporal Trends in the Abundance and Distribution of Forage Fish in Pelagic Waters of the Eastern Bering Sea During Late Summer, 2002–2016

Contributed by Ellen Yasumiishi, Kristin Cieciel, Alex Andrews, and Elizabeth Siddon
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Contact: ellen.yasumiishi@noaa.gov
Last updated: August 2017

Description of indicator: Pelagic fish were sampled using a trawl net towed in the upper 20 m of the eastern Bering Sea during the Alaska Fisheries Science Center's Bering Arctic Subarctic Integrated Surveys (BASIS) during late summer, 2002–2016. Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes. Area swept was estimated from horizontal net opening and distance towed.

Fish catch was estimated in kilograms. Surveys were not conducted in the south (<60°N) during 2013 and 2015 and north (≥60°N) during 2008 but fish densities in these areas were estimated using geostatistical modeling methods (Thorson et al., 2015). Four forage fish are commonly captured in the trawl: Capelin (*Mallotus villosus*), Pacific herring (*Clupea pallasii*), Sand lance (*Ammodytes hexapterus*), and Pacific sandfish (*Trichodon trichodon*).

Abundance and distribution (center of gravity and area occupied) were estimated using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 1.0.136 and R software version 3.3.0 (R Development Core Team, 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components.

Status and trends: Temporal trends in the estimated abundance of these forage fish species indicate a decline during 2016 (Table 5). Pacific herring were the most abundant species followed Capelin, Pacific sandfish, and Sand lance. Trends in abundance did not track the recent warm (2002–2005, 2014–2016) and cold (2007–2013) years.

The distribution of forage fish in pelagic waters varied among species and years. Capelin were distributed on the central and northern Bering Sea shelf (Figure 53). Pacific herring were distributed in the northeastern Bering Sea middle and inner domains (0–100 m bottom depth) (Figure 54). Sand lance were captured primarily in the inner domain of the eastern Bering Sea shelf (plot not shown), while Pacific sandfish were distributed on the southeastern Bering Sea shelf (Figure 55).

Table 5: Index of abundance (metric tonnes) ± 1 standard error (SD), and the coefficient of variation (CV; %) for forage fish in pelagic waters of the eastern Bering Sea during late summer, 2002–2016.

	Capelin			Pacific herring		
Year	Estimate	SD	CV	Estimate	SD	CV
2002	693	270	39%	16,614	4,029	24%
2003	117	84	72%	19,523	4,753	24%
2004	54	32	60%	48,091	11,128	23%
2005	553	344	62%	25,644	6,171	24%
2006	135	79	59%	39,032	9,430	24%
2007	1,024	393	38%	40,475	7,262	18%
2008	133	166	125%	19,272	13,962	72%
2009	4,115	1,219	30%	12,378	2,962	24%
2010	15,216	5,092	33%	12,532	2,671	21%
2011	4,986	1,480	30%	22,390	5,051	23%
2012	6,034	1,683	28%	7,462	2,312	31%
2013	6,483	4,844	75%	24,840	8,248	33%
2014	1,746	932	53%	46,933	10,782	23%
2015	4,200	2,651	63%	21,453	6,944	32%
2016	1,238	868	70%	14,407	4,376	30%
Mean	3,115	1,343	56%	24,736	6,672	29%

	Sand lance			Pacific sandfish		
Year	Estimate	SD	CV	Estimate	SD	CV
2002	98	64	66%	15,592	4,221	27%
2003	60	29	48%	3,053	943	31%
2004	155	99	64%	2,233	562	25%
2005	4	4	96%	638	231	36%
2006	31	9	30%	576	260	45%
2007	80	31	39%	4,588	1,274	28%
2008	17	19	107%	1,009	494	49%
2009	83	46	56%	7,640	3,328	44%
2010	843	486	58%	612	287	47%
2011	98	46	47%	200	136	68%
2012	51	25	49%	97	54	56%
2013	42	29	67%	228	388	171%
2014	743	420	57%	346	187	54%
2015	175	127	72%	442	689	156%
2016	34	20	60%	78	63	81%
Mean	168	97	61%	2,489	874	61%

Center of gravity indicated that Pacific sandfish was distributed farther west during warm stanzas (2002–2005 and 2014–2016) and farther east during the cold stanza (2008–2013). No warm and cold year trend in the latitudinal or longitudinal distribution were observed in the distribution of Capelin, Pacific herring, or Sand lance in the survey area (center of gravity plots not shown). Area occupied indicated that these fish did not expand or contract their ranges during warm years relative to cold years (plots not shown).

Factors influencing observed trends: Forage fish had lower abundances during 2016, the third consecutive warm year, indicating poor environmental conditions for the growth and survival of forage fish in the eastern Bering Sea. However, over the 15 year time series, trends in the abundances of forage fish did not coincide with warm or cold conditions.

Implications: Recent declines in the abundance of forage fish in pelagic waters during late summer implies poor conditions for growth and survival of pelagic fish species in our survey area during August and September. Lower forage fish abundance may impact the feeding and survival of birds, fish, and marine mammals that rely on them for prey.

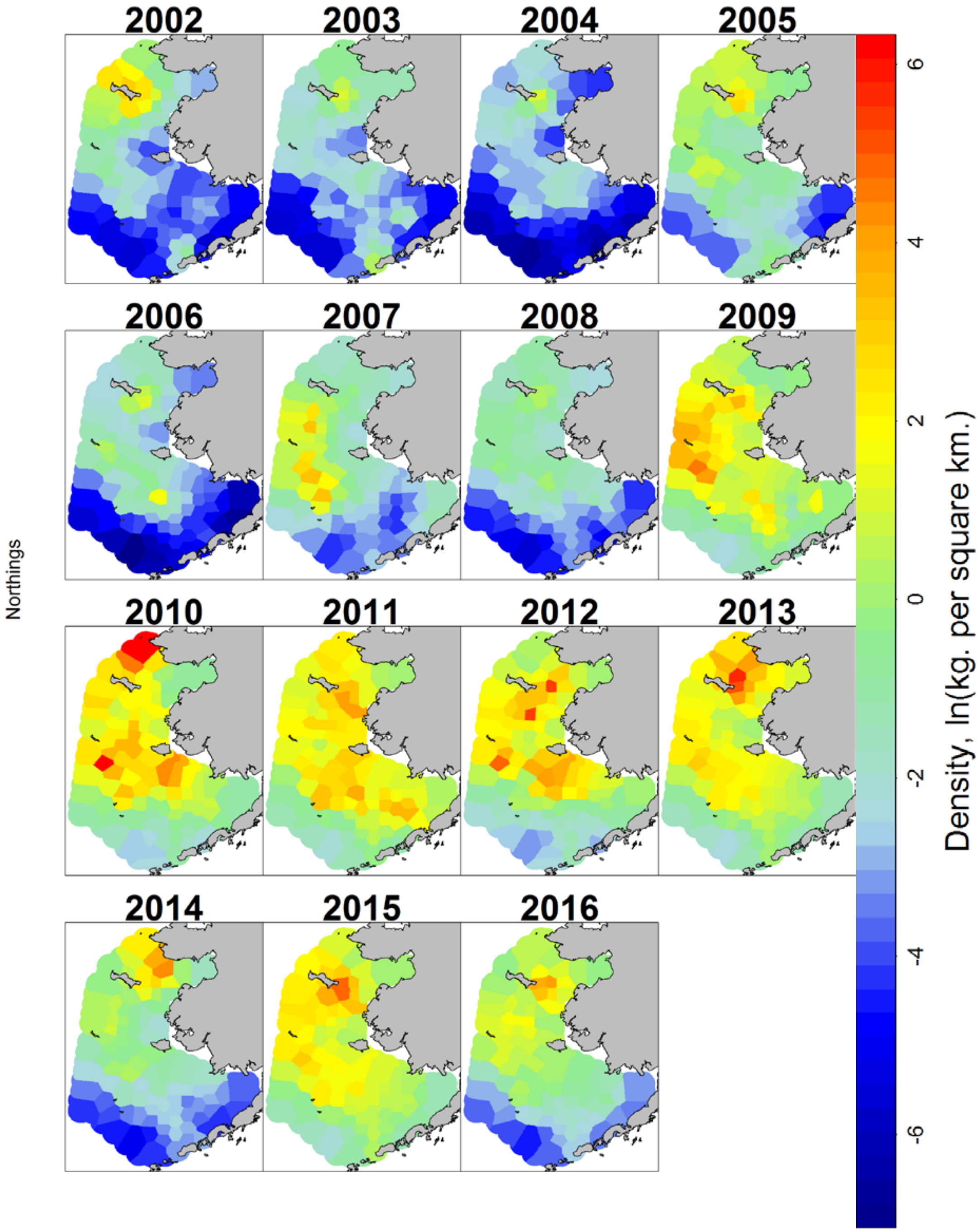

Figure 53: Predicted field densities of Capelin in pelagic waters of the eastern Bering Sea during late summer, 2002-2016

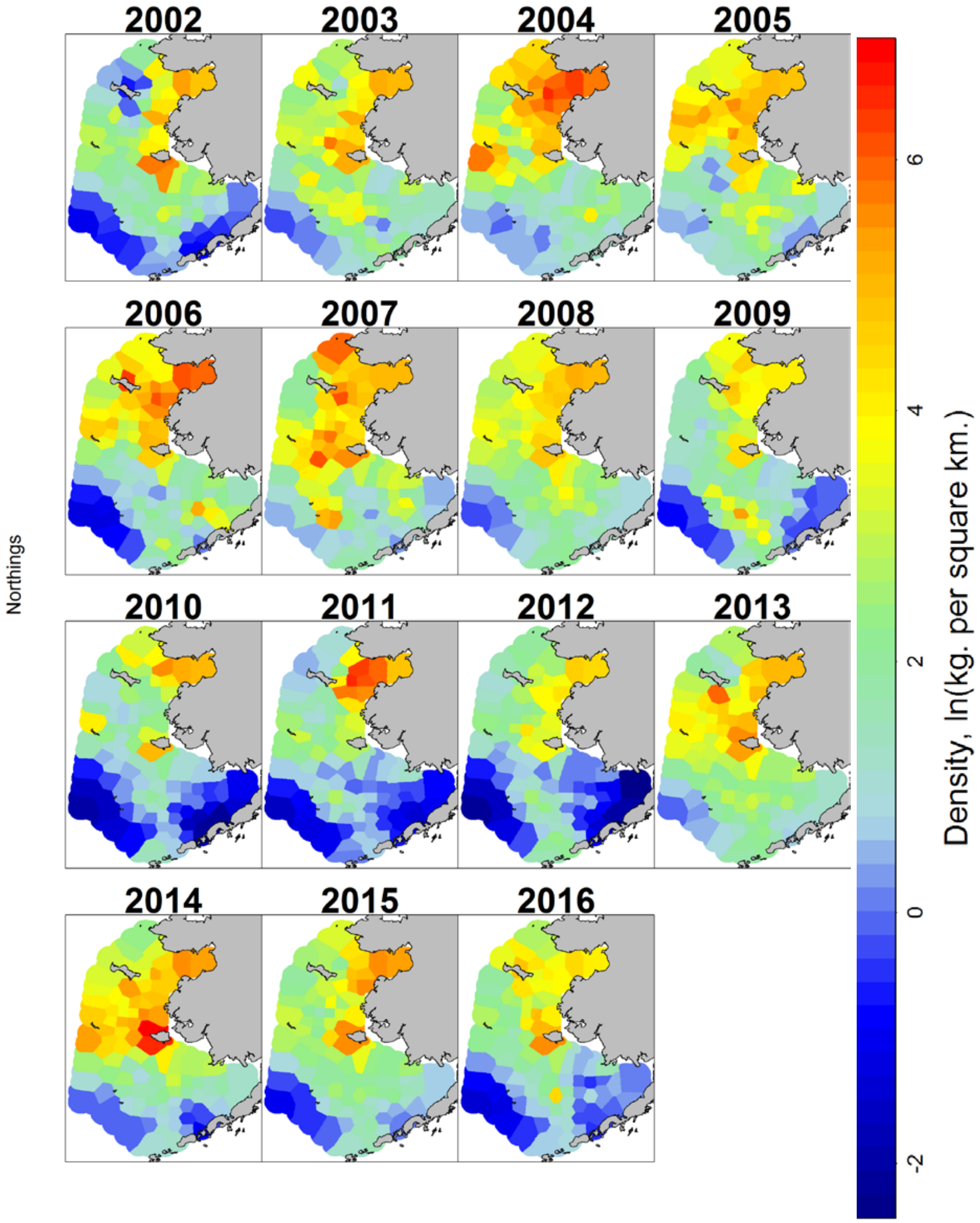

Figure 54: Predicted field densities of Pacific herring in pelagic waters of the eastern Bering Sea during late summer, 2002–2016.

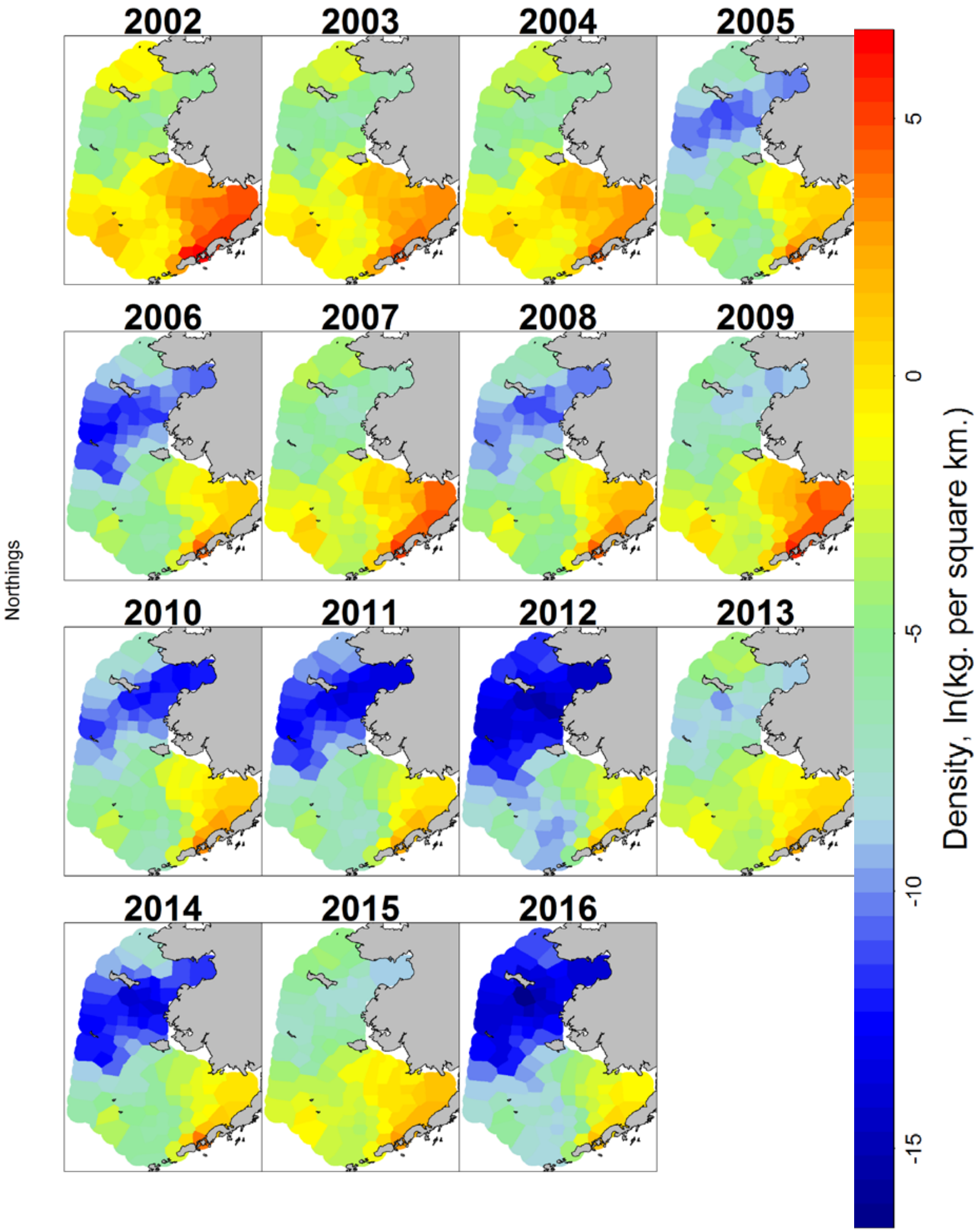

Figure 55: Predicted field densities of Pacific sandfish in pelagic waters of the eastern Bering Sea during late summer, 2002–2016.

Salmon

Juvenile Chinook Salmon Abundance in the Northern Bering Sea

Contributed by Jim Murphy[1] and Kathrine Howard[2]
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Last updated: October 2017

Description of indicator: An index of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) abundance was constructed for the Canadian-origin (Upper Yukon) stock group of the Yukon River, 2003–2017. Juvenile (first year at sea) abundance is estimated during late-summer (typically September) during surface trawl and oceanographic surveys in the northern Bering Sea. Estimates are based on trawl CPUE data, estimates of genetic stock composition, and mixed layer depth. Abundance for the Canadian-origin stock group have ranged from 0.7 million to 2.9 million juveniles with an overall average of 1.7 million juvenile Chinook salmon from 2003–2017 (Figure 56).

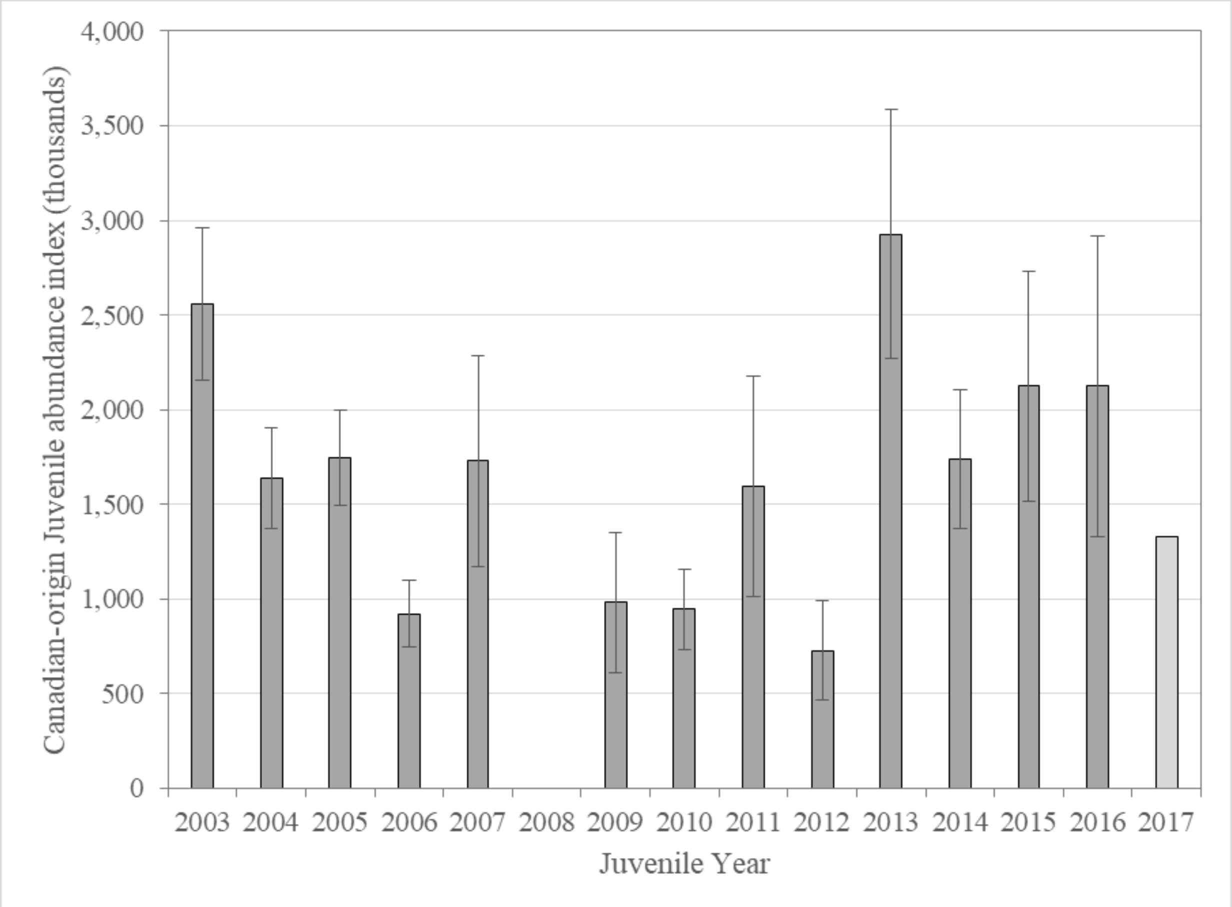

Figure 56: Juvenile abundance estimates for the Canadian-origin stock group of Chinook salmon in Yukon River, 2003 to 2017. The 2017 estimate is preliminary. Error bar range is two standard deviations of juvenile abundance estimates.

Status and trends: Abundance estimates in 2017 are preliminary and are based on average stock composition and mixed layer depth corrections; final estimates will be available in the spring of 2018. The preliminary estimate of Canadian-origin juvenile Chinook salmon in the northern Bering Sea in 2017 is 1.3 million juveniles, which is below the overall average of 1.7 million.

Factors influencing observed trends: Changes in the early life-history (freshwater and early marine) survival, as indicated by the number of juveniles-per-spawner (Figure 57), is the primary factor impacting juvenile abundance in the northern Bering Sea. Preliminary estimates of juveniles-per-spawner in 2017 is the lowest we have observed since 2003. The number of spawning adults is also an important contributing factor to the number of juveniles present in the northern Bering Sea.

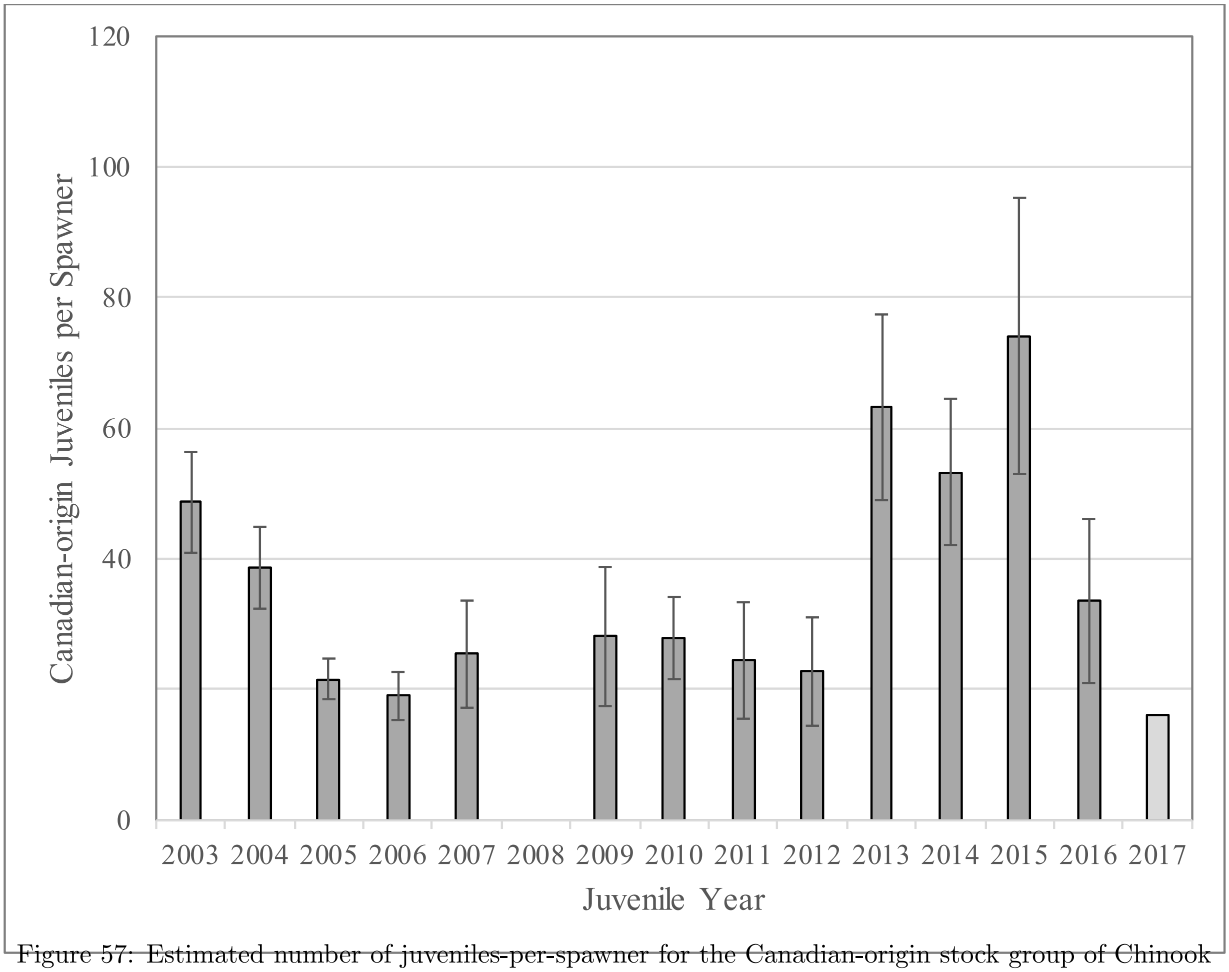

Figure 57: Estimated number of juveniles-per-spawner for the Canadian-origin stock group of Chinook salmon in the Yukon River, 2003 to 2017. The 2017 estimate is preliminary. Error bar range is two standard deviations of juvenile abundance estimates.

Implications: Juvenile abundance is significantly correlated ($r = 0.87$, $p < 0.001$) (Figure 58) with adult returns, indicating that much of the year-to-year variability in survival of Yukon River Chinook salmon occurs during their early life stages (freshwater and initial marine). The Canadian-origin stock group of Chinook salmon is the largest stock group of Chinook salmon in the Yukon River and has a complex management framework, directed by both domestic and international (US/Canada) management policies and decisions. Juvenile abundance data are used to assist these pre-season fisheries management decisions in the Yukon River. Juvenile Chinook salmon abundance also has important implications for abundance-based bycatch caps for Chinook salmon in the eastern Bering Sea Walleye pollock (*Gadus chalcogrammus*) fishery, as low juvenile abundance increases the probability of reduced bycatch caps three to four years in the future.

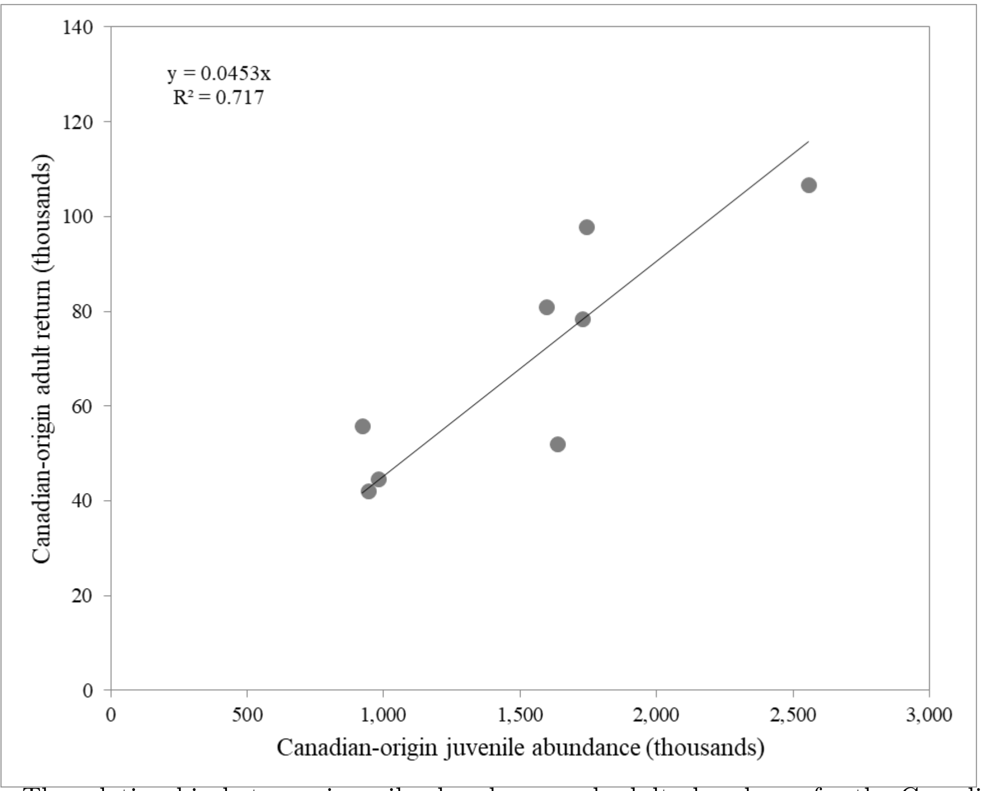

Figure 58: The relationship between juvenile abundance and adult abundance for the Canadian-origin stock group of Chinook salmon in the Yukon River for juvenile years 2003–2011. Adult abundance is the number of returning adults and only includes years where all juveniles have returned to the Yukon River.

Spatial and Temporal Trends in the Abundance and Distribution of Juvenile Pacific Salmon in the Eastern Bering Sea During Late Summer, 2002–2016

Contributed by Ellen Yasumiishi, Kristin Cieciel, Jim Murphy, Alex Andrews, and
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Last updated: August 2017

Description of indicator: Juvenile Pacific salmon were sampled using a trawl net towed in the upper 20 m of the eastern Bering Sea during the Alaska Fisheries Science Center's Bering Arctic Subarctic Integrated Surveys (BASIS) during late summer, 2002–2016. Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes. Area swept was estimated from horizontal net opening and distance towed.

Fish catch was estimated in kilograms. Surveys were not conducted in the south (<60°N) during 2013 and 2015 and north (≥60°N) during 2008 but fish densities in these areas were estimated using geostatistical modeling methods (Thorson et al., 2015). As juveniles during the first year at sea, four of the five salmon species were commonly captured in the trawl: Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), and sockeye salmon (*O. nerka*).

Abundance and distribution (center of gravity and area occupied) were estimated using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 1.0.136 and R software version 3.3.0 (R Development Core Team, 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components.

Status and trends: Temporal trends in the estimated abundance of juvenile salmon indicated a recent increase in the eastern Bering Sea (Table 6). Juvenile sockeye were the most abundant species followed pink, chum, and Chinook salmon. Both juvenile pink and sockeye salmon had an alternating year pattern with higher abundances in even-numbered years. Juvenile salmon were typically more abundant during warm years (2002–2005 and 2014–2016) than during cold years (2007–2013), with the exception of higher juvenile pink and chum salmon abundances during 2007 and 2009.

The distribution of juvenile salmon varied among species and years. Chinook were concentrated in the inner domain (<50m) of the north and southeastern Bering Sea indicating an origin of Norton Sound (Yukon River) in the north and the Kuskokwim River in the south. Chum salmon were most abundant around Nunivak Island (60°N) and were likely from the Kuskokwim River. Sockeye salmon were abundant in the south indicating primarily Bristol Bay origin. Center of gravity indicated that juvenile Chinook, chum, and pink salmon were farther south during warm years, while juvenile sockeye salmon were distributed farther north and west in warm years (Figure 59). Area occupied indicated that all juvenile salmon species expanded their distribution in 2016 relative to 2015, except for pink salmon (Figure 60). Juvenile sockeye and Chinook salmon were the only species that occupied a smaller area during cold years and a larger area in warm years.

Factors influencing observed trends: Higher abundances of juvenile salmon during recent warm years indicate improved environmental conditions for the survival in the eastern Bering Sea during summer and/or in freshwater rivers and lakes of western Alaska. Juvenile sockeye salmon responded to warming with an expansion in their range and a distribution farther north. The northern-origin juveniles distributed farther south in warm years, possibly in search of food such as age-0 Walleye pollock (*Gadus chalcogrammus*) during years with low abundances of large zooplankton (Coyle et al., 2011).

Implications: Recent increases in the abundance of juvenile salmon in our survey area during later summer implies improved conditions for growth and survival of salmon from western Alaska lakes and rivers and/or a change in the distribution of juvenile salmon into our survey area during August and September. Juvenile indices may be an early indication for the numbers of returning adults to the region of origin.

Table 6: Index of abundance (metric tonnes) ± 1 standard deviation (SD), and the coefficient of variation (CV; %) for Pacific salmon in the eastern Bering Sea during late summer, 2002–2016.

	Chinook			Chum		
Year	Estimate	SD	CV	Estimate	SD	CV
2002	411	60	15%	2,850	419	15%
2003	632	100	16%	2,097	371	18%
2004	418	58	14%	1,001	167	17%
2005	502	74	15%	1,054	206	19%
2006	129	26	20%	343	82	24%
2007	428	71	17%	1,642	262	16%
2008	269	203	76%	355	244	69%
2009	288	85	29%	2,170	525	24%
2010	222	41	18%	1,416	271	19%
2011	185	42	23%	862	263	30%
2012	108	28	26%	585	173	30%
2013	1,218	375	31%	832	396	48%
2014	708	147	21%	3,803	951	25%
2015	717	216	30%	2,017	697	35%
2016	817	183	22%	1,971	387	20%
Mean	470	114	25%	1,533	361	27%

	Pink			Sockeye		
Year	Estimate	SD	CV	Estimate	SD	CV
2002	474	108	23%	3,182	574	18%
2003	1,532	397	26%	3,161	525	17%
2004	746	143	19%	2,085	322	15%
2005	713	143	20%	5,200	792	15%
2006	126	44	35%	892	285	32%
2007	1,662	270	16%	3,917	1,177	30%
2008	494	374	76%	616	256	42%
2009	1,257	268	21%	1,308	465	36%
2010	366	75	21%	710	295	42%
2011	427	104	24%	398	181	45%
2012	58	18	32%	673	244	36%
2013	2,349	1,311	56%	384	410	107%
2014	1,066	354	33%	8,159	1,593	20%
2015	3,214	1,492	46%	1,082	1,142	106%
2016	2,028	542	27%	3,712	774	21%
Mean	1,101	376	32%	2,365	602	39%

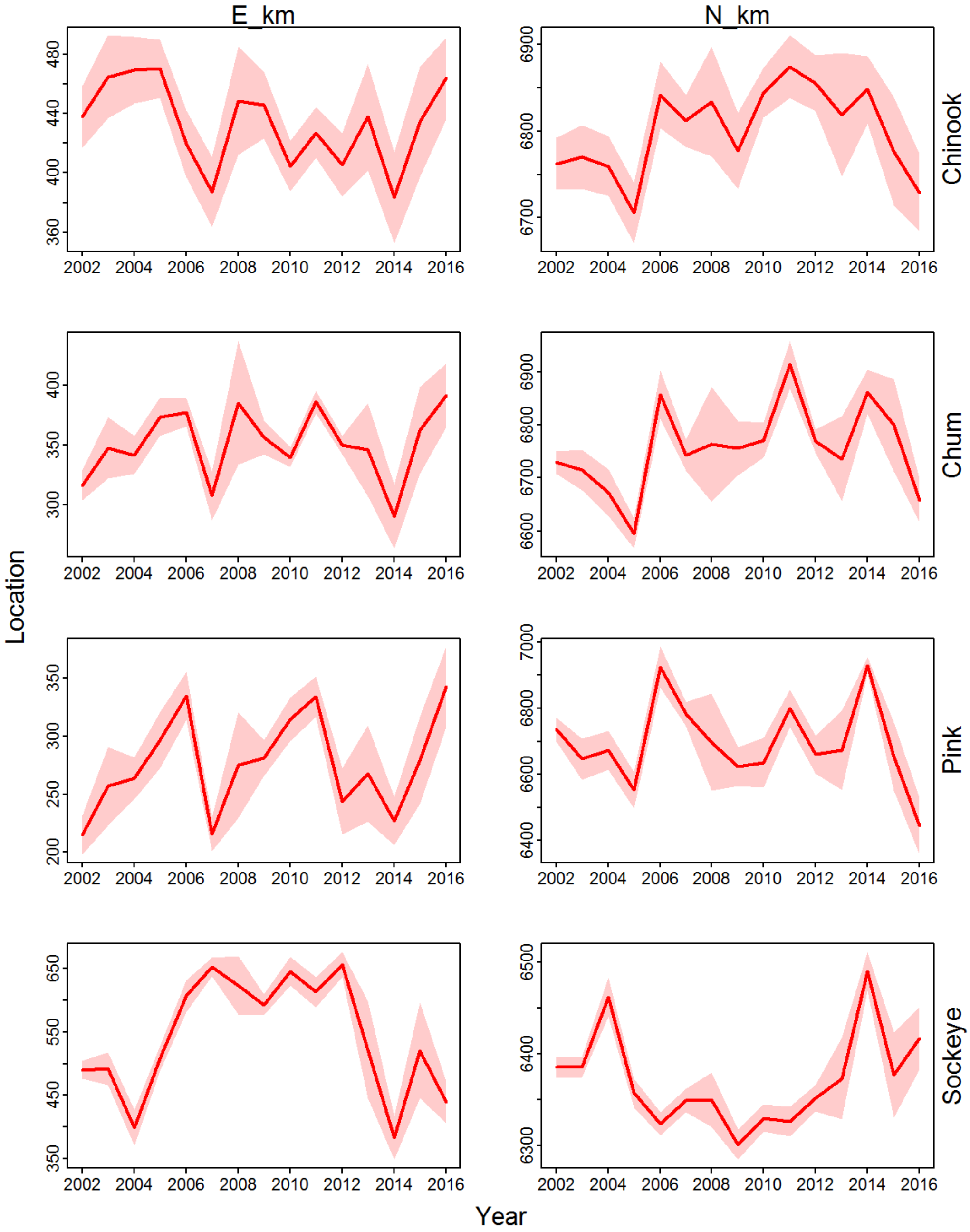

Figure 59: Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution ± 1 standard deviation in UTM (km) for juvenile Pacific salmon on the eastern Bering Sea during late summer, 2002–2016.

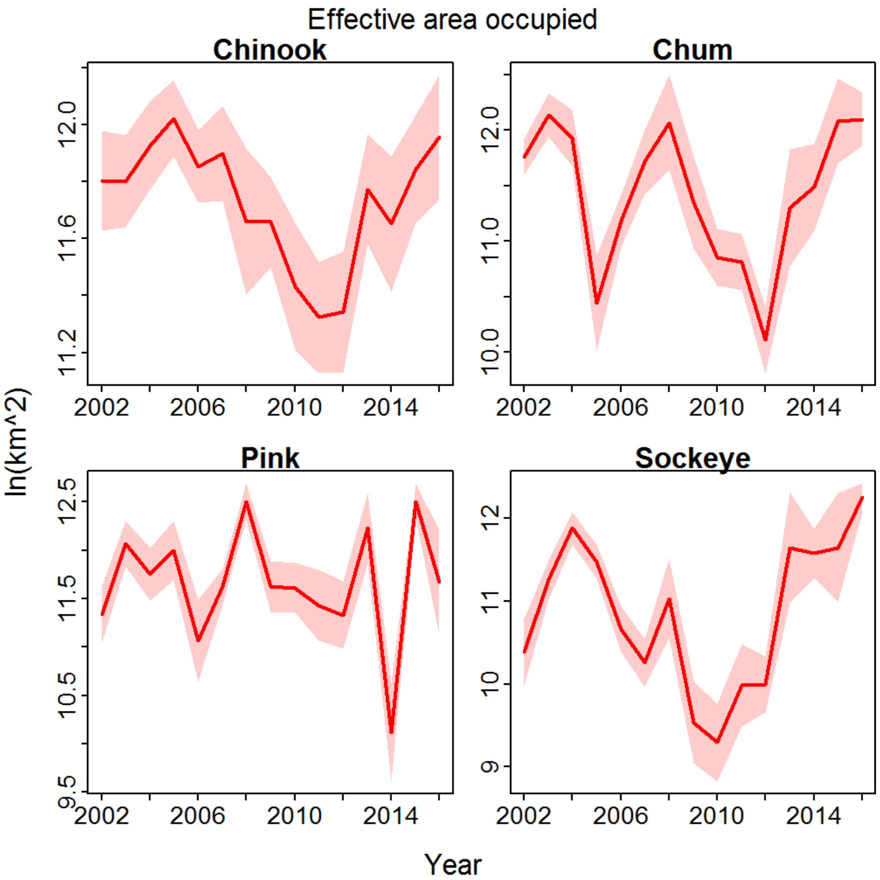

Figure 60: Effective area occupies ($\ln(\mathrm{km}^2)$) indicating range expansion/contraction ± 1 standard deviation for juvenile Pacific salmon on the eastern Bering Sea shelf during late summer, 2002–2016.

