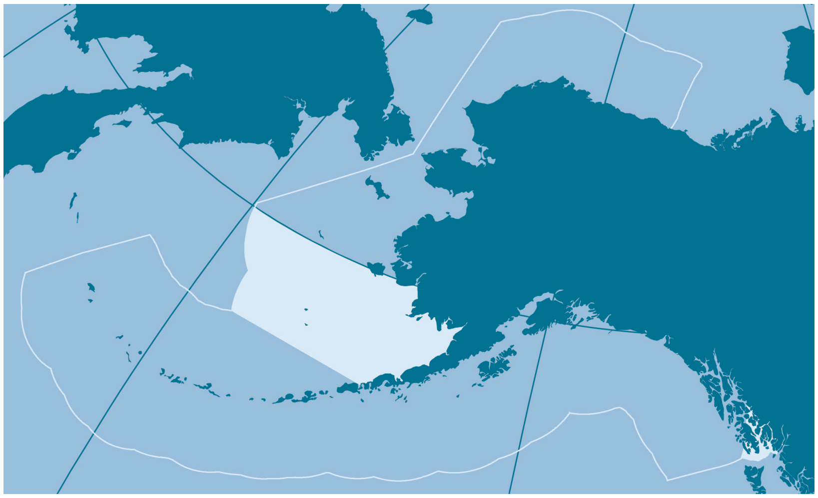
Ecosystem Considerations 2016

Status of the
Eastern Bering Sea Marine Ecosystem



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Reviewed by:
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Bering Sea, Aleutian Islands, and Gulf of Alaska

November 14, 2016
North Pacific Fishery Management Council
605 W. 4th Avenue, Suite 306
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Eastern Bering Sea 2016 Report Card

- The **eastern Bering Sea in 2016 was characterized by warm conditions** that began in late 2013. The **PDO remained positive** with **neutral to weak La Niña conditions predicted for the winter of 2016-17**.
- The extent of **sea ice during winter and spring continued to be reduced** and the **cold pool was retracted over the northern shelf**.
- Zooplankton Rapid Assessments in spring and fall 2016 show **euphausiids were rare over the EBS shelf** and acoustic estimates of euphausiids from the summer trawl survey have **declined since 2009 with 2016 being the lowest in the time series**.
- **Jellyfish abundances** (principally *Chrysaora melanaster*) **declined 79% from 2015 to 2016** to one of the lowest observed levels since 1989.
- **Survey biomass of motile epifauna has been above its long-term mean** since 2010, with no noted trend in the past 6 years. There has been a unimodal increase in **brittle stars** since 1989, with a with a particularly large **34% increase** between 2015 and 2016. Sea urchins, sea cucumbers, and sand dollars doubled between 2004-2005 and have stayed at those high levels since then.
- **Survey biomass of benthic foragers showed a dip in 2015, but have returned to near-average levels in 2016**. The decline in 2015 was due to a 25% decline in northern rock sole, which remain at lower levels in 2016 (lowest since 1990). The return of the guild to average was due to a **50% increase in yellowfin sole** between 2015 and 2016.
- **Survey biomass of pelagic foragers decreased to its 34-year mean after increasing steadily** from 2009 to 2015. While this is primarily driven by the **increase in walleye pollock** from its historical low in the 2009 survey and **dip downward in 2015-2016**, it is also a result of **fluctuations in capelin**, which increased during the cold years between 2010-2013, **then dropped back to pre-2010 levels in 2016**.
- **Fish apex predator survey biomass is currently above its 30-year mean**, although the increasing trend seen from 2009-2014 has leveled. **The increase from below average values in 2009** back towards the long term mean is driven primarily by increases in Pacific cod from low levels in the early 2000s.
- **The multivariate seabird breeding index is well below the long term mean**, indicating that seabirds bred later and less successfully in 2016. This suggests that **foraging conditions were not favorable for piscivorous seabirds**.
- **Northern fur seal pup production for St. Paul Island remained low**. Preliminary estimates show **a decrease between 10.0 and 15.0%** on St. Paul compared to the 2014 estimates.
- A **new method for estimating seafloor habitat disturbance** due to fishing gear (pelagic and non-pelagic trawl, longline, and pot) shows **interactions have decreased steadily from 2008 through December 2014**.

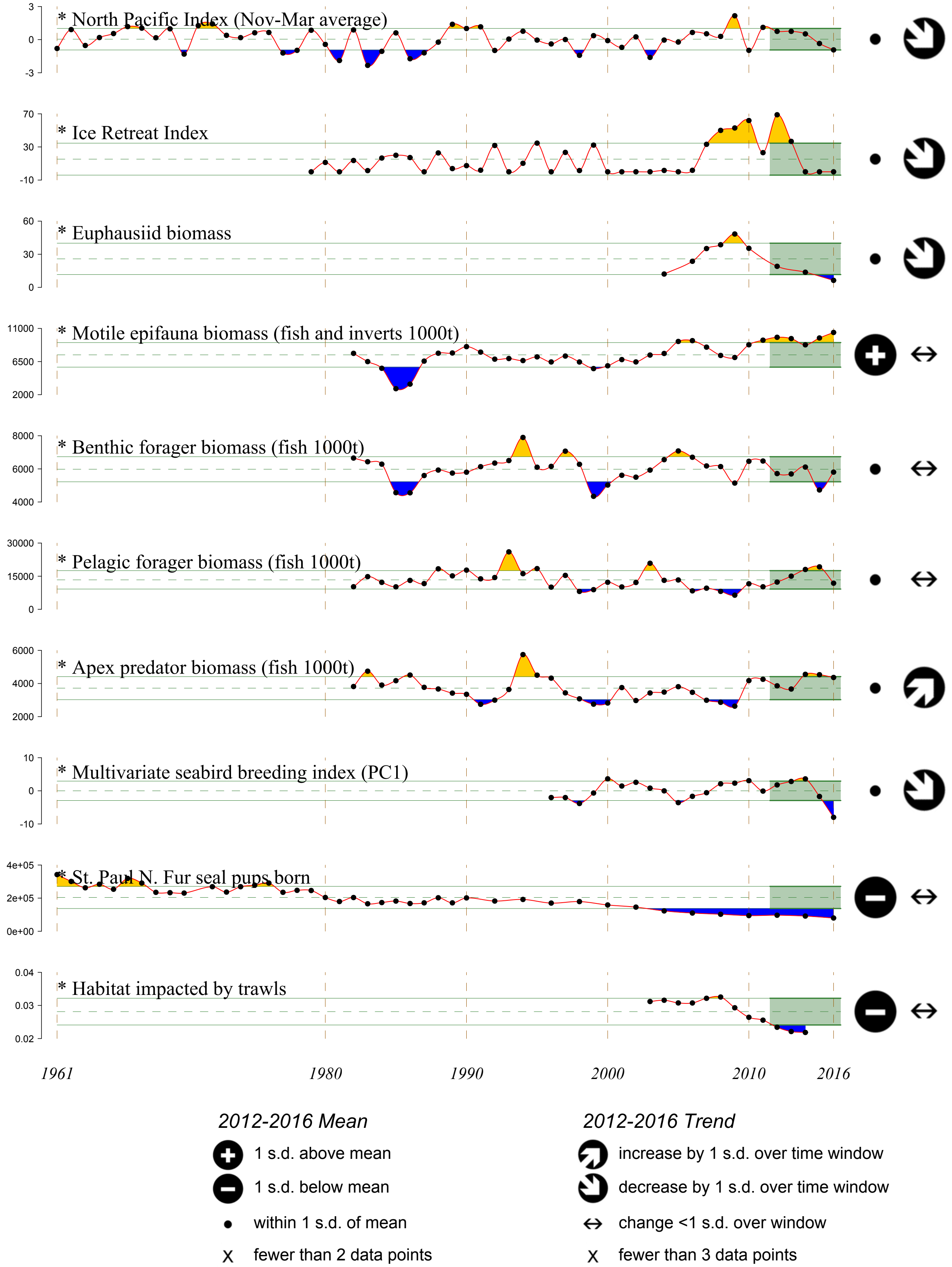

Figure 1: Eastern Bering Sea ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2016.

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 Fisheries Trends.

Physical and Environmental Trends

North Pacific Trends

- The state of the North Pacific atmosphere-ocean system during 2015-2016 featured the continuance of warm sea surface temperature anomalies that became prominent late in 2013, with some changes in the pattern (p. 48).
- A strong El Niño developed during winter 2015-2016 (p. 53)
- However, the climate models used for seasonal weather predictions are indicating borderline to weak La Niña conditions for the winter of 2016-17 (p. 55).
- The Pacific Decadal Oscillation (PDO) remained positive during the past year (p. 53).
- The North Pacific Index (NPI) was strongly negative, implying a deeper than normal Aleutian Low, which was accompanied by anomalous winds from the south and relatively warm air along the west coast of North America (p. 53).
- The North Pacific Gyre Oscillation (NPGO) transitioned from negative in 2015 to near-neutral in 2016, implying that flows in the Alaska Current portion of the Subarctic Gyre and the California Current strengthened to normal (p. 53).
- Anomalously positive sea surface temperatures are predicted throughout much of the north east Pacific during the upcoming winter. The magnitude of the anomalies is projected to be greatest in the GOA and eastern Bering Sea (p. 55).
- The North Pacific climate may be in a state of rather low predictability, yet is unlikely that the upcoming winter in Alaska will be as mild as those of the last three years (p. 55).
- Model projections of a muted atmospheric response in the mid-latitudes to the equatorial Pacific during the next two seasons could be a reflection of the enormous amount of extra heat in the upper ocean now present along most of the west coast of North America (p. 55).

Eastern Bering Sea Trends

- A warm year for 2016 followed the warm years of 2014 and 2015 in response to warm sea temperatures in the northeastern Gulf of Alaska (return of the positive Pacific Decadal Oscillation, PDO) and related higher pressures (p. 57).
- Reduced springtime sea ice extent (p. 48) and reduced summer cold pool extent continued from 2014 through 2016 (p. 57).
- Spring 2016 had the lowest sea ice cover over the Bering Sea shelf in the timeseries and the cold pool was retracted over the northern shelf (p. 57).
- Both surface and bottom temperature means for the 2016 eastern Bering Sea shelf were the highest on record in the 35 year bottom trawl survey time-series (p. 63).
- CTD data collected from EBS slope in 2012 and 2016 showed that 2016 was a much warmer year than 2012 throughout the slope, salinity was generally highest in 2016 and was fairly uniform over the slope, and oxygen concentrations were lower in 2016 than in 2012 (p. 64).
- Temperatures above the MLD were warmer than average for all regions in 2014, but only in 2 regions (Alaska Peninsula and south outer shelf) in 2015 due to fall mixing and deepening of the MLD (p. 69).
- Temperatures below the MLD were warmer than average over the southern shelf in 2014 and 2015 (p. 69).
- The 2016 springtime drift patterns on the southern Eastern Bering Sea shelf appear to be consistent with years of below-average recruitment for winter-spawning flatfish (NRS, ATF, Flathead sole) following a year of above-average recruitment (2015) (p. 72).

Ecosystem Trends

- In 2016, the relative catch rates for both sponges and sea anemones were significantly lower (p. 74).
- The abundance of corals caught in the EBS slope environment is highly variable: lowest abundance in 2012 and highest abundance in 2016. Sponge abundance was high in 2008 and 2010, significantly decreased in 2012, and increased slightly in 2016 (still below long-term mean). Sea whips had very high abundance in 2010 and 2012 with a significant drop in 2016 to slightly below long-term mean (p. 74).
- In 2016, corals were primarily distributed in the NBS with highest abundance between Zhemchug and Pribilof Canyons. Sponges were abundant and widely distributed along the EBS slope habitat. Sea whips are patchy throughout the slope habitat (p. 77).
- Between 2003-2012, phytoplankton biomass was greatest over the southern outer shelf with large phytoplankton over the inner shelf and near the Pribilof Islands and small phytoplankton over the south middle and outer shelf (p. 81).
- Surface silicate (silicic acid) levels are positively correlated with age-0 Walleye pollock weight; silicic acid and age-0 pollock weights were above-average for 2014 and 2015 relative to 2006-2015 (p. 85).
- Higher coccolithophore levels (>10%) were observed in 2007, 2009, 2011, and 2014 for the middle shelf and in 2011 and 2014 for the inner shelf (p. 87).
- Zooplankton Rapid Assessment (ZRA) in Fall 2015 showed the zooplankton community was dominated by small copepods. Large copepods were seen near M5 and Unimak Pass while euphausiids were rare over the shelf (p. 91).

- ZRA in Spring 2016 showed the zooplankton community still dominated by small copepods over the shelf with large copepods near the outer shelf and some inner domain stations. High percentages of large copepods occurred near M4. Euphausiid juveniles occurred in the inner and middle domains (p. 91).
- ZRA in Early Fall 2016 showed small copepods comprised 99% of the zooplankton community in all samples across all domains while overall sample volumes appeared qualitatively low, relative to past sampling (p. 91).
- ZRA in Late Fall 2016 showed small copepods made up the majority of zooplankton at all stations sampled, with large copepods comprising as much as 20% of the zooplankton at the northern stations on the 70m isobath (p. 91).
- A time series hindcast based on ZRA categories showed agreement with the OCH with warm periods characterized by small copepods and cold periods by large copepods (p. 97).
- Summertime euphausiid density increased on the eastern Bering from 2004-2009, but subsequently declined 2010 through 2016 (2016 is the lowest value in the time series) (p. 98).
- The relative CPUE for jellyfishes in 2016 was a 79% decrease from 2015, and one of the lowest observed since 1989 (p. 103).
- In 2015 in the northern Bering Sea, jellyfish biomass decreased compared to previous years and the dominant species was *Chrysaora melanaster* (p. 104).
- Pacific herring occur in higher abundances during warm years over the EBS shelf, while in cold years they are contracted over a smaller area to the north and nearshore (p. 111).
- Chinook salmon abundance in the Arctic-Yukon-Kuskokwim region has been declining since 2007 and in 2015 Chinook salmon harvests continued to be low (p. 115).
- The 2014 harvest of coho salmon in Bristol Bay was the largest in the last 20 years, while the 2015 catch was considerably less (p. 115).
- The 2014 Bristol Bay sockeye salmon run was 55% above the preseason forecast and was 19% above the previous 20-year average (1994-2013). The 2015 run was 70% above the recent 20-year average and 12% above the preseason forecast (p. 115).
- The 2015 estimate of Canadian-origin juvenile Chinook salmon in the northern Bering Sea was above-average, a continuing trend since 2013 (p. 118).
- The current age-0 pollock energetics model indicates that the 2015 year-class is predicted to have intermediate overwinter survival to age-1 and recruitment success to age-3. In 2015, age-0 pollock may have utilized the cold pool as a refuge which could buffer against recruitment declines (p. 122).
- The energetic content of age-0 pollock diets was lower during the warm years of 2003-2005, intermediate during 2006, and reached higher levels during the cold years of 2007-2012. Diet energy density was intermediate during the warm years of 2014-2015 (p. 124).
- Increased availability of large zooplankton prey is favorable for age-0 pollock survival and recruitment to age-1 (p. 125).
- The Temperature Change (TC) index for the 2014 year class of pollock was below the long-term average, therefore lower than average recruitment to age-1 is expected. The TC index for the 2015 year class was above the long-term average, therefore slightly above average recruitment to age-1 is expected in 2016 (p. 129).
- Below average age-1 pollock recruitment is expected for the 2013-2015 year classes based on 2016 biophysical indices indicating below average ocean productivity (chum salmon growth), warm spring sea temperatures in 2016 (less favorable), and high predator abundances (pink salmon) (p. 131).
- Estimated age-1 natural mortality (based on the CEATTLE model) for Walleye pollock, Pacific cod, and Arrowtooth flounder is high in 2016 (highest in the timeseries since 1979) (p. 132).

- Length-weight residuals (measure of groundfish condition) for all groundfish species (except Arrowtooth flounder) were less in 2015 than in 2016, indicating larger weight at length in the most recent year (p. 135).
- The 2016 CPUE of eelpouts increased by 26% and CPUE of sea stars increased by 6%. Similar trends occurred for both taxa since 2003, suggesting there may be a relationship between bottom temperature and catch rate (p. 140).
- Biomass of commercial crab stocks is highly variable over the time series with negative trends in 2016 (p. 140).
- Capelin occur in higher abundances during cold years over the EBS shelf, while in the recent warm year of 2014 they are contracted over a smaller area to the north (p. 107).
- A multivariate seabird index indicates later hatch dates for all species and lower reproductive success for cormorants and common murres in 2016. The dominant temporal trend among kittiwake reproductive success data continues to be an alternating biennial pattern with decreased reproductive success in 2016 (p. 144).
- The preliminary 2016 pup production estimates for St. Paul and St. George Islands indicate a change between -5.0 and 16.0% on St. George, and a decrease between 10.0 and 15.0% on St. Paul, compared to the 2014 estimates (p. 147).
- Dynamic Factor Analysis using 16 biological time series suggests the eastern Bering Sea has experienced multiple regime shifts, including the well-documented late 1970's regime shift as well as a subsequent shift in 2008 (p. 149).
- Human population of the eastern Bering Sea increased 10.3% between 1990 and 2015, and northern Bering Sea 29.0%, which was lower than State trends (34.1%). However, 41% of eastern Bering Sea communities and 19% of northern Bering Sea communities experienced population decline during this time period because of out-migration (p. 187).
- Alaska maintains high rates of population turnover because of migration; overall population increase has occurred mainly in urban areas such as Anchorage and the Matanuska-Susitna Borough (p. 187).
- Between 2010 and 2014, eastern Bering Sea and northern Bering Sea communities had among the highest rates of intrinsic population increase (1.0-3.0%) yet lowest net migration (<0) in the State, with populations largely comprised of Alaska Natives (p. 187).
- Between 1995 and 2015, unemployment rates of northern Bering Sea communities were consistent with, yet higher, than State and National levels, whereas eastern Bering Sea rates were lower. The unemployment rate of eastern Bering Sea communities increased from 1.60 in 1990 to 3.29 in 2015, and northern Bering Sea from 6.89 in 1990 to 12.77 in 2015 (p. 187).
- Total CPUE from the EBS trawl survey shows a 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. The increase in total CPUE in 2014 was largely due to an increase in Walleye pollock catches in the bottom trawl survey (p. 154).
- Species richness and diversity on the EBS shelf have undergone significant variations from 1982 to 2016. Both richness and diversity decreased through 2014 with a moderate increase in 2015/2016 and a large and significant increase in Shannon diversity in 2016. Richness tends to be highest along the 100 m isobath, while diversity tends to be highest on the middle shelf (p. 156).
- Both the latitudinal and depth distribution of the demersal community on the eastern Bering Sea shelf show significant distributional shifts to the north and into shallower waters. 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 and shallower in 2015/2016 than in any previous year and, in 2016, was considerably further North than in any previous year since the survey has been standardized (p. 158).

Fishing and Fisheries Trends

- Discard rates in the Bering Sea pollock trawl sector declined to 1% in 1998 and have remained low; in the fixed gear sector, discard rates have fluctuated between 10% and 14% since 1996 (p. 161).
- Non-target species catch has been highest in the EBS compared to GOA and AI ecosystems. The catch of jellyfish peaked in 2014 then dropped by more than half in 2015. Years of high jellyfish catch are typically followed by sharp drops the following year. The catch of assorted invertebrates decreased between 2003-2009 and has generally increased between 2010-2015 (p. 163).
- The number of seabirds caught incidentally in EBS fisheries in 2015 increased from 2014, but remained below the 2007-2014 average. No short-tailed albatross and few black-footed albatross were caught. The estimated numbers of birds caught incidentally in the EBS exceeded that in the GOA and AI (p. 166).
- Habitat impacts due to fishing gear (pelagic and non-pelagic trawl, longline, and pot) interactions have decreased steadily from 2008 through December 2014 in the Bering Sea (p. 169).
- As of 2016, with the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling (p. 170).
- As of June 30, 2016, no BSAI or GOA groundfish stock or stock complex is subjected to overfishing or is considered to be overfished or approaching an overfished condition. The only crab stock considered to be overfished is the Pribilof Islands blue king crab stock, which is in year 2 of a rebuilding plan (p. 175).
- Annual Surplus Production levels were low in 2004-2007 and relatively high in more recent years, largely driven by fluctuations in walleye pollock. Excluding walleye pollock, non-pollock surplus production has also been moderately high in the most recent time period (p. 182).
- The number of vessels participating in federally-managed fisheries off Alaska has generally decreased since 1992, though participation has remained relatively stable in recent years. Participating vessels are largely those using hook and line or jig gear (600 such vessels in 2015). The number of trawl-gear vessels has decreased steadily to around 180 in each of the last 5 years. Pot-gear activity has steadily declined, with 154 pot vessels active in 2015 (p. 186).

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* indicates contribution updated in 2016
† indicates new contribution

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

December 2015 SSC Comments

As in the past, the Ecosystem Considerations Chapter of the SAFE documents is well written, informative, and continues to improve. The Editor and authors are to be congratulated on an excellent presentation covering a great deal of complex and important information. Perhaps most exciting are the efforts to develop prediction capacity. The Chapter is moving toward providing the sort of information that will allow the use of environmental information to predict future fish recruitment. The predictions may still be preliminary and qualitative, but it is great to see the attempt to go beyond recounting what has passed.

Thank you. This year, the ecosystem reporting efforts have benefited from the assistance of Elizabeth Siddon with the eastern Bering Sea report and Ellen Yasumiishi coordinating Auke Bay Lab's contributions.

The SSC was very pleased to see the first edition of the GOA report card. We commended the effort to develop a broader base for the process for selecting the list of indicators and we support the effort to continue to refine this list. The SSC appreciates having a Mobile Epifauna Biomass Index for the GOA. However, given the use of survey trawls with roller gear in the GOA that do not track as close to the bottom as the EBS trawl gear, consideration should be given as to whether this index is reliable. For instance, GOA trawl catches of crabs and scallops have been used as indices of presence/absence but generally not as a quantitative index of abundance. If the Mobile Epifauna Biomass Index is deemed reliable in the GOA, the SSC supports its continued inclusion in the report card.

Stephani Zador held a workshop session with the principal investigators of the GOA IERP project in early 2016 to refine the list of indicators. First, the majority of the group agreed that the differences between the western and eastern Gulf of Alaska warranted having two separate report cards. Thus, we present two report cards. While the general indicator categories are similar between the two report cards, some individual indicators differ. For example, the PDO was selected to be best climate indicator in the western, and the MEI (multivariate ENSO index) was selected to be the most appropriate in the east. However, as with the Aleutian Islands report card, the division highlights data gaps. For example, comparable forage fish indicators are not available for both regions. Also, while fresh water input was considered informative for the west, a comparable oceanographic indicator remains to be selected for the east. The version of the report card continues to include the motile epifauna trawl survey index until we find a more suitable index. However, it is only included for the west, as is the apex fish foraging guild, because summarizing these values for the eastern region, where survey efforts vary among years, was not finalized in time for this edition.

The SSC looks forward to continued development of the Arctic assessment and report card, as this will be critical to our overall understanding of the resources there and how they may best be managed.

We also look forward to continued development and hope to make plans for a workshop and/or report card development soon. This year we had very little to update in our preliminary Arctic assessment, and so have decided not to produce an annual update but rather focus of producing separate LME-based reports for the other areas (see below). We plan to have a complete and separate Arctic Ecosystem Considerations report next year.

The Editor and authors have been very responsive to the past comments of the SSC. The SSC notes the welcome addition of the section on Disease Ecology and the expanded information on the status of zooplankton in the EBS and GOA. The SSC found the ongoing effort to develop alternate sampling methods or platforms to provide information on forage fish trends very helpful. The SSC echoes the concerns of the PT regarding the ecosystem indicator that describes the trawl disturbance area. As currently estimated, there is potential for underestimating reductions in trawl effort and the SSC supports the PT recommendation that alternatives to this index be investigated.

Based on positive feedback for the Zooplankton Rapid Assessment, that indicator has been expanded to include seasonal updates from Fall 2015 through late Fall 2016. In addition, we received a new indicator based on the Zooplankton Rapid Assessment categories that developed a hindcast time-series of zooplankton abundance from 1997 - 2012. There are a few new forage fish indicators presented this year. Yasumiishi et al contributed new spatial analyses of capelin and herring trends in the eastern Bering Sea, and Zador and Frandsen present new multivariate capelin and sand lance indicators for the Gulf of Alaska. There has been a great deal of effort over the past year in developing new habitat disturbance indicators to replace the previous estimates of trawl disturbance. We present a new indicator based on the Fishing Effects model for the eastern Bering Sea, which has also replaced the previous one in the report card. We also replaced the previous trawl disturbance indicator in the Aleutian Islands report card. We anticipate several more indicators of this type, including for the Gulf of Alaska and updated to the previous calendar year, in next year's reports.

The EBS bottom temperature information and the OSCURS model results for 2014 and 2015 corroborate the BSAI stock authors and GPTs concerns/ discussions regarding the impacts of temperatures and advection on flatfish migration and behavioral responses to the survey trawl, both of which impact Q.

The SSC notes that there is a lack of attention to humans in the Ecosystem Considerations chapter. While there are historical reasons that partially explain this – the ecosystem SAFE was conceived after the treatment of some economic and social issues had been assigned to a separate economic SAFE – the SSC believes this separation should not continue. At a fundamental level, the subject of interest is how humans are contributing to changes in the ecosystems of which they are part, and how they are reacting to these changes. The SSC suggests that it is time to rethink how the *human component is incorporated into the SAFE process. As a specific example of how the current approach is deficient, the SSC notes that fisheries policy stands virtually alone, compared to other industry/policy settings, in the total absence of attention to the carbon footprint of commercial fishing and the influence of policy on that footprint.*

We agree that evaluating the carbon footprint of commercial fisheries would be a valuable research area and would support this analysis in these reports. This year, after consultation with AFSC's economists, we include new human dimensions indicators for all LMEs that focus on population and unemployment trends. As human dimensions in fisheries is an active area of research, we anticipate modifying and expanding this section in the future.

The document has grown over the years and the increasing length in some ways makes it difficult for the reader, despite the useful Report Card and Hot Topics sections. Not all parts are of equal value. It would be nice if the meat of the document were tightened up so that the important parts totaled 100 to 150 pages. That might help the reader to absorb more of the critical material. It might be useful to have a sub-committee try to sort out which, if any, indices might be dropped. For example, there are a number of indices or reports on herring. We recognize the importance of information on the status of the Togiak Bay (Bering Sea) spawning run, but perhaps the considerable set of reports on herring in Southeast Alaska (Gulf of Alaska) could consolidated into a broader overview of southeast regional trends.

As of this year, the Ecosystem Considerations report has been divided by LME into three separate documents. Within each LME, we have organized indicators by trophic level (Primary Production, Zooplankton, Groundfish, Benthic Communities and Non-target Fish Species, Ecosystem or Community Indicators, Disease Ecology Indicators). This accomplishes several objectives. First, the ecosystem status of each LME is more cohesively represented by report card, summary, assessment, and detailed contribution in a separate document. This makes it easier for the reader (and editors) to integrate across the broad scope of indicators available in each LME. Second, the arrangement highlights data gaps and research needs, which vary by LME. Third, this framework more easily allows for ecosystem experts to participate in the indicator curation and synthesis in their area of expertise. Fourth, each report is shorter and hopefully easier to absorb for those readers that may have more specific, regional interests. While many indicators and sections have developed over the past few years to allow for this restructuring, we acknowledge that there are some redundancies among reports that we will address in next year's editions. We welcome SSC and GPT feedback on the new structure.

Many of the individual Index Reports miss the opportunity to draw comparisons among regions (EBS, GOA, etc.), species, and other indices. Such integration would help the authors and readers see the "big picture". The Editor attempts to do this in the introductory portions of the Chapter, but if the Index Reports come in at the last moment, it is hard for the Editor to integrate them. It would be helpful to group indices by region- EBS, AI, GOA, then, within region by species or species group. Again, that would aid the reader in seeing the connections among indices.

As stated above, the indices have now been fully grouped be LME into separate reports. We understand that this might make inter-regions (i.e., Alaska-wide) comparisons more difficult, but we hope that the synthesis in the assessments allows for these comparisons when informative.

As in the past, a number of indices were not updated for this years Ecosystem Considerations Chapter. If these indices are important for management, then they should be updated in a timely *fashion. If not important, they can be dropped. For example, the EBS Sea Ice Index analysis was not updated, nor were the indices on the western sub-population of the Steller Sea Lion. Both would seem important.*

We acknowledge the importance of timely updates to indicators and that the SSC and GPT rely on this information annually. We will continue to make every effort to include updated indicator information. The Ice Retreat Index was updated this year.

In the discussion of jellyfish (Page 141), we learn for the first time that the BASIS Surveys have been shifted to alternate years. Since the BASIS survey has been of considerable importance in developing and testing of our understanding of the EBS, it would seem that this important change ought to be highlighted up front. The SSC is surprised and disappointed that this was not discussed with the Council before being implemented.

We acknowledge the importance of the BASIS survey and the numerous Ecosystem Indicators that result from that time series. The decision to transition to alternate years was based on budgetary constraints, although we note that special funds were acquired to execute a 2015 survey thereby augmenting the time series.

Introduction

The goal of the Ecosystem Considerations report is to provide stronger links between ecosystem research and fishery management and to spur new understanding of the connections between ecosystem components by bringing together the results of many diverse research efforts into one document. However, this year the report has been split into four separate documents, one for the Gulf of Alaska, Aleutian Islands, eastern Bering Sea, and the Arctic[1]. This new presentation allows for a more cohesive focus on each large marine ecosystem (LME). While this simplifies navigation for the reader, it also better highlights data gaps and research needs within each LME. As before, each report contains four main sections:

- Report Cards
- Executive Summary
- Ecosystem Assessment
- Ecosystem Status and Management Indicators

The purpose of the first section, the Report Cards, 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 assessment originally provided a short list of key indicators to track in the EBS, AI, and GOA, using a stepwise framework, the DPSIR (Drivers, Pressure, Status, Indicators, Response) approach (Elliott, 2002). In applying this framework we initially determined four

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[1] The Arctic report is under development

objectives based, in part, on stated ecosystem-based management goals of the NPFMC: maintain predator-prey relationships, maintain diversity, maintain habitat, and incorporate/monitor effects of climate change. Drivers and pressures pertaining to those objectives were identified and a list of candidate indicators were selected that address each objective based on qualities such as, availability, sensitivity, reliability, ease of interpretation, and pertinence for addressing the objectives (Table 1). Use of this DPSIR approach allows the Ecosystem Assessment to be in line with NOAA's vision of Integrated Ecosystem Assessments (IEA)(Figure 2).

Table 1: Objectives, drivers, pressures and effects, significance thresholds and indicators for fishery and climate induced effects on ecosystem attributes. Indicators in italics are currently unavailable

Pressures/Effects	Significance Threshold	Indicators
Objective: Maintain predator-prey relationships and energy flow **Drivers: Need for fishing; per capita seafood demand**		
Availability, removal, or shift in ratio between critical functional guilds	Fishery induced changes outside the natural level of abundance or variability, taking into account ecosystem services and system-level characteristics and catch levels high enough to cause the biomass of one or more guilds to fall below minimum biologically acceptable limits. Long-term changes in system function outside the range of natural variability due to fishery discarding and offal production practices	• Trends in catch, bycatch, discards, and offal production by guild and for entire ecosystem • Trophic level of the catch • Sensitive species catch levels • *Population status and trends of each guild and within each guild* • *Production rates and between-guild production ratios ("balance")* • *Scavenger population trends relative to discard and offal production levels* • Bottom gear effort (proxy for unobserved gear mortality on bottom organisms)
Energy redirection		• Discards and discard rates • Total catch levels
Spatial/temporal concentration of fishery impact on forage	Fishery concentration levels high enough to impair long term viability of ecologically important, nonresource species such as marine mammals and birds	• Degree of spatial/temporal concentration of fishery on pollock, Atka mackerel, herring, squid and forage species (qualitative)
Introduction of nonnative species	Fishery vessel ballast water and hull fouling organism exchange levels high enough to cause viable introduction of one or more nonnative species, invasive species	• Total catch levels • Invasive species observations
Objective: Maintain diversity **Drivers: Need for fishing; per capita seafood demand**		
Effects of fishing on diversity	Catch removals high enough to cause the biomass of one or more species (target, non-target) to fall below or to be kept from recovering from levels below minimum biologically acceptable limits	• Species richness and diversity • Groundfish status • Number of ESA listed marine species • Trends for key protected species
Effects on functional (trophic, structural habitat) diversity	Catch removals high enough to cause a change in functional diversity outside the range of natural variability observed for the system	• Size diversity • Bottom gear effort (measure of benthic guild disturbance) • HAPC biota bycatch

Effects on genetic diversity	Catch removals high enough to cause a loss or change in one or more genetic components of a stock that would cause the stock biomass to fall below minimum biologically acceptable limits	• Size diversity • Degree of fishing on spawning aggregations or larger fish (qualitative) • Older age group abundances of target groundfish stocks
Objective: Maintain habitat **Drivers: Need for fishing; per capita seafood demand**		
Habitat loss/ degradation due to fishing gear effects on benthic habitat, HAPC biota, and other species	Catch removals high enough or damage caused by fishing gear high enough to cause a loss or change in HAPC biota that would cause a stock biomass to fall below minimum biologically acceptable limits	• Areas closed to bottom trawling • Fishing effort (bottom trawl, longline, pot) • Area disturbed • HAPC biota catch • HAPC biota survey CPUE
Objective: Incorporate/ monitor effects of climate change **Drivers: Concern about climate change**		
Change in atmospheric forcing resulting in changes in the ocean temperatures, currents, ice extent and resulting effects on production and recruitment	Changes in climate that result in changes in productivity and/or recruitment of stocks	• North Pacific climate and SST indices (PDO, AO, NPI, and NINO 3.4) • Combined standardized indices of groundfish recruitment and survival • Ice indices (retreat index, extent) • Volume of cold pool • Summer zooplankton biomass in the EBS

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 upon 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, that has been divided into Western and Eastern Gulf of Alaska report cards this year.

While all sections follow the DPSIR approach in general, 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. Future assessments will address additional ecosystem objectives identified above. 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. We plan to convene teams of experts to produce a report card and full assessment for the Arctic in the near future.

The purpose of the fourth section, Ecosystem Status and Management Indicators, is to provide detailed information and updates on the status and trends of ecosystem components as well as to provide either early signals of direct human effects on ecosystem components that might warrant

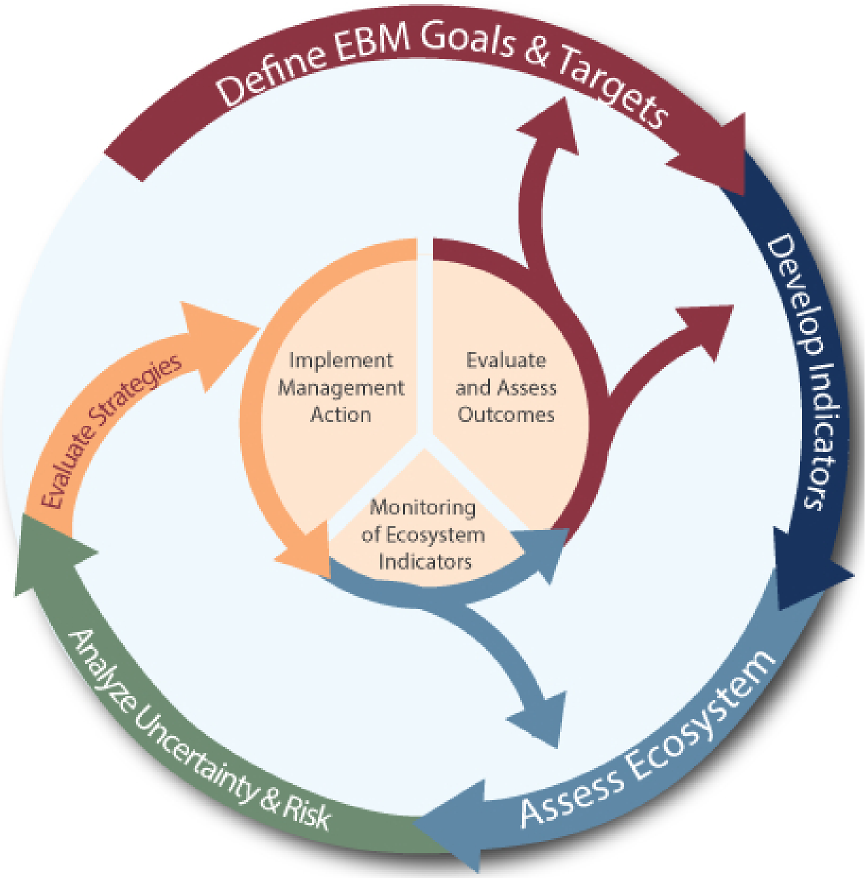

Figure 2: The IEA (integrated ecosystem assessment) process.

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 nonextractive 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 Bering Sea, Aleutian Island, and Gulf of Alaska 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 effect 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 ecosystem 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 has included some new contributions in this regard 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 recommendations or time/space allocations of catch.

In the past, 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. The primary stakeholders in this case are the North Pacific Fisheries Management Council. Research and development of risk analyses and management strategies is ongoing and will be referenced or included as possible.

It was requested that contributors to the ecosystem 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. 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.

Mismatch Between Walleye Pollock Larvae and Lipid Rich Prey on the Eastern Bering Sea Shelf?

The primary objective of the 2016 Eco-FOCI/EMA spring ichthyoplankton survey was to assess the abundance and spatial distribution of Walleye Pollock *Gadus chalcogrammus* larvae over the eastern Bering Sea shelf. A new sampling grid that included nearshore areas not previously surveyed for pollock larvae was used (Figure 3). Zooplankton and ichthyoplankton were sampled using a paired 20 and 60-cm bongo array with 153μm and 505μm mesh nets, respectively.

A preliminary assessment of larval abundance was determined at sea by counting the number of pollock larvae collected at each station. Larvae were abundant on the eastern side of the sampling grid, consistent with previous observations during warm years in the Bering Sea (Figure 3). Abundance was greatest between 50 and 100 m depth in the north, and between 30 and 70 m in the south (Figure 3). Zooplankton collections were examined to determine the spatial distribution of the proportions of small ($<$ 2 mm) and large ($>$ 2 mm) copepod taxa, euphausiids, chaetognaths, and other zooplankton (Figure 4). In general, large copepod taxa were dominant on the outer shelf, small copepod taxa dominated the middle and inner shelves, and the inner shelf had the greatest diversity of species (Figure 4).

Large copepod species are lipid rich and therefore may be a more nutritious source of prey for fish than smaller copepod species. Pollock larvae do not feed directly on the adult stage copepods described in this report, however characterization of the adult taxa provides an indication of the production and availability of earlier stages (microzooplankton) that are potentially available as prey to larvae. Comparing the distributions of larvae (Figure 3) and zooplankton (Figure 4) shows that larvae were most likely feeding on the early stages of the less nutritious small copepod species and this mismatch may have consequences for survival of later stages of pollock.
Contributed by Steve Porter

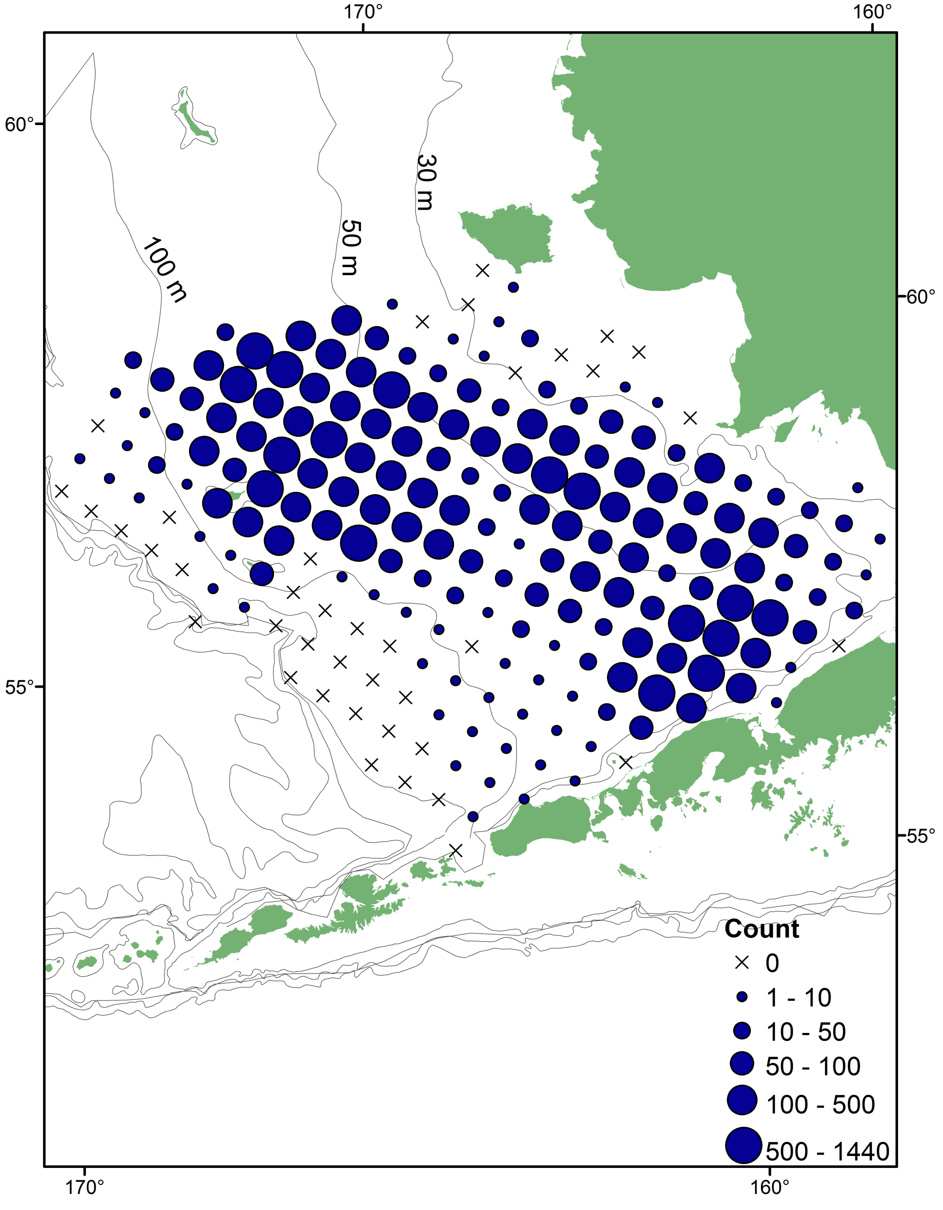

Figure 3: Abundance of Walleye Pollock larvae based on number of larvae counted at sea from bongo tows. Data are preliminary and will be verified at the AFSC.

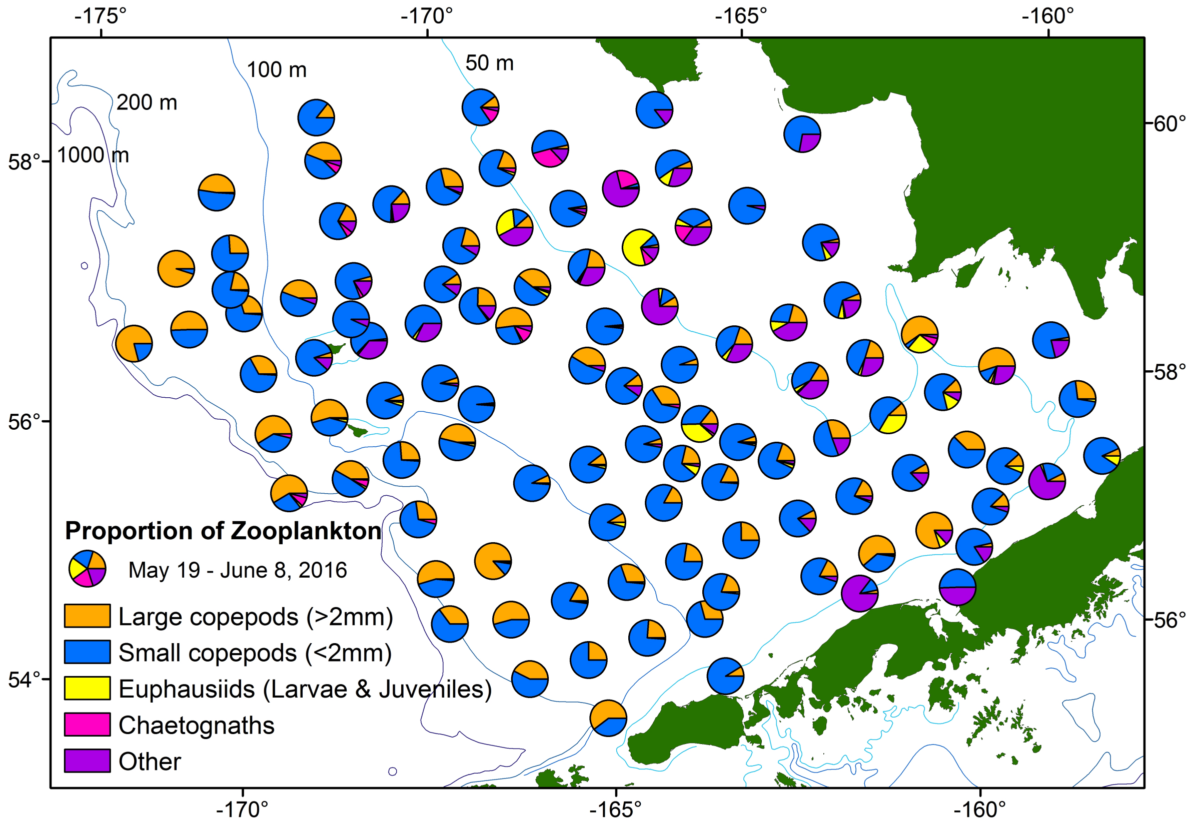

Figure 4: Distribution of zooplankton taxa based on at-sea Zooplankton Rapid Assessment analyses. Data are preliminary and will be verified at the AFSC. Figure provided by Colleen Harpold (see contribution p. 91).

Recap of the 2015 ecosystem state

Some ecosystem indicators that we follow are updated to the current year's state (2016), while others can be updated only to the end of the previous calendar year or before due to the nature of the data collection, processing, or modelling. Thus some of the "new updates" in each Ecosystem Considerations report reflect information from the previous year. Below is an updated summary of last year (i.e., 2015) that includes 2015 information that we have received in 2016. Our goal is to provide a complete picture of 2015 based on the status of most of the indicators we follow. The next section provides a summary of the 2016 ecosystem state based on indicators that are updated in the current year.

2015 was the second consecutive year of significantly above-average thermal conditions over the EBS shelf, beginning in the winter 2014-2015, during which the PDO reached the highest winter value seen in the record extending back to 1900. Air temperatures were 1-3°C warmer than normal over the winter. The warm weather was attributed mostly to relatively warm and moist air aloft over the Bering Sea shelf due to an atmospheric circulation that suppressed the development of extremely cold air masses over Alaska, the usual source of the lower-atmospheric flow for the Bering Sea shelf. The extent of sea ice during winter was reduced, as was as the size of the cold pool of bottom water during the summer. Temperatures above the Mixed Layer Depth (MLD) were warmer than average for all shelf regions the previous fall, but only in 2 regions (Alaska Peninsula and south outer shelf) in fall 2015 due to mixing and deepening of the MLD. However, temperatures below the MLD were warmer than average over the southern shelf in 2015. The climate models used for seasonal weather predictions showed strong El Niño conditions for the winter of 2015-16, which served to maintain a positive state for the PDO, and warm conditions continued into summer and fall 2016 (see *Current conditions: 2016* below).

The status of the lower trophic levels appear to follow predictions of the revised Oscillating Control Hypothesis during warm conditions with little sea ice. Small copepods comprised the majority of the zooplankton identified during the spring Zooplankton Rapid Assessment. Lipid-rich large zooplankton and euphausiids were observed in the north near the retreating ice edge. The prevalence of small copepods, as expected during warm years, suggested that the condition of the age-0 pollock may not be favorable for overwinter survival of this year class. However, surface silicate (silicic acid) levels, which are positively correlated with age-0 pollock weight, were above-average for 2014 and 2015. The balance of these influential factors on recruitment of the 2015 year class is still to be determined.

The catch of jellyfish peaked in 2014 then dropped by more than half in 2015. In 2015 in the northern Bering Sea, jellyfish biomass decreased compared to previous years (the dominant species was *Chrysaora melanaster*), possibly signaling an end to the recent predominance of jellyfish in the EBS.

Survey biomass of motile epifauna has been above its long-term mean since 2010. However, the trend of the last 30 years shows a decrease in crustaceans (especially commercial crabs) and a long-term increase in echinoderms, including brittle stars, sea stars, and sea urchins. In fact, there has been a unimodal increase in brittle stars since 1989, and there was a large step increase for sea urchin in 2004-2005. Possible explanations for these trends include both bottom-up and top-down influences. Habitat impacts due to fishing gear has decreased steadily in the EBS (see new indicator p. 169); it is possible that less habitat disturbance has promoted brittle star abundance trends. An alternative hypothesis could be related to the long-term decrease in crabs, which along with

Flathead sole and eelpouts, eat the most brittle stars. Decreased crabs populations could indicate less depredation on brittle stars.

Note: We have replaced the previous measure of trawl disturbance with a new indicator (p. 169). This indicator uses the Fishing Effects model to estimate habitat reduction over the EBS shelf using spatially-explicit VMS data. The time series began in 2003 and the indicator includes data through 2014. The indicator more accurately reflects an estimate of time that gear is in contact with the substrate. The method may be refined in the future to include estimating impacts through summer of the current fishing season.

Survey biomass of benthic foragers decreased substantially in 2015, which contributed to the change in their previously stable recent trend to negative. Interannual variability in this foraging guild is driven by short-term fluctuations in Yellowfin and Rock sole abundance. Recent declines could possibly be related to the consecutive years of springtime drift patterns that have been linked with poor recruitment of flatfish. The 2015 springtime drift pattern was onshelf, which appears to be consistent with years of good flatfish recruitment. This followed three years (2012-2014) of wind patterns that were more offshelf, which is considered less favorable for recruitment.

Survey biomass of pelagic foragers continued an increasing trend noted since 2009 and remained above its 30-year mean. While this was primarily driven by the increase in Walleye pollock from its historical low in the survey in 2009, it was also a result of increases in Capelin during the sequence of cold years. Interestingly, Capelin abundance did not drop in the past two warm summers. There appeared to be no cohesive salmon response to the state of the ecosystem. The 2015 harvests for Chinook salmon were low and coho salmon harvests were considerably lower than in 2014 (largest in the last 20 years). However, the 2015 Bristol Bay sockeye salmon run was 70% above the recent 20-year average. Fish apex predator survey biomass was above its 30-year mean, although the increasing trend seen in recent years leveled off. The increase since 2009 back towards the mean was driven primarily by the increase in Pacific cod from low levels in the early 2000s.

Seabirds breeding on the Pribilof Islands experienced overall late nesting and low reproductive success, indicating that foraging conditions were not favorable for these piscivorous and planktivorous predators. This hypothesis was supported by the observation of elevated numbers of dead birds observed floating at sea, with many found in the coccolithophore bloom over the southern middle domain of the shelf (see new indicator p. 87). Given that nearly all of the birds examined were emaciated and none had indications of disease or toxins, it is likely that the birds starved to death due to lack of food or because their ability to forage was affected. The number of seabirds caught incidentally in EBS fisheries in 2015 increased from 2014, which may further support the hypothesis that foraging conditions were not favorable, with the result that more birds turned to fisheries as a food source. Counts of fur seal pups are conducted biannually so no updated data was available in 2015.

In general, many ecosystem indicators showed an overall decrease in productivity, with conditions characterized by the above-average thermal conditions, such as smaller copepod community size. Exceptions include motile epifauna, which may not be nutrient-limited and thus not respond to interannual variations in physical conditions and associated productivity.

New human dimensions indicators for the 2016 Report focus on population and unemployment trends through calendar year 2015. The overall populations in the EBS and NBS have increased, although 41% and 19% of communities, respectively, within those regions experienced declines due to out-migration. Unemployment rates in the EBS were lower than State and National levels whereas NBS rates were higher (see new indicator p. 187).

Current conditions: 2016

The eastern Bering Sea is experiencing above-average thermal conditions that began in late 2013 and have continued to present. Ecosystem-level responses have varied in magnitude or direction; notable trends are summarized below. In 2015, the second consecutive warm year, negative impacts of warm conditions may have been mitigated by the presence of the cold pool over the northern Bering Sea shelf. However, as latent heat has continued to build in the North Pacific, 2016 saw sea surface temperatures reaching 14°C with a >3°C positive anomaly over the entire shelf.

In 2016, 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 timeseries 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 and temperatures over the slope were also warm.

In the third consecutive warm year, the zooplankton composition continued to reflect taxa that typify warm thermal regimes. The Zooplankton Rapid Assessment was conducted seasonally (spring and fall) on surveys over the EBS shelf and showed a continuance of small copepods dominating the community. In Spring 2016, large copepods occurred near the outer shelf and some inner domain stations, but were spatially mismatched with larval pollock (see 'Hot Topic' p. 33). By Fall 2016, 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. Summertime euphausiid density in 2016 was the lowest value in the time series.

The abundance of jellyfish (principally *Chrysaora melanaster*) continued to decline in 2016 with a 79% decrease from 2015 to one of the lowest observed values since 1989. The abundance of jellyfish from the EBS bottom trawl survey shows two gradual increases followed by more abrupt declines over the time series (see p. 103). Jellyfish increased in abundance in the 1990's, reaching a peak in 2000, followed by a steep decline in 2001 and abundances persisted at low levels until 2008. Abundances increased again between 2009 - 2011, but have been declining ever since.

The 2016 springtime drift patterns on the southern shelf are consistent with years of below-average recruitment for winter-spawning flatfish (Northern rock sole, Arrowtooth flounder, Flathead sole) following a year of above-average recruitment (2015). In addition, estimated age-1 natural mortality (based on the CEATTLE model) for Walleye pollock, Pacific cod, and Arrowtooth flounder was high in 2016 (highest in the timeseries since 1979). That said, the abundance of adult-stage benthic foragers sampled on the EBS bottom trawl survey changed trend from declining in 2015 to neutral in 2016 (see EBS Report Card p. 2). In addition, length-weight residuals, a measure of groundfish condition, increased for all groundfish species (except Arrowtooth flounder) in 2016 indicating larger weight at length. This disparity may reflect poor conditions for larval dispersal and survival, yet more favorable conditions for adult-stage benthic foragers and groundfish under current climatic conditions.

The species richness and diversity of fish and invertebrates captured during the 2016 EBS bottom trawl survey showed moderate increases in 2015 and 2016, with a large increase in Shannon diversity in 2016. The distribution of the demersal community shifted significantly to the north and into shallower waters. The average center of gravity was considerably farther north than in any previous year since the survey has been standardized. Anecdotal reports from the 2016 northern Bering Sea survey described catches of adult Pacific cod and adult walleye pollock in waters east of St. Lawrence Island (∼64°N).

The survey 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 declines in the biomass of commercial crab stocks in 2016.

Abundance trends of structural epifauna reversed for several groupings. From the EBS bottom trawl survey, sponges and sea anemones had shown general increases since 2007 and 2001, respectively, but both groups declined significantly in 2016. Coral abundance has been variable with lowest catch rates in 2012 followed by highest abundance in 2016. The abundance of sea whips was stable from the bottom trawl survey, but decreased on the slope survey (see new indicator p. 74).

The trend in pelagic forager biomass, which is mainly driven by fluctuations in walleye pollock as well as capelin and sand lance, changed from increasing in 2015 to neutral in 2016. This likely reflects the cumulative negative effects of warm thermal conditions and poor prey quality on survival and recruitment success. Conversely, the trend in apex predator biomass changed from neutral in 2015 to increasing in 2016, driven mainly by increases in Pacific cod.

Preliminary 2016 pup production estimates for Northern fur seals from the Pribilof Islands show population declines compared to the 2014 estimates (survey is biannual). The trend in the multivariate seabird breeding index contined to decline in 2016. Seabird hatch dates were later in 2016 for all species while cormorants and common murres showed lower reproductive success (lowest values in the time series). Kittiwakes also showed decreased reproductive success in 2016. Visual predators, such as seabirds, were also likely negatively impacted by the extensive coccolithophore bloom over the southern EBS shelf. In addition, the decrease in jellyfish abundance may have impacted seabird foraging success, as seabirds have been shown to target forage fish prey that associate with (seek refuge in) jellyfish tentacles.

In 2016, many ecosystem indicators showed a continued decrease in productivity, consistent with hypothesized ecosystem-level responses to above-average thermal conditions. This was particularly evident in the Zooplankton Rapid Assessment, acoustic euphausiid estimates, jellyfish abundance, Northern fur seal pup production, and seabird indices. Exceptions include motile epifauna (i.e., brittle stars) and apex predator biomass (i.e., Pacific cod). Finally, in the third consecutive warm year, increased diversity of fish and invertebrates was observed, perhaps indicating new niche availability in the ecosystem, as well as significant northward shifts in species' distributions.

Forecasts and Predictions

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 November of each year run through July of the following year, including predictions covering the majority of the annual EBS 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 prediction. Skill metrics for this system have been reported in Wen et al. (2012).

The 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 5 shows the 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 2016, is shown for summer (July) 2017.

The 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 for 2017 indicates **continued warm conditions and a small cold pool**. It is worth noting that the model has not yet been tested in a prediction of a warm-to-cold transition.

Recruitment predictions: The EBS Ecosystem Considerations Report includes several indicators which make recruitment predictions for Walleye pollock. 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.

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 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.

2012 year class: Survival to age-3, as assessed by Ianelli et al. (2015), indicates that the 2012 year class is stronger than predicted. The Temperature Change index (see p. 129) was above the long-term average, therefore above average recruitment to age-1 was predicted. Large zooplankton abundance, which is significantly related to the abundance of age-3 pollock (see p. 125), predicted stronger recruitment for the 2012 year class based on high abundances of large zooplankton prey available. A new leading indicator (see p. 124) shows that the energetic content of age-0 pollock diets is also related to pollock recruitment success. In 2012, diet energy density was greater than observed age-0 pollock energy density, indicating that high quality prey was available to age-0 pollock. While the average energy density of age-0 pollock was high in 2012 (see p. 122), the fish were quite small, which resulted in lower average energy content (product of average energy

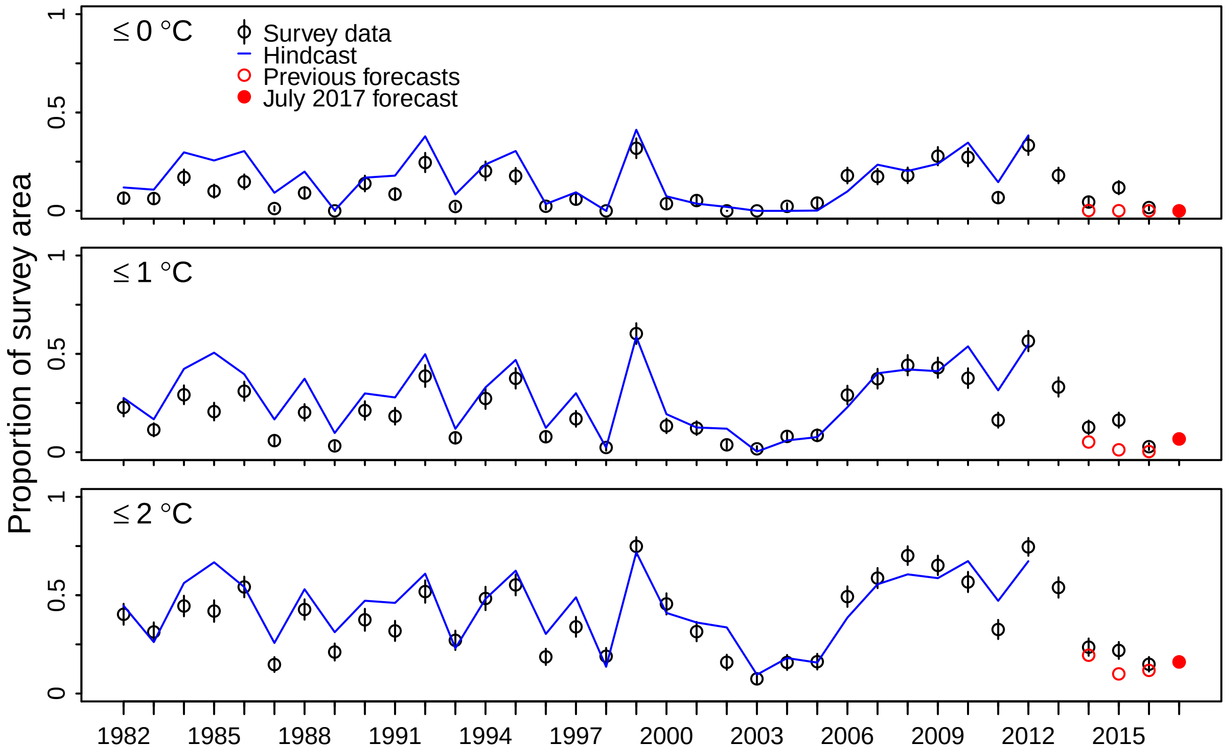

Figure 5: The eastern Bering Sea cold pool with limits of 0°C, 1°C, and 2°C. Shown are BTS survey data, ROMS hindcast results 1982-2012, and ROMS 9-month ahead predictions. The most recent prediction, made in October 2016, is shown for summer 2017.

density and individual mass) and a poor recruitment prediction for the 2012 year class. Multiple indicators predicted strong recruitment for the 2012 year class while the energy density index, which accounted for small fish size, predicted weaker recruitment than has been observed.

2015 year class: Ecosystem indicators show mixed predictions for the 2015 year class. The Temperature Change index was again above the long-term average, therefore above average recruitment to age-1 is predicted. However, below-average recruitment was predicted based on the 2016 biophysical indices that indicate below-average ocean productivity (chum salmon growth), warm spring sea temperatures, and high predator abundances (p. 131). The leading indicator of diet energy density as well as the energy density index predict intermediate recruitment success for the 2015 year class. 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., In press).

Description of the Report Card indicators

1. The North Pacific Index (NPI) (Nov - Mar): 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^o to 65^oN, 160^oE to 140^oW (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 $\tilde{5}9^o$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^oN and 164^oW (Stabeno et al., 2012). We chose the 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 (see contribution on p.98).

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 forager, 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 2). For each guild, time trends of biomass are presented for 1977-2016. 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 was 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 2: 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.140 and 140). There are ten commerical 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, 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 pollock, other forage fish such as herring, capelin, eulachon, and sandlance, 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, Arrowtooth flounder, Kamchatka flounder, Pacific halibut, 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. Further detail on this index is reported on p. 144.

9. Fur seals pup production, St. Paul: 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 Is. 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. 169.

Gaps and needs for future EBS assessments

This section includes the remaining gaps and needs that were described during the development of the EBS assessment and report card in 2010 and have not yet been resolved.

Climate index development: We hope to present a multivariate index of the climate forcing of the Bering Sea shelf in the near future. This index will likely have the NPI as one of its elements, but also incorporate variables related to the regional atmosphere including winds and temperatures. The primary application for this index, which has yet to be determined, will guide the selection of the exact variables, and the domains and seasons for which they will be considered. Three biologically significant avenues for climate index predictions include advection, setup for primary production, and partitioning of habitat with oceanographic fronts and temperature preferences.

Primary production time series: No suitable indicator for primary production is currently available. We are lacking direct measurements of primary production that could be assembled into a time series. We do, however, have indices of phytoplankton biomass and size structure. Our chlorophyll measurements are from M2, 70m isobath, and from satellites. Satellite (SeaWiFS) estimated chlorophyll (and productivity) go back to 1997 or 1998, but are spotty due to cloud cover. Continuous chlorophyll fluorescence measurements at M2 started in 1995. Stabeno is working on generating a fluorescence-to-chlorophyll conversion factor based on ground truth samples taken each year. These derived estimates will have a significant error, but satellite data is hindered by gaps due to cloud cover and surface-only data. Fluorescence at M2 was measured at 3 depths. The derived measurements may also allow us to estimate what percent of phytoplankton standing stock ends up on the seafloor.

In the future we would like to develop the ability to measure chlorophyll in sediments as is done for the Northern Bering Sea by Grebmeier and Cooper. It will be important to decide where such measurements should be taken. New production at M2 is thought to be low and may not be good for epibenthic fish.

Some index of stratification may be a proxy for new production. We have stratification data for M2, but no primary production data to go with it. In addition, new indicators based on late summer (BASIS) survey data will provide time series of Mixed Layer Depth as well as nutrients above and below the MLD over the Bering Sea shelf, providing additional information on productivity.

Spatial scales for assessment: The team reviewed EBS bottom trawl survey data at the guild level to determine whether there were striking changes in distribution patterns over time. No patterns of immediate concern were detected; however, the team felt that including a thorough spatial investigation of key indices would be a high priority in upcoming assessments. For example, spatial distributions of zooplankton, benthos, and forage fish would be critical for predicting the foraging success of central place foragers such as seabirds and pinnipeds. It may be desirable to examine the selected indices by domain (e.g., outer, middle, and inner shelf) rather than EBS-wide. Distributional indices could be developed for foraging guilds, indicator species, and fisheries (see below) similar to some already presented in this Report (see Mueter et al. on p. 158). In addition, an index of cold-pool species or other habitat specific groups could be developed and tracked. Spatially explicit indicators could be used to investigate observed patterns such as the relative success of commercial crabs in Bristol Bay versus further out on the EBS shelf.

Considerable work is already underway to address processes at different spatial scales, in particular for central place foragers. NMML has the following active fur seal research programs at the Pribilof Islands:

1. Bienniel pup production estimation at each rookery (see Towell et al. on p. 147)
2. Adult female summer foraging, physiology, and energy transfer to pup with specific focus on differences by rookery and foraging habitat in the eastern Bering Sea
3. Adult female and pup overwinter satellite tracking to determine foraging and pelagic habitat differences by year and rookery
4. Pup and adult female tagging to determine fur seal survival and reproductive rates

These programs have been underway since the early 2000s, but particularly in the case of item 4 above, take many years (e.g., decades to determine reproductive rates of such a long-lived species) to produce results. NMML needs to continue this field work, and couple it with habitat and ecosystem models to help us understand the differences in fur seal population responses between

Bogoslof and the Pribilof Islands, and differences in responses between air-breathing and fish apex predator responses over the last 20 years.

Fishery performance index needed: Several measures of the performance of current management relative to the goals and objectives of the NPFMC should be considered. An obvious candidate is an index of the catch relative to the TAC, ABC, and OFL. The phase diagram showing the distribution of current biomass/B_{MSY} and catch/OFL provides a quick assessment of whether the stock is overfished or whether overfishing is occurring. However, for some stocks, the TAC is set well below the ABC and OFL. Therefore an assessment of whether the TAC is fully utilized may serve as a better indicator of the performance of the fishery relative to the predicted level of catch. Likewise, catch relative to TAC may be a useful indicator for the efficiency of the walleye pollock fishery because the 2 million t cap constrains this fishery when the stock is in high abundance.

Other measures of net income or revenue might be considered as fishery performance indicators. For example, when stocks are low, the price may increase, this may compensate for longer search time. Thus, when pollock is at a high abundance, and search time is low, the price per pound may be lower than when pollock are scarce.

Integration with stock assessments: Integrating the stock assessments with this ecosystem assessment is an ongoing goal. During the 2010 meeting, the assessment team noted that dominant species often dictate the time trend in aggregate indicators. Several times the team strayed into conversations that were focused on relationships between a select group of species. It is important that the synthesis chapter is dynamically linked to the single species ecosystem assessments so that specifics on how climate impacts dominant species, their prey, and their distribution can be readily obtained if a person wishes to drill down to the single species interactions underlying the guild responses provided.

The development of predictive models for single species or a small group of interacting species (e.g., multispecies stock assessments) is moving ahead at a rapid pace. Some stock assessments already include forecasts that incorporate climate forcing and efforts to address predation on natural mortality rate and prey availability on growth are currently underway. As noted above it will be important to provide a dynamic link between the description of these innovations to stock assessments and the synthesis chapters. We expect that description of the models will continue to appear in the stock assessment. This will allow a thorough review of the mathematical formulations used to depict the relationships between predators, prey, competition, and environmental disturbance within the assessment.

Future use of ecosystem/climate models in development: Several reviews of the utility of ecosystem models are available. Hollowed et al. (2011) examined which quantitative modeling tools were needed to support an Ecosystem Approach to Management (EAM) in the EBS. This review revealed that a diverse suite of models were utilized to support an EAM in the EBS (Table 3). Single-species stock assessment and projection models are the most commonly used tools employed to inform managers. Comprehensive assessments (e.g., Management Strategy Evaluation) are emerging as a new and potentially valuable modeling approach for use in assessing trade-offs of different strategic alternatives. In the case of management in the eastern Bering Sea, end-to-end models and coupled biophysical models have been used primarily to advance scientific understanding, but have not been applied in a management context. In future synthesis attempts, we will add a section that brings forward predictions from different models to initiate an evaluation of the predictive skill of different assessment tools.

Table 3: Suite of models used for implementation of an ecosystem approach to management in the Bering Sea (From Hollowed et al. (2011)).

Model	**Application**	**Issue**	**Example reference**
Stock assessment models	Tactical	Evaluate stock status	Ianelli (2005); Methot (2005)
Stock projection models	Tactical	Assessing overfished condition	Turnock and Wilderbuer (2009)
Management strategy evaluation	Strategic	Assessing the performance of a harvest strategy	Amar et al. (2008); NOAA (2004)
Habitat assessment	Strategic	Evaluating the long-term impact of fishing on EFH	Fujioka (2006)
Multispecies Yield-per-recruit	Strategic	Assessing the implications of prohibited species caps	Spencer et al. (2002)
Multispecies technical interaction model	Strategic	Assessing the performance of harvest strategies on combined groundfish fisheries	NOAA (2004)
Coupled biophysical models	Research	Assessing processes controlling recruitment and larval drift	Hinckley et al. (2009)
Integrated Ecosystem Assessments	Strategic	Assessing ecosystem status	Zador and Gaichas (2010)
Mass Balance models	Strategic	Describing the food-web	Aydin and Mueter (2007)
Dynamic food web models	Strategic	Describing trade-offs of different harvest strategies through food-web	Aydin and Mueter (2007)
FEAST	Strategic	End-to-end model	

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 2016

Summary: *The state of the North Pacific atmosphere-ocean system during 2015-2016 featured the continuance of warm sea surface temperature (SST) anomalies that became prominent late in 2013, with some changes in the pattern. The evolution of the SST distribution can be attributed to the seasonal mean sea level pressure (SLP) and wind anomalies, particularly cyclonic wind anomalies in the central Gulf of Alaska in winter 2015-16 and spring 2016, with a reversal to anticyclonic flow in the following summer of 2016. The Bering Sea experienced the third consecutive winter of reduced sea ice, in what may turn out to be the early stage of an extended warm spell. The Pacific Decadal Oscillation (PDO) was positive during the past year, especially during spring 2016. The climate models used for seasonal weather predictions are indicating borderline to weak La Niña conditions for the winter of 2016-17, while maintaining North Pacific SST anomalies in a PDO-positive sense.*

Regional Highlights:

West Coast of Lower 48. This region continues to be impacted by warm ocean temperatures. These anomalies were not restricted to just the very upper part of the water column but rather extended to as much as 200-300 meters depth based on data from ARGO profilers. The winter of 2015-16 featured above-normal precipitation in the Pacific Northwest and below normal precipitation in southern California, with ∼1 standard deviation warmer than normal temperatures along the entire coast. The end of winter snowpack was above normal in the Pacific Northwest and near normal in northern California; relatively warm weather in spring 2016 resulted in an early melt. Many streams ran low and warm in the summer of 2016 but not as severe an extent as was observed in 2015. The spring and summer of 2016 from ∼Vancouver Island to Point Conception included relatively robust upwelling in the northern portion and a thin strip of water of moderate temperatures in the immediate vicinity of the coast. Further south, downwelling wind anomalies prevailed.

Gulf of Alaska. The upper ocean in this region was relatively salty in fall 2015, presumably at least in part due to the lack of lower elevation snow that was melted during the fall rains. On the other hand, there was an early freshening in 2016 due to the anomalously warm winter and hence more rain than snow than usual in coastal watersheds. The sub-arctic front was farther north than usual, which is consistent with the poleward surface currents shown in the Ocean Surface Currents (see Papa Trajectory Index contribution in the Gulf of Alaska Assessment). The coastal wind anomalies were generally downwelling favorable during winter and spring but switched to more upwelling favorable during the summer of 2016. A prominent eddy was located on the outer shelf south of the Kenai Peninsula during the summer of 2016 and probably contributed to enhanced cross-shelf exchanges in its immediate vicinity.

Alaska Peninsula and Aleutian Islands. The waters of this region were relatively warm, especially in the fall of 2015 and summer of 2016. In part this can be attributed to the overall warmth of the North Pacific and in part to the weather, which featured persistently above normal air temperatures during the past year with only short and minor exceptions. Based on synthetic data from NOAA's Global Ocean Data Assimilation System (GODAS), the Alaskan Stream appears to have had a relatively strong westward flow from late 2015 into 2016. The GODAS product suggests there were pulses in the strength of the eastward flow associated with the Aleutian North Slope Current.

Bering Sea. The Bering Sea shelf experienced a much warmer than normal winter and spring, for the 3rd year in a row. The warm weather can be attributed mostly to the deeper than usual Aleutian low and a preponderance of air masses of maritime rather than of Arctic or continental origins. There was little sea ice south of 59°N and consequently a lack of a cold pool in the middle domain of the southern Bering Sea shelf. The early summer of 2016 was also less stormy than typical. During August 2016, total heat contents on the shelf were at or near record levels.

Arctic. Remarkably warm air temperatures occurred in the central Arctic during the winter of 2015-16, mostly due to an anomalous atmospheric circulation leading to intrusions of mild air from the mid-latitudes. One implication is that there was probably less growth than usual in the thickness of first-year ice over much of the Arctic. A modest cold snap in late September in the Chukchi and Beaufort Seas marked the end of the 2015 melt season, but it was not until November 2015 before the shelf regions of these seas were covered by ice. A coastal polynya developed early in the season (the first week of May) in the eastern Chukchi Sea from approximately Cape Lisburne to Point Barrow. In the Beaufort Sea, rapid melting during August of a large area near the coast resulted in a broad band of open water from near Point Barrow to beyond the Mackenzie River delta. During summer 2016, the sea ice extent in the Beaufort Sea was considerably less than any of the previous four summers; for the Chukchi Sea the ice extent during the summer of 2016 has been comparable to that of recent summers. For the Arctic as a whole, the area of sea ice cover during the middle of August 2016 was slightly less than 2 standard deviations below normal, which represents the 3rd lowest value in the observational record.

Sea Surface Temperature and Sea Level Pressure Anomalies

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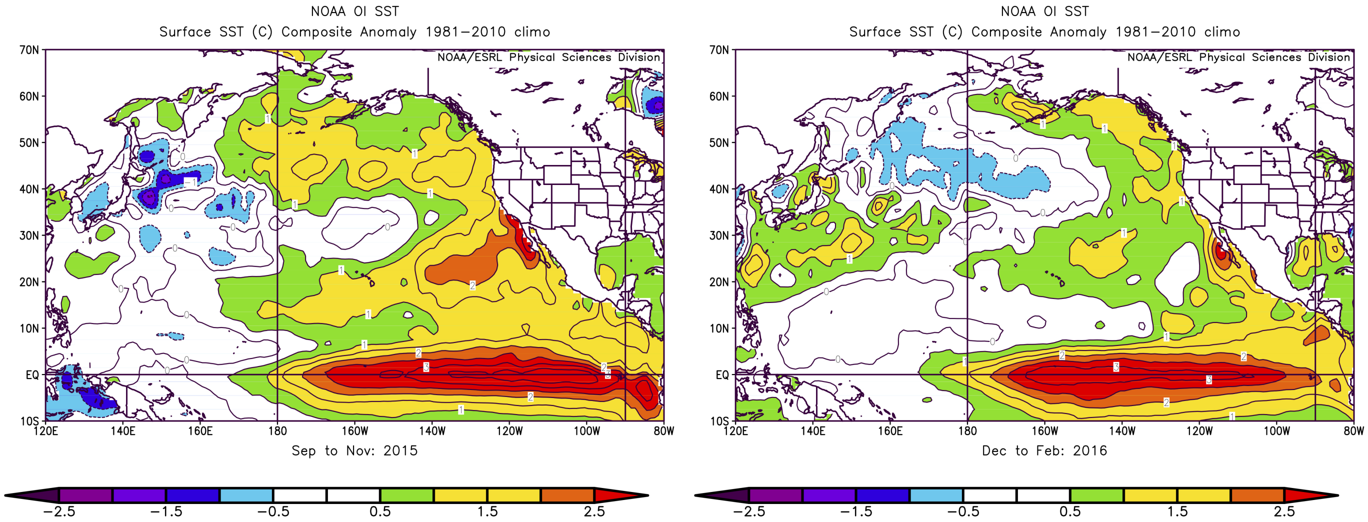
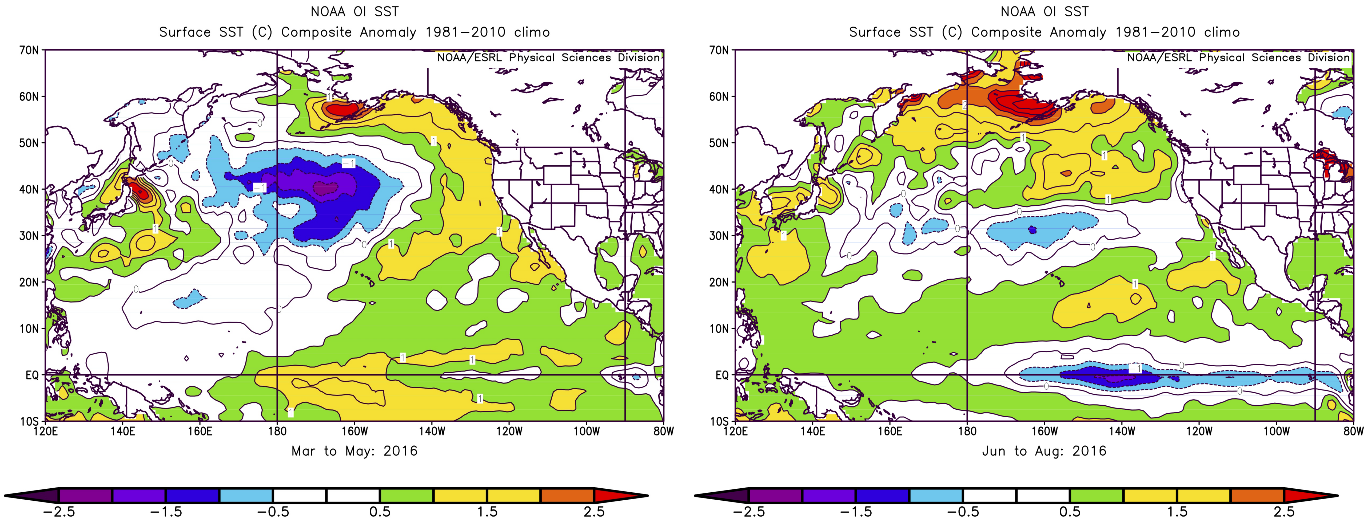
Description of indices: The state of the North Pacific climate from autumn 2015 through summer 2016 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981-2010. The SST data are from NOAA's Optimum Interpolation Sea Surfacae 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`. Previous versions of this overview included SST anomaly distributions based on NOAA's Extended Reconstructed Sea Surface Temperature (ERSST) V4; here the OISST analysis is used because of its finer-scale resolution, and incorporation of satellite data, which is valuable in regions where direct observations of SST by ships and buoys are sparse.

Status and trends: The anomalies that occurred during the past year in the North Pacific beginning in autumn of 2015 reflect, to a large extent, the maintenance of conditions that developed during the previous 1-2 years. In particular, a leading large-scale climate index for the North Pacific, the Pacific Decadal Oscillation (PDO), remained positive, following a transition in sign early in 2014. 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 2015 (Figure 6a) was warmer than normal east of the dateline. The positive anomalies were especially prominent off southern and Baja California and in the eastern tropical Pacific, the latter in association with a strong El Niño. The pattern of anomalous SLP during autumn 2015 featured strongly negative anomalies extending from Bering Strait into northwestern Canada with higher than normal pressure from the Kamchatka Peninsula into the central Gulf of Alaska (GOA). This SLP pattern implies wind anomalies from the west across the Bering Sea and anomalous upwelling in the coastal waters of the GOA.

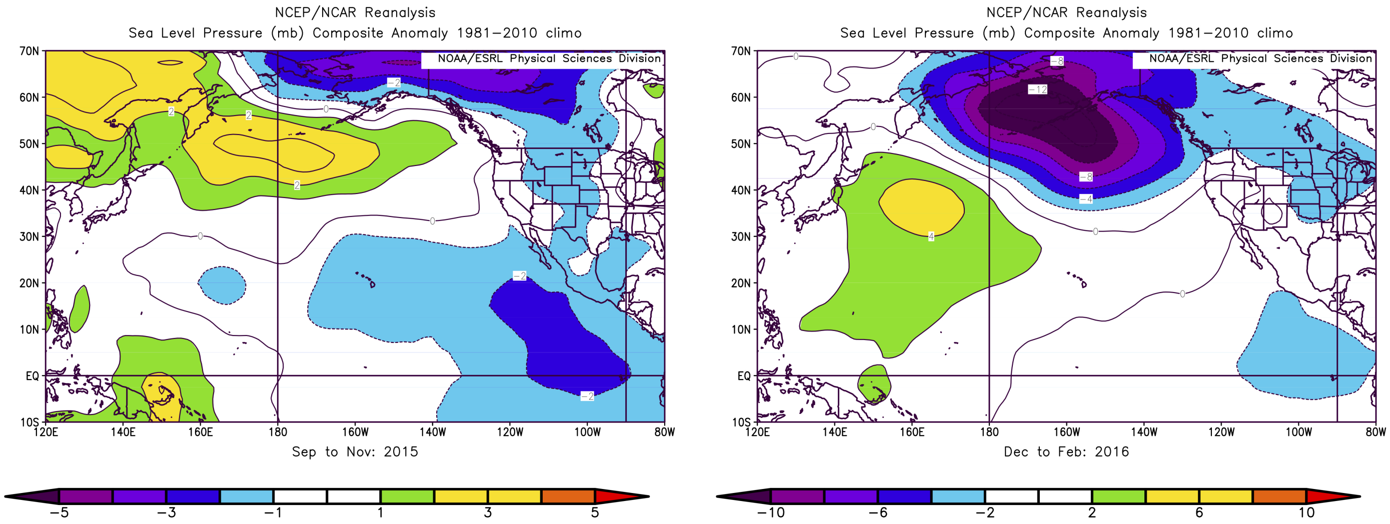


(a) Autumn (b) Winter

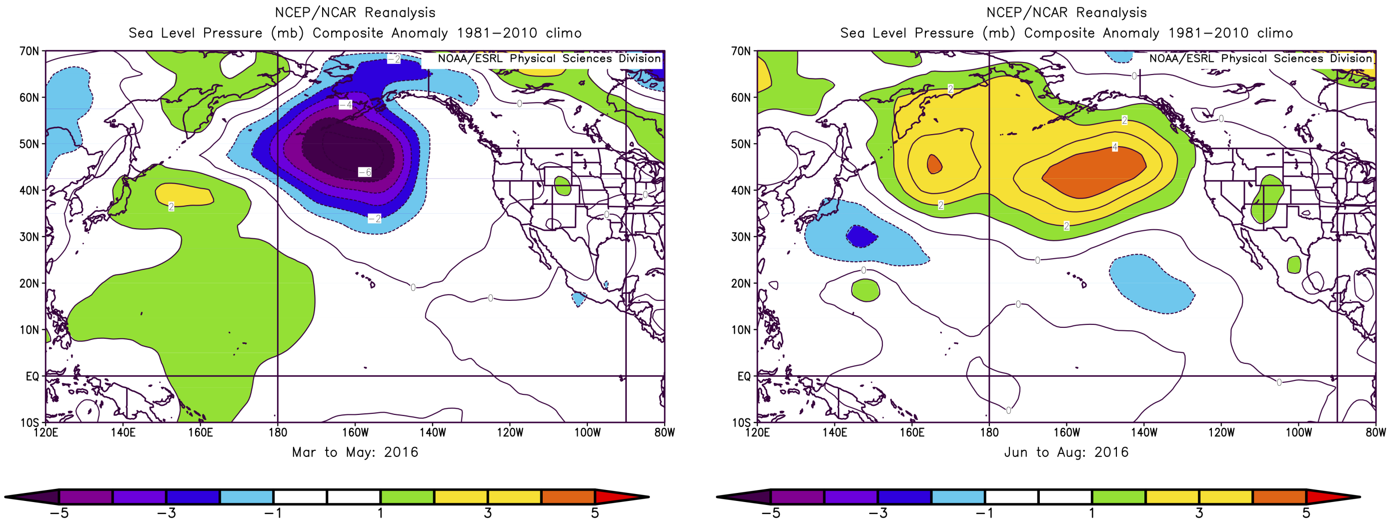


(c) Spring (d) Summer

Figure 6: SST anomolies for autumn (September-November 2015), winter (December 2015 -February 2016), spring (March - May 2016), and summer (June - August 2016).



(a) Autumn (b) Winter



(c) Spring (d) Summer

Figure 7: SLP anomolies for autumn (September-November 2015), winter (December 2015 -February 2016), spring (March - May 2016), and summer (June - August 2016).

The pattern of North Pacific SST during winter (Dec-Feb) of 2015-16 relative to the seasonal mean (Figure 6b) resembled that of the preceding autumn with the exception of the western Bering Sea and Aleutian Islands, which cooled to near normal. The latter cooling was associated with anomalous winds out of the northwest in association with extremely low SLP (negative anomalies exceeding 12 mb) over the eastern Bering Sea and western GOA (Figure 7b). For the area of 50°N to 60°N, 170°W to 150°W, the SLP was more than 3 mb lower than that during any other December through February in the record back to 1949. This meant relatively frequent gale force winds and high wave heights for the region. A deeper than normal Aleutian Low commonly occurs during El Niño (whose signature is prominent in Figure 6b) but the center of the anomalous SLP was displaced to the northwest from its usual position during winters with strong El Niños. The anomalous southerly flow to the east of the SLP anomaly minimum brought relatively warm air to the northern Gulf of Alaska, especially from late January into February during which surface air temperatures were about 6°C above normal. The coastal region of the GOA therefore received a greater proportion of rain versus snow than usual at lower elevations, but it is uncertain whether the GOA experienced significantly more freshwater runoff than typical for the season.

The distribution of anomalous SST in the North Pacific during spring (Mar-May) of 2016 (Figure 6c) bore some resemblance to that of the season before, with an increase in the magnitude of the positive anomalies in the eastern Bering Sea and GOA. Moderate cooling occurred in the central North Pacific in the vicinity of 40°N, 170°W. The overall pattern projected strongly on the positive phase of the Pacific Decadal Oscillation (PDO) as will be discussed further below. The SST anomalies in the central and eastern tropical Pacific decreased as El Niño wound down. The SLP anomaly pattern (Figure 7c) for spring 2016 was similar to that of the previous winter season, with a weaker negative anomaly shifted southeast of its previous location. Lower than normal SLP over a broad region extending from the southeastern Bering Sea towards the west coast of the lower 48 states often occurs in the springs following El Niño winters.

The SST anomaly pattern in the North Pacific during summer (Jun-Aug) 2016 is shown in Figure 6d. It was warmer than normal in the north, with especially positive anomalies exceeding 3°C in the southeastern Bering Sea. Relatively cool water was present in a broad band between roughly 25°N and 40°N from the east coast of Asia to the central North Pacific, with the most negative anomalies located north of the Hawaiian Islands. Warm water persisted in the subtropical North Pacific. Finally, cold anomalies developed in a narrow strip along the equator in the east-central Pacific, signifying the demise of El Niño and the potential for the development of La Niña. The distribution of anomalous SLP (Figure 7d) during summer 2016 featured higher than normal pressure between the Alaska Peninsula and the Hawaiian Islands that was almost opposite to that of the previous season. The relatively high SLP extended into the Bering Sea and was associated with seasonally suppressed storminess and hence scant vertical mixing of the upper ocean, resulting in the very warm surface temperatures shown in Figure 6d. The higher than normal SLP off the coast of the Pacific Northwest and California brought about strong coastal upwelling, and a moderation of SST in the immediate vicinity of the coast.

Climate Indices

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Description of indices: Climate indices provide a complementary perspective on the North Pacific atmosphere-ocean climate system to the SST and SLP anomaly maps presented above. The focus here is on five commonly used indices: the NINO3.4 index to characterize 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 2006 through early summer 2016 are plotted in Figure 8.

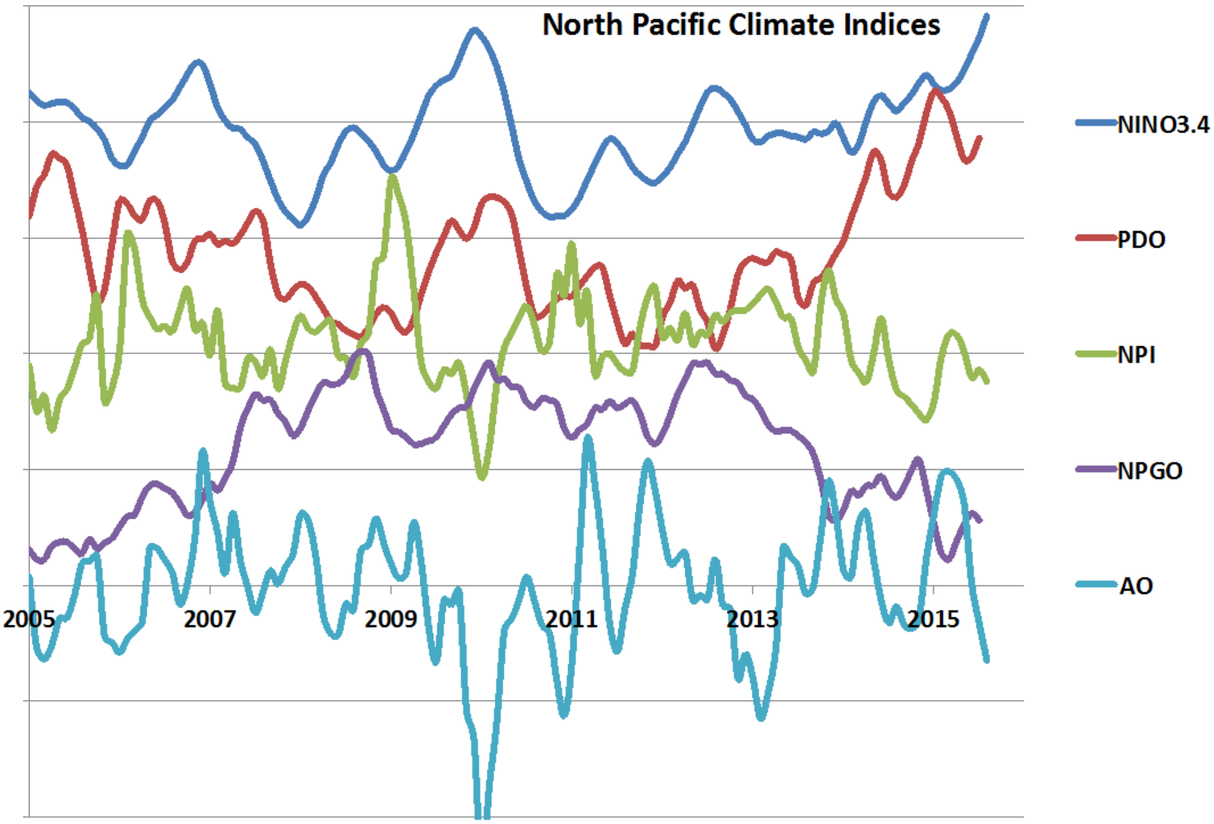

Figure 8: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 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 has been in a highly perturbed state recently. Specifically, NINO3.4 reached a peak value of 2.3 in December 2015 in association with the strong El Niño of 2015-16. This measure of ENSO has declined over the first 8 months of 2016 and is now slightly negative. 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) during the last 2 years. The magnitude of the PDO actually decreased in 2015 during the ramp-up of El Niño, which is unusual. It generally tracks ENSO, with a lag of a few months, as illustrated here for the period of 2008-13 in Figure 8. The PDO did increase in early 2016 to a value exceeding +2, followed by a decrease in late spring/early summer 2015. The NPI was strongly negative during the past winter and spring, which implies a deeper than normal and often displaced Aleutian Low, as indicated in Figures 6b and 7b. This represents a typical atmospheric response to El Niño. The deep Aleutian Low was accompanied by anomalous winds from the south and relatively warm air along the west of North America, i.e., atmospheric forcing favoring a positive trend in the PDO.

The North Pacific Gyre Oscillation (NPGO) underwent a transition from negative in 2015 to a near-neutral state in 2016. A negative sense of this index, which is formally related to the 2$^{\text{nd}}$ mode of variability in sea surface height in the North Pacific, implies a reduced west wind drift and projects on weaker than normal flows in both the Alaska Current portion of the Subarctic Gyre and the California Current. 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 latter portion of 2015, and then mostly negative during early 2016. Most winters since 2009-10 have included relatively strong and persistent (multi-month) signals in the AO, in either the positive or negative sense, but that was not the case for the winter of 2015-16.

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

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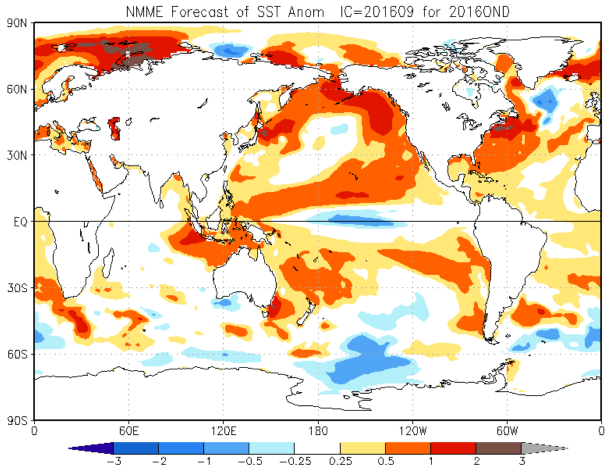
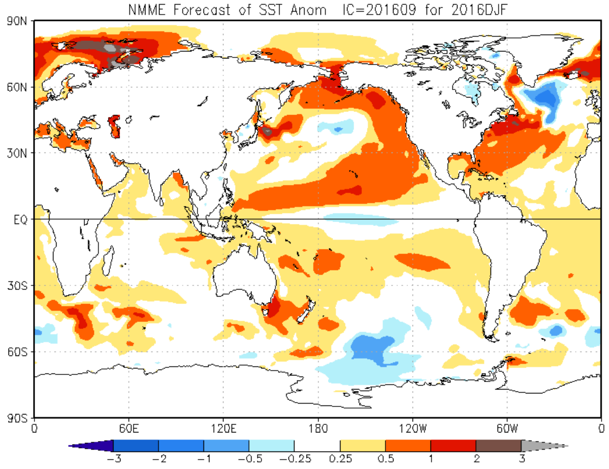
Last updated: August 2016

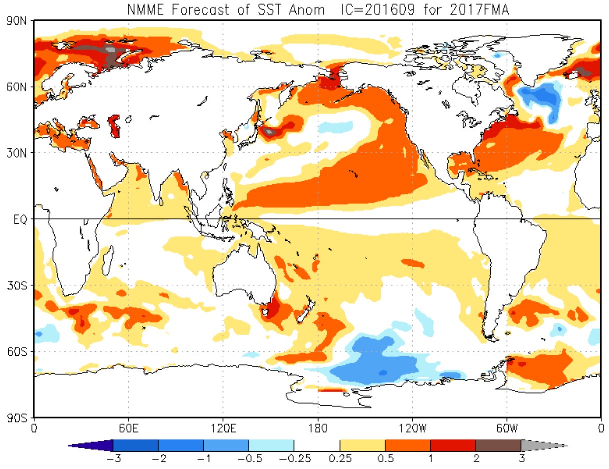
Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 9. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight models. The uncertainties 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/`.



(a) Months OND



(b) Months DJF



(c) Months FMA

Figure 9: Predicted SST anomalies from the NMME model for OND (1 month lead), DJF (3 month lead), and FMA (5 month lead) for the 2016-2017 season.

Status and trends: 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 2016) with a smaller region of near normal temperatures northwest of the Hawaiian Islands (Figure 9a). The magnitude of the positive anomalies is projected to be greatest (exceeding 1^o) in the GOA and eastern Bering Sea. Negative SST anomalies are projected in the central equatorial Pacific. The latter are associated with the potential for a weak La Niña. As of August 2016, 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 a 55 to 60% chance of La Niña by fall 2016. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2016 - February 2017 (Figure 9b) and February - April 2017 (Figure 9c) with a modest cooling in the central North Pacific and moderation of negative anomalies in the equatorial Pacific.

Implications It is unclear whether the equatorial Pacific will be perturbed enough, particularly with respect to the intensity and distribution of deep atmospheric convection, to cause the usual response to La Niña. Past La Niña events have included a weaker than normal Aleutian low and a relatively cold winter for Alaska, western Canada, and the Pacific Northwest. On the other hand, the models comprising the NMME are indicating remote responses to the equatorial Pacific that are relatively weak, and in consensus, slightly warmer than normal temperatures for western North America. These competing signals suggest that the North Pacific climate may be in a state of rather low predictability. That being said, it is unlikely that the upcoming winter in Alaska and western Canada will be as mild as those of the last three years.

Also, the SST anomaly maps shown in Figure 9 share an unusual feature, and that is the co-existence of a relatively cold equatorial Pacific with a horseshoe-shaped pattern of warm water along the west coast of North America, a signature of the positive phase of the PDO. The closest analog to that situation in recent decades was from late 1980 into spring 1981. In that case, the PDO was not as strongly positive as predicted for the upcoming winter and spring, and the NINO3.4 anomalies were of modest amplitude (about -0.4 in early 1981). The maintenance of positive PDO conditions in the North Pacific during the upcoming year, despite an ENSO state that generally brings about an SST anomaly pattern associated with the negative phase of the PDO, could be a reflection of the enormous amount of extra heat in the upper ocean now present along most of the west coast of North America, and the model projections of a muted atmospheric response in the mid-latitudes to the equatorial Pacific during the next 2 seasons.

Eastern Bering Sea Climate - FOCI

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Last updated: October 2016

Summary. A warm year for 2016 followed the warm years of 2014 and 2015, in response to warm sea temperatures in the northeastern Gulf of Alaska (return of the positive Pacific Decadal Oscillation, PDO) and related higher pressures (a continuation of the Ridiculously Resiliant Ridge, RRR;

Swain (2015)). A large persistent Aleutian low pressure centered in southwestern Alaska teamed with RRR to route warm Pacific air across south central Alaska continuing over the southeastern Bering Sea from January through April. Summer was represented by higher than normal sea level pressures and warm temperatures across the Bering Sea. Reduced springtime sea ice extent and reduced summer cold pool extent continued from 2014 through 2016 in contrast to previous cold years. Some persistence to the PDO pattern suggests a possible continuation of warm conditions into 2017.

Air temperatures. Positive near surface air temperature anomalies for winter- spring in southwest Alaska and the southeastern Bering Sea were extreme with monthly averaged values at +3°C over eastern regions (Figure 10). Alaska conditions were driven by the continued return of the Pacific Decadal Oscillation (PDO) and a large persistent Aleutian low (AL) pressure feature centered over the Aleutian Islands, a generally western location for the AL. The return of the strong positive PDO, not seen since 2003, has 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 11) to the east and the AL to the west, giving southerly winds that advect warm temperatures into Alaska. Summer was characterized by warm air temperatures and high pressure across the entire southern Bering Sea (Figure 12 and Figure 13).

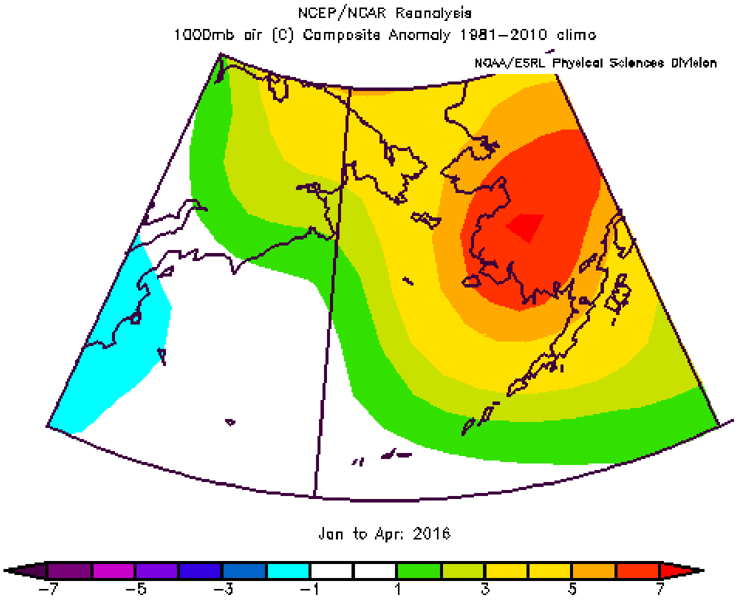

Figure 10: Near surface positive air temperature anomaly over the southeastern Bering Sea for Winter-Spring 2016.

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. Sea ice extents in 2008, 2010, 2012, and 2013 were close to record maximum extents not seen since the early 1970s, and contrast to the warm years of 2000-2005 (except 2002). Spring 2014 and 2015 had a return to less sea ice cover while Spring 2016 had the lowest sea ice cover over the Bering Sea shelf in the time series (Figure 14). Sea ice concentration over the northern shelf (north of 60°N)

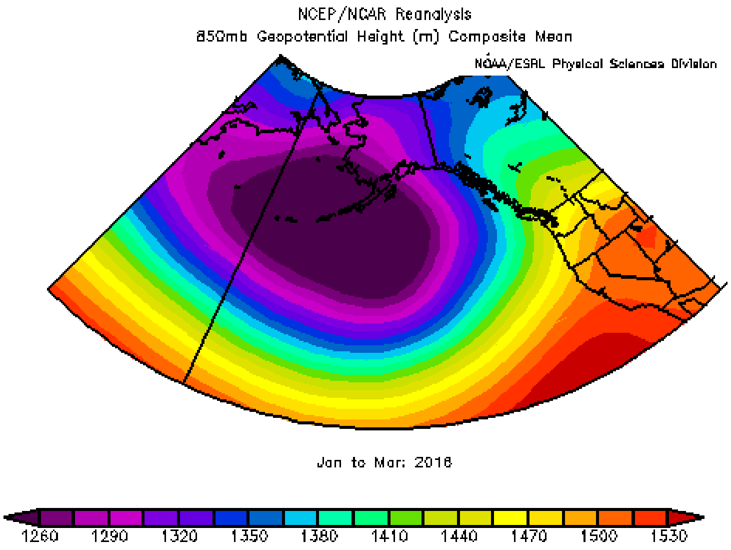

Figure 11: Geopotential height anomaly over western North America for Winter-Spring 2016. Winds follow the contours of constant heights thus showing strong wind from the south reaching Alaska and the southeastern Bering Sea over this extended period. See Bond contribution p. 48.

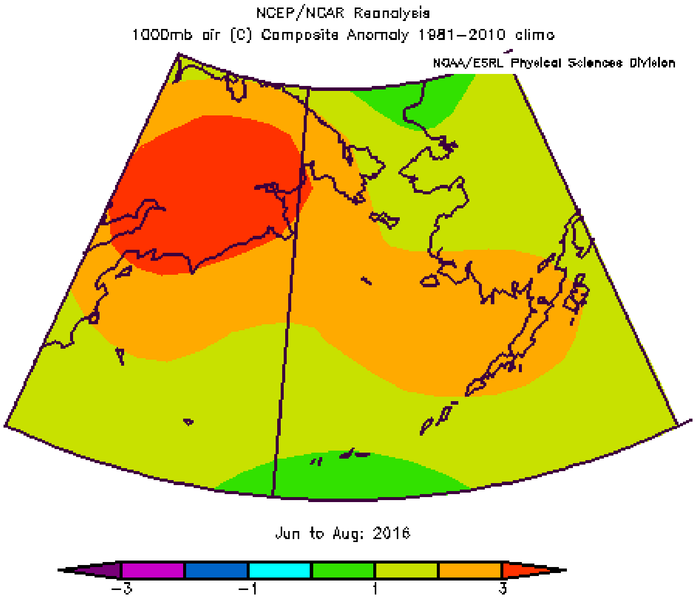

Figure 12: Near surface air temperature anomalies over the greater Bering Sea region for Summer 2016.

ranged from 60-75% from February - May 2016 with some peaks to 90% coverage (Figure 15).

Ocean temperatures. The cold pool, defined by bottom temperatures <2°C, influences not only

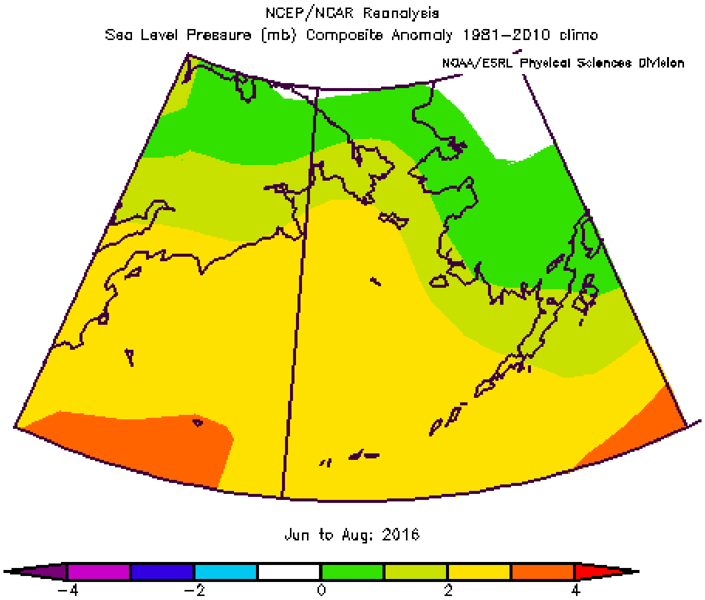

Figure 13: Weak positive sea level pressure anomaly over the greater Bering Sea for Summer 2016.

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 2014 and 2015 retreated in area compared to the prominent sequence of recent cold years. In 2016 the cold pool was retracted over the northern shelf and similar in size to 2002 (Figure 16).

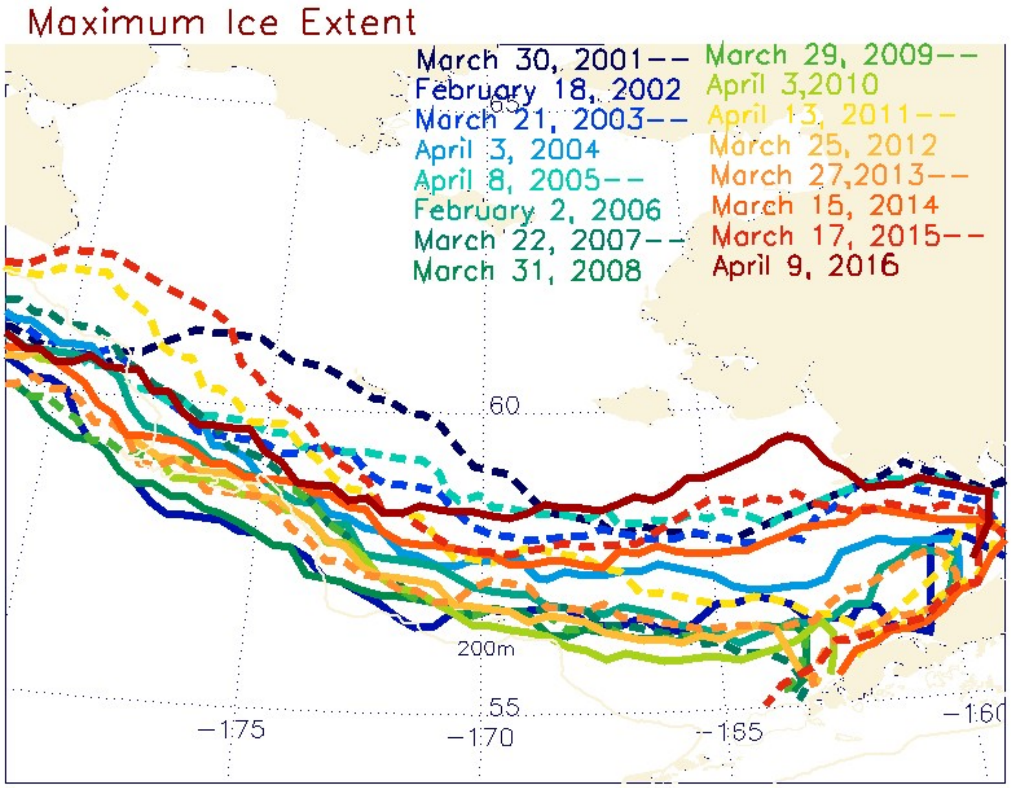

Figure 14: Recent springtime ice extents in the Bering Sea.

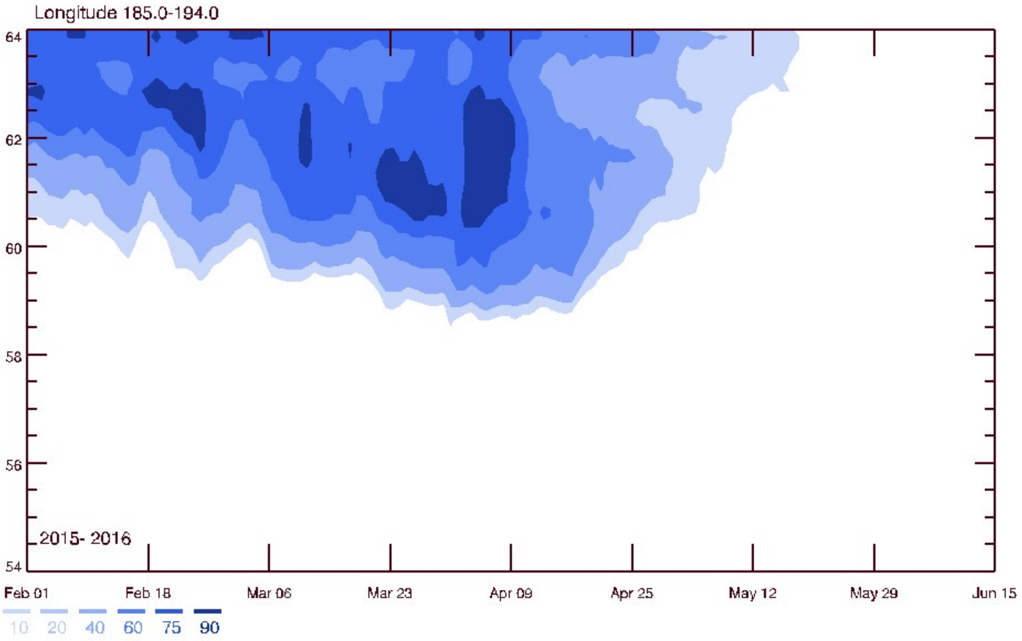

Figure 15: Ice concentration over time.

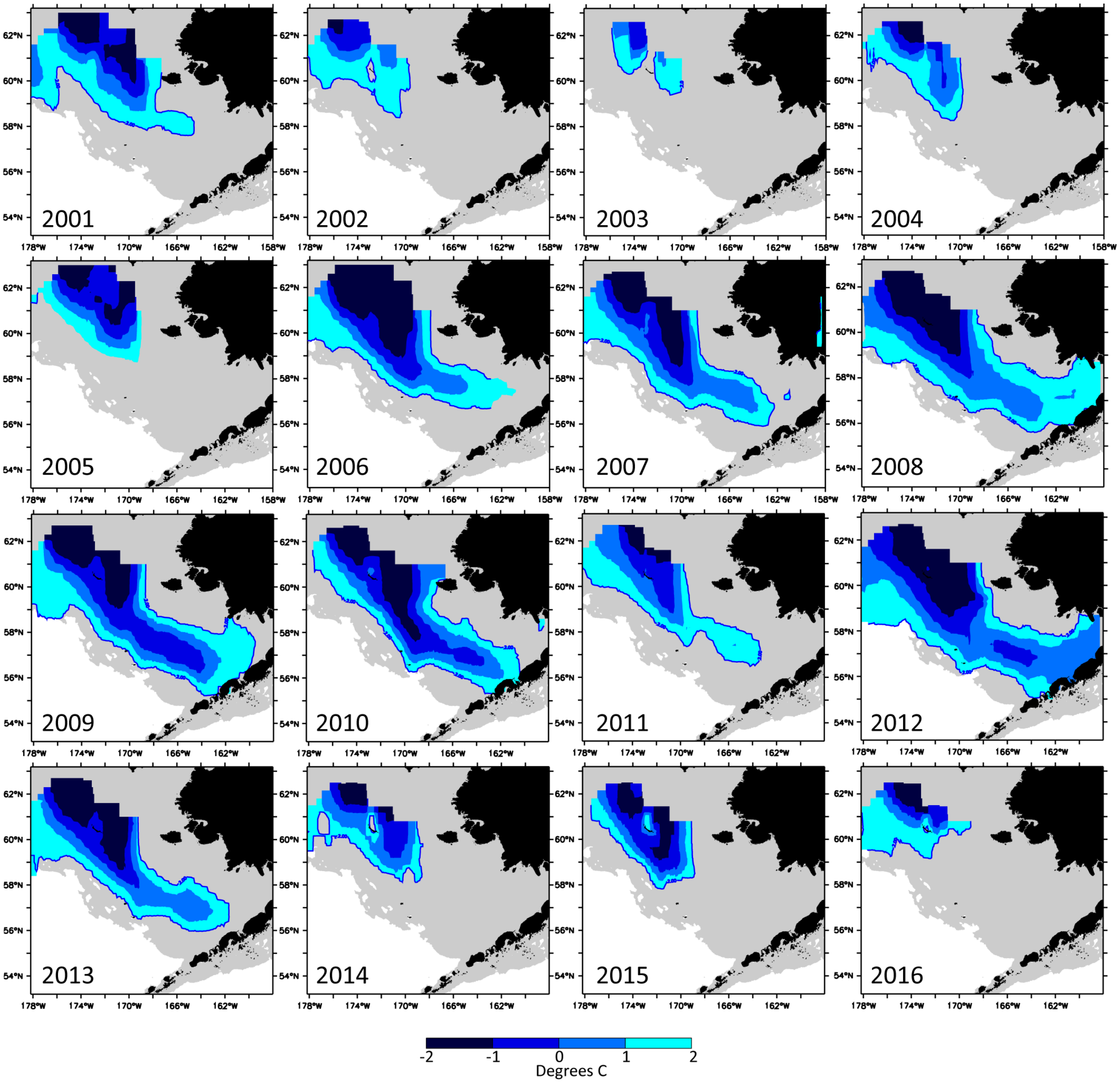

Figure 16: Cold pool extent in the southeast Bering Sea from 2001 to 2016. After an extensive sequence of cold years, the years 2014 - 2016 more resemble earlier warm years.