Groundfish

Spatial and Temporal Trends in the Abundance and Distribution of Groundfish in the Eastern Bering Sea During Late Summer, 2002–2016

Contributed by Ellen Yasumiishi, Kristin Cieciel, Alex Andrews, and Elizabeth Siddon
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Last updated: August 2017

Description of indicator: Groundfish were sampled using a trawl net towed in the upper 20 m of the eastern Bering Sea during the Alaska Fisheries Science Center's Bering Arctic Subarctic Integrated Surveys (BASIS) during late summer, 2002–2016. Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes. Area swept was estimated from horizontal net opening and distance towed.

Fish catch was estimated in kilograms. Surveys were not conducted in the south (<60°N) during 2013 and 2015 and north (≥60°N) during 2008 but fish densities in these areas were estimated using geostatistical modeling methods (Thorson et al., 2015). Four species were commonly caught with the surface trawl: age-0 Pacific cod (*Gadus macrocephalus*), age-0 Walleye pollock (*Gadus chalcogrammus*), Atka mackerel (*Pleurogrammus monopterygius*), and Yellowfin sole (*Limanda aspera*).

Abundance and distribution (center of gravity and area occupied) were estimated using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 0.99.896 and R software version 3.3.0 (R Development Core Team, 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components.

Status and trends: Temporal trends in the estimated abundance of these groundfish species indicated a decline in 2016 (Table 7). Age-0 pollock were the most abundant groundfish species in the survey area followed by Yellowfin sole, Atka mackerel, and then Pacific cod.

The distribution of groundfish in pelagic waters varied among species and years. Age-0 Pacific cod were distributed on the southern Bering Sea shelf near Unimak Pass (Figure 61). Age-0 pollock were the most widely distributed species; they were primarily in the middle domain of the southeastern shelf, but distributed farther north during warm years (Figure 62). Atka mackerel were captured primarily in the outer domain of the southeastern Bering Sea shelf (plots not shown). Yellowfin sole were distributed in the southern inner and middle domains (plots not shown).

Temporal trends in the distribution (center of gravity) indicated that age-0 pollock were distributed farther north during recent warm years. No warm and cold year trend was observed in the distribution of age-0 Pacific cod or Yellowfin sole. Atka mackerel were generally distributed farther north during warm stanzas and farther south during the cold stanza (plots not shown). Area occupied (plots not shown) indicated that age-0 pollock had an expanded range during warm years relative to cold years (Figure 62).

Table 7: Index of abundance (metric tonnes) ± 1 standard deviation (SD) and the coefficient of variation (CV; %) for groundfish in pelagic waters of the eastern Bering Sea during late summer, 2002–2016.

	Age-0 Pacific cod			Age-0 Walleye pollock		
	Estimate	SD	CV	Estimate	SD	CV
2002	776	345	44%	28,989	10,705	37%
2003	15	10	69%	16,866	4,027	24%
2004	122	37	31%	92,590	21,439	23%
2005	1,086	335	31%	88,836	23,511	26%
2006	937	179	19%	10,371	2,076	20%
2007	51	15	28%	2,325	547	24%
2008	105	39	37%	4,254	1,587	37%
2009	1	1	118%	82	41	51%
2010	324	80	25%	809	259	32%
2011	1,490	856	57%	1,562	924	59%
2012	110	29	26%	751	150	20%
2013	9	21	238%	1,565	2,139	137%
2014	66	24	36%	60,583	22,268	37%
2015	36	54	152%	126,858	134,018	106%
2016	3	3	86%	16,437	4,358	27%
Mean	342	135	67%	30,192	15,203	44%

	Atka mackerel			Yellowfin sole		
	Estimate	SD	CV	Estimate	SD	CV
2002	113	61	54%	2,028	644	32%
2003	1,857	733	39%	194	104	53%
2004	638	270	42%	1,928	439	23%
2005	125	65	52%	1,956	455	23%
2006	79	37	46%	4,608	1,042	23%
2007	529	193	36%	1,860	368	20%
2008	156	215	138%	1,308	623	48%
2009	72	47	66%	2,448	913	37%
2010	53	38	72%	3,724	1,107	30%
2011	15	18	122%	4,231	1,685	40%
2012	12	13	108%	2,706	815	30%
2013	29	63	221%	922	994	108%
2014	10,831	2,537	23%	3,393	1,820	54%
2015	18	33	181%	1,464	1,347	92%
2016	1,432	1,063	74%	493	407	83%
Mean	1,064	359	85%	2,218	851	46%

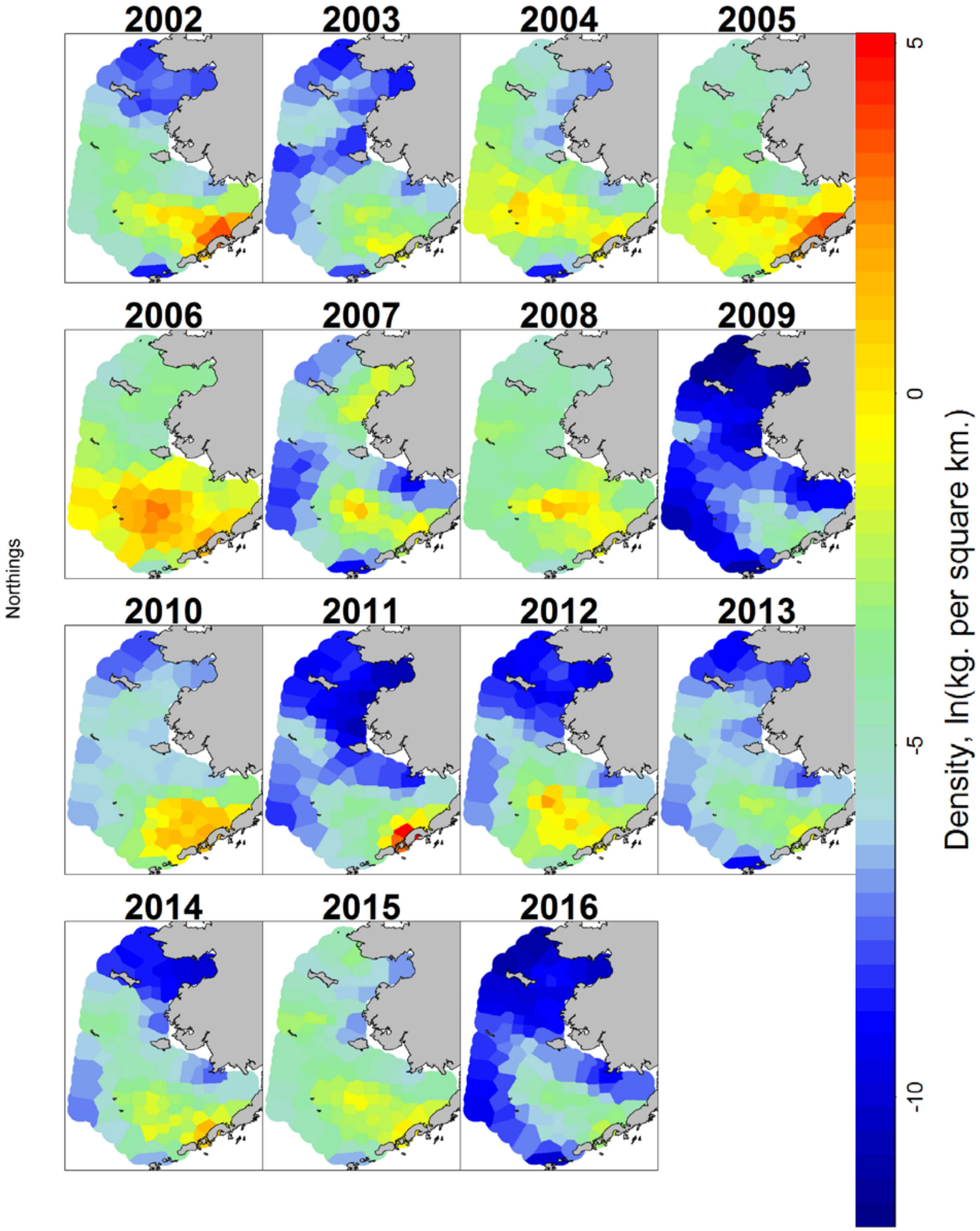

Figure 61: Predicted field densities of age-0 Pacific cod in pelagic waters of the eastern Bering Sea during late summer, 2002–2016.

Factors influencing observed trends: Lower abundances of groundfish in pelagic waters during 2016, the third consecutive warm year, indicate poor environmental conditions for the growth and survival in the eastern Bering Sea during summer or movement out of the survey area. Age-0 pollock appeared to respond to warming with an expansion in their range and a distribution farther north. Movement of age-0 pollock and Atka mackerel farther north during warm years indicate a response to warming by changing their distribution.

Implications: Lower abundances of groundfish in surface waters during 2016 indicate a change in productivity of pelagic waters. Age-0 pollock were distributed primarily in the southeastern Bering Sea middle domain, but were farther north during warm years with higher population densities. This is possibly a response to a search for prey during years of low lipid-rich taxa (e.g., *Calanus* spp.; Coyle et al. (2011)).

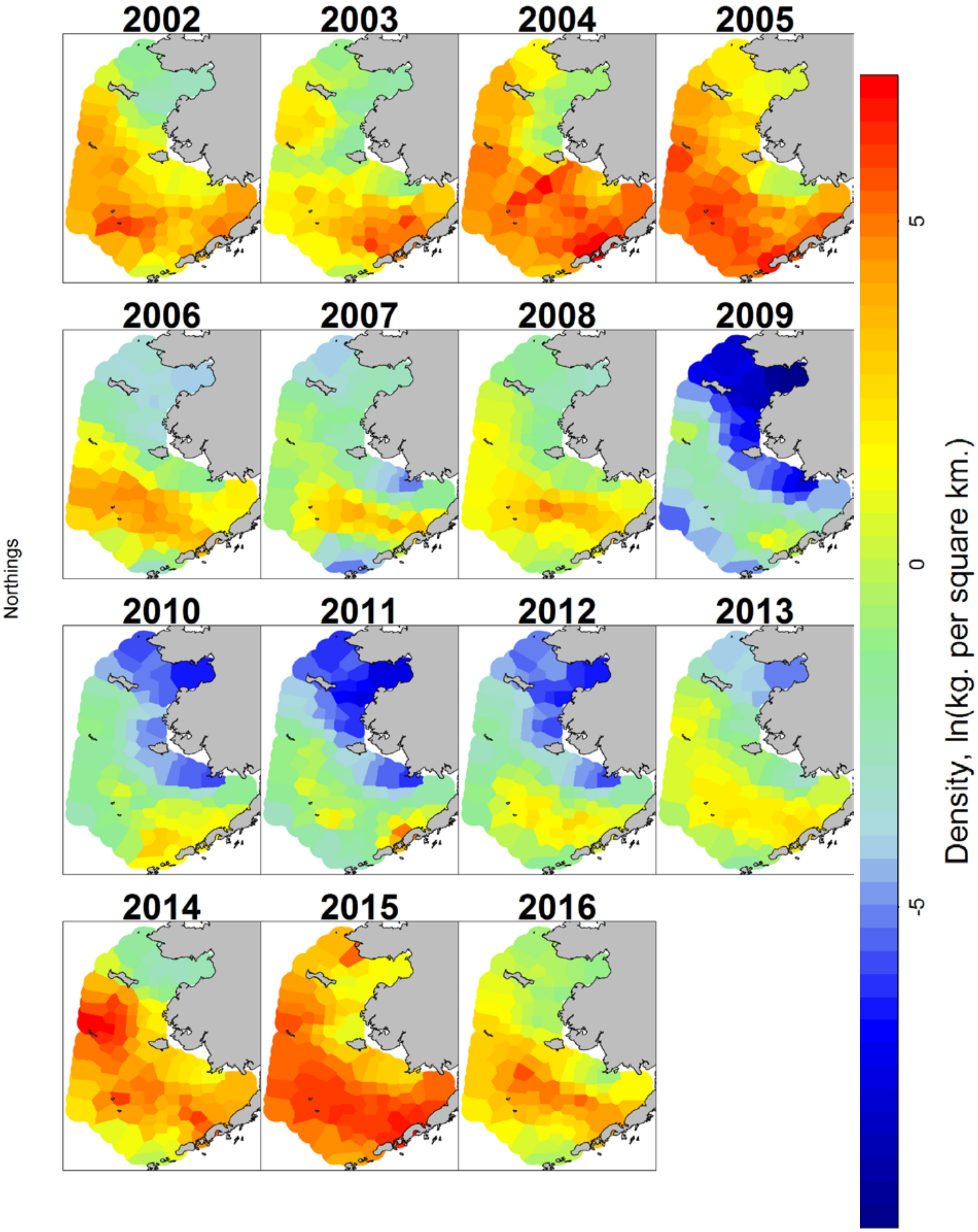

Figure 62: Predicted field densities of age-0 Walleye pollock in pelagic waters of the eastern Bering Sea during late summer, 2002–2016.

Eastern Bering Sea Groundfish Condition

Contributed by Jennifer Boldt[1], Chris Rooper[2], and Jerry Hoff[2]
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[2]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2017

Description of indicator: Length-weight residuals are an indicator of somatic growth (Brodeur et al., 2004) and, therefore, a measure of fish condition. Fish condition is an indicator of how heavy a fish is per unit body length, and may be an indicator of ecosystem productivity. Positive length-weight residuals indicate fish are in better condition (i.e., heavier per unit length) whereas negative residuals indicate fish are in poorer condition (i.e., lighter per unit length). Fish condition may affect fish growth and subsequent survival (Paul et al., 1997; Boldt and Haldorson, 2004).

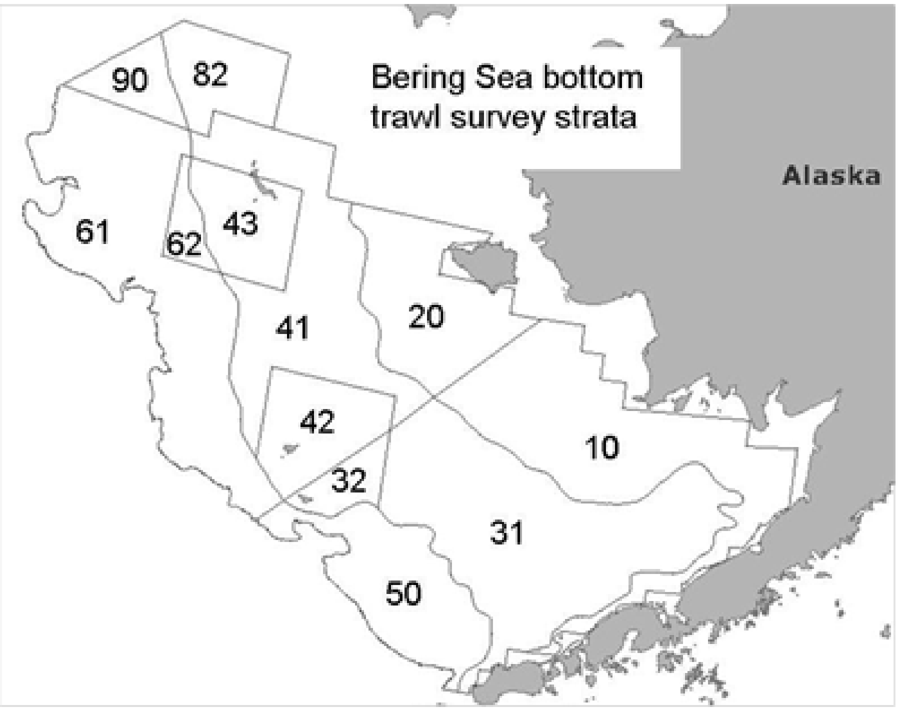

Figure 63: NMFS summer bottom trawl survey strata. Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 82 and 90 were excluded from analyses because they are not standard survey strata.

The AFSC eastern Bering Sea shelf bottom trawl survey data were utilized to acquire lengths and weights of individual fish for Walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), Arrowtooth flounder (*Atheresthes stomias*), Yellowfin sole (*Limanda aspera*), Flathead sole (*Hippoglossoides elassodon*), Northern rock sole (*Lepidopsetta polyxystra*), and Alaska plaice (*Pleuronectes quadrituberculatus*). Only summer standard survey strata and stations were included in analyses, no corner stations were included (Figure 63). Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 82 and 90 were excluded from analyses because they are not standard survey strata.

Length-weight relationships for each of the seven species were estimated with a linear regression of log-transformed values over all years where data were available (during 1982–2013). Additionally, length-weight relationships for age-1+ pollock (length from 100–250 mm) were also calculated independent from the adult life history stages. Predicted log-transformed weights were calculated and subtracted from measured log-transformed weights to calculate residuals for each fish. Length-weight residuals were averaged for the entire EBS and for the 6 strata sampled in the standard summer survey. Temporal and spatial patterns in residuals were examined.

Status and trends: Length-weight residuals have varied over time for all species with a few notable patterns (Figure 64). Residuals for all species where there were data were negative in 1999, a cold year in the Bering Sea. Residuals became positive or more positive in 2002 for five of the seven species examined. Flatfish residuals were generally positive from 2002 to 2004 or 2005 depending on species. Age-1 pollock and Pacific cod residuals were positive from 2001 to 2004 or 2005. In 2008, all species except Flathead sole and pollock had negative residuals. There has been a distinct negative trend in Pacific cod since a peak value in 2003. Condition of pollock older than age 1 in 2017 was the second lowest on record. Age-1 pollock and older pollock were not well correlated in most years. Length-weight residuals for all species were less in 2017 than in 2016 indicating poorer condition in the most recent year (Arrowtooth flounder was the only exception).

Spatial trends in residuals were also apparent for some species. Generally, fish were in better condition on the outer shelf (strata 50 and 60; Figure 65). For all species except Yellowfin sole (which did not occur in outer shelf strata), residuals were almost always positive on the northern outer shelf (stratum 60; Figure 65). For Yellowfin sole, residuals were positive in the outermost shelf strata in which they occurred (stratum 40) except in 1999. In addition to having positive residuals on the outer shelf, gadids tended to have negative residuals on the inner shelf (Figure 65). Pollock residuals were generally positive in strata 50 and 60 and negative in strata 10, 20, and 40. Cod residuals were generally positive in stratum 60 and negative in strata 10 and 20. Spatial patterns in flatfish residuals were also apparent but varied among species. Alaska plaice residuals were almost always negative in stratum 40. Flathead sole residuals were often positive in strata 40 (Figure 64).

Factors influencing observed trends: One potential factor causing the observed temporal variability in length-weight residuals is temperature. The year 1999 was a particularly cold year in the Bering Sea and also a year of negative length-weight residuals for all groundfish examined (where data existed). Despite the abundant large crustacean zooplankton and relatively high microzooplankton productivity present in 1999 (Hunt et al., 2008) the spatial distribution of some groundfish species is affected by temperatures and a cold year may, therefore, have affected the spatial overlap of fish and their prey. Cold temperatures may have also affected fish energy requirements and prey productivity. Conversely, the continuing warmer than normal 2016 temperatures across the Bering Sea shelf may have resulted in negative trends for length-weight residuals.

Other factors that could affect length-weight residuals include survey sampling timing and fish migration. The date of the first length-weight data collected annually varied from late May to early June (except 1998, where the first data available were collected in late July). Also, the bottom trawl survey is conducted throughout the summer months, and as the summer progresses,

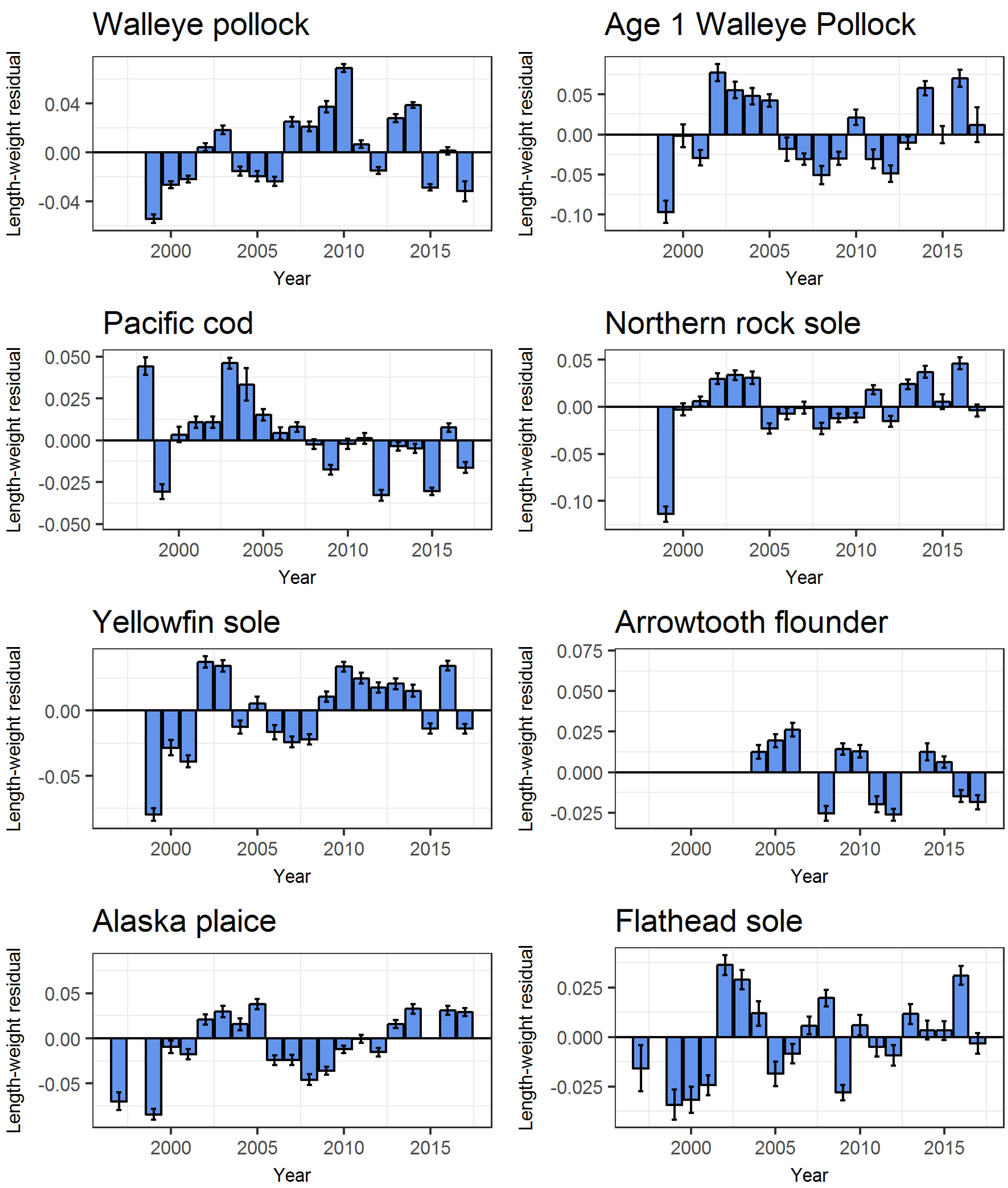

Figure 64: Length-weight residuals for seven eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997–2017.

we would expect fish condition to improve. Since the survey begins on the inner shelf and progresses to the outer shelf, the higher fish condition observed on the outer shelf may be due to the fact that they are sampled later in the summer. We also expect that some fish will undergo seasonal and, for some species, ontogenetic migrations through the survey months. For example, seasonal migrations of pollock occur from overwintering areas along the outer shelf to shallow waters (90–140 m) for spawning (Witherell, 2000). Pacific cod concentrate on the shelf edge and upper slope (100–250 m) in the winter, and move to shallower waters (generally <100 m) in the summer (Witherell, 2000). Arrowtooth flounder are distributed throughout the continental shelf until age 4, then, at older ages, disperse to occupy both the shelf and the slope (Witherell, 2000). Flathead sole overwinter

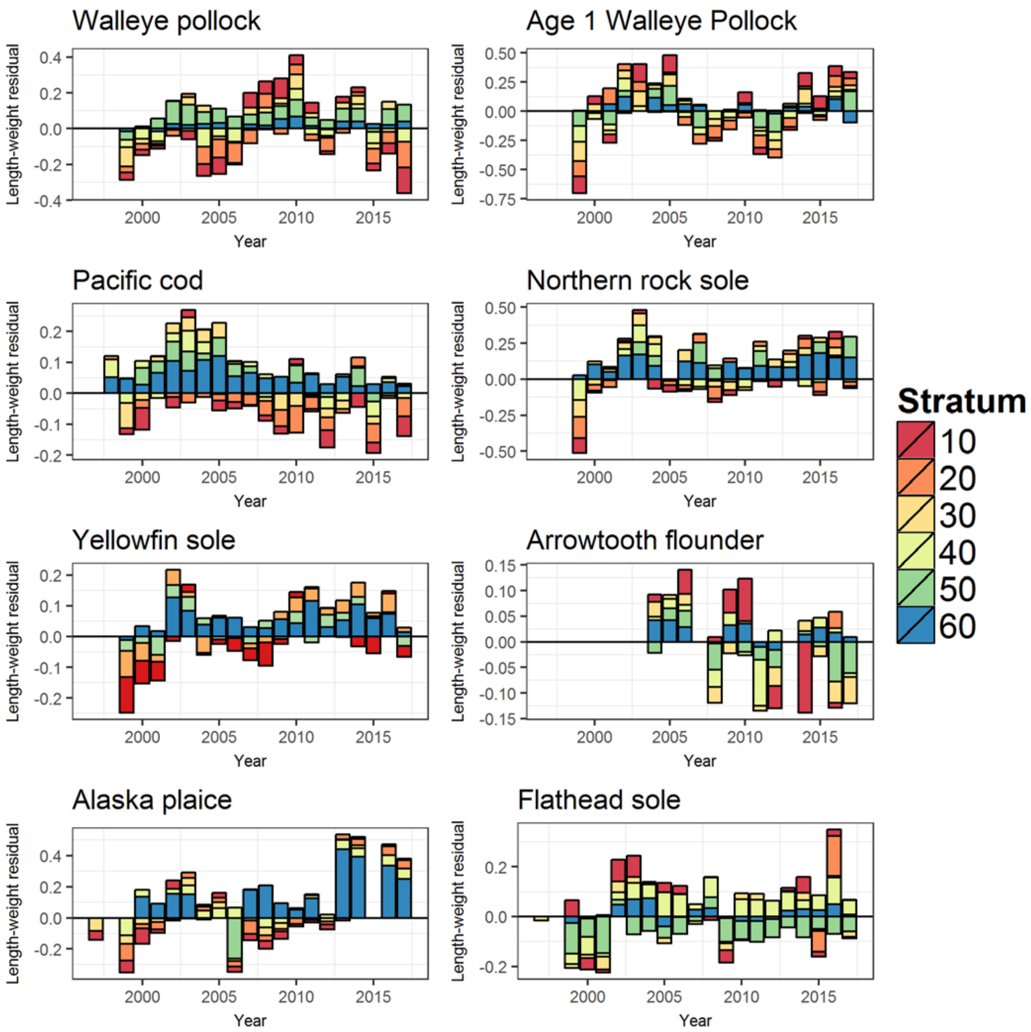

Figure 65: Length-weight residuals for seven eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997–2017, by survey strata (10–60). NMFS summer bottom trawl survey strata are shown in the lower right panel. Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 82 and 90 were excluded from analyses because they are not standard survey strata.

along the outer shelf, and move to shallower waters (20–180 m) in the spring (Witherell, 2000). Yellowfin sole concentrate on the outer shelf in the winter, and move to very shallow waters (<30 m) to spawn and feed in the summer (Witherell, 2000). How these migrations affect the length-weight residuals is unknown at this time.

Implications: A fish's condition may have implications for its survival. For example, in Prince William Sound, the condition of Pacific herring prior to the winter may in part determine their survival (Paul and Paul, 1998). The condition of Bering Sea groundfish may therefore partially contribute to their survival and recruitment. In the future, as years are added to the time series, the relationship between length-weight residuals and subsequent survival can be examined further. It is likely, however, that the relationship is more complex than a simple correlation. Also important to consider is the fact that condition of all sizes of fish were examined and used to predict survival.

Perhaps, it would be better to examine the condition of juvenile fish, not yet recruited to the fishery, or the condition of adult fish and correlations with survival. This work has not yet been done for the 2017 bottom trawl survey data, but we are preparing a manuscript describing the juvenile-adult condition correlation and further splitting of juvenile and adult fishes and anticipate including it in the 2018 Ecosystem Status Report.

The reduced condition for all species in 2017 compared to 2016 is a potential cause for concern and may be a leading indicator of poor overwinter survival and the potential for smaller stocks in 2018. It should be noted anecdotally that the commercial fishery was finding pollock in poorer condition during the summer season as well.

Multispecies Model Estimates of Time-varying Natural Mortality

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Last updated: October 2017

Description of indicator: We report trends in age-1 total mortality for Walleye pollock (*Gadus chalcogrammus*), Pacific cod (*Gadus macrocephalus*), and Arrowtooth flounder (*Atheresthes stomias*) from the eastern Bering Sea. Total mortality rates are based on residual mortality inputs (M1) and model estimates of annual predation mortality (M2) produced from the multi-species statistical catch-at-age assessment model known as CEATTLE (Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics). See Appendix 1 of the BSAI Walleye pollock stock assessment (Ianelli et al., 2017), Holsman et al. (2016), Holsman and Aydin (2015), Ianelli et al. (2015), and Jurado-Molina et al. (2005) for more information.

Status and trends: Estimated age-1 natural mortality (i.e., M1+M2) for pollock, Pacific cod, and Arrowtooth flounder peaked in 2016 and, for the third year in a row, remained elevated in 2017 at levels above those observed since the late 1980's (Figure 66). At 1.69 yr^{-1} age-1 mortality estimated by the model was greatest for pollock relative to Pacific cod or Arrowtooth flounder. Age-1 mortality was lower for Pacific cod and Arrowtooth flounder, with total age-1 natural mortality stable at around 0.69 and 0.65 yr^{-1}, respectively, although both were above long-term means in 2015–2017.

Factors influencing observed trends: Temporal patterns in natural mortality reflect annually-varying changes in predation mortality that primarily impact age-1 fish (but also impact ages 2 and 3 fish in the model). Pollock are primarily consumed by older conspecifics, and pollock cannibalism accounted for 55% (on average) of total predation mortality for age-1 pollock except for 2006–2008 when predation by Arrowtooth flounder exceeded cannibalism as the largest source of predation mortality of age-1 pollock (Figure 67).

Combined annual predation demand (annual ration) of pollock, Pacific cod, and Arrowtooth flounder in 2017 was 6.07 million t, down slightly from the 7.65 million t annual average during the warm years of 2014–2016. Pollock represent approximately 78% of the model estimates of combined prey consumed with 4.84 consumed annually by all three predators in the model (Figure 68).

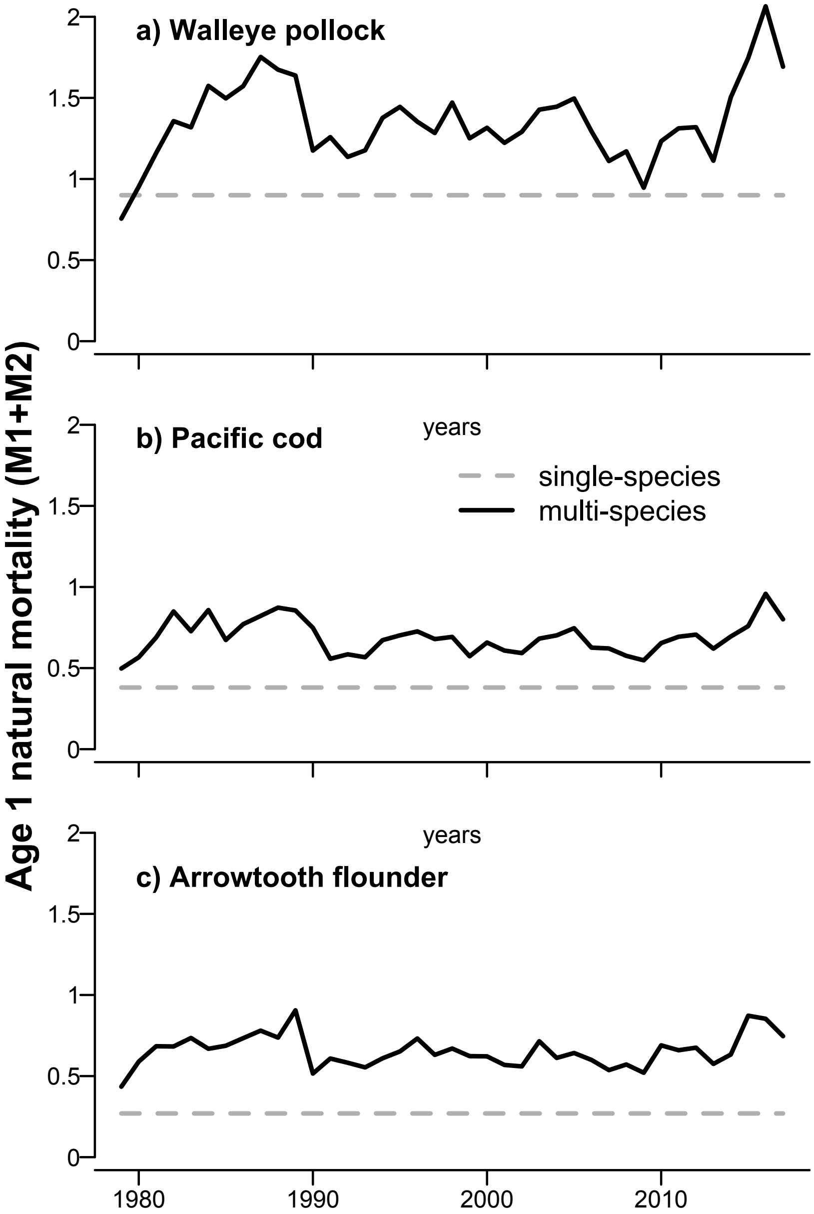

Figure 66: Annual variation in total mortality ($M1_{i1} + M2_{i1,y}$) for age-1 pollock (a), Pacific cod (b), and Arrowtooth flounder (c) from the single-species models (dashed gray line) and the multi-species models with temperature (black line). Updated from Holsman and Aydin (2015); more model detail can be found in Appendix 1 of the BSAI Walleye pollock stock assessment (Ianelli et al., 2017).

Implications: We find evidence for recent elevated rates of predation mortality on age-1 pollock, Pacific cod, and Arrowtooth flounder. This pattern may reflect higher metabolic (and energetic) demand of predators under warm conditions combined with maturing large 2010–2012 age classes of pollock and Pacific cod that have increased predator demand in the eastern Bering Sea (Holsman and Aydin, 2015; Spencer et al., In press; Hunsicker et al., 2013; Zador et al., 2011). This pattern

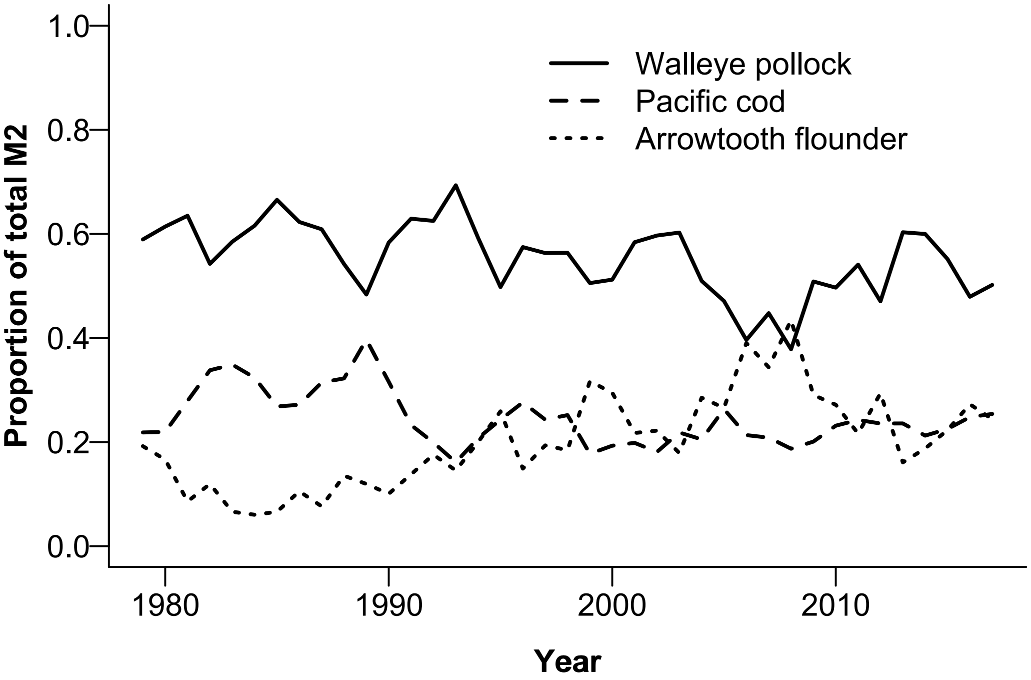

Figure 67: Proportion of total predation mortality for age-1 pollock from pollock (solid), Pacific cod (dashed), and Arrowtooth flounder (dotted) predators across years. Updated from Holsman and Aydin (2015); more model detail can be found in Appendix 1 of the BSAI Walleye pollock stock assessment (Ianelli et al., 2017).

may also explain low model estimates of recruitment of eastern Bering Sea pollock and Pacific cod in recent years.

Between 1980 and 1993, the relatively high natural mortality rates reflect patterns in combined annual demand for prey by all three predators that was highest in the mid 1980's (collectively 7.84 million t per year), and in recent years (collectively 7.25 million t per year). The peak in predation mortality of age-1 pollock in 2006 corresponds to the maturation of a large age class of 5–7 year old pollock and 2 year old Pacific cod that dominated the age composition of the two species in 2006. Similarly, the recent peaks in mortality in 2016 reflect maturation of the large 2012 year class of pollock.

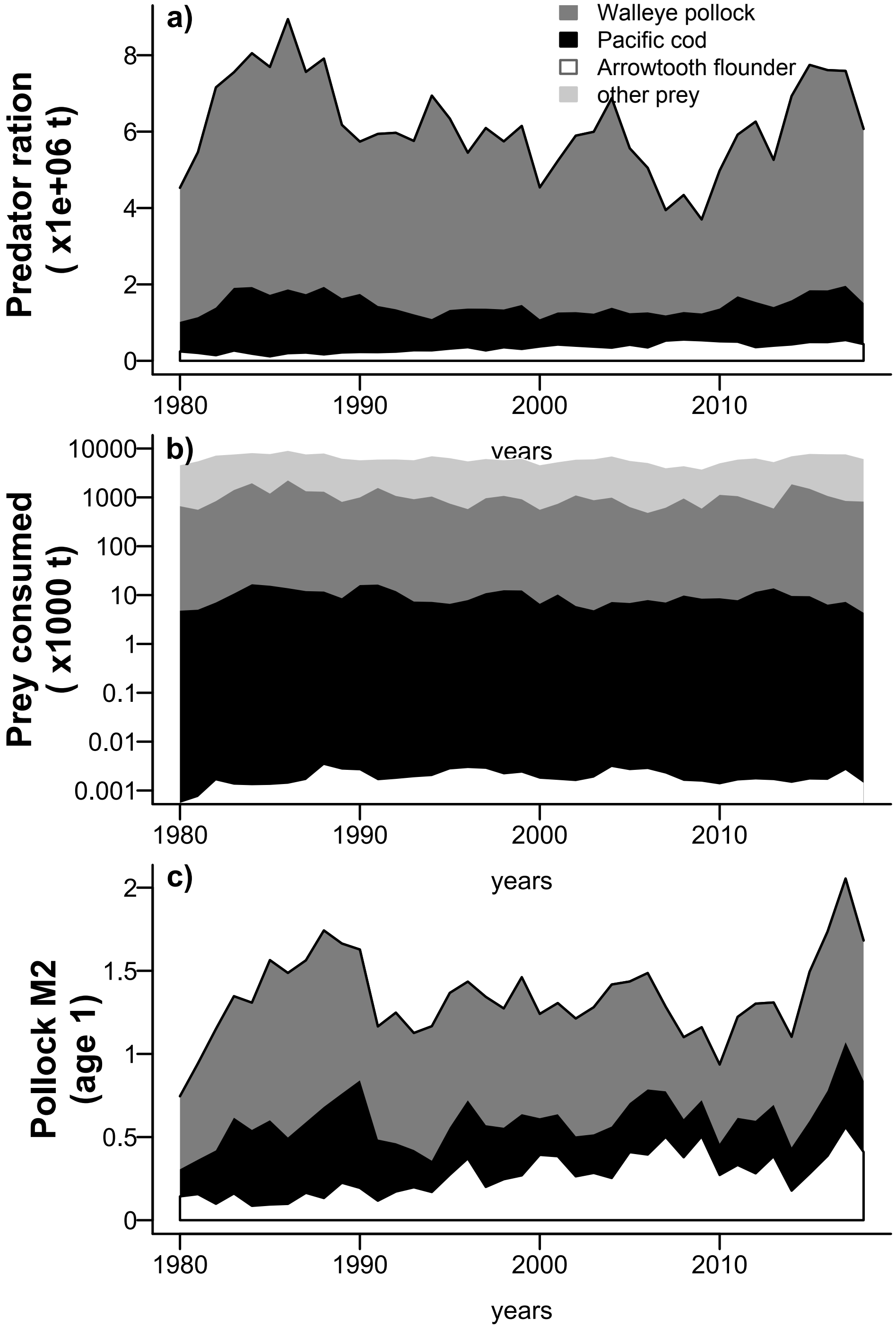

Figure 68: Multispecies estimates of annual predator demand for prey, prey consumed, and age-1 natural mortality of pollock. a) Combined total predator ration (all three predators combined) over time grouped by predator, b) total prey consumed by all three predators combined (note the log scale), and c) pollock predation mortality (M2; age-1 only) consumed by each predator species.