Summer Bottom and Surface Temperatures - Eastern Bering Sea Shelf

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Last updated: October 2016

Description of indicator: Survey operations for the annual AFSC eastern Bering Sea shelf bottom trawl survey in 2016 started on 31 May and ended on 26 July.

Status and trends: Both surface and bottom temperature means for the 2016 eastern Bering Sea shelf were the highest on record in the 35 year bottom trawl survey time-series (Figure 17). The 2016 mean surface temperature was 9.5°C, which was 2.3°C higher than 2015 and 3.1°C above the time-series mean (6.4°C). The mean bottom temperature was 4.5°C, which was 1.2°C higher than 2015 and 2.2°C above the time-series mean (2.4°C). The 'cold pool', defined as the area where temperatures <2°C, was the smallest in the time series and confined to the upper middle shelf (Figure 18).

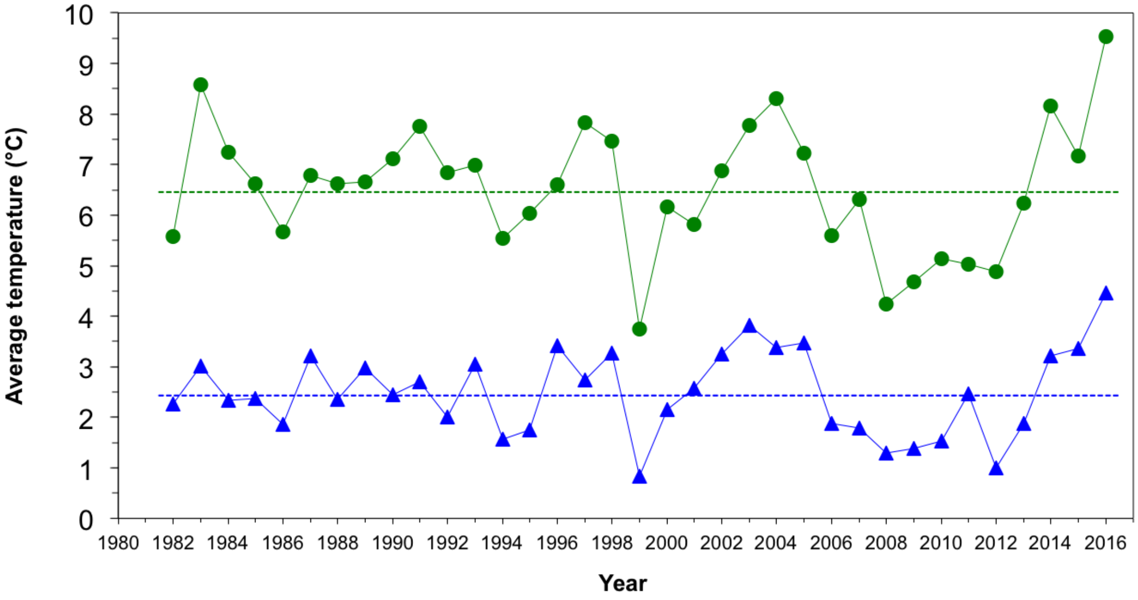

Figure 17: Average summer surface (green dots) and bottom (blue triangles) temperatures (°C) of the eastern Bering Sea shelf collected during the standard bottom trawl surveys from 1982-2016. Water temperature samples from each station were weighted by the proportion of their assigned stratum area. Dotted lines represent the time-series mean for 1982-2016.

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

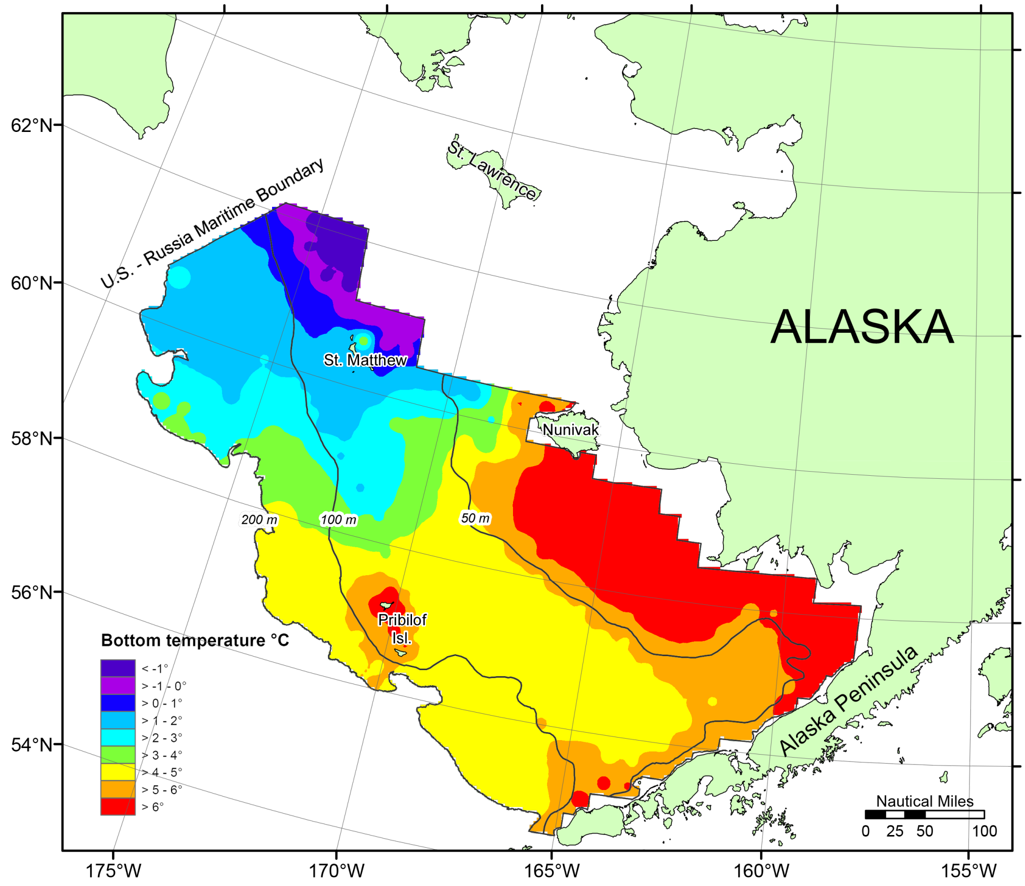

Figure 18: Contour map of the near-bottom temperatures from the 2016 eastern Bering Sea shelf bottom trawl survey.

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).

Spatial Patterns in Near Bottom Oceanographic Variables Collected During AFSC Bottom Trawl Surveys

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Last updated: October 2016

Description of indicator: In 2012 the RACE Division purchased four SeaGuard CTD units (funded by the North Pacific Research Board and Deep Sea Coral Research and Technology Program). These units were purchased to increase the oceanographic data collections during bottom trawl surveys of the eastern Bering Sea slope, Gulf of Alaska, and Aleutian Islands.

The CTD units collect concurrent depth, temperature, salinity, pH, oxygen, and turbidity data. The units are deployed on the headrope of the AFSC bottom trawls during most survey hauls. To date, the data have been collected on the 2012 and 2016 EBS slope, the 2013 and 2015 GOA, and the 2014 and 2016 Aleutian Islands bottom trawl surveys.

The data are presented here as a series of maps of bottom variables (the average value of each variable during the on-bottom period of the bottom trawl haul). The data have been interpolated to a 1 km by 1 km raster using R software. For salinity, pH, and oxygen, kriging with a fitted exponential semi-variance model was used based on the spatial pattern in semi-variance plots. The turbidity data exhibited a linear decrease in semi-variance with distance, so inverse distance weighting was used for this variable. The EBS slope data collection in 2012 ($n = 188$ trawl hauls) and 2016 ($n = 157$ trawl hauls) covered the entire continental slope at depths from approximately 200 m to 1200 m (Figure 19). The data were not corrected for time of the year, so some within-season temporal effects could be present because of the prosecution of the EBS slope survey from south to north in the first half of the survey and then a return south in the second half of the survey.

Status and trends: 2016 was a much warmer year than 2012 throughout the slope. In 2012, the warmest water was in the south and temperatures decreased moving north, however, in 2016 there were pockets of warm water throughout the slope area with no south-north trend (Figure 20).

Salinity was generally highest in 2016 and was fairly uniform over the slope, although water tended to become slightly less salty at shallower depths. In 2012, salinity over the slope was generally less. Salinity varied between 32.8 and 34.3 ppm in 2012 and 33.2 and 34.6 in 2016.

Oxygen concentrations were lower in 2016 than in 2012. The spatial patterns in oxygen were similar between the two years, with higher oxygen concentrations in Bering Canyon and in some of the canyons to the north (particularly the southern arm of Pribilof Canyon), but oxygen was uniformly lower in 2016.

The pH was distinctly different between the two years. The pH was measured from 7.5 to 7.9 in 2012, while it was only 7.1 to 7.2 in 2016. This is a suspiciously large change over the two years and may point to some issues with the equipment. The pH meters have been untrustworthy with at least 3 failures in the last 2 years. A better measurement system for pH is needed.

Turbidity was constant and low in both 2012 and 2016, with the exception of a station between Zhemchug and Pervenets Canyons, which had elevated turbidity (> 115) in 2016.

Factors influencing observed trends: The observed spatial trends in near bottom temperature and salinity are likely caused by relationships to depth in the EBS. The trends in other variables are likely the result of areas of differential primary production and other oceanographic features. The observed spatial patterns in oxygen in the eastern Bering Sea slope are probably a result of

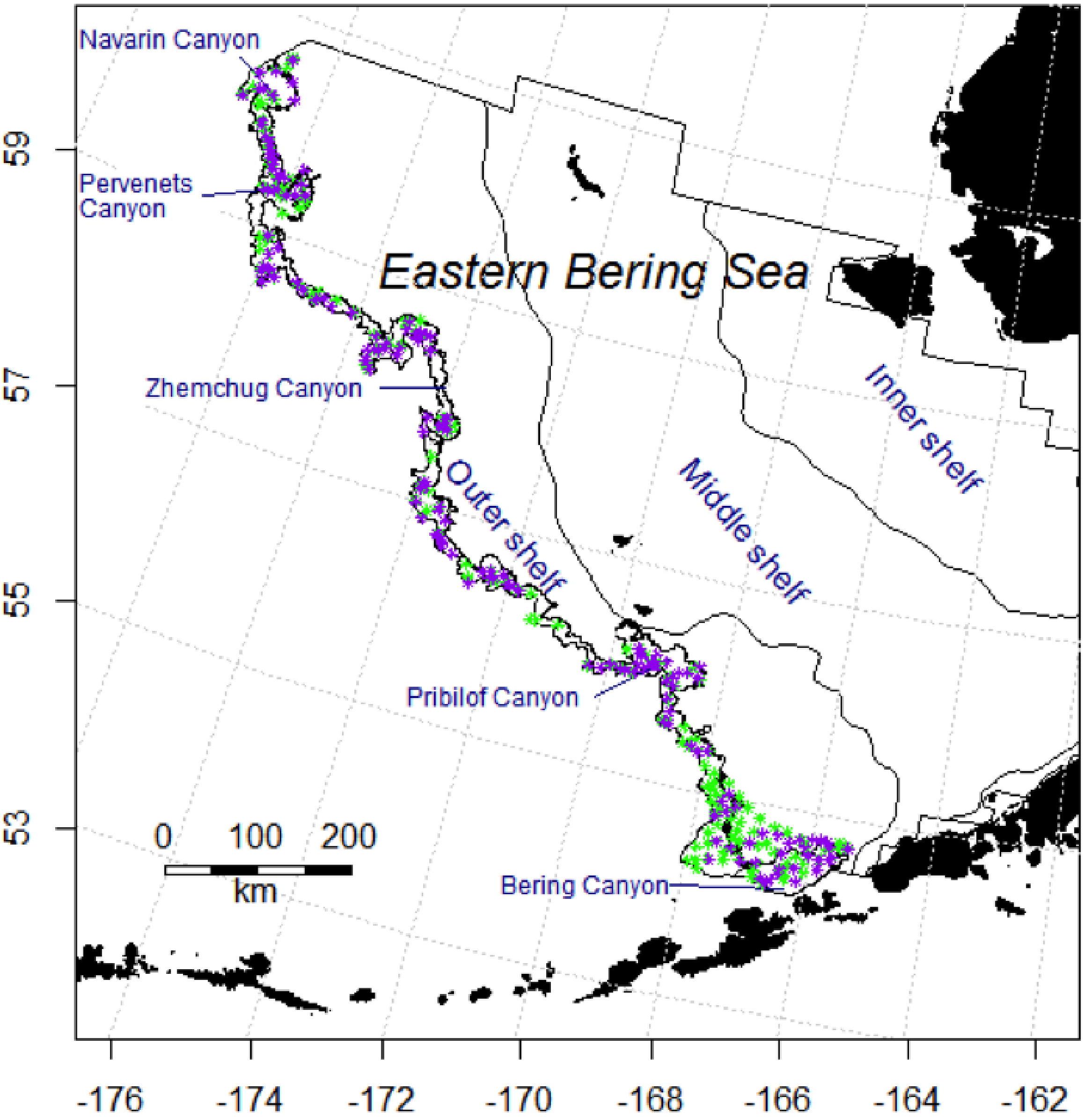

Figure 19: Locations for 2012 (green, $n = 188$) and 2016 (purple, $n = 157$) CTD deployments on the headrope of the bottom trawl used in the eastern Bering Sea slope bottom trawl survey.

the interaction between depth and currents moving up through the canyons along the slope.

Implications: As more of these data are collected, relationships between fish and invertebrate distributions will be explored. When more years of data have been collected for each area, variability of spatial patterns may be important.

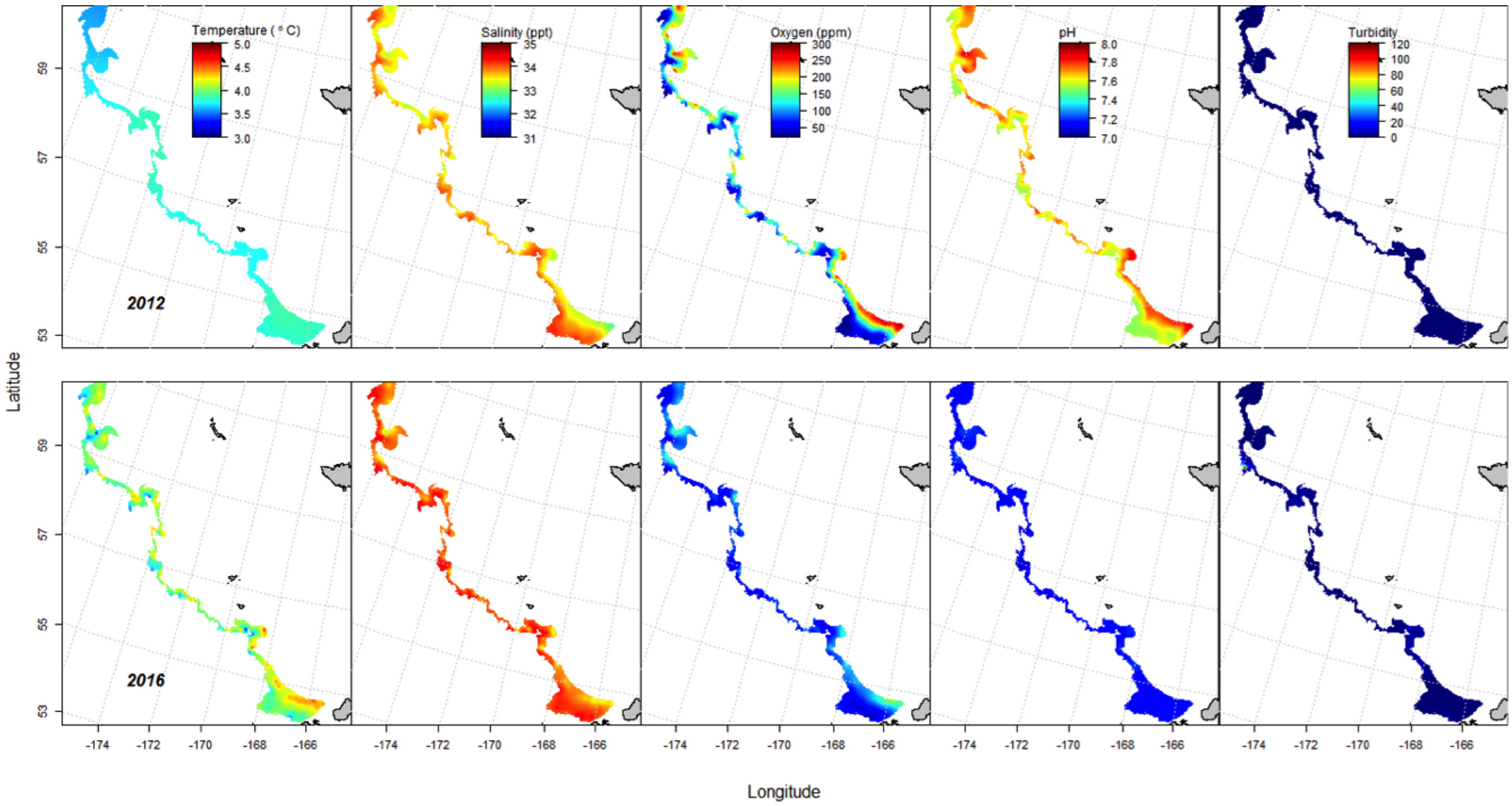

Figure 20: Maps of interpolated temperature, salinity, oxygen concentration, pH, and turbidity for the eastern Bering Sea slope in 2012 and 2016. The data were collected at bottom trawl survey stations, averaged for the on-bottom portion of the bottom trawl haul, and were interpolated to a 1 km by 1 km grid for the slope.

Variations in Temperature and Salinity During Late Summer/Early Fall 2002-2015 in the Eastern Bering Sea - BASIS

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Last updated: August 2016

Description of indicator: Oceanographic and fisheries data were collected over the eastern Bering Sea (EBS) shelf during fall 2002-2015 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 2002-2015 normalized by standard deviation) of temperature and salinity were separately computed for each Bering Sea Project region (Ortiz et al., 2012). Normalized anomalies of MLD were similarly estimated for middle and outer domain regions. Only station locations sampled 5+ years were included in the analyses (Figure 21).

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 (Figure 22, Figure 23). In 2014, Tabove was high for all regions, whereas in 2015 it was above average in only two regions, likely due to the early onset of fall mixing which deepened the MLD (Figure 22). Tbelow was above average primarily in southern regions in 2014 and 2015, unlike the earlier warm periods of 2003-2005 when above average Tbelow extended up to ∼Bering Strait (Figure 23). 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, 2014-2015) than in cold years (2006-2012) (Figure 24, Figure 25). 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 26).

Factors influencing observed trends: Sea ice during winter and spring extended further to the south as the climate cooled. The cold pool is related to sea ice and thus extends further to the 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 sea 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. 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

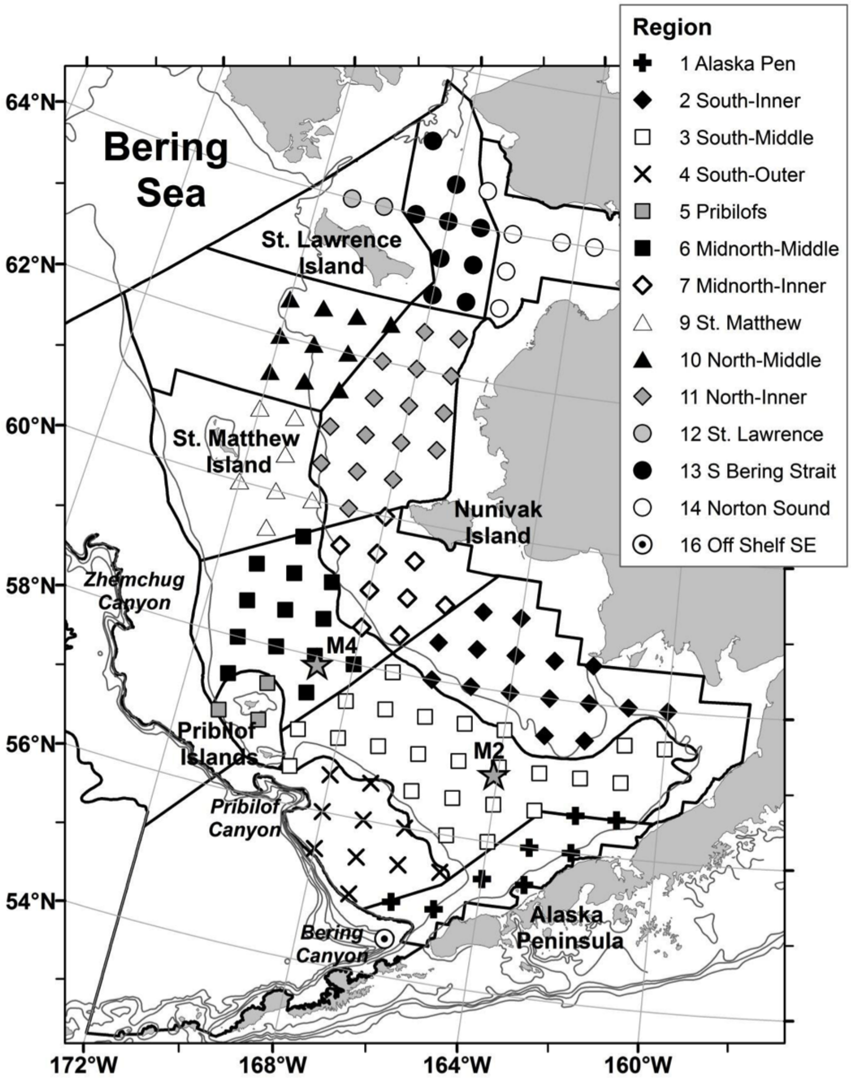
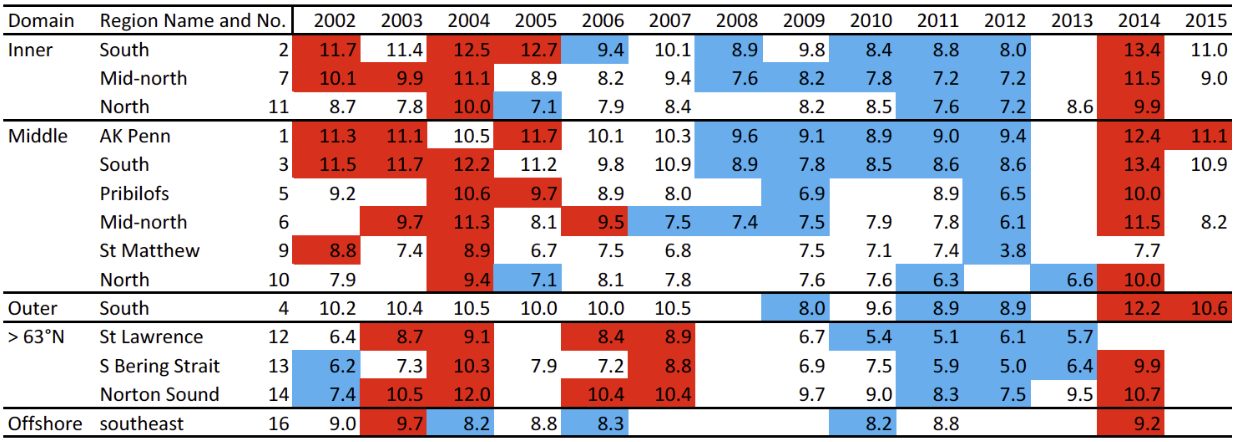


Figure 21: Stations within each Bering Sea Project region (Ortiz et al., 2012) sampled a minimum of 5 years between 2002 and 2015. We sampled three inner shelf regions (regions 2, 7, 11), six middle shelf regions (regions 1, 3, 5, 6, 9, 10), one outer shelf region (region 4), and three regions north and east of St. Lawrence Island (regions 12, 13, and 14).

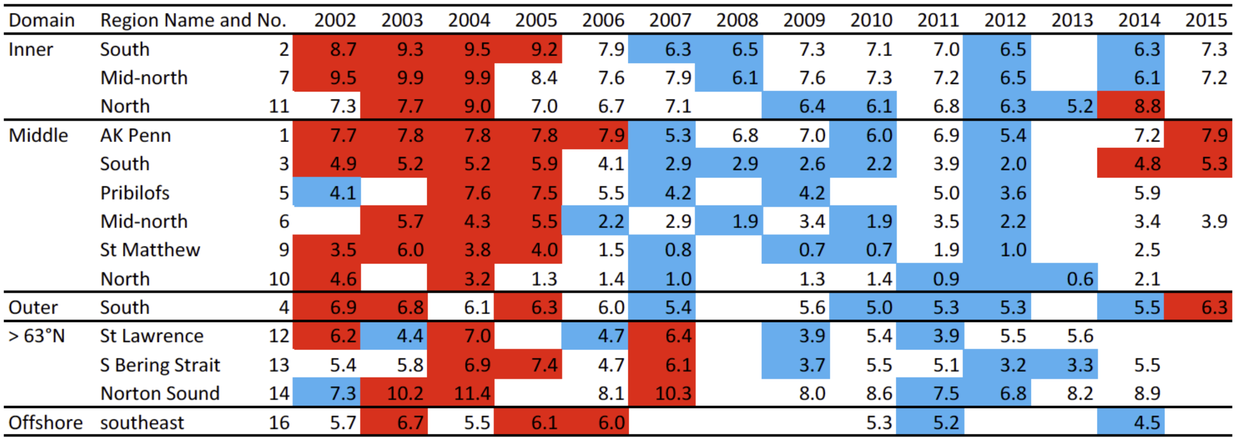
warmer than average in the middle domain regions 3, 6, and 9 reflecting the lack of sea ice during spring. In contrast, Tabove was average in these regions, due to high wind mixing in August prior to and during the survey (Eisner et al., 2015).

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).



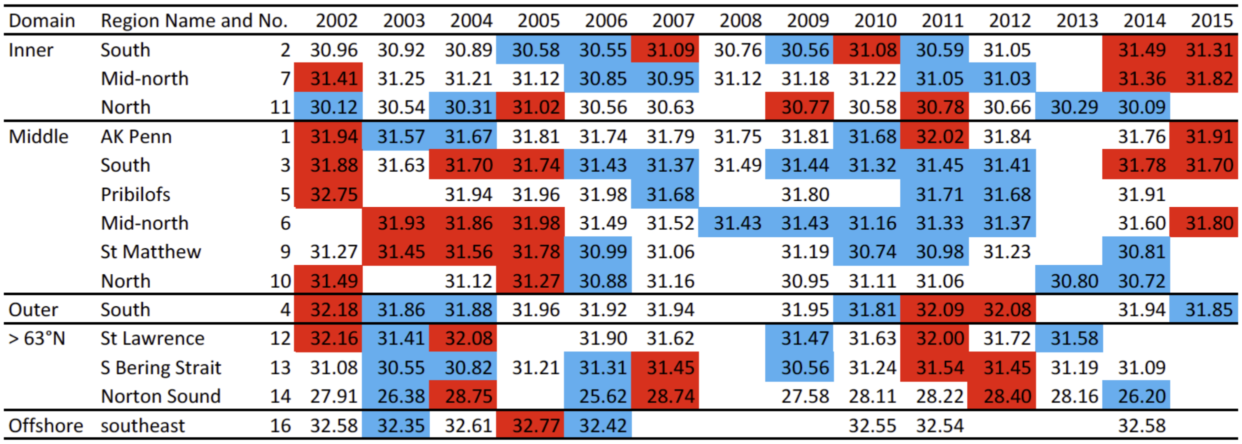
Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Inner	South	2	11.7	11.4	12.5	12.7	9.4	10.1	8.9	9.8	8.4	8.8	8.0		13.4	11.0
	Mid-north	7	10.1	9.9	11.1	8.9	8.2	9.4	7.6	8.2	7.8	7.2	7.2		11.5	9.0
	North	11	8.7	7.8	10.0	7.1	7.9	8.4		8.2	8.5	7.6	7.2	8.6	9.9	
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
	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
	Pribilofs	5	9.2		10.6	9.7	8.9	8.0		6.9		8.9	6.5		10.0	
	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
	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	
	North	10	7.9		9.4	7.1	8.1	7.8		7.6	7.6	6.3		6.6	10.0	
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
> 63°N	St Lawrence	12	6.4	8.7	9.1		8.4	8.9		6.7	5.4	5.1	6.1	5.7		
	S Bering Strait	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	
	Norton Sound	14	7.4	10.5	12.0		10.4	10.4		9.7	9.0	8.3	7.5	9.5	10.7	
Offshore	southeast	16	9.0	9.7	8.2	8.8	8.3				8.2	8.8			9.2	

Figure 22: Mean Tabove (°C) color coded with anomaly 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 below average (< -0.5) normalized anomaly.



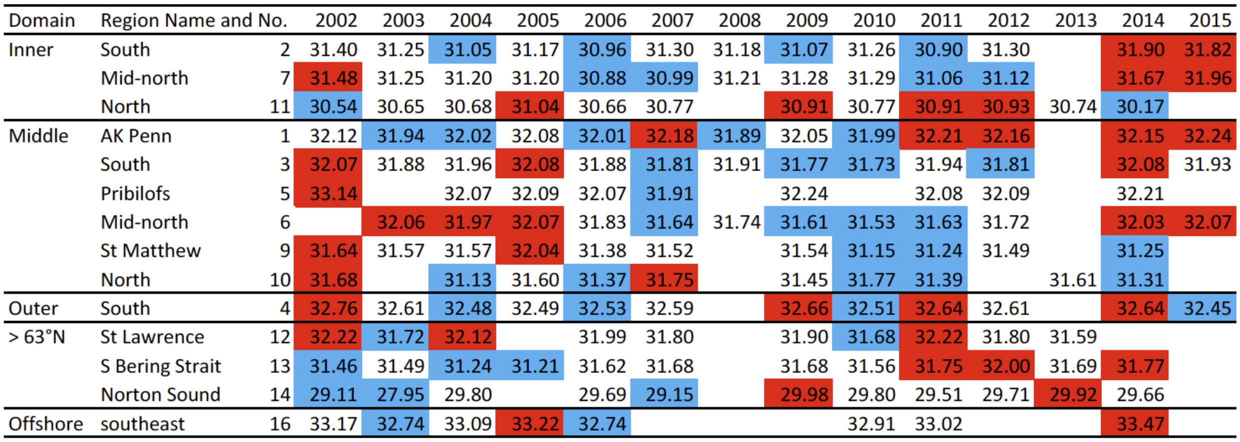
Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Inner	South	2	8.7	9.3	9.5	9.2	7.9	6.3	6.5	7.3	7.1	7.0	6.5		6.3	7.3
	Mid-north	7	9.5	9.9	9.9	8.4	7.6	7.9	6.1	7.6	7.3	7.2	6.5		6.1	7.2
	North	11	7.3	7.7	9.0	7.0	6.7	7.1		6.4	6.1	6.8	6.3	5.2	8.8	
Middle	AK 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
	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
	Pribilofs	5	4.1		7.6	7.5	5.5	4.2		4.2		5.0	3.6		5.9	
	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
	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	
	North	10	4.6		3.2	1.3	1.4	1.0		1.3	1.4	0.9		0.6	2.1	
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
> 63°N	St Lawrence	12	6.2	4.4	7.0		4.7	6.4		3.9	5.4	3.9	5.5	5.6		
	S Bering Strait	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	
	Norton Sound	14	7.3	10.2	11.4		8.1	10.3		8.0	8.6	7.5	6.8	8.2	8.9	
Offshore	southeast	16	5.7	6.7	5.5	6.1	6.0				5.3	5.2			4.5	

Figure 23: Mean Tbelow (°C) color coded by normalized anomaly as described in Figure 22.



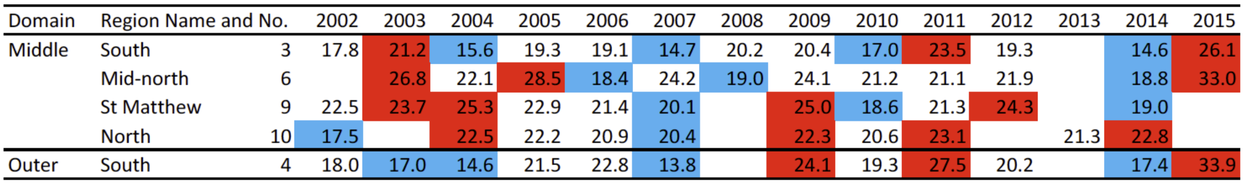
Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Inner	South	2	30.96	30.92	30.89	30.58	30.55	31.09	30.76	30.56	31.08	30.59	31.05		31.49	31.31
	Mid-north	7	31.41	31.25	31.21	31.12	30.85	30.95	31.12	31.18	31.22	31.05	31.03		31.36	31.82
	North	11	30.12	30.54	30.31	31.02	30.56	30.63		30.77	30.58	30.78	30.66	30.29	30.09	
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
	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
	Pribilofs	5	32.75		31.94	31.96	31.98	31.68		31.80		31.71	31.68		31.91	
	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
	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	
	North	10	31.49		31.12	31.27	30.88	31.16		30.95	31.11	31.06		30.80	30.72	
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
> 63°N	St Lawrence	12	32.16	31.41	32.08		31.90	31.62		31.47	31.63	32.00	31.72	31.58		
	S Bering Strait	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	
	Norton Sound	14	27.91	26.38	28.75		25.62	28.74		27.58	28.11	28.22	28.40	28.16	26.20	
Offshore	southeast	16	32.58	32.35	32.61	32.77	32.42				32.55	32.54			32.58	

Figure 24: Mean Sabove (PSU) color coded by normalized anomaly as described in Figure 22.



Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
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
	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
	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	
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
	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
	Pribilofs	5	33.14		32.07	32.09	32.07	31.91		32.24		32.08	32.09		32.21	
	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
	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	
	North	10	31.68		31.13	31.60	31.37	31.75		31.45	31.77	31.39		31.61	31.31	
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
> 63°N	St Lawrence	12	32.22	31.72	32.12		31.99	31.80		31.90	31.68	32.22	31.80	31.59		
	S Bering Strait	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	
	Norton Sound	14	29.11	27.95	29.80		29.69	29.15		29.98	29.80	29.51	29.71	29.92	29.66	
Offshore	southeast	16	33.17	32.74	33.09	33.22	32.74				32.91	33.02			33.47	

Figure 25: Mean Sbelow (PSU) color coded by normalized anomaly as described in Figure 22.



Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
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
	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
	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	
	North	10	17.5		22.5	22.2	20.9	20.4		22.3	20.6	23.1		21.3	22.8	
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

Figure 26: MLD (m) color coded by normalized anomaly as described in Figure 22.

Update on Eastern Bering Sea Winter Spawning Flatfish Recruitment and Wind Forcing

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Last updated: August 2016

Description of indicator: Wilderbuer et al. (2002, 2013) summarized a study examining 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 changed to off-shore in the 1990-97 time series and coincided with below-average recruitment for Northern rock sole, Arrowtooth flounder, and Flathead sole 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 2016 and shown for 2008 through 2016 in Figure 27.

Status and trends: The 2016 springtime drift patterns appear to be consistent with years of below-average recruitment for winter-spawning flatfish. Two out of the past nine OSCURS runs for 2008-2016 were 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

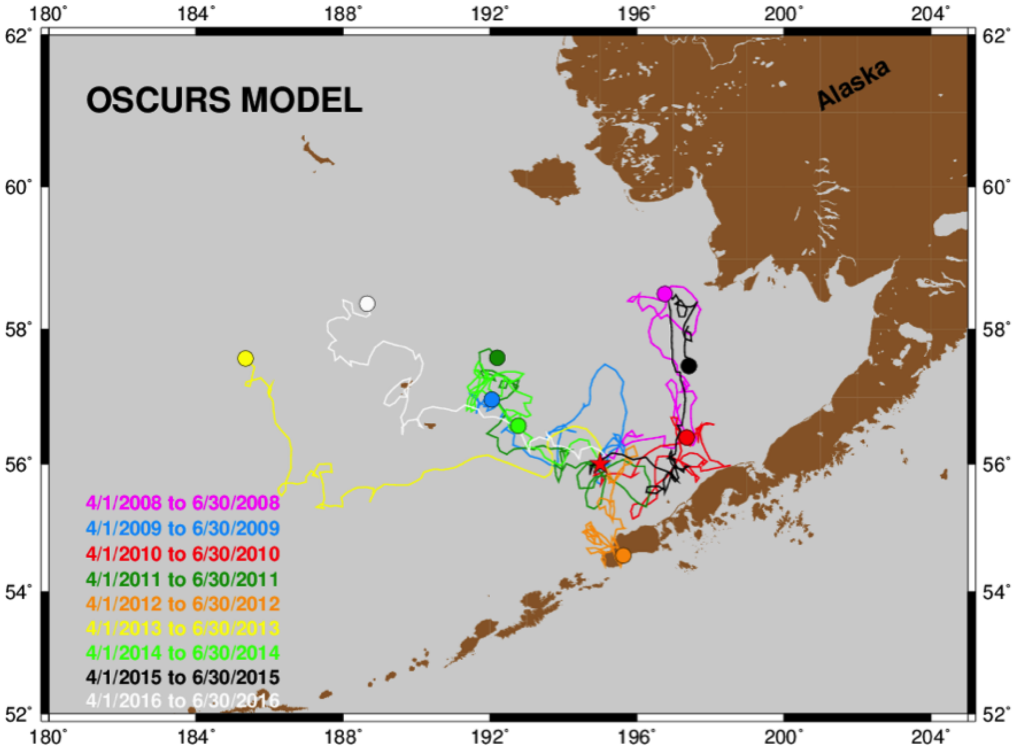

Figure 27: OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56°N, 164°W from April 1-June 30 for 2008-2016.

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 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 role. 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 2016 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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Last updated: October 2016

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 1982-2016. 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 were significantly lower in 2016 compared to sea whips, which changed little. One of the difficulties in detecting trends of structural epifauna groups in the eastern Bering Sea shelf is the low taxonomic resolution within the groups and because the quality and specificity of field identifications and their enumeration have varied over the time series (Stevenson et al., In press; Stevenson and Hoff, 2009). Moreover, relatively large variability in the relative CPUE values makes trend analysis difficult (Figure 28).

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.

Coral, Sponge, and Sea Whip Trends in the Eastern Bering Sea Slope Environment

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Last updated: October 2016

Description of indicator: Presented are the mean CPUE (kg/km^2) of the coral, sponge, and sea whips from standard bottom trawl surveys along the eastern Bering Sea upper continental slope. The survey is nominally conducted on a biennial schedule and was completed in 2002, 2004, 2008,

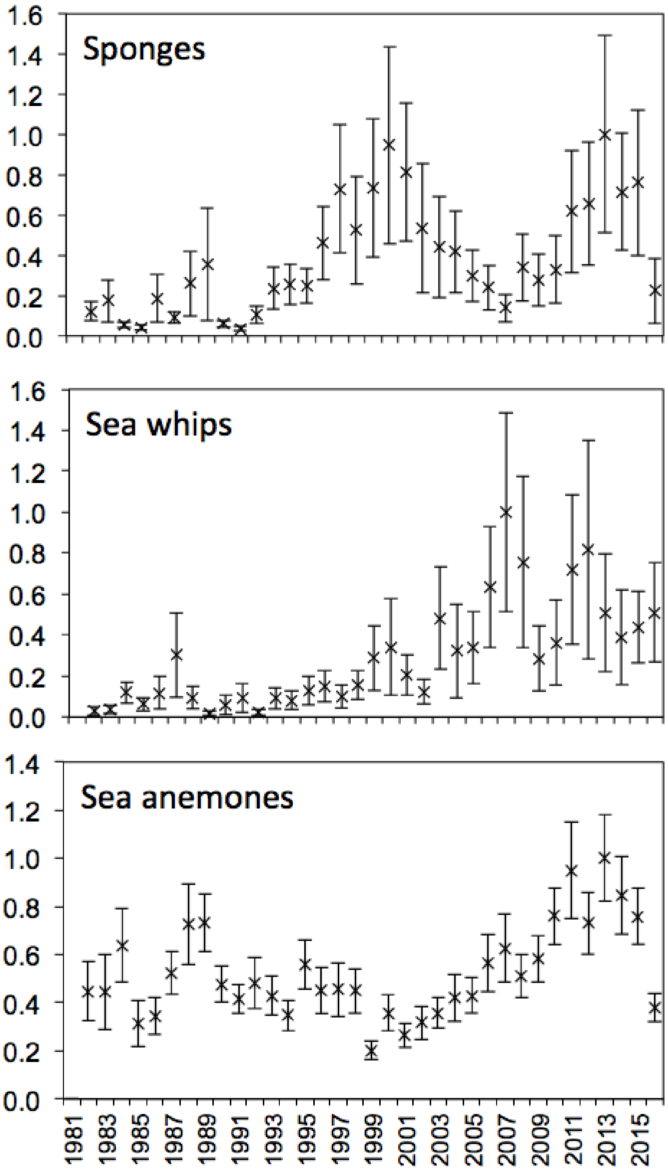

Figure 28: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for benthic epifauna during the May to August time period from 1982-2016.

2010, 2012, and 2016. These three groups of benthic sessile organisms constitute an important component of the habitat by adding three dimensional structure and habitat complexity in an otherwise relatively flat sandy environment.

Status and trends: All indicators are highly variable across the time series presented. Corals are highly variable; the 2016 value is the highest recorded for the group since 2002. The 2016 estimate increased from the lowest value in 2012 to the highest in 2016. Sponges were very high during the 2008 and 2010 surveys with a significant drop in abundance in 2012. The mean CPUE from the 2016 survey is slightly higher from the 2012 survey for sponges. Sea whips were very high in abundance during the 2010 and 2012 surveys with a significant drop in abundance in 2016. The mean CPUE from the 2016 survey is slightly below the overall mean for the group with higher abundance than the 2002-2008 surveys (Figure 29).

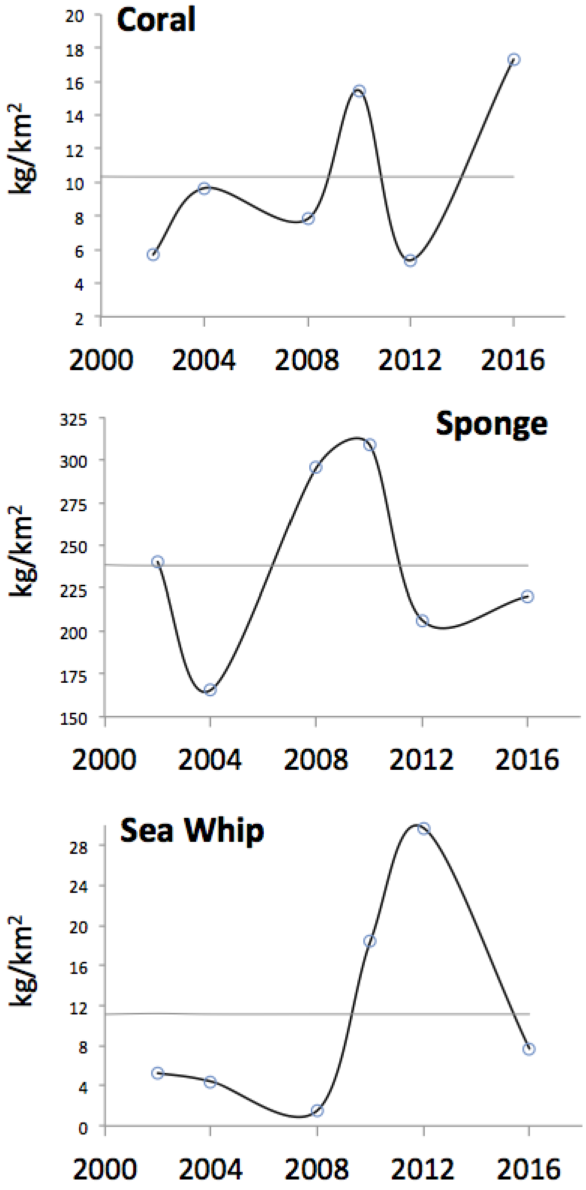

Figure 29: Mean CPUE (kg/km^2) from the eastern Bering Sea upper continental slope groundfish survey for all corals (top), sponges (middle), and sea whips (bottom) encountered. The overall time trend mean is included on each plot for reference (solid horizontal line).

Factors influencing observed trends: Corals, sponges, and sea whips are very patchy along the EBS upper continental slope and relatively low in abundance. The highly variable nature of these indicators is typical of relatively rare species and patchy distributions.

Implications: Although these three groups (coral, sponge, sea whips) are widely recognized as important indicators of ecosystem health and long lived species that are vulnerable to habitat perturbations, the data presented here are difficult to interpret as possessing any long term trends or speculate on impact to ecosystem health from these highly variable groups of species. Consistent monitoring and taxonomic resolution of species complexes in these groups will aid in understanding these trends and their environmental significance.

Coral, Sponge, and Sea Whip Distribution and Composition Trends in the Eastern Bering Sea Slope Environment

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Last updated: October 2016

Description of indicator: Presented are the CPUE (kg/km^2) distributions (coral, sponge, sea whips) from 2016, and composition trends across the time series (2002-2016) of corals and sea whips from the standard bottom trawl surveys conducted along the eastern Bering Sea upper continental slope. These three groups of benthic sessile organisms constitute an important component of the habitat by adding three dimensional structure and habitat complexity in an otherwise relatively flat sandy environment.

Status and trends: *Distribution:* Corals were primarily distributed in the northern Bering Sea region from Pervenets to Pribilof Canyon, with no records in 2016 from the Bering Canyon subarea. The highest abundance recorded came from between Zhemchug and Pribilof Canyons. Sponges are abundant and widely distributed in the eastern Bering Sea and were found in all subareas and depth strata. Sea whips were relatively rare occurrences in 2016 with the greatest encounters occurring in the far northern region of the survey in Navarin and Pervenets canyons. Sea whips were only encountered in a single area (two stations) between Pribilof and Bering Canyon in the southern Bering Sea region. Although highly abundant along the upper slope region, they are patchy and often slightly shallower than the depth range that the slope survey encounters (Figure 30).

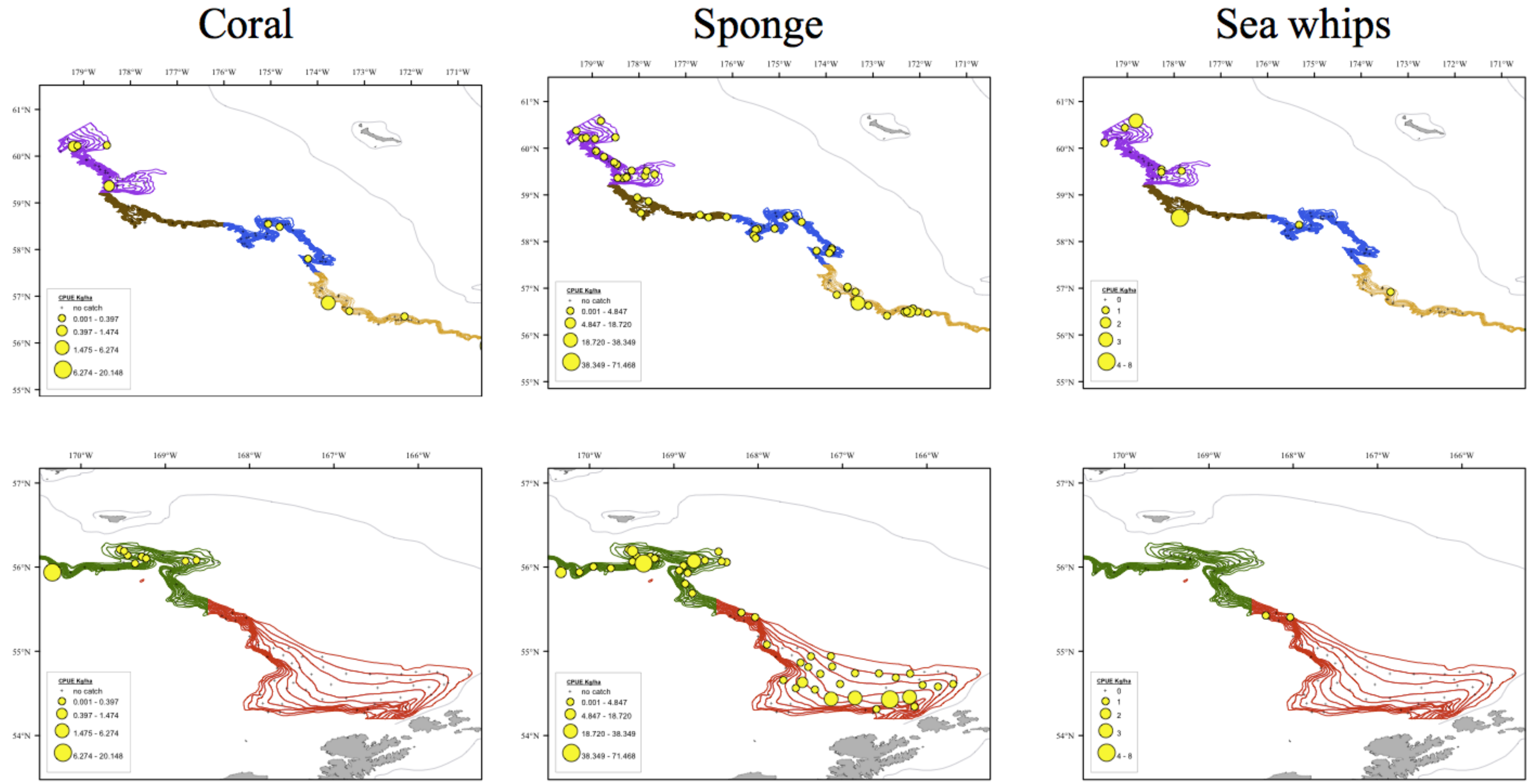

Figure 30: Distribution and relative abundance (CPUE) of all coral (left panel), sponge (center panel), and sea whips (right panel) in the northern (top row) and southern (bottom row) regions from the 2016 eastern Bering Sea upper continental slope groundfish survey. Colors depict slope regions. Circle size is proportional to catch; plus signs denote no catch.

Composition trends: Coral composition for survey years from 2002-2016 shows that *Paragorgia*, a species of Kamchatka coral, and *Isidella*, a species of bamboo coral, were the predominant catches comprising nearly 90% of corals encountered by weight in nearly all years except 2010 where these two species comprised a little more than 70% of the coral composition. Other important species encountered along the slope include *Primnoa* species, *Amphilaphis* species, and *Anthomastus* species (Figure 31).

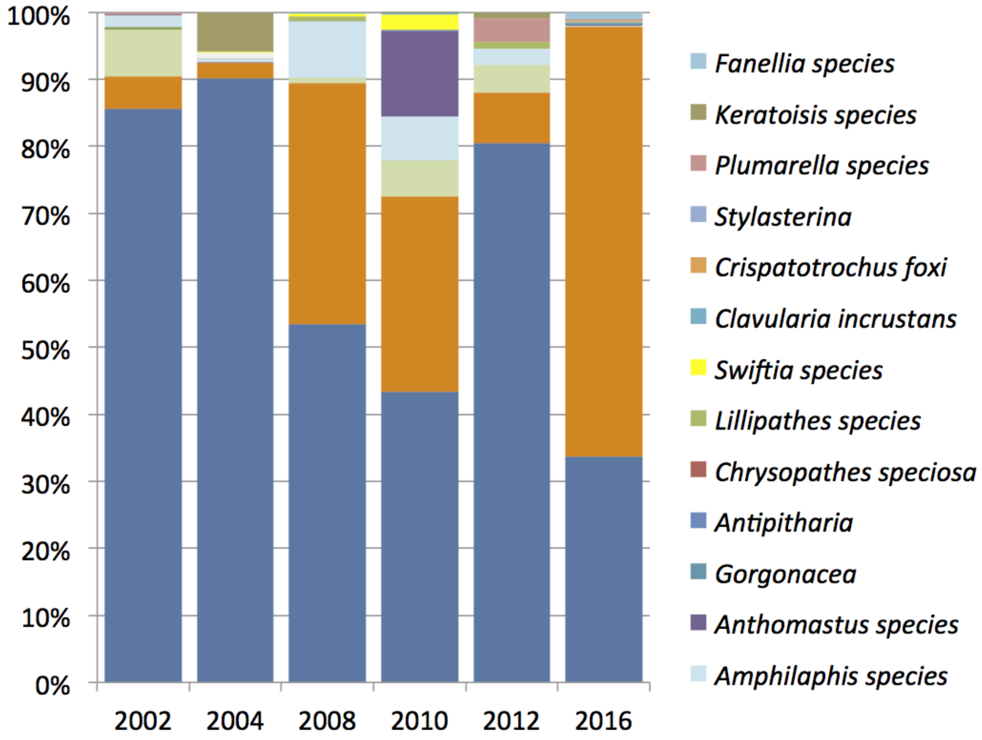

Figure 31: Composition of coral species from the eastern Bering Sea upper continental slope groundfish survey for survey years from 2002-2016. Data represents the proportion of CPUE (kg/ha) for each species or group of coral. Some species may occur in more than a single group when the higher taxonomic level was used for unidentified species.

Sponge species composition is not presented due to the poor taxonomic understanding and species identification recorded for the group over the survey period. In general most sponge species are recorded as Porifera at the family level and little species identification occurs on a routine basis during the slope survey.

Sea whips are frequently grouped in the Pennatulacea family during the survey due to limited identification guides and knowledge of the species. However, in several survey years (2008, 2016), when effort in identification was applied, the species composition was dominated by *Anthoptilium* species and *Halipteris* species (Figure 32).

Factors influencing observed trends: In all cases, increased taxonomic knowledge and effort and complete identification guides will improve our understanding of species diversity and specific habitat use.

Implications: Although these three groups (coral, sponge, sea whips) are widely recognized as important indicators of ecosystem health and long lived species that are vulnerable to habitat per-

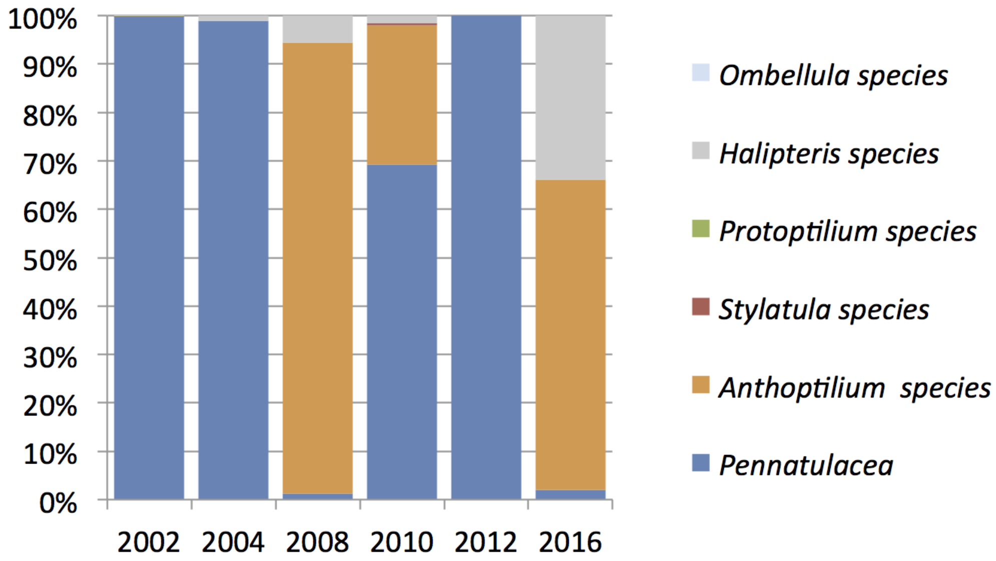

Figure 32: Composition of sea whip species from the eastern Bering Sea upper continental slope groundfish survey for survey years from 2002-2016. Data represents the proportion of CPUE (kg/ha) for each species or group of sea whip. Some species may occur in more than a single group when the higher taxonomic level was used for unidentified species.

turbations, the data presented shows a single years' distribution and trend in species composition. Consistent monitoring and taxonomic resolution of species complexes in these groups will aid in understanding distributions, habitat use, and their environmental significance.