Groundfish Recruitment Predictions

Age-0 Recruitment of Pacific Cod (*Gadus macrocephalus*) in the Eastern Bering Sea as Predicted by the Average of the North Pacific Index from October through December

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Description of indicator: The North Pacific Index (NPI) was developed by Trenberth and Hurrell (1994), and represents the area-weighted sea level pressure over the region 30°N–65°N, 160°E–140°W. Monthly values of the NPI since January 1899 are reported at `https://climatedataguide.ucar.edu/sites/default/files/npindex_monthly.txt`. Specifically, the indicator used in this analysis is the average of the monthly NPI values from October–December in each year.

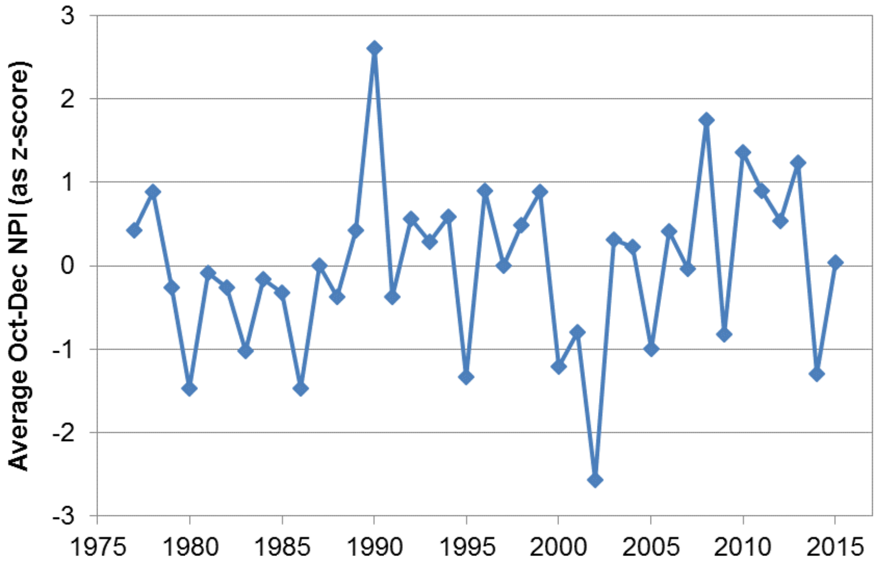

Figure 69: Average North Pacific Index (NPI) between October–December. The z-score is calculated as the average Oct.–Dec. NPI minus the mean of the time series divided by the standard deviation of the time series.

In the 2012 assessment of the eastern Bering Sea (EBS) stock of Pacific cod (*Gadus macrocephalus*) (Thompson and Lauth, 2012), annual log-scale recruitment deviations (from the mean) estimated by the assessment model were regressed against each of several environmental indices summarized by Zador et al. (2011). The highest univariate correlation was obtained for the spring–summer NPI. Further investigations were conducted with monthly NPI data from the website referenced above. The best univariate model obtained in the 2012 analysis was a linear regression of recruitment deviations from 1977–2011 against the October–December average NPI (from the same year). Vestfals et al. (2014) also noted a positive correlation between Pacific cod recruitment and the NPI, although not the October–December average NPI in particular.

Status and trends: In the 2016 assessment of the EBS stock of Pacific cod (Thompson and Lauth, 2016), the 2015 average October–December NPI was reported as being barely positive (z-score = 0.018). The 1977–2015 time series is shown in Figure 69. The trend depends on the range of years considered. If the regression starts in 2014, the trend is positive; if the regression starts anywhere from 2006 through 2013, the trend is negative; and if the regression starts anywhere from 1991 through 2005, the trend is positive.

In each assessment since 2012, the regression analysis has been updated. The regression in the 2016 assessment (Thompson and Lauth, 2016) resulted in a correlation of 0.55 (R^2=0.30). The time series, regression line, and 95% confidence interval from the 2016 regression are shown in Figure 70. According to this regression, the probability of the 2015 year class being higher than the median for the time series is 51%. However, the datum for 2015 (magenta diamond in Figure 70) falls quite a bit below the predicted value from the regression. This marks the first time in the last 11 years (cohorts) that the sign of the difference from the mean estimated by the assessment model differs from the sign predicted by the regression (although the difference from the mean for 2015 predicted by the regression is extremely close to zero [0.014]).

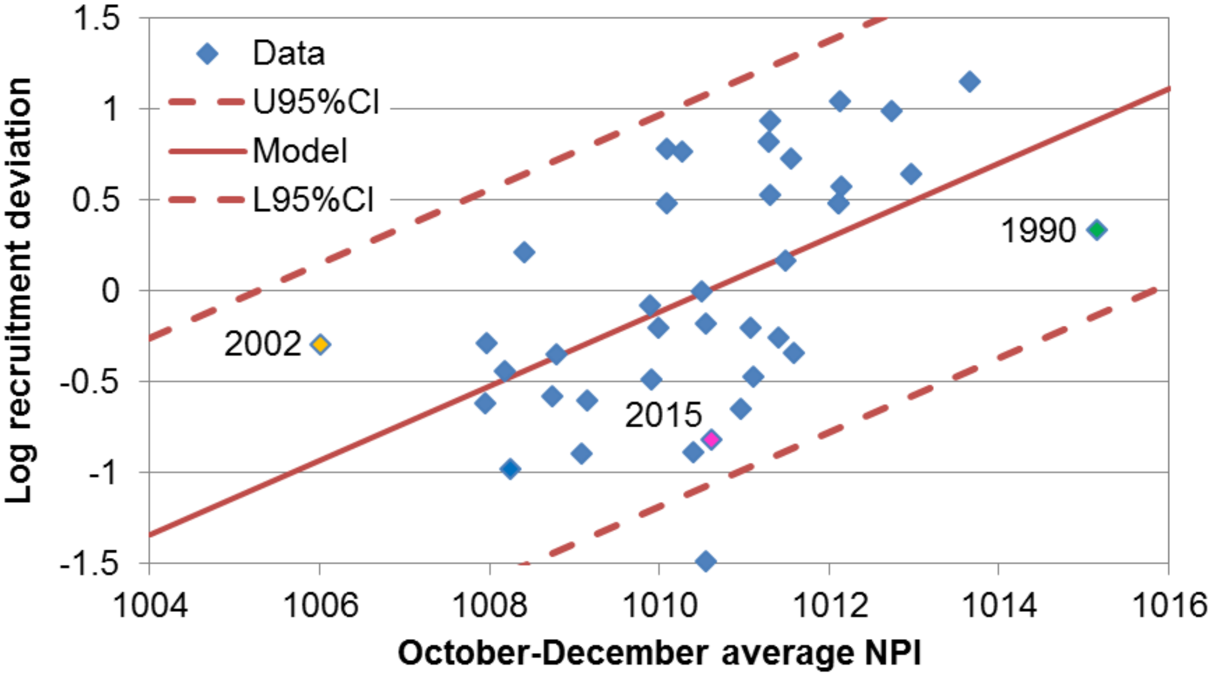

Figure 70: Estimated log recruitment deviations of age-0 Pacific cod versus same-year October–December average of the North Pacific Index, with regression line and 95% confidence interval.

Factors influencing observed trends: Two years, 1990 and 2002 (green and yellow diamonds in Figure 70), turned out to be far more influential than any other year in determining the magnitude of the estimated slope, and both of these influences were negative. Therefore, the positive slope is not due to the influence of outliers; if anything, the outliers are making the relationship appear less strong than would be the case without them.

Circulation patterns over the EBS shelf vary with large-scale climate drivers such as the Pacific Decadal Oscillation (see p. 68). The strength of the Bering Slope Current is correlated with the NPI

(Vestfals et al., 2014) with higher NPI values related to weaker along-shelf transport. The positive relationship between the NPI and Pacific cod recruitment may indicate that weaker circulation leads to better retention of age-0 fish in suitable nursery habitats (Vestfals et al., 2014).

Implications: Potential uses of the estimated relationship in the context of fishery management are: 1) as an independent means of corroborating initial estimates of year class strength, which are not made until the year class reaches age-1 (the first age at which the fish show up in the EBS shelf bottom trawl survey); 2) as a determinant of year class strength within the stock assessment model itself; and 3) in the event that the average October–December NPI can be forecast into the future, as a means of forecasting future year class strengths.

Pre- and Post-Winter Temperature Change Index and the Recruitment of Bering Sea Pollock

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Description of indicator: The temperature change (TC) index is a composite index for the pre- and post-winter thermal conditions experienced by Walleye pollock (*Gadus chalcogrammus*) from age-0 to age-1 in the eastern Bering Sea (Martinson et al., 2012). The TC index (year t) is calculated as the difference in the average monthly sea surface temperature in June (t) and August (t-1) (Figure 71) in an area of the southern region of the eastern Bering Sea (56.2°N to 58.1°N by 166.9°W to 161.2°W). Time series of average monthly sea surface temperatures were obtained from the NOAA Earth System Research Laboratory Physical Sciences Division website. Sea surface temperatures were based on NCEP/NCAR gridded reanalysis data (Kalnay et al., 1996), data obtained from `http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl`. Less negative values represent a cool late summer during the age-0 phase followed by a warm spring during the age-1 phase for pollock.

Status and trends: The 2017 TC index value is -6.16, lower than the 2016 TC index value of -3.19, indicating a decrease in conditions for pollock survival from age-0 and age-1 from 2016 to 2017, respectively. The decrease in expected survival is due to the larger difference in sea temperature from late summer (warmer) to the following spring (cooler). However, both the late summer sea surface temperature (13.0 °C) in 2016 and spring sea temperatures (6.4 °C) in 2017 were warmer than the long-term average of 9.7 °C in late summer and 5.1 °C in spring since 1949. The TC index was positively correlated with subsequent recruitment of pollock to age-1 through age-4 from 1964 to 2016, but not significantly correlated for the shorter period (1995–2016) (Table 8).

Factors causing observed trends: According to the original Oscillating Control Hypothesis (OCH), warmer spring temperatures and earlier ice retreat led to a later oceanic and pelagic phytoplankton bloom and more food in the pelagic waters at an optimal time for use by pelagic species (Hunt et al., 2002). The revised OCH indicated that age-0 pollock were more energy-rich and have higher over wintering survival to age-1 in a year with a cooler late summer (Coyle et al., 2011; Heintz et al., 2013). Therefore, the colder, later summers during the age-0 phase followed by warmer spring temperatures during the age-1 phase are assumed favorable for the survival of

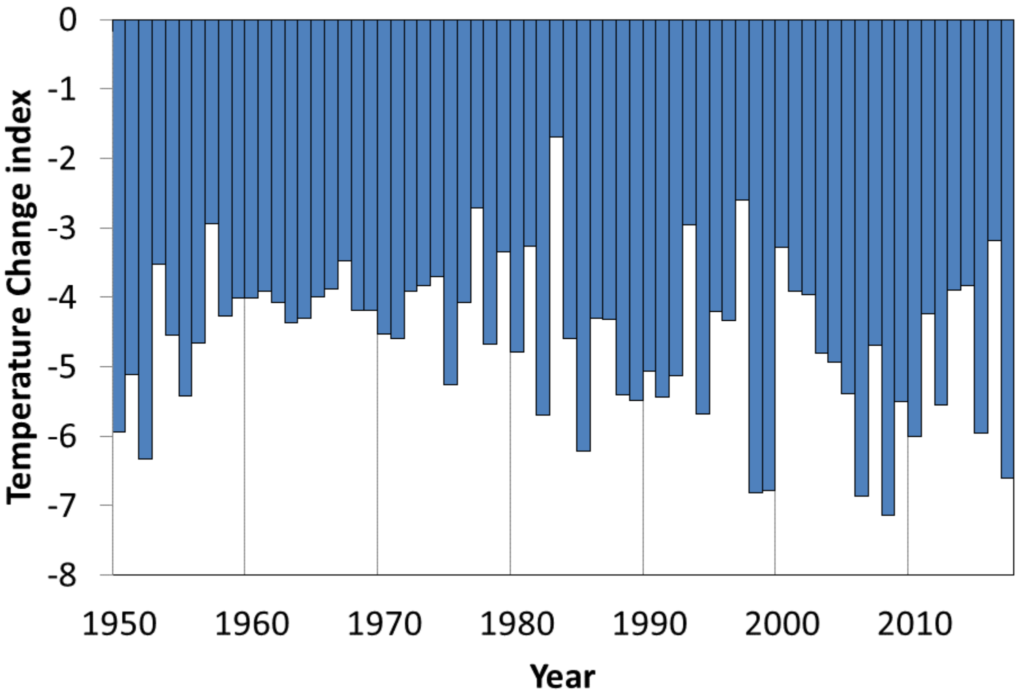

Figure 71: The Temperature Change index values from 1949–2017. Values represent the difference in sea surface temperatures experienced by the 1948–2016 year classes of Walleye pollock. Less favorable conditions (more negative values) represent a warm summer during the age-0 life stage followed by a relatively cool spring during the age-1 life stage. More favorable conditions (less negative values) represent a cool summer during the age-0 life stage followed by a relatively warm spring during the age-1 life stage.

pollock from age-0 to age-1. The 2016 year class of pollock experienced a warm summer during the age-0 stage and a cool spring in 2017 during the age-1 stage indicating poor conditions for overwintering survival from age-0 to age-1.

Implications: The 2017 TC index value of -6.16 was below the long-term average of -4.61, therefore we expect lower than average recruitment of pollock to age-3 in 2019 from the 2016 year class (Figure 72). The 2016 TC index value of -3.19 was above the long-term average of -4.60, therefore we expect slightly above average recruitment of pollock to age-3 in 2018 from the 2015 year class. The 2015 TC index value of -5.96 was below the long-term average, therefore we expect slightly below average recruitment of pollock to age-3 in 2017 from the 2014 year class.

Table 8: Pearson's correlation coefficient relating the Temperature Change index to subsequent estimated year class strength of pollock. Bold values are statistically significant ($p < 0.05$).

	Correlations					
	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6
1964–2016	**0.34**	**0.34**	**0.32**	0.27	0.23	0.21
1996–2016	0.37	0.41	0.36	0.35	0.40	0.38

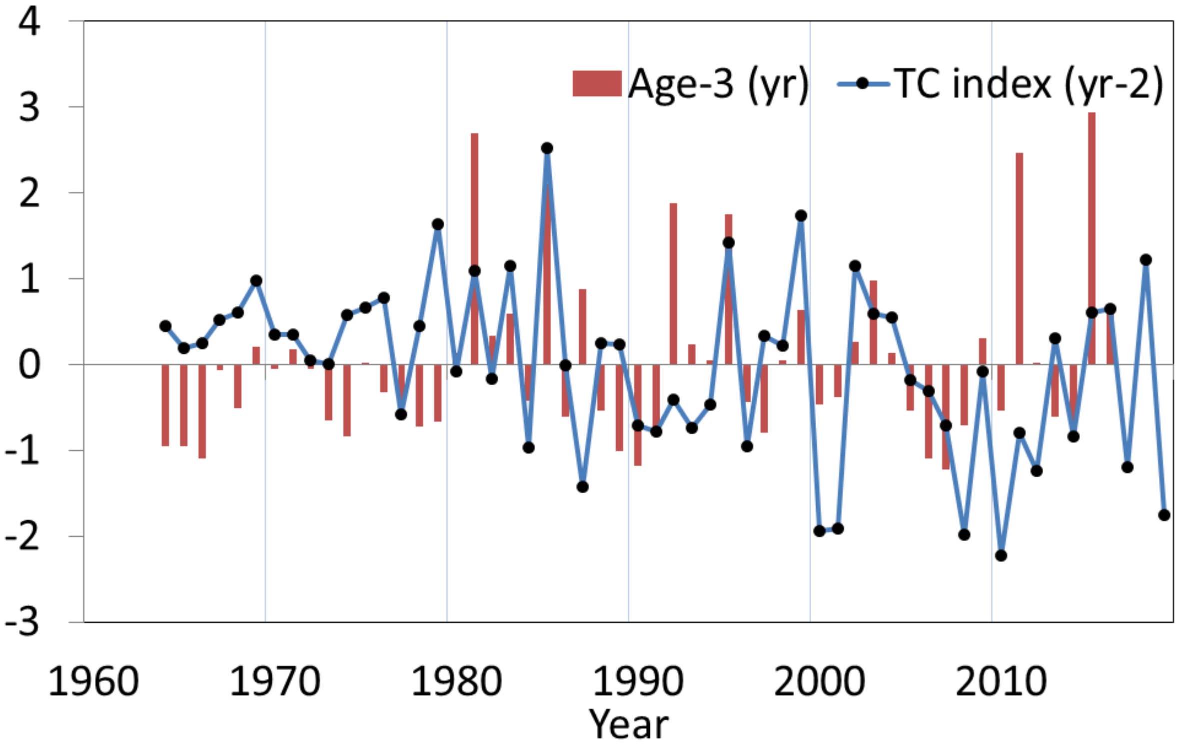

Figure 72: Normalized time series values of the Temperature Change Index (t-2) from 1964–2019 indicating conditions experienced by the 1961–2016 year classes of pollock during the summer age-0 and spring age-1 life stages. Normalized values of the estimated abundance of age-3 pollock in the eastern Bering Sea from 1964–2016 (t) for the 1961–2013 year classes. Age-3 pollock estimates are from Table 1.30 in Ianelli et al. (2016). The TC index indicates above average conditions for the 2015 year class and below average conditions for the 2014 and 2016 year classes of pollock.

Implications for Age-0 Walleye Pollock (*Gadus chalcogrammus*) Condition Based on Late Summer Surface Silicic Acid Concentrations.

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Last updated: August 2017

Description of indicator: Nitrogen (nitrate, nitrite, or ammonium) is usually the principal limiting nutrient in the eastern Bering Sea (EBS) for phytoplankton growth. It is, however, often near detection limits during late summer/early fall for stratified surface waters. Therefore, inter-annual variations in surface nitrogen are difficult to measure during this time. In contrast, surface silicate (silicic acid) is found in higher concentrations than nitrogen and inter-annual variations are reliably detectable making silicate a possible indicator of nutrient availability in surface waters.

The condition of age-0 Walleye pollock (*Gadus chalcogrammus*) during late summer/early fall can be an indicator for recruitment to age-1, where pollock weight is sometimes used as a general proxy for condition. Surface silicic acid is observed during late summer/early fall, in conjunction with age-0 pollock weights, to look for possible connections between nutrients, phytoplankton growth, and young of the year (age-0) pollock condition as they approach their first winter at sea.

Status and trends: Surface silicic acid as well as age-0 pollock weights were above average for 2014–2016 when viewed within the years 2006–2016. Bering Sea pollock recruitment to age-1 during 2014 and 2015 were above average, while 2016 was below average (Ianelli et al., 2016). The year with the lowest surface silicic acid concentrations by the end of summer (2007), also had the lowest average body weights of age-0 pollock with low recruitment to age-1. In addition to 2007, 2012 had lowered silicic acid concentrations and age-0 pollock weights compared with other years (2006–2016). There was also low age-1 recruitment during 2008 and 2013. A scatterplot showing age-0 pollock weight with silicic acid values reveals a possible non-linear relationship between the two, with a threshold value somewhere near 5–6 μM [Si(OH)$_4$] (Figure 73). It may be that once silicic acid concentrations reach this threshold, the relationship with growth of age-0 pollock is diminished, with the data from 2016 continuing to support this theory.

Factors influencing observed trends: During summer, the strength and frequency of storm events and water column stratification will influence the amount of nutrients (including silicic acid) that are brought to surface waters from depth. Late summer concentrations of surface silicic acid may serve as an indicator of nutrient availability, with higher concentrations seen during windy years and lower stratification, and low concentrations seen when storm activity is minimal and stratification is high (Gann et al., 2016; Eisner et al., 2015). Diminished nutrient stores leading to lower production in the upper water column may directly affect food stores for higher trophic levels and lead to slowed growth of age-0 pollock during summer months.

Implications: The general positive correlation silicic acid has with age-0 pollock weight (Figure 74) could mark its potential as a variable for use in age-1 pollock recruitment models, especially when silicic acid concentrations fall below 5–6 μM [Si(OH)$_4$]. Future possibilities for this index may include the use of age-0 pollock energy content, as well as chlorophyll or other lower trophic level indicators.

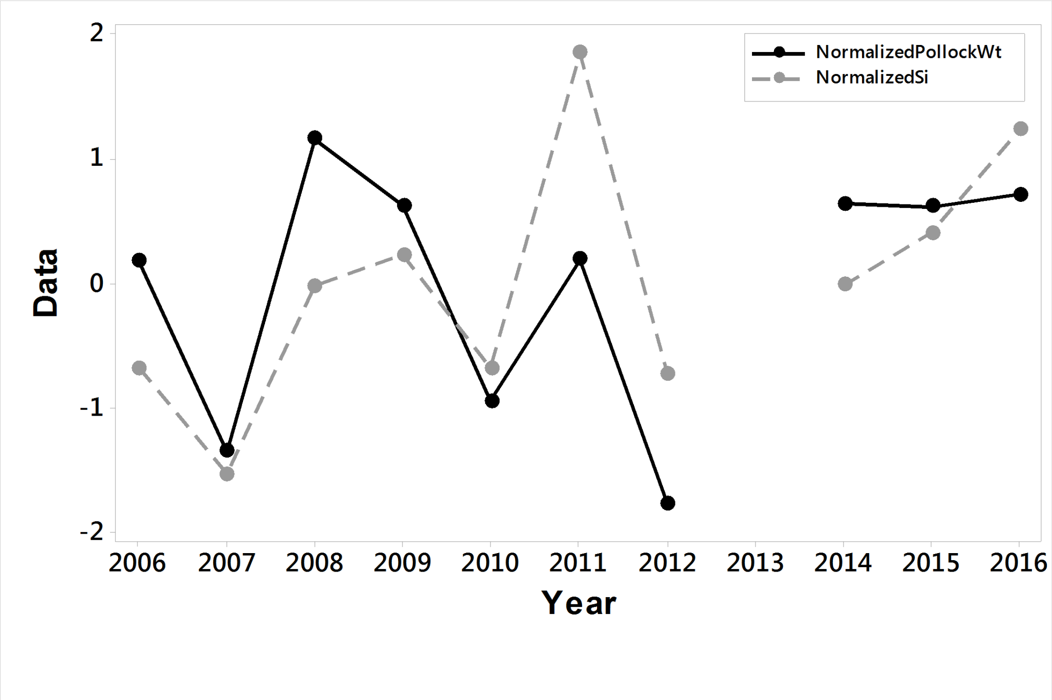

Figure 73: Inter-annual variability of normalized surface silicic acid ($Si(OH)_4$), from Bering Sea south middle shelf (region 3) and normalized mean weights of age-0 Walleye pollock (south of 60°N). Values were normalized by subtracting the mean from the value for each year and dividing by the standard deviation.

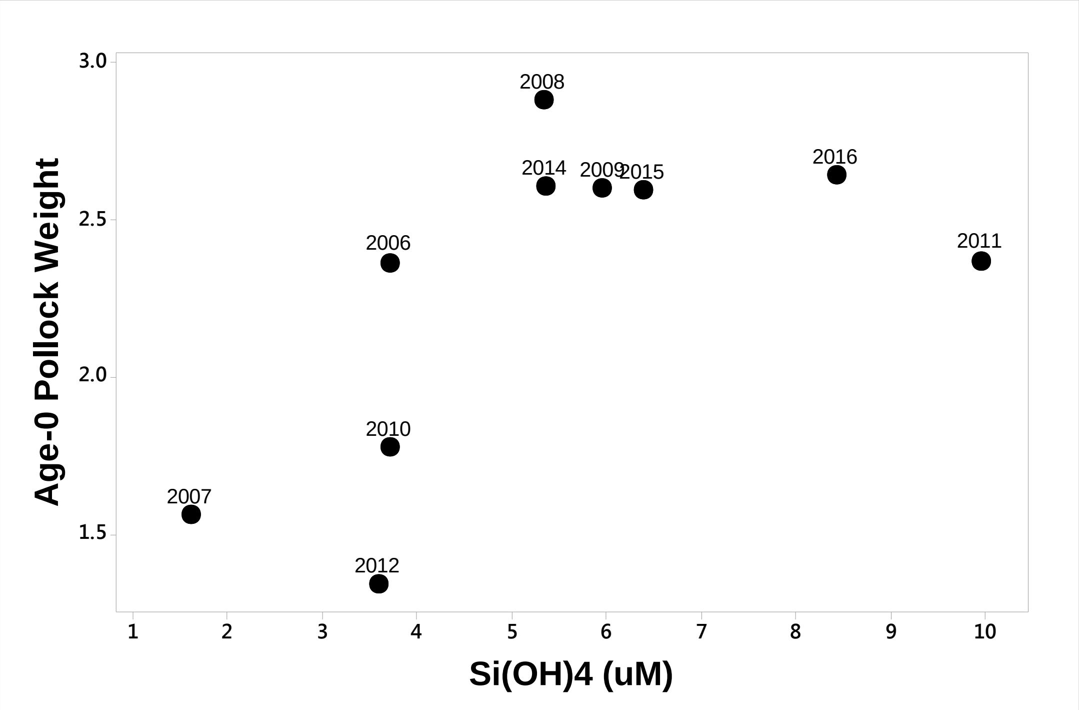

Figure 74: Yearly averages for age-0 Walleye pollock weight and silicic acid ($Si(OH)_4$), with a possible threshold for age-0 Walleye pollock dependence on nutrient availability at approximately 5–6 μM [$Si(OH)_4$].

Large Zooplankton Abundance as an Indicator of Pollock Recruitment to Age-1 and Age-3 in the Southeastern Bering Sea

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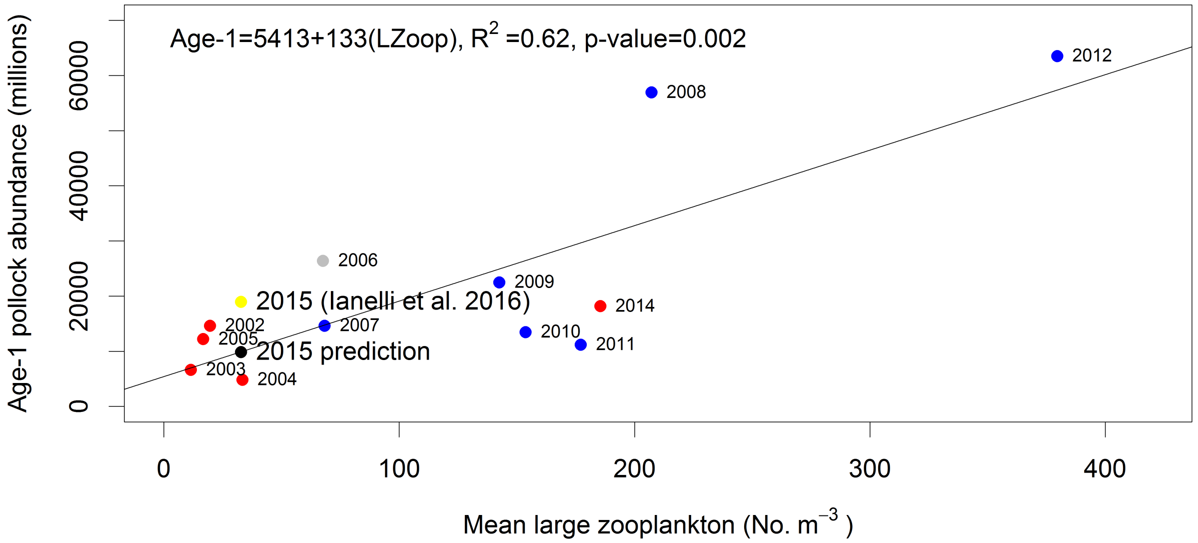
Description of indicator: Interannual variations in large zooplankton abundance (sum of most abundant large taxa, typically important in age-0 Walleye pollock [*Gadus chalcogrammus*] diets, Coyle et al. (2011)) were compared to age-1 and age-3 pollock abundance (millions of fish for the 2002–2014 year classes) on the southeastern Bering Sea shelf (south of 60°, < 200 m bathymetry). Zooplankton samples were collected with oblique bongo tows over the water column using 60 cm, 505 μm mesh nets for 2002–2011 data, and 20 cm, 153 μm mesh and 60 cm, 505 μm nets, depending on taxa, for 2012, 2014, and 2015 data. Taxa included in the index are large copepods (copepodite stage 3–adult), *Calanus marshallae/glacialis*, *Eucalanus bungii*, *Metridia pacifica*, and *Neocalanus* spp., the chaetognath, *Parasaggita elegens*, and the pteropod, *Limacina helicina* (505 μm net only). Data were collected on BASIS fishery oceanography surveys during mid-August to late September, for four warm years (2002–2005) followed by one average (2006), six cold (2007–2012), and two warm (2014 and 2015) years using methods in Eisner et al. (2014). Zooplankton data were not available for 2013. Pollock abundance was available from the stock assessment report for the 2002–2015 year classes (Ianelli et al., 2016).

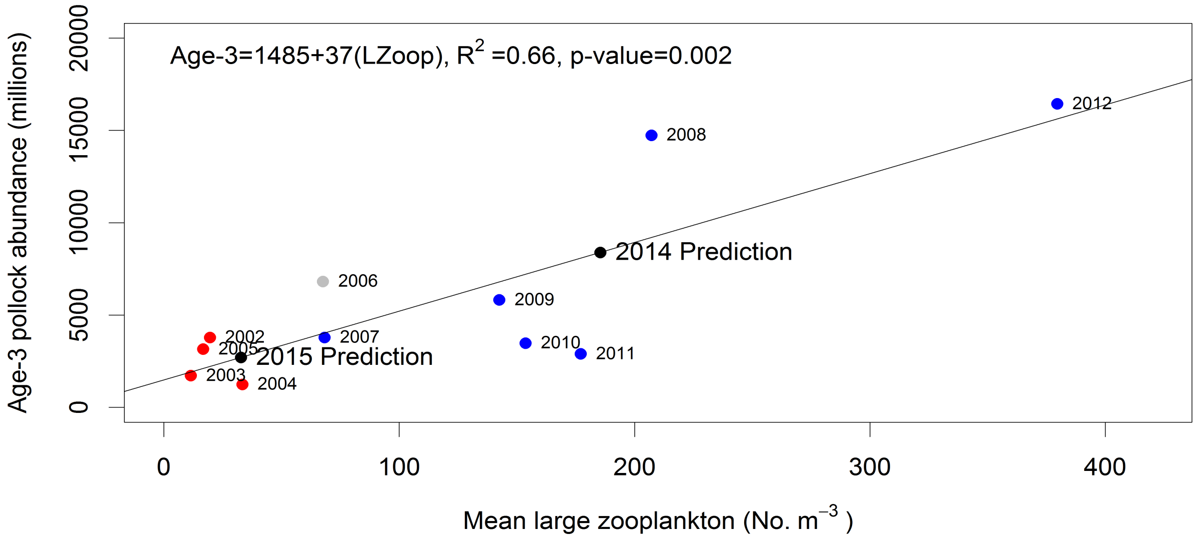
Status and trends: A positive significant ($P = 0.002$) linear relationship was found between mean abundances of large zooplankton during the age-0 stage of pollock and stock assessment estimates of abundance of age-1 pollock for the 2002–2015 year classes (Figure 75a) and age-3 pollock for the 2002–2013 year classes (Figure 75b) (Ianelli et al., 2016).

To predict age-1 pollock abundance, we used a model relating of zooplankton abundance to the age-1 pollock stock assessment estimates for the 2002–2014 year classes ($Age1$=5413 + 133*$LZoop$, R^2=0.62, p=0.002). Model predictions from large zooplankton abundance (32.75) in 2015 estimated there would be 9,895 million (standard error = 4,619 million) age-1 pollock in 2016 (from the 2015 year class), below average age-1 pollock abundance for the time series (Figure 76a).

Likewise, to predict age-3 pollock abundance, we used a model relating zooplankton abundance (2002–2012) to the age-3 pollock stock assessment estimates in 2005–2015 (for the 2002–2012 year classes) ($Age3$=1485 + 37*$LZoop$, R^2=0.66, p=0.002). Large zooplankton abundance in 2014 (185) predicted 8,389 million (standard error = 1,1816 million) age-3 pollock in 2017 from the 2014 year class, average age-3 pollock abundance for the time series (Figure 76b). Model predictions from large zooplankton abundance in 2015 predicted 2,704 million (standard error = 1,188 million) age-3 pollock in 2018 from the 2015 year class, below average age-3 pollock abundance for the time series.



(a) Age-1 Walleye pollock abundance in relation to large copepod densities in the southeastern Bering Sea by year class.

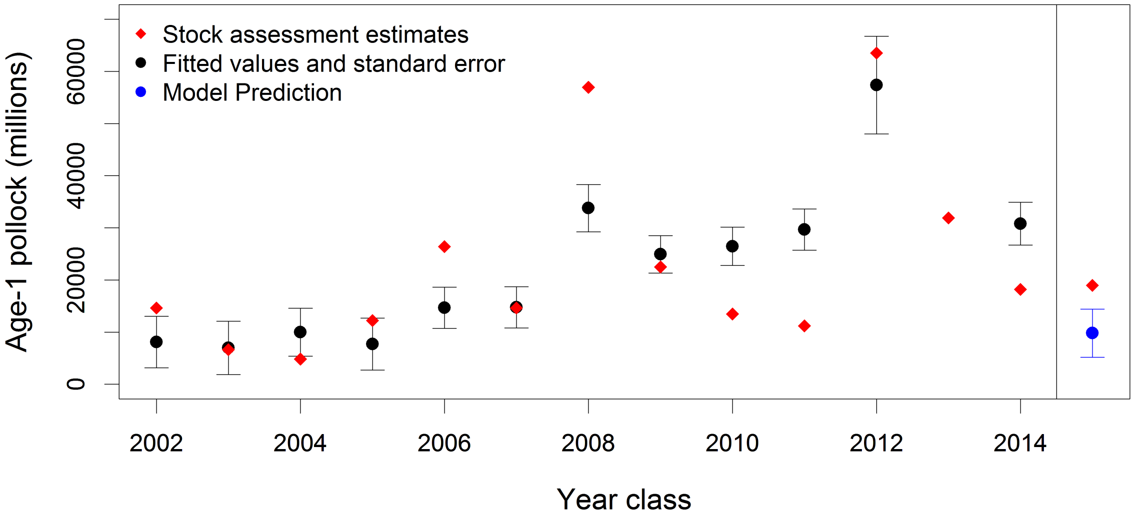


(b) Age-3 Walleye pollock abundance in relation to large copepod densities in the fall in the southeastern Bering Sea by year class.

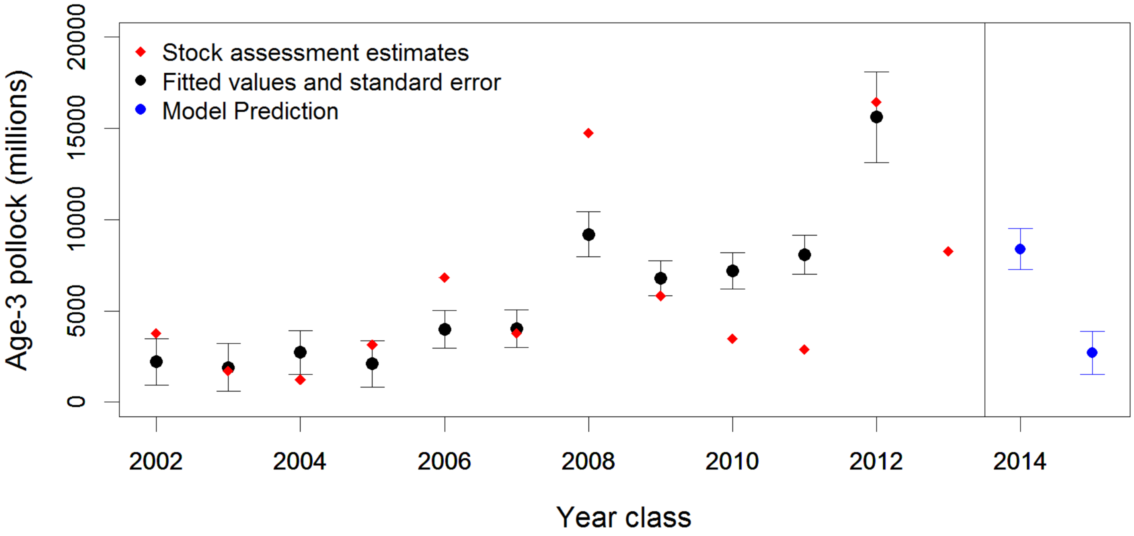
Figure 75: Linear relationships between mean large zooplankton abundance during the age-0 life stage of Walleye pollock and the estimated abundance of age-1 pollock abundance of the year class (2002–2015) from Ianelli et al. (2016). In (a), the 2015 point is the observed stock assessment estimate of age-1 pollock from Ianelli et al. (2016) and the predicted numbers of age-1 pollock from our regression model and the large zooplankton values for 2015 (32.75). Points are labeled with year class. Red points are warm (low ice) years, blue are cold (high ice) years, gray is an average year and black is the predicted 2014 and 2015 year classes value from the model. No zooplankton data were available for 2013.

Factors influencing observed trends: Increases in sea ice extent and duration were associated with increases in large zooplankton abundances on the shelf (Eisner et al., 2014, 2015), increases in large copepods and euphausiids in pollock diets (Coyle et al., 2011), and increases in age-0 pollock lipid content (Heintz et al., 2013). The increases in sea ice and associated ice algae and phytoplankton blooms may provide an early food source for large crustacean zooplankton reproduction and growth (Baier and Napp, 2003; Hunt et al., 2011). These large zooplankton taxa contain high lipid concentrations (especially in cold, high ice years) which in turn increases the lipid content in their predators such as age-0 pollock and other fish that forage on these taxa. Increases in energy density (lipids) in age-0 pollock allow them to survive their first winter (a time of high mortality) and eventually recruit into the fishery. Accordingly, a strong relationship has been shown for energy density in age-0 fish and age-3 pollock abundance (Heintz et al., 2013).

Implications: Our results suggest that decreases or low abundances in the availability of large zooplankton prey during the first year at sea in 2015 were not favorable for age-0 pollock survival and recruitment to age-1 and age-3. If the relationship between large zooplankton and age-3 (age-1) pollock remains significant in our analysis, the index may be used to predict the recruitment of pollock three (one) years in advance of recruiting to age-3 (age-1), from zooplankton data collected three (one) years prior. This relationship also provides further support for the revised Oscillating Control Hypothesis that suggests as the climate warms, reductions in the extent and duration of sea ice could be detrimental to large crustacean zooplankton and subsequently to the pollock fishery in the southeastern Bering Sea (Hunt et al., 2011).



(a) Predicting age-1 Walleye pollock abundance using large copepod densities in the southeastern Bering Sea by year class.



(b) Predicting age-3 Walleye pollock abundance using large copepod densities in the southeastern Bering Sea by year class.

Figure 76: Fitted values and standard errors of the abundance of Walleye pollock estimated from the linear regression model relating the estimate pollock abundance from (Ianelli et al., 2016) to the estimated abundance of large zooplankton in the southeastern Bering Sea during the age-0 life stage of pollock. Red symbols are stock assessment estimates of pollock abundance from (Ianelli et al., 2016). Our regression model parameters and estimated abundance of large zooplankton in 2014 predicted an abundance of 9,805 million age-1 pollock with a standard error of 4,619 million for the 2014 year class and an abundance of 8,389 million age-3 pollock with a standard error of 1,116 million (blue) for the 2014 year class and 2,704 million age-3 pollock with a standard error of 1,188 million for the 2015 year class (blue).

Spatial Overlap of Age-0 Walleye Pollock and Foraging Landscapes Predicts Survival and Recruitment Success

Contributed by Elizabeth Siddon[1], Alex Andrews[1], Tayler Jarvis[1], and Kirstin Holsman[2]
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Last updated: October 2017

Description of indicator: Age-0 Walleye pollock (*Gadus chalcogrammus*) abundance was estimated from the Bering-Arctic-Subarctic Integrated Survey (BASIS) conducted during late summer in 2003–2014. Zooplankton was sampled contemporaneously and provides information on available foraging landscapes. Year-, station-, and taxa-specific zooplankton biomass were weighted by year (or stanza)- and taxa-specific lipid values in order to determine spatially explicit estimates of prey availability.

The spatial overlap between age-0 pollock and prey availability was quantified using the Proportional Similarity Measure (Slobodchikoff and Schulz, 1980) (Figure 77). Index values range from 0–1, with higher values indicating greater proportion of overlap between age-0 pollock and lipid-rich zooplankton prey. This index of spatial overlap forecasts pollock cohort strength (as age-1 recruits per spawner; Ianelli et al. (2016)) and indicates that different mechanisms may govern survival in warm versus cold years (Figure 78).

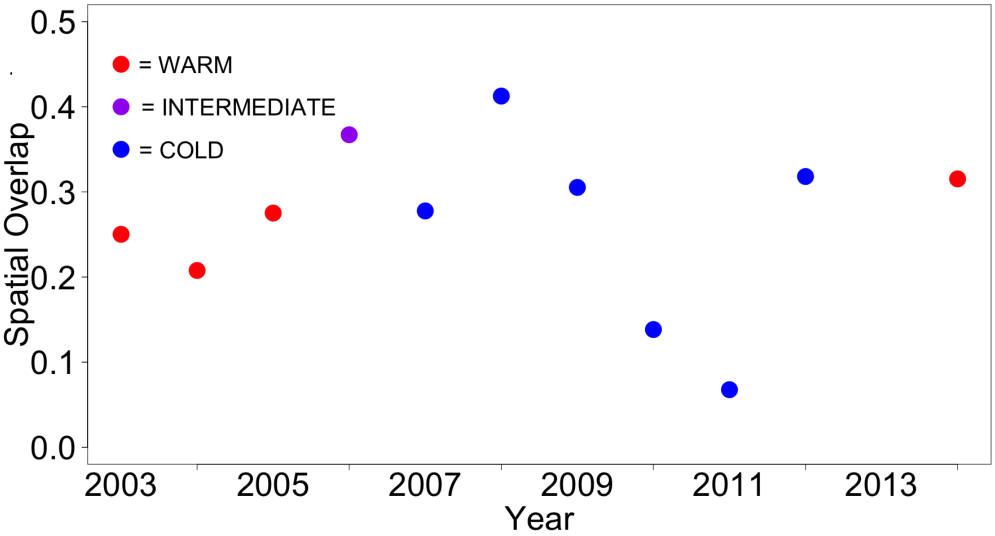

Figure 77: Index of spatial overlap for 2003–2014 (no survey in 2013). Values range 0–1 with higher values indicating greater proportion of overlap between age-0 Walleye pollock (*Gadus chalcogrammus*) and available zooplankton prey.

Status and trends: The eastern Bering Sea experienced above-average (warm) conditions characterized by an early ice retreat and small or retracted cold pool between 2003–2005. Thermal conditions in 2006 were intermediate, indicating a transition, and ice retreated much later in the years 2007–2013 (i.e., cold conditions). Warm conditions returned in 2014. No clear pattern ex-

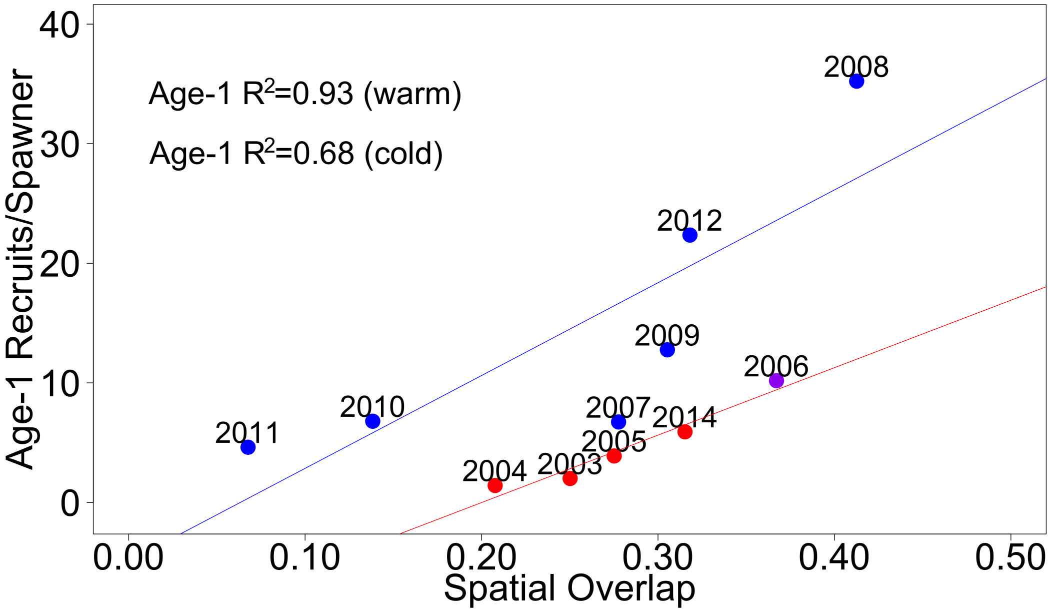

Figure 78: Relationship between the index of spatial overlap and the number of age-1 recruits per spawner from the 2016 stock assessment (Ianelli et al., 2016). The intermediate year (average thermal conditions; 2006) was not included in either relationship. No survey occurred in 2013.

ists between the index of spatial overlap and thermal conditions (Figure 77). However, a strong correlation between the overlap index and recruitment exists by climate stanza (warm versus cold years). In warm years (2003–2005, 2014), the overlap with lipid-rich prey accounts for 93% of the variation in the number of age-1 recruits per spawner. In cold years (2007–2012), overlap explains 68% of the variability (Figure 78).

Factors influencing observed trends: In the eastern Bering Sea, bottom-up processes shape foraging landscapes that ultimately determine the energetic condition and overwinter survival of age-0 pollock (Heintz et al., 2013). Additionally, timing of sea ice retreat and the spatial extent of the cold pool affect the distribution of age-0 pollock and also impact the distribution of adult pollock and other predators (e.g., Arrowtooth flounder, *Atheresthes stomias*) (Hollowed et al., 2013).

Multiple-year climate stanzas of warm conditions precipitate a trophic cascade that leads to a restructuring of the prey base, reduced energetic condition of age-0 pollock, and reduced overwinter juvenile pollock survival success (Duffy-Anderson et al., 2017). Under cold conditions, zooplankton prey are both larger and more lipid-rich; age-0 pollock are better provisioned going into winter; and have greater overwinter survival (Heintz et al., 2013). Therefore, survival (and subsequent recruitment) of age-0 pollock may be governed by different mechanisms in warm (bottom-up) and cold (bottom-up and top-down) years.

Implications: The spatial overlap of age-0 pollock and foraging landscapes helps to explain recruitment variability in the eastern Bering Sea. During periods of warm conditions, bottom-up processes affecting prey availability and condition (i.e., lipid content) appear to have a greater influence on survival and recruitment strength. Under cold conditions, bottom-up processes are important, while top-down processes that delineate the spatial overlap with predators also contribute.

Fall Energetic Condition of Age-0 Walleye Pollock Predicts Survival and Recruitment Success

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Last updated: September 2017

Description of indicator: Average Energy Content (AEC; kJ/fish) is the product of the average individual mass and average energy density of age-0 Walleye pollock (*Gadus chalcogrammus*) collected during the late-summer BASIS survey in the southeastern Bering Sea (SEBS). Fish were collected from surface trawls in all years except 2015 when oblique (water column) trawls were used. The average individual mass is calculated by dividing the total mass by the total number of age-0 pollock caught in each haul. The average energy density is estimated in the laboratory from multiple (2–5) fish within ± 1 standard deviation of the mean length (see Siddon et al. (2013*a*) for detailed methods). The haul-specific energy value is weighted by catch to estimate average energy density per station. The product of the two averages represents the average energy content for an individual age-0 pollock in a given year.

We relate AEC to the number of age-1 recruits per spawner (R/S) using the index of adult female spawning biomass as an index of the number of spawners. Relating the AEC of age-0 pollock to year class strength from the age-structured stock assessment indicates the energetic condition of pollock prior to their first winter predicts their survival to age-1.

Status and trends: Energy density (kJ/g), mass (g), and standard length (SL; mm) of age-0 pollock have been measured annually since 2003 (except 2013 when no survey occurred). Over that period, energy density has varied with the thermal regime in the SEBS. Between 2003 and 2005 the SEBS experienced warm conditions characterized by an early ice retreat. Thermal conditions in 2006 were intermediate, indicating a transition, and ice retreated much later in the years 2007–2013 (i.e., cold conditions). Warm conditions returned in 2014 through late-summer 2016.

The transition between warm and cold conditions is evident when examining energy density over the time series (Figure 79). Energy density was at a minimum in 2003 (3.63 kJ/g) and increased to a maximum of 5.26 kJ/g in 2010. In contrast, the size (mass or length) of the fish has been less influenced by thermal regime. The AEC of age-0 pollock in 2003–2016 accounts for 25% of the variation in the number of age-1 recruits per spawner (Figure 80). Extremely strong year classes occurred in 2008 and 2012 and this indicator does not capture those events well. Likely multiple favorable processes occurred simultaneously to result in such strong recruitment. With 2008 and 2012 removed from the model, the AEC accounts for 59% of the variability in age-1 survival (Figure 80).

Factors influencing observed trends: The AEC of age-0 pollock integrates information about size and energy density into a single index, therefore reflecting the effects of size dependent mortality over winter (Heintz et al., 2010) as well as prey conditions during the age-0 period. Late summer represents a critical period for energy allocation in age-0 pollock (Siddon et al., 2013*a*) and their ability to store energy depends on water temperatures, prey quality, and foraging costs (Siddon et al., 2013*b*).

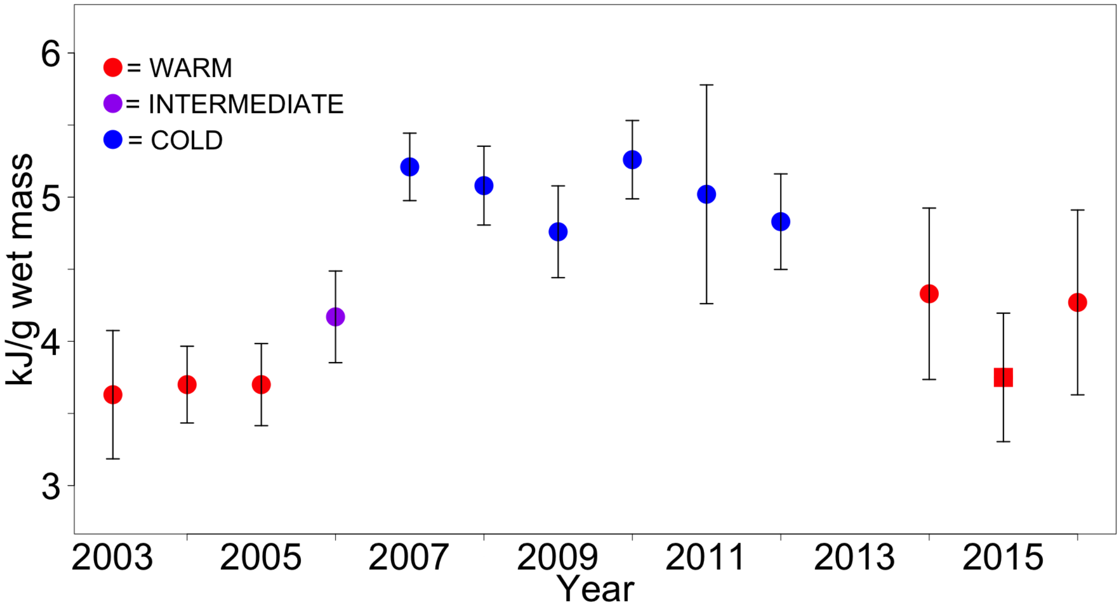

Figure 79: Average energy density (kJ/g) of age-0 Walleye pollock (*Gadus chalcogrammus*) collected during the late-summer BASIS survey in the eastern Bering Sea 2003–2016. Fish were collected with a surface trawl in all years except in 2015 when an oblique trawl was used.

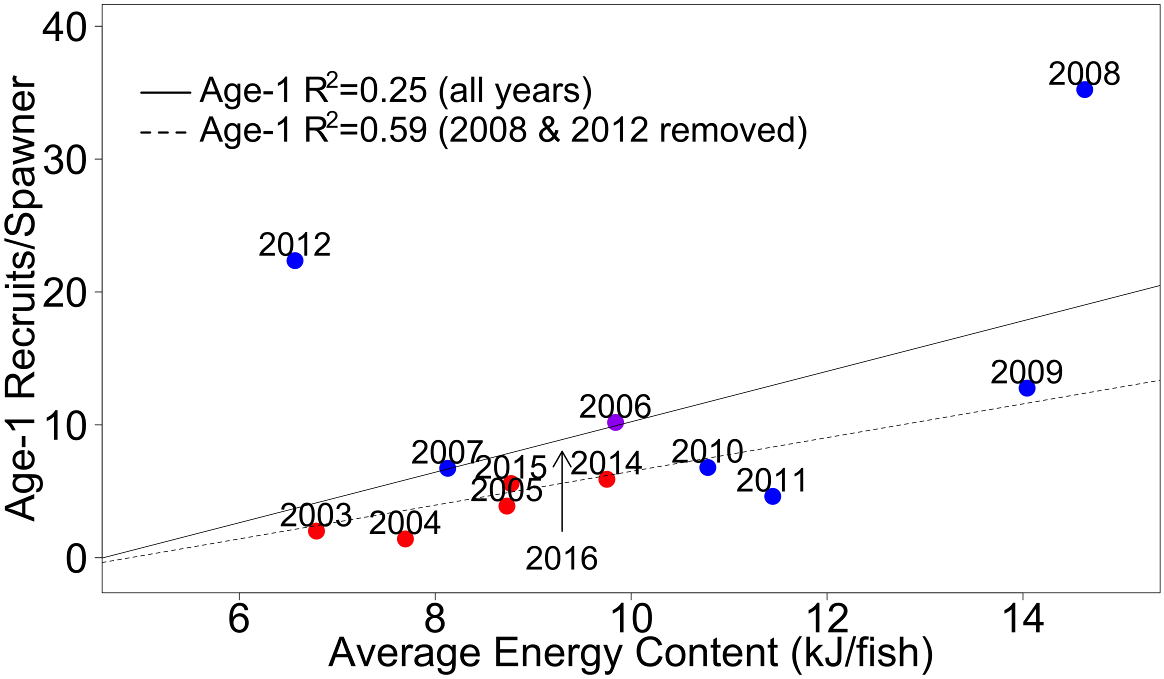

Figure 80: Relationship between average energy content (AEC) of individual age-0 Walleye pollock (*Gadus chalcogrammus*) and the number of age-1 recruits per spawner from the 2016 stock assessment (Ianelli et al., 2016). Fish were collected with a surface trawl in all years except in 2015 when an oblique trawl was used.

Prey availability for age-0 pollock differs between warm and cold years with cold years having greater densities of large copepods (e.g., *Calanus marshallae*) over the SEBS shelf (Hunt et al., 2011; Coyle et al., 2011). Zooplankton taxa available in cold years are generally higher in lipid content, affording age-0 pollock a higher energy diet than that consumed in warm years. Lower water temperatures also optimize their ability to store lipid (Kooka et al., 2007).

Implications: The full model (all years) indicates that the 2016 year-class is predicted to have above average survival to age-1, while the constrained model (2008 and 2012 removed) predicts intermediate survival, comparable to that of the 2014 and 2015 year classes. The SEBS experienced warm conditions through late-summer 2016, although age-0 pollock in 2016 seem to have mitigated harsh environmental conditions by utilizing the cold pool (which may act as a thermal refuge) and consuming more lipid-rich euphausiid prey (Duffy-Anderson et al., 2017).

Benthic Communities and Non-target Fish Species

Miscellaneous Species - Eastern Bering Sea Shelf

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Last updated: October 2017

Description of indicator: "Miscellaneous" species fall into three groups: eelpouts (Zoarcidae), poachers (Agonidae), and sea stars (Asteroidea). The three species comprising the eelpout group are the wattled eelpout (*Lycodes palearis*) and shortfin eelpout (*L. brevipes*) and to a lesser extent the marbled eelpout (*L. raridens*). The biomass of poachers is dominated by a single species, the sturgeon poacher (*Podothecus acipenserinus*) and to a lesser extent the sawback poacher (*Leptagonus frenatus*). The composition of sea stars in shelf trawl catches are dominated by the purple-orange sea star (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. Relative CPUE by weight was calculated and plotted for each species or species group by year for 1982–2017. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: The 2017 relative CPUE for eelpouts decreased by 15% from 2016, but was still among the highest estimates over the last 11 years. The poacher group CPUE decreased by 30% since 2016 and by 48% since 2015. The 2017 poacher estimate ranked as the lowest since 2001. Only during a single 3-year time period from 1984 to 1986 were poacher estimates significantly lower. The sea stars as a group increased by 21% from 2016 to 2017, and the 2017 CPUE ranked as the second highest since 1982 (Figure 81).

Factors causing observed trends: Determining whether these trends represent real responses to environmental change or are simply an artifact of standardized survey sampling methodology (e.g., temperature dependent catchability) will require more specific research on survey trawl gear selectivity relative to interannual differences in bottom temperatures and on the life history characteristics of these epibenthic species.

Implications: Eelpouts have important roles in the energy flow within benthic communities. For example, eelpouts are a common prey item of Arrowtooth flounder (*Atheresthes stomias*). However, it is not known at present whether these changes in CPUE are related to changes in energy flow.

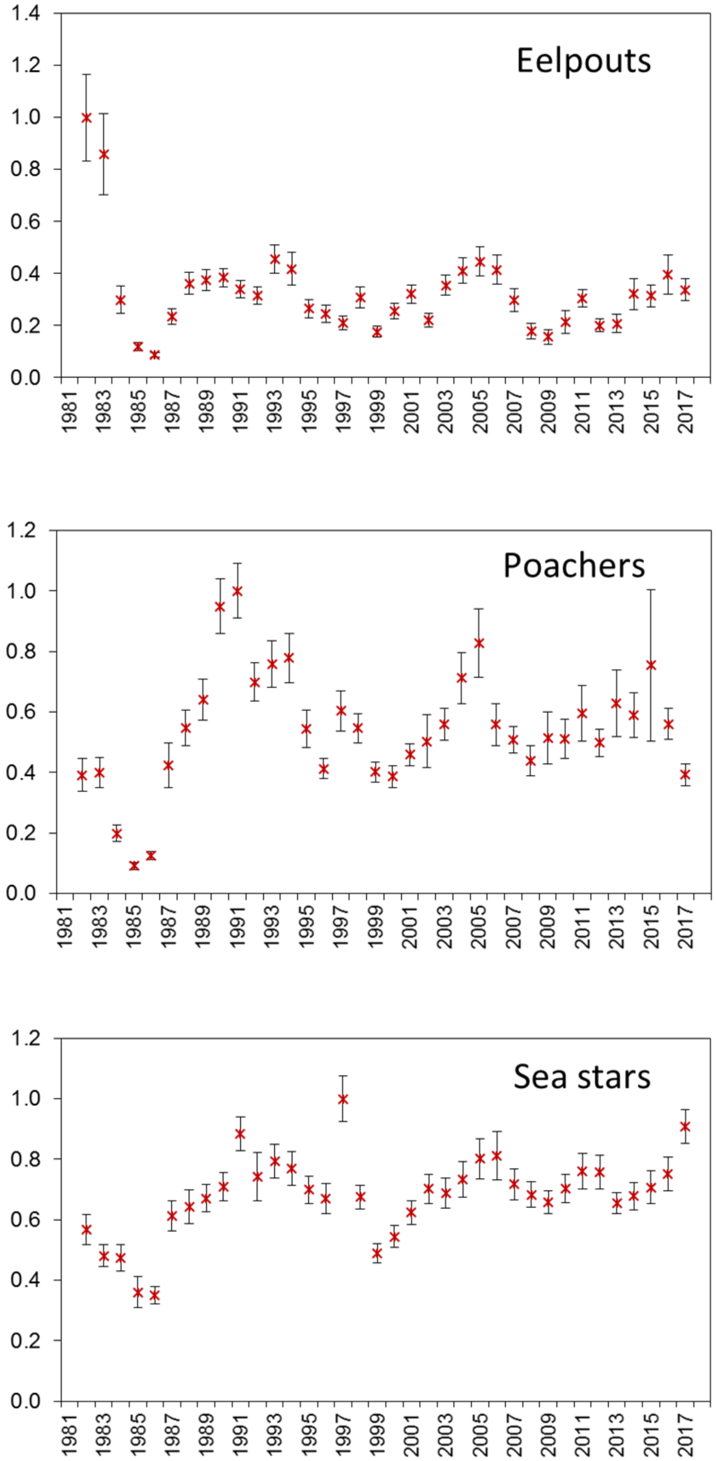

Figure 81: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for miscellaneous fish species during the May to August time period from 1982–2017.

Eastern Bering Sea Commercial Crab Stock Biomass Indices

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Last updated: October 2017

Description of indicator: This indicator is the commercial crab species biomass time series in the eastern Bering Sea and may be indicative of trends in benthic production or benthic response to environmental variability. The commercial crab biomass also indicates trends in exploited resources over time.

Status and trends: The historical trends of commercial biomass are highly variable. The current trends are negative in the most recent year (Figure 82, Figure 83).

Factors influencing observed trends: Environmental variability and exploitation affect trends in commercial crab biomass over time.

Implications: Implications are dramatic variability in benthic predators and ephemeral (seasonal) pelagic prey resources when crab are in larval stages.

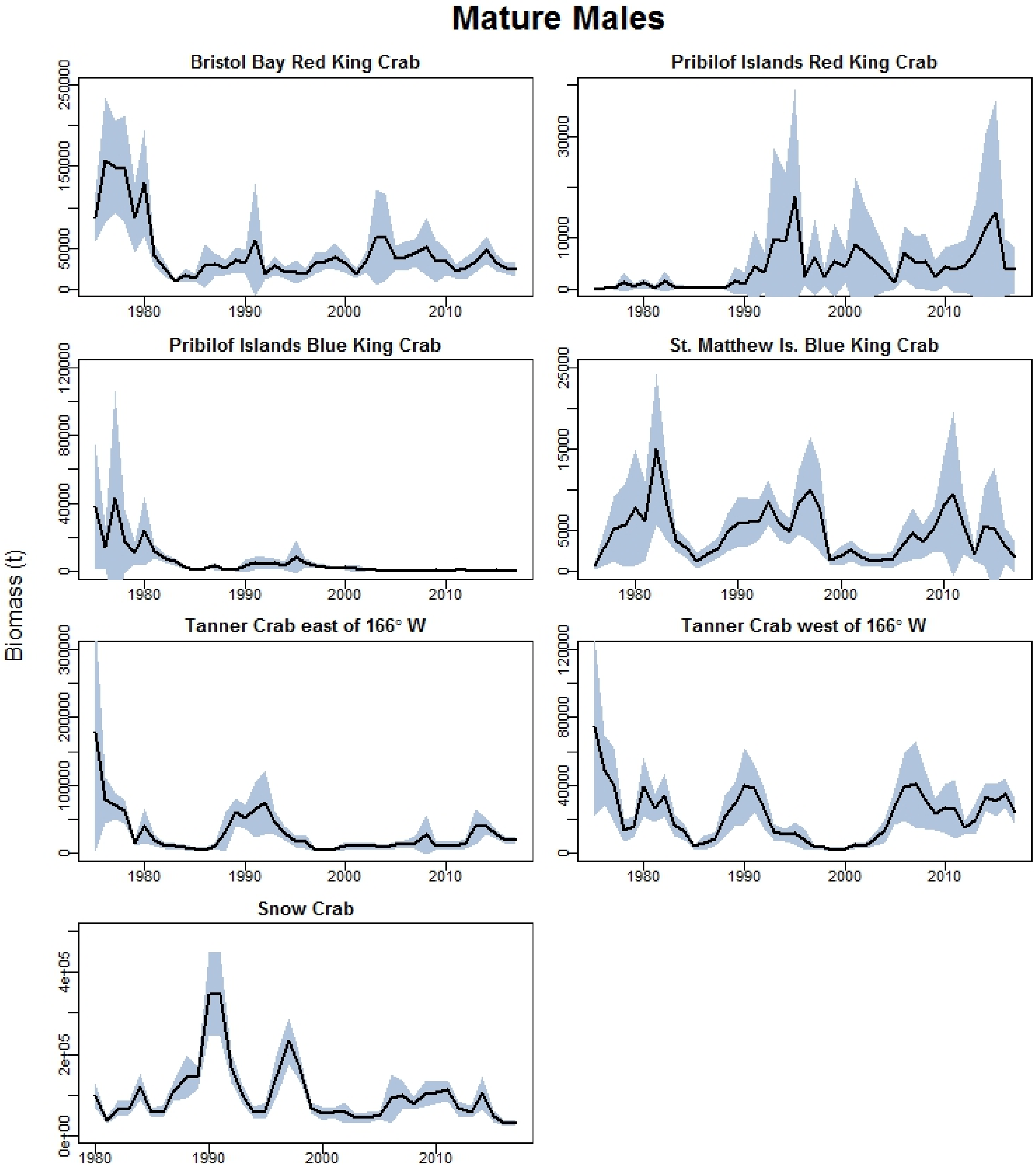

Figure 82: Historical mature male biomass (t, gray area indicates ± 95% CI) for six commercial species caught on the National Marine Fisheries Service eastern Bering Sea bottom trawl surveys (1975–2017).

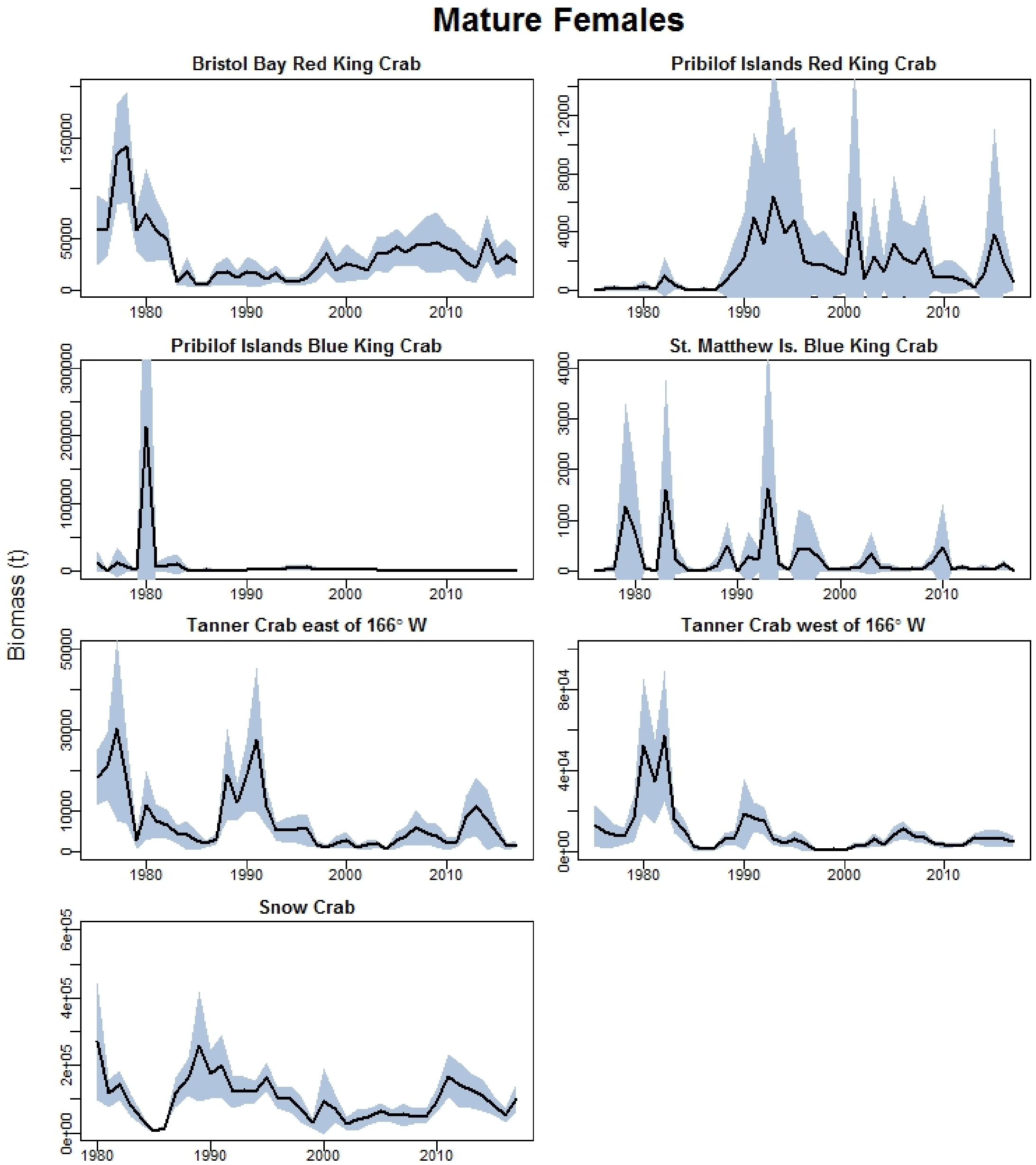

Figure 83: Historical mature female biomass (t, gray area indicates ± 95% CI) for six commercial species caught on the National Marine Fisheries Service eastern Bering Sea bottom trawl survey (1975–2017). Biomass was calculated using actual maturity (abdominal flap morphology and clutch fullness index), as opposed to the size cut-off method used for males.

Seabirds

Seabird Monitoring Summary from Alaska Maritime National Wildlife Refuge

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Last updated: October 2017

Description of indicator: The Alaska Maritime National Wildlife Refuge has monitored seabirds at colonies around Alaska in most years since the early- to mid-1970's. Time series of annual breeding success and phenology (among other parameters) are available from over a dozen species at eight Refuge sites in the Gulf of Alaska, Aleutian Islands, and Bering and Chukchi Seas. Monitored colonies in the eastern Bering Sea include St. Paul and St. George Islands. Here, we focus on cliff-nesting, primarily fish-eating species: black-legged kittiwake (*Rissa tridactyla*), red-legged kittwake (*R. brevirostris*), common murre (*Uria aalge*), thick-billed murre (*U. lomvia*), and red-faced cormorants (*Phalacrocorax urile*). Reproductive success is defined as the proportion of nest sites with eggs (or just eggs for murres that do not build nests) that fledged a chick.

Status and trends: Cliff-nesting seabirds showed overall poor reproductive success in 2017 at both islands, with the exception of nearshore-feeding red-faced cormorants (Figure 84). This was the third consecutive year of poor reproduction for both black-legged and red-legged kittiwakes. This was the second year of poor reproduction for both common and thick-billed murres; common murres at St. George had some reproductive success (0.33) but fewer than normal birds showed up to breed. Mean hatching dates were late across the board for those species that hatched any chicks.

Factors influencing observed trends: In general, these species appear to have had negative responses to the marine heat wave in the Northeast Pacific over the past few years, with widespread reproductive failures, die-offs, and low attendance at breeding colonies. Kittiwakes began to fail during the first year of the heatwave in 2015, while the murres did not show negative responses until 2016. This pattern may reflect differences in natural history, with murres able to buffer reproductive success in poor conditions to some degree (Burger and Piatt, 1990). Historically, kittiwakes fail to fledge any chicks about one in six years at the Pribilof Islands, whereas for murres this was unprecedented before 2016.

Implications: Reproductive activity of central-place foraging seabirds can reflect ecosystem conditions at multiple spatial and temporal scales. For piscivorous species that feed at higher trophic levels, continued reduced reproductive success may indicate that the ecosystem has not yet shifted back from warm conditions and/or there is a lagged response of the prey. Despite environmental changes returning back to more neutral conditions (see p. 63), seabird foraging conditions do not appear to have recovered in the eastern Bering Sea. In contrast, the improvement in attendance and minimal reproductive activity among murres in the Gulf of Alaska during 2017 indicates some improvement in foraging conditions for those species.

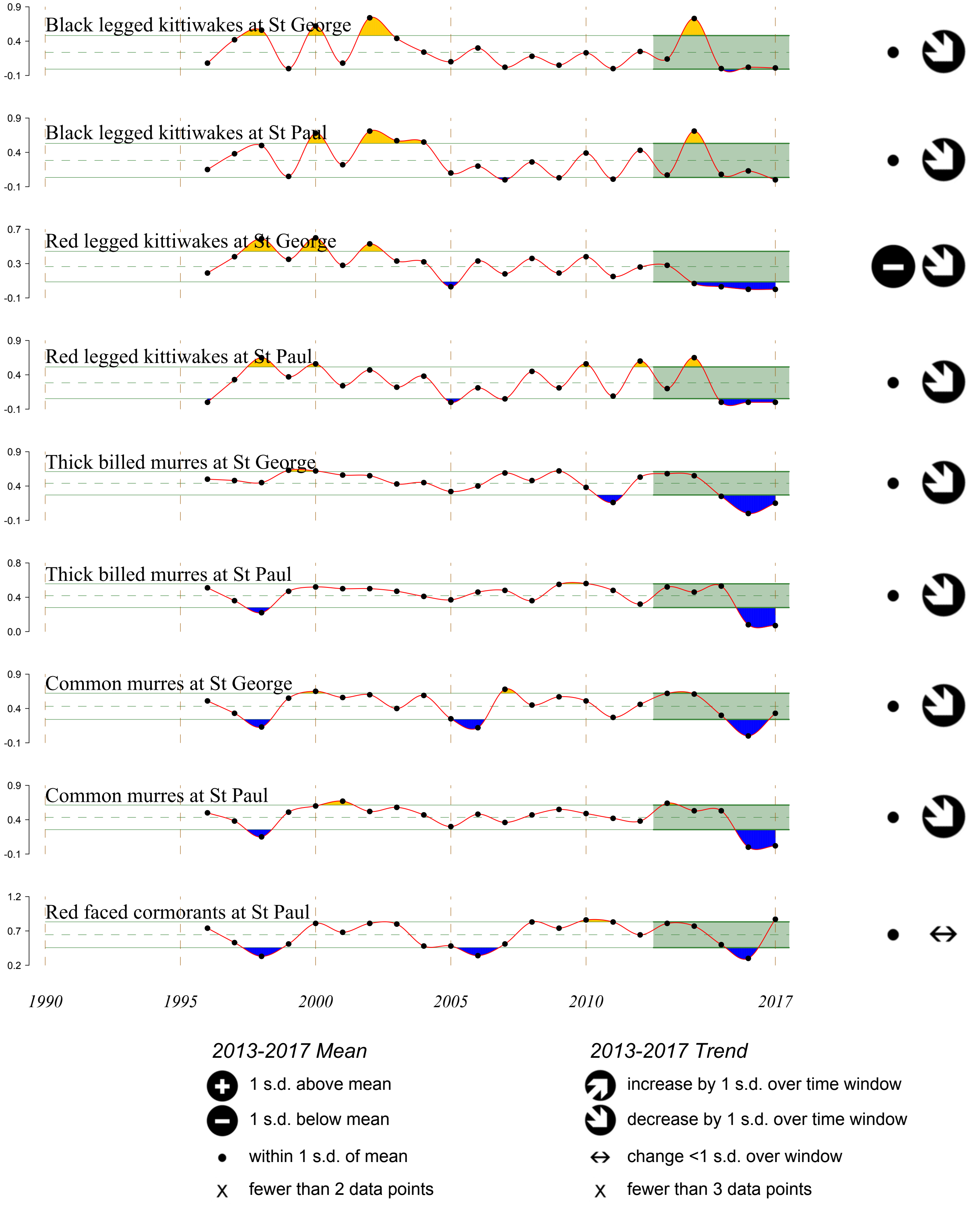

Figure 84: Reproductive success of five seabird species at St. George and St. Paul Islands between 1996–2017.

Marine Mammals

The Marine Mammal Protection Act requires stock assessment reports to be reviewed annually for stocks designated as strategic, annually for stocks where there is significant new information available, and at least once every 3 years for all other stocks. Each stock assessment includes, when available, a description of the stock's geographic range, a minimum population estimate, current population trends, current and maximum net productivity rates, optimum sustainable population levels and allowable removal levels, as well as estimates of annual human-caused mortality and serious injury through interactions with commercial fisheries and subsistence hunters. The most recent (2014) Alaska Marine Mammal stock assessment was released in August 2015 and can be downloaded at `http://www.nmfs.noaa.gov/pr/sars/region.htm`.

Northern Fur Seal (*Callorhinus ursinus*) Pup Production in the Bering Sea

Contributed by Rod Towell, Rolf Ream, John Bengtson, Michael Williams, and Jeremy Sterling
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Last updated: October 2017

Description of indicator: The northern fur seal (*Callorhinus ursinus*) ranges throughout the North Pacific Ocean from southern California north to the Bering Sea and west to the Okhotsk Sea and Honshu Island, Japan. Breeding in the U.S. is restricted to only a few sites: the Pribilof Islands and Bogoslof Island in Alaska, and San Miguel and the Farallon Islands off California (Muto et al., 2016). Two separate stocks of northern fur seals are recognized within U.S. waters: an Eastern Pacific stock (Pribilof and Bogoslof Islands) and a California stock.

Northern fur seals were listed as depleted under the Marine Mammal Protection Act (MMPA) in 1988 because population levels had declined to less than 50% of levels observed in the late 1950s, with no compelling evidence that carrying capacity had changed (NMFS, 2007). Fisheries regulations were implemented in 1994 (50 CFR 679.22(a) (6)) to create a Pribilof Islands Area Habitat Conservation Zone (no fishing with trawl permitted), in part to protect northern fur seals. Under the MMPA, this stock remains listed as "depleted" until population levels reach at least the lower limit of its optimum sustainable population (estimated at 60% of carrying capacity). A Conservation Plan for the northern fur seal was written to delineate reasonable actions to protect the species (NMFS, 2007). Pup production of northern fur seals on Pribilof and Bogoslof Islands is estimated by the Marine Mammal Laboratory biennially using a mark-recapture method (shear-sampling) on 1–2 month old pups. The most recent pup production estimate for the Pribilof Islands was conducted during August 2016; pup production on Bogoslof Island was assessed in August 2015.

Status and trends: We estimated 80,641 (standard error [SE] = 717) pups were born on St. Paul Island and 20,490 (SE = 460) pups were born on St. George Island in 2016. The observed pup mortality rates were 2.7% on St. Paul Island and 1.1% on St. George Island. The total estimated number of pups born on St. Paul Island in 2016 (not including Sea Lion Rock) was 12.1% less than in 2014, which was 5.3% less than in 2012 (Towell et al., In press). On St. George Island there was an 8.2% increase between 2014 and 2016, following a 17.0% increase between 2012 and 2014 (Figure 85).