Primary Production

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

Contributed by Lisa Eisner[1], Kristin Cieciel[1], Jeanette Gann[1], and Carol Ladd[2]
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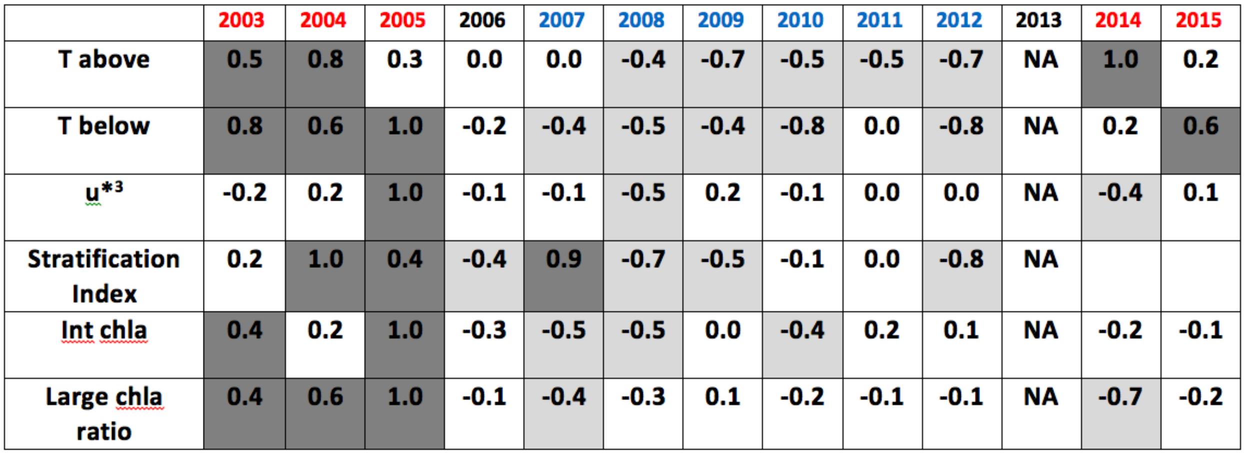
Last updated: August 2016

Description of indicator: BASIS fisheries oceanography surveys were conducted in the eastern Bering Sea from mid-August to late September for five warm (2003-2005, 2014-2015), 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). Large (>10 μm) phytoplankton biomass and fraction of total biomass (>10 μm / total chla) were estimated from discrete water samples filtered through GFF and 10 μm filters. 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^{*3}), a proxy for wind mixing, was obtained from NCEP reanalysis at M2 (courtesy of Nick Bond). Normalized anomalies of temperature, u^{*3}, stratification index, integrated chla, and large size fraction chla are shown for the southeastern Bering Sea middle shelf for 2003-2015 (Figure 33).



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
T above	0.5	0.8	0.3	0.0	0.0	-0.4	-0.7	-0.5	-0.5	-0.7	NA	1.0	0.2
T below	0.8	0.6	1.0	-0.2	-0.4	-0.5	-0.4	-0.8	0.0	-0.8	NA	0.2	0.6
u^{*3}	-0.2	0.2	1.0	-0.1	-0.1	-0.5	0.2	-0.1	0.0	0.0	NA	-0.4	0.1
Stratification Index	0.2	1.0	0.4	-0.4	0.9	-0.7	-0.5	-0.1	0.0	-0.8	NA		
Int chla	0.4	0.2	1.0	-0.3	-0.5	-0.5	0.0	-0.4	0.2	0.1	NA	-0.2	-0.1
Large chla ratio	0.4	0.6	1.0	-0.1	-0.4	-0.3	0.1	-0.2	-0.1	-0.1	NA	-0.7	-0.2

Figure 33: Normalized anomalies calculated for 2003 to 2015 or to 2012 (stratification index) for the southeastern Bering Sea middle shelf (Bering Sea Project regions 3 and 6; Ortiz et al. (2012)) for temperature (T) above and below the pycnocline, friction velocity cubed (u^{*3}) at PMEL Mooring M2, August stratification index, integrated chla, and the ratio of large (>10 μm) to total chla over top 50 m (August-September) from BASIS data. Data normalized to maximum anomaly for each variable. Years are colored as red for warm, black for average, and blue for cold. Shading indicates if anomaly is positive (dark gray, 0.4 to 1), small (no shading, -0.3 to 0.3), or negative (light gray, -1 to -0.4).

Status and trends: The 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 34). 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 35). 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 later warm years (2014, 2015), total chlorophyll and the large size fraction were average, except for size fractions in 2014 which had the lowest percent large (highest % small) phytoplankton for the time series (Figure 35). This 2014 anomaly was due to an extensive coccolithophore bloom over the shelf (see p. 87). Coccolithophores are small phytoplankton cells (2-5 μm) with calcium carbonate plates that give the water a milky aqua appearance.

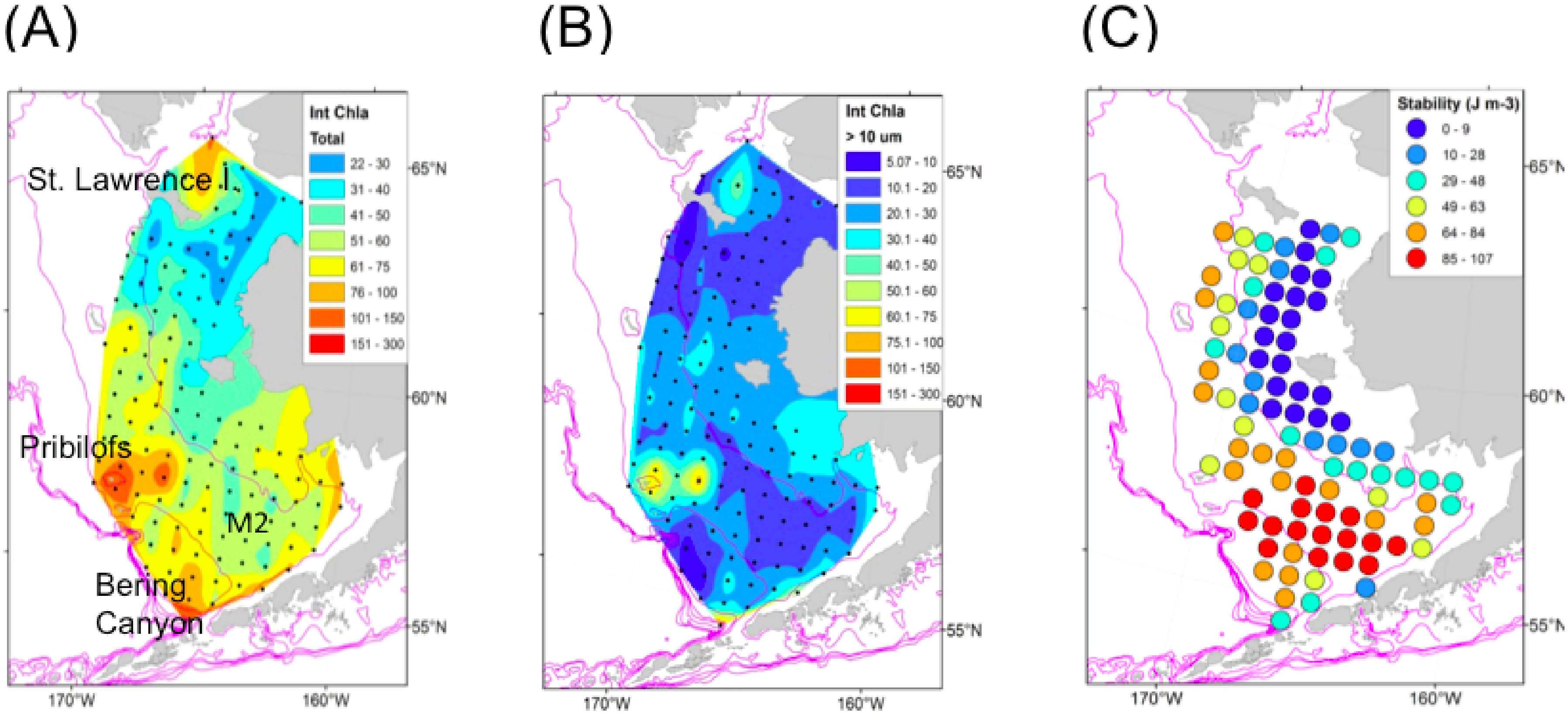


Figure 34: Contours of integrated total chla (mg m^{-2}) (A) and integrated >10 μm chla (B) averaged over 2003-2012, and stability (C) averaged over 2003-2009. Bathymetry contours are shown for 50 m, 100 m, and 200 m (shelf break).

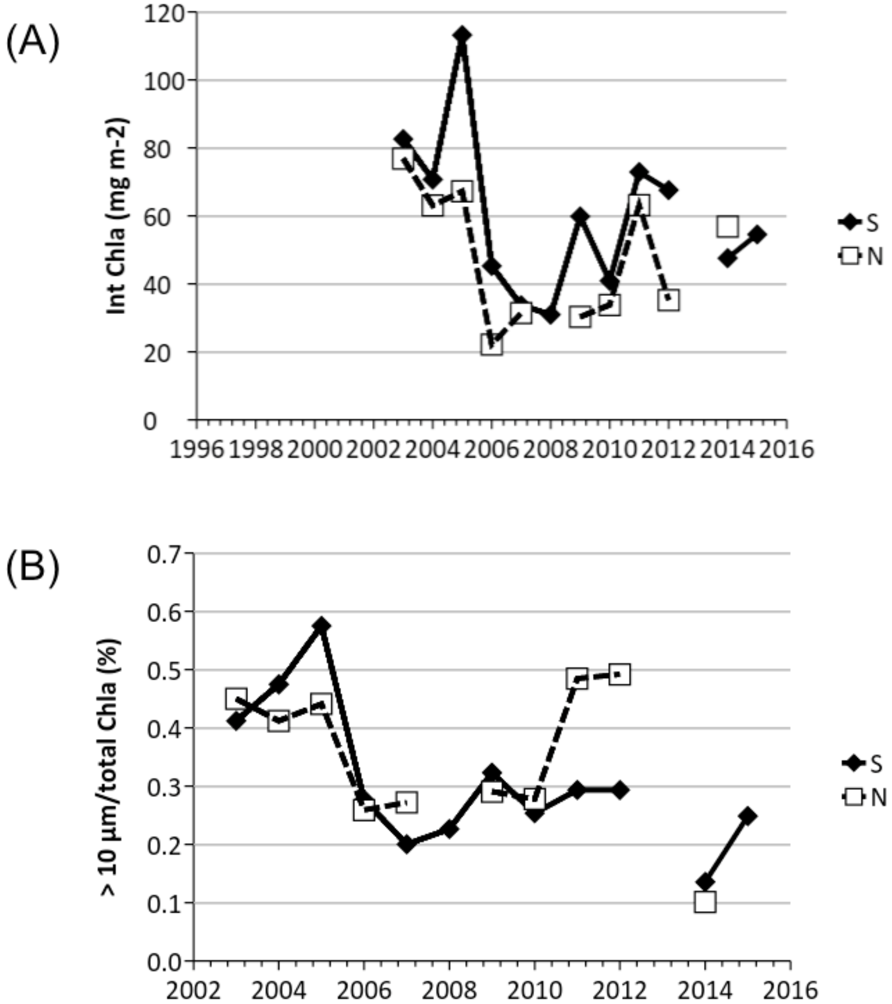


Figure 35: Integrated total chla (A) and ratio of large assemblages to total (>10 μm /total chla) (B) in the middle domain in the south (S, 54.5 - 59.5 °N, Bering Sea Project regions 3 and 6) and north (N, 60 - 63 °N, Bering Sea Project regions 9 and 10) for 2003-2015. Data not available for 2013 (S and N) or 2015 (N).

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 36). Deep nutrient-rich waters may be mixed to the surface to fuel production of large assemblages 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 33). 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 34).

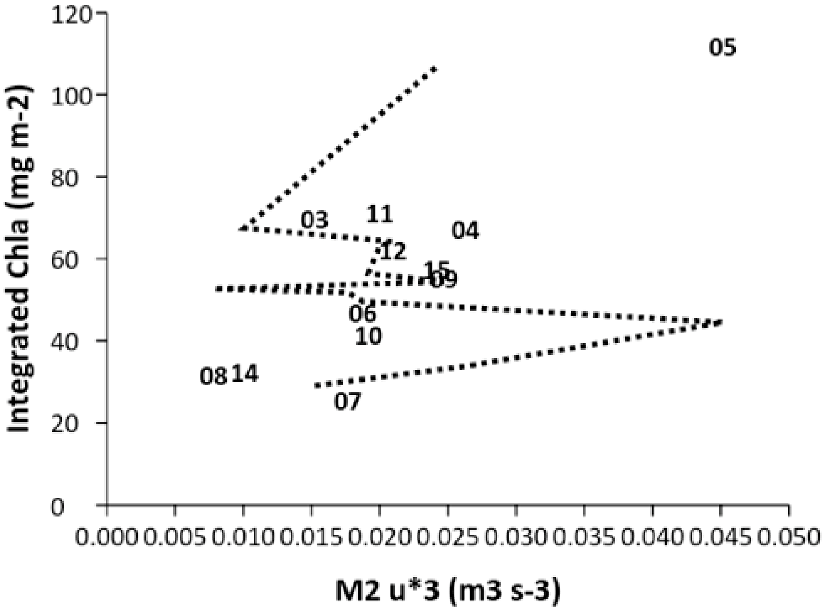


Figure 36: Linear regression between mean August u^{*3}, an indicator of wind mixing, at mooring M2 and integrated chla for the southeastern Bering Sea middle shelf in Bering Sea Project region 3 (region around M2) for 2003-2015 (no 2013 data available).

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 sea birds, 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 pollock, cod, salmon) (Eisner et al., 2015).

Late Summer Surface Silicate in the Eastern Bering Sea; Implications for Age-0 Walleye Pollock (*Gadus chalcogrammus*) Condition

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Last updated: August 2016

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. In contrast, surface silicate (silicic acid) is found in higher concentrations than nitrogen and inter-annual variations are more detectable. The condition of age-0 Walleye pollock 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 enter their first winter at sea.

Status and trends: Surface silicic acid as well as age-0 pollock weights were above average for both 2014 and 2015 when compared within the years 2006-2015, and in conjunction, Bering Sea pollock recruitment to age-1 for 2015 was relatively substantial (Ianelli et al., 2015). 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. Silicic acid concentrations were below 2 μM during late summer of 2007, a value observed in laboratory experiments to be a threshold, below which, diatom dominance (an important group of phytoplankton for movement of energy through the food web) is no longer possible (Egge and Aksnes, 1992). In addition to 2007 and 2012 had lowered silicic acid concentrations and age-0 pollock weights compared with other years (2006-2015) with low age-1 recruitment during 2008 and 2013 (Figure 37). 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 38). It may be that once silicic acid concentrations reach this threshold, the relationship with growth of age-0 pollock is diminished.

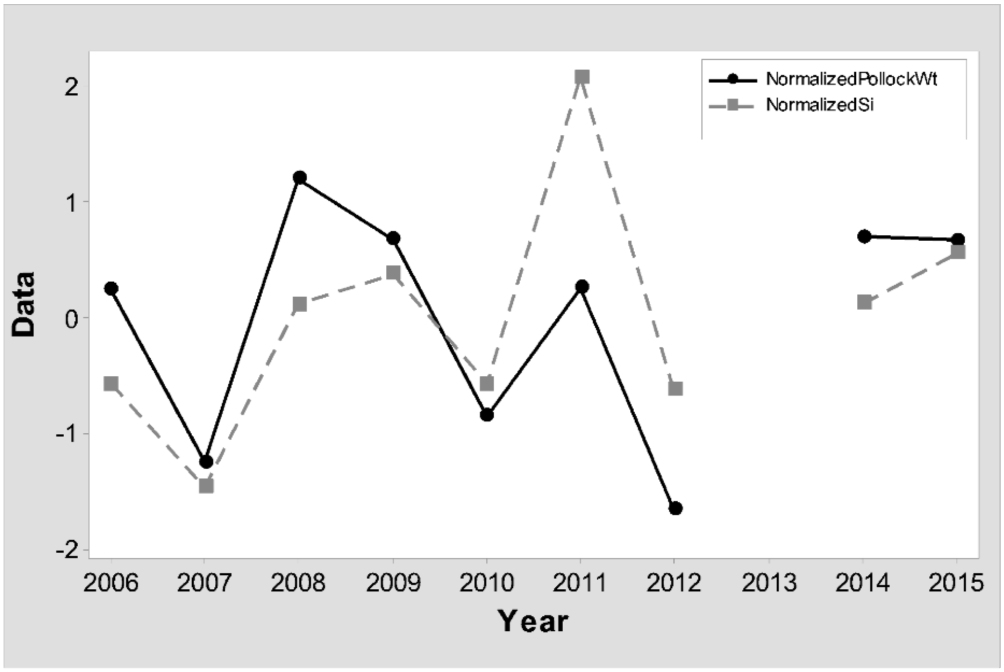

Figure 37: Inter-annual variability of normalized surface silicic acid ($Si(OH)_4$), from the Bering Sea south middle shelf (region 3) and normalized mean weights of age-0 Walleye pollock (south of 60°N). Values were normalized by subtracting the mean from each value and dividing by the standard deviation.

Factors influencing observed trends: During summer, the strength and frequency of summer storm events and water column stratification will influence how much silicic acid and other nutrients 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

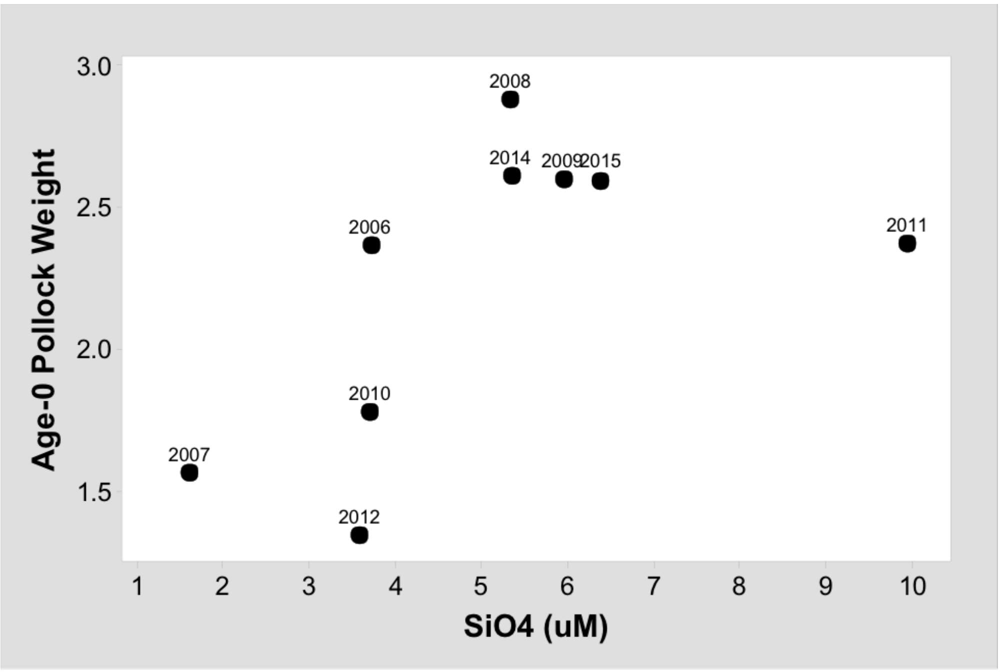

Figure 38: Yearly averages for age-0 pollock weight and silicic acid (Si(OH)$_4$).

is high (Gann et al., In press; Eisner et al., 2015). 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 could mark its potential as a variable for use in age-1 pollock recruitment models. 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.

Coccolithophores in the Bering Sea

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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 39). 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., 2012, 2002). Using methodology developed by Iida et al. (2012, 2002), we identify the number of satellite ocean color pixels associated with coccolithophores. 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) south of 60°N. Using only days that are more than 10% cloud-free, coccolithophore indices were calculated as an average area (km^2) covered by coccolithophores during the period 1 August - 30 September of each year. Blooms are most commonly observed during this time of year. In addition, reduced cloud cover during August/September allows better quantification.

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 common. Satellite ocean color data suggest that blooms are only found where water depths are between 20 and 100m. Blooms typically peak in September and appear to be related to strong stratification (Iida et al., 2012).

Status and trends: Annual images (Figure 39) show the spatial and temporal variability of coccolithophore blooms in August/September. Annual indices are obtained from these satellite data by averaging spatially over the inner and middle shelf (Figure 40). Coccolithophore abundance was particularly high during the early part of the record (1998 - 2000), with an index (averaged over the 3 years) of 186,420 km^2 for the middle and inner shelf combined. In 2001, the index dropped to 137,881 km^2 and remained low ($<$80,000 km^2) until 2006. In 2007, the index rose above 100,000 km^2. A higher index ($>$ 80,000 km^2) was observed in 2007, 2009, 2011, 2014, and 2016 for the middle shelf and in 2011 and 2014 ($>$ 40,000 km^2) for the inner shelf.

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 vise 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.

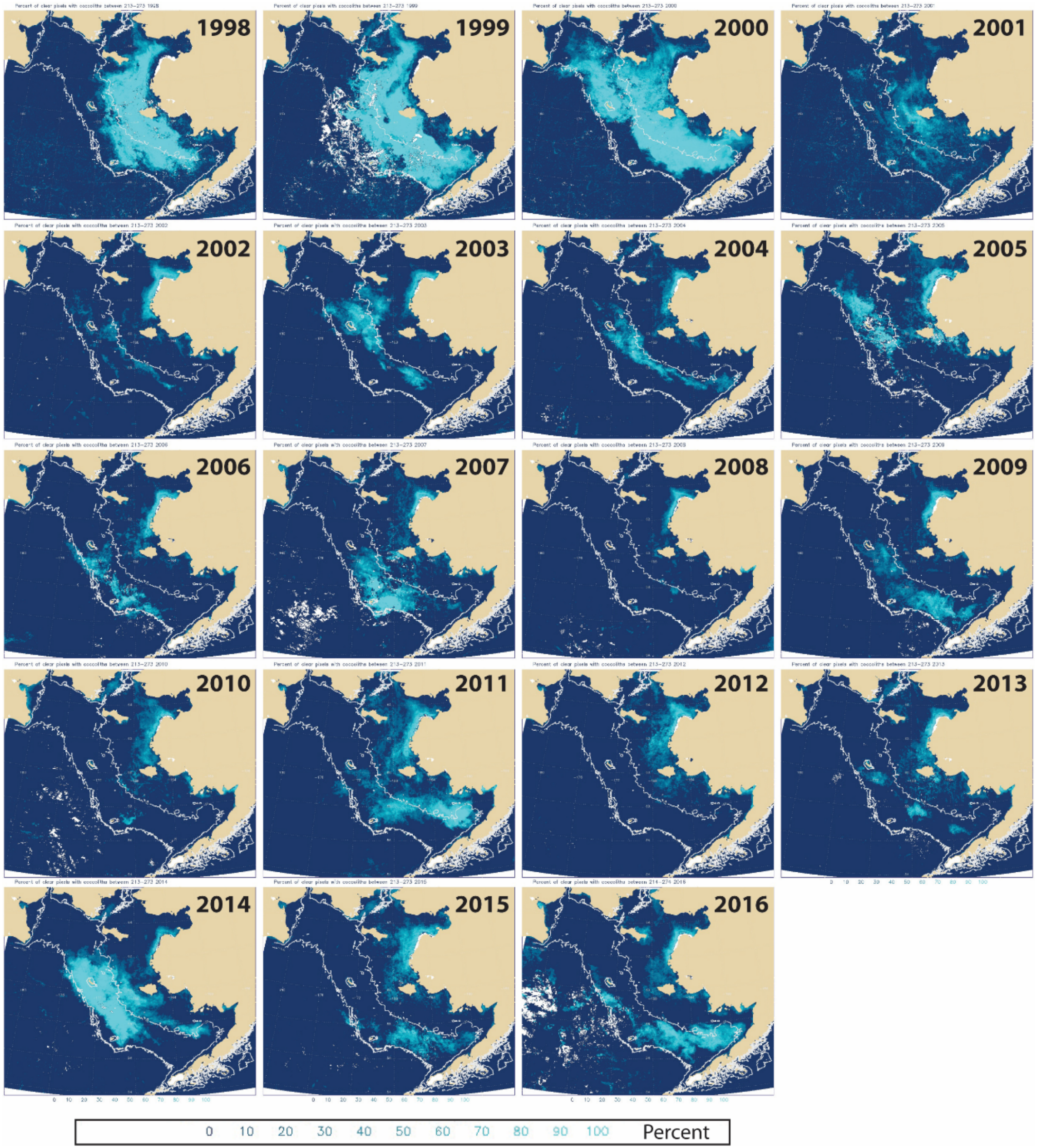

Figure 39: Color indicates the percent of cloud-free days in August-September for which each satellite ocean color pixel indicates coccolithophores. These data are used to calculate the areal index in Figure 40.

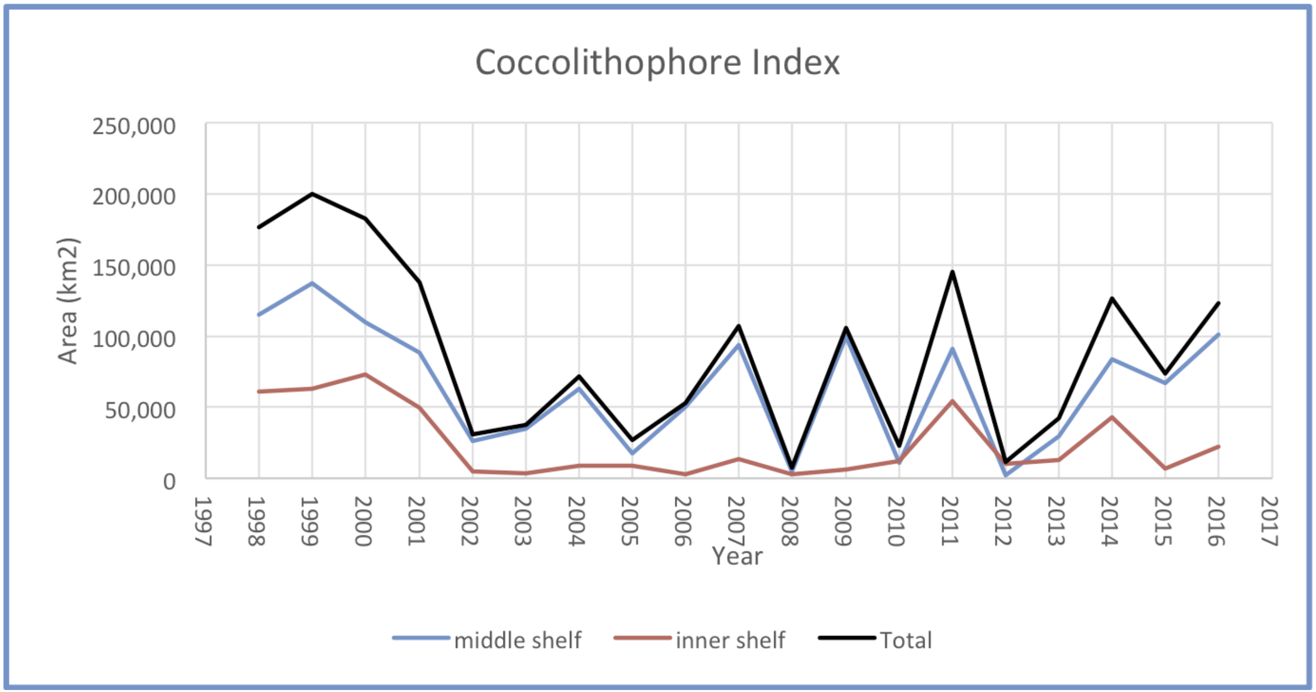

Figure 40: Coccolithophore Index for the southeastern Bering Sea shelf (south of 60°N). Blue: average over the inner shelf (30 - 50 m depth), Red: average over the middle shelf (50 - 100 m depth), Black: Total.

Zooplankton

Bering Sea Zooplankton Rapid Assessment

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Description of indicator: In 2015 EcoFOCI implemented a method for an at-sea zooplankton rapid assessment (ZRA) to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The ZRA, which is a rough count of zooplankton (from paired 20 and 60-cm bongo array with 153μm and 505μm mesh nets, respectively, towed to 10m off-bottom or 300m, whichever is shallower), provides preliminary estimates of zooplankton proportion and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories: small copepods, large copepods, euphausiids, chaetognaths, and 'other' were chosen for their ecological importance and appear to be influenced by warm and cold thermal conditions. Small copepods are categorized as $\leq$ 2mm total length and include species such as *Pseudocalanus* spp. and *Oithona similis.* Large copepods are those > 2mm total length and include *Calanus marshallae* and *Neocalanus* spp. The euphausiid category comprises all life stages. Small copepods were counted from the 153μm mesh, 20 centimeter bongo net. Large copepods, euphausiids, and chaetognaths were counted from the 505μm mesh, 60 centimeter bongo net. In 2016 the method was refined and personnel counted a minimum of 100 organisms per sample at sea to improve zooplankton estimates. Euphausiid stages reported for 2016 are larvae / juveniles <15mm. An additional taxonomic category 'other' (from 153 and 505μm mesh) was added to include abundant taxa that do not fit into previously determined categories. Other rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method. Additional categories of decapoda and the shelled pteropod *Limacina helicina* were added in Fall 2016. Detailed information on these taxa and others are provided following in-lab processing protocols (1 year+ post survey).

Status and trends: *1. Fall 2015* As in Spring 2015, the majority of plankton was composed of small copepods (Figure 41). Ice was not present in the Fall which allowed sampling to occur farther north than the Spring, reaching the M8 mooring. Small copepods proportionally dominated the catch south of 60°N and large copepods were found in high proportions, greater than 50%, near the M5 mooring and Unimak Pass. This pattern was similar to Spring but shifted northward. Euphausiid larvae and juveniles were present at only three stations. Chaetognaths were most prevalent between the M4 and M8 moorings on the 70m isobath. Chaetognaths were not counted during the Spring, therefore proportionality of the species group is unknown and cannot be compared to Fall.

2. Spring 2016 Similar to 2015, small copepods made up the majority of the plankton at most stations (Figure 42). However, large copepods made up a higher proportion of the plankton at the outer shelf stations (bottom depth >100m), as well as some of the southeastern inner domain stations. There were also high percentages of large copepods southeast of mooring M4, consistent with what was seen in Spring and Fall 2015. Euphausiid larvae and juveniles <15mm occurred at 19 stations in the inner and middle domains. Chaetognaths had the highest occurrence in the northern

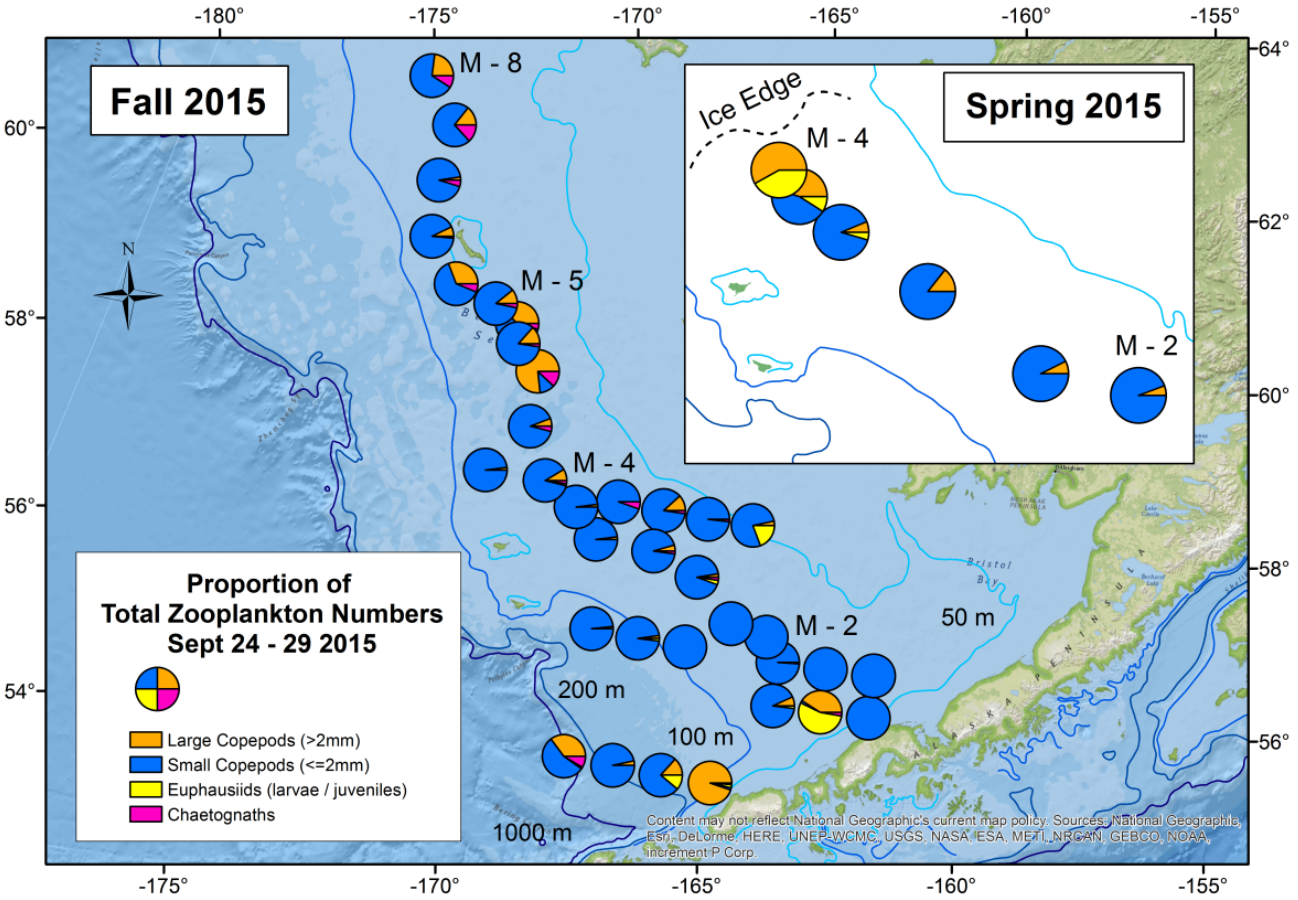

Figure 41: Proportion of total zooplankton numbers as determined by the Zooplankton Rapid Assessment in Spring and Fall 2015. Inset, Spring 2015 results. In Fall 2015, sampling was conducted south to north, along the 70m isobath, along with several cross shelf (east - west) transects from September 24 - 29, 2015.

part of the inner domain. The ice edge had retreated to regions north of the sampling area, so the zooplankton community composition relative to the ice edge is unknown. A new category was added for ‘other’ organisms and made up a large portion of the plankton in many of the stations in the inner and northern middle domains. This category was primarily composed of crab larvae, gelatinous zooplankton, and polychaetes.

3. Early Fall 2016 Small copepods comprised 99% of the zooplankton community in all samples across all domains (Figure 43). Very few large copepods were observed anywhere over the entire southeast Bering Sea shelf, except for very small aggregations observed in selected areas of deeper water. At southern transects the highest large copepod proportions were found in the westernmost stations in the outer domain (depth >100m), decreasing eastward. As transects moved further north, aggregations of large copepods were also found across the outer to middle domain (depth >70m) stations. In all cases, higher proportions of large copepods primarily consisted of mostly

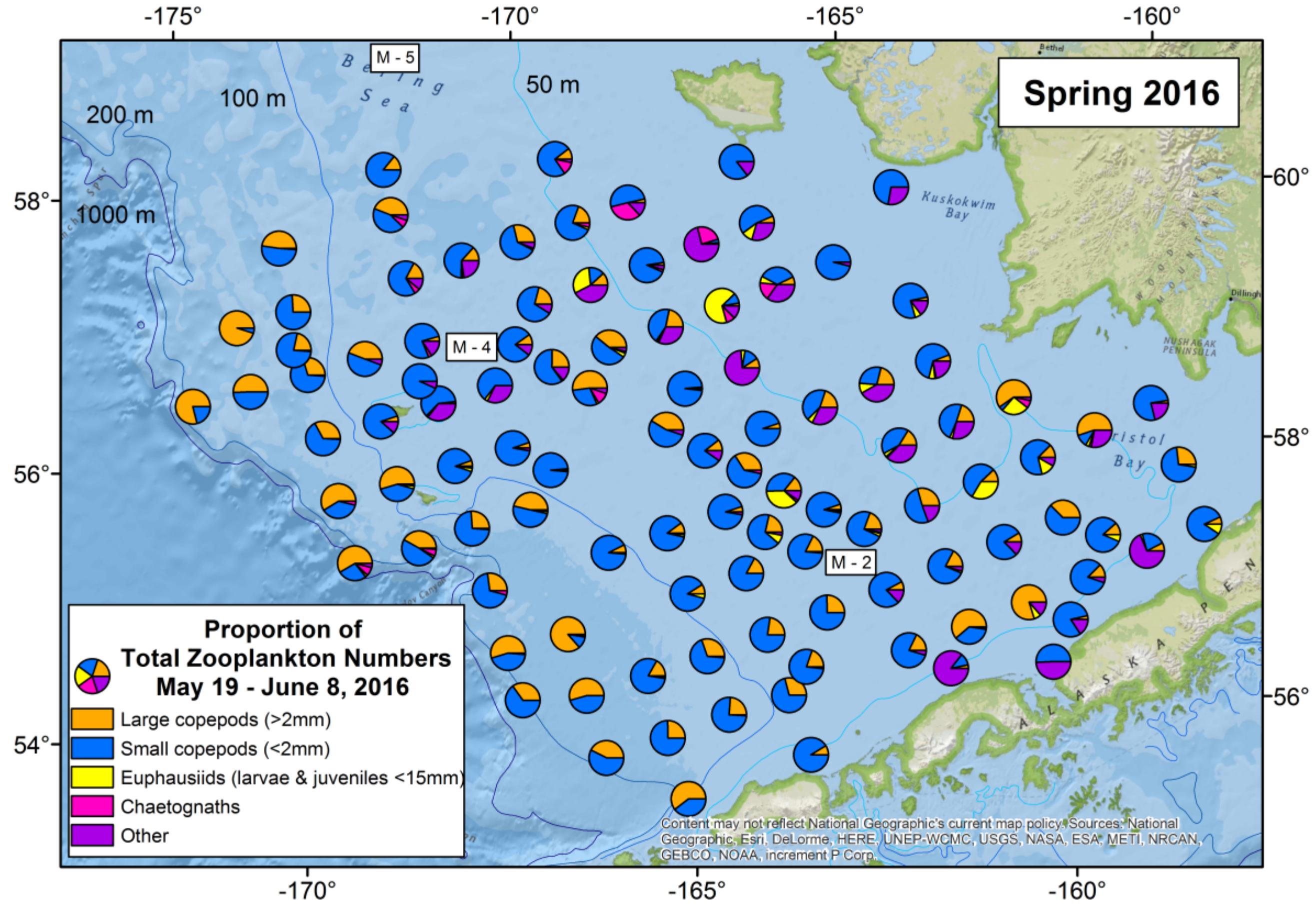

Figure 42: Proportion of total zooplankton numbers as determined by the Zooplankton Rapid Assessment in Spring 2016. Sampling was conducted on transects from southwest to northeast, across the outer, middle, and inner domains from May 14 - June 8, 2016.

Calanus marshallae with few *Neocalanus* spp. At the eastern edge of the middle to inner domain stations, there were large patches of the pteropod *Limacina helicina* and high proportions of the 'other' category, which was overwhelmingly comprised of the hydrozoan *Eutonina indicans*. Similar to 2015, high proportions of both small euphausiids and chaetognaths were found at the northern stations of the middle domain as well (Figure 44).

Anecdotally, overall sample volumes appeared qualitatively low, relative to past sampling. Many sample jars were virtually devoid of zooplankton biomass (samples were primarily water), especially the southeastern portion of the sampling grid. Quantitative estimates of zooplankton displacement volumes (biomass proxy) will be available within the year.

4. Late Fall 2016 Small copepods made up the majority of zooplankton at all stations sampled, with large copepods comprising as much as 20% of the zooplankton at the northern stations on the 70m isobath (Figure 45). Large copepods were present at most southern stations as well, but

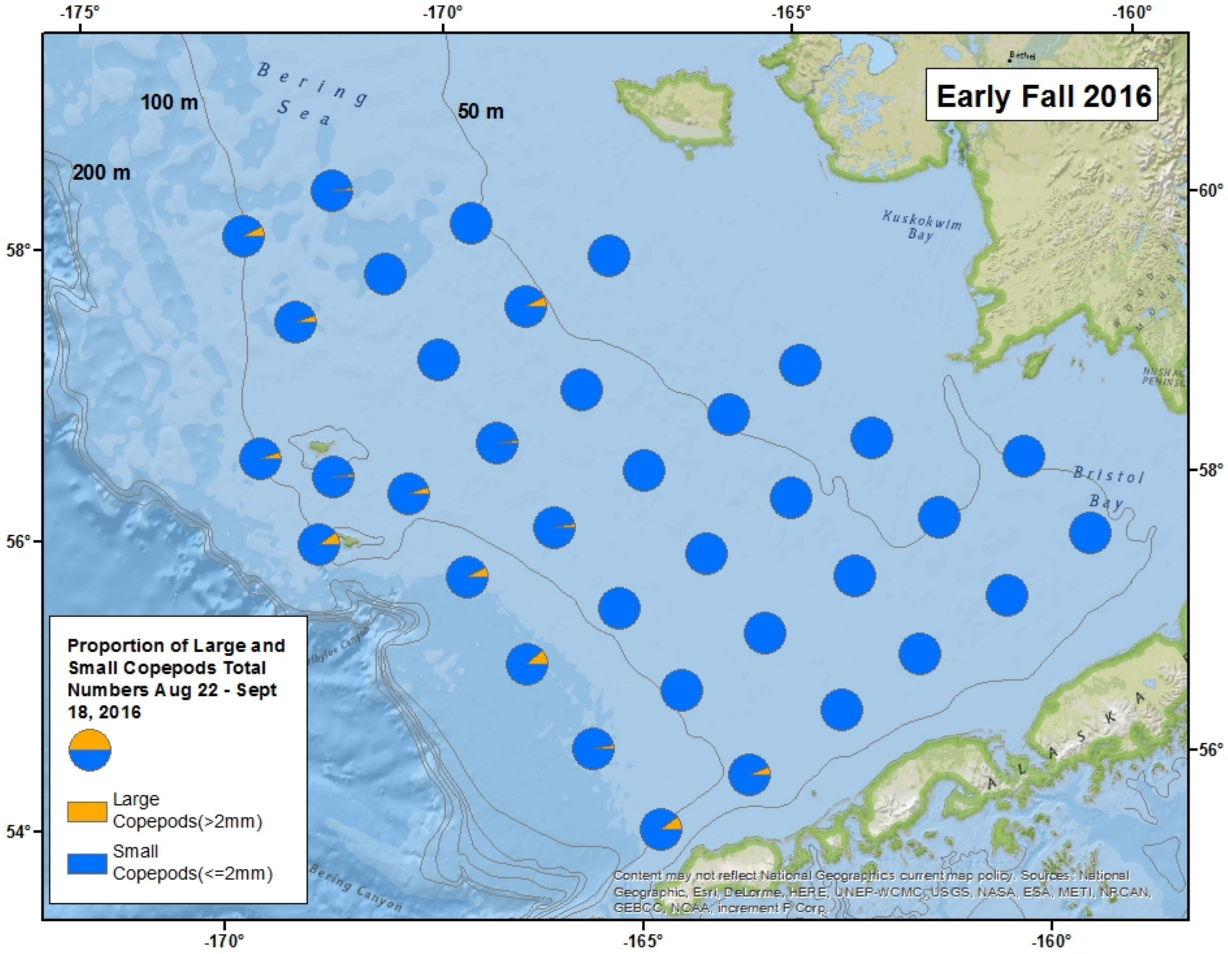

Figure 43: Proportions of large to small copepods as determined by the Zooplankton Rapid Assessment in early Fall 2016. Small copepods comprised the overwhelming proportions of all the samples taken. Sampling was conducted on transects from southwest to northeast, across the outer, middle, and inner domains from August 22 - September 18, 2016.

in very low proportions (so low they are difficult to see in the figure). Overall zooplankton sample volumes were lower in the southern stations on the 70m isobath, but increased north of 59.7°N. Zooplankton community structure shifted at 59.7°N, with an increase in large copepods (mostly *Calanus marshallae*) with a concurrent increase in sample volume. Euphausiid larvae / juveniles, chaetognaths, and 'other' organisms were present in small proportions in the northern and southern parts of the 70m isobath. The Unimak Pass region revealed a plankton community likely influenced by input from the Gulf of Alaska (Figure 45). Overall plankton volumes were higher in Unimak Pass than elsewhere and included several species of large copepods not observed on the 70m isobath (*Eucalanus bungii* and *Metridia* spp.) as well as more numerous *Calanus marshalle*. There were also several species of amphipod and tunicates only present in the Unimak area. The zooplankton sampled nearest to shore around Unimak was very different than the others, with fewer large copepods and more 'other' organisms including larvaceans and shrimps. Being closer to the shore

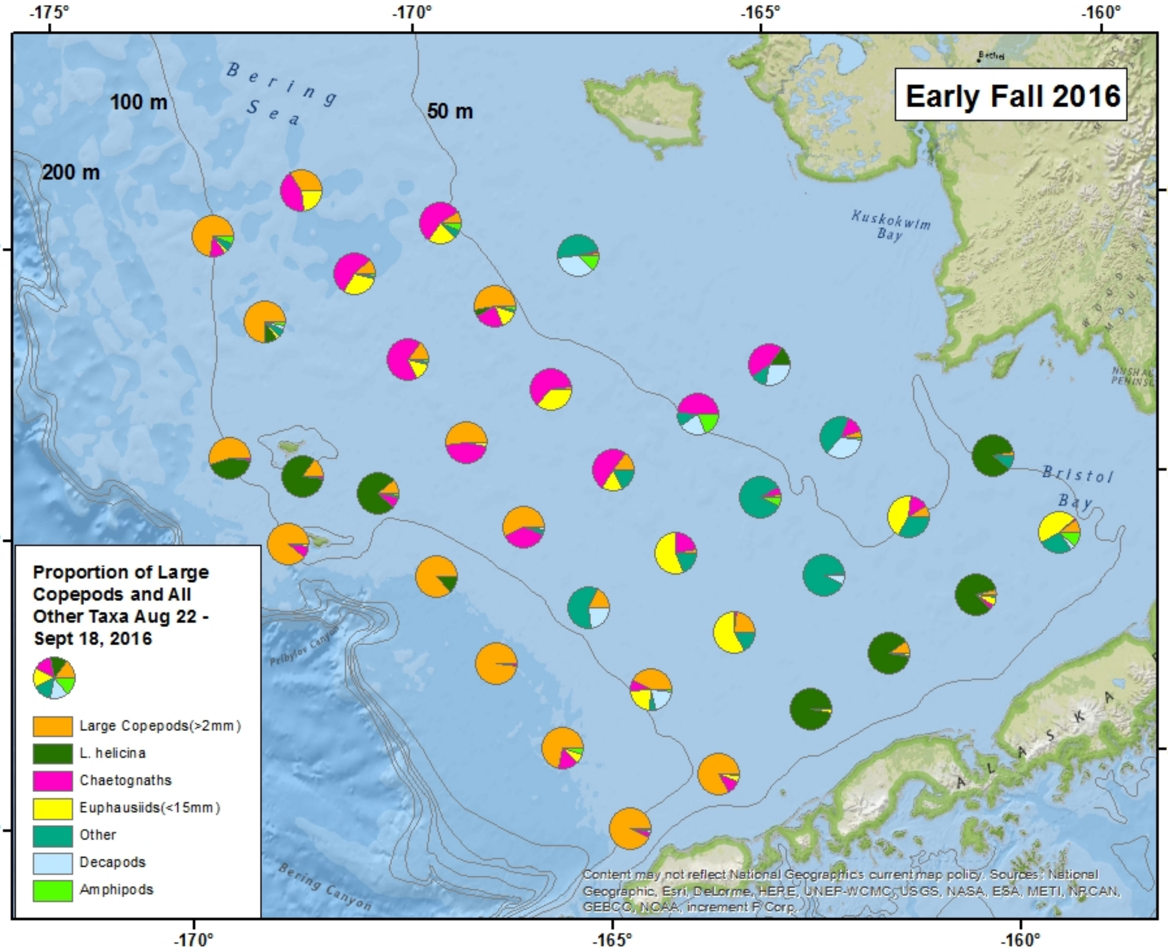

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Figure 44: Proportions of total zooplankton proportions *other than small copepods* as determined by the Zooplankton Rapid Assessment in early Fall 2016. The subtraction of small copepods is to show the distribution of all other plankton taxa found in the samples. The legend has all taxa listed from highest to lowest proportions.

and shallower than the other stations, it is likely composed of more coastal zooplankton species, accounting for the shift in community structure.

Factors influencing observed trends: *1. Fall 2015* As in 2014 and Spring 2015, sea surface temperatures continued to be warm in Fall 2015. The large proportion of small copepods throughout the study area in Fall was also consistent with trends observed in previous warm years. Large copepods have consistently made up a higher percentage of the zooplankton community in the northern part of the middle domain on the 70m isobath, with the area of high occurrence shifting slightly north or south, likely depending on the position of the cold pool (Duffy-Anderson et al., In press).

2. Spring 2016 Sea surface temperatures continued to be warm in Spring 2016 (as shown elsewhere in this report). Again, the large proportion of small copepods throughout the study area in the

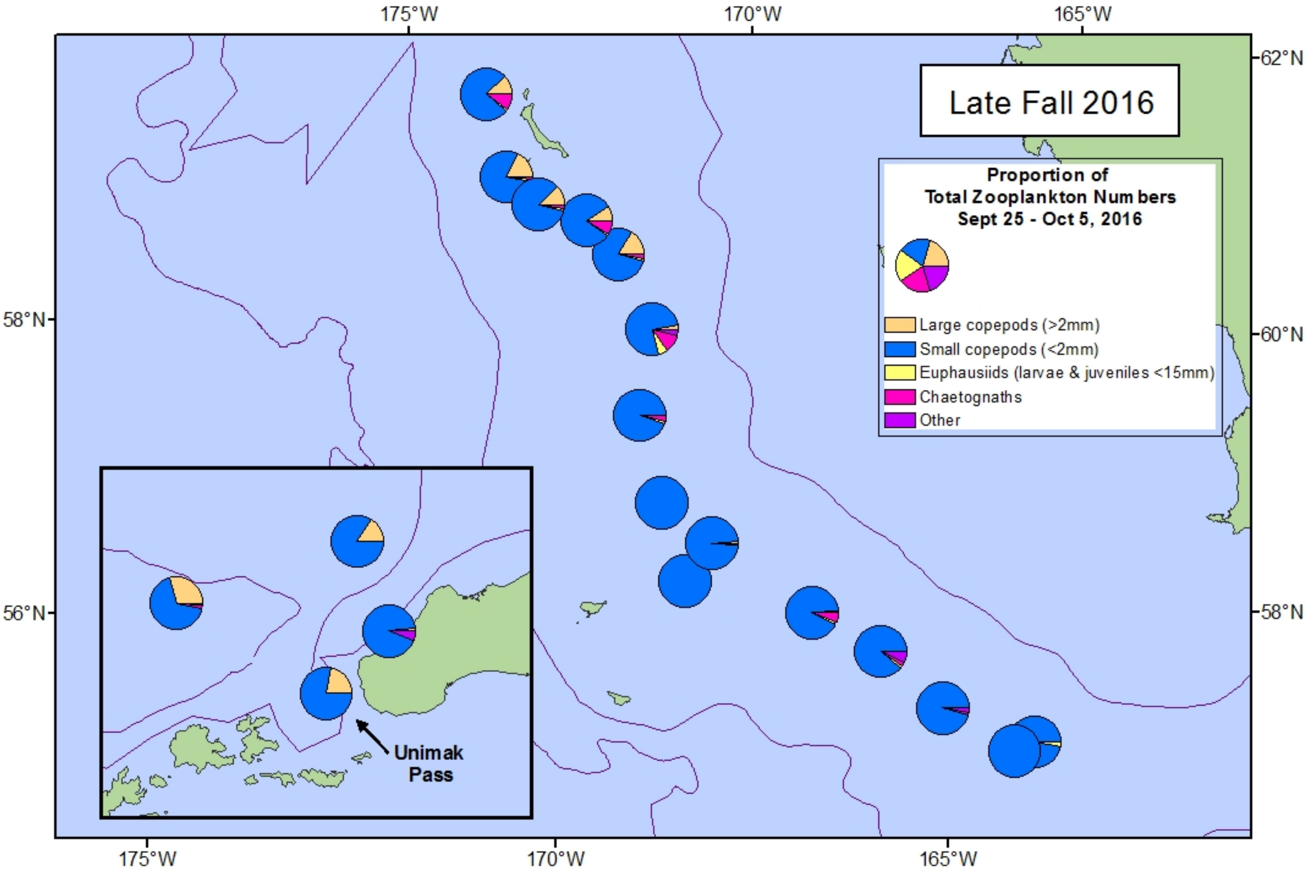

Figure 45: Proportion of total zooplankton numbers as determined by the Zooplankton Rapid Assessment in late Fall 2016. Shelled pteropods *L. limacina* and decopoda present, but data not shown due to very low numbers. Sampling was conducted south to north, along the 70m isobath and at four stations across Unimak Pass from September 25 October 5, 2016.

Spring is consistent with trends observed in previous warm years. The addition of the 'other' category showed that crab larvae, gelatinous zooplankton, and polychaetes can make up a very large percentage of the plankton community and are an important addition to this index.

3. Early Fall 2016 The large proportion of small copepods is consistent with trends of the previous warm years. However, the overwhelming proportions of small copepods combined with predominately very low sample volumes could be due to the cumulative effects of three years of persistent warm conditions. Both mean sea surface and bottom temperatures were warmer than 2014 and 2015 (mean SST = 9.5°C; mean bottom temperature = 4.5°C), accompanied by a stratified water column and a very condensed cold pool to the north (as shown in the Physical Environment portion of this report). All of these factors could suggest conditions that would inhibit primary production and therefore overall zooplankton biomass.

4. Late Fall 2016 Overall, we saw similar patterns as in Fall 2015 and early Fall 2016. Small copepods dominated, large copepods appeared north of ∼59°N, and overall zooplankton volumes increased in the outer domain (bottom depth >100m). Overall zooplankton volumes and proportions of large copepods declined along the 70m isobath in Fall 2016 when compared to 2015. This indicates that in the third consecutive warm year, lipid rich prey (large copepods) decreased in availability for juvenile walleye pollock and other zooplanktivores. The additional sampling in the Unimak Pass region showed a zooplankton community most likely influenced by the strong currents in the region advecting zooplankton from the Gulf of Alaska and shallow nearshore stations with coastal zooplankton species.

Implications: Previous research suggests the ratio of small to large copepods may be particularly important to juvenile walleye pollock survival through the first winter which varies from cold to warm years (Hunt et al., 2011). Throughout all of our surveys, large copepods (*Calanus marshallae* and *Neocalanus* spp.) were primarily located in high percentages in the outer domain or to the north. The lack of large copepods during Fall 2016 in the southeast Bering Sea may limit survival of overwintering juvenile walleye pollock, as suggested by Hunt et al. (2011) and Duffy-Anderson et al. (In press). Furthermore, observations of young-of-the-year pollock catches from the early fall 2016 survey were spatially mismatched from distributions of large copepods (A. Andrews, pers.comm.), suggesting either a mismatch in distributions and/or the water column being grazed out of large copepods. Results suggest a paucity of lipid-rich prey for juvenile pollock provisioning for winter, and the potential for poor survival to age-1.