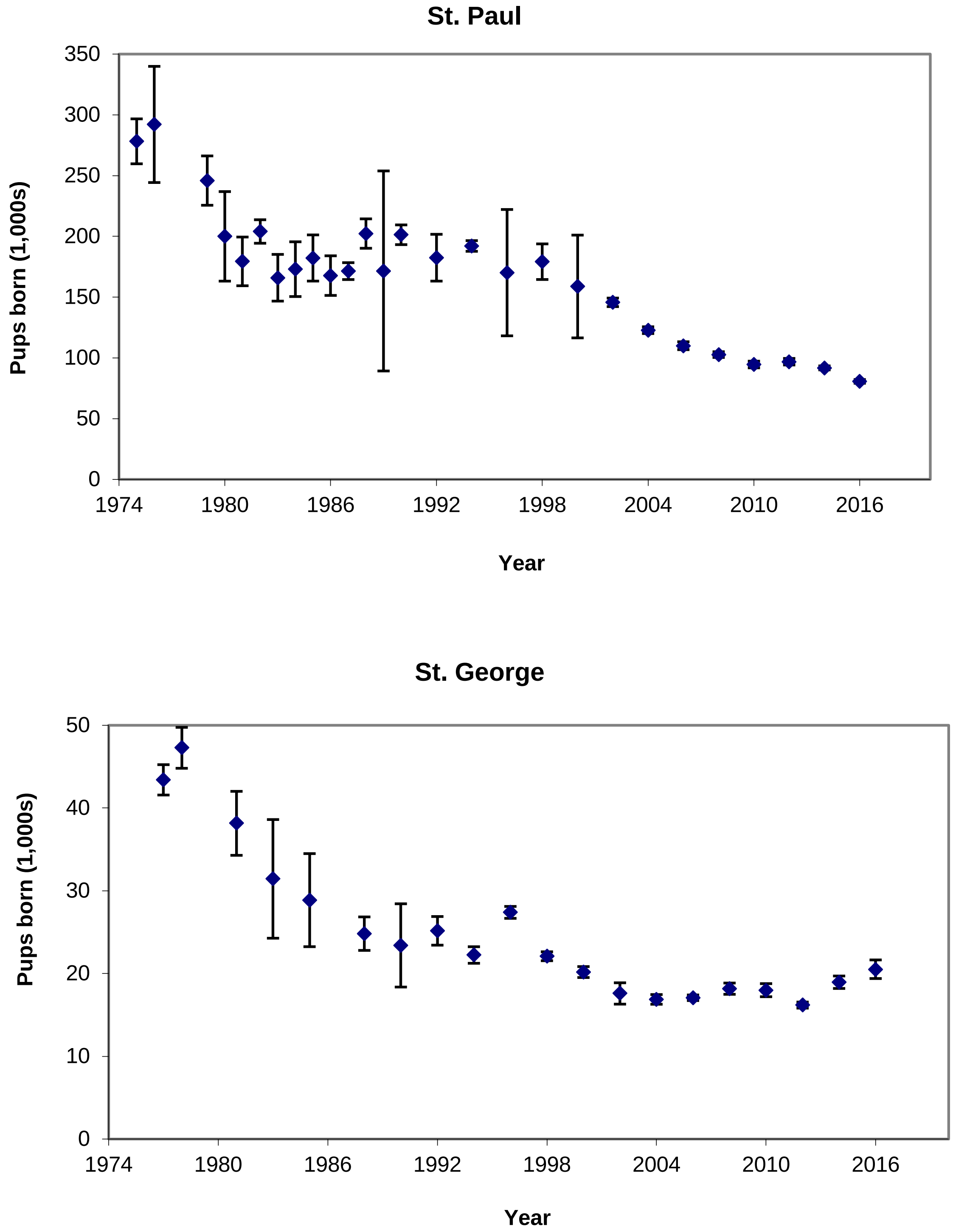

Figure 85: Estimated number of northern fur seal pups born on the Pribilof Islands 1975–2016. Error bars are approximate 95% confidence intervals. Note that St. Paul Island estimates do not include pups

Pup production has been declining since 1998 at an average annual rate of 4.12% (SE = 0.40%, $P < 0.01$) on St. Paul Island and shows no significant trend (SE = 0.57%, P = 0.13) on St. George Island over the same time period. The overall rate of decline on the Pribilof Islands (excluding Sea Lion Rock) was 3.50% (SE = 0.40%, $P < 0.01$) annually from 1998 to 2016.

Since 2002, pup production has been lower than was estimated in 1921 on St. Paul Island and in 1918 on St. George Island, when the populations were recovering at 8% annually from a pelagic harvest that ended in the early 20th century. On a positive note, St. George Island pup production has shown an increase for two censuses in a row, an increase of 26.6% in 2016 from 2012.

Factors influencing observed trends: While overall pup production has declined on the Pribilof Islands, it has increased on Bogoslof Island. The last Bogoslof survey occurred in August 2015 at which time pup production had increased at approximately 10.1% (SE = 1.08) per year since 1997. This rate is faster than what could be expected from a completely closed population of fur seals, indicating that at least some of the increase is due to females moving from the Pribilof Islands (presumably) to Bogoslof Island to give birth and breed. However, recent volcanic activity (December 2017 to September 2017) will likely impact pup production at Bogoslof Island this season. Additionally, declines observed on the Pribilof Islands are much greater than the increase in numbers on Bogoslof Island, indicating that the decline on the Pribilof Islands cannot be due entirely to emigration.

Implications: Differences in trends between the largely shelf-foraging Pribilof fur seals and the pelagic-foraging Bogoslof fur seals likely reflect differences in their summer foraging success, and are unlikely related to large-scale changes in the North Pacific Ocean (e.g., regime shifts, Pacific Decadal Oscillation), since these populations both occupy the same habitats in the North Pacific Ocean during the fall, winter, and spring.

Ecosystem or Community Indicators

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys on the Eastern Bering Sea Shelf, 1982–2017

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Description of indicator: The index provides a measure of the overall biomass of demersal and benthic fish and invertebrate species. We obtained catch-per-unit-effort (CPUE in kg ha) of fish and major invertebrate taxa for each successful haul completed during standardized bottom trawl surveys on the eastern Bering Sea shelf (EBS), 1982–2017. Total CPUE for each haul was computed as the sum of the CPUEs of all fish and major invertebrate taxa. To obtain an index of average CPUE by year across the survey region, we modeled log-transformed total CPUE ($N = 13{,}338$ hauls) as a smooth function of depth, Julian Day and location (latitude / longitude) with year-specific intercepts using Generalized Additive Models following Mueter and Norcross (2002). Hauls were weighted based on the area represented by each station. The CPUE index does not account for gear or vessel differences, which are confounded with interannual differences and may affect results prior to 1988.

Status and trends: Total log(CPUE) in the EBS shows an apparent long-term increase from 1982–2005, followed by a decrease from 2005 to 2009, increased CPUE in 2010–2013, and a substantial increase in 2014 to the highest observed value in the time series (Figure 86). Estimated means prior to 1988 may be biased due to unknown gear effects and because annual differences are confounded with changes in mean sampling date, which varied from as early as June 15 in 1999 to as late as July 16 in 1985. On average, sampling occurred about a week earlier since the 2000s compared to the 1980s.

Factors influencing observed trends: Commercially harvested species accounted for approximately 95% of survey catches. Fishing is expected to be a major factor determining trends in survey CPUE, but environmental variability is likely to account for a substantial proportion of the observed variability in CPUE through variations in recruitment, growth, and distribution. The increase in survey CPUE in the early 2000s primarily resulted from increased abundances of Walleye pollock (*Gadus chalcogrammus*) and a number of flatfish species (Arrowtooth flounder, *Atheresthes stomias*; Yellowfin sole, *Limanda aspera*; Rock sole, *Lepidopsetta bilineata*; and Alaska plaice, *Pleuronectes quadrituberculatus*) due to strong recruitments in the 1990s. Decreases in 2006–2009 and subsequent increases are largely a result of fluctuations in pollock recruitment and abundance. Increases in pollock and Pacific cod biomass in 2010 resulted in the observed increase in log(CPUE). Models including bottom temperature suggest that, in the EBS, CPUE is greatly reduced at low temperatures ($< 1^{\circ}$C) as evident in reduced CPUEs in 1999 and 2006–2009, when the cold pool covered a substantial portion of the shelf. Overall, there is a moderate positive relationship between average bottom temperatures and CPUE in the same year ($r = 0.53$, $p = 0.0089$), but not in the following years. The reduction in CPUE during cold periods is likely due to a combination of

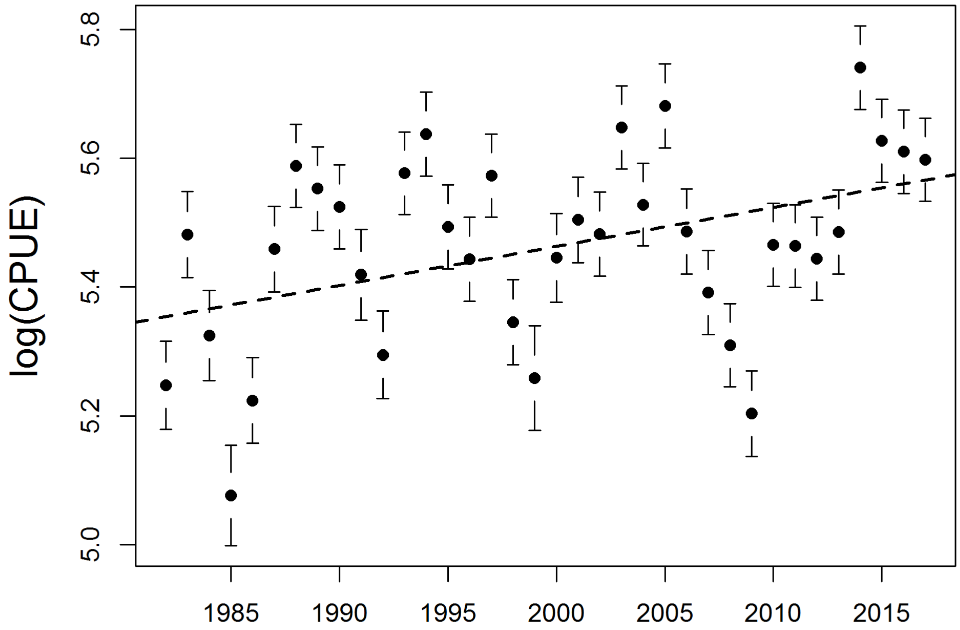

Figure 86: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2017 in the Bering Sea with approximate pointwise 95% confidence intervals and linear time trend. Estimates were adjusted for differences in depth, day of sampling and sampling locations among years. Gear differences prior to 1988 were not accounted for. The linear time trend based on generalized least squares regression assuming 1st order auto-correlated residuals was not statistically significant at the 95% significance level ($t = 1.627$, $p = 0.113$).

actual changes in abundance, temperature-dependent changes in catchability of certain species (e.g. flatfish, crab), and changes in distribution as a result of the extensive cold pool displacing species into shallower (e.g., red king crab) or deeper (e.g., Arrowtooth flounder) waters. The increase in total CPUE in the Bering Sea in 2014 was largely due to an increase in pollock catches in the bottom trawl survey. CPUE decreased in 2015 and has remained stable since then.

Implications: This indicator can help address concerns about maintaining adequate prey for upper trophic level species and other ecosystem components. Relatively stable or increasing trends in the total biomass of demersal fish and invertebrates, together with a relatively constant size composition of commercial species, suggest that the prey base has remained stable over recent decades, but displays substantial fluctuations over time, largely as a result of variability in pollock biomass. Decreasing CPUE in the eastern Bering Sea in the early 2000s was a concern, but biomass has increased as a result of several strong year classes of pollock entering the survey.

Average Local Species Richness and Diversity of the Eastern Bering Sea Groundfish Community

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Description of indicator: Indices of local species richness and diversity are based on standard bottom trawl surveys in the eastern Bering Sea (EBS). We computed the average number of fish and major invertebrate taxa per haul (richness) and the average Shannon index of diversity (Magurran, 1988) by haul based on CPUE (by weight) of each taxon. Indices for the EBS were based on 45 fish and invertebrate taxa that were consistently identified throughout all surveys since 1982 (Table 1 in Mueter and Litzow (2008), excluding Arctic cod *Boreogadus saida* because of unreliable identification in early years). Indices were computed following Mueter and Norcross (2002). Briefly, annual average indices of local richness and diversity were estimated by first computing each index on a per-haul basis, then estimating annual averages with confidence intervals across the survey area using a Generalized Additive Model that accounted for the effects of variability in sampling locations, depth, and date of sampling. In addition to trends over time, we mapped average spatial patterns for each index across the survey region.

Status and trends: Species richness and diversity on the EBS shelf have undergone significant variations from 1982 to 2017 (Figure 87). The average number of species per haul increased by one to two species per haul from 1995 to 2004, remained relatively high through 2011, and both richness and diversity decreased through 2014 with a moderate increase in richness in 2015 and a large and significant increase in Shannon diversity in 2016/2017. Richness tends to be highest along the 100 m isobath, while diversity tends to be highest on the middle shelf (Figure 88). Local richness is lowest along the slope and in the northern part of the survey region, while diversity is lowest in the inner domain.

Factors influencing observed trends: Local richness and diversity reflect changes in the spatial distribution, abundance, and species composition that may be caused by fishing, environmental variability, or climate change. If species are, on average, more widely distributed in the sampling area, the number of species per haul increases. Spatial shifts in distribution from year to year can cause high variability in local species richness in certain areas, for example along the 100m contour. These shifts appear to be the primary drivers of changes in species richness over time. Local species diversity is a function of how many species are caught in a haul and how evenly CPUE is distributed among these species, hence time trends (Figure 87) and spatial patterns (Figure 88) in species diversity differ from those in species richness. Diversity typically increases with species richness, but decreases when the abundance of dominant species increases. For example, low species diversity in 2003 occurred in spite of high average richness, primarily because of the high dominance of Walleye pollock (*Gadus chalcogrammus*), which increased from an average of 18% of the catch per haul in 1995–98 to 30% in 2003, but decreased again to an average of 21% in 2004. The increase in species richness, which was particularly pronounced on the middle shelf, has been attributed to subarctic species spreading into the former cold pool area as the extent of the

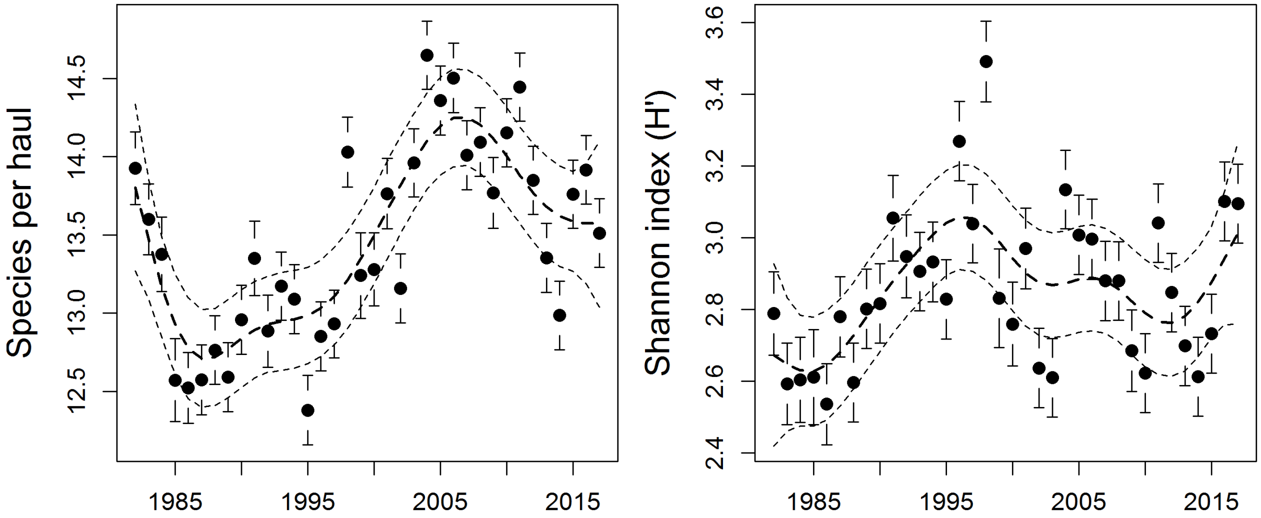

Figure 87: Model-based annual averages of species richness (average number of species per haul, dots) and species diversity (Shannon index) in the Eastern Bering Sea, 1982–2017, based on 45 fish and invertebrate taxa collected by standard bottom trawl surveys with pointwise 95% confidence intervals (bars) and loess smoother with 95% confidence band (dashed/dotted lines). Model means were adjusted for differences in depth, date of sampling, and geographic location.

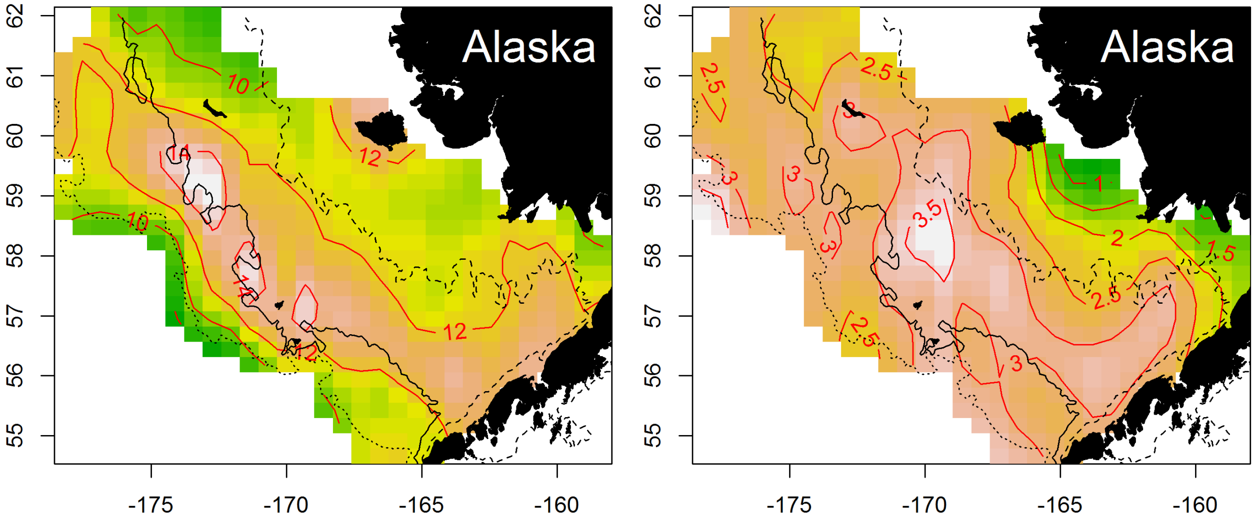

Figure 88: Average spatial patterns in local species richness (left, number of taxa per haul) and Shannon diversity in the eastern Bering Sea. The 50m (dashed), 100m (solid), and 200 m (dotted) depth contours are shown. Note highest richness along 100 m contour, highest diversity on middle shelf.

cold pool decreased from 1982 to 2005 (Mueter and Litzow, 2008). However, species diversity has varied substantially over the recent decade and these fluctuations have occurred independently of temperature (correlation = 0.29, p = 0.094).

Implications: There is evidence from many systems that diversity is associated with ecosystem stability, which depends on differential responses to environmental variability by different species or functional groups (e.g., McCann, 2000). To our knowledge, such a link has not been established for marine fish communities. In the EBS, local species richness may be particularly sensitive to long-term trends in bottom temperature as the cold pool extent changes (Mueter and Litzow, 2008) and may provide a useful index for monitoring responses of the groundfish community to projected climate warming.

Spatial Distribution of Groundfish Stocks in the Bering Sea

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Description of indicator: We provide indices of changes in the spatial distribution of groundfish on the eastern Bering Sea shelf. The first index provides a simple measure of the average North-South displacement of major fish and invertebrate taxa from their respective centers of gravity (e.g., Woillez et al., 2009) based on AFSC-RACE bottom trawl surveys for the 1982–2017 period. Annual centers of gravity for each taxon were computed as the CPUE-weighted mean latitude across 285 standard survey stations that were sampled each year and an additional 58 stations sampled in 34 of the 35 survey years. Each station (N=343) was also weighted by the approximate area that it represents. Initially, we selected 46 taxa as in Table 1 of Mueter and Litzow (2008). Taxa that were not caught at any of the selected stations in one or more years were not included, resulting in a total of 39 taxa for analysis. In addition to quantifying N-S shifts in distribution, we computed CPUE and area-weighted averages of depth to quantify changes in depth distribution. Because much of the variability in distribution is likely to be directly related to temperature variability, we removed linear relationships between changes in distribution and temperature by regressing distributional shifts on annual mean bottom temperatures. Residuals from these regressions are provided as an index of temperature-adjusted shifts in distribution.

Status and trends: Both the latitudinal and depth distribution of the demersal community on the eastern Bering Sea shelf show strong directional trends over the last three and a half decades, indicating significant distributional shifts to the North and into shallower waters (Figure 89). The distribution shifted slightly to the south and deeper in recent cold years (2006–2013) and has shifted back to the North and shallower since 2014 with a substantial shift to the Northwest (along the main axis of the shelf) in 2016. The distribution shifted back towards the South in 2017. Strong shifts in distribution over the 35 year time series remain evident even after adjusting for linear temperature effects (Figure 89). Average spatial displacements across all species by year (Figure 90) suggest that most interannual shifts in distribution occur along a NW-SE axis (i.e., along the main shelf/slope axis), but that a pronounced shift to the Northeast and onto the shelf occurred between the 1990s and 2000s. On average, there was a gradual shift to the north from 2001 to 2005, which reversed only slightly as temperatures cooled after 2006. From 2009 through 2015, the average center of gravity has shifted between deeper and shallower waters along a SW-NE axis and was further NE (Figure 90) and shallower (Figure 89) in 2015/2016 than in any previous year and, in 2016, was considerably farther North than in any previous year since the standardized survey began. The center of gravity of most individual species shifted to the Northwest along the shelf and/or to the Northeast onto the shelf in 2016, the warmest year in the survey time series. Cooler temperatures in 2017 appeared to result in an immediate and substantial southeastward shift, in contrast to a more moderate response to similar cooling in 2006.

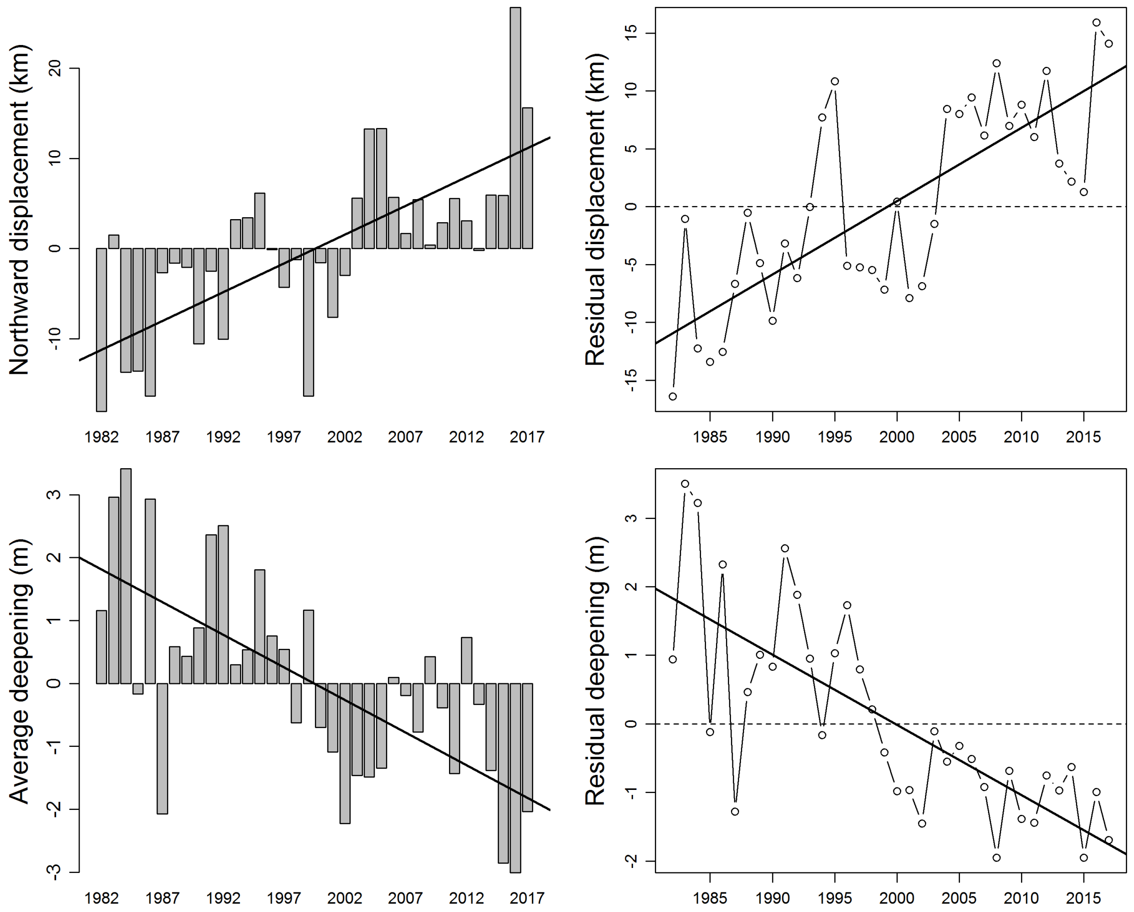

Figure 89: Left: Distributional shifts in latitude (average northward displacement in km from species-specific mean latitudes) and shifts in depth distribution (average vertical displacement in m from species-specific mean depth, positive indices indicate deeper distribution). Right: Residual displacement from species-specific mean latitude (top) and species-specific mean depth (bottom) after adjusting the indices on the left for linear effects of mean annual bottom temperature on distribution. Residuals were obtained by linear regression of the displacement indices on annual average temperature (Northward displacement: $R^2 = 0.27$, $t = 4.30$, $p<0.001$; depth displacement: $R^2 = 0.25$, $t = -4.04$, $p<0.001$). Solid lines denote linear regressions over time (Northward displacement: $R^2 = 0.38$, $t = 3.50$, $p=0.001$; Residual northward displacement: $R^2 = 0.47$, $t = 3.45$, $p=0.002$; depth displacement: $R^2 = 0.52$, $t = -5.00$, $p<0.001$; residual depth displacement: $R^2 = 0.63$, $t = -7.39$, $p<0.001$).

Factors influencing observed trends: Many populations shift their distribution in response to temperature variability. Such shifts may be the most obvious response of animal populations to global warming (Parmesan and Yohe, 2003). However, distributional shifts of demersal populations in the Bering Sea are not a simple linear response to temperature variability (Mueter and

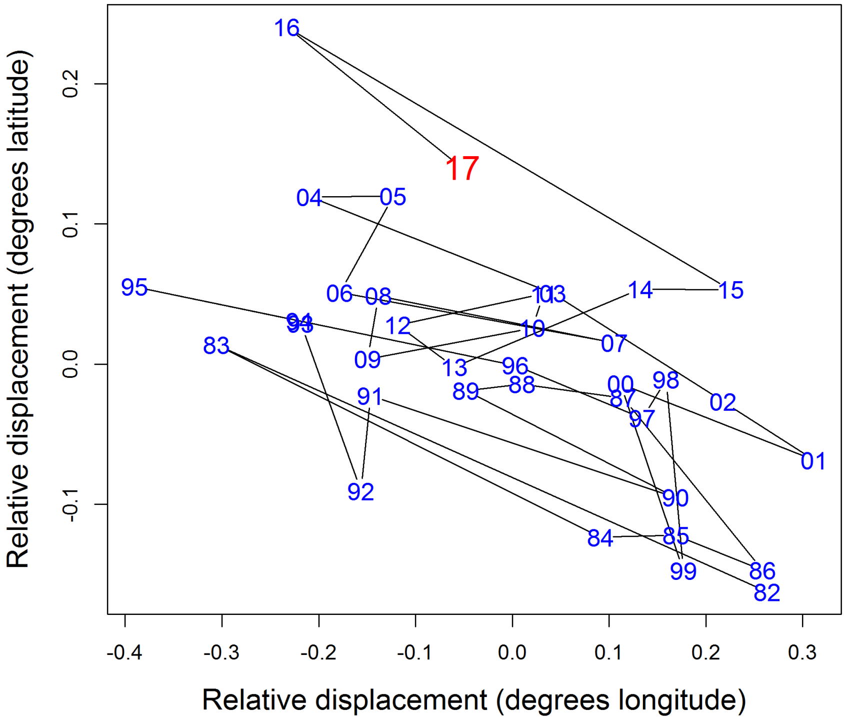

Figure 90: Average North-South and East-West displacement across 39 taxa on the eastern Bering Sea shelf relative to species-specific centers of distribution.

Litzow (2008); Figure 89). The reasons for strong residual shifts in distribution that are not related to temperature changes remain unclear but could be related to density-dependent responses (Spencer, 2008) in combination with internal community dynamics (Mueter and Litzow, 2008). Unlike groundfish in the North Sea, which shift to deeper waters in response to warming (Dulvy et al., 2008), the Bering Sea groundfish community shifted to shallower waters during warm periods (Figure 89) because of the retreat of the cold pool from the middle shelf that allowed subarctic species to expand from the outer shelf into shallower shelf regions.

Implications: Changes in distribution have important implications for the entire demersal community, for other populations dependent on these communities, and for the fishing industry. The demersal community is affected because distributional shifts change the relative spatial overlap of different species, thereby affecting trophic interactions among species (Hunsicker et al., 2013; Spencer et al., 2016) and, ultimately, the relative abundances of different species. Upper trophic level predators, for example fur seals and seabirds on the Pribilof Islands and at other fixed locations, are affected because the distribution and hence availability of their prey changes. Finally, fisheries are directly affected by changes in the distribution of commercial species, which alters the economics of harvesting because fishing success within established fishing grounds may decline and travel distances to new fishing grounds may increase (Haynie and Pfeiffer, 2013).

Mean Lifespan of the Fish Community

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Last updated: October 2017

Description of indicator: The mean lifespan of the community is defined by Shin et al. (2010) as “a proxy for the mean turnover rate of species and communities” and is intended to reflect ecosystem stability and resistance to perturbations. The indicator for mean lifespan of the groundfish community is modeled after the method for mean lifespan presented in Shin et al. (2010). Lifespan estimates of groundfish species regularly encountered during the NMFS/AFSC annual summer bottom trawl survey of the eastern Bering Sea were retrieved from the AFSC Life History Database (`https://access.afsc.noaa.gov/reem/LHWeb/Index.php`). The groundfish community mean lifespan is weighted by the relative biomass of groundfish species sampled during the survey. This metric specifically applies to the demersal groundfish community that is sampled by the trawling gear employed in this survey.

Status and trends: The mean lifespan of the eastern Bering Sea demersal fish community is up slightly from 26.1 years in 2016 to 27.8 years in 2017. This is two years above the average mean lifespan of 25.2 years over the entire time series (1982–2017). Mean groundfish lifespan has generally been stable over the 36 year time series with only small year-to-year variation, and shows no indication of a long-term trend (Figure 91). Mean lifespan peaked at 30.3 years in 1985 and reached a low of 19.8 years in 1993.

Factors influencing observed trends: Fishing can affect the mean lifespan of the groundfish community by preferentially targeting larger, older fishes, leading to decreased abundance of longer-lived species and increased abundance of shorter-lived species (Pauly et al., 1998). Interannual variation in mean lifespan can be influenced by the spatial distribution of species and the differential selectivity of species to the trawling gear used in the survey. Strong recruitment events or periods of week recruitment could also influence the mean community lifespan by altering the relative abundance of species.

Implications: The groundfish mean lifespan has been stable over the time series of the summer bottom trawl survey. There is no indication that longer-lived species have decreased in relative abundance or are otherwise being replaced by shorter-lived species. Species that are short-lived are generally smaller and more sensitive to environmental variation than larger, longer-lived species (Winemiller, 2005). Longer-lived species help to dampen the effects of environmental variability, allowing populations to persist through periods of unfavorable conditions and to take advantage when favorable conditions return (Berkeley et al., 2004; Hsieh et al., 2006).

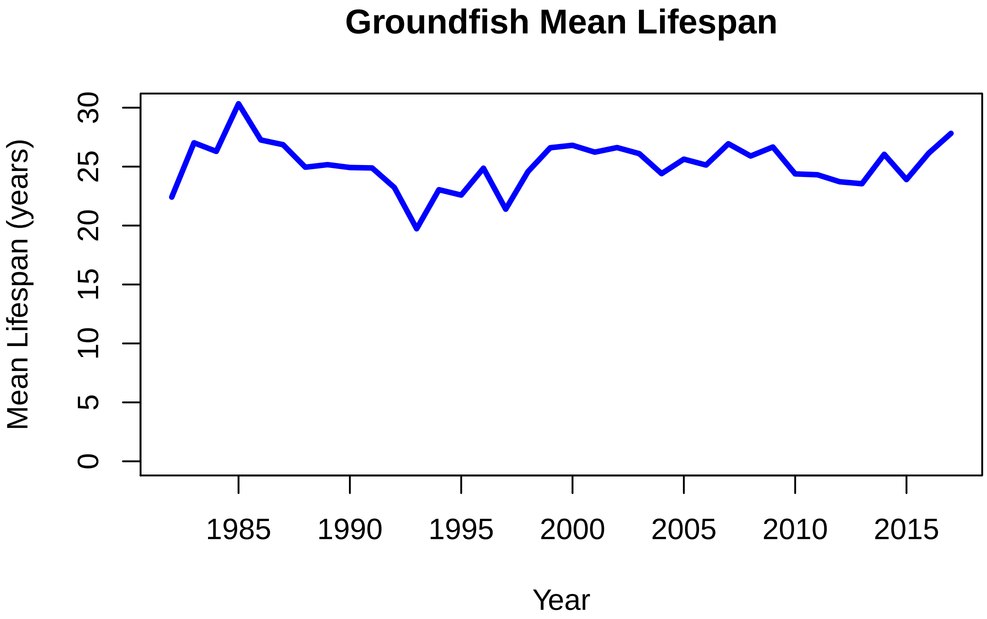

Figure 91: The mean lifespan of the eastern Bering Sea demersal fish community, weighted by relative biomass calculated from the NMFS/AFSC annual summer bottom trawl survey.

Mean Length of the Fish Community

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Description of indicator: The mean length of the groundfish community tracks fluctuations in the size of groundfish over time. This size-based indicator is thought to be sensitive to the effects of commercial fisheries because larger predatory fish are often targeted by fisheries and their selective removal would reduce mean size (Shin et al., 2005). Fish lengths are routinely recorded during the annual bottom trawl survey of the eastern Bering Sea, which has occurred each year since 1982. Species-specific mean lengths are calculated for groundfish species from the length measurements collected during the trawl survey. The mean length for the groundfish community is calculated with the species-specific mean lengths, weighted by their relative biomass (Shin et al., 2010). This indicator specifically applies to the demersal groundfish community sampled with the trawling gear used by NMFS during their annual summer bottom trawl survey of the eastern Bering Sea, at the standard survey sample stations (for survey details see Conner and Lauth (2016)).

Status and trends: The mean length of the eastern Bering Sea groundfish community in 2017 was 38.6 cm. This is down 0.5 cm from 2016, but above the average of 35 cm over the entire time series. Since 1982, the mean length has shown variation from year to year but has been generally stable, and does not indicate an obvious trend (Figure 92).

Factors influencing observed trends: This indicator is specific to the fishes that are routinely caught and sampled during the NMFS summer bottom trawl survey. The estimated mean length can be biased if specific species-size classes are sampled more or less than others, and is sensitive to spatial variation in the size distribution of species. Changes in fisheries management or fishing effort could also affect the mean length of the groundfish community. Modifications to fishing gear, fishing effort, and targeted species could affect the mean length of the groundfish community if different size classes and species are subject to changing levels of fishing mortality. The mean length of groundfish could also be influenced by fluctuations in recruitment, where a large cohort of an abundant species could initially reduce mean length of the community, then later increase mean length of the community as the cohort ages and individuals grow progressively larger. Environmental factors could also influence mean length by affecting the availability of food or by direct effects on growth rate.

Implications: The mean length of the groundfish community in the eastern Bering Sea has been stable over the bottom trawl time series (1982–2017). There is no evidence at this time of an obvious trend in mean size or indication that an external pressure is altering the community size distribution.

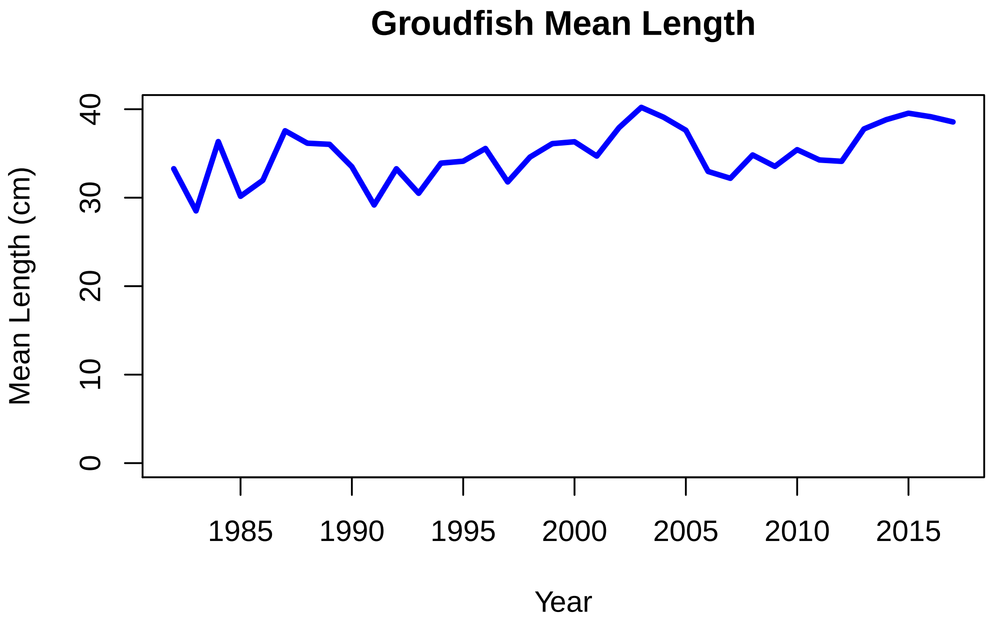

Figure 92: Mean length of the groundfish community sampled during the NMFS/AFSC annual summer bottom trawl survey of the eastern Bering Sea (1982–2017). The groundfish community mean length is weighted by the relative biomass of the sampled species.

Stability of Groundfish Biomass

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Description of indicator: The stability of the groundfish community total biomass is measured with the indicator, 1 divided by the coefficient of variation of total groundfish biomass (1/CV[B]). The variability of total community biomass is thought to be sensitive to fishing and is expected to increase with increasing fishing pressure (Blanchard and Boucher, 2001). This metric is calculated following the methods presented in Shin et al. (2010). The CV is calculated as the mean total groundfish biomass over the previous 10 years divided by the standard deviation over the same span. The biomass index for groundfish species was calculated from the catch of the NMFS/AFSC annual summer bottom trawl survey of the eastern Bering Sea. Since 10 years of data are required to calculate this metric, the indicator values start in 1991, the tenth year in the trawl survey time series (1982–2017). This metric is presented as an inverse, so as the CV increases the value of this indicator decreases, and if the CV decreases the value of this indicator increases.

Status and trends: The state of this indicator in 2017 was 4.9, which is up from 4.8 in 2016. 1/CV[B] peaked in 1992 at 7.6 and reached a low of 3.6 in 2001. After a decrease from 1992 to

1993 near the start of this time series, this indicator has remained generally stable to the present and does not exhibit a clear trend (Figure 93). Since 1991, the mean value for this metric is 5.0.

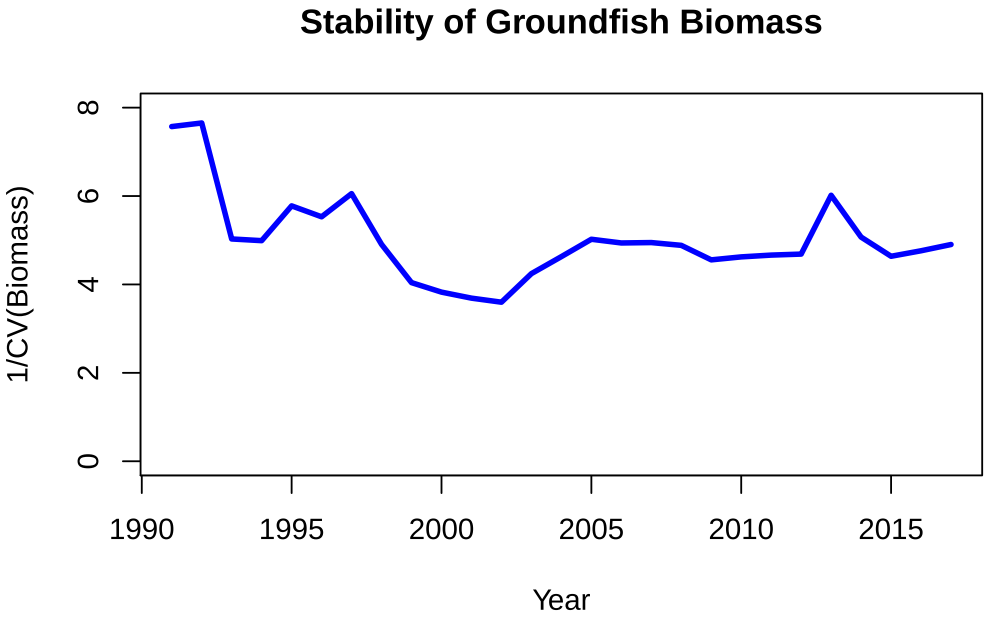

Figure 93: The stability of groundfish in the eastern Bering Sea represented with the metric 1/CV[B]. Ten years of data are required to calculate this metric, so this time series begins in 1991 after the tenth year of the NMFS/AFSC annual summer bottom trawl survey.

Factors influencing observed trends: Fishing is expected to influence this metric as fisheries can selectively target and remove larger, longer-lived species affecting population age structure (Berkeley et al., 2004; Hsieh et al., 2006). Larger, longer-lived species can become less abundant and be replaced by smaller, shorter-lived species (Pauly et al., 1998). Larger, longer-lived individuals help populations to endure prolonged periods of unfavorable environmental conditions and can take advantage of favorable conditions when they return (Berkeley et al., 2004). A truncated age-structure could lead to higher population variability (CV) due to increased sensitivity to environmental dynamics (Hsieh et al., 2006). Interannual variation in this metric could also be influenced by interannual variation in species abundance in the trawl survey catch or patchy spatial distribution for some species.