Eastern Bering Sea Zooplankton Rapid Assessment Time-Series Hindcast

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Description of indicator: Zooplankton records within 15 km of mooring location M2 (56.88°N, 164.06°W) and M4 (57.85°N, 168.87°W) were compiled from 1997 to 2012. Zooplankton were collected using a dual-frame bongo net array with a 20 cm, 153 μm mesh net and a 60 cm, 333 μm mesh net. Data were not collected in 2001 and 2002 in the eastern Bering Sea. Selected copepod taxa that were dominant members of the zooplankton were then placed into one of three categories that were used in the Zooplankton Rapid Assessment (see p. 91). The category Euphausiids consisted of juvenile and adult stages of the following taxa: *Euphausia pacifica*, *Thysaneossa inermis*, *T. inspinata*, *T. longipes*, *T. raschii*, and *T. spinifera*. The category small copepods (< 2 mm) consisted of *Acartia* spp. stages CI-CVI, *Oithona* spp. stages CI-CVI, *Metridia* spp. stages CI-CIV, and *Pseudocalanus* spp. stages CIV-CVI and were collected using the 20 cm, 153 μm mesh bongo net. The category large copepods consisted of *Calanus marshallae* stages CI-CVI, *Eucalanus bungii* stages CI-CVI, *Metridia* spp. stages CV-CVI, *Neocalanus cristatus* stages CII-CVI, and *Neocalanus plumchrus/flemingeri* stages CII-CVI and were collected using the 60 cm, 333 μm mesh bongo net. The mean, annual abundance of each category at each mooring location was plotted. The data represent primarily April, May, and September as the months with the greatest sampling frequency. A series of warm and cold periods had been identified in the eastern Bering Sea (Stabeno et al., 2012, In press) and years were categorized as warm, average, or cold. Temperature values showed interannual variability until 2001 when a 5-year warm period occurred which was followed by a

7-year cold period.

Status and trends: Euphausiid abundance showed similar trends over time at both locations. Euphausiid abundance was lowest during the warm period of 2001-2006. Euphausiid abundance increased in 2007 in both time-series before declining during the subsequent cold period. Abundance rose again at mooring location M2, but not M4 (Figure 46, top row). Copepod abundance was dominated by small copepods at both locations in terms of total abundance (note difference in scales). Small copepod abundance peaked during the warm period in 2005 at both locations and declined as temperatures declined (Figure 46, bottom row). Large copepod abundances were variable during the early part of the data record, with some high abundances during the warm periods of 2003-2005. Large copepod abundance increased during the latter portion of the data record when temperatures were colder, particularly at location M2 (Figure 46, middle row). Both small and large copepods appeared to decline precipitously during the warm-to-cold transition in 2006.

Factors influencing observed trends: The hypothesis that warm periods are better characterized by small copepods and cold periods by large copepods is supported by the time-series. Large copepod abundance reached its nadir during the warm period of 2001-2006 and peaked during the latter part of the cold period 2007-2012 (Figure 46). The importance of physical and biological processes that influence observed trends requires further investigation.

Implications: The data are consistent with the Oscillating Control Hypothesis (Hunt et al., 2011) in that cold periods were associated with larger copepods that are more lipid-rich than smaller copepods. When large copepods represented a greater proportion of the zooplankton community, recruitment strength of Walleye pollock was higher (Hunt et al., 2011). In contrast, small copepod abundance remained high during warm periods, while large copepod abundance declined, and this has been associated with low survival of age-0 pollock over the winter as their lipid reserves are reduced (Hunt et al., 2011). It is possible that the small/large copepod abundance in the system may be an ecosystem indicator that integrates system productivity over time. For example, increased temperatures may be favorable to small copepods that have multiple generations per year and thus do not accumulate fatty acids for diapause. In contrast, larger copepods may respond favorably to colder conditions that reduce metabolic rates and allow accumulation of fatty acids.

Eastern Bering Sea Euphausiids ('Krill')

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Last updated: October 2016

Description of indicator: Ressler et al. (2012) developed a survey of the abundance and biomass of euphausiids on the middle and outer shelf of the eastern Bering Sea, using acoustic and Methot trawl data from 2004-2010 surveys of midwater walleye pollock (*Gadus chalcogrammus*, e.g., Honkalehto and McCarthy (2015)). The method has been used to estimate an index of euphausiid abundance on a biennial schedule since that time. Acoustic backscatter classified

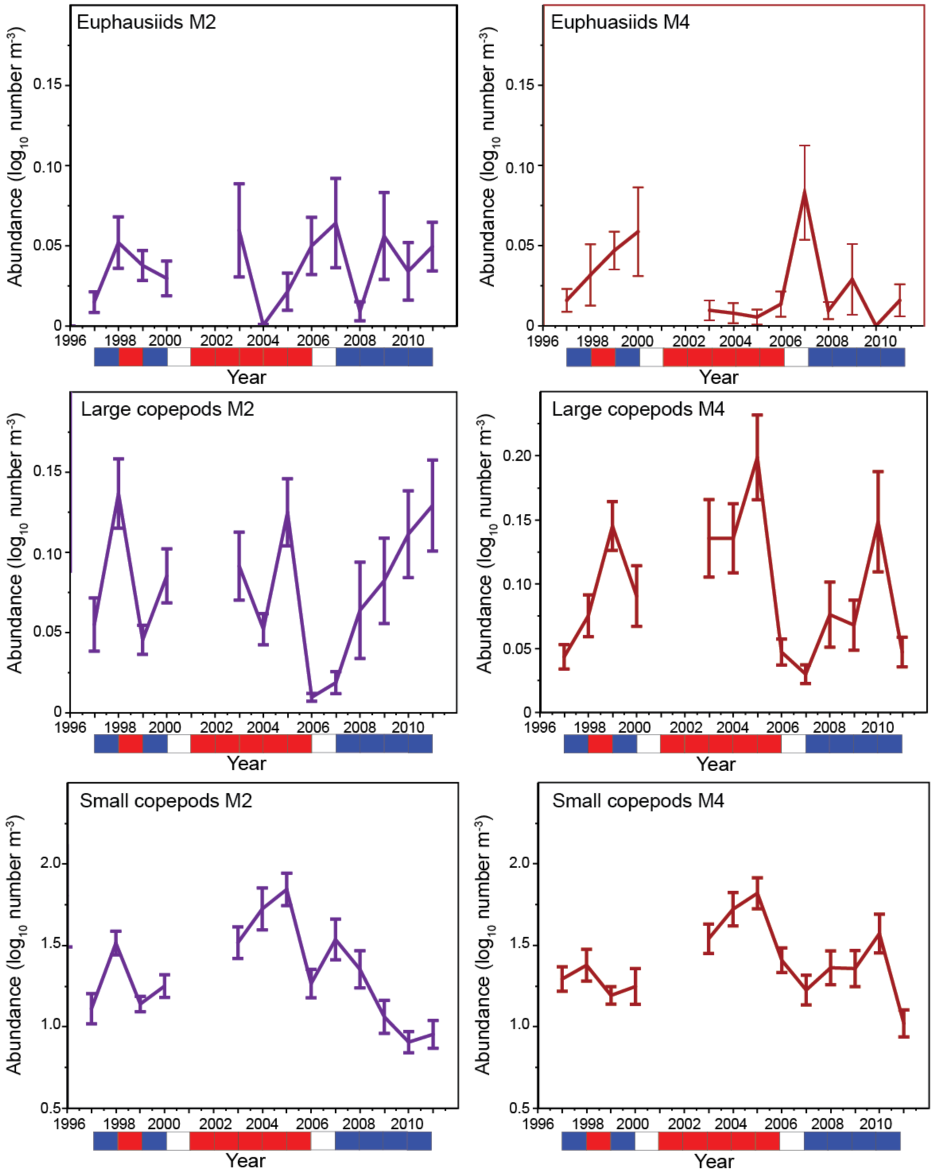

Figure 46: Annual mean abundance (log$_{10}$ abundance (number m^{-3}) of Euphausiids, Large (> 2 mm), and Small (< 2 mm) copepods at mooring locations M2 and M4. Error bars represent standard error of the mean.

as euphausiids (Figure 47) was used to compute the numerical density (no. m^3) of euphausiids along acoustic-trawl survey transects; these values were then averaged over the water column and across the surveyed area to produce annual averages (Figure 48). Because few trawl samples were available in the early years of the times series, the conversion from euphausiid backscatter to numerical density (target strength; Smith et al. (2013)) was modeled using the average of length and species composition from samples collected 2004-2014 (counts from trawl samples collected in 2016 are not yet available). There is large uncertainty about the absolute abundance of euphausiids in the eastern Bering Sea (Hunt et al., In press), but the relative trends in this index are probably robust. Error bars indicate 95% confidence intervals computed from geostatistical estimates of relative estimation error due to sampling variability (Petitgas, 1993).

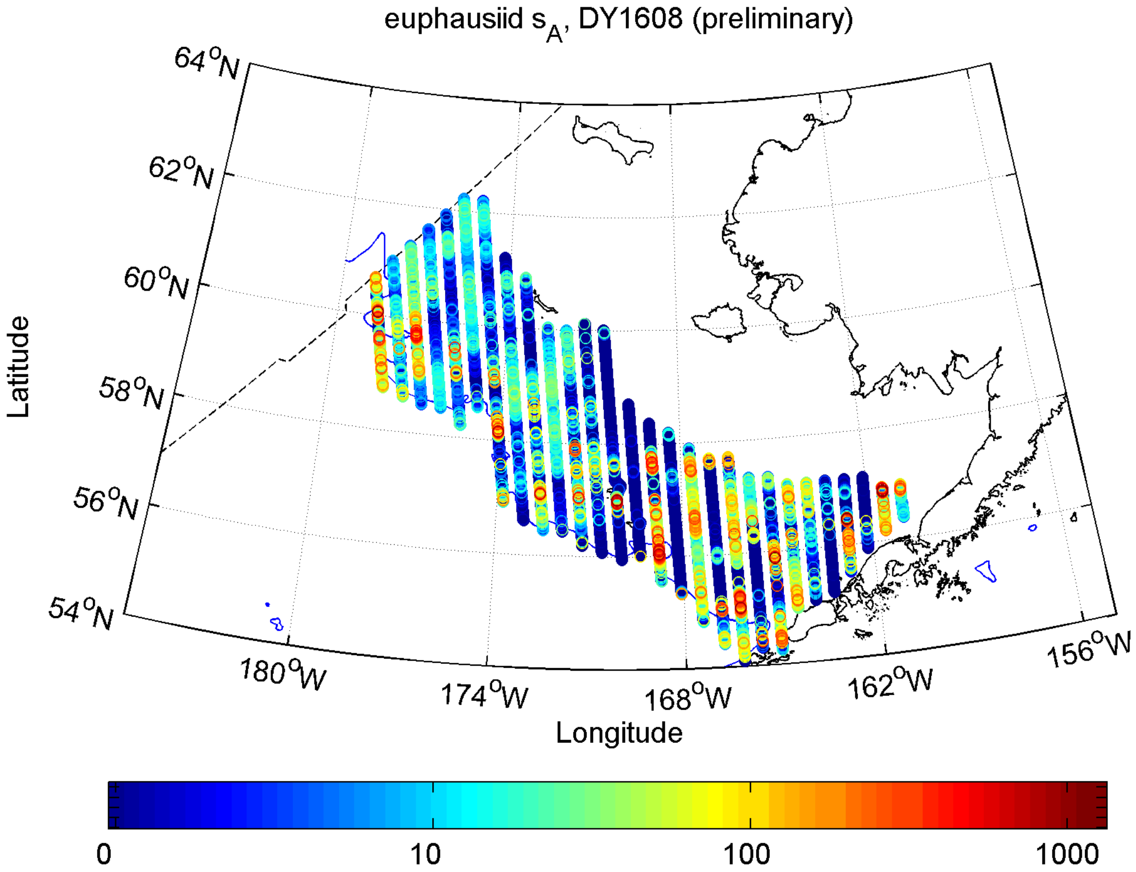

Figure 47: Spatial distribution of acoustic backscatter density (s_A at 120 kHz, m^2 nmi^{-2}) attributed to euphausiids in the 2016 NOAA-AFSC eastern Bering Sea summer acoustic-trawl survey.

Since the previous update to this index, a) euphausiid backscatter observations from the 2016 acoustic-trawl survey of pollock and b) euphausiid length and species composition from net tows conducted during the 2014 survey were added to the analysis. The addition of these new data changed the absolute abundance given in previous reports, but the temporal pattern remained the same. Net catches from euphausiid layers in 2004-2014 were dominated numerically by euphausiids (mean 86%). The average length of euphausiids was between 18 and 20 mm, *Thysanoessa inermis* dominated species composition on the outer shelf, and *T. raschii* dominated inshore. These observations of length and species composition are consistent with what is known from the literature (Smith, 1991; Coyle and Pinchuk, 2002). There is some indication that euphausiids were smaller in 2004-2009 than in later years (by 1-2 mm). Overall though, no large changes in length or species composition of euphausiid scattering layers have been identified. Euphausiid length and species composition from 2016 net samples are not yet available.

Status and trends: Summertime euphausiid density increased on the eastern Bering from 2004-2009, but subsequently declined 2010 through 2016 (2016 is the lowest value in the time series).

Factors influencing observed trends: Factors controlling annual changes in euphausiid abundance in the north Pacific are not well understood; possible candidates include bottom-up forcing

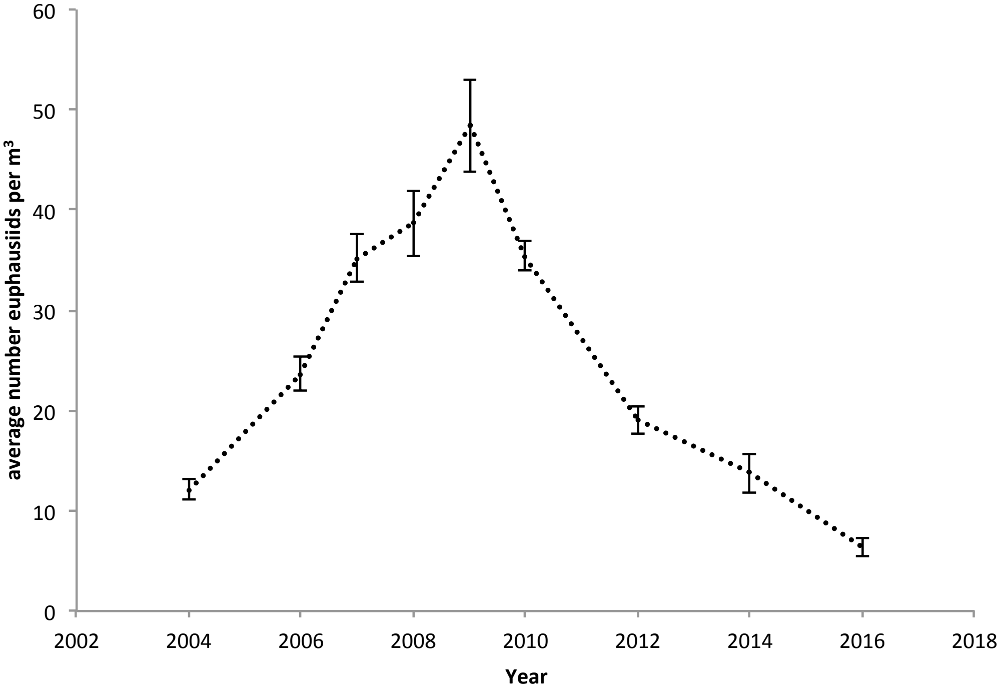

Figure 48: Acoustic estimate of average euphausiid abundance (no. m^3) from NOAA-AFSC EBS summer acoustic-trawl surveys. Error bars are approximate 95% confidence intervals computed from geostatistical estimates of sampling error (Petitgas, 1993).

by temperature and food supply, and top-down control through predation (Hunt et al., In press). When factors including temperature, pollock abundance, primary production, and spatial location have been considered in spatially-explicit multiple regression models, increases in euphausiid abundance have been strongly correlated with cold temperatures in the eastern Bering Sea (Ressler et al., 2014), but not in the Gulf of Alaska (Simonsen et al., 2016). The summers of 2014-2016 have been unusually warm on the Bering Sea shelf (Zador (2015), see Lauth contribution p. 63). The biomass of eastern Bering Sea pollock (a major predator) is currently above the historical mean (Ianelli et al., 2015), though euphausiid abundance has not been strongly correlated with the pollock biomass in models of either the eastern Bering Sea or the Gulf of Alaska.

A second factor influencing observed trends could be methodological: backscatter from other animals could confound correct classification of euphausiid backscatter. This problem could be more severe at low euphausiid densities, i.e., a decreased signal in the presence of increased noise. Ressler et al. (2012) discussed such masking of euphausiid backscatter by walleye pollock, a well-defined class of acoustic targets likely to overlap spatially with euphausiids, and found the effect to be negligible in practice. However, the effect of backscatter from animals other than pollock and euphausiids is difficult to quantify if their acoustic properties are unknown or not well-defined (Woillez et al., 2012). De Robertis et al. (2010) advocated for the use of a mean normal deviate (z-score) of the frequency response to judge the quality of the multifrequency classification process used here, where a value of 1 indicates that the frequency response is within 1 standard deviation of the known response for a given class of acoustic targets. For euphausiids, this value has averaged 0.87 (range 0.75 - 1.15) from 2004-2016, with highest values occurring in 2004 (mean 0.99), 2014 (mean 0.97), and 2016 (mean 1.15), when large amounts of unclassified backscatter was present in the surveyed area (cf. Fig. 17 in Honkalehto and McCarthy (2015); Honkalehto and McCarthy (In prep)) and euphausiid densities were low (Figure 48). These higher than average z-scores could be consistent with noise from other acoustic targets in the euphausiid classification process. In summary, the overall pattern of relative euphausiid abundance presented here (Figure 48) is probably correct, but values in 2004, 2014, and 2016 could be biased low for this methodological reason.

Implications: Euphausiids are food for many species of both ecological and commercial importance in the eastern Bering Sea, including walleye pollock (Aydin and Mueter, 2007). The data presented here suggest that euphausiid prey have become less available in 2012-2016 compared to 2006-2010, perhaps at levels comparable to 2004, which data from many sources suggest was a year with very low euphausiid densities (reviewed in Hunt et al. (In press)).

Jellyfish

Jellyfish - Eastern Bering Sea Shelf

Contributed by Robert Lauth
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Last updated: October 2016

Description of indicator: The time series for jellyfishes (principally *Chrysaora melanaster*) relative CPUE by weight was updated for 2016 (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.

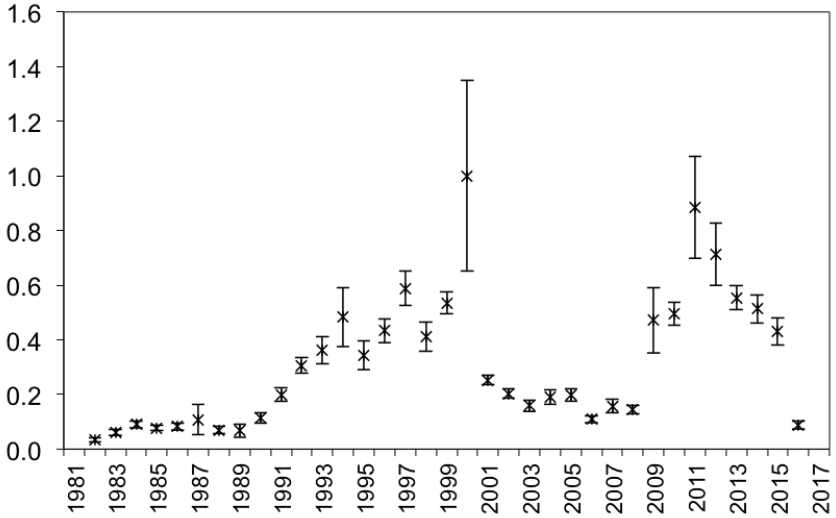

Figure 49: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for jellyfish during the May to August time period from 1982-2016.

Status and trends: The relative CPUE for jellyfishes in 2016 was a 79% decrease from 2015, and one of the lowest observed since 1989. This low CPUE was within the range of those observed during the first ten years of the time series. There was a period of increasing biomass of jellyfishes throughout the 1990's (Brodeur et al., 1999) followed by a second period of low CPUEs from 2001 to 2008 and then a second period with relatively higher CPUEs from 2009-2015.

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

Trends in Jellyfish Bycatch from the BASIS Survey

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Last updated: September 2016

Description of indicator: Jellyfish sampling was incorporated aboard the BASIS (Bering-Arctic-SubArctic Integrated Survey (BASIS) vessels beginning in 2004 and continued through 2014. Starting in 2015 in the southeastern Bering Sea (SEBS), a gear change occurred resulting in no jellyfish data from surface trawls. The northern Bering Sea data remains uninterrupted and in 2016 surface trawls were conducted from which jellyfish data will be available to continue this time series. All jellyfish medusae caught in the surface trawl (top 18-20 m of the water column) are 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.

Status and trends: The biomass in 2015 in the north decreased compared to previous years and the dominant species in terms of biomass and abundance was *C. melanaster* (Figure 50). The south index, which could not be updated after 2014 data, had the highest CPUE on record for the 11 years of the time series. Several anecdotal reports of large die offs were observed in the southeastern Bering Sea in early August of 2015; no reports had been received in prior years to indicate similar conditions. Yearly distributions throughout the sample grid for all species have been patchy. Despite uneven distributions throughout oceanographic domains, highest concentrations of all species were found in the middle domain. Of the six species sampled, *C. melanaster* had the highest CPUE for all years.

Starting in 2007, notable declines in jellyfish species compostion were observed for all taxa except *C. melanaster* and continued through 2012 (Figure 51). The dominant species continues to be *C. melanaster*, nearly quadrupling its biomass in 2012 compared to 2004. During 2007-2012, biomass of all other species have remained low in comparison to 2004-2006, suggesting that the trend for the region had shifted from multiple species to a single dominant species. There could possibly be a shift back to multiple taxa present in the future as seen by changes in the presence of other taxa in 2014.

Factors causing observed trends: The cause for these shifts in biomass and distribution do not seem to rely solely on physical ocean factors (e.g., 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

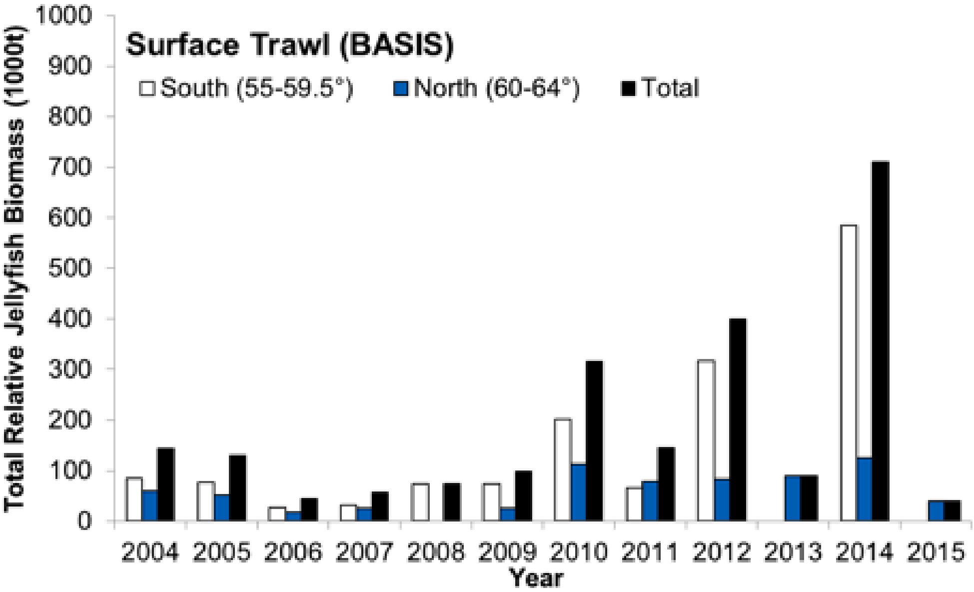

Figure 50: Total annual jellyfish biomass (1000 t) split by region. Includes combined species caught in surface trawls in the eastern Bering Sea during August-October. Biomass was calculated using average effort per survey area in km^2 by year. Data are absent for the north 2008 and in the south for 2013 and 2015.

Bering Sea foodweb through jellyfish predation on zooplankton and larval fish, and could result in limiting carbon transfer to higher trophic levels (Condon et al., 2011).

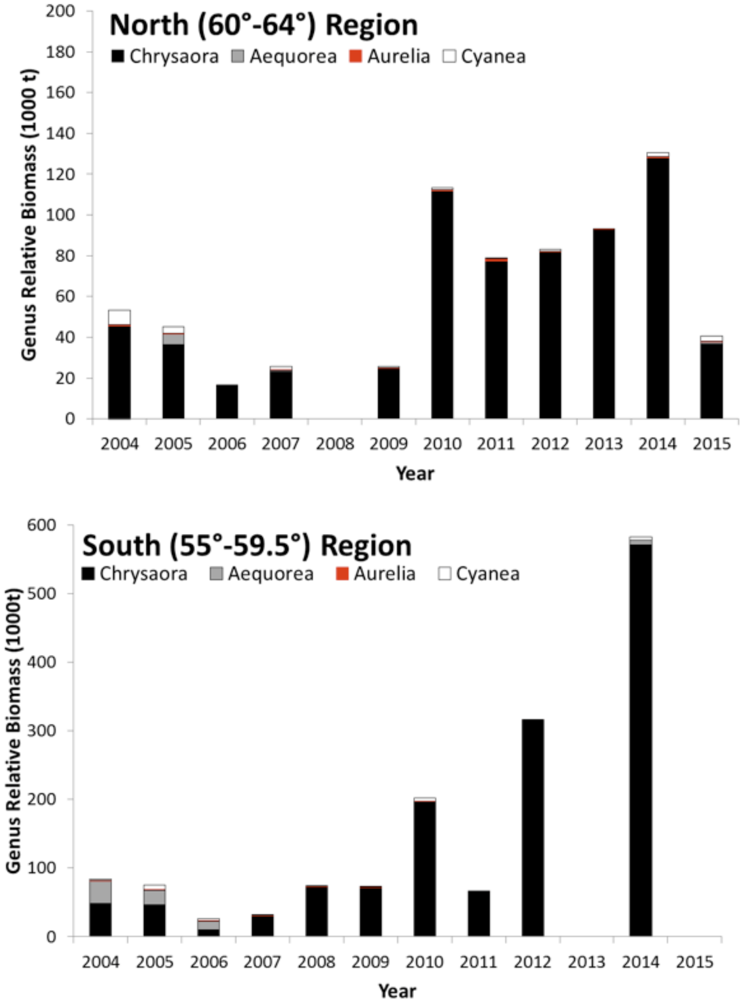

Figure 51: BASIS surface trawl biomass of jellyfish (1000 t) by genus for 2004-2015 in the north and southeastern Bering Sea during August -October. Biomass was calculated using average effort per survey area in km^3 by year.

Ichthyplankton

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 Capelin (*Mallotus villosus*) in the Eastern Bering Sea During Late Summer, 2002-2015

Contributed by Ellen Yasumiishi, Kristin Cieciel, Alex Andrews, and Elizabeth Siddon
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Last updated: October 2016

Description of indicator: Capelin (*Mallotus villosus*) were captured using surface trawls in the eastern Bering Sea during the late summer (September) from 2002-2015 in the Bering Arctic Subarctic Integrated Surveys (BASIS). Abundance and distribution were estimated using a standardized geostatistical index developed for stock assessments and management (Thorson et al., 2015). Survey stations were approximately 30 nautical miles apart. A trawl net was towed in the upper 20 m of the water column for approximately 30 minutes. Fish catch was estimated in kilograms at each station. Area swept was calculated as the product of the haversine distance of the tow and the horizontal spread of the net. Geostatistical analysis was conducted using R statistical software version 0.99.896 and the SpatialDeltaGLMM package version 3l (Thorson et al., 2015) to estimate abundance and distribution. We used a lognormal distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components, and a spatial resolution with 100 knots.

Status and trends: Capelin were primarily distributed in the middle domain of the continental shelf in the eastern Bering Sea during late summer (Figure 52). Field densities were higher in cold years and lower in warm years (Figure 52). North-south elongation of the anistropy ellipse indicated that densities are correlated over a longer distance in the north-south direction than in the east-west direction (Figure 53). Capelin were distributed farther north in warm years than in cold years (Figure 54) and also more contracted over a smaller area in 2014 (Figure 55). Estimated abundance of Capelin ranged from 226 metric tonnes in 2004 to 19,182 metric tonnes in 2015 (Figure 56, Table 4). The general trend was of higher abundances in cold years. These estimates likely include multiple year classes.

Factors influencing observed trends: The eastern Bering Sea has recently undergone a series of warm (2002-2006), cold (2008-2012), and warm (2014, 2015) stanzas. The estimated abundance of Capelin was generally higher in cold years than in warm years. Climate may influence abundance through the impact of prey quality for Capelin in the eastern Bering Sea (Andrews et al., In press). Capelin were distributed farther north in warm years.

Implications: Possible implications for increases in the abundance of Capelin include increased

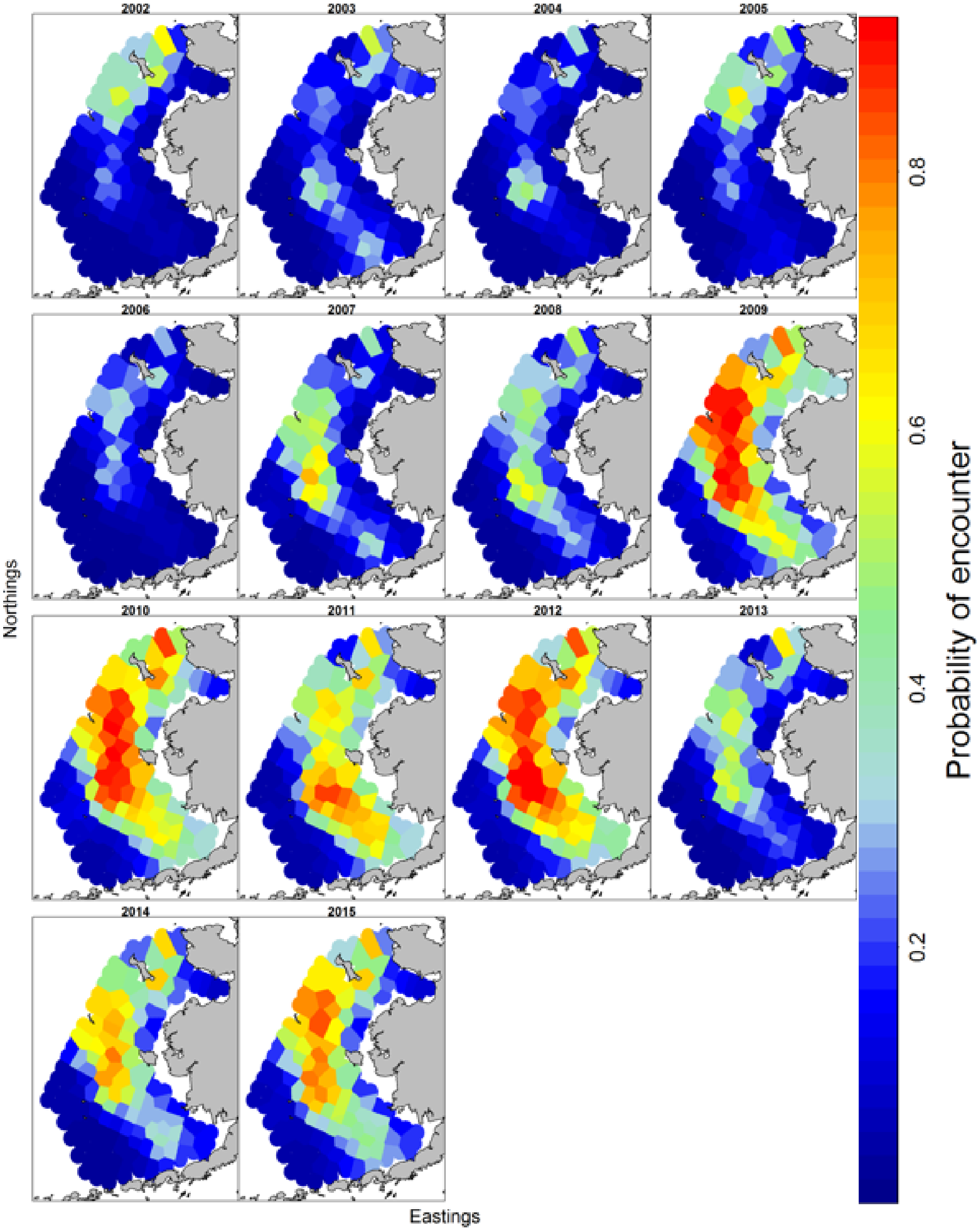

Figure 52: Density of Capelin in the eastern Bering Sea during late summer, 2002-2015. Densities were estimated using the geostatistical delta-generalized linear mixed model from Thorson et al. (2015).

prey availability for piscivores.

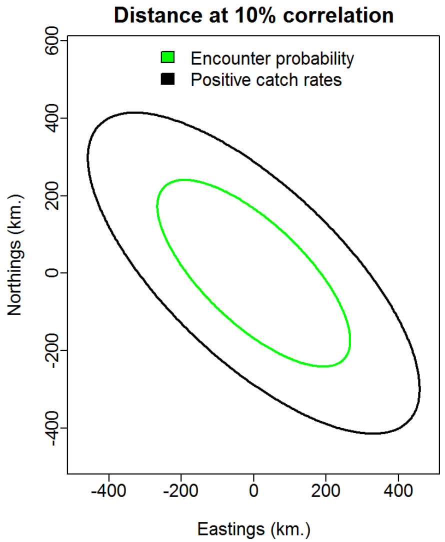

Figure 53: Geometric anistropy plots for encounter probability and catch rates of Capelin on the eastern Bering Sea shelf during late summer, 2002-2015.

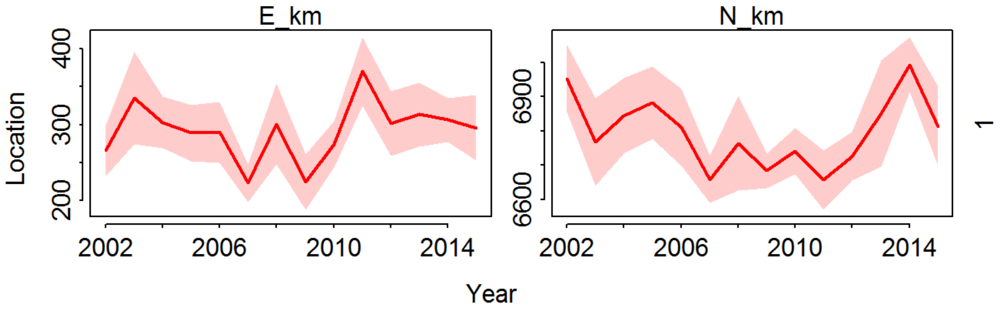

Figure 54: Northward and eastward center of gravity (distribution) in units of km for Capelin on the eastern Bering Sea during late summer, 2002-2015.

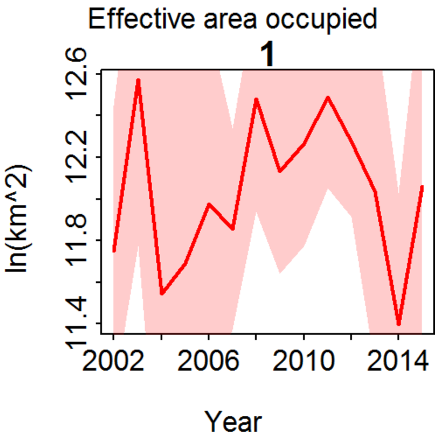

Figure 55: The effective area ($\ln(\mathrm{km}^2)$) occupied by Capelin on the eastern Bering Sea shelf during late summer, 2002-2015.

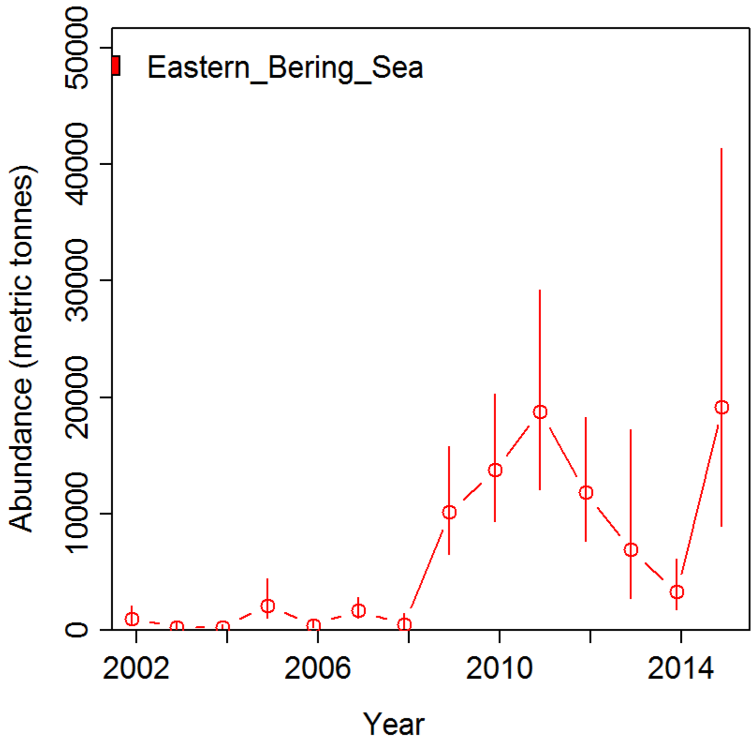

Figure 56: Estimated index of abundance with 95% confidence intervals for Capelin in the eastern Bering Sea during late summer, 2002-2015. Abundance was estimated using the geostatistical delta-generalized linear mixed model from Thorson et al. (2015).

Table 4: Estimated abundance in metric tonnes of Capelin in the eastern Bering Sea during late summer, 2002-2015. SD is standard deviation.

Year	Estimate (metric tonnes)	SD (log)	SD (natural)
2002	952.72	0.79	753.14
2003	237.59	0.94	222.65
2004	226.36	0.73	165.02
2005	2,109.37	0.74	1,558.22
2006	414.89	0.73	304.32
2007	1,698.77	0.5	849.8
2008	420.76	1.25	522.05
2009	10,098.01	0.44	4,477.98
2010	13,739.12	0.39	5,339.88
2011	18,783.38	0.44	8,288.27
2012	11,793.76	0.44	5,158.36
2013	6,880.23	0.92	6,301.66
2014	3,256.83	0.63	2,051.19
2015	19,182.85	0.77	14,739.92

Herring

Spatial and Temporal Trends in the Abundance and Distribution of Pacific Herring (*Clupea pallasii*) in the Eastern Bering Sea During Late Summer, 2002-2015

Contributed by Ellen Yasumiishi, Kristin Cieciel, Alex Andrews, and Elizabeth Siddon
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Last updated: October 2016

Description of indicator: Pacific herring (*Clupea pallasii*) were captured in trawl nets towed in the upper 20 m of the water column in the eastern Bering Sea during the late summer from 2002-2015 in the Bering Arctic Subarctic Integrated Surveys (BASIS). Abundance and distribution were estimated using a standardized geostatistical index developed for stock assessments and management (Thorson et al., 2015). Stations were approximately 30 nautical miles apart. A trawl net was towed for approximately 30 minutes. Fish catch was estimated in kilograms. Area swept was estimated from horizontal net opening and distance towed. Geostatistical analyses were conducted using R statistical software version 0.99.896 and the SpatialDeltaGLMM package version 3l (Thorson et al., 2015). We used a lognormal distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components, and a spatial resolution with 100 knots.

Status and trends: Pacific herring were distributed in northern and nearshore areas of the eastern Bering Sea during late summer (Figure 57). Field densities were generally higher in warm years than in cold years. North-south elongation of the anistropy ellipse indicated that Pacific herring densities were correlated over a longer distance in the north-south direction than in the east-west direction (Figure 58). The distribution of Pacific herring was more nearshore and north in 2010-2012 (Figure 59) and also more contracted over a smaller area in 2010-2011 (Figure 60) than in 2002-2009 and 2012-2015. Estimated abundance of Pacific herring ranged from 15,745 metric tonnes in 2002 to 149,456 metric tonnes in 2014 (Figure 61, Table 5). The general trend was of higher abundances in warm years and lower abundances in cold years.

Factors influencing observed trends: The eastern Bering Sea has recently undergone a series of warm (2002-2006), cold (2008-2012), and warm (2014, 2015) stanzas. The estimated abundance of Pacific herring was higher in warm years and lower in cold years. This model, however, does not account for the age of Pacific herring so estimates of abundance likely include multiple year classes.

Implications: Possible implications for increases in abundance of Pacific herring include increased prey availability for piscivores.

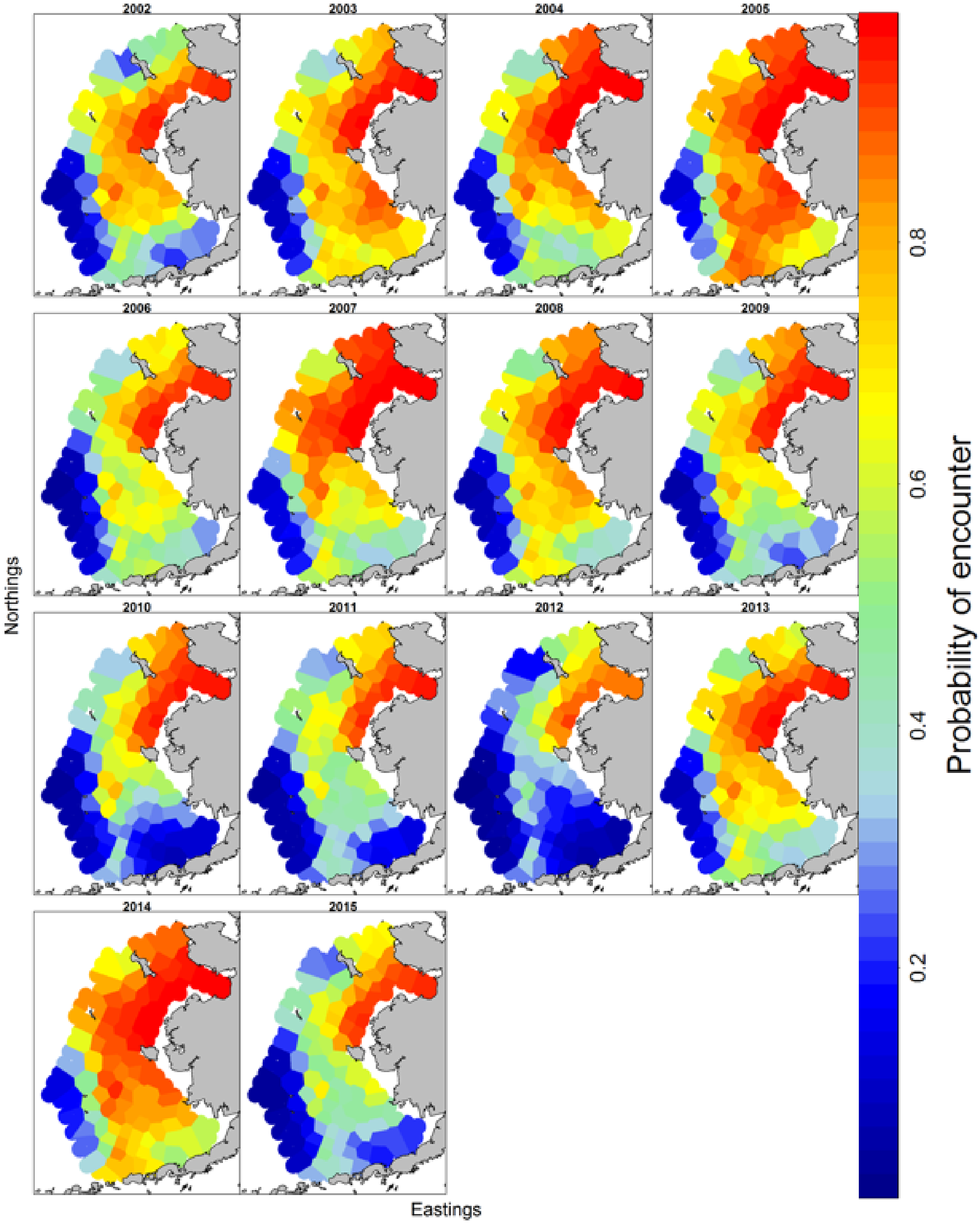

Figure 57: Density of Pacific herring in the eastern Bering Sea during late summer, 2002-2015. Densities were estimated using the geostatistical delta-generalized linear mixed model from Thorson et al. (2015).

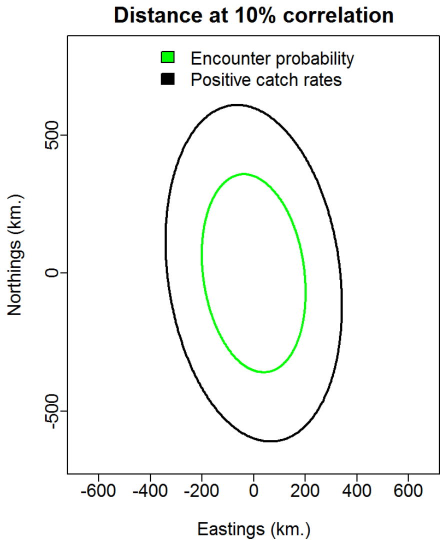

Figure 58: Geometric anistropy plots for encounter probability of Pacific herring on the eastern Bering Sea shelf during late summer, 2002-2015.

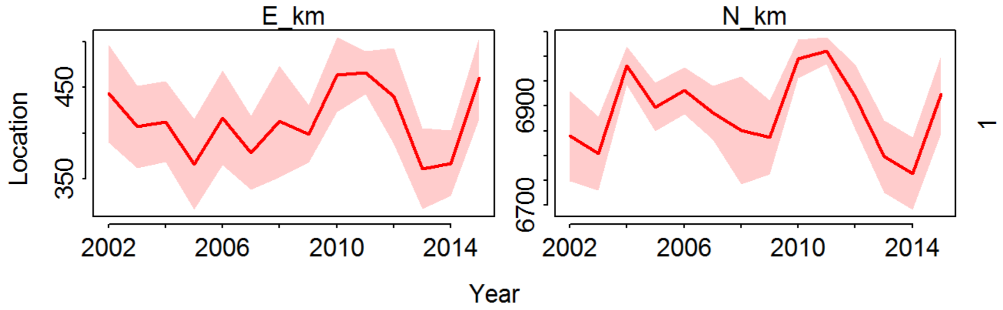

Figure 59: Northward and eastward center of gravity (distribution) in units of km for Pacific herring on the eastern Bering Sea during late summer, 2002-2015.

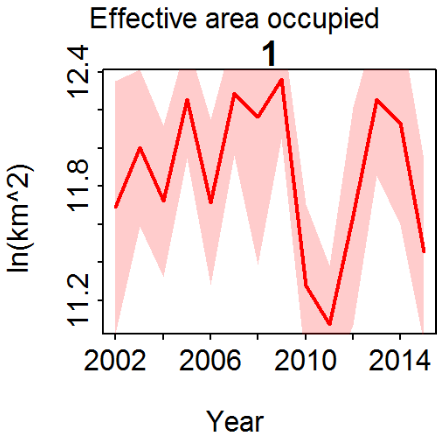

Figure 60: The effective area ($\ln(\mathrm{km}^2)$) occupied by Pacific herring on the eastern Bering Sea shelf during late summer, 2002-2015.

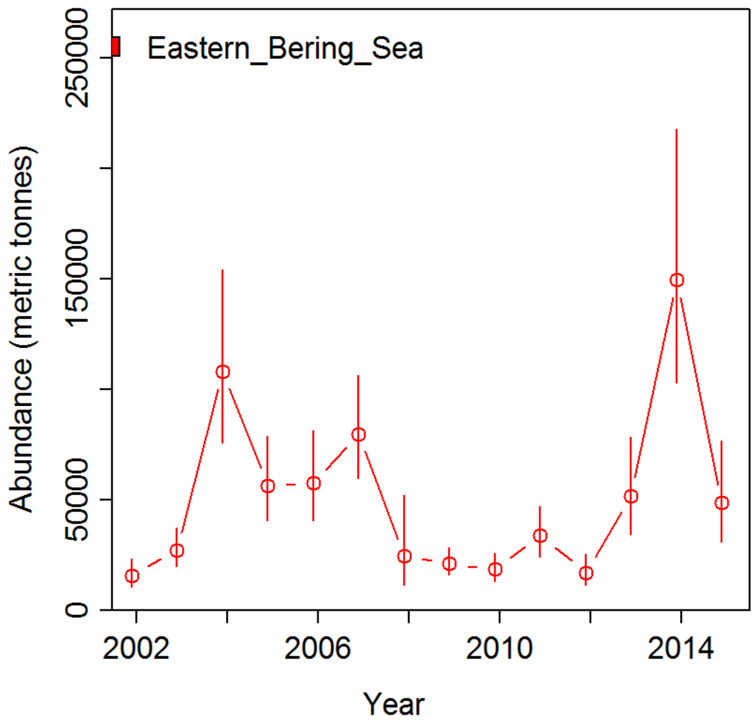

Figure 61: Estimated index of abundance with 95% confidence intervals for Pacific herring in the eastern Bering Sea during late summer, 2002-2015. Abundance was estimated using the geostatistical delta-generalized linear mixed model from Thorson et al. (2015).

Table 5: Estimated abundance in metric tonnes of Pacific herring in the eastern Bering Sea during late summer, 2002-2015. SD is standard deviation.

Year	Estimate (metric tonnes)	SD (log)	SD (natural)
2002	15,745.16	0.39	6,130.8
2003	27,051.98	0.32	8,640.1
2004	108,028.98	0.36	38,474.97
2005	56,371.99	0.33	18,699.17
2006	57,293.63	0.35	19,918.21
2007	79,624.55	0.29	23,028.57
2008	24,289.43	0.76	18,478.78
2009	21,070.3	0.29	6,106.61
2010	18,410.66	0.33	6,155.88
2011	33,681.06	0.34	11,300.79
2012	16,834.02	0.41	6,858.82
2013	51,733.96	0.41	21,352.86
2014	149,456.46	0.38	56,081.85
2015	48,632.97	0.45	22,073.26

Salmon

Editor's synthesis: Alaska salmon returns have been generally strong over the past 35-40 years. Some smaller runs such as Bering Sea Chinook and chum have had direct impacts on groundfish fisheries through bycatch limits in years with especially poor runs and/or high bycatch.

Historical and Current Alaska Salmon Trends

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Last updated: September 2016

Description of indicator: This contribution provides historic and current catch information for salmon of the Bering Sea and takes a closer look at a stock that could be informative from an ecosystem perspective: Bristol Bay sockeye salmon. This contribution summarizes available information that is included in current Alaska Department of Fish and Game (ADF&G) agency reports (Brenner and Munro, 2016).

Pacific salmon in Alaska are managed in four regions based on freshwater drainage basins (`http://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmonareas`): Southeast/Yakutat, Central (encompassing Prince William Sound, Cook Inlet, and Bristol Bay), Arctic-Yukon-Kuskokwim, and Westward (Kodiak, Chignik, and Alaska Peninsula). ADF&G prepares harvest projections for all areas rather than conducting run size forecasts for each salmon run. There are five Pacific salmon species with directed fisheries in Alaska: sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*).

Status and trends: *Statewide:* Catches from directed fisheries on the five salmon species have fluctuated over the last 35-40 years (Figure 62), but in total have been generally strong. According to ADF&G, total salmon commercial harvests from 2015 totaled 268.3 million fish, which was about 47.5 million more than the preseason forecast of 220.8 million. The 2015 total salmon harvest is substantially more than the 2014 total harvest of 157.9 million and was bolstered by the catch of 190.6 million pink salmon. In 2016 ADF&G is forecasting a decrease in the total commercial salmon catch to 161 million fish, due to an expected decrease in the number of pink salmon. Projections for 2017 are not yet available.

Bering Sea: Chinook salmon abundance in the Arctic-Yukon-Kuskokwim region has been declining since 2007 and in 2015 Chinook salmon harvests continued to be low. For the eighth consecutive year, no commercial periods targeting Chinook salmon were allowed on the mainstem of the Yukon River. In the Kuskokwim Area, Chinook salmon abundance was poor and only 9 of 13 escapement goals were met. In Norton Sound, all Chinook salmon escapement goals were met. In Bristol Bay, Chinook salmon were primarily caught during directed sockeye periods. The total 2015 Chinook salmon harvest in Bristol Bay was about 55,000 which is within 4% of the 20-year average.

The 2014 harvest of 287,000 coho salmon in Bristol Bay was the largest coho harvest in the last 20

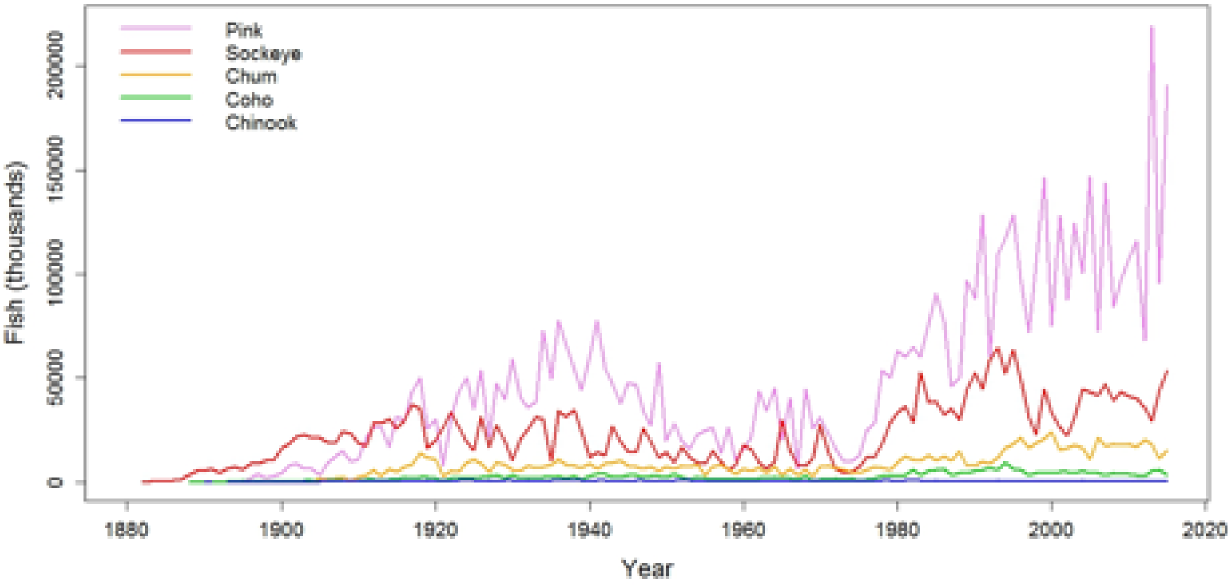

Figure 62: Alaska historical commercial salmon catches, 2016 values are preliminary. Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.

years. In contrast, the 2015 catch of coho salmon in Bristol Bay was considerably less, only 34,530. The 2015 harvest of coho salmon in Norton Sound and the Yukon River fall season harvest were the highest on record. Chum salmon abundance in the Arctic-Yukon-Kuskokwim region was variable. Chum salmon harvest in Kuskokwim was close to expected numbers while in Norton Sound the chum salmon harvest was the highest in 30 years.

The 2014 Bristol Bay sockeye salmon run of 41.1 million fish was 55% above the preseason forecast of 26.6 million, and was 19% above the previous 20-year average (1994-2013) of 34.7 million. In 2015 this trend continued with a total run of 58 million fish which was the second highest run of sockeye salmon over the last 20 years (1995-2014). The 2015 run was 70% above the recent 20-year average and 12% above the preseason forecast of 52 million. Historically, total runs to Bristol Bay have been highly variable, but in recent years (2004-2011) sockeye salmon runs have been well above the long term mean (Figure 62). Run size decreased each year from 2009 to 2013, when the run size dipped below the long-term historical average run size of 32.4 million fish before rebounding in 2014. The 2015 harvest of 36.6 million Bristol Bay sockeye salmon was below the preseason forecast of 37.6 million fish but was 53% higher than the recent 20-year average harvest. The forecast for 2016 Bristol Bay sockeye is for another above-average run size but smaller than 2015 at 46.54 million. Preliminary information suggests that the 2016 forecast may have been low (Figure 63). Recruitment for most Bristol Bay sockeye salmon stocks was moderate to strong in the 1980s and into the mid-1990s. The number of returning adult sockeye salmon produced from each spawner increased dramatically for most Bristol Bay stocks, beginning with the 1973 brood year (>1979 return year) (Fair, 2003). Poor returns in 1996-98, however, suggested a return to a level of productivity similar to the pre-1978 period (Fair, 2003). Fish from the 1996-98 return years reared in the ocean when temperatures were above average, whereas, cooler than average ocean temperatures characterized the pre-1978 period.

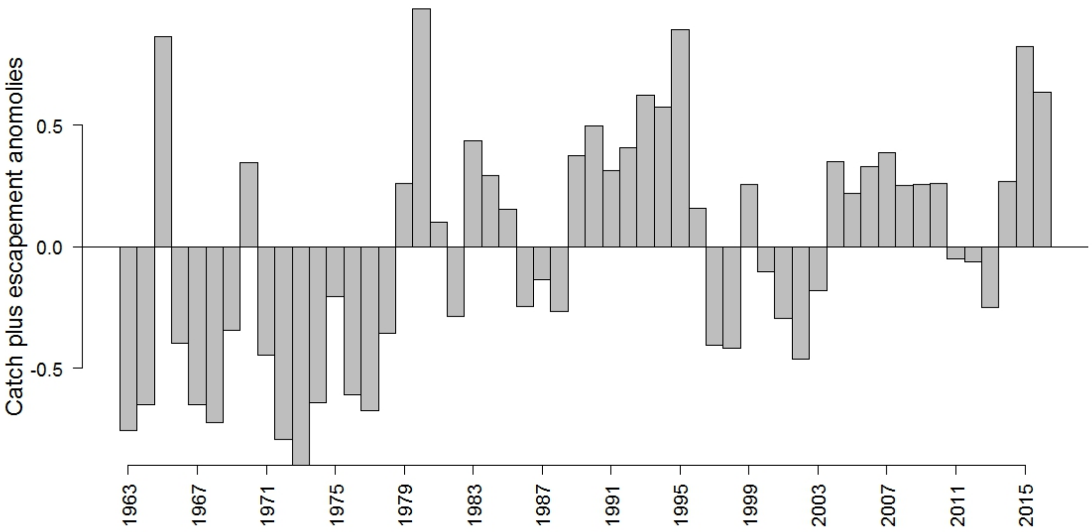

Figure 63: Historical catch plus escapement anomalies of Bristol Bay sockeye salmon, 1956-2015. Data provided by Charles Brazil (ADF&G). Note: the value for 2016 is preliminary and subject to revision.

Factors influencing observed trends: In the Bering Sea, chum salmon are generally caught incidental to other species and catches may not be good indicators of abundance. There were no directed openings for Chinook salmon in the Yukon River due to low early season returns. In other areas of Bristol Bay, Chinook salmon are taken incidentally and mainly in the early portions of the sockeye salmon fisheries.

Bristol Bay sockeye salmon display a variety of life history types. For example, their spawning habitat is highly variable and demonstrates the adaptive and diverse nature of sockeye salmon in this area (Hilborn et al., 2003). Therefore, productivity within these various habitats may be affected differently depending upon varying conditions, such as climate (Mantua et al., 1997), so more diverse sets of populations provide greater overall stability (Schindler et al., 2010). The abundance of Bristol Bay sockeye salmon may also vary over centennial time scales, with brief periods of high abundance separated by extended periods of low abundance (Schindler et al., 2006).

Implications: Salmon have important influences on Alaska marine ecosystems through interactions with marine food webs as predators on lower trophic levels and as prey for other species such as Steller sea lions. In years of great abundance, salmon may exploit prey resources more efficiently than their competitors. A negative relationship between seabird reproductive success and years of high pink salmon abundance has recently been demonstrated (Springer and van Vliet, 2014). Directed salmon fisheries are economically important for the state of Alaska. The trend in total salmon catch in recent decades has been for generally strong harvests, despite annual fluctuations.

Juvenile Chinook Salmon Abundance in the Northern Bering Sea with Implications for Yukon River Salmon Fisheries Management and Evaluating Chinook Salmon Bycatch Caps in the Eastern Bering Sea Pollock Fishery

Contributed by Jim Murphy[1] and Katharine Howard[2]
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Last updated: October 2016

Description of indicator: A time series of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) abundance was constructed for the Canadian-origin (Upper Yukon) stock group of the Yukon River from late-summer (typically during the month of September) pelagic rope trawl surveys in the northern Bering Sea, 2003-2015. Abundance is estimated from trawl catch-per-unit-effort data, genetic stock composition, and mixed layer depth in the northern Bering Sea. Juvenile Chinook salmon abundance estimates for the Canadian-origin stock group have ranged from 0.6 million to 2.6 million juveniles with an overall average of 1.5 million juvenile Chinook salmon from 2003 to 2015 (Figure 64).

Status and trends: The preliminary estimate of Canadian-origin juvenile Chinook salmon in the northern Bering Sea in 2015 is 2.0 million juveniles, which is higher than the overall average of 1.5 million and reflects a continued above-average juvenile abundance in the northern Bering Sea since 2013.

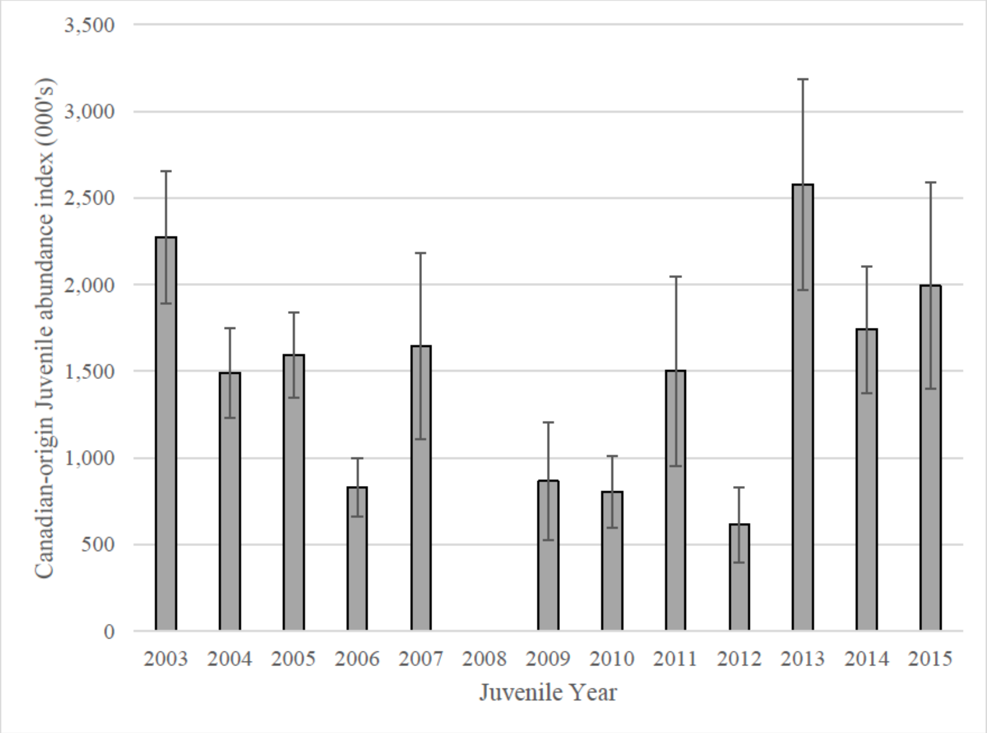

Figure 64: Juvenile abundance estimates for the Canadian-origin stock group of Chinook salmon in the Yukon River, 2003 to 2015. Error bar range is two standard deviations.

Factors influencing observed trends: Increased productivity of Canadian-origin Chinook salmon during their early life history (freshwater and early marine) periods have contributed to the increase in juvenile abundance. The number of juveniles per spawner increased from an average of 26 (2003 to 2012) to an average of 59 from 2013 to 2015 (Figure 65).

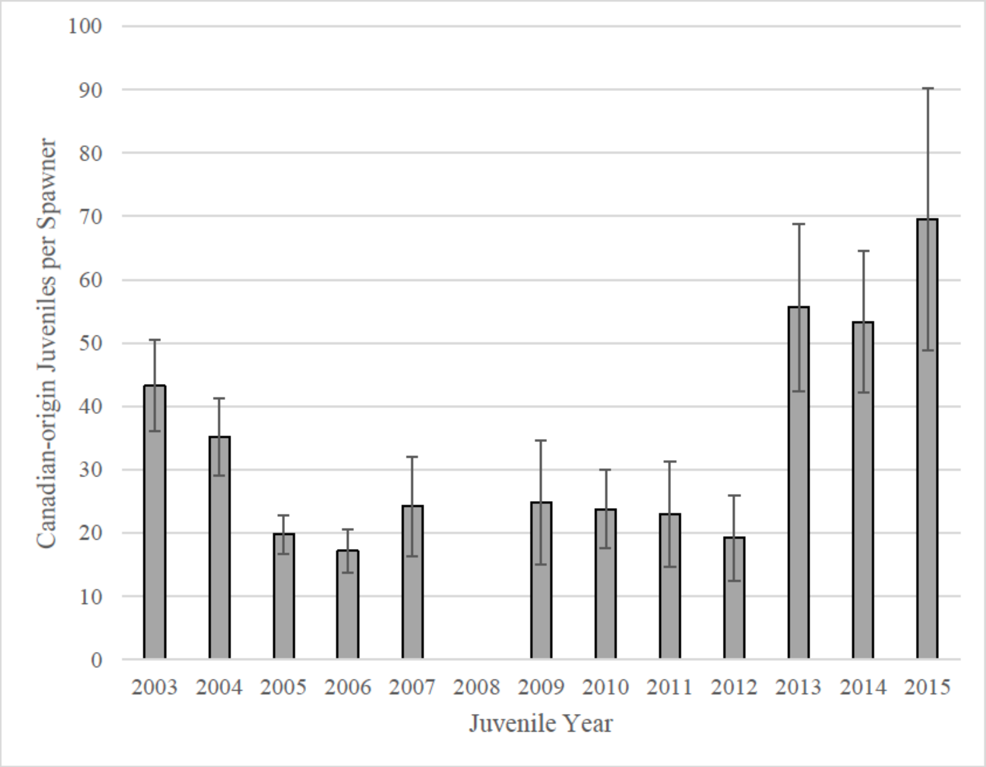

Figure 65: Estimated number of juveniles per spawner for the Canadian-origin stock group of Chinook salmon in the Yukon River, 2003 to 2015. Error bar range is two standard deviations.

Implications: Juvenile abundance is significantly correlated (r = 0.87, $p < 0.001$; Figure 66) with adult returns, indicating that much of the year-to-year variability in survival of the Canadian-origin Chinook salmon occurs during their early life stages (freshwater and early marine). This allows a reasonably accurate projection of future returns of the Canadian-origin stock group to the Yukon River based on juvenile abundance. Recent production declines in Chinook salmon have triggered closures of commercial, sport, and personal use fisheries and severe restrictions on subsistence fisheries in the Yukon River. The number of adults projected to return from juvenile abundance estimates indicate that fishing opportunities on the Canadian-origin stock group of Chinook salmon in the Yukon River could significantly improve as early as 2016.

Juvenile Chinook salmon abundance also has important implications for Chinook salmon bycatch in the eastern Bering Sea pollock fishery. The North Pacific Fishery Management Council established hard caps on Chinook salmon bycatch in the eastern Bering Sea pollock fishery based on a three system index of Western Alaska Chinook salmon, which includes the Unalakleet River, Upper Yukon River (Canadian-origin), and Kuskokwim River Chinook salmon stock groups. Hard caps of 60,000 and 45,000 Chinook salmon bycatch are applied to annual bycatch limits when the three system index is above and below 250,000 Chinook salmon, respectively. The Upper Yukon stock group (Canadian-origin) run size and the three system index are significantly correlated (r = 0.92,

$p < 0.001$; Figure 67), reflecting the importance of the Canadian-origin stock group to the three system index, as well as the coherent trend in productivity of Chinook salmon stocks present in the index. This indicates that juvenile abundance data for the Canadian-origin stock group is also applicable to forward projection models of the three system index, which can be used to define future Chinook salmon bycatch cap probabilities in the eastern Bering Sea pollock fishery.

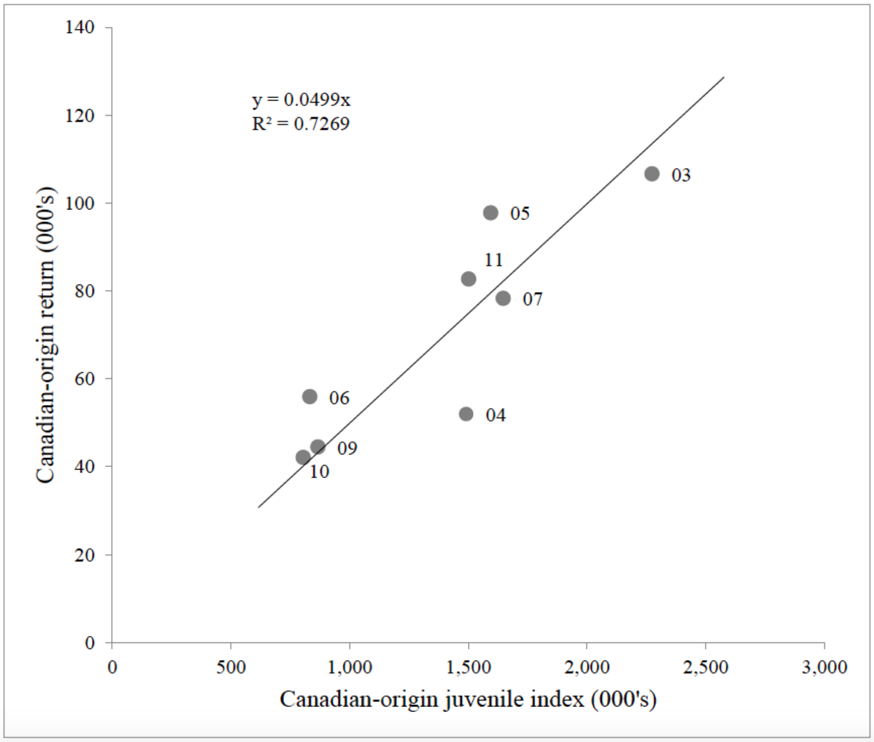

Figure 66: The relationship between juvenile and adult return abundance for the Canadian-origin stock group of Chinook salmon in the Yukon River, 2003 to 2011. Adult abundance is the number of returning adults by juvenile year. Data labels indicate the juvenile year.

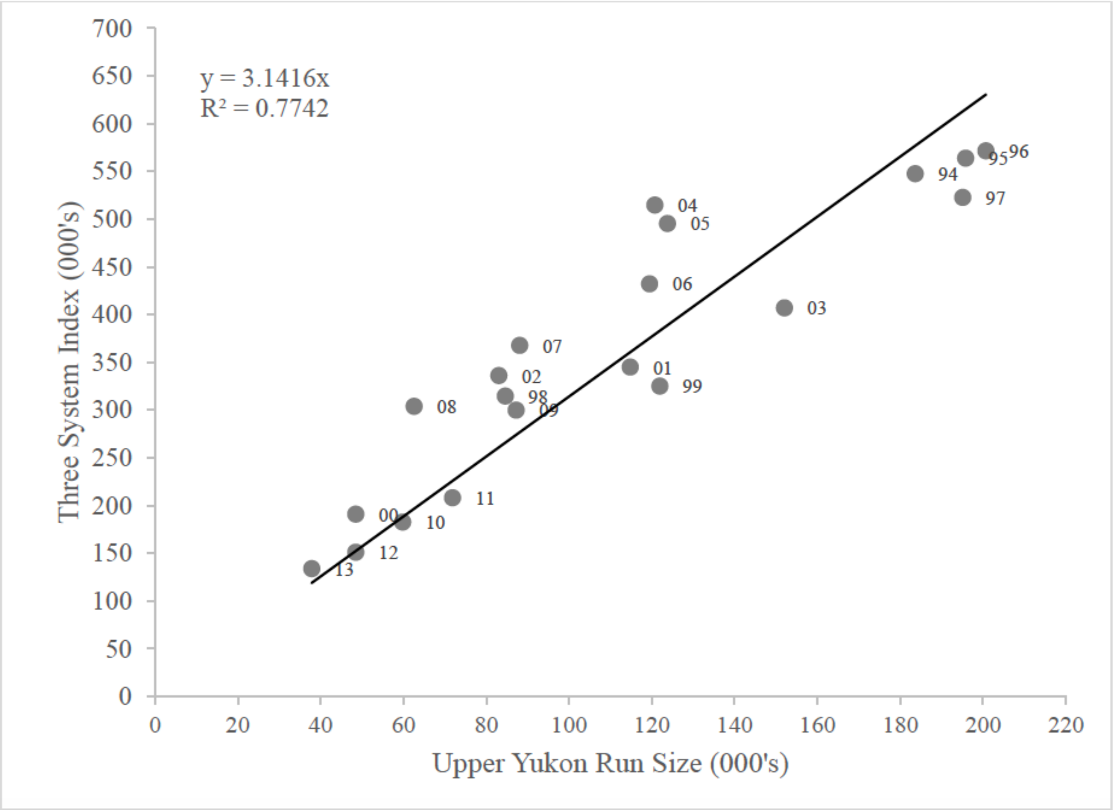

Figure 67: The relationship between the Upper Yukon (Canadian-origin Chinook from the Yukon River) run size and the three system index for Western Alaska Chinook salmon, 1994 to 2013. Data labels indicate the return year.

Groundfish

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

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Last updated: August 2016

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*; hereafter 'pollock') collected during the late-summer BASIS survey in the southeastern Bering Sea (SEBS). Fish were collected from surface trawls between 2003-2014 and from oblique (water column) trawls in 2015. 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 (n=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 the 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 and age-3 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 and recruitment success to age-3.

Status and trends: Energy density (kJ/g), mass (g), and standard length (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 southeastern Bering Sea 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 2007-2012 (i.e., cold conditions). Warm conditions returned in 2014 and have persisted through at least late summer 2016.

The transition between warm and cold conditions is evident when examining energy density over the time series (Figure 68). 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 (data not shown). The AEC of age-0 pollock in 2003-2015 accounts for 46% of the variation in the number of age-1 recruits per spawner and 47% of the variation in the number of age-3 recruits per spawner (Figure 69).

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*).

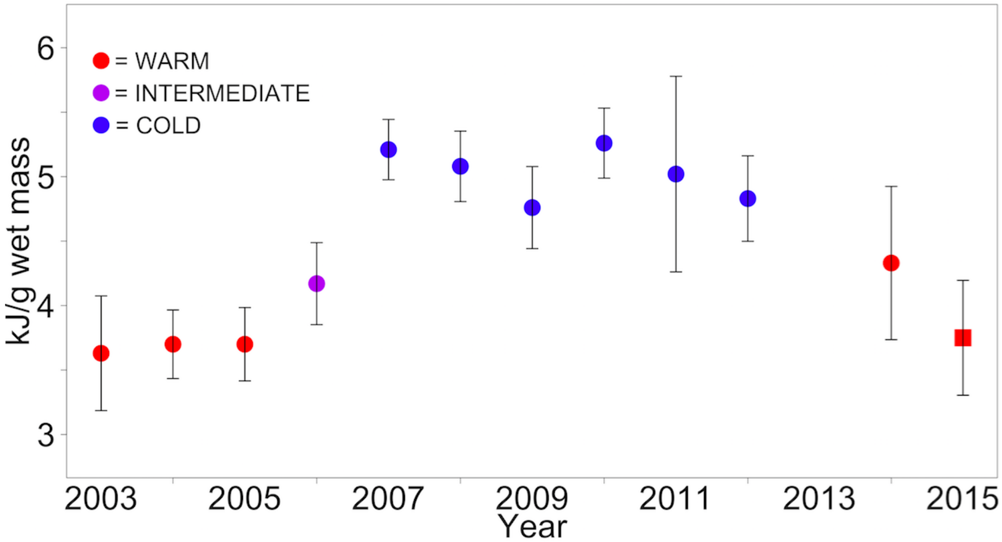

Figure 68: Average energy density (kJ/g) of young-of-the-year Walleye pollock (*Gadus chalcogrammus*) collected during the late-summer BASIS survey in the southeastern Bering Sea 2003-2015. Fish were collected with a surface trawl in 2003-2014 and an oblique trawl in 2015.

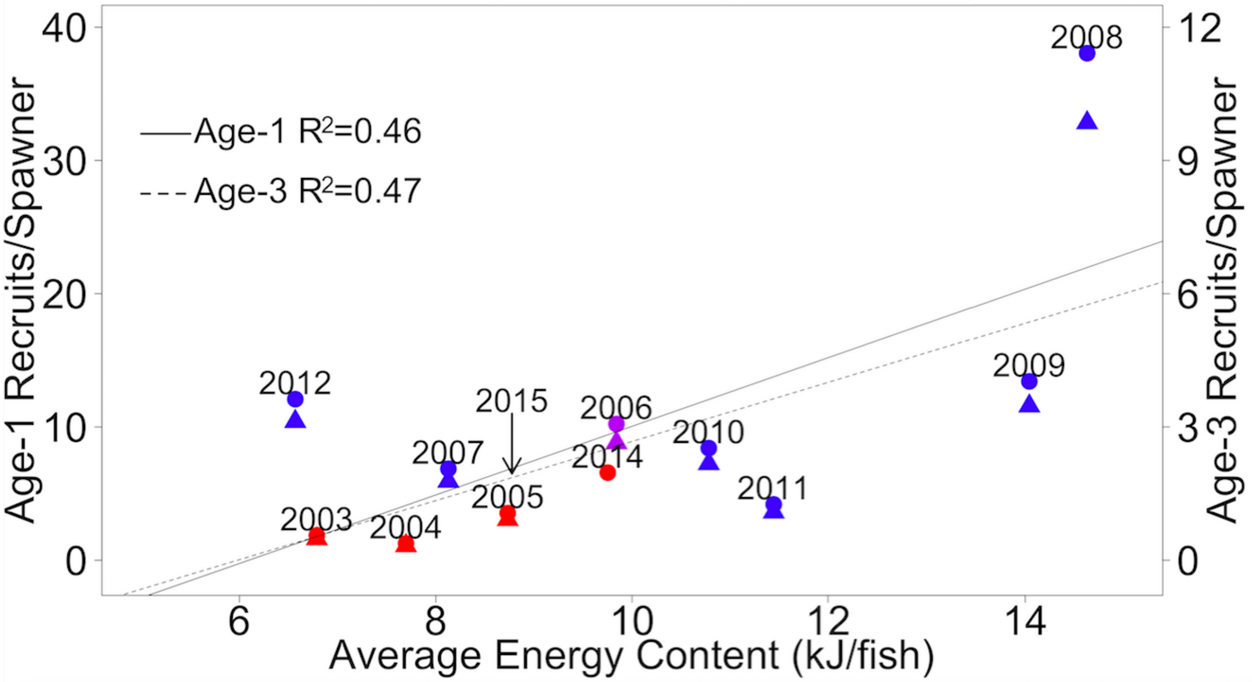

Figure 69: Relationship between average energy content (AEC) of individual young-of-the-year Walleye pollock (*Gadus chalcogrammus*) and the number of age-1 (circles) and age-3 (triangles) recruits per spawner from the 2015 stock assessment (Ianelli et al., 2015). Fish were collected with a surface trawl in 2003-2014 and an oblique trawl in 2015.

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). 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 current model indicates that the 2015 year class is predicted to have intermediate overwinter survival to age-1 and recruitment success to age-3. The SEBS is experiencing warm conditions, although age-0 pollock in 2015 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., In press).

A New Index of Age-0 Walleye Pollock Prey Quality Provides a Leading Indicator of Energetic Content

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Last updated: August 2016

Description of indicator: This leading indicator uses data obtained from on-board diet analyses of age-0 Walleye pollock (*Gadus chalcogrammus*) collected from the middle domain during the southeastern Bering Sea survey (BASIS). The indicator provides a rapid assessment of prey quality as a predictor of age-0 pollock energetic content. Energetic content of age-0 pollock has been linked to overwinter survival and recruitment success to age-1 (Heintz et al., 2013) as well as age-3 (see Heintz contribution p. 122). Previous research indicates that zooplankton composition (i.e., ratio of small and large copepod taxa) changes with thermal regime (Coyle et al., 2011). These changes in prey availability are linked with changes in energy content and recruitment success of age-0 pollock (Siddon et al., 2013*b*).

The composition of prey contents was summarized by taxonomic group (Figure 70). A weighted average of the energetic content of age-0 pollock diets was calculated using energetic density values from the literature. The weighted averages of dietary energetic content were plotted with the energetic content of age-0 pollock collected from the same surveys and showed a strong correlation.

Status and trends: The energetic content of age-0 pollock diets varies across thermal regime (Figure 71); diet energy density was lower during the warm years of 2003-2005, intermediate during 2006, and higher diet energy density was observed during the cold years of 2007-2012. No survey occurred during 2013 and diet energy density was intermediate during the warm years of 2014-2015. Thermal conditions continued to be warm in 2016; diet energy density data will be available in late fall 2016.

Factors influencing observed trends: Oceanographic forcing has resulted in dynamic zooplankton composition between warm and cold stanzas over the southeastern Bering Sea shelf (Coyle et al., 2011). Prey quality varies across taxa, with warm-year taxa generally having lower energy density than cold-year taxa (Siddon et al., 2013*b*). Such changes in the prey composition are transferred up the food chain and result in age-0 pollock having lower (higher) energy content in warm (cold) years.

Implications: Ongoing research suggests the energetic content of age-0 pollock is a good predictor

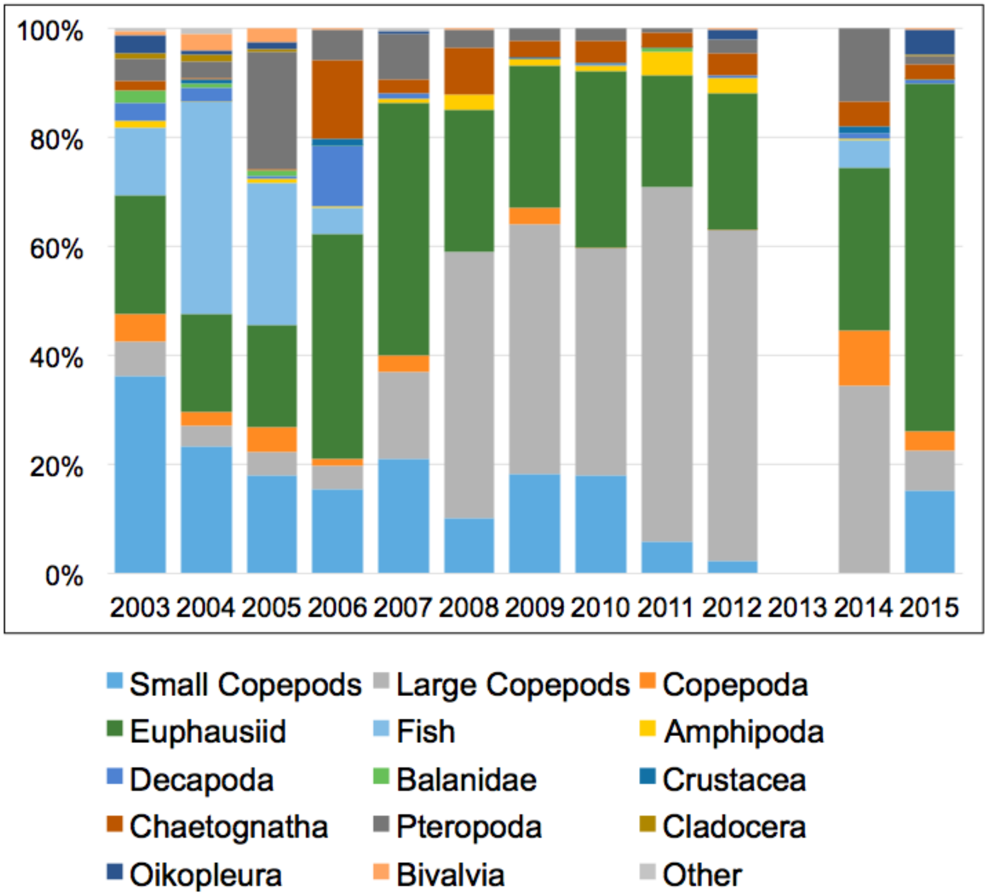

Figure 70: Percent composition of age-0 pollock prey from the middle domain in the southeastern Bering Sea. On-board diet analyses are conducted during the late summer/early fall BASIS survey and are available soon after the survey is completed.

of overwinter survival and subsequent recruitment success (Heintz et al. (2013), see Heintz contribution p. 122). Under the current warm conditions (beginning in late 2013 and continuing through at least the fall of 2016), prey quality and diet energy content are expected to be low and therefore age-0 pollock energy density is also predicted to be low. Low age-0 pollock energy density typically results in below-average recruitment success.

Age-0 pollock energy density must be determined in the laboratory and is not available for the Groundfish Plan Team Meetings in the fall. Age-0 diet energy density can be calculated from on-board diet analyses and available soon after the survey, therefore it may provide a useful leading indicator of age-0 pollock energy density in the current year.

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

Contributed by Lisa Eisner[1] and Ellen Yasumiishi[2]
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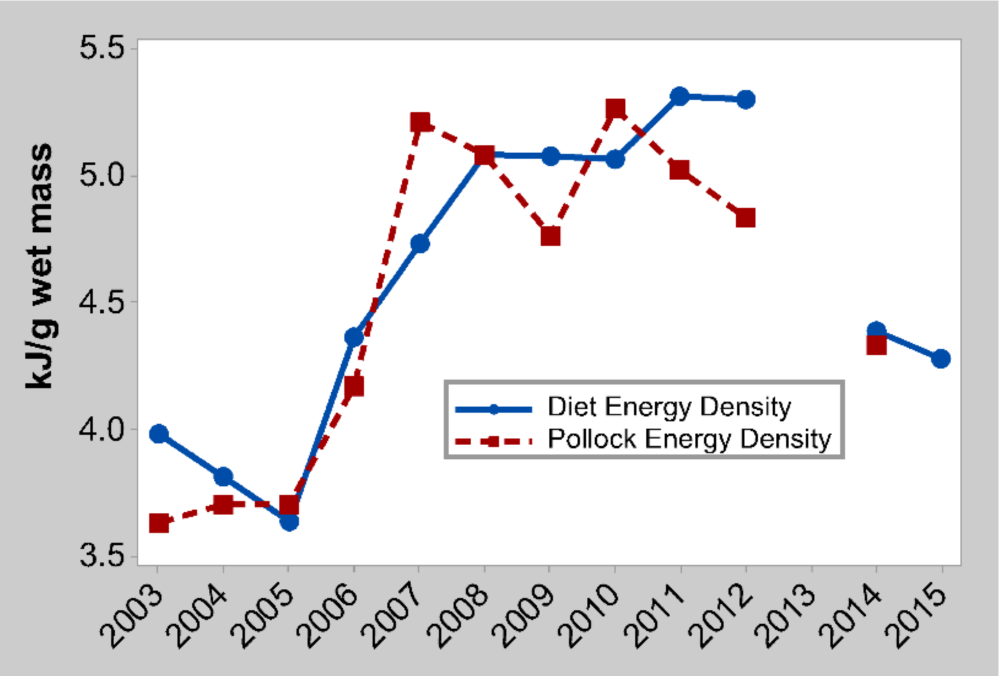

Figure 71: Comparison of the diet energy density (blue line) calculated from on-board diets to whole fish energy density (red dashed line) determined in the laboratory.

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Last updated: August 2016

Description of indicator: Interannual variations in large zooplankton abundance (sum of most abundant large taxa typically important in age-0 pollock diets, Coyle et al. (2011)) were compared to age-1 and age-3 walleye pollock abundance (millions of fish) and abundance per biomass (thousands of tons) of spawner on the southeastern Bering Sea shelf (south of 60°N, <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 and 2014 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) year, six cold years (2007-2012), and one warm year (2014) using methods in (Eisner et al., 2014). Pollock abundance and biomass was available from the stock assessment report for the 2002-2015 year classes (Ianelli et al., 2015).

Status and trends: A positive significant (P = 0.04) linear relationship was found between mean abundances of large zooplankton during the age-0 stage of pollock and estimated abundance of age-1 pollock from Ianelli et al. (2015) for the 2002-2012 year classes (Figure 72). Age-1 pollock abundance is primarily derived from age-3 data, therefore relationships between large zooplankton and age-1 and age-3 abundances are similar. No significant relationship occurred between large zooplankton abundance and recruits-per-spawner for the 2002-2012 year classes, unlike the prior update for 2003-2010 data. The prior update also used geometric instead of arithmetic mean large zooplankton abundance. Using the 2014 zooplankton abundance (185 m^{-3}), we compared the model prediction with the observed abundance of age-1 pollock for the 2014 year class from (Ianelli et al., 2015) (Figure 73). Our regression models predicted an abundance of 27,303 million age-1 pollock with a standard error of 4,897 million and an abundance of 7,303 million age-3 pollock with a standard error of 1,268 million for the 2014 year class.

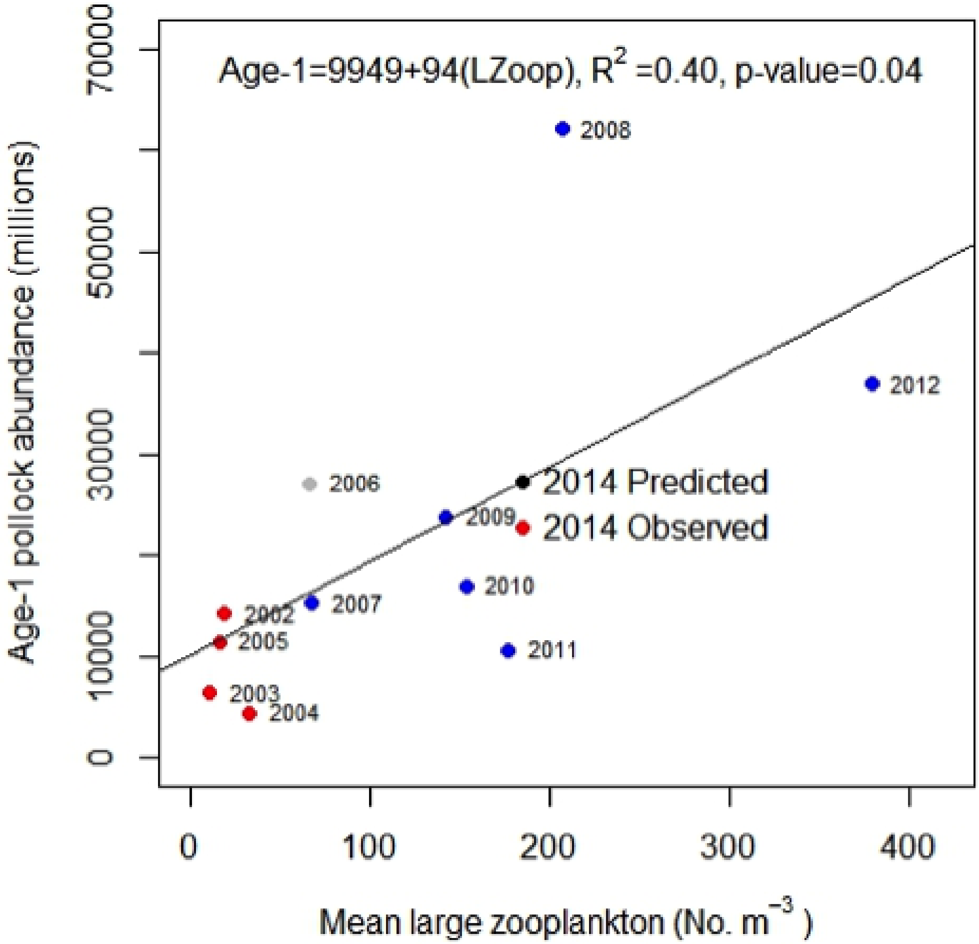

Figure 72: Linear relationships between mean large zooplankton abundance during the age-0 life stage of pollock and the estimated abundance of age-1 pollock abundance of the year class 2002-2012, from Ianelli et al. (2015). The 2014 points are the observed stock assessment estimates of age-1 pollock from Ianelli et al. (2015) and the predicted age-1 pollock estimates are from our regression model using large zooplankton abundance for 2014. Points are labeled with year class. Red points are warm (low ice) years, blue are cold (high ice) years, and gray is an average year. For comparison, the linear regression for age-3 pollock using large zooplankton abundance is: $Age\text{-}3=2573 + 24 * LZoop$, $R^2 = 0.40$, $p\text{-}value=0.04$.

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

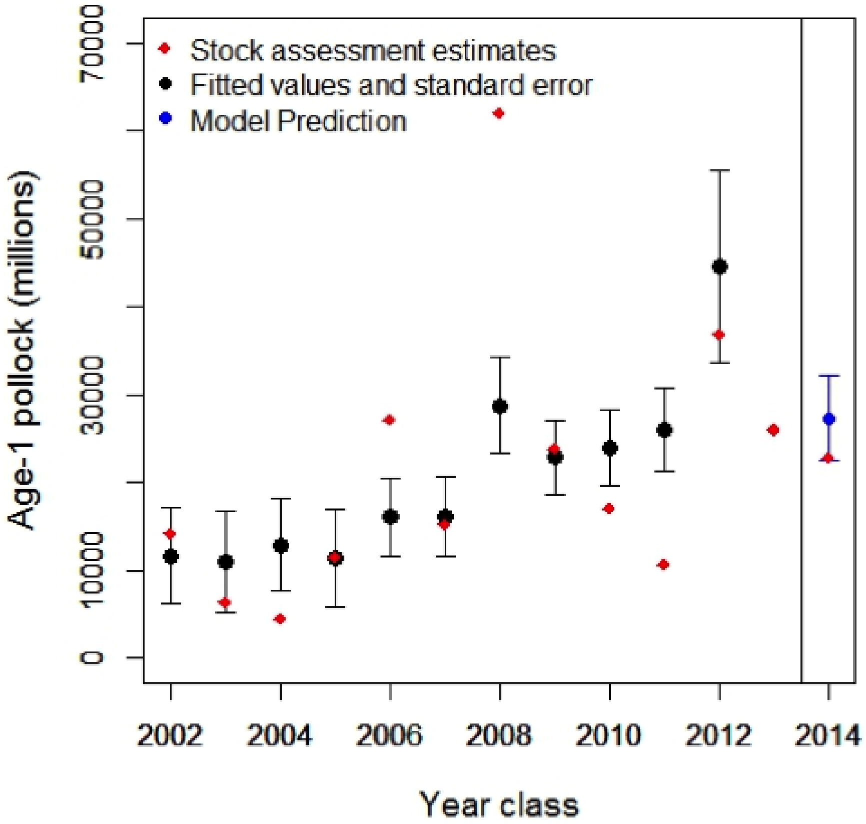

Figure 73: Fitted values and standard errors of age-1 pollock abundance, estimated from the linear regression model relating the abundance of age-1 pollock from (Ianelli et al., 2015) to the abundance of large zooplankton during the age-0 life stage of pollock. Red symbols are stock assessment estimates (Ianelli et al., 2015).

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 forage fish. 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 increases in the availability of large zooplankton prey during the first year at sea were favorable for age-0 pollock overwinter survival to age-1 and recruitment into the fishery at age-3. If the relationship between large zooplankton and age-1 (age-3) pollock remains significant in our analysis, the index may be used to predict the recruitment of pollock one (three) years in advance of recruiting to age-1 (age-3), from zooplankton data collected one (three) 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).

Table 6: Pearson's correlation coefficient relating the Temperature Change index to subsequent estimated abundance of pollock at age by year class. Bold values are statistically significant ($p < 0.05$).

	Correlations					
	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6
1963-2014	**0.35**	**0.34**	**0.31**	0.26	0.22	0.22
1995-2014	0.35	0.31	0.31	0.38	0.37	0.36

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

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Last updated: August 2016

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 is calculated as the difference in the average monthly sea surface temperature in June during the age-1 life stage and in August during the age-0 life stage (Figure 74) in an area of the southern region of the eastern Bering Sea (56.2°N to 58.1°N latitude by 166.9°W to 161.2°W longitude). 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 TC index value of -3.19 corresponding with the conditions experienced by the 2015 year class of pollock was higher than the TC index value of -5.96 experienced by the 2014 year class of pollock, indicating improved conditions for pollock for the 2015 year class due to the lower difference in sea temperature from late summer of 2015 to the following spring of 2016 than from 2014 to 2015 (Figure 74). However, both the late summer sea surface temperature (11.7°C) in 2015 and the spring sea temperatures (8.5°C) in 2016 were warmer than the long-term average of 9.7°C in late summer and 5.1°C in spring since 1950. The TC index was positively correlated with subsequent recruitment of pollock to age-1 through age-4 from 1963 to 2014 year classes, but not significantly correlated for the shorter period (1995-2014) (Table 6).

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

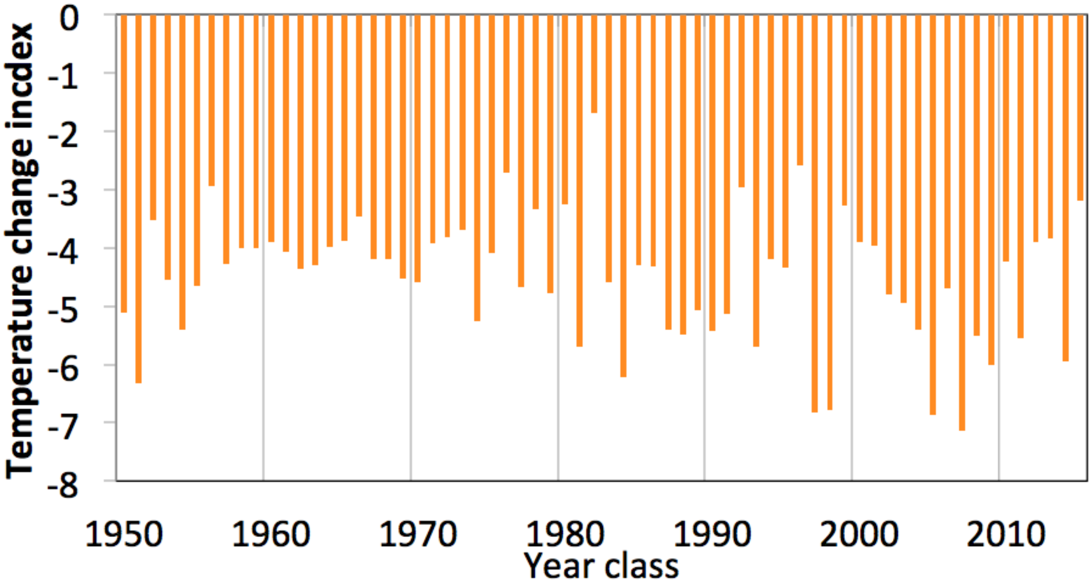

Figure 74: The Temperature Change index values from 1950-2015.

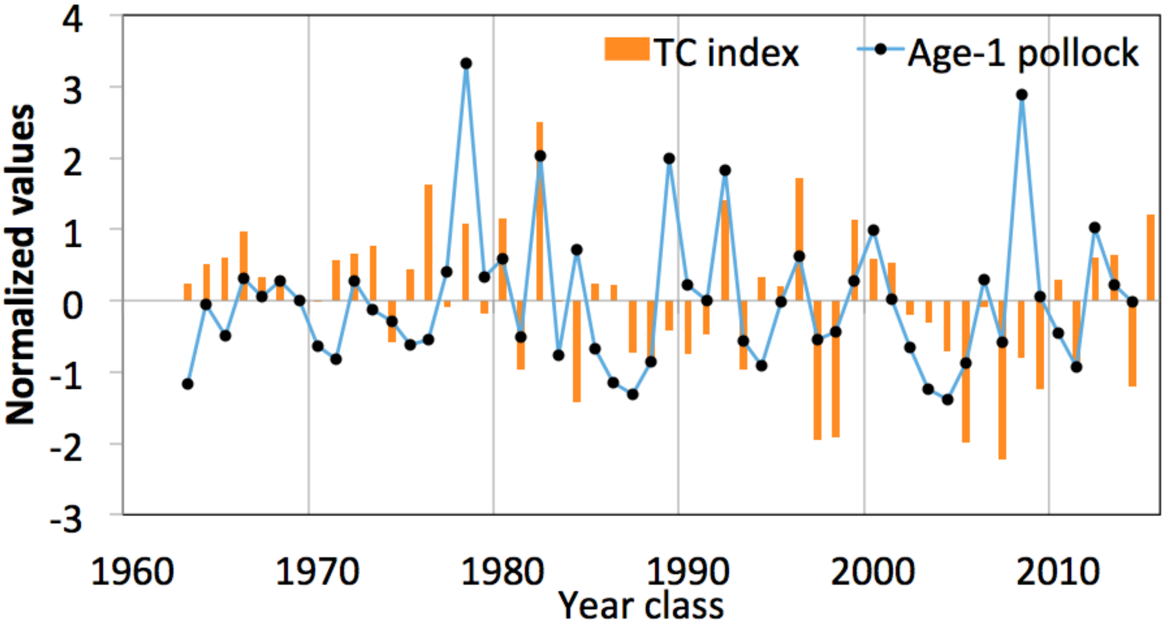

Figure 75: Normalized time series values of the Temperature Change index and the estimated abundance of age-1 Walleye pollock in the eastern Bering Sea by year class from Table 1.25 in Ianelli et al. (2015).

by warmer spring temperatures during the age-1 phase are assumed favorable for the survival of pollock from age-0 to age-1.

Implications: The TC index value of -5.96 for the 2014 year class of pollock was below the long-term average of -4.54, therefore we expect lower than average recruitment of pollock to age-1 in

2015 from the 2014 year class (Figure 75). The TC index value of -3.19 for the 2015 year class of pollock was above the long-term average TC index value, therefore we expect slightly above average recruitment of pollock to age-1 in 2016 from the 2015 year class.

Salmon, Sea Temperature, and the Recruitment of Bering Sea Pollock

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Last updated: August 2016

Description of indicator: Chum salmon growth, sea temperature, and adult pink salmon abundance were used to predict the year class strength of Walleye pollock (*Gadus chalcogrammus*; Yasumiishi et al. (2015)). The intra-annual growth in body weight of immature and maturing age-4 chum salmon incidentally captured in the commercial fisheries for pollock in the eastern Bering Sea was used as a proxy for ocean productivity experienced by age-0 pollock on the eastern Bering Sea shelf. A multiple linear regression model was used to describe stock assessment estimates of pollock abundance from Ianelli et al. (2015) for the 2001-2011 year classes as a function of chum salmon growth, sea temperature, and adult pink salmon returns from Irvine and Ruggerone (2016). Model parameters and updated biophysical indices were used to predict the abundance of age-1 and age-3 pollock for the 2013-2015 year classes.

Status and trends: For last year's model (2015), an alternating year pattern was observed in the residuals, so this year we added pink salmon as a predictor in the model due to their alternating life cycle and interaction with age-0 and age-1 pollock. The best fit 2016 model (lowest Bayesian information criterion) included chum salmon growth during the age-0 stage, spring sea temperature during the age-1 stage, and adult pink salmon returns during the age-0 stage, indicating that adult pink salmon are possible predators of age-0 pollock ($R^2 = 0.85$; p-value = 0.003).

The model parameters (2001-2011) and biophysical indices from 2013 to 2016 were used to predict the abundance of age-1 and age-3 pollock for the 2013-2015 year classes (Figure 76). For the 2013 year class, high chum salmon growth (0.97 kg) in 2013, average spring sea temperatures (3.95°C) in 2014, and high adult pink salmon returns to Asia and North America in 2013 (806,999 metric tonnes) produced a forecast of 7,166 million age-1 pollock (SE=155 million) and 39 million age-3 pollock (SE=1,855). For the 2014 year class, average chum salmon growth (0.79 kg), warm spring sea temperatures (4.0°C), and low adult pink salmon returns (493,683 million) produced a forecast of 9,095 million age-1 pollock (SE=5,252) and 2,349 million age-3 pollock (SE=1,359 million). For the 2015 year class, low chum salmon growth (0.53 kg), warm spring sea temperatures (5.50°C), and high adult pink salmon returns (742,601 million) produced a forecast of -32,208 million age-1 pollock (SE=9,060 million) and -8,341 million age-3 pollock (SE=2,346 million). Our model predicted low abundance for the 2013-2015 year classes.

Factors influencing observed trends: The 2016 biophysical indices indicated below average ocean productivity (chum salmon growth), warm spring sea temperatures in 2016 (less favorable), and high pink salmon abundances (predation on age-0 pollock by adult pink salmon during the spring and early summer) (Coyle et al., 2011). These factors are expected to result in below average recruitment of pollock for the 2013-2015 year classes.

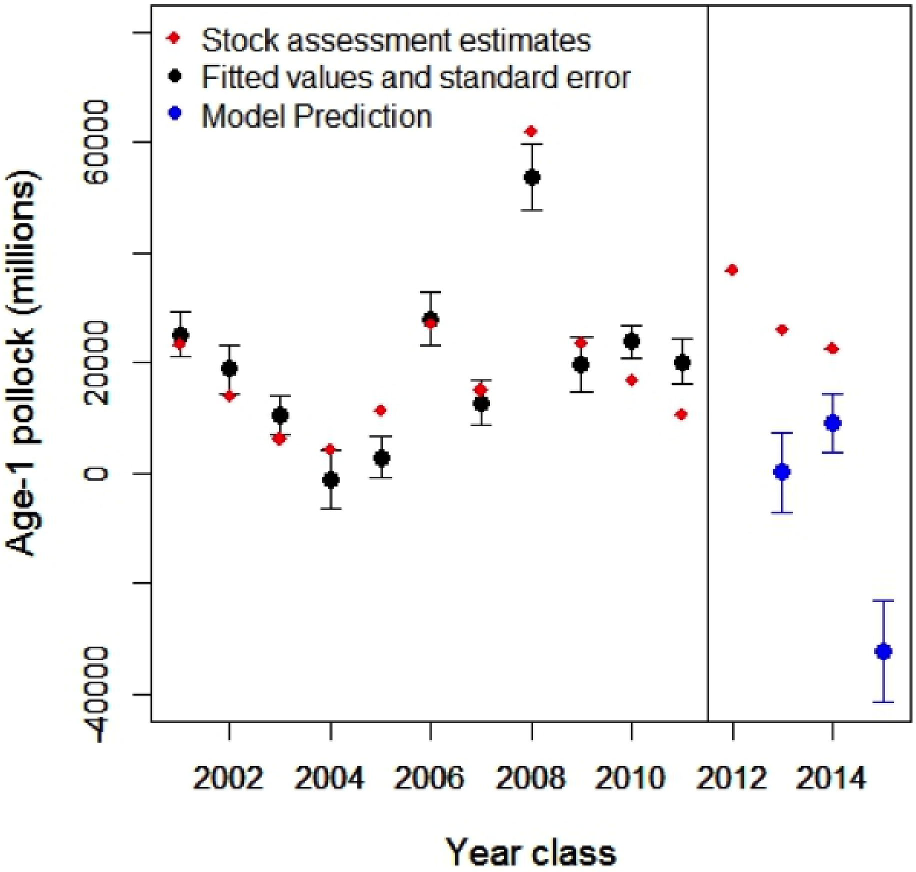

Figure 76: Model output from the linear regression model relating the estimated pollock abundance from Ianelli et al. (2015) to the intra-annual growth of age-4 chum salmon during the age-0 life stage of pollock, abundance of adult pink salmon returns to Asia and North America during the age-0 stage, and spring sea temperatures in the southeastern Bering Sea during the age-1 life stage of pollock.

Implications: The biophysical indicators and 2016 model predicts a below-average recruitment of pollock to age-1 for the 2013-2015 year classes.

Multispecies Model Estimates of Time-varying Natural Mortality

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Last updated: November 2016

Description of indicator: We report trends in age-1 total mortality for Walleye pollock (*Gadus chalcogrammus*; hereafter 'pollock'), Pacific cod (*Gadus macrocephalus*; hereafter 'P. cod'), 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 Holsman et al. (In press), 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, P. cod, and Arrowtooth flounder was higher in 2016 than any previous year in the time series (1979-2016; Figure 77) and at 2.02 yr^{-1} was greatest for pollock (relative to P. cod or Arrowtooth flounder). Age-1 mortality was lower for P. cod and Arrowtooth flounder, with total age-1 natural mortality stable at around 0.68 and 0.64 yr^{-1}, respectively, although both were slightly higher in 2016.

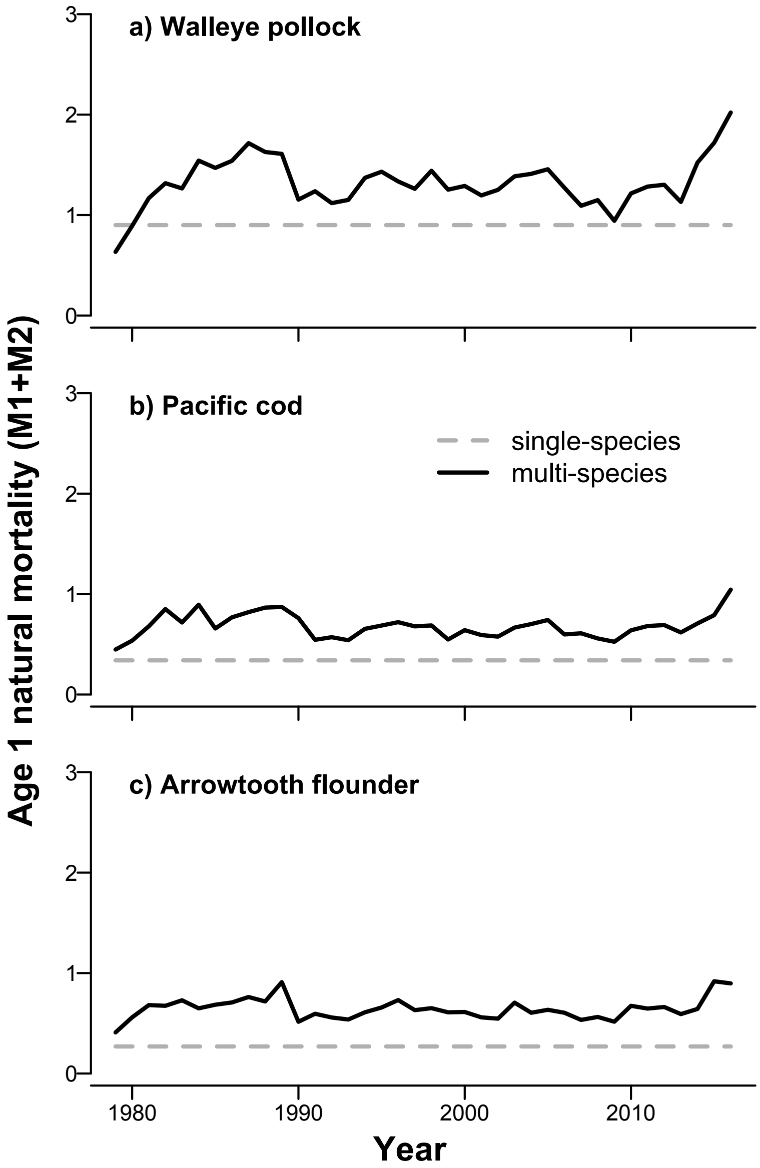

Figure 77: Annual variation in total mortality ($M1_{i1} + M2_{i1,y}$) for age-1 pollock (a), Pacific cod (b), and Arrowtooth flounder (c) from the single-species models (dashed gray line) and the multi-species models with temperature (black line). Updated from Holsman et al. (In press).

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 56% (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 78).

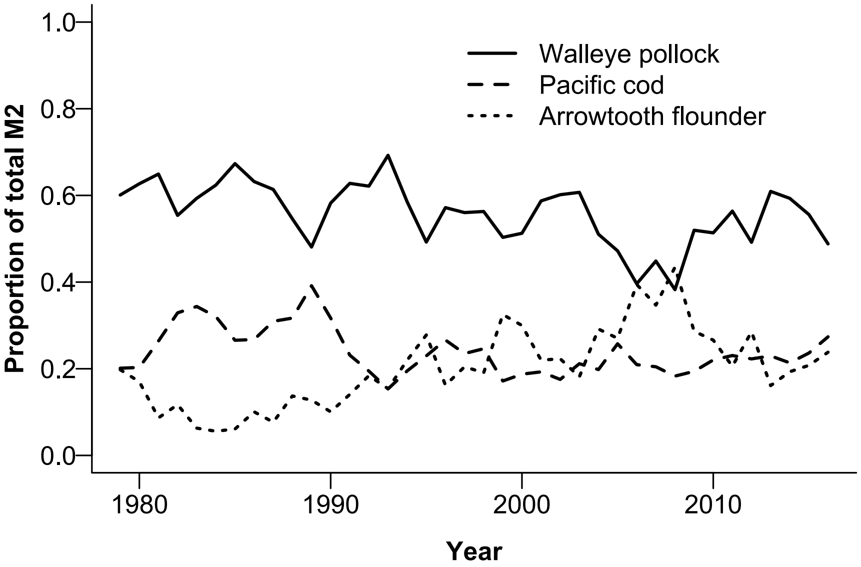

Figure 78: Proportion of total predation mortality for age-1 pollock from pollock (solid), Pacific cod (dashed), and Arrowtooth flounder (dotted) predators across years. Updated from Holsman et al. (In press).

Implications: We find evidence for a recent shift in the dominant predator of Bering Sea pollock, with oscillating importance of Arrowtooth flounder predation on pollock since 2000. This pattern may reflect changes in spatial overlap among prey of Arrowtooth flounder and pollock driven by thermal conditions that favor Arrowtooth flounder, higher metabolic (and energetic) demand under warm conditions, and increases in Arrowtooth flounder biomass in the Bering Sea (Holsman and Aydin, 2015; Spencer et al., In press; Hunsicker et al., 2013; Zador et al., 2011). This suggests that increasing trends in Arrowtooth flounder biomass could negatively impact pollock populations in the Bering Sea, particularly during warm years when thermal conditions increase Arrowtooth flounder predation pressure on juvenile pollock.