Implications: The measure 1/CV[B] indicates that the eastern Bering Sea groundfish community is stable over the time period examined. There is no indication of a clear trend or any driving influence on the stability of the groundfish community.

Disease Ecology Indicators

There are no updates to Disease Ecology indicators in this year's report. See the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Fishing and Human Dimensions Indicators

Indicators presented in this section are intended to provide a summary of the status of several ecosystem-scale indicators related to fishing and human economic and social well-being. These indicators are organized around objective categories derived from U.S. legislation and current management practices (see Table 1 for a full list of objective categories and resulting indicators):

- Maintaining diversity
- Maintaining and restoring fish habitats
- Sustainability (for consumptive and non-consumptive uses)
- Seafood production
- Profits
- Recreation
- Employment
- Socio-cultural dimensions

The indicators presented are meant to represent trends in different aspects of the general management objective, but some indicators are better proxies than others. For example, seafood production is a fairly good proxy for the production of seafood to regional, national, and international markets but ex-vessel and wholesale value are imperfect proxies for harvesting and processing sector profits. This suite of indicators will continue to be revised and updated to provide a more holistic representation of human/environment interactions and dependencies.

Maintaining Diversity: Discards and Non-Target Catch

Time Trends in Groundfish Discards

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Description of indicator: Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Region's blend data, while estimates for 2003 and later come from the Alaska Region's Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards. Discard rates as shown here 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 on FMP-managed groundfish targets: not included are groundfish discards in the halibut fishery and discards of non-FMP groundfish species, such as forage fish and species managed under prohibited species catch (PSC) limits.

Status and trends: Since 1993 discard rates of groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in both pollock and non-pollock trawl fisheries in the Bering Sea (BS). Discard rates in the BS pollock trawl sector declined from 20% to about 1% in 1998 and have remained at or below this level. Rates in the non-pollock trawl sector have declined from a high of 50% in 1994 and have remained below 8% since 2011. Discard rates and volumes in the BS fixed gear sector have been stable relative to trawl sectors but have trended slightly upward since 2012, with the 2016 rate (14.3%) representing the highest annual rate since 1998 and the 2016 discard weight (26.7K metric trons), the highest annual weight over the entire time series (Figure 94).

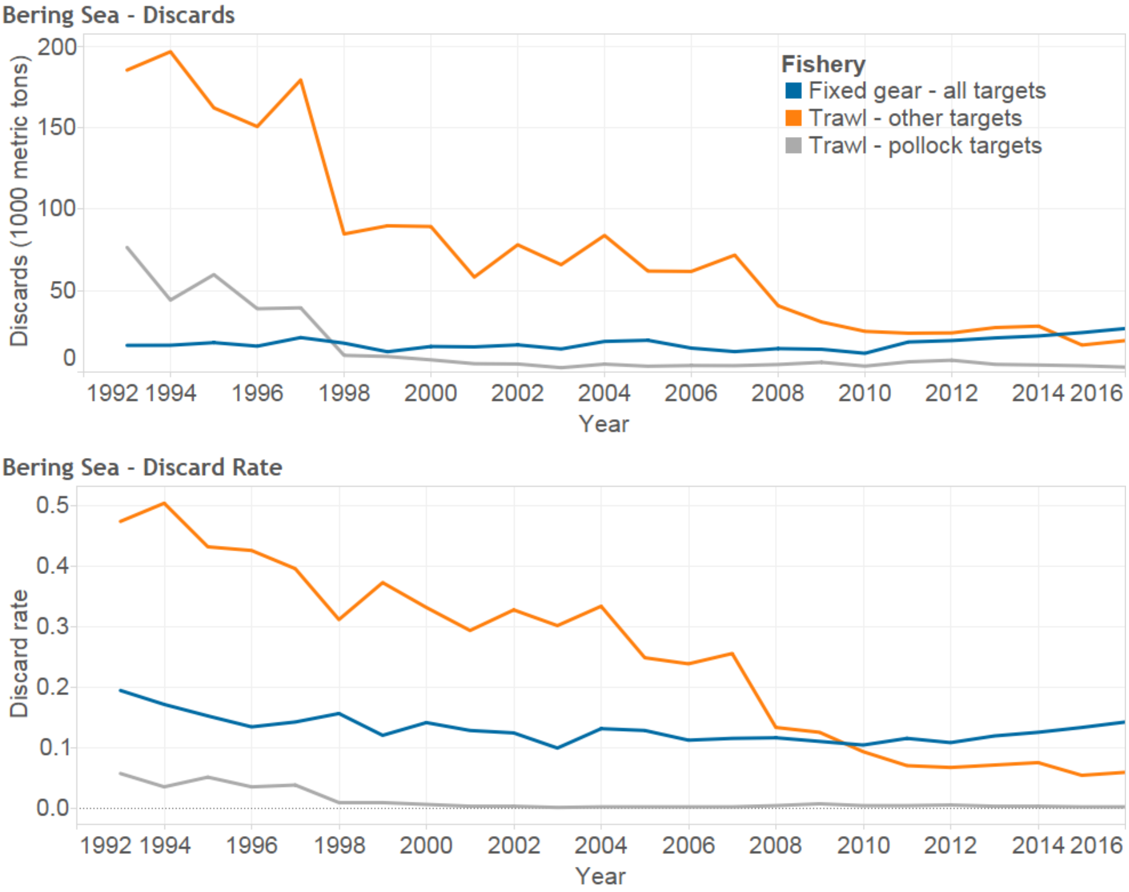

Figure 94: Total biomass and percent of total catch biomass of managed groundfish discarded in the fixed gear, pollock trawl, and non-pollock trawl sectors, 1993–2016. Discard rates are calculated as total discard weight of FMP groundfish divided by total catch weight of FMP groundfish for the gear-area-target sector (includes only catch counted against federal TACs).

Factors influencing observed trends: Since the early 1990s fisheries managers in North Pacific groundfish fisheries have employed various measures to address the problem of discards, including:

- Limited access privilege programs (LAPP) that reduce economic discards by removing the race for fish
- In-season closure of fisheries once target or bycatch species quotas are reached
- Minimum retention and utilization standards for certain fisheries
- Maximum retainable amounts (MRAs), which specify the amounts of "bycatch only" species that harvesters may retain relative to other groundfish species that remain open to directed fishing. MRAs reduce regulatory discards by allowing for limited retention of species harvested incidentally in directed fisheries.

In the Bering Sea, management and conservation measures aimed at reducing bycatch have contributed to an overall decline in groundfish discards over time. Pollock roe stripping, wherein harvesters extract only the highest value pollock product and discard all of the remaining fish, was prohibited in 1991. Throughout the 1990s, declines in total catch and discard of non-pollock groundfish in the pollock fishery coincided with the phasing out of bottom trawl gear in favor of pelagic gear, which allows for cleaner pollock catches. Full retention requirements for pollock and Pacific cod were implemented in 1998 for all vessels fishing for groundfish. Pollock discards declined significantly across both trawl gear sectors and have been effectively nonexistent in the trawl pollock fishery since it was rationalized in 2000 and became subject to more comprehensive observer coverage. Between 1997 and 1998 annual discard rates for cod fell from 13% to 1% in the non-pollock trawl sector and from 50% to 3% in the pollock trawl sector.

Low retention rates in the non-AFA trawl catcher processor (head and gut) fleet prompted adoption of Amendments 79 and 80 to the BSAI Groundfish FMP in 2008. Amendment 79 established a Groundfish Retention Standard (GRS) Program with minimum retention and utilization requirements for vessels at least 125 feet LOA (industry-internal monitoring of retention rates has since replaced the GRS Program). Amendment 80 expanded the GRS program to all vessels in the head and gut fleet and established a cooperative-based LAPP with fixed allocations of certain non-pollock groundfish species. These allocations are intended to eliminate the race for fish and remove the economic incentive to discard less valuable species caught in the multi-species flatfish fishery. Groundfish discard rates in the trawl flatfish fishery fell from 23% to 12% between 2007 and 2008 and have continued on a gradual decline since then.

Since 2003 across all Bering Sea sectors combined, discard rates for species groups historically managed together as the "other groundfish" assemblage (skate, sculpin, shark, squid, and octopus) have ranged from 65% to 80%, with skates representing the majority of discards by weight. In the fixed gear sector other groundfish typically account for at least 70% of total groundfish discards annually. Fluctuations in discard volumes and rates for these species may be driven by changes in market conditions and in fishing behavior within the directed fisheries in which these species are incidentally caught. For example, low octopus catch from 2007–2010 may be attributable to lower processor demand for food-grade octopus and decreases in cod pot-fishing effort stemming from declines in cod prices.

Implications: Characterizing fishery bycatch, which includes discards of groundfish, is an important component of ecosystem-based management. Discards add to the total human impact on biomass without providing a benefit to the Nation and as such are seen as "contrary to responsible stewardship and sustainable utilization of marine resources" (Kelleher, 2005). Bycatch in general constrains the utilization of commercial species (resulting in forgone income) and increases the uncertainty around total fishing-related mortality, making it more difficult to assess stocks, define overfishing levels, and monitor fisheries for overfishing. Although ecosystem effects of discards are not fully understood, discards of whole fish and offal have the potential to alter energy flow within ecosystems and have been observed to result in changes to habitat (e.g., oxygen depletion in the benthic environment) and community structure (e.g., increases in scavenger populations).

Minimizing fishery discards is recognized as an ecological, economic, and moral imperative in various multilateral initiatives and in National Standard 9 of the Magnuson-Stevens Fishery Conservation and Management Act. Over the last three decades, management measures in North Pacific groundfish fisheries have generally been effective in increasing groundfish retention and utilization and reducing discards. Monitoring discards and discard rates provides a way to assess the continuing efficacy of such measures.

Time Trends in Non-Target Species Catch

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Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the eastern Bering Sea (EBS). In previous years we included the catch of "other" species, "non-specified" species, and forage fish in this contribution. However, stock assessments have now been developed or are under development for all groups in the "other species" category (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), some of the species in the "non-specified" group (giant grenadier, other grenadiers), and forage fish (e.g., capelin, eulachon, Pacific sand lance, etc.), therefore we no longer include trends for these species/groups here (see AFSC stock assessment website at `http://www.afsc.noaa.gov/refm/stocks/assessments.htm`). 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 Region's Catch Accounting System. This sampling and estimation process does result in uncertainty in catches, which is greater when observer coverage is lower and for species encountered rarely in the catch.

The catch of non-target species/groups from the eastern Bering Sea includes the reporting areas 508, 509, 512, 513, 514, 516, 517, 521, 523, 524, and 530 (`https://alaskafisheries.noaa.gov/sites/default/files/fig1`). In previous years this contribution included reporting areas 518 and 519 as part of the eastern Bering Sea. Starting with this year's contribution, reporting areas 518 and 519 are now considered part of the Aleutian Islands. This change will make this contribution consistent with the spatial boundaries used for the ecosystem assessments in this report.

Status and trends: The catch of Scyphozoan jellyfish has fluctuated over the last six years and peaked in 2014 (Figure 95). Highs in jellyfish catch in 2011 and 2014 were followed by sharp drops the following year to catches less than half the size. The catch of jellyfish in 2014 is more than double the catch in 2015 and is more than five times the catch in 2016. Jellyfish are primarily caught in the Walleye pollock (*Gadus chalcogrammus*) fishery.

The catch of structural epifauna has been relatively steady from 2011 to 2016 (Figure 95). Benthic urochordata, anemones, and sponges comprised the majority of the structural epifauna catch from 2011–2016. Sponges were the dominant component of the structural epifauna catch in 2011 and were primarily caught in non-pelagic trawls. Benthic urochordate caught in non-pelagic trawls were the dominant component of the structural epifauna catch in 2012, 2015, and 2016. In 2013 and 2014, anemones caught in the Pacific cod fishery were the dominant part of the structural epifauna catch.

Sea stars comprise the majority of the assorted invertebrates catch in all years (2011–2016) and are primarily caught in flatfish fisheries (Figure 95). The catch of assorted invertebrates has generally trended upward from 2011–2015, and has decreased slightly in 2016.

Factors influencing observed trends: The catch of non-target species may change if fisheries change, or ecosystems change, or both. Because non-target species catch is unregulated and unintended, if there have been no large-scale changes in fishery management in a particular ecosystem, then large-scale signals in the non-target catch may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish in the EBS are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, sea ice phenology, wind-mixing, ocean currents, and prey abundance (Brodeur et al., 2008).

Implications: The catch of structural epifauna species and assorted invertebrates is very low compared with the catch of target species. Structural epifauna species may have become less available to the EBS fisheries (or the fisheries avoided them more effectively) since 2005. The lack of a clear trend in the catch of scyphozoan jellies may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries. Abundant jellyfish may have a negative impact on fishes as they compete with planktivorous fishes for prey resources (Purcell and Arai, 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).

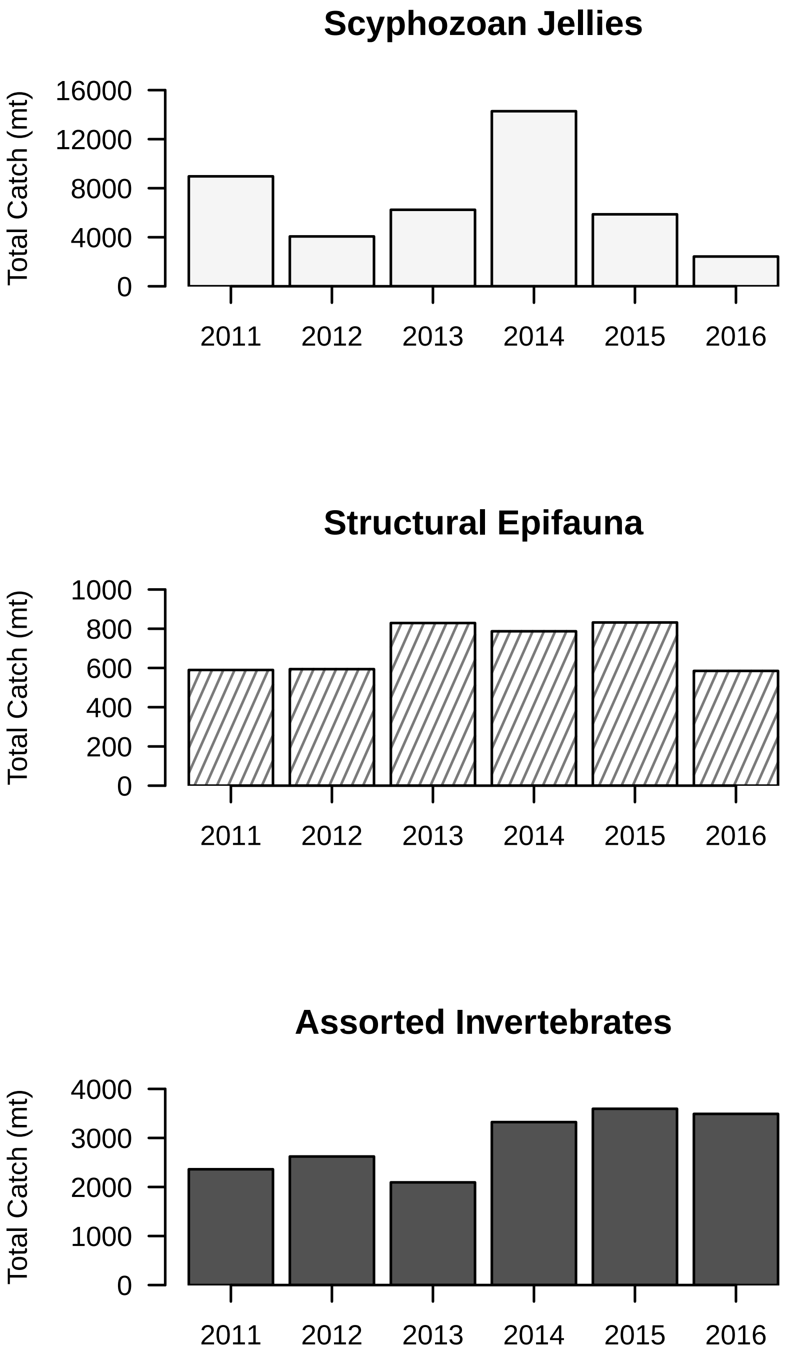

Figure 95: Total catch of non-target species (tons) in the eastern Bering Sea groundfish fisheries (2011–2016). **Please note the different ordinate axis scales** among species groups.

Seabird Bycatch Estimates for Groundfish Fisheries in the Eastern Bering Sea, 2007–2016

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Last updated: October 2017

Description of indicator: This report provides estimates of the numbers of seabirds caught as bycatch in commercial groundfish fisheries operating in federal waters of the eastern Bering Sea of the U.S. Exclusive Economic Zone for the years 2007 through 2016. 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 observer program, although some small amounts of halibut fishery information were collected in previous years when an operator had both halibut and sablefish individual fishing quota (those previous years of halibut data, from 2007–2012, are not included in the data presented in this report).

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. The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2010, 2014). 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. It is also used for the provision of estimates of non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. At each data run, the CAS produces estimates based on current data sets, which may have changed over time. Changes in the data are due to errors that were discovered during observer debriefing, data quality checks, and analysis. Examples of the possible changes in the underlying data are: changes in species identification; deletion of data sets where data collection protocols were not properly followed; or changes in the landing or at-sea production reports where data entry errors were found.

Status and trends: The numbers of seabirds estimated to be caught incidentally in eastern Bering Sea fisheries in 2016 increased from that in 2015, and exceeded the 2007–2015 average of 5,247 by 78% (Table 9). Notably, 2016 experienced the second highest number of birds estimated to be caught incidentally in eastern Bering Sea fisheries in this time series, 2007–2016. This increase was largely due to an increase in shearwater and northern fulmar bycatch. In 2016, the number of shearwaters increased by 338% compared to that of the 2007–2015 average of 722 and by 793% compared to 2015. The number of northern fulmars increased in 2016 by 61% compared to that of the 2007–2015 average of 3,226. Besides northern fulmars and shearwaters, gulls were the most common species group caught incidentally. No short-tailed albatross or black-footed albatross were caught, and an average number of Laysan albatross were caught incidentally. The estimated numbers of birds caught incidentally in the eastern Bering Sea exceeded that in the Gulf of Alaska and the Aleutian Islands, as has been the case in all years in this time series (Figure 96). However,

Table 9: **Estimated** seabird bycatch in eastern Bering Sea groundfish fisheries for all gear types, 2007 through 2016. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species Group	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Unidentified Albatross	0	0	0	0	0	0	0	11	0	0
Short-tailed Albatross	0	0	0	15	5	0	0	9	0	0
Black-footed Albatross	18	7	5	9	2	0	1	5	2	0
Laysan Albatross	2	7	14	16	30	48	19	17	28	18
Northern Fulmar	3,158	2,132	7,215	1,932	5,405	3,114	2,885	706	2,489	5,189
Shearwaters	2,821	1,185	571	569	160	526	196	118	354	3,162
Storm Petrels	1	0	0	0	0	0	0	0	0	0
Gull	717	1,348	911	719	1,651	835	416	573	925	599
Kittiwake	10	0	16	0	6	5	3	9	12	6
Murre	6	6	13	102	14	6	3	47	0	58
Puffin	0	0	0	9	0	0	0	0	0	11
Auklets	0	3	0	0	0	7	4	99	19	29
Other Alcid	0	0	105	0	0	0	0	0	0	0
Cormorant	0	0	0	0	0	0	0	0	3	0
Other Birds	0	0	136	0	0	0	0	0	0	0
Unidentified	461	267	501	253	377	307	276	77	157	284
Grand Total	7,194	4,955	9,487	3,625	7,649	4,848	3,803	1,671	3,990	9,355

the number of albatross caught incidentally in the eastern Bering Sea is less than that in the Gulf of Alaska and the Aleutian Islands, as has been the case in all but two years in this time series (Figure 97).

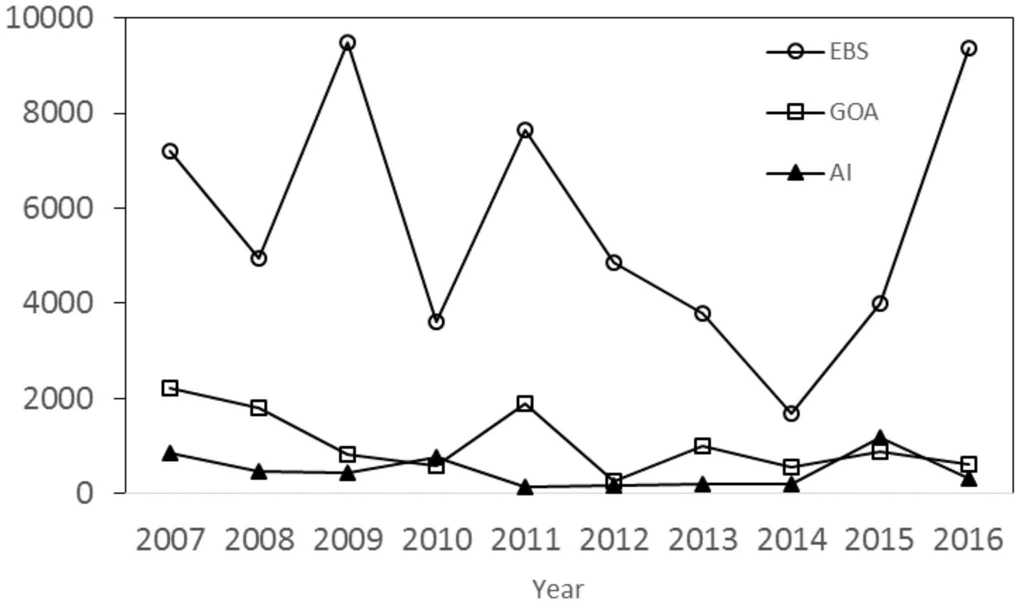

Figure 96: Total estimated seabird bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007–2016.

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. For example, a marked decline in overall numbers of birds caught after 2002 reflected the increased use of seabird mitigation devices. A large portion of the freezer longline fleet adopted these measures in 2002, followed by regulation requiring them for the rest of the fleet beginning in February 2004. Since 2002, seabird bycatch estimates have varied annually but have not returned to the level seen prior to the use of seabird mitigation devices. Since 2004, work has continued on developing new and refining existing mitigation gear (Dietrich and Melvin, 2008).

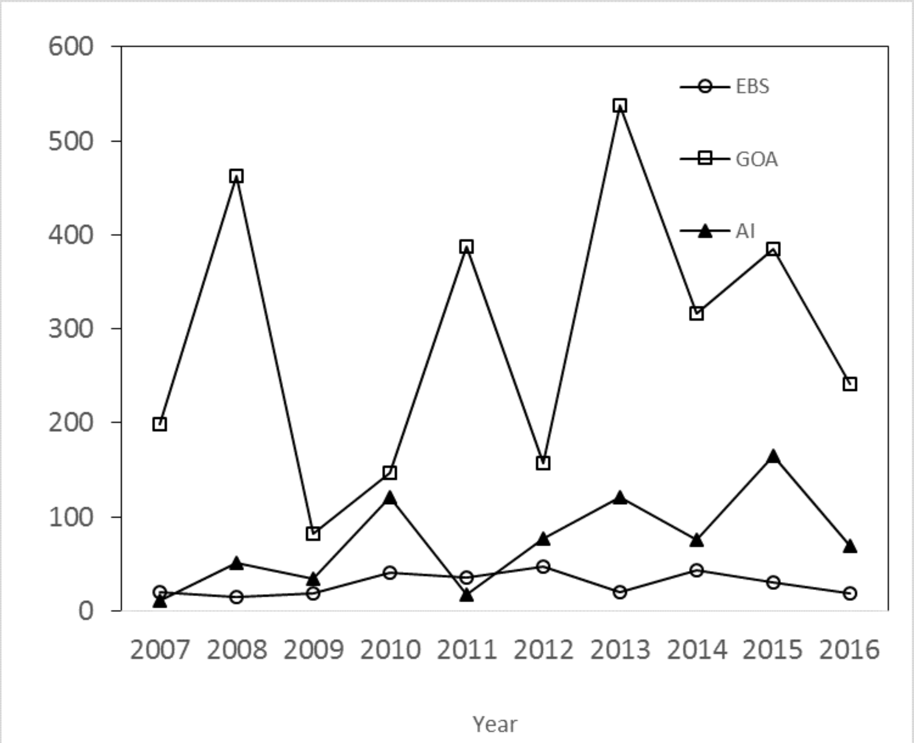

Figure 97: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007–2016.

The longline fleet has traditionally been responsible for about 90% of the overall seabird bycatch in Alaska, as determined from the data sources noted above. However, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates are downward biased (S. Fitzgerald, pers. comm.). For example, this study shows that the 2010 estimate of trawl-related seabird mortality is 823, while the additional observed mortalities (not included in this estimate and not expanded to the fleet) were 112. Observers now record the additional mortalities they see on trawl vessels and the AFSC Seabird Program has contracted an analyst to work on how these additional numbers can be folded into an overall estimate. The challenge to further reduce seabird bycatch is great given the rare nature of the event. For example, (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. However, given the vast size of the fishery, the total bycatch can add up to hundreds of albatross or thousands of fulmars (Table 9).

Implications: The increase in seabirds caught incidentally in the eastern Bering Sea in 2016 relative to the year before was primarily due to increases in northern fulmar and shearwater bycatch. Increases were not seen in the Aleutian Islands or Gulf of Alaska, leaving reason to believe that there was a localized change in the eastern Bering Sea in seabird distribution, fishing effort, and/or seabird prey supply, all of which could impact bycatch.

It is difficult to determine how seabird bycatch numbers 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. In 2014 seabird bycatch off Alaska was at relatively low levels (driven by lower northern fulmar and gull bycatch) but albatross numbers were the highest at any time between 2002 and 2016. This could indicate poor ocean conditions in the North Pacific as albatross traveled from the Hawaiian Islands to Alaska. Broad changes in overall seabird bycatch, up to 5,750 birds per year, occurred between 2007 and 2016. This probably indicates changes in food availability rather than drastic 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 the Eastern Bering Sea

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Last updated: October 2017

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 model to estimate the habitat reduction of geological and biological features over the eastern Bering Sea domain, utilizing spatially explicit VMS data. The time series for this indicator is available since 2003, when widespread VMS data became available.

Status and trends: Habitat impacts due to fishing gear (pelagic and non-pelagic trawl, longline, and pot) interactions have decreased steadily from a high of about 3.5% between 2003–2008 to the present level of about 2.3% in the eastern Bering Sea (Figures 98 and 99).

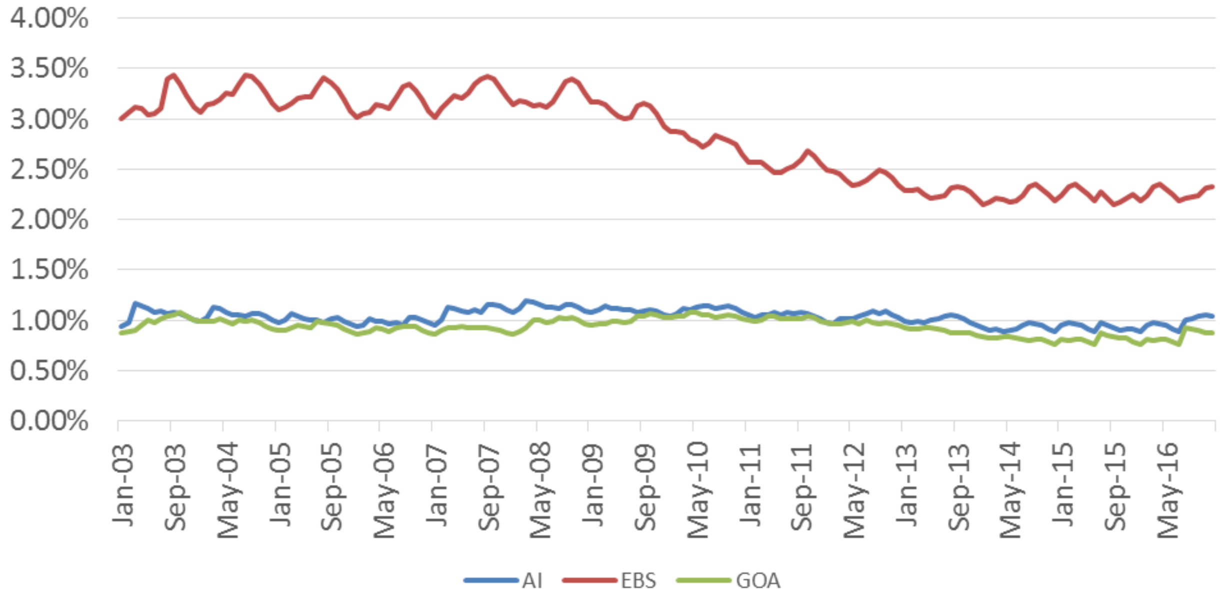

Figure 98: Percent habitat reduction, all gear types combined, from 2003 through 2016.

Factors influencing observed trends: 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, increased fishing skills (e.g., increased ability to find fish), markets for fish products, and changes in vessel horsepower and fishing gear.

Between 2003 and 2008, variability in habitat reduction was driven largely by the seasonality of fishing in the eastern Bering Sea. In 2008, Amendment 80 was implemented, which allocated BSAI Yellowfin sole, Flathead sole, Rock sole, Atka mackerel, and Aleutian Islands Pacific ocean perch to

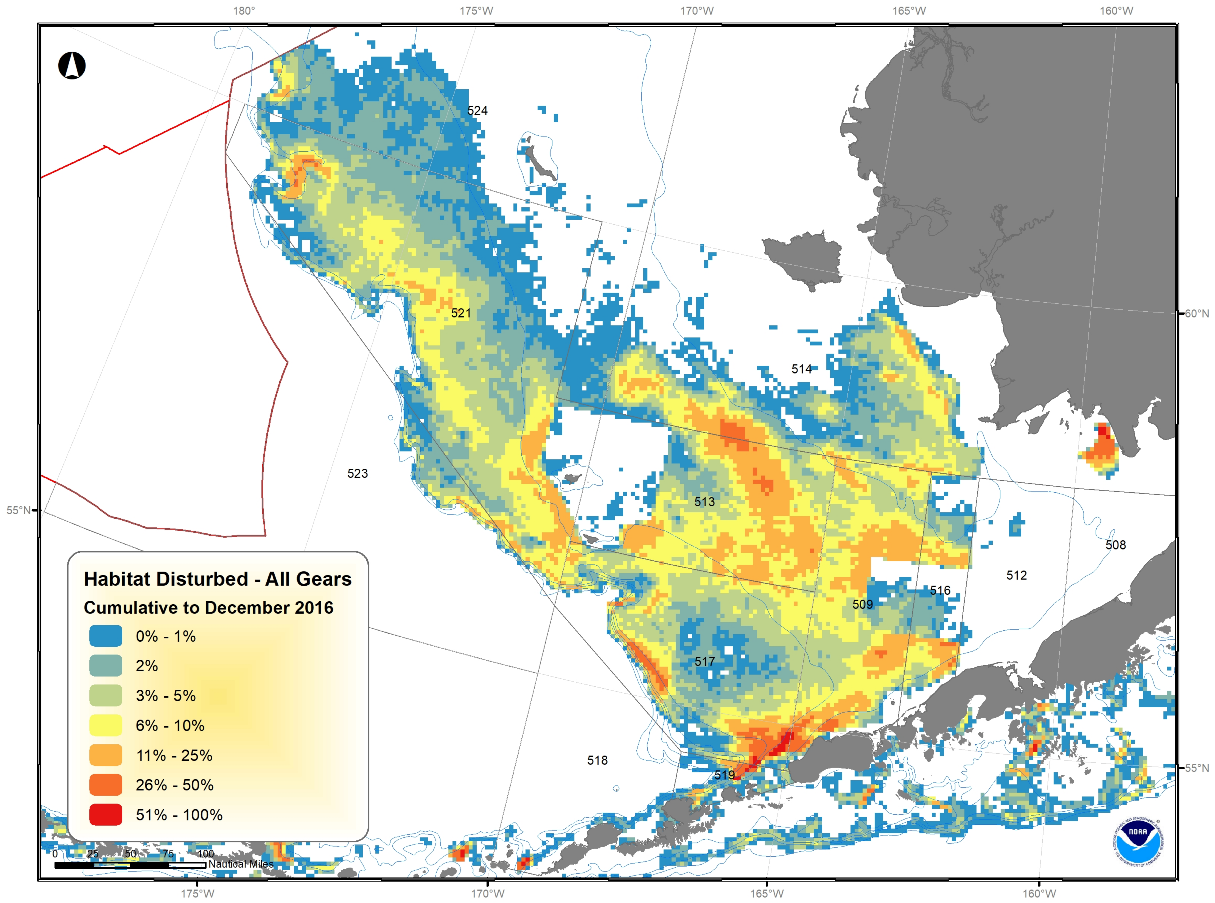

Figure 99: Map of percentage habitat disturbed in the eastern Bering Sea by all gear types. Effects are cumulative and consider impacts and recovery of features from January 2003 to December 2016.

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. In 2010, trawl sweep gear modifications were implemented on non-pelagic trawls in the eastern Bering Sea, resulting in less gear contacting the seafloor and less habitat impact.

Implications: Habitat impacts vary with the biological and geological characteristics of the areas fished, recovery rates of those biological and geological structures, and management changes that result in spatial redistribution of fishing effort. Although the impacts of fishing across the domain are very low, it is possible that localized impacts may be occurring. The issue of local impacts is an area of ongoing development with the Fishing Effects model. The 2015 EFH 5-year review was completed in 2017, and AFSC stock assessment authors considered habitat impacts to managed species for the first time. In no cases was the effects of fishing on Essential Fish Habitat considered to be more than minimal or not temporary. The EFH 5-year Review Summary Report has been published as a Processed Report and can be found here: `ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/TM_NMFS_AFKR/TM_NMFS_FAKR_15.pdf`.

Sustainability (for consumptive and non-consumptive uses)

Fish Stock Sustainability Index and Status of Groundfish, Crab, Salmon, and Scallop Stocks

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Last updated: August 2017

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 (`http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`). 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 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 36 FSSI stocks and an overall FSSI of 144 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). Prior to 2015 there were 35 FSSI stocks and maximum possible score of 140. To keep FSSI scores for Alaska comparable across years we report the total Alaska FSSI as a percentage of the maximum possible score (i.e., 100%). Additionally, there are 29 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement. None of the non-FSSI stocks are known to be overfished, approaching an overfished condition, or subject to overfishing. For more information on non-FSSI stocks see the Status of U.S. Fisheries webpage.

Within the BSAI region there are 22 FSSI stocks. The assessment for sablefish is based on aggregated data from the GOA and BSAI regions. In previous FSSI contributions, the sablefish FSSI score was included among BSAI species. Starting with this year's contribution, sablefish is removed from the BSAI FSSI contribution and is now included in the GOA FSSI contribution (see the Gulf of Alaska Ecosystem Considerations Report).

Table 10: Summary of status for the 22 FSSI stocks in the BSAI, updated through June 2017.

BSAI FSSI (22 stocks)	Yes	No	*Unknown*	*Undefined*	N/A
Overfishing	1	21	0	0	0
Overfished	1	20	1	0	0
Approaching Overfished Condition	0	20	1	0	1

Status and trends: As of June 30, 2017, no BSAI groundfish stock or stock complex is subjected to overfishing, is considered to be overfished, or to be approaching an overfished condition (Table 10). Among BSAI crab stocks, the Pribilof Islands blue king crab stock is considered to be overfished and is subject to overfishing. This stock is in year 3 of a rebuilding plan.

The current overall Alaska FSSI is 132.5 out of a possible 144, or 92%, based on updates through June 2017 and is unchanged from last year (Figure 100). The overall Alaska FSSI has generally trended upwards from 80% in 2006 to 92% in 2017. The BSAI groundfish FSSI score is 56 out of a maximum possible 56, and BSAI king and tanner crabs are 25.5 out of a possible 32. The overall Bering Sea/Aleutian Islands score is 81.5 out of a maximum possible score of 88 (Table 11). Since 2006 the BSAI overall FSSI has increased from 74% up to 93% in 2017 (Figure 101).

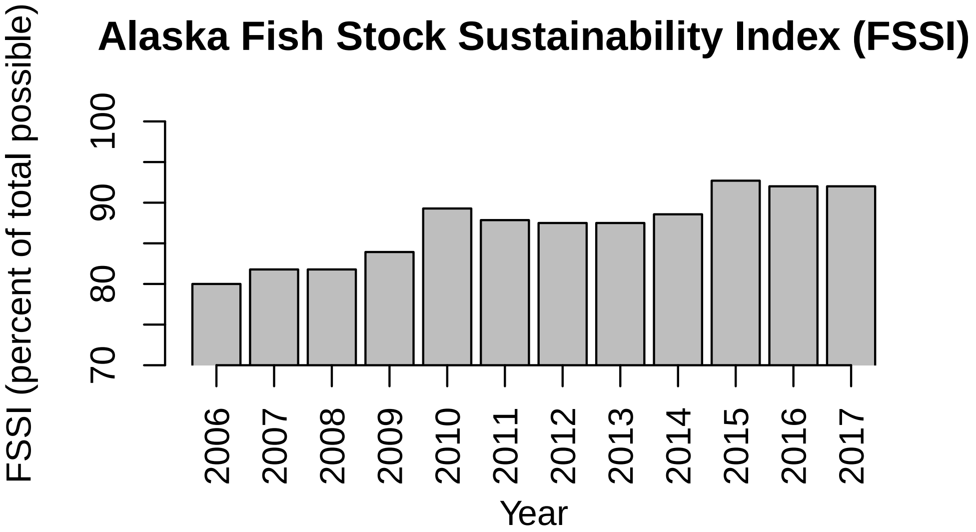

Figure 100: The trend in overall Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2017. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 on it is 144. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Factors influencing observed trends: Although the overall Alaska FSSI score is unchanged from last year, there have been changes in the FSSI scores for one BSAI crab stock and one BSAI groundfish stock. The Pribilof Islands blue king crab stock lost one point when it was determined they were subject to overfishing. The primary driver of decline for this stock is thought to be changes in environmental conditions that negatively affect reproduction. One point was gained when the biomass of the BSAI Greenland halibut stock increased to greater than 80% of B_{MSY}.

The two point changes offset and the result in no net change to the overall Alaska FSSI. Other crab groups in the BSAI region with FSSI scores less than 4 are golden king crab-Aleutian Islands (FSSI=1.5) and blue king crab-St. Matthew's Island (FSSI=3). Neither of these king crab stocks are subject to overfishing. It is unknown if the golden king crab-Aleutian Islands stock is overfished and B_{MSY} is not estimated.

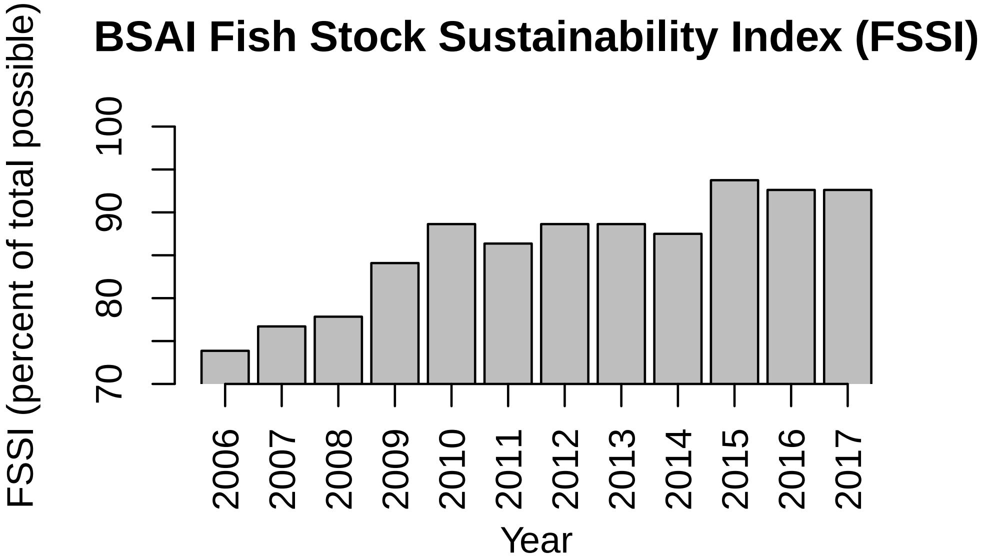

Figure 101: The trend in FSSI from 2006 through 2017 for the BSAI region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Implications: The majority of Alaska groundfish fisheries appear to be sustainably managed. A single stock in the BSAI is considered to be overfished and subject to overfishing (Pribilof Islands blue king crab). No other stocks or stock complexes in the BSAI are known to be approaching an overfished condition.