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 1980s (collectively 8.97 billion t per year), and in recent years (collectively $\sim$ 7.74 billion 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 P. cod that dominated the age composition of the two species in 2006. Similarly, the recent peaks in mortality in 2011 and 2014 reflect maturation of the large 2008 year class of pollock.

Eastern Bering Sea Groundfish Condition

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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). The AFSC eastern Bering Sea shelf bottom trawl survey data was utilized to acquire lengths and weights of individual fish for Walleye pollock, Pacific cod, Arrowtooth flounder, Yellowfin sole, Flathead sole, Northern rock sole, and Alaska plaice. Only summer standard survey strata and stations were included in analyses, no corner stations were included (Figure 79). 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 was available (1982-2013). Additionally, length-weight relationships for age 1+ Walleye 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 varied over time for all species with a few notable patterns (Figure 80). Residuals for all species where there was 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 Walleye pollock and Pacific cod residuals were positive from 2001 to 2004 or 2005. In 2008, all species except Flathead sole and Walleye pollock had negative residuals. There has been a distinct negative trend in Pacific cod since a peak value in 2003, although the 2016 Pacific cod condition was improved. Age-1 Walleye Pollock and older Walleye pollock were not well correlated in most years. Length-weight residuals for all species were less in 2015 than in 2016, indicating larger weight at length 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 81). 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 81). For Yellowfin sole, residuals were positive in the outermost

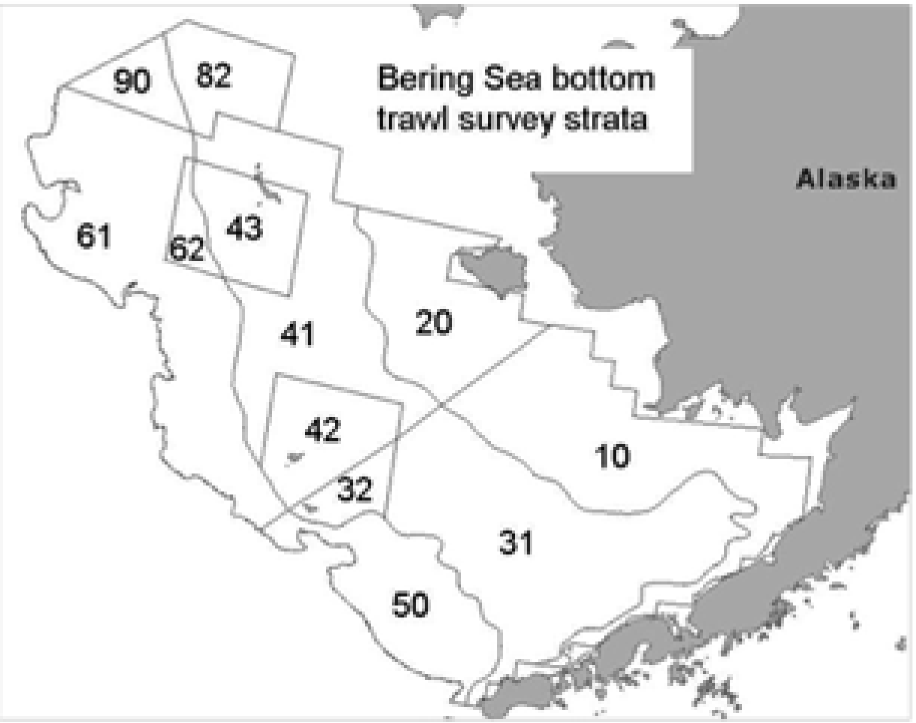

Figure 79: NMFS summer bottom trawl survey strata. Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 82 and 90 were excluded from analyses because they are not standard survey strata.

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 81). Pollock residuals were generally positive in strata 50 and 60 and negative in strata 10, 20, and 40. Pacific 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 80).

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 warmer than normal 2015 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 was collected in late July). Also, the bottom

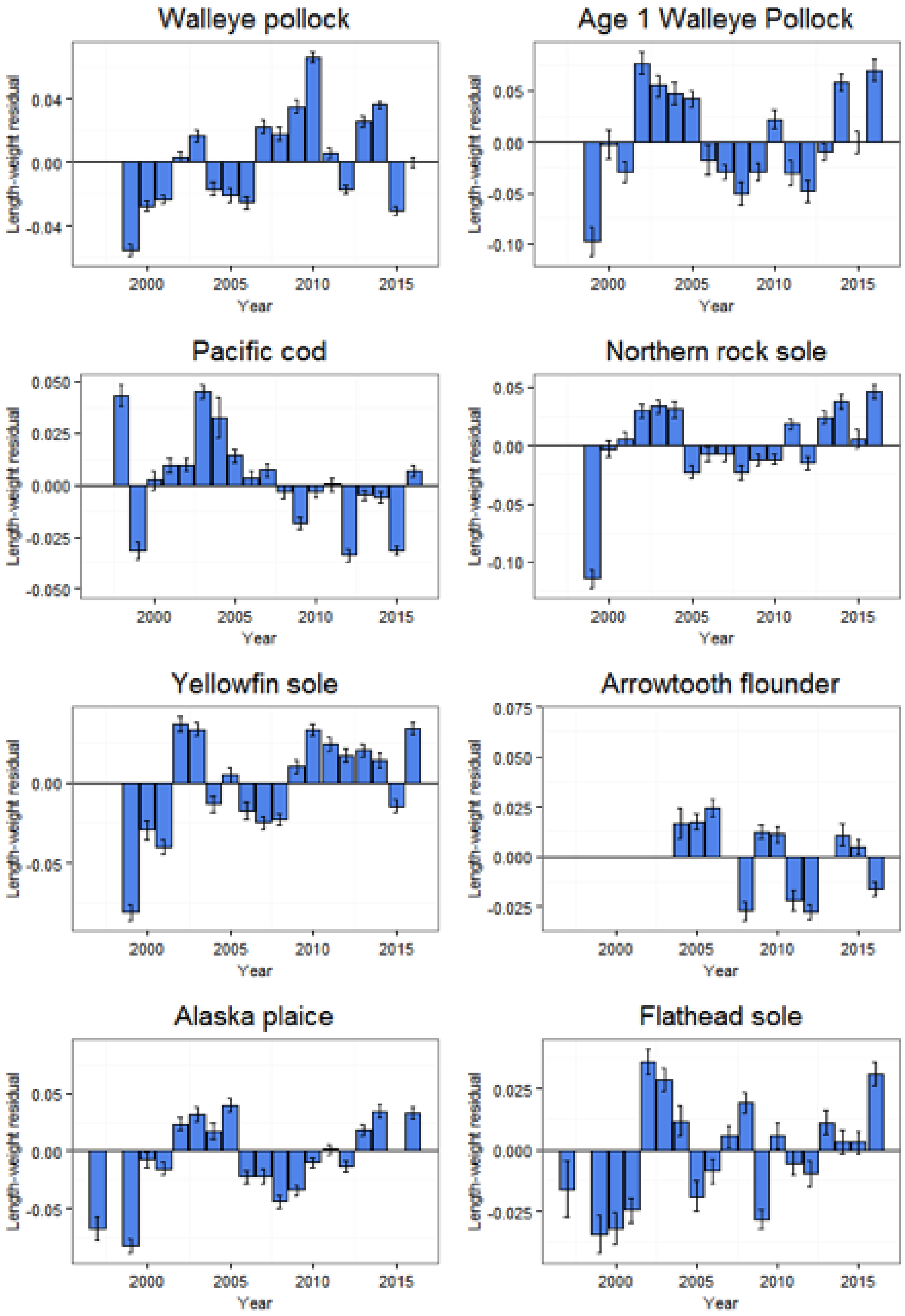

Figure 80: Length-weight residuals for seven eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997-2016.

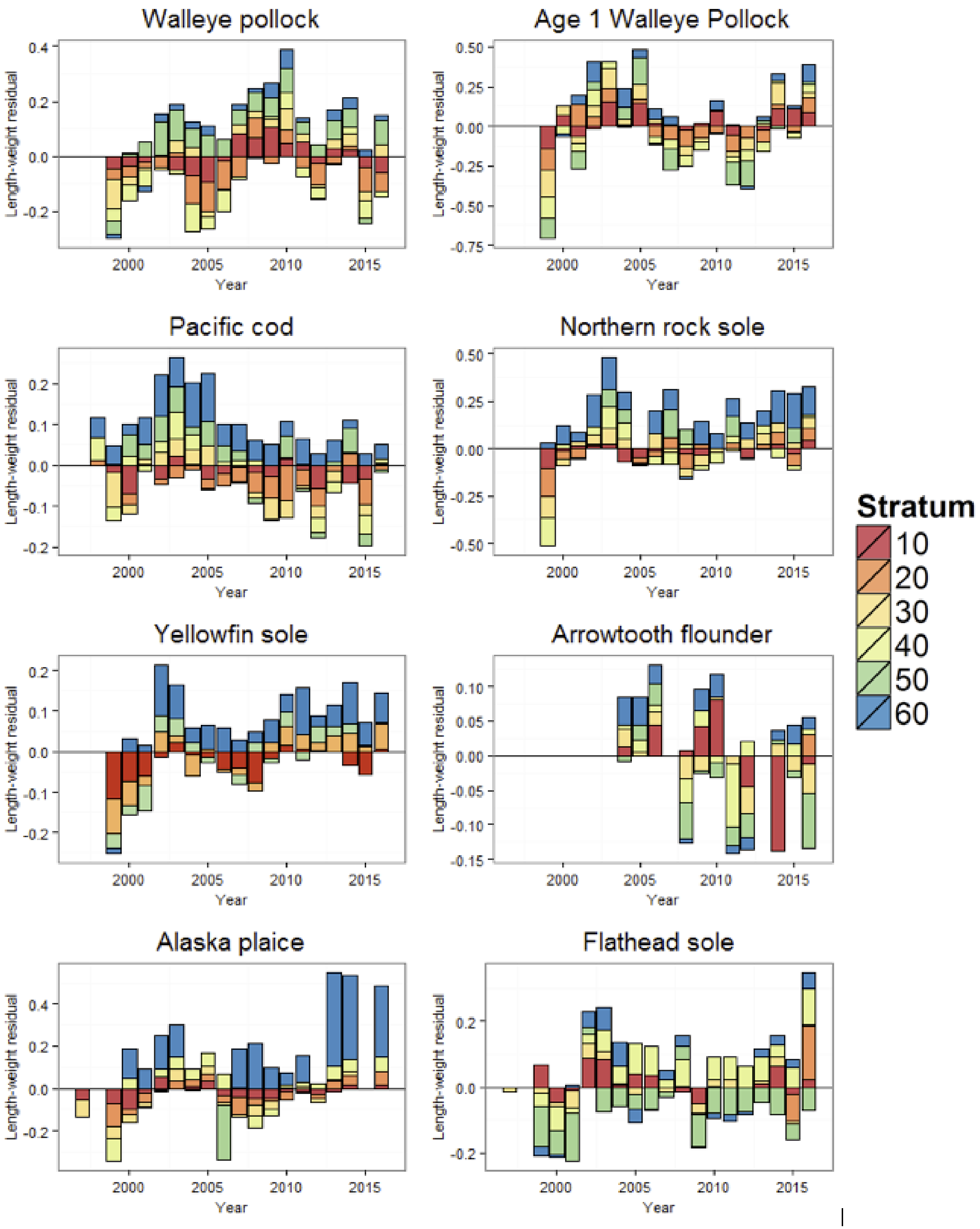

Figure 81: Length-weight residuals for seven eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997-2016, by survey strata (10 - 60). NMFS summer bottom trawl survey strata are shown in the right panel. Survey strata 31 and 32 were combined as stratum 30; strata 61 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.

trawl survey is conducted throughout the summer months, and as the summer progresses, 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 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 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.

Benthic Communities and Non-target Fish Species

Miscellaneous Species - Eastern Bering Sea Shelf

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Last updated: October 2016

Description of indicator: "Miscellaneous" species fall into three groups: eelpouts (Zoarcidae), poachers (Agonidae), and sea stars (Asteroidea). The three dominant species comprising the eelpout group are marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*), and shortfin eelpout (*L. brevipes*). The biomass of poachers is dominated by a single species, the sturgeon poacher (*Podothecus acipenserinus*) and to a lesser extend 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 was calculated and plotted for each species or species group by year for 1982-2016. 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 trend in relative CPUE for eelpout and sea star groups was very similar to 2015. The eelpout group CPUE increased by 26% and sea stars by 6%. For both taxa there is a similar trend since 2003 suggesting there may be a relationship between bottom temperature and catch rate. The poacher group CPUE decreased by 26% with a 79% decrease in standard error; however, relatively higher standard errors during the previous ten years make it difficult to distinguish a definitive trend (Figure 82).

Factors causing observed trends: Determining whether this trend represents a real response to environmental change or is 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 in benthic communities. For example, eelpouts are a common prey item of Arrowtooth flounder. However, it is not known at present whether these changes in CPUE are related to changes in energy flow.

Eastern Bering Sea Commercial Crab Stock Biomass Indices

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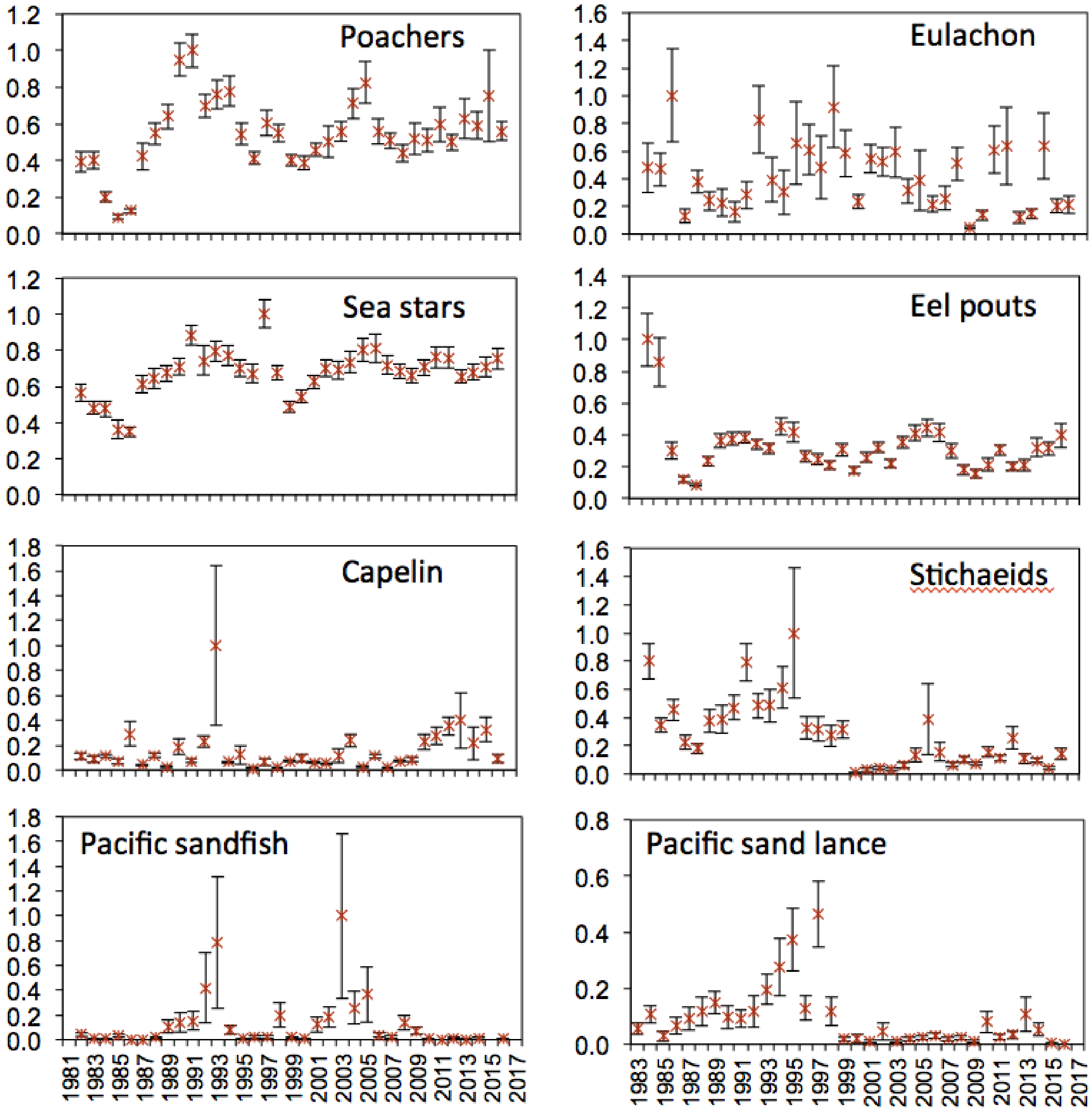

Figure 82: AFSC eastern Bering Sea shelf bottom trawl survey relative CPUE for miscellaneous fish species during the May to August time period from 1982-2016.

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 83, Figure 84).

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.

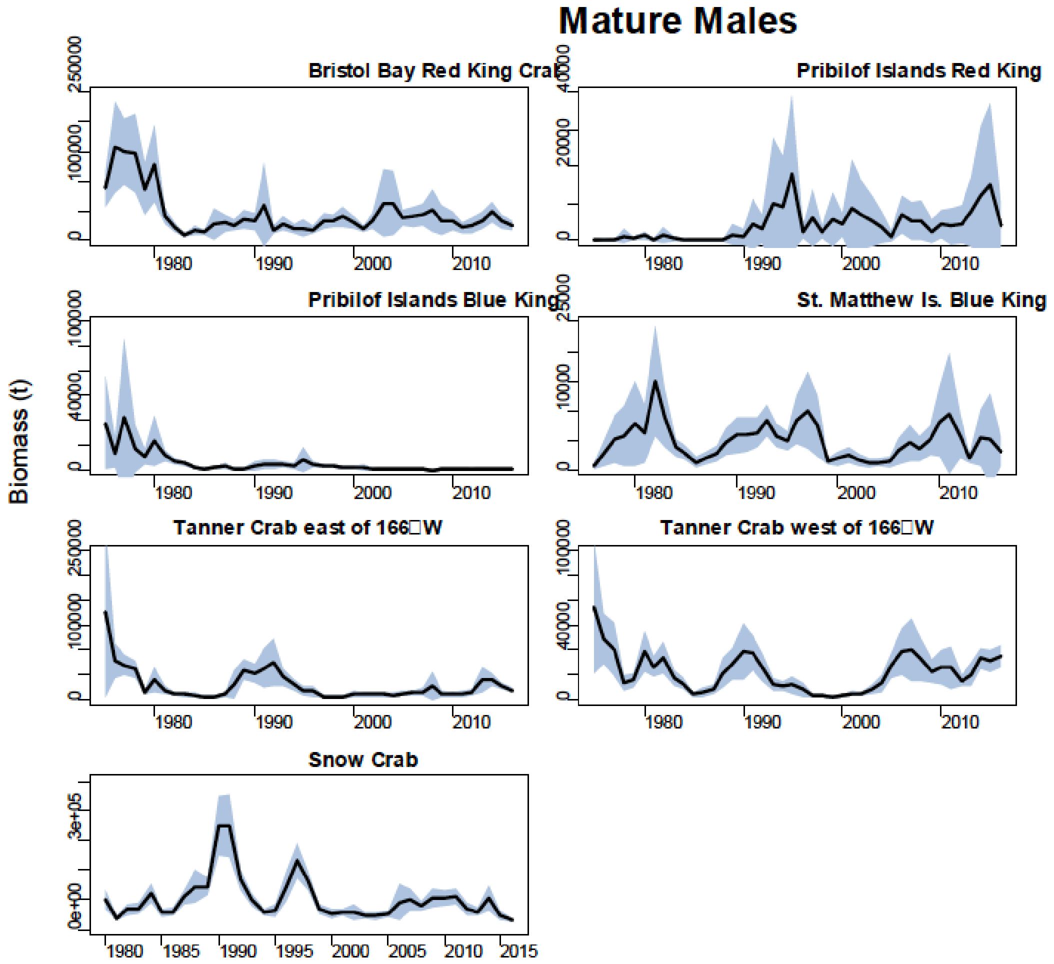

Figure 83: Historical mature male biomass (t, gray area indicates ± 95% CI) for six commercial species caught on the National Marine Fisheries Service eastern Bering Sea bottom trawl surveys (1975-2016).

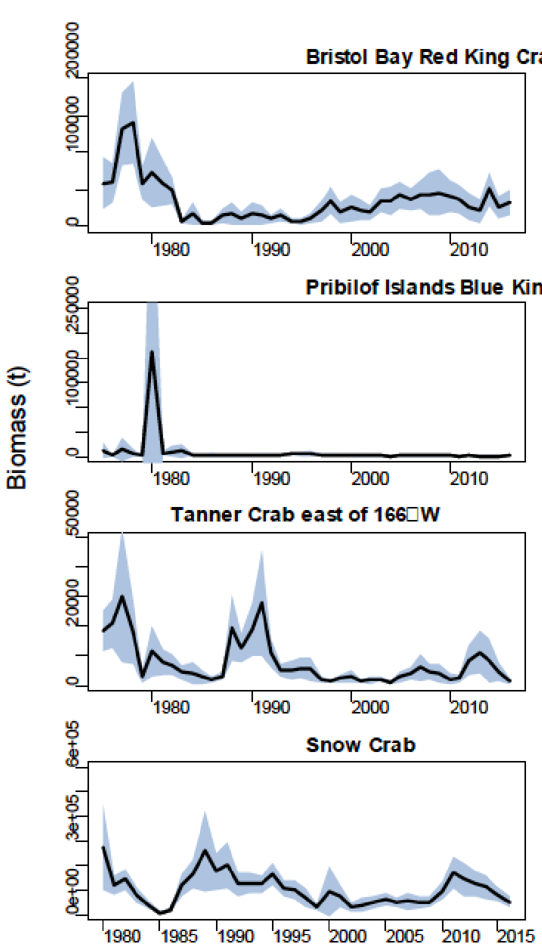

Figure 84: Historical mature female biomass (t, gray area indicates ± 95% CI) for six commercial species caught on the National Marine Fisheries Service eastern Bering Sea bottom trawl survey (1975-2016). Biomass was calculated using actual maturity (abdominal flap morphology and clutch fullness index), as opposed to the size cut-off method used for males.

Seabirds

Multivariate Seabird Indicators for the Eastern Bering Sea

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Last updated: October 2016

Description of indicator: The index is derived from the first two principal components of a principal components analysis (PCA) that combines reproductive effort data (mean hatch date and reproductive success) from common murre *Uria aalge*, thick-billed murre *U. lomvia*, black-legged kittiwake *Rissa tridactyla*, red-legged kittiwake *R. brevirostris*, and red-faced cormorants *Phalacrocorax urile* breeding on the Pribilof Islands. Data are collected by the USFWS Alaska Maritime National Wildlife Refuge. The most recent PCA includes 17 individual data sets spanning 1996 to 2016.

All data were standardized (mean of zero and variance of 1) to assure equal weighting. PCAs were performed using the `prcomp` function in R. We considered the 2 leading principal components (PC1 and PC2) successful candidates for combined seabird indices if they explained a sufficient level (>20% each) of the variance in the datasets. Inspection of the time series of breeding parameters loading most strongly on each PC (loading strength >0.2) enabled interpretation of the biological meaning of the indices. Methodological detail can be found in Zador et al. (2013).

The same datasets were used to perform a Dynamic Factor Analysis, which is similar to a PCA, but is designed for time series (Zuur et al., 2007). These results will be investigated further for inclusion in the 2017 report and possible replacement of the seabird index in the eastern Bering Sea Report Card.

Status and trends: The PCA on the 21 year annual time series (1996-2016) explained 70.0% of the variance in the data in the first two components. All seabird phenology and red-faced cormorant and common murre reproductive success time series were associated (loadings ≥ 0.2) with PC1, which explained 50.5% of the total variance (Figure 85). All kittiwake reproductive success time series were strongly associated (loadings ≥ 0.3) with PC2, which explained 19.5% of the total variance. St. Paul thick-billed murre reproductive success and St. Paul black-legged kittiwake hatch timing were also associated (loadings ≥ 0.2) with PC2.

The temporal trend in PC1 had been increasing since 2011, but dropped sharply in 2015 and again in 2016. The 2016 value is the lowest in the time series. This indicates that there were later hatch dates for all species and lower reproductive success for cormorants and common murres (Figure 86). The dominant temporal trend among kittiwake reproductive success data is an alternating biennial pattern. PC2 continued the nearly annual trend reversal with the 2016 value showing a decrease from the previous year and indicating a decrease in kittiwake reproductive success.

Factors influencing observed trends: Time series analysis of PC1 and PC2, calculated from 1996-2011 data, against selected environmental variables showed significant, but in most cases lagged, relationships between ocean conditions and seabird reproductive effort (Zador et al., 2013).

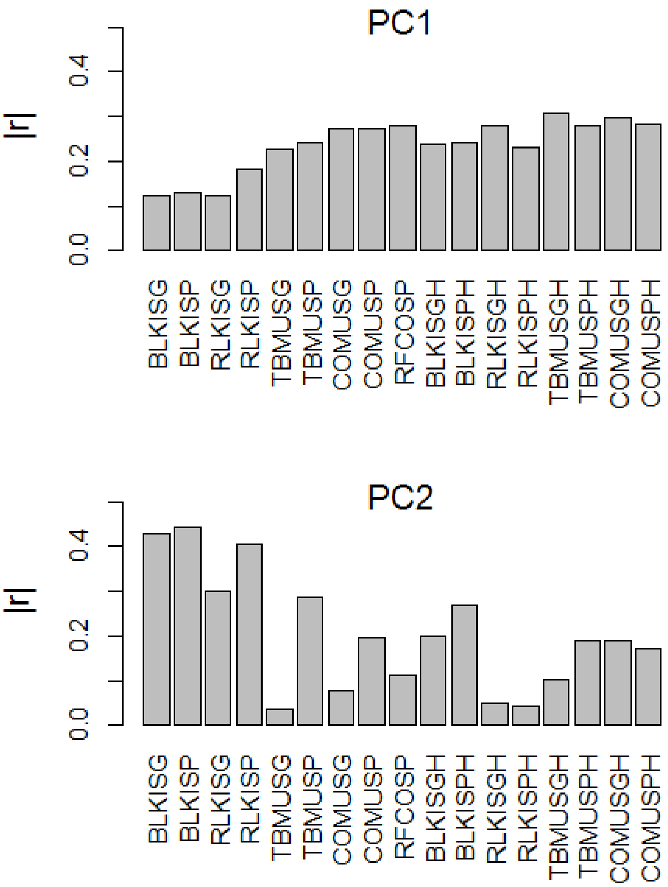

Figure 85: Loadings (absolute correlations) measuring the strength of association between individual time series and the first (PC1, top) and second (PC2, bottom) principal components. The datasets are labeled in order with a 4-letter bird species code following American Ornithological Union convention (e.g., BLKI: black-legged kittiwake), a 2-letter island code (SP: St. Paul; SG: St. George), and H if it is a hatch date time series.

Warmer bottom and surface temperatures, greater wind mixing, and higher stratification correlated with delayed and lower productivity for most seabirds up to two years later. Later ice retreat was correlated with lower kittiwake productivity two years later, but higher local abundances of age-1 Walleye pollock were linked to higher kittiwake productivity the following year. The biennial pattern in PC2 negatively correlates with pink salmon abundance using the reconstructed Kamchatka pink salmon run size through 2012 from Springer and van Vliet (2014)($t = 3.5$, $p = 0.003$).

Implications: These results indicate that 2016 was a poor reproductive year for Pribilof seabirds. The eastern Bering Sea and the North Pacific, where many Pribilof seabirds overwinter, experienced the third warm year after several sequential cold years. These oceanographic changes have influenced biological components of the ecosystem, which appears to have negative influences on seabird reproductive activity. Also, years of high pink salmon abundance, the odd-numbered years after 1997, correlate with poor kittiwake productivity. This correspondence may be a result of competition between abundant zooplanktivorous (pink salmon and kittiwakes) or related responses to environmental conditions. The winter distribution of kittiwakes overlaps with the pink salmon

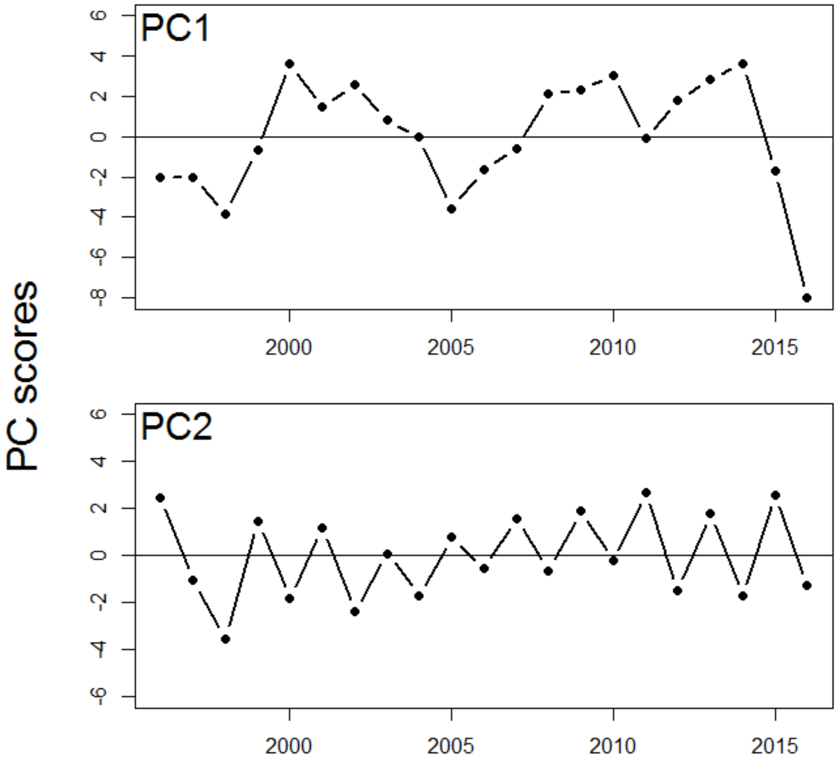

Figure 86: The value of PC1 (top) and PC2 (bottom) over time. Higher values of PC1 indicate earlier seabird hatch dates and higher cormorant and common murre reproductive success. Higher values of PC2 indicate higher kittiwake reproductive success and, to a lesser degree, St. Paul thick-billed murre reproductive success and earlier St. Paul kittiwake hatch dates.

in the North Pacific, thus broad-scale environmental exposure may be similar.

These indicators can provide fisheries managers with useful information through both their current state (most recent annual index values) and past relationships with environmental conditions. For example, a current index value indicating high reproductive success and/or early breeding that is assumed to be mediated through food supply could indicate better than average recruitment of year classes that seabirds feed on (e.g., age-0 pollock), or better than average supply of forage fish that commercially-fished species feed on (e.g., capelin eaten by both seabirds and Pacific cod). Also, better understanding of past relationships between the seabird indicators and environmental conditions could help managers to anticipate ecosystem-level effects of varying ecosystem states.

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 are 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, and 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

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Last updated: October 2016

Description of indicator: The northern fur seal 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 US 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 (Pribilofs and Bogoslof) and a California stock.

Northern fur seals were listed as depleted under the 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 Bogoslof and Pribilof Islands is estimated by NMML 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 was assessed in August 2015.

Status and trends: Preliminary estimates of northern fur seal pup production on the Pribilof Islands in 2016 total between 96,000 and 104,000, a decrease ranging from 6.0 to 13.3% since 2014: between 78,000 and 82,000 pups were born on St. Paul Island and between 18,000 and 22,000 pups were born on St. George Island. The preliminary 2016 pup production estimates for St. Paul and St. George Islands indicate a change between -5.0 and 16.0% on St. George, and a decrease between 10.0 and 15.0% on St. Paul, compared to the 2014 estimates (Figure 87). Estimated pup production on both Pribilof Islands in 2016 was similar to the level observed in the early 1900s (1915

St. Paul, 1918 St. George); however the population trend almost 100 years ago was much different than it is now. During that time, the northern fur seal population was increasing at approximately 8% per year following the cessation of extensive pelagic sealing, while currently (1998 through 2016) pup production on both Pribilof Islands is estimated to be decreasing at 4.12% per year (SE = 0.40). It should be noted, however, that pup production on St. George Island shows no significant trend between 2000 and 2014 (P = 0.34).

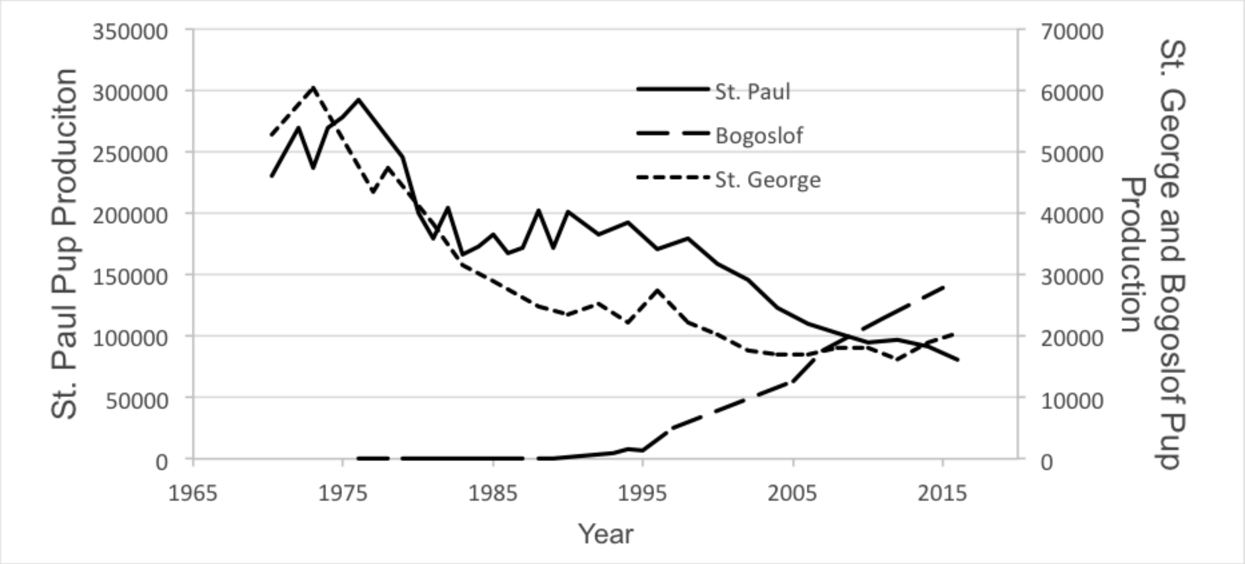

Figure 87: Northern fur seal pup production estimates for the Pribilof Islands (St. Paul and St. George Islands) and Bogoslof Island, 1970-2016 (2016 Pribilof estimates are preliminary).

Factors influencing observed trends: The estimate of northern fur seal pup production in 2015 on Bogoslof Island was 27,750 (SE = 228). The recent trend in pup production on Bogoslof Island has been opposite to that on the Pribilofs (Figure 87). Pup production increased at approximately 10.1% (SE = 1.08) per year on Bogoslof Island between 1997 and 2015. 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 to give birth and breed. However, declines observed on the Pribilof Islands are much greater than the increase in numbers on Bogoslof, indicating that the decline on the Pribilofs 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

Regime Shift Indicators for the Eastern Bering Sea

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Last updated: August 2016

Description of indicator: A dynamic factor analysis (DFA) was performed using 16 biological time series for the eastern Bering Sea, a geographical subset of those first used by Hare and Mantua (2000), and later updated by Litzow et al. (2014). PCA was used in the previous analyses. DFA is similar to PCA in that it reduces multiple data sets to fewer common trends, which can then be used to investigate regime shifts. However, unlike PCA, DFA is designed for time series and allows for model selection.

A description of each biological time series used is provided in Table 8. Commercial salmon catch data, provided by ADF&G (Byerly et al., 1999), was lagged to account for the "year of ocean entry" (Litzow et al., 2014). Groundfish data series were obtained from AFSC North Pacific Groundfish Stock Assessments. For the series that are surveyed every other year, the data from the last even year stock assessment was used. Halibut data was provided by the IPHC. All data series, except for the CPUE time series, were log-transformed before analysis.

Table 7: Eastern Bering Sea model selection results.

R	m	logLik	delta.AICs	Ak.wt	Ak.wt.cum
diagonal and unequal	4	-744.8	0	0.61	0.61
diagonal and unequal	5	-729.9	0.88	0.39	1.00
diagonal and unequal	3	-776.6	31.44	0.00	1.00
diagonal and unequal	2	-805.4	56.11	0.00	1.00
diagonal and equal	3	-817.4	77.79	0.00	1.00
diagonal and equal	2	-834.1	79.64	0.00	1.00
equalvarcov	3	-817.4	80.09	0.00	1.00
equalvarcov	2	-834.1	81.83	1.00	1.00
diagonal and equal	4	-807.0	87.59	0.00	1.00
equalvarcov	4	-806.9	89.64	0.00	1.00
diagonal and equal	5	-794.2	91.26	0.00	1.00
equalvarcov	5	-794.2	93.76	0.00	1.00
diagonal and unequal	1	-863.9	139.17	0.00	1.00
equalvarcov	1	-882.4	146.09	0.00	1.00
diagonal and equal	1	-883.5	146.11	0.00	1.00
unconstrained	3	-681.2	199.25	0.00	1.00
unconstrained	4	-669.4	225.04	0.00	1.00
unconstrained	1	-750.9	237.16	0.00	1.00
unconstrained	2	-726.5	239.43	0.00	1.00
unconstrained	5	-671.3	276.82	0.00	1.00

Table 8: Description of eastern Bering Sea biologic time series. I = macroinvertebrate, G = groundfish recruitment, S = salmon catch. The scientific names are given for the first taxon. The management areas are provided for the first occurrence of each region.

Name	Year Range	Type	Description
EBS jellyfish biomass	1982 - 2015	I	CPUE of large medusae (Scyphozoa) from NOAA summer bottom trawl survey.
EBS Pollock recruitment	1965 - 2015	G	Recruitment of age-1 *Gadus chalcogrammus* by year class, log transformed.
EBS Pacific cod recruitment	1977 - 2014	G	Recruitment of age-0 *Gadus macrocephalus* by year class, log transformed.
EBS Yellowfin sole recruitment	1965 2009	G	Recruitment of age-5 *Limanda aspera* by year class, log transformed.
EBS Greenland turbot recruitment	1965 - 2015	G	Recruitment of age-0 *Reinhardtius hippoglossoides* by year class, log-transformed.
EBS Arrowtooth flounder recruitment	1974 2009	G	Recruitment of age-2 *Atheresthes stomias* by year class, log transformed.
EBS Rock sole recruitment	1971 - 2007	G	Recruitment of age-4 *Lepidopsetta* spp. by year class, log-transformed.
EBS Flathead sole recruitment	1977 2014	G	Recruitment of age-3 *Hippoglossoides elassodon* by year class, log-transformed.
EBS Alaska plaice recruitment	1975 - 2011	G	Recruitment of age-3 *Pleuronectes quadrituberculatus* by year class, log-transformed.
Aleutian Is. Atka mackerel recruitment	1977 - 2015	G	Recruitment of age-1 *Pleurogrammus monopterygius* by year class, log transformed.
Aleutian Is. Pacific ocean perch recruitment	1977 - 2011	G	Recruitment of age-3 *Sebastes alutus* by year class, log-transformed.
W. Alaska Chinook salmon catch	1965 - 2012	S	Commercial catch of *Oncorhynchus tsawytscha* in Bristol Bay, Peninsula, and AYK management areas, log-transformed and lagged 3 years.
W. Alaska Chum salmon catch	1965 2012	S	Commercial catch of *Oncorhynchus keta*, log-transformed and lagged 3 years.
W. Alaska Coho salmon catch	1965 2014	S	Commercial catch of *Oncorhynchus kisutch*, log-transformed and lagged 1 year.
W. Alaska Pink salmon catch	1965 2014	S	Commercial catch of *Oncorhynchus gorbuscha*, log-transformed and lagged 1 year.
W. Alaska Sockeye salmon catch	1965 - 2013	S	Commercial catch of *Oncorhynchus nerka*, log-transformed and lagged 2 years.

DFA model selection was performed using AICc (Zuur et al., 2003) among candidate models with various combinations of the covariance matrix, R, and number of hidden trends, m. A varimax rotation was conducted on the results in order to maximize the variance between the time series loadings for better interpretation (Holmes et al., 2014).

A sequential F-test analysis was conducted using Regime Shift Detection Software (RSDS) on the trends from the best DFA model to detect possible regime shifts (Rodionov and Overland, 2005). The target significance level used was 0.05, with a cutoff length of 15 years, and a Huber weight parameter of 6. The IP4N method was used in order to account for autocorrelation in the DFA and PCA results, with a subsample length of 5 years.

Status and trends: The best DFA model for the eastern Bering Sea yielded 4 trends, with R-matrix having different variances and no covariance (Table 7). However, the support for a 5 trend model was nearly as strong as for the 4 trend. Trend 1 most strongly ($|\text{loading}|>0.2$) describes the jellyfish, which loaded positively, and western Alaska chum, coho, pink, and sockeye salmon, which loaded negatively (Figure 88). The time series which loaded strongly onto Trend 2 include Pacific ocean perch, Arrowtooth flounder, Flathead and Rock sole, which all load negatively onto the trend. Arrowtooth flounder, which loads positively, and Alaska plaice and western Alaska Chinook salmon, which load negatively, are the time series which load strongly onto Trend 3. The fourth trend is loaded onto strongly by jellyfish, loading positively, and Greenland turbot, which loads negatively. The jellyfish time series loaded strongly onto the first and fourth trends, but is most strongly described by the first trend. Arrowtooth flounder loads onto trend 2 and 3, but is best described by the second trend.

Trend one shows a sharp drop in 1977 and seems to stay down for the remainder of the time series (Figure 88). The second trend also drops around 76/77 and jumps up greatly in the late 2000s. The third trend sees a jump in the late 90s followed by an immediate drop into the early 2000s, another jump, followed by a decrease around 2010 into the present. The fourth trend increases in the late 70s and early 80s, and is followed by a series of peaks. One regime shift was detected for the first trend in 1977. A regime shift was detected in 1976 and 2008 for the second trend. The third trend shows a regime shift in 1997. Lastly, the fourth trend detected a shift occurring around 1981. The detected shifts in 76/77 for the first two trends, as well as the 2008 regime shift of the second trend, are consistent with past research findings (Litzow et al., 2014; Hare and Mantua, 2000).

Factors influencing observed trends: The difference between this study's results compared to past studies (Litzow et al., 2014; Hare and Mantua, 2000) can be attributed to the difference in statistical methods of analysis. Past studies have used PCA rather than DFA. The updates in the time series themselves did not contribute to the difference in results. A PCA was also conducted on the same biological time series, which were also used by Litzow and Mueter (2014) and Hare and Mantua (2000), which produced very similar results to the past studies. This suggests that the difference is in fact associated with the use of the DFA rather than a PCA.

Three of the DFA trends indicate shifts around the time of the well-documented late 1970's regime shift, which has been linked with broad scale changes in climate such as depicted by the Pacific Decadal Oscillation (Hare and Mantua, 2000; Anderson and Piatt, 1999). Litzow et al. (2014) found both climate and commercial fishing to be influential in a late 1990s Alaska-wide shift and suggested the importance of recognizing incremental ecosystem forcing by multiple factors on biological change. The onset of cold conditions in 2006 may have influenced the 2008 shift in trend 2,

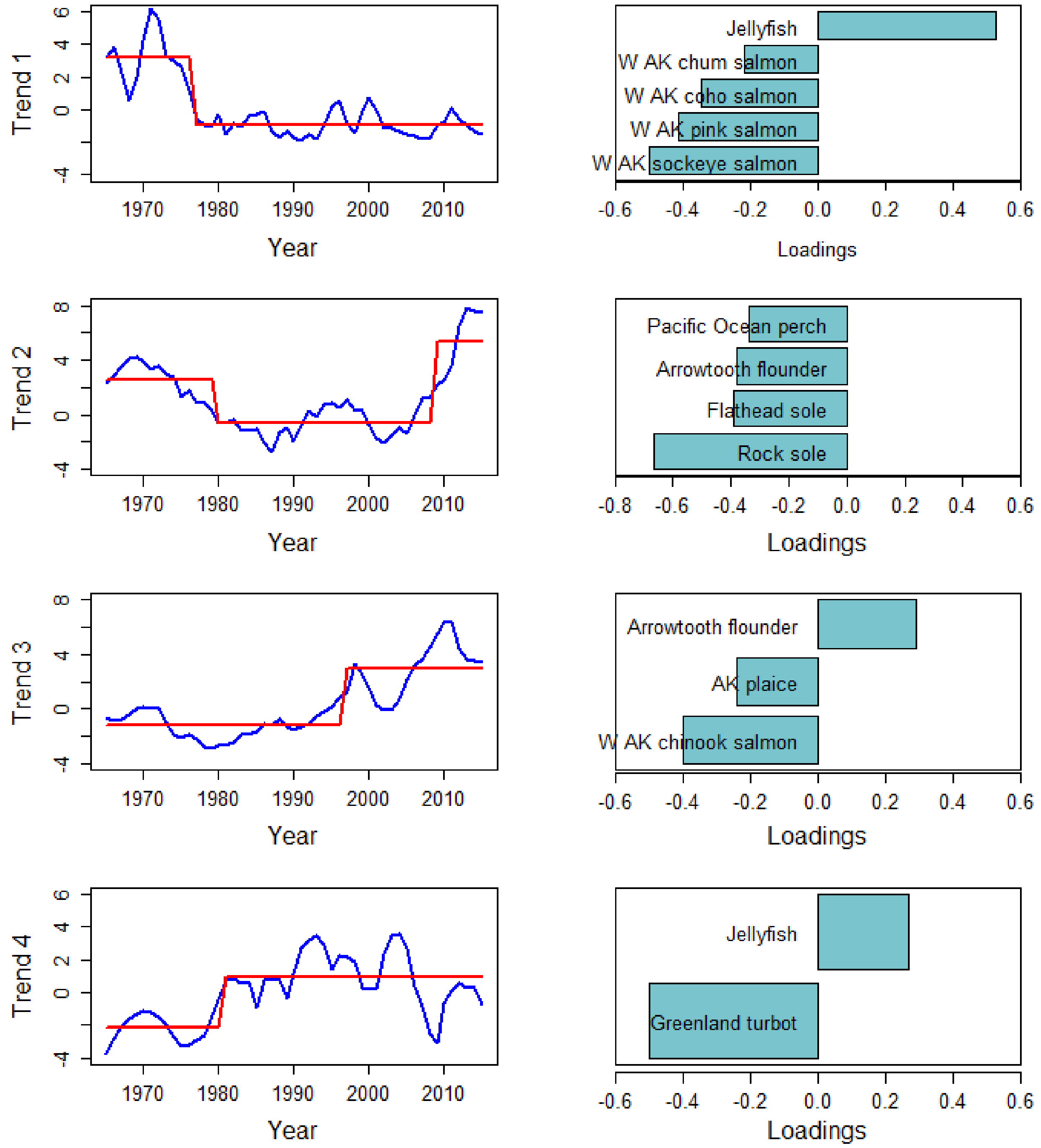

Figure 88: Trends and loadings of time series for the eastern Bering Sea region. The red line on the left plots represents the Regime Shift Detection Software (RSDS) values, while the blue is the calculated DFA trend. The bar plots on the right depict the time series which load most strongly onto each trend (loading > |0.2|).

as the distribution of some species such as Arrowtooth flounder were reduced following the change from warm conditions to cold (Spencer, 2008; Zador and Fitzgerald, 2008).

Implications: The DFA suggests that the EBS has seen multiple differing trends in the biological community over time. Past research suggests that there are complex interacting factors influencing these trends that require further research to disentangle (Litzow et al., 2014).

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys on the Eastern Bering Sea Shelf, 1982-2016

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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), 1982-2016. 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 ($N = 12{,}962$ 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 89). 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 in 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 and a number of flatfish species (Arrowtooth flounder, Yellowfin sole, Rock sole, and Alaska plaice) due to strong recruitments in the 1990s. Decreases in 2006-2009 and subsequent increases are largely a result of fluctuations in Walleye 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 ($< 1^{o}$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

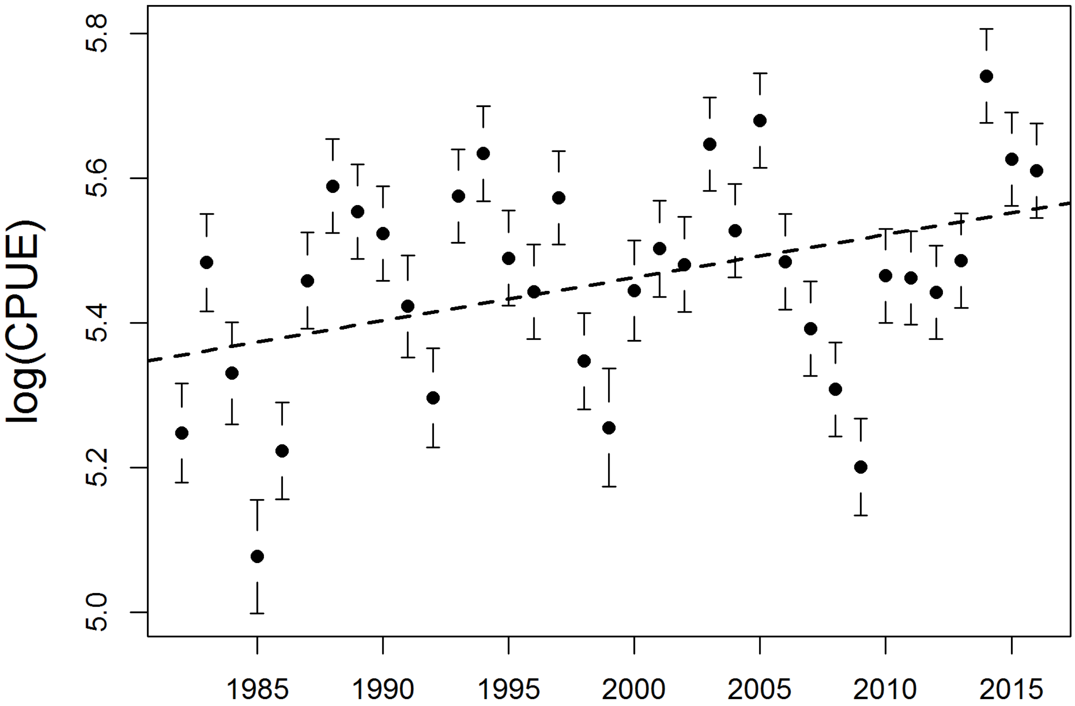

Figure 89: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2016 in the Bering Sea with approximate pointwise 95% confidence intervals and linear time trend. Estimates were adjusted for differences in depth, day of sampling, and sampling locations among years. Gear differences prior to 1988 were not accounted for. The linear time trend based on generalized least squares regression assuming 1^{st} order auto-correlated residuals was not significant at the 95% significance level (t = 1.511, p = 0.140).

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 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 Walleye pollock catches in the bottom trawl survey.

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 Walleye 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 Walleye pollock entering the survey.

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

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Description of indicator: This section provides indices of local species richness and diversity 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 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 geographic location (latitude/longitude), depth, and date of sampling. In addition to trends in the indices over time, we mapped average spatial patterns for each index across the survey region.

Status and trends: Species richness and diversity on the eastern Bering Sea shelf have undergone significant variations from 1982 to 2016 (Figure 90). The average number of species per haul increased by one to two species from 1995 to 2004, remained relatively high through 2011, and both richness and diversity decreased through 2014 with a moderate increase in richness in 2015/2016 and a large and significant increase in Shannon diversity in 2016. Richness tends to be highest along the 100 m isobath, while diversity tends to be highest on the middle shelf (Figure 91). 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 both of how many species are caught in a haul and how evenly CPUE is distributed among these species, hence time trends (Figure 90) and spatial patterns (Figure 91) in species diversity differ from those in species richness. Diversity typically increases with species richness and decreases when the abundance of dominant species increases. However, low species diversity in 2003 occurred in spite of high average richness, primarily because of the high dominance of Walleye pollock, 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 cold pool decreased from 1982 to 2005 (Mueter

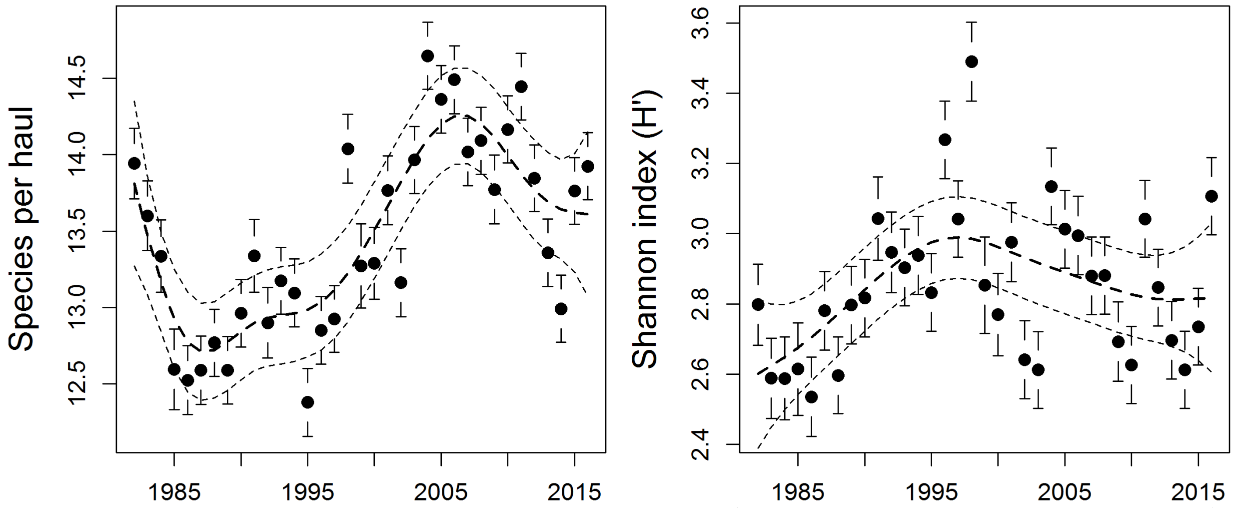

Figure 90: Model-based annual averages of species richness (average number of species per haul, dots), and species diversity (Shannon index) in the eastern Bering Sea, 1982-2016, based on 45 fish and invertebrate taxa collected by standard bottom trawl surveys with pointwise 95% confidence intervals (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.

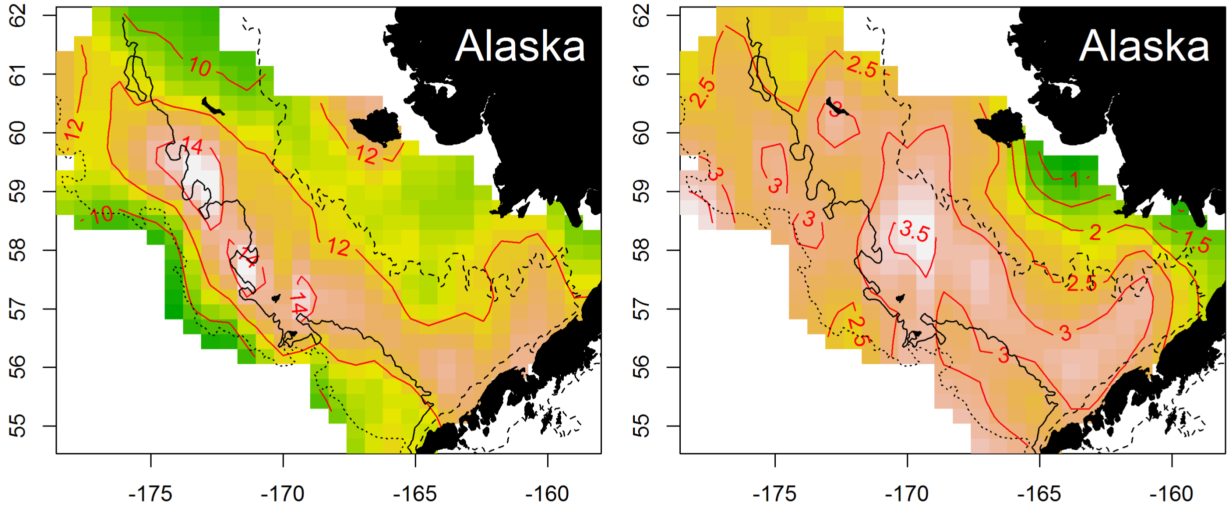

Figure 91: Average spatial patterns in local species richness (left, number of taxa per haul) and Shannon diversity in the eastern Bering Sea. The 50m (dashed), 100m (solid), and 200m (dotted) depth contours are shown. Note highest richness along 100 m contour, highest diversity on middle shelf.

and Litzow, 2008). However, species diversity has varied substantially over the recent decade and these fluctuations have occurred independently of temperature, although the diversity index from 1984-2016 was positively correlated with bottom temperatures over the previous 3 years ($r = 0.35$, $p = 0.045$).