Table 11: BSAI FSSI stocks under NPFMC jurisdiction updated through June 2017 adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`. See Box A for endnotes and definition of stocks and stock complexes.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/Bmsy	FSSI Score
Blue king crab - Pribilof Islands[a]	Yes	Yes	N/A	Reduce mortality, continue rebuilding	Year 3 of plan	0.09	1
Blue king crab - Saint Matthews Island	No	No	No	N/A	N/A	0.57	3
Golden king crab - Aleutian Islands	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Red king crab - Bristol Bay	No	No	No	N/A	N/A	1.04	4
Red king crab - Norton Sound	No	No	No	N/A	N/A	1.29	4
Red king crab - Pribilof Islands	No	No	No	N/A	N/A	1.64	4
Snow crab - Bering Sea	No	No	No	N/A	N/A	0.94	4
Southern Tanner crab - Bering Sea	No	No	No	N/A	N/A	2.67	4
BSAI Alaska plaice	No	No	No	N/A	N/A	2.03	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.41	4
BSAI Arrowtooth Flounder	No	No	No	N/A	N/A	2.67	4
BSAI Blackspotted and Rougheye Rockfish[b]	No	No	No	N/A	N/A	0.90	4
BSAI Flathead Sole Complex[c]	No	No	No	N/A	N/A	2.07	4
BSAI Rock Sole Complex[d]	No	No	No	N/A	N/A	1.66	4
BSAI Skate Complex[e]	No	No	No	N/A	N/A	1.99	4
BSAI Greenland halibut	No	No	No	N/A	N/A	1.15	4
BSAI Northern rockfish	No	No	No	N/A	N/A	1.92	4
BS Pacific cod	No	No	No	N/A	N/A	1.56	4
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.72	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	1.02	4
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.88	4
BSAI Yellowfin sole	No	No	No	N/A	N/A	1.83	4

Box A. Endnotes and stock complex definitions for FSSI stocks listed in Table 11, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/`.

(a) A new rebuilding plan for this stock was implemented January 1, 2015 but does not specify a target rebuilding date because it is not known when the stock is expected to rebuild. There is no directed fishing for the blue king crab-Pribilof Islands and the majority of blue king crab habitat is closed to bottom trawling, and beginning in 2015 there is a prohibition on directed cod pot fishing in the Pribilof Islands Habitat Conservation Zone (PIHCZ). For this stock to rebuild, the stock would likely require multiple years of above average recruitment and/or a change in environmental conditions to increase larval productivity around the Pribilof Islands.

(b) BSAI Blackspotted and Rougheye Rockfish consists of Blackspotted Rockfish and Rougheye Rockfish. An assessment of the combined species provides the overfished determination, and the OFL is based on the combined-species assessment.

(c) 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 OFL, which is computed from the combined abundance estimates for the two species.

(d) 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.

(e) 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.

Seafood Production

Economic Indicators in the Eastern Bering Sea Ecosystem - Landings

Contributed by Benjamin Fissel[1], Jean Lee[1,2], and Steve Kasperski[1]
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Last updated: October 2017

Description of indicator: Landings are a baseline metric for characterizing commercial economic production in the eastern Bering Sea. Landings are the retained catch of fish and are plotted here by functional group (Figure 102). While many species comprise a functional group, it is the handful of species that fishermen target that dominate the economic metrics in each group. The primary target species in the apex predators' functional group are Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), Sablefish (*Anoplopoma fimbria*), and Arrowtooth flounder (*Atheresthes stomias*). The primary target species in the pelagic foragers' functional group are Walleye pollock (*Gadus chalcogrammus*), Atka mackerel (*Pleurogrammus monopterygius*), and Pacific ocean perch (*Sebastes alutus*). The primary target species in the benthic foragers' functional group are Yellowfin sole (*Limanda aspera*), Rock sole (*Lepidopsetta bilineata*), and Flathead sole (*Hippoglossoides elassodon*). The primary target species in the salmonid functional group are Chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*), and pink (*O. gorbuscha*) salmon. The primary target species in the motile epifauna functional group are king, bairdi, and snow crab. Because of significant differences in the relative scale of landings across functional group, landings are plotted on a log scale (figures based on Fissel et al. (2016)).

Status and trends: Landings in the eastern Bering Sea are predominantly from the pelagic forager functional group. The primary species landed within this group is pollock whose landings are an order of magnitude larger than that of any other species or functional group. Trends in the landings of the apex predator functional group are primarily driven by TAC levels in the Pacific cod stock which has remained healthy and has remained slightly higher since 2011 than before. Landings were increasing up to 2008 in the flatfish fisheries which make up the benthic foragers functional group. Total flatfish catches are well below their respective TACs and stocks remain healthy. EBS salmon landings have remained largely stable from 2004–2016 with a temporary decline from 2011–2013. Landings in the crab stocks which comprise the motile epifauna group have trended up gradually since 2003 reflecting the increasing health of the stocks following rationalization of the crab fisheries.

Factors influencing observed trends: Between 2008–2010 conservation-based reductions in the pollock Total Allowable Catch (TAC) resulted in reduced landings for the pelagic forager functional group. In 2008 Amendment 80 to the BSAI groundfish FMP was implemented rationalizing the major flatfish fisheries which resulted in significant reductions in bycatch.

Total catch of the groundfish that comprise the pelagic forager, apex predators, and benthic foragers' functional groups in the Bering Sea is capped at 2 million metric tons. The sum of the Allowable Biological Catches (ABC) for these groups are typically above the cap and TACs are reduced from the ABC by the North Pacific Fishery Management Council to meet the cap require-

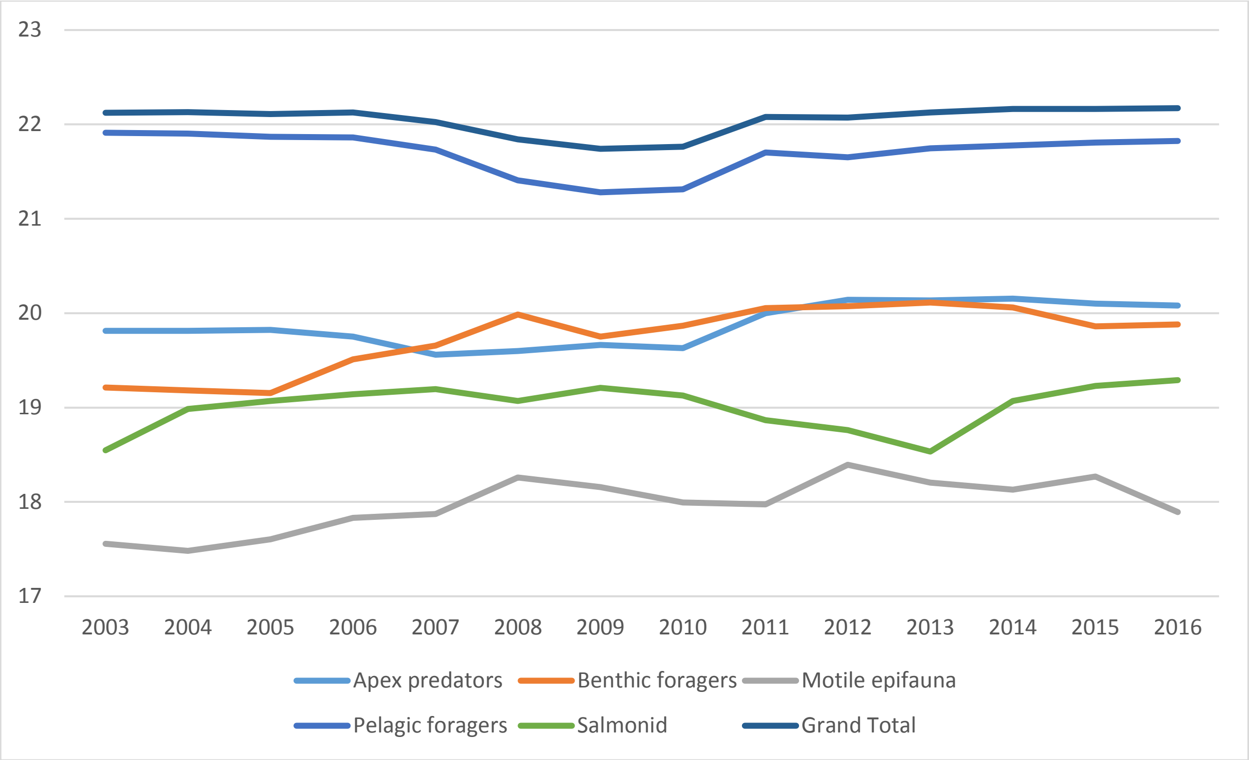

Figure 102: Eastern Bering Sea landings by function group (log pounds).

ment. This cap system influences interpretation of trends in landings relative to their underlying stocks as changes in landings may not be the direct result of changes in biomass.

Implications: Landings depict one aspect of the raw stresses from harvesting imposed on the eastern Bering Sea ecosystem's functional groups through fishing. This information can be useful in identifying areas where harvesting may be impacting different functional groups in times where the functional groups within the ecosystem might be constrained. What is clear from Figure 102 is that pelagic foragers have been by far the largest share of total landings over the 2003–2016 period, while motile epifauna represent the smallest share. Monitoring the trends in landings stratified by ecosystem functional group provides insight on the fishing-related stresses on ecosystems. The ultimate impact that these stresses have on the ecosystem cannot be discerned from these metrics alone and must be viewed within the context of what the ecosystem can provide.

Halibut and Salmon Subsistence Trends in the Eastern Bering Sea

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Description of indicator: Subsistence uses of wild resources are defined as "noncommercial, customary and traditional uses" for a variety of purposes including nutritional, trade, and cultural purposes (Alaska Department of Fish & Game, `http://www.adfg.alaska.gov`). In the eastern Bering Sea coastal region, Pacific halibut (*Hippoglossus stenolepis*), Pacific herring (*Clupea pallasii*), salmon, and crab are harvested for subsistence and contribute to the mixed subsistence and cash economy, as well as a cultural practice (Group, 2011; Huntington et al., 2013). On average, rural Alaskans harvest 155 pounds of fish per person per year (Fall et al., 2017). For these reasons, subsistence harvests of two focal species–halibut and salmon–were considered informative.

Harvest data were collected from The Alaska Department of Fish & Game Division of Subsistence for the years 1994–2014 (`http://www.adfg.alaska.gov/index.cfm?adfg=subsistence.harvest`). ADF&G reports that 1994 was the first year for which data from all subsistence fisheries were available and comparable to current collections. Subsistence data are largely collected from household surveys.

Status and trends:
Halibut
According to ADF&G, statewide subsistence halibut harvest (in pounds) declined substantially between 2004–2012, with a slight uptick in 2013 (Figure 103). There were approximately 4,506 subsistence permits issued in Alaska, harvesting an estimated 40,698 halibut in 2014. In comparison, the International Pacific Halibut Commission estimated that the total halibut harvest (commercial, recreational, and subsistence) in Alaska was 33,804 million pounds, with subsistence harvests representing 2.3% of the total harvest in 2014. Just 9% of all subsistence halibut harvest occurred in Area 4E in the eastern Bering Sea in 2014 (Fall and Lemons, 2015).

Salmon
ADF&G records report an increase in household permits, however the data reflect a downward trend in subsistence harvest, particularly in Chinook salmon (*Oncorhynchus tshawytscha*; Figure 104). The historical average since 1994 is 940,444 salmon, with the most recent total salmon subsistence harvest in 2014 estimated at 932,596 fish. The 2014 estimate for Chinook subsistence harvest is the lowest estimate on record. Chinook salmon is particularly important to EBS communities, with the Bristol Bay Management Area harvesting the largest percentage of subsistence Chinook (41%), followed by the Kuskokwim Management Area (21%) in 2014. EBS communities represented 43% of all subsistence Sockeye salmon (*O. nerka*) harvests in 2014 and 69% of all Coho salmon (*O. kisutch*) subsistence harvests in 2013 (Fall et al., 2017).

Factors influencing observed trends: The reasons for the decline in subsistence halibut harvest are complex, and in large part related to participation in the survey and methodology (Fall and Lemons, 2015). Due to budgetary constraints, data collection efforts were reduced in size and scope,

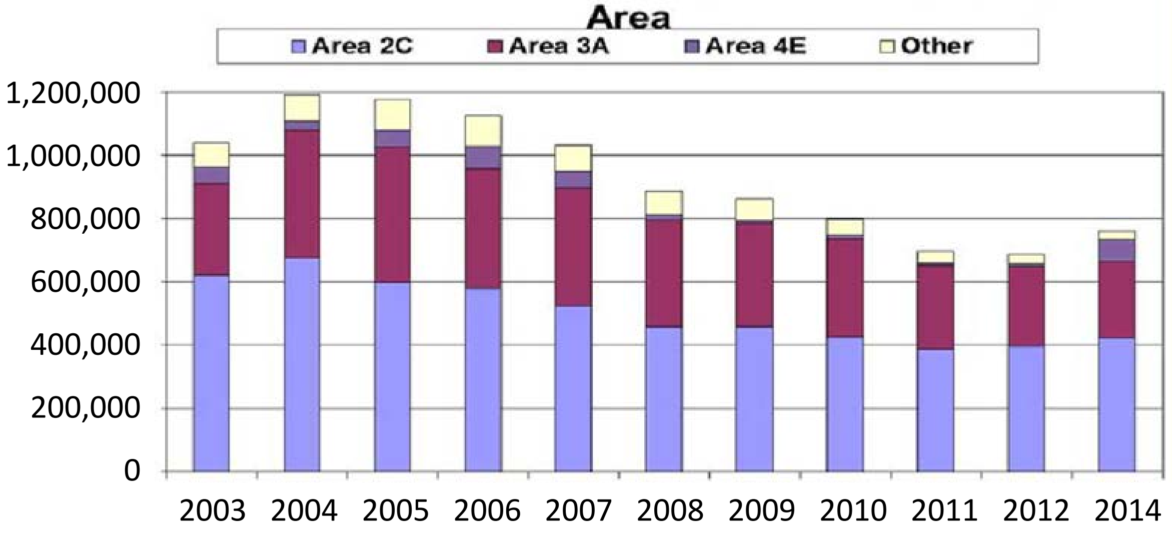

Figure 103: Estimated subsistence harvests of Pacific halibut in Alaska 2003–2012 & 2014 (lbs. net weight) by area.

which is consistent with the decrease in reported harvests, suggesting that some of the decrease in halibut harvest is a result of a lower participation in the survey. In certain regulatory areas, there is a down turn in renewal of halibut permits (SHARCs) after the initial rise in participation after the start of the SHARC program (Fall and Lemons, 2015). Non-renewal of SHARCs, low survey participation rates, and the lack of follow-up field work indicates halibut harvest was under estimated. Survey methodology differed in some regions. The decrease in response rate could suggest survey fatigue. In 2014, an effort was made to follow up with non-participants in some regions to complete the survey, increasing the reported harvest estimates.

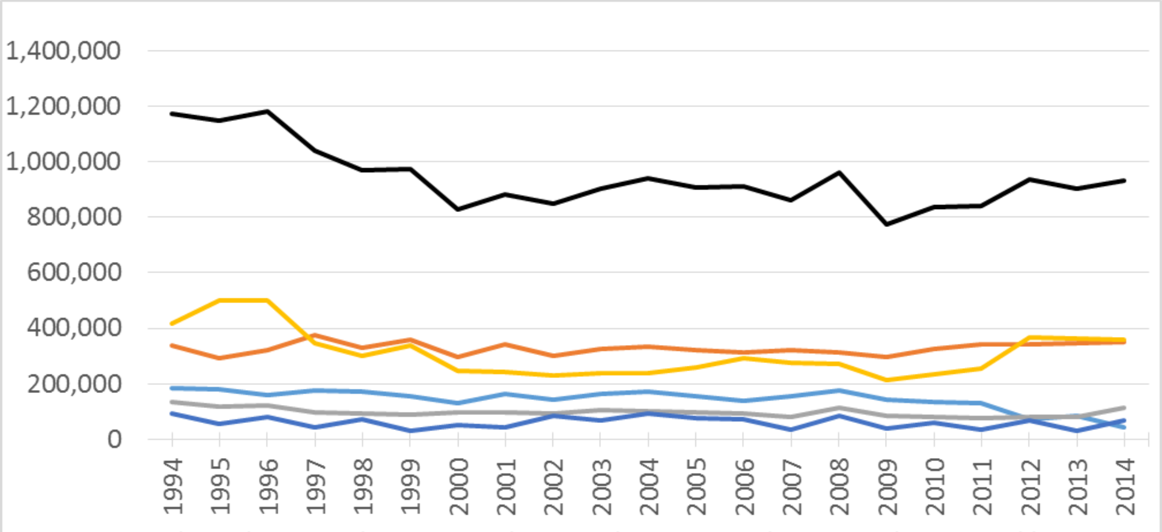

Figure 104: Subsistence salmon harvests in the eastern Bering Sea between 1994–2014.

Implications: Although household subsistence halibut and salmon permits continued to increase slightly, both species show declines in harvests since 1996. Subsistence fishing and hunting represent a major source of food security and cultural identity for many Alaskans. Rural households rely on subsistence resources to supplement food during the winter when other sources of food may be unavailable or prohibitively expensive (Loring and Gerlach, 2009). Equally important, subsistence practices represent a way of life which supports community bonds of sharing and inter-reliance, and reinforces community connections to land and a shared heritage (Holen, 2014; Picou et al., 1992).

Profits

Economic Indicators in the Eastern Bering Sea Ecosystem - Value and Unit Value

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Description of indicator: Three plots are used to characterize economic value in an ecosystem context for the eastern Bering Sea. Ex-vessel value is the un-processed value of the retained catch (Figure 105). Ex-vessel value can informally be thought of as the revenue that fishermen receive from the catch.

First-wholesale value is the revenue from the catch after primary processing by a processor (Figure 106). First-wholesale value is a more comprehensive measure of value to the fishing industry as it includes ex-vessel value as well as the value-added revenue from processing which goes to processing sector.

The first-wholesale value to total catch unit value is the ratio of value to biomass extracted as a result of commercial fish harvesting (Figure 107). The measure of biomass extracted in this index included retained catch, discards, and prohibited species catch. This metric answers the question: “how much revenue is the fishing industry receiving per-unit biomass extracted from the ecosystem?” The first-wholesale to total catch unit value is analogous to a volumetrically weighted average price across functional groups which is inclusive of discards. However, discards represent a relatively small fraction of total catch. Because of the comparatively larger volume and value from pelagic foragers’ the unit value index is more heavily weighted towards this group.

Figures 105 and 106 are plotted by functional group. While many species comprise a functional group, it is the handful of species that fishermen target that dominate the economic metrics in each group. The primary target species in the apex predators functional group are Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), Sablefish (*Anoplopoma fimbria*), and Arrowtooth flounder (*Atheresthes stomias*). The primary target species in the pelagic foragers functional group are Walleye pollock (*Gadus chalcogrammus*), Atka mackerel (*Pleurogrammus monopterygius*), and Pacific ocean perch (*Sebastes alutus*). The primary target species in the benthic foragers functional group are Yellowfin sole (*Limanda aspera*), Rock sole (*Lepidopsetta bilineata*), and Flathead sole (*Hippoglossoides elassodon*). The primary target species in the salmonid functional group are Chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*), and pink (*O. gorbuscha*) salmon. The primary target species in the motile epifauna functional group are king, bairdi, and snow crab. Because of significant differences in the relative scale of value across functional group, value is plotted in logs. Revenues in Figures 105–107 have been adjusted for inflation using the GDP chain-type deflator (figures based on Fissel et al. (2016)).

Status and trends: Ex-vessel value is the revenue from landings, consequently trends in ex-vessel value and landings are closely connected. Ex-vessel value is highest in the pelagic forager functional group because of the volume of landings in the pollock fishery. Benthic forager flatfish revenues were

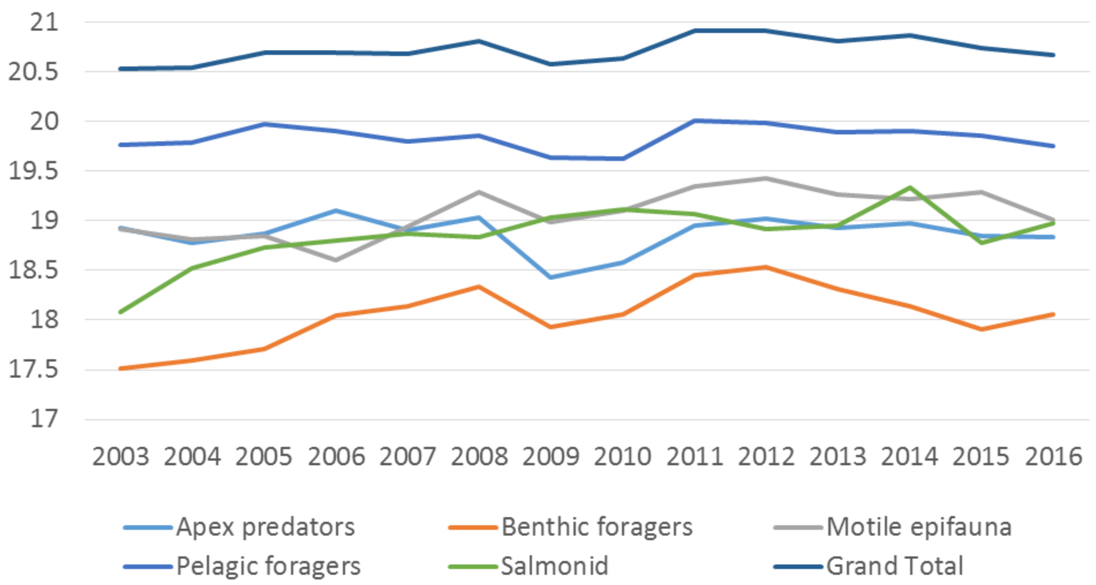

Figure 105: Eastern Bering Sea real ex-vessel value by functional group (log 2016 dollars).

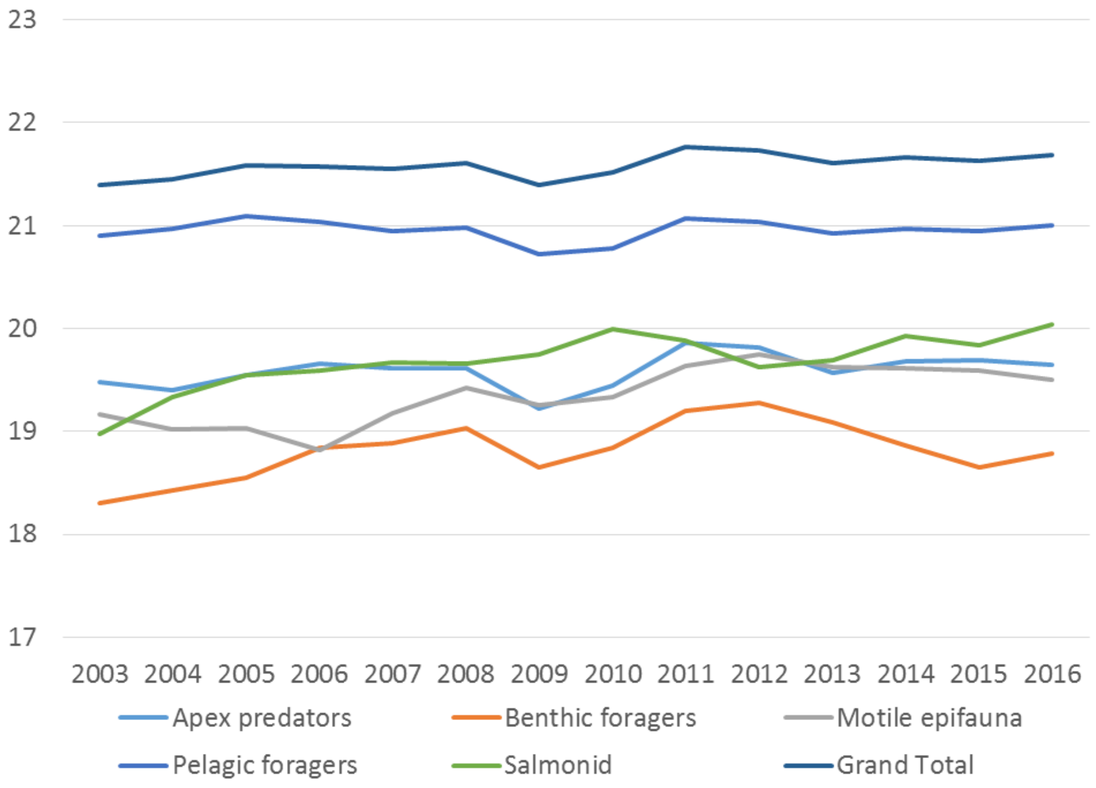

Figure 106: Eastern Bering Sea real first-wholesale value by functional group (log 2016 dollars).

increasing from 2000–2008 with increase landings volume but recent declines in value have been the result of decreased prices. Value in the motile epifauna group has been increasing with crab landings. The generally increasing trend in salmon value is the result of generally stable landings and strong prices.

Differences in the relative level of the indices between the landings and ex-vessel value in Figure 105 reflect differences in the average prices of the species that make up the functional group. Hence, landings of benthic forager flatfish may be larger than salmon, but salmon ex-vessel value is higher because it commands a higher price.

First-wholesale value was generally increasing for each of the functional groups up to about 2008–2010 with stable or increasing landings and gradually increasing prices. After this, variation in landings or in prices has had differential impacts. The value of the pelagic forager group has been relatively stable with the exception of 2008–2009 when landings we low. Since 2013 prices for pollock have decreased as global pollock supply has been high, but increased landings have had the combined effect of only marginal decreases in value. First-wholesale value dipped in the apex predator group with a decrease in Pacific cod prices in 2009, but prices rebounded after and stable landings resulted in fairly stable revenue. Benthic forager first-wholesale value decreased from 2012 to 2015 with decreases in flatfish prices as demand for these products plateaued with significant supply. Decreased landings in 2012 brought down salmon value but a price increase buoyed value in 2013 as landings continued to decline after which landing and value have remained at roughly 2010 levels. Value in the motile epifauna group continued to increase with increasing crab prices through 2012 but has since stabilized and value has decreased slightly with marginal reductions in landing.

The unit value index increased from 2003–2008 with generally increasing prices across all functional groups. Pollock prices fell somewhat in 2013 with significant global pollock supply. Salmon and motile epifauna prices also rose in 2010 and have shown significant volatility since. Apex predator prices dipped in 2009, rebounded in 2010–2011, declined in 2013, and have since leveled out. Benthic forager prices declined through 2009, increased from 2009–2012 and decreased after before leveling out in 2014. The cumulative effect of this price changes is that the first-wholesale unit value index increased to 2008, was relatively volatile at this high level through 2012 then decreased somewhat in 2013 and has vacillated at approximately that level since.

Factors influencing observed trends: The reduction in revenue from 2008–2010 was the result of conservation based reductions in the pollock Total Allowable Catch (TAC). Supply reductions in the pollock fishery which began in 2008 resulted in increased first-wholesale prices which account for the significant increase in the 2008 unit value and the relatively high level maintained through 2012. In recent years, increasing global supply has put downward pressure on minimally processed whitefish product prices which has filtered through to the ex-vessel market. As a result, revenue has decreased since 2013 in the pelagic forager and apex predator groups despite strong landings.

Ex-vessel prices are influenced by a multitude of potential factors including demand for processed products, the volume of supply (both from the fishery and globally), the first-wholesale price, inflation, fishing costs, and bargain power between processors and fishermen. However, annual variation in the ex-vessel prices tends to be smaller than variations in catch and short to medium term variation in the landings and ex-vessel revenue indices appear similar.

First-wholesale value is the revenue from the sale of processed fish. Some fish, in particular pollock and Pacific cod, are processed into numerous product forms which can influence the generation of revenue by the processing sector. Level shifts in the relative location of the first-wholesale indices compared to the ex-vessel indices are influenced by differences in the amount and types of

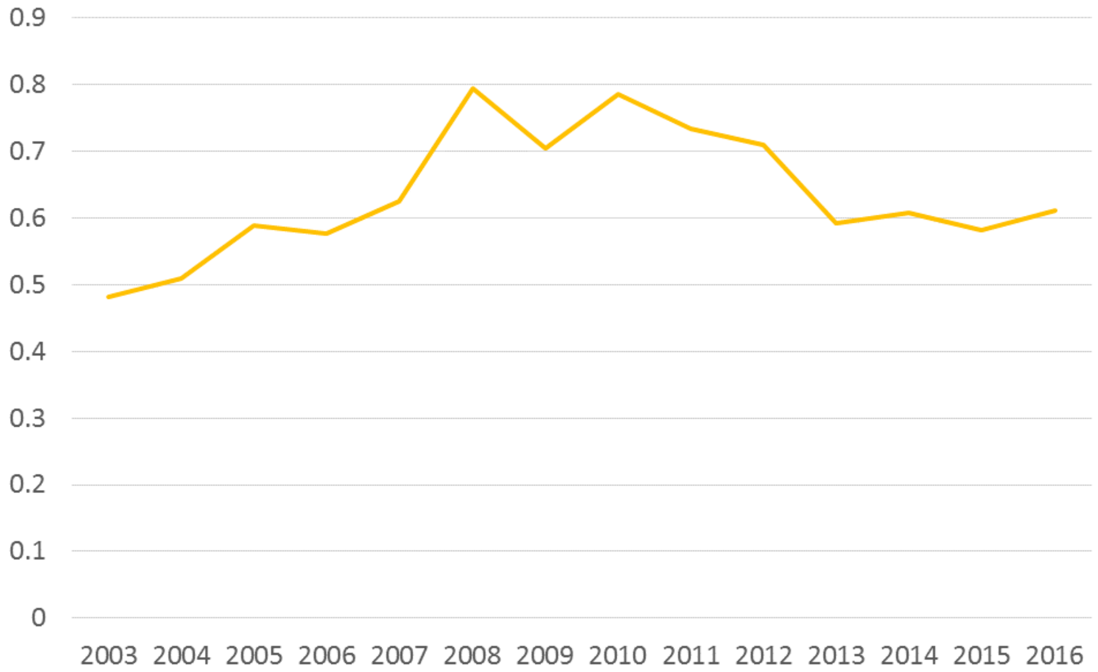

Figure 107: Real first-wholesale to total catch unit value in the Eastern Bering Sea (2016 dollars).

value-added processing in each functional group.

Implications: The economic metrics displayed here provide perspective on how the human component of the ecosystem utilizes and receives value from the fish species within the eastern Bering Sea ecosystem. Ex-vessel and first-wholesale value metrics are a measure of the ultimate value from the raw resources extracted and how humans add value to the harvest for their own uses. In contrast to the landings metrics that are heavily dominated by the pelagic forager functional group, ex-vessel and first-wholesale revenues are more evenly distributed across functional groups, which indicates the importance of the groups with lower landings and higher prices to the fishing sector.

Situations in which the value of a functional group are decreasing but catches are increasing indicate that the per-unit value of additional catch to humans is declining. This information can be useful in identifying areas where fishing effort could be reallocated across functional groups in times where the functional groups within the ecosystem might be constrained while maintaining value to the human component of the ecosystem. Monitoring the economic trends stratified by ecosystem functional group provides insight on the fishing related stresses on ecosystems and the economic factors that influence observed fishing patterns. The ultimate impact that these stresses have on the ecosystem cannot be discerned from these metrics alone and must be viewed within the context of what the ecosystem can provide.

Recreation

Saltwater Recreational Fishing Participation in the Eastern Bering Sea: Number of Anglers and Fishing Days

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Description of indicator: Federal fisheries management objectives include managing healthy ecosystems in part to provide recreational fishing opportunities. We use saltwater fishing participation to represent trends in recreational fishing in Alaska. The magnitude of recreational saltwater fishing participation is captured by (a) the days fished and (b) the number of anglers. The Alaska Department of Fish and Game (ADF&G) conducts an annual survey of anglers to collect information on participation, catch, and harvest (e.g., Jennings et al. (2015); Romberg (2016)). Annual estimates of the total number of saltwater anglers are available from 1996 to 2015. Estimates of the total number of saltwater fishing days are available from 1981 through 2015. For the purposes of this indicator, ADF&G Sport Fishing Areas A to H and J to Q correspond to the Gulf of Alaska, while Areas R-Z comprise the eastern Bering Sea (EBS) (see `http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=main.home`).

Status and trends: In the EBS, the total number of days fished has remained under 30,000, reflecting the low level of saltwater sport fishing that occurs in the region. Since the mid-1990s, there have only been two years with more than 15,000 fishing days in saltwater. In recent years, the annual fishing days has been just shy of 10,000 fishing days (Figure 108). The annual number of saltwater anglers fishing in the EBS has declined overall since the mid-1990s and is currently at about 2,000 anglers (Figure 109).

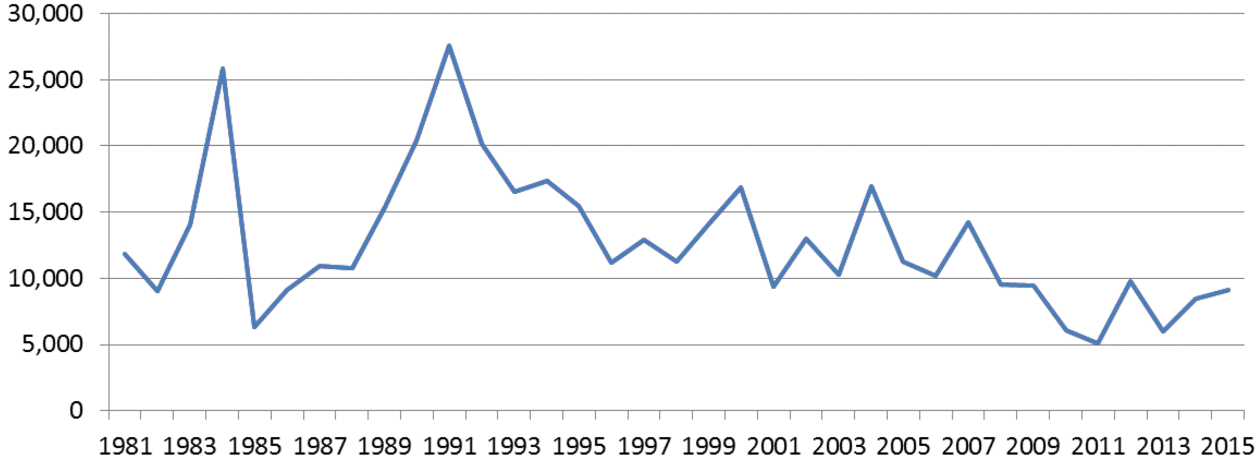

Figure 108: The total number of days fished in saltwater in the eastern Bering Sea.

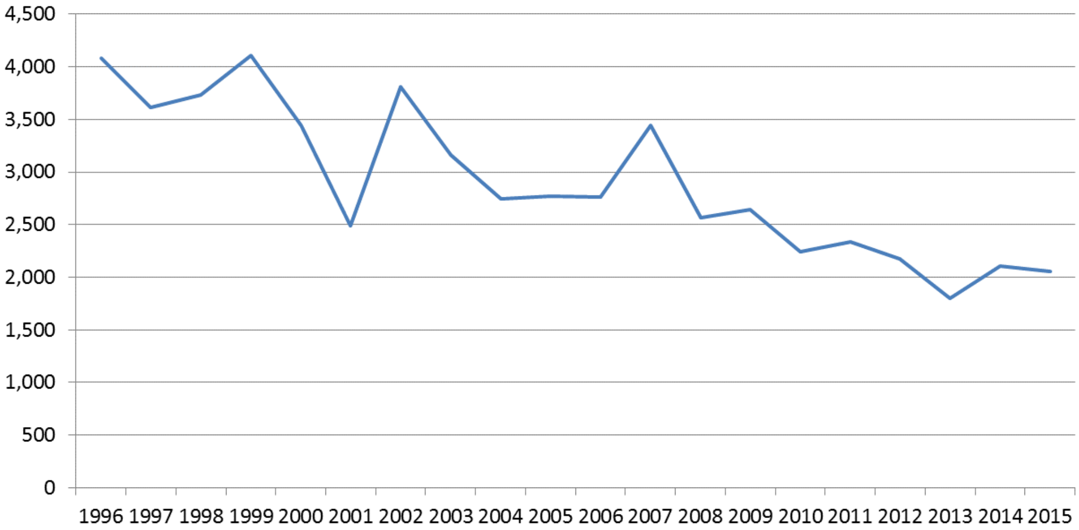

Figure 109: The number of saltwater anglers in the eastern Bering Sea.

Factors influencing observed trends: The amount of saltwater recreational fishing occurring in the EBS is a small fraction of the amount in the Gulf of Alaska, in large part due to the remoteness of the EBS fishing locations and absence of large population centers. The difficulty in accessing fishing locations in the EBS for non-resident anglers means few non-residents fish in the region. The lower resident population sizes of EBS communities result in relatively low numbers of resident anglers as well.

Beyond geographic constraints, saltwater recreational fishing participation in Alaska generally is influenced by a number of factors, including fishing regulations for target species, social and economic factors affecting the angler and the angler's household, and expected fishing conditions (e.g., stock size, timing and size of runs, weather, etc.). Pacific halibut (*Hippoglossus stenolepis*) and Pacific salmon (*Oncorhynchus* spp.) are the most common target species, with other species less frequently being the principal target but being caught on trips targeting halibut or salmon. Fishing regulations for these fish influence decisions about whether or not to fish, where to fish, what species to fish for, and by what means to fish (e.g., unguided or guided fishing).

Fishing regulations in the Pacific halibut sport fishery were first established in 1973, but have changed significantly over the years in the EBS (Meyer, 2010). Beginning in 2014, Southcentral Alaska charter boat anglers, which includes those in Bristol Bay and the Alaska Peninsula, began facing charter-specific bag and size limit and other restrictions (see `https://alaskafisheries.noaa.gov/fisheries/2c-3a-halibut-regs`). Under the Halibut Catch Sharing Plan (CSP), which went into effect during 2014, the management tools used to regulate harvest of Pacific halibut in the recreational sport sector are evaluated annually (79 Federal Register 13906).

ADF&G manages Pacific salmon in Alaska primarily through a policy that involves maintaining spawning habitats and ensuring escapement levels through area closures (Heard, 2009). Allocation between the commercial and recreation sectors is set by the Alaska Board of Fish and can have a profound influence on observed trends.

Macroeconomic factors, such as economy-wide recessions, likely affect participation patterns in saltwater fishing in Alaska, though national-level factors are less likely to impact recreational fishing levels in the EBS due to the low number of non-resident anglers. Instead, the declining trend in the numbers of anglers since the mid-1990s may be related to demographic trends in communities in the EBS, such as the net out-migration of EBS residents in the last decade. The increase in the number of anglers and the number of fishing days in recent years (2013–2015) may be a consequence of households in the EBS turning to saltwater recreational fishing as a secondary food source as the state economy has been in a recession (ADLWD, 2017*a*). While conditions in the (primarily state and local) economy are likely to explain some of the observed trends, the statistics generally reflect micro-level decisions made by individual anglers (e.g., Lew and Larson (2011, 2012, 2015)).

Implications: Monitoring the number of saltwater anglers and fishing days provides a general measure of fishing effort and participation in the saltwater sport fishery and can reflect changes in ecosystem conditions, target stock status, management, economic factors, demographic trends, and other economic, social, and cultural factors. Generally, Alaska is well known for its sport fishing opportunities and draws anglers both from within and from outside Alaska. In the EBS, however, saltwater recreational fishing effort is currently low. As a result, it likely represents a trivial source of extraction for sport-caught species like Pacific halibut, Pacific salmon, and rockfish. Nevertheless, studies have indicated saltwater fishing in Alaska is valuable to anglers (e.g., Lew and Larson (2011, 2012, 2015)) and contributes to the economy by creating jobs and generating sales to fishing and non-fishing businesses and income to households (Lovell et al., 2013). Recent estimates of the annual fishing days and total saltwater anglers in the EBS suggest the number of saltwater anglers and the number of fishing days are increasing slightly. Without significant changes in the demographics of the region or the ecological, economic, management, or socio-cultural factors that are likely to influence EBS-level participation in saltwater recreational fishing, it is likely that saltwater recreational fishing will remain at, or near, recently observed levels.

Employment

Trends in Unemployment in the Eastern Bering Sea

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Last updated: October 2017

Description of indicator: Unemployment is a significant factor in the eastern Bering Sea (EBS) ecosystem as an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems research have demonstrated the importance of incorporating social variables in ecosystem management and monitoring, and unemployment reflects economic settings of a socio-ecological system (Turner et al., 2003; Ostrom, 2007). For example, variation in resource access or availability or employment opportunities may influence human migration patterns, which in turn may decrease human activity in one area of an ecosystem while increasing activity in another.

This section summarizes trends in unemployment rates over time in the EBS. This includes the Lake and Peninsula (facing the Bering Sea), Bristol Bay, Dillingham, and Bethel Borough communities located below 60° latitude. The 34 EBS fishing communities included in analysis comprise most of the population that resides along the coast. Communities were included if they are within 25 miles of the coast, and/or based on their historical involvement in Bering Sea fisheries, or if they were included in one of the North Pacific Fishery Management Council's Bering Sea fishery programs, such as the Community Quota Entity program. Unemployment data were aggregated and weighted to account for varying community populations across Alaska Boroughs. Estimates are presented annually from 1990–2017 (ADLWD, 2017*b*). Population was calculated by summing community level data at decadal scales from 1890–1990 (DCCED, 2016) and annually from 1990–2015 (ADLWD, 2017*b*).

Status and trends: Unemployment rates in the EBS from 1990 to 2016 were lower than state and national rates (Figures 110 and 111). The unemployment rate in the EBS was lowest in 1990 (1.6%) and highest in 2014 (3.6%), with an increase of 105.6% between 1990 and 2015. The unemployment peaks of 1996, 2003, and 2010 reflect state trends yet the EBS had the second lowest unemployment rate (central Aleutian Islands had the lowest) of all regions. The unemployment rate in EBS communities decreased from 3.29% in 2015 to 3.16% in 2016.

Factors influencing observed trends: Alaska has experienced several boom and bust economic cycles. Peaks in employment occurred during the construction of the Alaska pipeline in the 1970s and oil boom of the 1980s, whereas unemployment peaks occurred following completion of the pipeline, during the oil bust of the late 1980s, and during the great recession of 2007–2009 (ADLWD, 2016*b*). However, during the great recession, Alaska's employment decreased only 0.4% whereas the national drop was 4.3% partly because of the jobs provided by the oil industry (ADLWD, 2016*a*). The EBS area had the second lowest unemployment rates between 1990 and 2015 (Figures 110 and 111). Many communities in the region rely upon seasonal fisheries and construction opportunities for employment, and individuals seek these types of employment in Dillingham (Himes-Cornell et al., 2013).

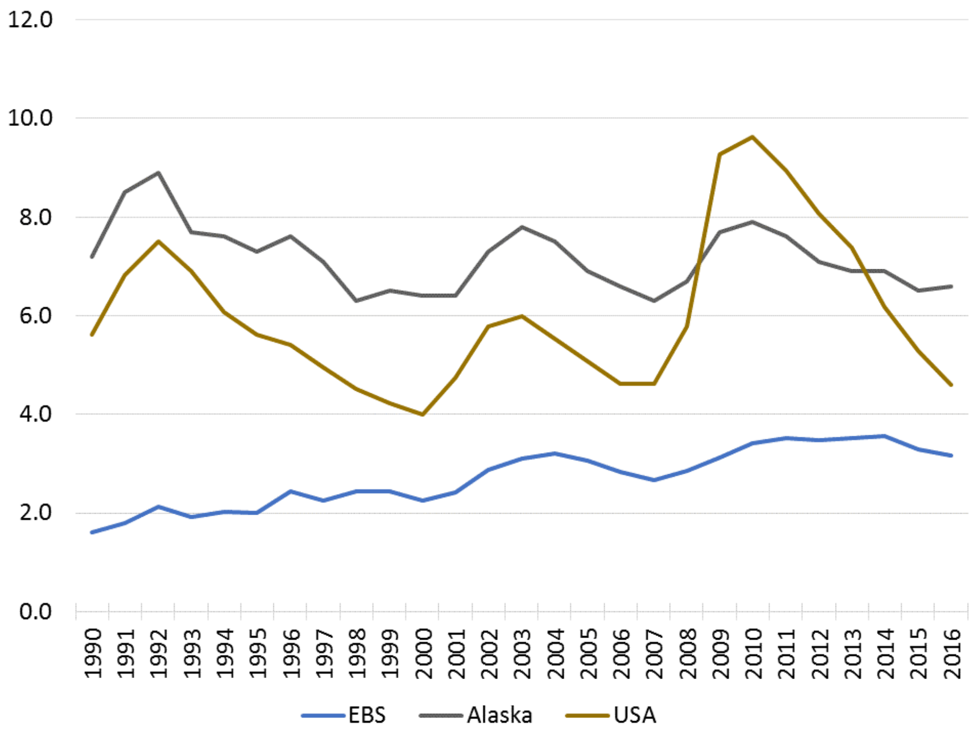

Figure 110: Unemployment rates for the eastern Bering Sea, Alaska, and USA.

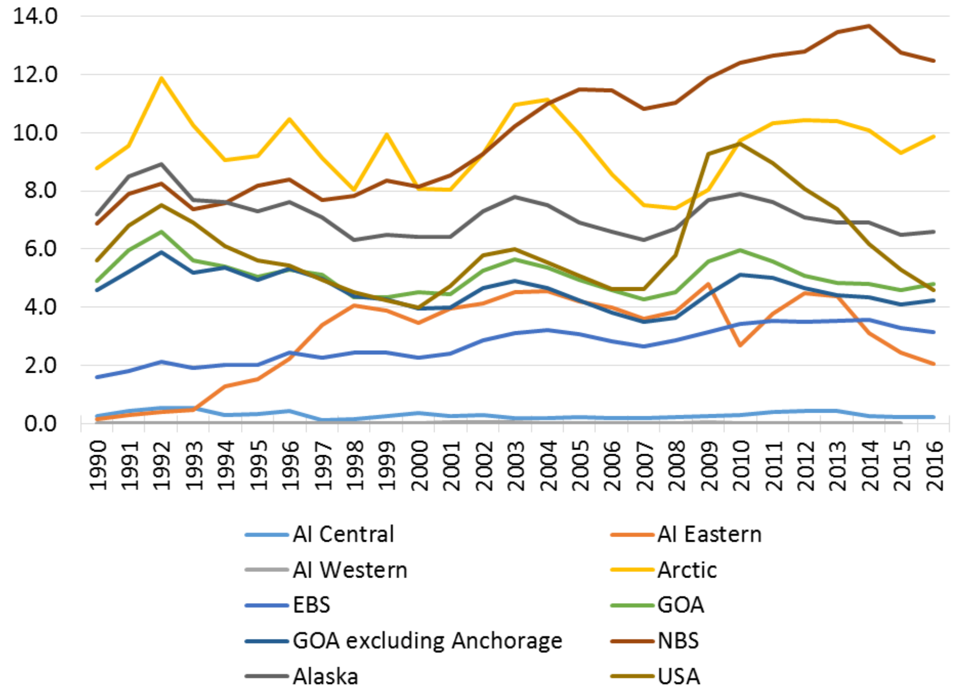

Figure 111: Unemployment rates for all regions, Alaska, and USA.

Implications: Fisheries contribute to community vitality of the EBS and reduced fishing opportunities and employment may lead to out-migration and population decline, particularly in small communities with few job alternatives (Donkersloot and Carothers, 2016). Changes in groundfish policy and management may have implications for small communities and those of the Bering Sea Community Quota Entities. Also, with a large proportion of the EBS population being Native Alaskans, resource managers may benefit from working with communities holding traditional ecological knowledge (TEK) to incorporate TEK into ecosystem management (Huntington et al., 2004).

Trends in Unemployment in the Northern Bering Sea

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Description of indicator: Unemployment is a significant factor in the northern Bering Sea (NBS) ecosystem as an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems research have demonstrated the importance of incorporating social variables in ecosystem management and monitoring, and unemployment reflects economic settings of a socio-ecological system (Turner et al., 2003; Ostrom, 2007). For example, variation in resource access or availability or employment opportunities may influence human migration patterns, which in turn may decrease human activity in one area of an ecosystem while increasing activity in another.

This section summarizes trends in unemployment rates over time in the NBS. This includes communities of the Bethel Borough located north of 60° latitude and those of the Kusilvak and Nome Boroughs. The 58 NBS fishing communities included in analysis comprise most of the population that resides along the coast. Communities were included if they are within 25 miles of the coast, and/or based on their historical involvement in Bering Sea fisheries, or if they were included in one of the North Pacific Fishery Management Council's Bering Sea fishery programs, such as the Community Quota Entity program. Unemployment data were aggregated and weighted to account for varying community populations across Alaska Boroughs. Estimates are presented annually from 1990–2017 (ADLWD, 2017*b*). Population was calculated by summing community level data at decadal scales from 1890–1990 (DCCED, 2016) and annually from 1990–2015 (ADLWD, 2017*b*).

Status and trends: Unemployment rates in the NBS from 1990 to 2016 were higher than state and national rates (Figures 112 and 111). The unemployment rate in the NBS was lowest in 1990 (6.9%) and highest in 2014 (13.7%), an increase of 85.3% between 1990 and 2015. The unemployment peaks during the 1990s and early 2000s reflect state trends yet the unemployment rate of the NBS continued to increase despite state and national decline after 2010. Only the Arctic region had periods of higher unemployment than the NBS until the year 2000, and between 2002 and 2004. The unemployment rate in NBS communities decreased from 12.77% in 2015 to 12.48% in 2016.

Factors influencing observed trends: Alaska has experienced several boom and bust economic cycles. Peaks in employment occurred during the construction of the Alaska pipeline in the 1970s

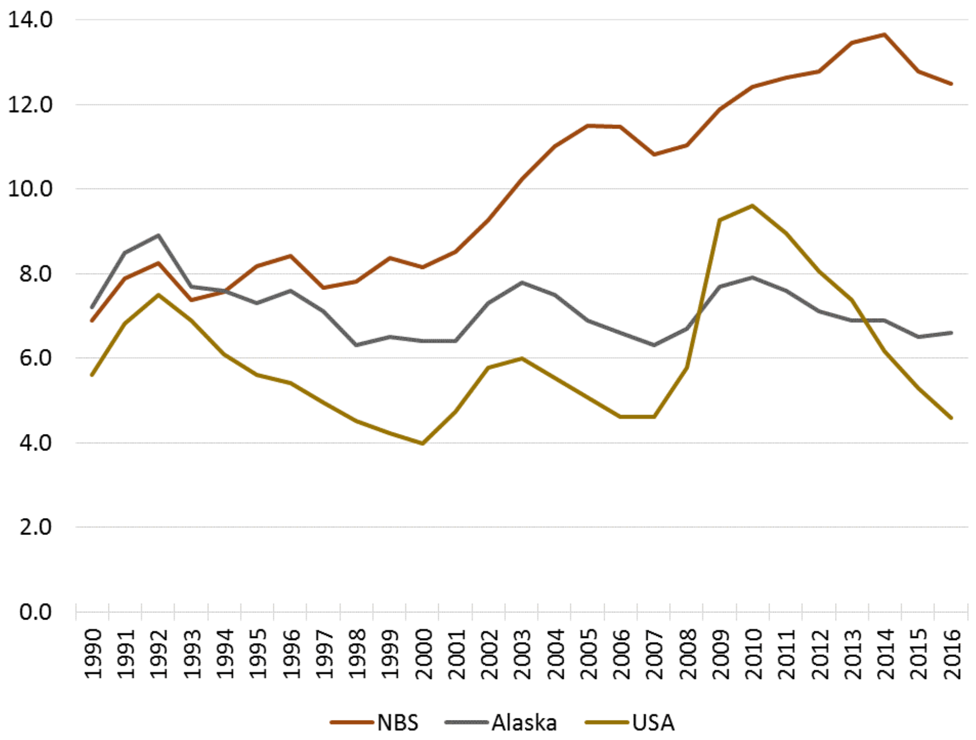

Figure 112: Unemployment rates for the northern Bering Sea, Alaska, and USA.

and oil boom of the 1980s, whereas unemployment peaks occurred following completion of the pipeline, during the oil bust of the late 1980s, and during the great recession of 2007–2009 (ADLWD, 2016*b*). However, during the great recession, Alaska's employment decreased only 0.4% whereas the national drop was 4.3% partly because of the jobs provided by the oil industry (ADLWD, 2016*a*). The NBS area had the highest unemployment rates between 2004 and 2015 (Figures 112 and 111). Communities in the region rely mainly upon seasonal employment and subsistence activity year-round employment opportunities are sparse (Himes-Cornell et al., 2013).

Implications: The communities of the NBS are relatively stable in terms of population maintenance, however, secure employment is lacking in the region and unemployment rates are high. Changes in groundfish policy and management may have implications for small communities and those of the Bering Sea Community Quota Entities. Also, with a large proportion of the NBS population being Native Alaskans, resource managers may benefit from working with communities holding traditional ecological knowledge (TEK) to incorporate TEK into ecosystem management (Huntington et al., 2004).

Socio-Cultural Dimensions

Trends in Human Population in the Eastern Bering Sea

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Description of indicator: Human population is a significant factor in the eastern Bering Sea (EBS) ecosystem, as many communities in the region rely upon fisheries to support their economies and to meet subsistence and cultural needs. As with areas neighboring the Arctic, population is an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems (SES) research have demonstrated the importance of incorporating social variables in ecosystem management and monitoring (Turner et al., 2003; Ostrom, 2007). For example, variation in resource access or availability or employment opportunities may influence human migration patterns, which in turn may decrease human activity in one area of an ecosystem while increasing activity in another.

This section summarizes trends in human population over time in the EBS. This includes the Lake and Peninsula (facing the Bering Sea), Bristol Bay, Dillingham, and Bethel Borough communities located below 60° latitude. The 34 EBS fishing communities included in analysis comprise most of the population that resides along the coast. Communities were included if they are within 25 miles of the coast, and/or based on their historical involvement in Bering Sea fisheries, or if they were included in one of the North Pacific Fishery Management Council's Bering Sea fishery programs, such as the Community Quota Entity program. Population was calculated by summing community level data at decadal scales from 1890–1990 (DCCED, 2016) and annually from 1990–2016 (ADLWD, 2017*b*).

Status and trends: As of 2016 the population of all EBS communities was 10,150 and the population of small communities (population less than 1,500) was 7,834. This figure excludes the population of Dillingham. The overall population has increased steadily since 1880 with the greatest population increase of 44.2% occurring between 1950 and 1960 (Table 12 and Figure 113). This is consistent with Alaska state trends as population change peaked during these periods (over 75% by 1960 and 36.9% by 1990). Population increase leveled off after 1990 with lower rates in the following decades in the EBS and Alaska state.

Between 1990 and 2016, the population of EBS increased 8.7% which was lower than state trends during this time period (34.5%). The population of the EBS has remained relatively stable (based on aggregated data), yet 41% of communities in the EBS experienced population decline between 1990 and 2016. For example, Portage Creek had a documented population of 5 in 1990, it increased to 45 in 2003 and was reduced to 1 in 2016 (an 80% decrease between 1990 and 2016). Nelson Lagoon, King Salmon, South Naknek, St. Paul, and St. George also experienced population declines ranging from 47.8% to 59.0% during this time period. Conversely, Port Alsworth had the greatest population increase over this time period (296%).

Many EBS communities are small and/or remote and Indigenous Americans comprise up to 82% of the population of small communities in remote areas and more Native Americans reside in Alaska

Table 12: Eastern Bering Sea (EBS) population 1880–2016. Percent change rates are decadal until 2010.

Year	Alaska	% change	EBS	% change
1880	33,426		1,504	
1890	32,052	-4.11	1,022	-32.05
1900	63,592	98.4	1,203	17.71
1910	64,356	1.2	688	-42.81
1920	55,036	-14.48	1,279	85.9
1930	59,278	7.71	1,369	7.04
1940	72,524	22.35	2,292	67.42
1950	128,643	77.38	3,212	40.14
1960	226,167	75.81	4,633	44.24
1970	302,583	33.79	5,445	17.53
1980	401,851	32.81	7,428	36.42
1990	550,043	36.88	9,339	25.73
2000	626,932	13.98	10,383	11.18
2010	710,231	13.29	10,025	-3.45
2016	739,828	4.17	10,150	3.72

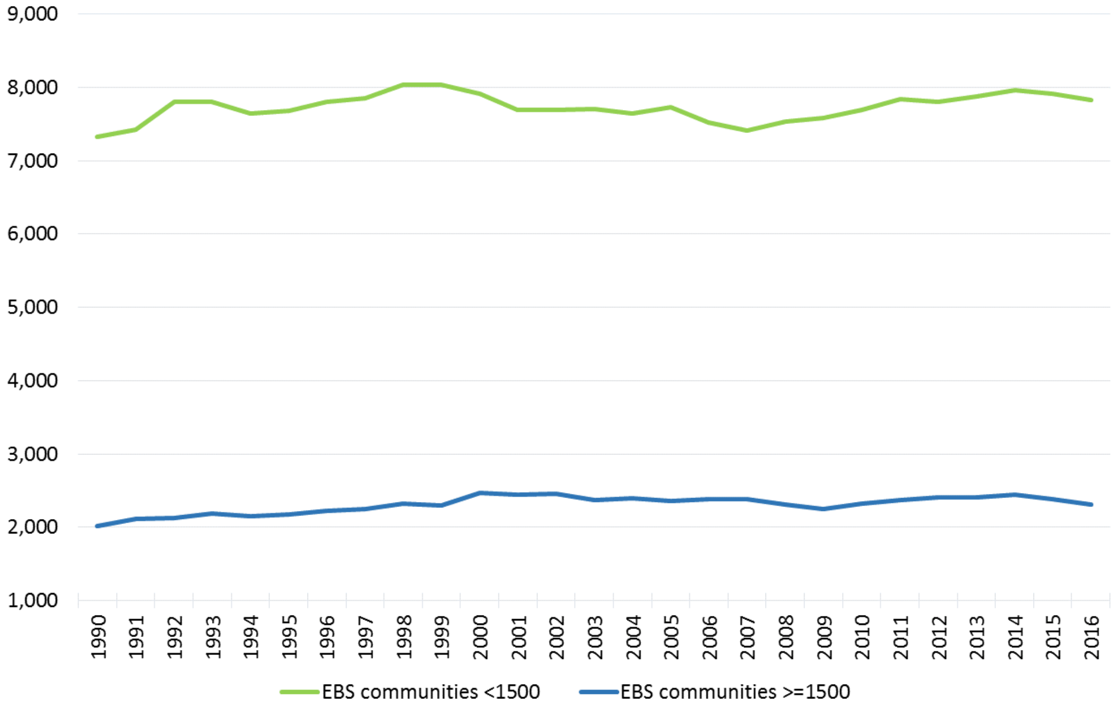

Figure 113: Eastern Bering Sea population 1990–2016.

than any other U.S. state (Goldsmith et al., 2004). As of 2014, 15% of Alaska's population was Alaska Native or American Indian (ADLWD, 2016*c*) and as of 2015, 75.7% of the population in the EBS identified as Native American alone or in combination with another race (DCCED, 2016). In addition, there has been increased migration of Alaska Natives from rural to urban areas (Goldsmith et al., 2004; Williams, 2004). The majority of population growth that has occurred in Alaska is of the Caucasian demographic (ADLWD, 2016*c*).

Factors influencing observed trends: Overall population increase in the EBS between 1990 and 2016 (8.7%) was consistent with, yet much lower than, state trends (34.5%). The much lower increase in the EBS is because population growth is highest in urban areas, such as Anchorage, where 40% of Alaska's population currently resides (ADLWD, 2016*c*, 2017*b*). Alaska has high rates of population turnover because of migration (ADLWD, 2016*c*). The main factors that affect population growth are natural increase (births minus deaths) and migration, with the latter being the most unpredictable aspect of population change (Williams, 2004; ADLWD, 2016*c*). In 2010, 61% of Alaska's population was born out of state (Rasmussen et al., 2015). In terms of natural growth, from 2010 to 2014 the average annual birth rate in Alaska was 1.6 per 100 people which was higher than the national rate of 1.3 (ADLWD, 2016*c*). From 2010–2014 the Aleutian chain and Southeast Alaska had the lowest natural increase (0.0–1.0%) whereas the northern Bering Sea area had the highest (1.5–3.0%), and the estimated natural growth rate of the EBS had a range of 0.5–3.0% (ADLWD, 2016*c*). The net annual migration of the EBS was very low (<0) since the region has among the lowest migration rates in the state (Williams, 2004; ADLWD, 2016*c*). The GOA region has the highest net migration in the state and the Matanuska-Susitna Borough has the highest growth rate (ADLWD, 2016*c*).

Population trends in Alaska are largely the result of changes in resource extraction and military activity (Williams, 2004). Historically, the gold rush of the late 19th century doubled the state's population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD, 2016*c*). The population of some communities declined in the 1990s because of Coast Guard cut-backs and military base closures (Williams, 2006). The fishing industry also influences community population. Kodiak and the Aleutian Islands have the most transient populations because of the seafood processing industry (Williams, 2004). Some EBS communities experienced fishery permit loss because of population decline, such as South Naknek, and factors that influence population shifts/migration include employment, retirement, educational choices, cost of living, climate, and quality of life (Donkersloot and Carothers, 2016).

Implications: Population shifts can affect pressures on fisheries resources, however inferences about human impacts on resources should account for economic shifts and global market demand for seafood and other extractive resources of the ecoregion. Population change in Alaska is largely fueled by increased net migration rather than natural increase, and there has been increased migration from rural to urban areas; this is evident with population decline of many small communities. Fisheries contribute to community vitality of the EBS and reduced fishing opportunities and employment may lead to out-migration and population decline, particularly in small communities with few job alternatives (Donkersloot and Carothers, 2016). Changes in groundfish policy and management may have implications for small communities and those of the Bering Sea Community Quota Entities. Also, with a large proportion of the EBS population being Native Alaskans, resource managers may benefit from working with communities holding traditional ecological knowledge (TEK) to incorporate TEK into ecosystem management (Huntington et al., 2004).

Trends in Human Population in the Northern Bering Sea

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Last updated: October 2017

Description of indicator: Human population is a significant factor in the northern Bering Sea (NBS) ecosystem, as many communities in the region rely upon fisheries to support their economies and to meet subsistence and cultural needs. As with areas neighboring the Arctic, population is an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems (SES) research have demonstrated the importance of incorporating social variables in ecosystem management and monitoring (Turner et al., 2003; Ostrom, 2007). For example, variation in resource access or availability or employment opportunities may influence human migration patterns, which in turn may decrease human activity in one area of an ecosystem while increasing activity in another.

This section summarizes trends in human population over time in the NBS. This includes communities of the Bethel Borough located north of 60° latitude and those of the Kusilvak and Nome Boroughs. The 58 NBS fishing communities included in analysis comprise most of the population that resides along the coast. Communities were included if they are within 25 miles of the coast, and/or based on their historical involvement in Bering Sea fisheries, or if they were included in one of the North Pacific Fishery Management Council's Bering Sea fishery programs, such as the Community Quota Entity program. Population was calculated by summing community level data at decadal scales from 1890–1990 (DCCED, 2016) and annually from 1990–2015 (ADLWD, 2017*b*).

Status and trends: As of 2016 the population of all NBS communities was 33,780 and the population of small communities (population less than 1,500) was 23,759. This figure excludes the populations of Bethel and Nome. The overall population increased steadily since 1880 with the greatest population increase occurring between 1890 and 1900 (901.1%) and later between 1950 and 1960 (47.6%) (Table 13 and Figure 114). The latter increase is consistent with Alaska state trends as population increased by over 75% between 1950 and 1960. Population increase leveled off after 1990 with lower rates in the following decades in the NBS and Alaska state.

Between 1990 and 2016, the population of the NBS increased 29.1% which was lower than state trends during this time period (34.5%). The population of communities in the NBS has remained relatively stable. Only 21% of all NBS communities experienced population decline between 1990 and 2016. Many NBS communities are small and/or remote and of the smaller communities, Brevig Mission had the highest population increase of 111% during this time period. Diomede, Shageluk, and Holy Cross had the largest decreases in their populations during this time period (50.6%, 44.6%, and 44.0% respectively). The population trend between 1990 and 2016 for smaller communities was consistent with the overall population for the region. The greatest population increases occurred in 1900 (301.9%) and 1960 (49.9%).

Indigenous Americans comprise up to 82% of the population of small communities in remote areas and more Native Americans reside in Alaska than any other U.S. state (Goldsmith et al., 2004). As of 2014, 15% of Alaska's population was Alaska Native or American Indian (ADLWD, 2016*c*) and as of 2015, 90.2% of the population in the NBS identified as Native American alone or in combination

Table 13: Northern Bering Sea (NBS) population 1880–2016. Percent change rates are decadal until 2010.

Year	Alaska	% change	NBS	% change
1880	33,426		3,270	
1890	32,052	-4.11	2,043	-37.52
1900	63,592	98.4	20,453	901.13
1910	64,356	1.2	5,201	-74.57
1920	55,036	-14.48	4,669	-10.23
1930	59,278	7.71	5,688	21.82
1940	72,524	22.35	7,777	36.73
1950	128,643	77.38	9,490	22.03
1960	226,167	75.81	14,010	47.63
1970	302,583	33.79	16,569	18.27
1980	401,851	32.81	20,845	25.81
1990	550,043	36.88	26,157	25.48
2000	626,932	13.98	30,219	15.53
2010	710,231	13.29	31,600	4.57
2016	739,828	4.17	33,780	8.63

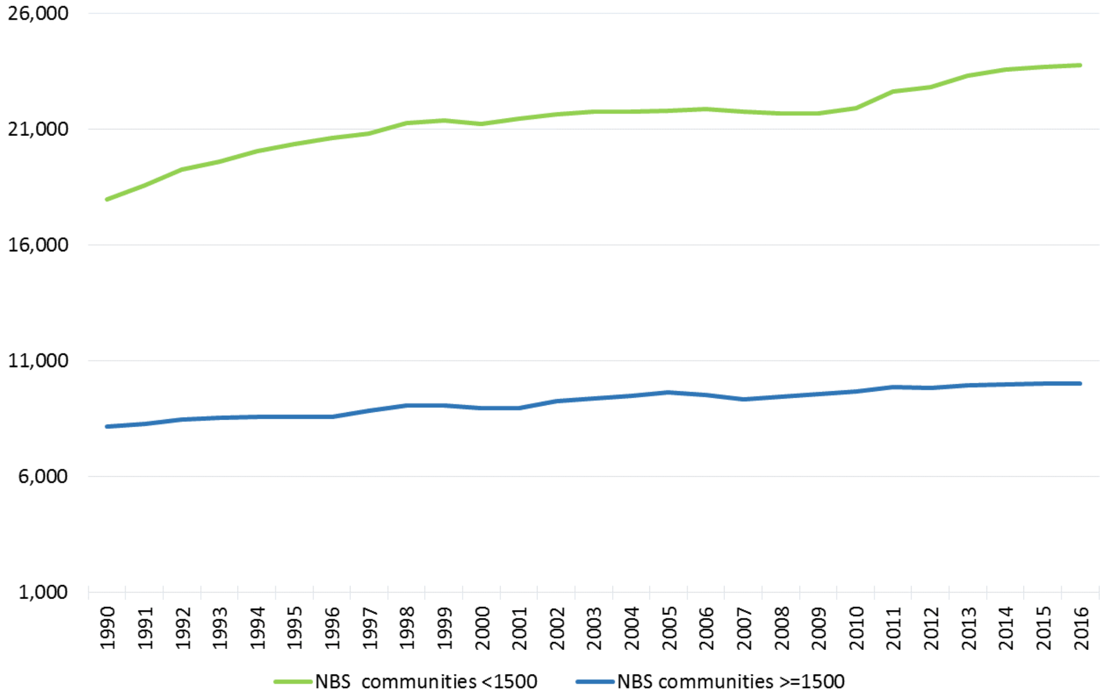

Figure 114: Northern Bering Sea population.

with another race (DCCED, 2016). There has been increased migration of Alaska Natives from rural to urban areas (Goldsmith et al., 2004; Williams, 2004). The majority of population growth that has occurred in Alaska is of the Caucasian demographic (ADLWD, 2016*c*).

Factors influencing observed trends: Overall population increase in the NBS between 1990 and 2015 (29.1%) was consistent with, yet lower than, state trends (34.5%). Alaska has high rates of population turnover because of migration, and population growth has occurred mainly in urban areas (ADLWD, 2016*c*). The main factors that affect population growth are natural increase (births minus deaths) and migration, with the latter being the most unpredictable aspect of population change (Williams, 2004; ADLWD, 2016*c*). In 2010, 61% of Alaska's population was born out of state (Rasmussen et al., 2015). In terms of natural growth, from 2010 to 2014 the average annual birth rate in Alaska was 1.6 per 100 people which was higher than the national rate of 1.3 (ADLWD, 2016*c*). From 2010–2014 the Aleutian chain and Southeast Alaska had the lowest natural increase (0.0–1.0%) whereas the NBS area had the highest (1.5–3.0%). The Kusilvak census area had the highest birth rate of 3 births per 100 people (ADLWD, 2016*c*). The net annual migration of the NBS was very low (<0) since the region has among the lowest migration rates in the state (Williams, 2004; ADLWD, 2016*c*). The GOA region has the highest net migration in the state and the Matanuska-Susitna Borough has the highest growth rate (ADLWD, 2016*c*). There was low migration related population increase in the NBS because growth occurs highest in urban areas, such as Anchorage, where 40% of Alaska's population currently resides (ADLWD, 2016*c*, 2017*b*). However, the NBS area has steadily increased in population with higher than national level birth rates and net migration of less than zero (ADLWD, 2016*c*).

Population trends in Alaska are largely the result of changes in resource extraction and military activity (Williams, 2004). Historically, the gold rush of the late 19th century doubled the state's population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD, 2016*c*). The NBS high population increase of 1900 occurred in Nome because of the gold rush, making the town the largest in Alaska at that time. However, the population of some communities declined later in the 1990s because of Coast Guard cut-backs and military base closures (Williams, 2006). The fishing industry also influences community population. Kodiak and the Aleutian Islands have the most transient populations because of the seafood processing industry (Williams, 2004). Factors that influence population shifts/migration include employment, retirement, educational choices, cost of living, climate, and quality of life (Donkersloot and Carothers, 2016).

Implications: Population shifts can affect pressures on fisheries resources, however inferences about human impacts on resources should account for economic shifts and global market demand for seafood and other extractive resources of the ecoregion. Population change in Alaska is largely fueled by increased net migration rather than natural increase, and there has been increased migration from rural to urban areas. The communities of NBS are relatively stable in terms of population maintenance, however, secure employment is lacking in the region and unemployment rates are high. Fisheries contribute to community vitality and efforts could be made to better engage NBS in fisheries. Changes in groundfish policy and management may have implications for small communities and those of the Bering Sea Community Quota Entities. Also, with a large proportion of the NBS population being Native Alaskans, resource managers may benefit from working with communities holding traditional ecological knowledge (TEK) to incorporate TEK into ecosystem management (Huntington et al., 2004).

Trends in School Enrollment in Coastal Communities in the Eastern Bering Sea

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Last updated: August 2017

Description of indicator: Ensuring the productivity and sustainability of fishing communities is a core mandate of Federal fisheries management. One indicator to evaluate community vitality is K–12 public school enrollment. Enrollment trends are of particular relevant due to the value of schools to community cohesion and identity.

Public school enrollment was analyzed in the eastern Bering Sea (EBS) by borough and community level in order to examine broader regional trends as well as the social and economic vitality of individual rural communities. Enrollment statistics for K–12 grades by school and region were compiled for the years 1996–2014 from The National Center for Educational Statistics (`https://nces.ed.gov/ccd/elsi/tableGenerator.aspx`). More recent enrollment data were available for years 2014–2017 from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`). Current school locations and names were verified using the EPA EJ mapping tool (`https://ejscreen.epa.gov/mapper/`).

Status and trends: In the EBS region, school enrollment numbers have fluctuated widely since 1996, highlighting the difficulties in maintaining sustainable communities within the rural coastal Alaskan ecosystem. There has been a general trend toward decreasing school enrollment in most boroughs. Most notable, small rural communities appear to be experiencing reduced enrollments, with several community schools closing since 2005. Many areas have school closures including South Naknak, Portage Creek, Pedro Bay, Clark's Point, Ekwok, and Egegik (Figure 115).

Within the Aleutians West census area of the EBS, school enrollment has decreased substantially with one school closure in Nelson Lagoon in 2013. Both St. George and St. Paul City in the Pribilof Islands are experiencing dramatic declines. Enrollment in St. George City decreased from 48 students in 1996 to 6 students in 2017, a drop of 88%. During the same time period, St. Paul City's enrollment reduced from 152 students to 53 or 65% (Figure 116). Other rural communities had similar declines: Naknak CDP is down 65%, Nondalton City is down 63%, and Pilot Point has reduced enrollment by 56%.

Certain boroughs experienced increased enrollment since 1996. The Bethel census area shows a slight increase in enrollment in most area schools. Enrollment in Quinhagak City and Kongiganak CDP increased considerably (64% and 86%, respectively), suggesting a surge in population driving the increased enrollment (Figure 117).

Factors influencing observed trends: The EBS ecosystem varies substantially in population and community structure and vitality. The EBS is a large and diverse area with many small rural communities. High dependence on natural resources may drive population shifts according to season and availability. As people migrate to other areas, populations increase in adjacent communities. It is possible that enrollment may shift to the larger communities as more convenient schools open.

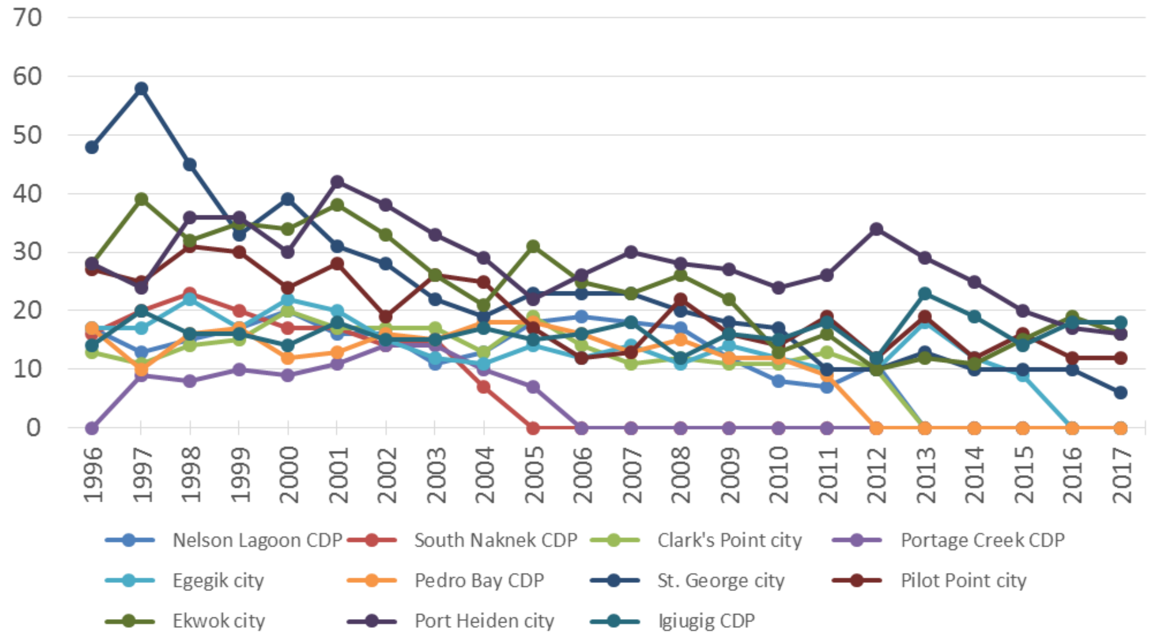

Figure 115: Eastern Bering Sea communities with enrollment under 20 students.

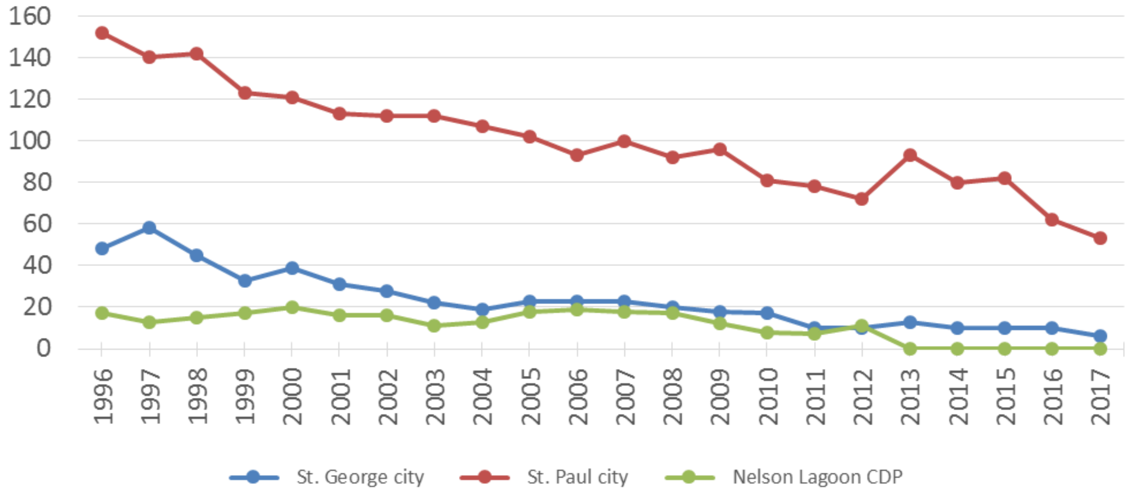

Figure 116: Aleutians West census area school enrollment (eastern Bering Sea).

However, other factors must be considered including existing infrastructure such as functional ports, airports, or medical facilities to provide support for a viable community structure. Those schools with under 30 students enrolled experience the greatest uncertainty in terms of educational stability.

As of 2017, 10 schools have enrollment under 30 students, and three schools have under 15 students. With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and possible community disruption. The reasons for decreasing enrollment likely involve

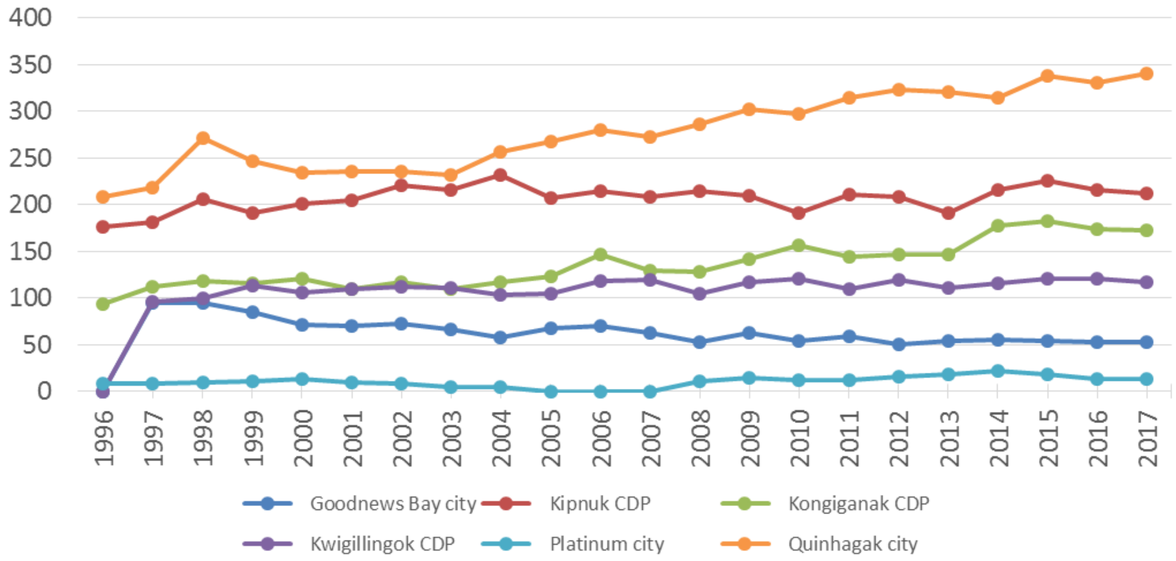

Figure 117: Bethel census area school enrollment (eastern Bering Sea).

complex social and economic drivers including migratory patterns, resource availability, and employment. Additional research into the specific reasons for diminishing school enrollment in rural areas, as well as the impacts on these communities would inform and benefit management decisions.

Implications: Community residents are closely tied to the ecosystem through sense of place and daily experience and activity. Schools are cultural centers and serve as important indicators of social and economic viability, and community well-being (Lyson, 2002, 2005). Within rural communities, in particular, schools are valuable symbols for community identity, autonomy, and shared social values (Peshkin, 1978, 1982; Lyson, 2005). Research indicates that school closures negatively affect communities (Buzzard, 2016). Patterns of diminishing enrollment and school consolidation suggest a decrease in property values and taxes, fragmented community, and lost business, as well as declines in scores that reflect quality of life (Sell and Leistritz, 1997; Lyson, 2002). Some research finds the rate of participation in community organizations decreases in communities experiencing school closures (Oncescu and Giles, 2014; Sell and Leistritz, 1997). These finding suggests that reduced enrollments and school closures may flag disruptions in social cohesion, possibility leading to less vibrant and sustainable communities.

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