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 1982-2016 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 92). 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. Strong shifts in distribution over the 35 year time series remain evident even after adjusting for linear temperature effects (Figure 92). Average spatial displacements across all species by year (Figure 93) 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 93) and shallower (Figure 92) in 2015/2016 than in any previous year and, in 2016, was considerably further North than in any previous year since the survey has been standardized. 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.

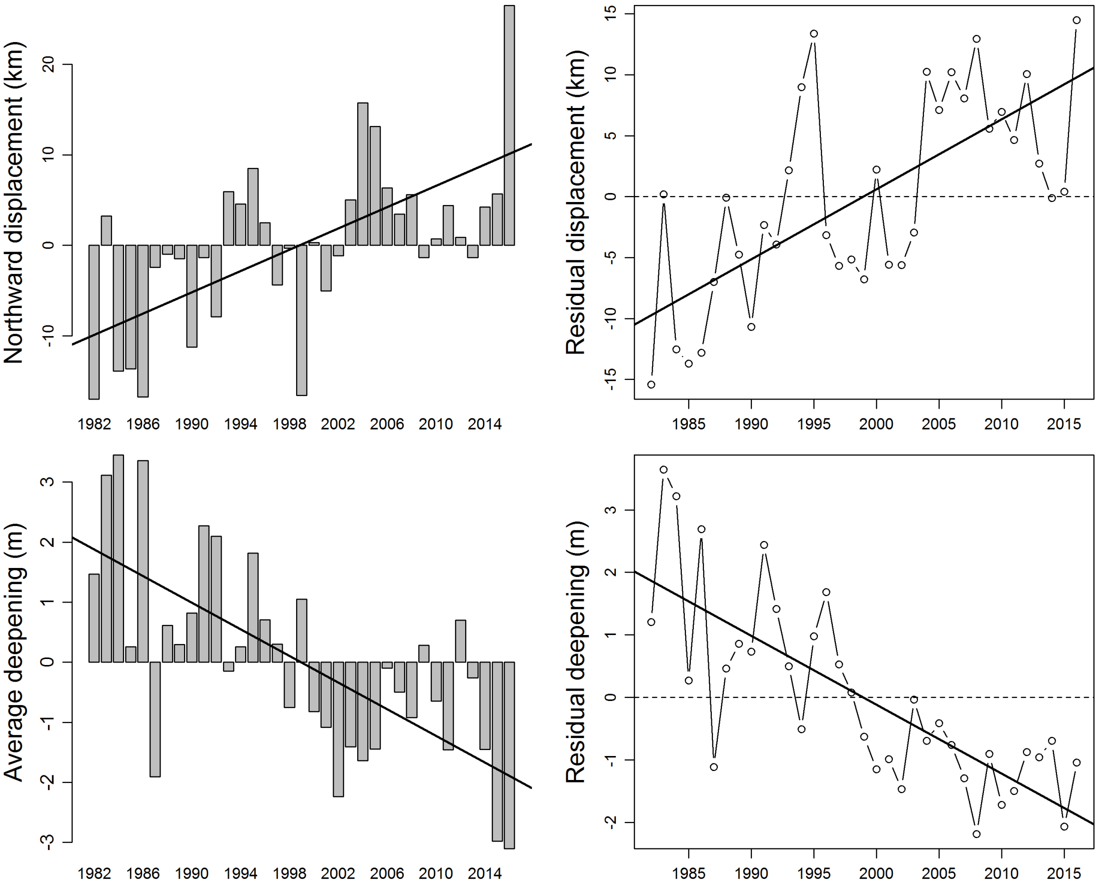

Figure 92: Left: Distributional shifts in latitude (average northward displacement in km from species-specific mean latitudes) and shifts in depth distribution (average vertical displacement in m from species-specific mean depth, positive indices indicate deeper distribution). Right: Residual displacement 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 Litzow (2008); Figure 92). The reasons for 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 shifted to deeper waters in response to warming (Dulvy et al., 2008), the Bering Sea groundfish community shifted to shallower waters during warm periods (Figure 92)

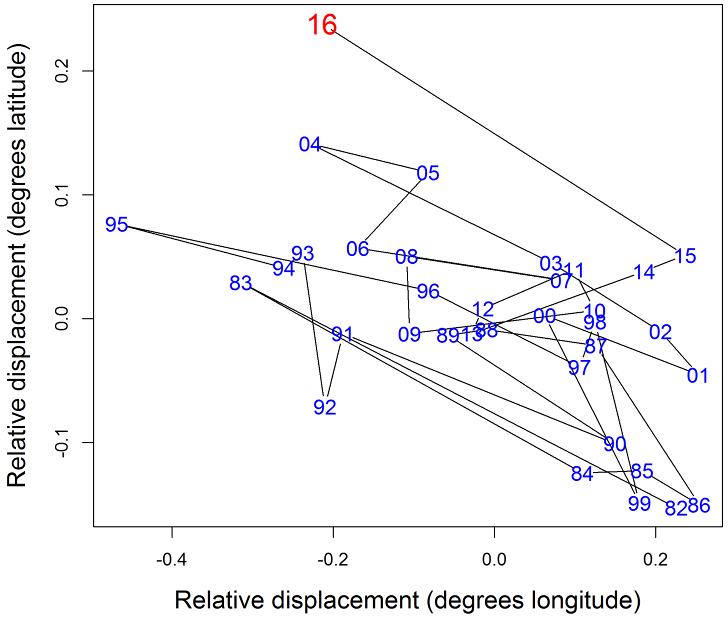

Figure 93: Average North-South and East-West displacement across 39 taxa on the eastern Bering Sea shelf relative to species-specific centers of distribution.

because of the retreat of the cold pool from the middle shelf.

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).

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`

Ecosystem-Based Management Indicators

Indicators presented in this section are intended to provide either early signals of direct human effects on ecosystem components that might warrant management intervention or to provide evidence of the efficacy of previous management actions. In the first instance, the indicators are likely to be ones that summarize information about the characteristics of the human influences (particularly those related to fishing, such as catch composition, amount, and location) that are influencing a particular ecosystem component.

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 Regions blend data, while estimates for 2003 and later come from the Alaska Regions Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards. 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. These figures include only catch on federally-managed groundfish targets (i.e., discards of groundfish estimated from the halibut fishery are not included).

Status and trends: Since 1993, discard rates of groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock fishery and in the non-pollock trawl sector in the Bering Sea. Discard rates in the Bering Sea pollock trawl sector declined to about 1% in 1998 and have remained at comparable levels since then. In the Bering Sea fixed gear sector, discard rates fell from around 20% in 1993 to 12% in 1996, and since then have generally fluctuated between 10% and 14% (Figure 94).

Factors influencing observed trends: Discards of groundfish may occur for economic or regulatory reasons. Economic discards include discards of lower value and unmarketable fish in order to maximize harvest or production value. Regulatory discards are those required by regulation, such as discards of species where harvest has reached the allowable catch limit and which may no longer be retained. Mechanisms for reducing discards in North Pacific groundfish fisheries include:

- Limited access privilege programs (LAPP) that reduce economic discards by removing the race for fish
- Closure of fisheries once target or bycatch quotas are reached

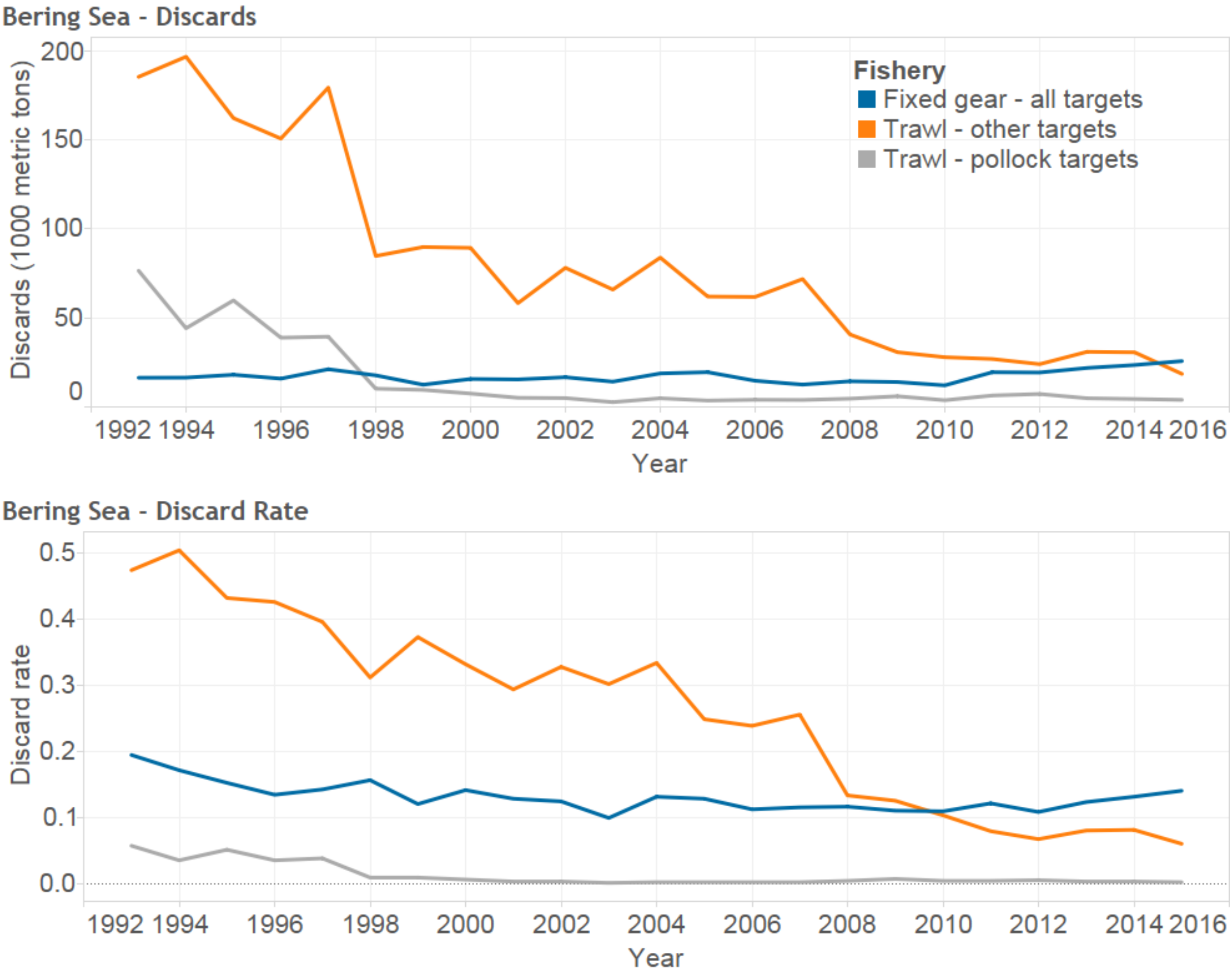

Figure 94: Total biomass and percent of total catch biomass of managed groundfish discarded in the fixed gear, pollock trawl, and non-pollock trawl sectors, 1993-2015. Includes only catch counted against federal TACs.

- 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, various management measures 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. Full retention requirements for pollock and Pacific cod were implemented in 1998 for all vessels fishing for groundfish, leading to declines in discards of these species across all sectors in the Bering Sea. Annual discard rates for Pacific cod between 1997 and 1998 fell from 13% to 1% in the non-pollock trawl sector and from 50% to 3% in the pollock trawl sector. Pollock discards also 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.

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. Beginning 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). To facilitate compliance with retention standards, NMFS increased the maximum retainable amounts for fish caught incidentally in the Arrowtooth flounder and Kamchatka flounder fisheries in 2013. Amendment 80, also in effect beginning with the 2008 fishing year, 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 eliminate the race for fish and remove the economic incentive to discard less valuable species caught in the multi-species flatfish fishery. Discard rates for flatfish in the broader non-pollock trawl sector fell from 24% to 11% between 2007 and 2008 and have continued on a gradual decline since then.

Since 2003 across all Bering Sea sectors combined, the discard rate for species historically managed together as the other groundfish assemblage (skate, sculpin, shark, squid, and octopus) has ranged from 65% to 80%, with skates accounting for the majority of discards by weight. In recent years retention of skates across all gear sectors has been around 30%.

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

Time Trends in Non-Target Species Catch

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Last updated: September 2016

Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the eastern Bering Sea (EBS), Gulf of Alaska (GOA), and Aleutian Islands (AI) ecosystems (Figure 95). 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 Regions 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.

Status and trends: The catch of all three non-target species groups has been highest in the EBS (Figure 95). Scyphozoan jelly catches in the GOA are two orders of magnitude lower than the EBS and three orders of magnitude lower in the AI. Catches of structural epifauna are intermediate in the AI and lowest in the GOA. The catches of assorted invertebrates in the EBS are about twice the catch in the GOA. The catch of assorted invertebrates is lowest in the AI.

In the EBS, the catch of Scyphozoan jellyfish has fluctuated over the last thirteen years and peaked in 2014. The catch of jellyfish in 2014 is more than double the catch in 2015 and 59% higher than the previous high catch in 2011. Highs in jellyfish catch in 2009, 2011, and 2014 were followed by sharp drops the following year to catches less than half the size. Jellyfish are primarily caught in the pollock fishery. The catch of structural epifauna decreased from 2003 to 2007 and has been generally steady since. Benthic urochordata, caught mainly by the flatfish fishery, comprised the majority of the structural epifauna catch in the EBS from 2003 through 2008. From 2009-2015 benthic urochordata accounted for most of the structural epifauna catch except for 2011 and 2014 when it was surpassed by sponges and sea anemones. Sea stars dominate the catch of assorted invertebrates in all years (2003-2015) and are primarily caught in flatfish fisheries. The catch of assorted invertebrates decreased each year from 2003-2009, and has generally trended upward from 2010-2015.

Factors influencing observed trends: The catch of non-target species may change if fisheries change, if ecosystems change, or both. Because non-target species catch is unregulated and unintended, if there have been no large-scale changes in fishery management in a particular ecosystem, then large-scale signals in the non-target catch may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish in the EBS are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellyfish 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 in all three ecosystems 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 interannual variation and lack of a clear trend in the catch of Scyphozoan jellyfish in

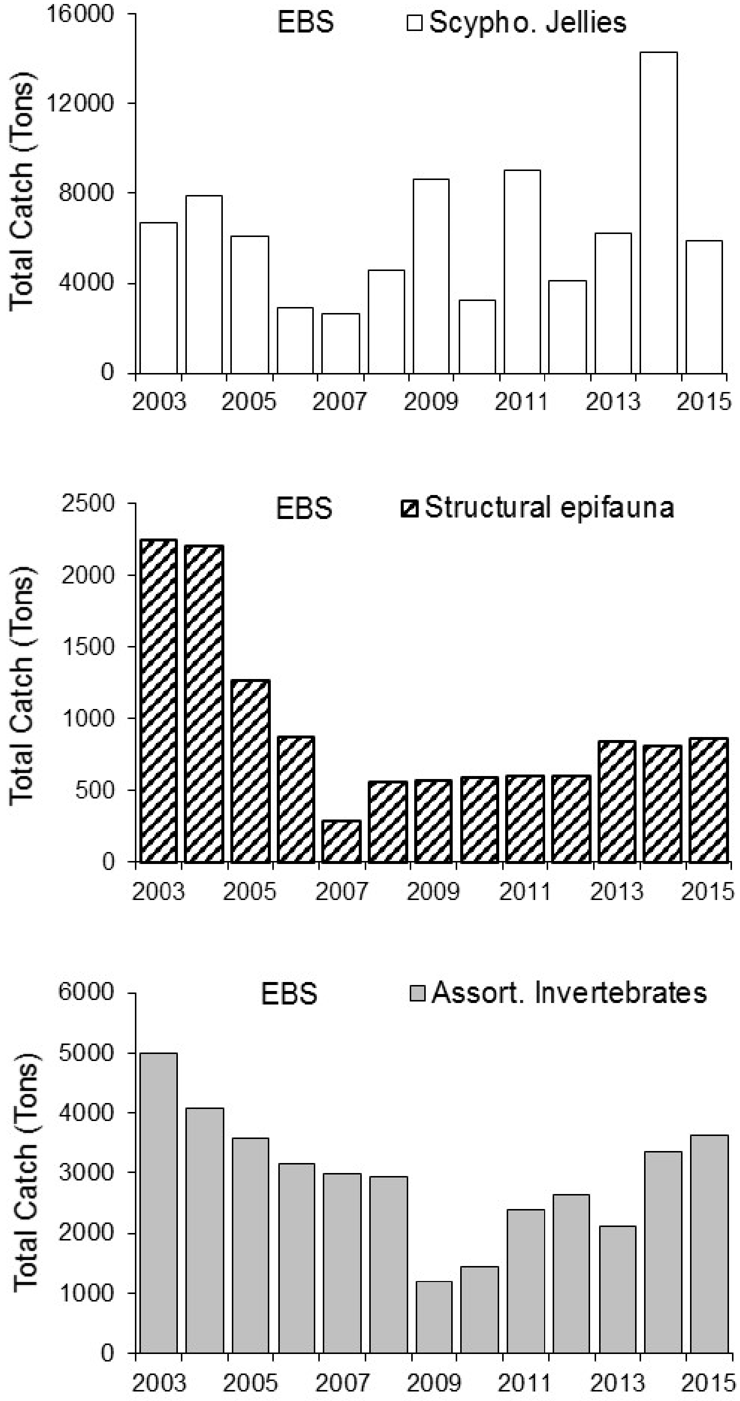

Figure 95: Total catch of non-target species (tons) in the EBS groundfish fisheries (2003-2014). **Please note the different y-axis scales** among species groups.

all three ecosystems 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).

Seabird Bycatch Estimates for Groundfish Fisheries in the Eastern Bering Sea, 2007-2015

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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 2015. 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 years previous when an operator had both halibut and sablefish individual fishing quota.

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). 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 2015 increased from that in 2014, but remained below the 2007-2014 average of 5406 (Table 9). This uptick was largely due to an increase in northern fulmar bycatch, which was at the lowest value in the time series the year before. Fulmars, gulls, and shearwaters were the most common species group caught incidentally. No short-tailed albatross and few black-footed albatross were caught, but more than average 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 (Figure 96).

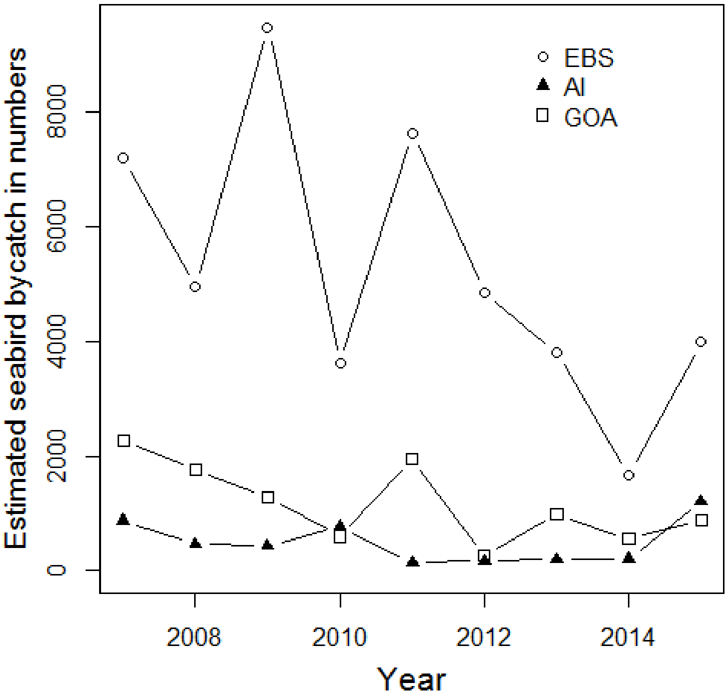

Figure 96: Total estimated seabird bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007 to 2015.

Factors influencing observed trends: 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. There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. Work has continued on developing new and refining existing mitigation gear (Dietrich and Melvin, 2008). The longline fleet has traditionally been responsible for about 91% 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 biased low (Fitzgerald et al., in prep). For example, 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 is seeking funds to support 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).

Table 9: **Estimated** seabird bycatch in eastern Bering Sea groundfish fisheries and all gear types, 2007 through 2015. 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
Unidentified Albatross	0	0	0	0	0	0	0	11	0
Short-tailed Albatross	0	0	0	15	5	0	0	9	0
Black-footed Albatross	18	7	5	9	2	0	1	11	2
Laysan Albatross	4	7	14	16	30	48	21	17	30
Northern Fulmar	3156	2132	7215	1932	5405	3114	2885	704	2489
Shearwaters	2826	1186	571	569	160	526	196	117	354
Storm Petrels	1	0	0	0	0	0	0	0	0
Cormorant	0	0	0	0	0	0	0	0	3
Gull	718	1348	911	719	1651	835	418	573	925
Kittiwake	10	0	16	0	6	5	3	9	12
Murre	6	6	13	102	14	6	3	47	0
Puffin	0	0	0	9	0	0	0	0	0
Auklets	0	3	0	0	0	7	4	99	19
Other Alcid	0	0	105	0	0	0	0	0	0
Other	0	0	136	0	0	0	0	0	0
Unidentified	461	267	501	253	377	307	279	77	157
Grand Total	7200	4956	9487	3625	7649	4848	3811	1675	3992

Implications: While there was only a slight increase in seabirds bycaught in 2015 relative to the year before, increases were noted throughout the AI, GOA, and EBS, leaving reason to believe that there was a widespread change in seabird distribution, fishing effort, and/or seabird prey supply, all of which could impact bycatch. The recent warm oceanic conditions, the “Blob”, have been linked to changes in the ecosystem and lower productivity. 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 2008 general seabird bycatch in Alaska was at relatively low levels (driven by lower fulmar and gull bycatch) but albatross numbers were the highest at any time between 2002 and 2013. 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 5,000 birds per year, occurred between 2007 and 2013. 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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Description of indicator: Fishing gear can impact habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. This indicator uses output from the Fishing Effects (FE) model to estimate the habitat reduction of geological and biological features over the 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 2008 to the present in the Bering Sea. Between 2003 and 2008 the trend had been consistent with seasonal variability since 2003 (Figure 97 and Figure 98).

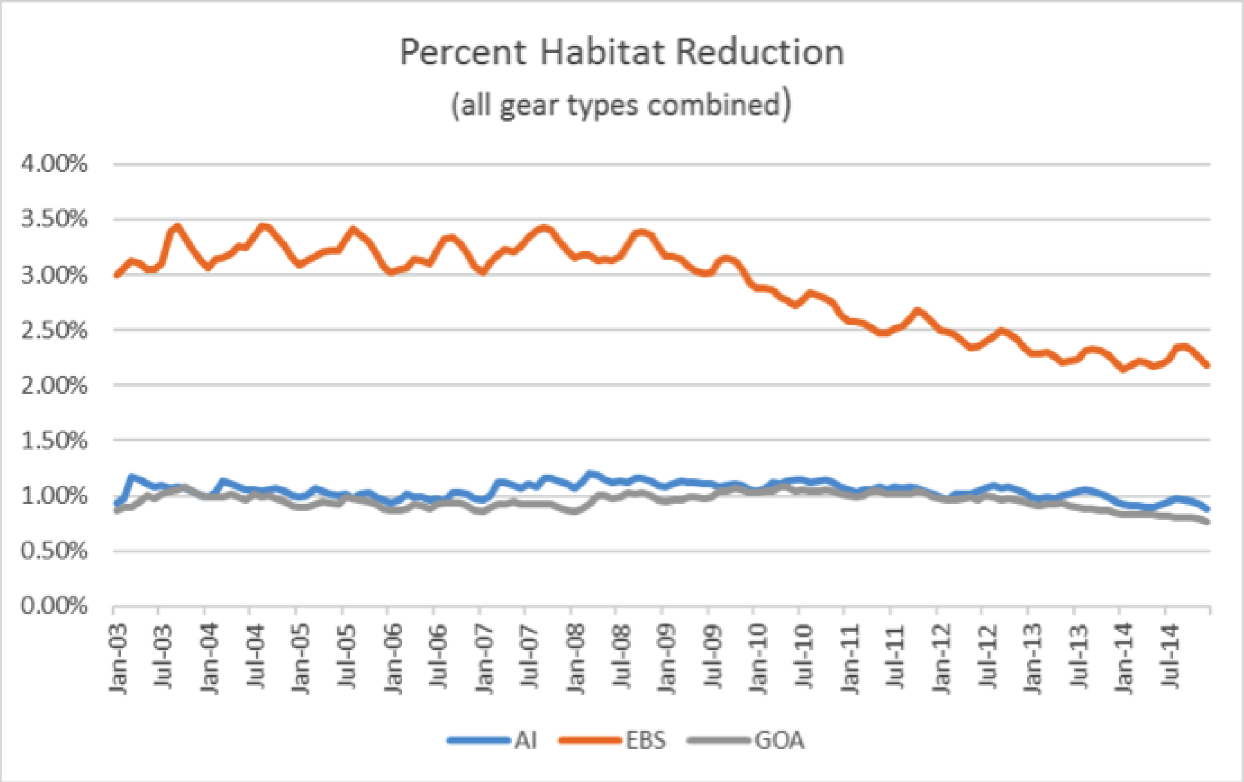

Figure 97: Percent habitat reduction, all gear types combined, from 2003 through 2014.

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.

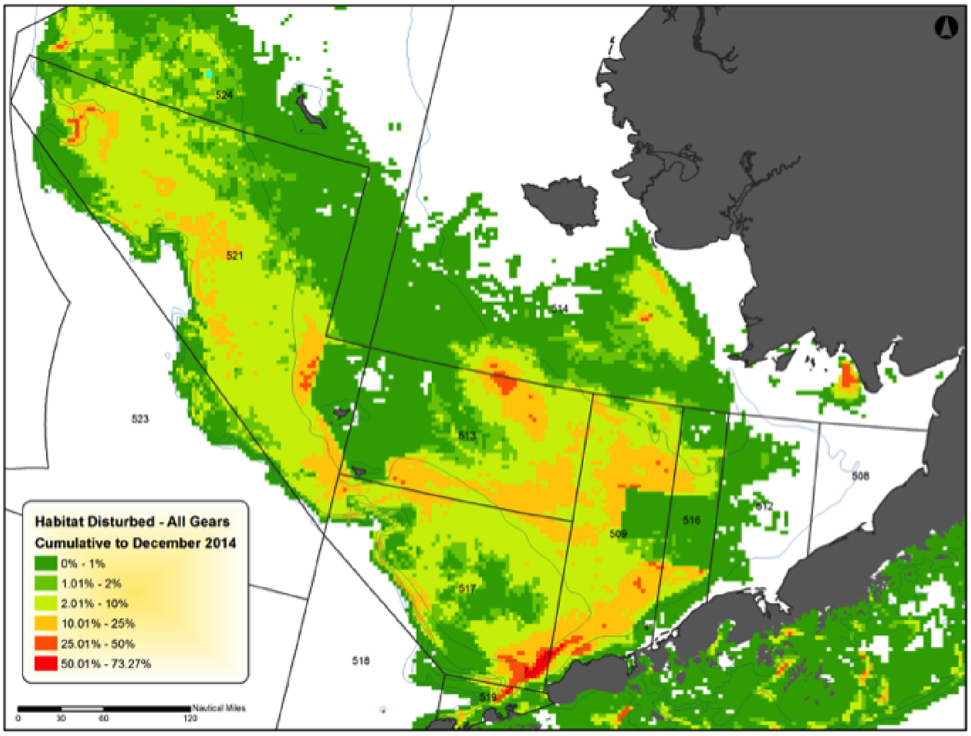

Figure 98: Map of percentage habitat disturbed in the eastern Bering Sea by all gear types. Effects are cumulative, and consider impacts and recovery of features from 2003 to 2014.

Between 2003 and 2008, variability in habitat reduction was driven largely by the seasonality of fishing in the Bering Sea. In 2008, Ammendment 80 was implemented, which allocated BSAI Yellowfin sole, Flathead sole, Rock sole, Atka mackerel, and Aleutian Islands Pacific ocean perch to the head and gut trawl catcher processor sector, and allowed qualified vessels to form cooperatives. The formation of cooperatives reduced overall effort in the fleet while maintaining catch levels. In 2010, trawl sweep gear modifications were implemented on non-pelagic trawls in the Bering Sea, resulting in less gear contacting the seafloor and less habitat impact.

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 will be reviewed in the ongoing Essential Fish Habitat 5-year review.

Areas Closed to Bottom Trawling in the EBS/AI and GOA

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Description of indicator: Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Figure 99, Table 10). Some of the trawl closures are in effect year-round while others are seasonal. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high.

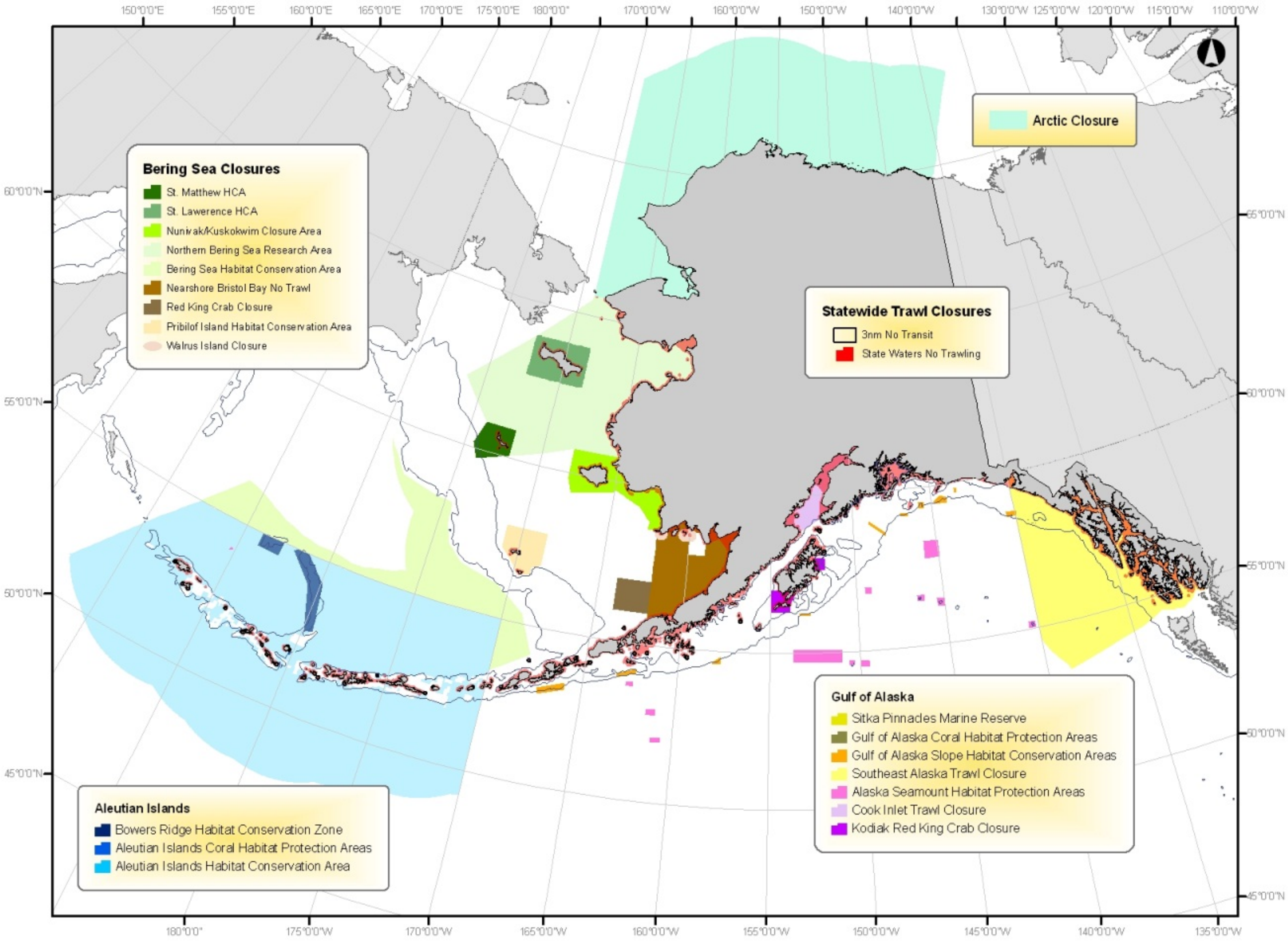

Figure 99: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Table 10: Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2008. LLP= License Limitation Program; HCA = Habitat Conservation Area; HCZ = Habitat Conservation Zone.

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

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

In 2010, the Council adopted area closures for Tanner crab east and northeast Kodiak Island. Federal waters in Marmot Bay are closed year round to vessels fishing with nonpelagic trawl gear. In two other designated areas, Chiniak Gully and ADF&G statistical area 525702, vessels with nonpelagic trawl gear can only fish if they have 100% observer coverage. To fish in any of the three areas, vessels fishing with pot gear must have minimum 30% observer coverage.

Substantial parts of the Aleutian Islands were closed to trawling for Atka mackerel and Pacific cod (the predominant target species in those areas) as well as longlining for Pacific cod in early 2011 as part of mitigation measures for Steller sea lions. Management area 543 and large sections of 542 are included in this closure. The western and central Aleutian Islands were subsequently reopened to trawling in 2014.

Implications: With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling.

For additional background on fishery closures in the U.S. EEZ off Alaska, see Witherell and Woodby (2005).

Steller Sea Lion closure maps are available here:

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

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

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

Table 11: Summary of status for FSSI and non-FSSI stocks managed under federal fishery management plans off Alaska, updated through June 2016.

Jurisdiction	Stock Group	Number of Stocks	Overfishing				Overfished				Approaching Overfished Condition
			Yes	No	Unk	Undef	Yes	No	Unk	Undef	
NPFMC	FSSI	36	0	36	0	0	1	32	3	0	0
NPFMC	NonFSSI	29	0	29	0	0	0	3	26	0	0
	Total	65	0	65	1	0	1	35	29	0	0

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: September 2016

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 assigning a score for each fish stock based on the following rules:

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 (Tables 11 and 12). 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 a 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 (Tables 11 and 13).

Status and trends: As of June 30, 2016, no BSAI or GOA groundfish stock or stock complex is subjected to overfishing, and no BSAI or GOA groundfish stock or stock complex is considered to be overfished or to be approaching an overfished condition (Table 11). The only crab stock considered to be overfished is the Pribilof Islands blue king crab stock, which is in year 2 of a rebuilding plan. None of the non-FSSI stocks are subject to overfishing, known to be overfished, or known to be approaching an overfished condition.

The current overall Alaska FSSI is 132.5 out of a possible 144, or 92%, based on updates through June 2016 (Table 12). The overall Bering Sea/Aleutian Islands score is 85.5 out of a maximum possible score of 92. The BSAI groundfish score is 59 (including BSAI/GOA sablefish, see Endnote-g in Box A) of a maximum possible 60 and BSAI king and tanner crabs score is 26.5 out of a possible 32. The Gulf of Alaska groundfish score is 47 of a maximum possible 52 (excluding BSAI/GOA sablefish). Overall, the Alaska total FSSI score decreased slightly from 92.7% 2015 to 92.0% in 2016 (Figure 100).

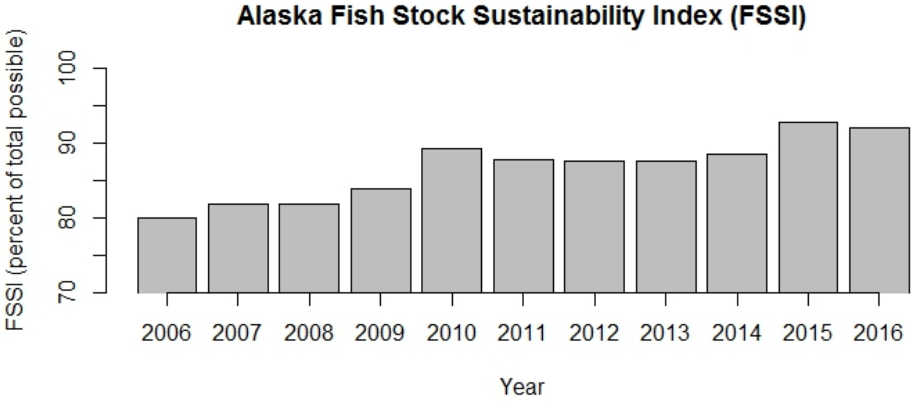

Figure 100: The trend in Alaska FSSI as a percentage of the maximum possible FSSI from 2006 through 2016. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 on it is 144. All scores are reported through the second quarter (June) of each year and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Factors influencing observed trends: One point was lost from last year‘s FSSI to this year for the St. Matthew Island blue king crab stock having their biomass drop below 80% of B_{MSY}. This one point loss accounts for the 0.7% drop in the overall Alaska FSSI score. 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-Pribilof Islands (FSSI=2). Neither of these king crab stocks are subject to overfishing. The Pribilof Islands blue king crab stock is considered overfished and is in year 2 of a rebuilding plan. Biomass for this stock is less than 80% of B_{MSY}. It is unknown if the golden king crab-Aleutian Islands stock is overfished and B_{MSY} is not estimated.

The only BSAI groundfish stock with an FSSI score less than 4 is the Greenland halibut, which loses a point for biomass being less than 80% of B_{MSY}.

GOA stocks that had low FSSI scores (1.5) are the thornyhead rockfish complex (shortspine thornyhead rockfish as the indicator species) and the demersal shelf rockfish complex (yelloweye rockfish as the indicator species). The low scores of these groups are because the overfished status determination is not defined and it is therefore unknown if the biomass is above the overfished level or if biomass is at or above 80% of B_{MSY}.

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

Table 12: FSSI stocks under NPFMC jurisdiction updated June 2016, 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/B_{MSY}	FSSI Score
Blue king crab - Pribilof Islands[a]	No	Yes	N/A	Year 2 of plan	Continue Rebuilding	0.06	2
Blue king crab - Saint Matthews Island[b]	No	No	No	N/A	N/A	0.67	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	1.07	4
Red king crab - Pribilof Islands[c]	No	No	No	N/A	N/A	1.55	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	1.87	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.49	4
BSAI Arrowtooth Flounder	No	No	No	N/A	N/A	2.75	4
BSAI Blackspotted and Rougheye Rockfish[d]	No	No	No	N/A	N/A	0.80	4
BSAI Flathead Sole Complex[e]	No	No	No	N/A	N/A	2.15	4
BSAI Rock Sole Complex[f]	No	No	No	N/A	N/A	2.38	4
BSAI Skate Complex[g]	No	No	No	N/A	N/A	1.76	4
BSAI Greenland halibut	No	No	No	N/A	N/A	0.52	3
BSAI Northern rockfish	No	No	No	N/A	N/A	1.89	4
BS Pacific cod	No	No	No	N/A	N/A	1.42	4
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.58	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	0.97	4
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.75	4
BSAI Yellowfin sole	No	No	No	N/A	N/A	1.60	4
BSAI GOA Sablefish[h]	No	No	No	N/A	N/A	1.00	4

Table 12: FSSI stocks under NPFMC jurisdiction updated June 2016, 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. (continued)

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/B_{MSY}	FSSI Score
GOA Arrowtooth flounder	No	No	No	N/A	N/A	3.26	4
GOA Flathead sole	No	No	No	N/A	N/A	2.54	4
GOA Blackspotted and Rougheye Rockfish complex[i]	No	No	No	N/A	N/A	1.96	4
GOA Deepwater Flatfish Complex[j]	No	No	No	N/A	N/A	2.46	4
GOA Shallow Water Flatfish Complex[k]	No	No	No	N/A	N/A	2.18	4
GOA Demersal Shelf Rockfish Complex[l]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
GOA Dusky Rockfish	No	No	No	N/A	N/A	1.61	4
GOA Thornyhead Rockfish Complex[m]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Northern rockfish - Western / Central GOA	No	No	No	N/A	N/A	1.45	4
GOA Pacific cod	No	No	No	N/A	N/A	1.78	4
GOA Pacific Ocean perch	No	No	No	N/A	N/A	1.55	4
GOA Rex sole	No	No	No	N/A	N/A	2.08	4
Walleye pollock - Western / Central GOA	No	No	No	N/A	N/A	0.96	4

Box A. Endnotes and stock complex definitions for FSSI stocks listed in Table 12, 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).

(b) Fishery in the EEZ is closed; therefore, fishing mortality is very low.

(c) Fishery in the EEZ is closed; therefore, fishing mortality is very low.

(d) 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.

(e) 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.

(f) 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.

(g) 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.

(h) Although Sablefish is managed separately in the Gulf of Alaska, Bering Sea, and Aleutian Islands, with separate overfishing levels, ABCs, and TACs based on the proportion of biomass in each respective region, separate assessments are not conducted for each of these three regions; the assessment is based on aggregated data from the Gulf of Alaska, Bering Sea, and Aleutian Islands regions. Therefore, it is not appropriate to list separate status determinations for these three regions.

(i) GOA 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.

(j) The Deep Water Flatfish Complex consists of the following stocks: Deepsea Sole, Dover Sole, and Greenland Turbot. Dover Sole is the indicator species for determining the status of this stock complex.

(k) The Shallow Water Flatfish Complex consists of the following stocks: Alaska Plaice, Butter Sole, C-O Sole, Curlfin Sole, English Sole, Northern Rock Sole, Pacific Sanddab, Petrale Sole, Sand Sole, Slender Sole, Southern Rock Sole, Speckled Sanddab, Starry Flounder, and Yellowfin Sole. The overfishing determination is based on the OFL, which is computed by using abundance estimates of the complex. A single, assemblage-wide OFL is specified, but overfishing was not defined for the other shallow-water flatfish stocks per se, because they are part of the overall shallow-water flatfish assemblage. SAFE report indicates that the shallow water flatfish complex was not subjected to overfishing and that neither of the indicator species (northern and southern rock sole) is overfished or approaching a condition of being overfished.

(l) The Demersal Shelf Rockfish Complex consists of the following stocks: Canary Rockfish, China Rockfish, Copper Rockfish, Quillback Rockfish, Rosethorn Rockfish, Tiger Rockfish, and Yelloweye Rockfish. The overfishing determination is based on the OFL, which is computed by using estimates of Yelloweye Rockfish and then increased by 10% to account for the remaining members of the complex.

(m) The Thornyhead Rockfish Complex consists of the following stocks: Longspine Thornyhead and Shortspine Thornyhead. The overfishing determination is based on the OFL, which is computed using abundance estimates of Shortspine Thornyhead.

Table 13: Non-FSSI stocks, Stocks managed under an International Agreement, and Ecosystem Component Species, updated June 2016, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`. See website for endnotes and definition of stocks and stock complexes.

Stock	Jurisdiction	Overfishing	Overfished	Approaching
BSAI Golden king crab - Pribilof Islands	NPFMC	No	Unknown	Unknown
BSAI Red king crab - Western Aleutian Islands	NPFMC	No	Unknown	Unknown
BSAI Octopus Complex	NPFMC	No	Unknown	Unknown
BSAI Other Flatfish Complex	NPFMC	No	Unknown	Unknown
BSAI Other Rockfish Complex	NPFMC	No	Unknown	Unknown
BSAI Sculpin Complex	NPFMC	No	Unknown	Unknown
BSAI Shark Complex	NPFMC	No	Unknown	Unknown
BSAI Skate Complex	NPFMC	No	No	No
BSAI Squid Complex	NPFMC	No	Unknown	Unknown
BSAI Kamchatka flounder	NPFMC	No	No	No
BSAI Shortraker rockfish	NPFMC	No	Unknown	Unknown
Walleye pollock - Bogoslof	NPFMC	No	Unknown	Unknown
AI Pacific cod	NPFMC	No	Unknown	Unknown
GOA Atka mackerel	NPFMC	No	Unknown	Unknown
GOA Big skate	NPFMC	No	Unknown	Unknown
GOA Octopus complex	NPFMC	No	Unknown	Unknown
GOA Squid Complex	NPFMC	No	Unknown	Unknown
GOA Other Rockfish Complex	NPFMC	No	Unknown	Unknown
GOA Sculpin Complex	NPFMC	No	Unknown	Unknown
GOA Shallow Water Flatfish Complex	NPFMC	No	No	No
GOA Shark Complex	NPFMC	No	Unknown	Unknown
GOA Alaska skate Complex	NPFMC	No	Unknown	Unknown
GOA Longnose skate	NPFMC	No	Unknown	Unknown
GOA Shortraker rockfish	NPFMC	No	Unknown	Unknown
Walleye pollock - Southeast Gulf of Alaska	NPFMC	No	Unknown	Unknown
Alaska Coho Salmon Assemblage	NPFMC	No	No	No
Chinook salmon - E. North Pacific Far North Migrating	NPFMC	No	No	No
Weathervane scallop - Alaska	NPFMC	No	Unknown	Unknown
Arctic cod - Arctic Management Area	NPFMC	No	Unknown	Unknown
Saffron cod - Arctic Management Area	NPFMC	No	Unknown	Unknown
Snow crab - Arctic Management Area	NPFMC	No	Unknown	Unknown
Stocks managed under an International Agreement				
Pacific halibut - Pacific Coast / Alaska	IPHC/NPFMC PFMC	Unknown	No	No
Ecosystem Component Species				
Fish resources of the Arctic mgmt. area - Arctic FMP	NPFMC	N/A	N/A	N/A
Scallop fishery off Alaska	NPFMC	N/A	N/A	N/A

Total Annual Surplus Production and Overall Exploitation Rate of Groundfish, Bering Sea

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Description of indicator: Total annual surplus production (ASP) of 17 groundfish and crab stocks on the eastern Bering Sea (EBS) shelf from 1979-2014 was estimated by summing annual production across major commercial groundfish stocks for which assessments were available (Table 14). For comparison, results for Gulf of Alaska (GOA) stocks are included here and are fully described in the Gulf of Alaska Ecosystem Considerations Report. These species represent at least 90% of the total catch in bottom trawl surveys. Annual surplus production in year t can be estimated as the change in total adult groundfish biomass across species from year t (Bt) to year t+1 ($Bt+1$) plus total catches in year t (Ct):

$$ASPt = \Delta Bt + Ct = Bt + 1 - Bt + Ct$$

All estimates of B and C are based on 2015 stock assessments. An index of total exploitation rate within each region was obtained by dividing the total groundfish catch across the major commercial species by the estimated combined biomass at the beginning of the year:

$$ut = Ct/Bt$$

Table 14: Species included in computing annual surplus production in the BSAI management area.

Stock (*BSAI unless otherwise indicated*)
EBS Walleye Pollock (*Gadus chalcogrammus*)
AI Walleye Pollock
EBS Pacific Cod (*Gadus macrocephalus*)
Yellowfin Sole (*Limanda aspera*)
Greenland Turbot (*Reinhardtius hippoglossoides*)
Arrowtooth Flounder (*Atheresthes stomias*)
Northern Rock Sole (*Lepidopsetta polyxystra*)
Flathead Sole (*Hippoglossoides* spp.)
Alaska Plaice (*Pleuronectes quadrituberculatus*)
Pacific Ocean Perch (*Sebastes alutus*)
Northern Rockfish (*S. polyspinus*)
Blackspotted Rockfish (*S. melanostictus*)
Alaska Skate (*Bathyraja parmifera*)
Atka Mackerel (*Pleurogrammus monopterygius*)
Red King Crab (*Paralithodes camtschaticus*)
Snow Crab (*Chionoecetes opilio*)
Tanner Crab (*C. bairdi*)

Status and trends: The resulting indices suggest high variability in groundfish production in the eastern Bering Sea (Figure 101) and a non-significant downward trend in production between 1979 and 2014 (slope = - 35,100 mt/year, t = -1.259, p = 0.217), which largely resulted from very high ASP in 1980 associated with a number of strong recruitment events for multiple groundfish species after the 1976/77 oceanographic regime shift. The most recent decade was characterized by some of the lowest ASP values (including negative ASP) in 2004-2007 and relatively high production in more recent years. Annual surplus production in the Bering Sea is considerably higher than in the Gulf of Alaska. Total exploitation rates for the groundfish complex ranged from 5.8 - 10.8% in the BSAI and are generally much higher than in the GOA (Figure 101). Overall exploitation rates were highest following periods of low surplus production in the late 1980s and mid-2000s (Figure 101). Trends in annual surplus production in the eastern Bering Sea are largely driven by variability in Walleye pollock. Therefore, ASP for the Bering Sea was also computed after excluding walleye pollock (Figure 102). The results suggest large variability and a long-term decrease in aggregate surplus production of all non-pollock species from a high of over 1 million tons in 1979, due to strong recruitment of a number of species, to a low of less than 200,000 t in the late 1990s. Annual non-pollock surplus production has been moderately high in the most recent time period.

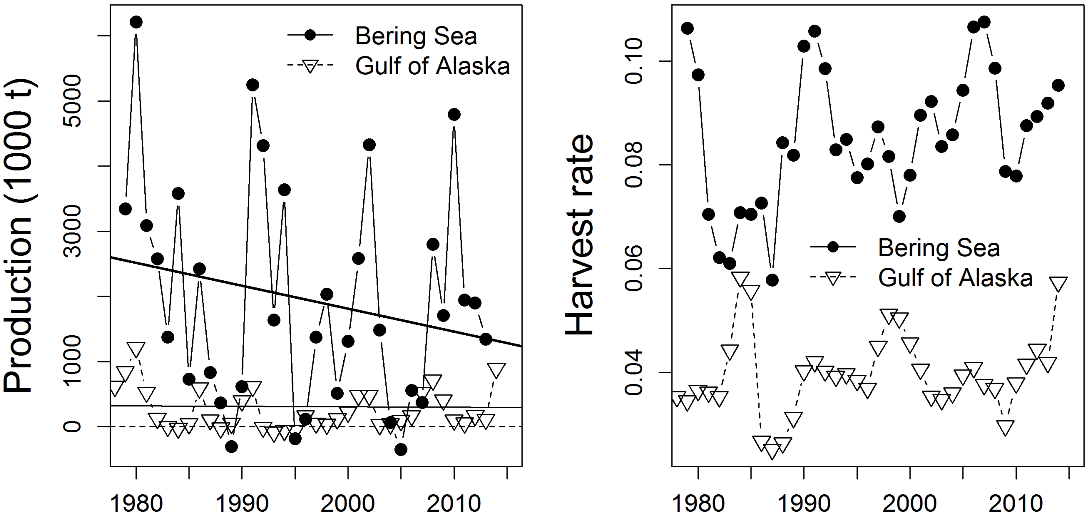

Figure 101: Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Bering Sea/Aleutian Islands with estimated linear trends and total harvest rate (total catch/beginning-of-year biomass, each summed across all major groundfish species).

Factors influencing observed trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e., mortality from all non-fishery sources) during a given year. It is highest during periods of increasing total biomass (e.g., 1991-92) and lowest during periods of decreasing biomass (e.g., 2004-2007). In the absence of a long-term trend in total biomass, ASP is equal to the long-term average catch. Theory suggests that surplus production of a population will decrease as biomass increases much above B_{MSY}, which is the case for many species in the BSAI management area. Exploitation rates are primarily determined by management and reflect a relatively precautionary management regime with rates that have averaged less than 10% across species in the BSAI.

Implications: Under certain assumptions, aggregate surplus production can provide an estimate

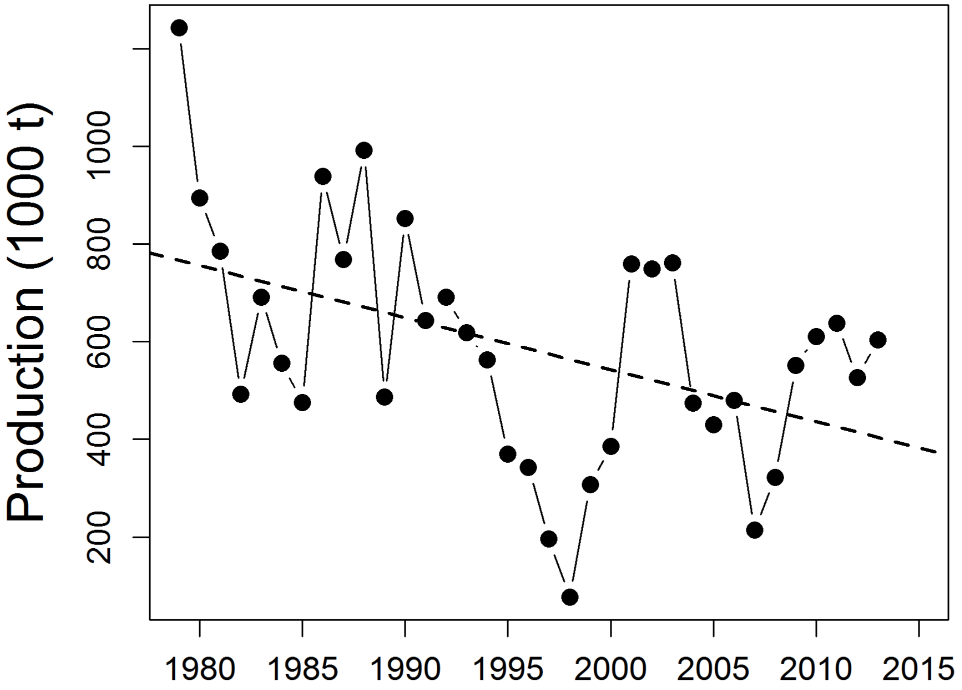

Figure 102: Total annual surplus production (change in biomass plus catch) in the Bering Sea across all major groundfish species, excluding Walleye pollock, with linear trendline (regression with first-order autocorrelated errors: t = -1.631, p = 0.112).

of the long-term maximum sustainable yield of these groundfish complexes (Mueter and Megrey (2006), Figure 103). Although there is relatively little contrast in total biomass over time, it appears that biomass was generally above the level that would be expected to yield maximum surplus production under a Graham-Schaefer model fit to aggregate ASP (Figure 103). The estimated maximum sustainable yield for the groundfish complex (17 stocks) was 2.4 million tons.

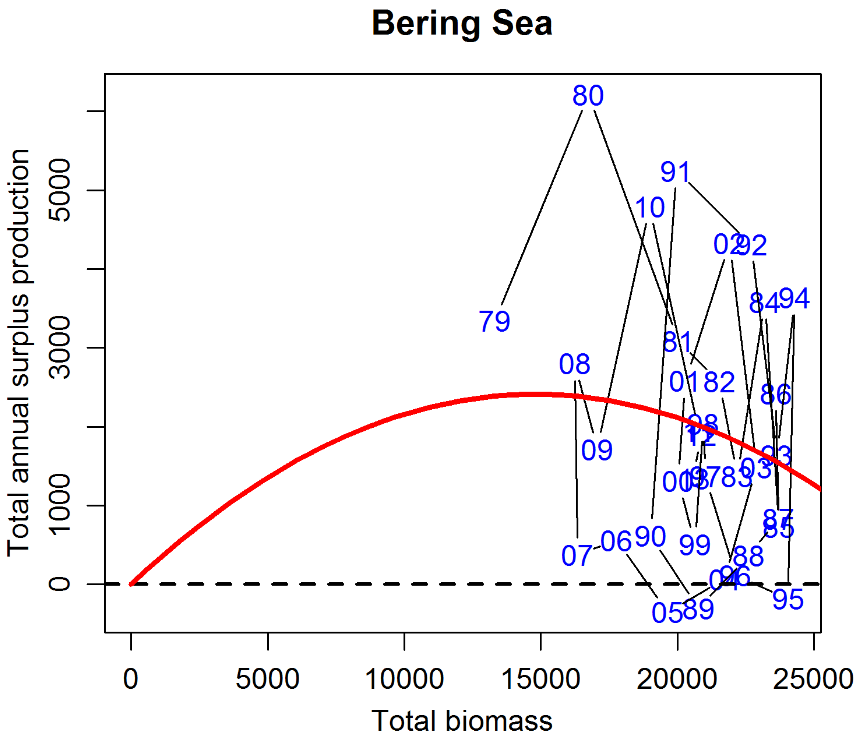

Figure 103: Estimated annual aggregated surplus production against total biomass of major commercial species with fitted Graham-Schaefer curve. Units on both axes are in 1000 t.

Humans as Part of Ecosystems

Groundfish Fleet Composition

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Description of indicator: Fishing vessels participating in federally-managed groundfish fisheries off Alaska principally use trawl, hook and line, and pot gear. Vessel counts were compiled from NMFS Alaska Region's blend and Catch-Accounting System (CAS) estimates and from fish ticket and observer data through 2015. These figures count vessels only for trips where federally-managed groundfish species are targeted.

Status and trends: The total number of vessels participating in federally-managed fisheries off Alaska has generally decreased since 1992, though participation has remained relatively stable in recent years. Vessels using hook and line or jig gear have accounted for most of the participating vessels from 1992 to 2015. Approximately 600 such vessels participated in 2015, compared to over 1,000 vessels annually from 1992 to 1994. The number of active trawl-gear vessels has decreased steadily from over 250 annually in the period from 1992 to 1999 to around 180 in each of the last 5 years. Pot-gear activity has steadily declined since a peak of 343 vessels in 2000, with 154 pot vessels active in 2015 (Figure 104).

Vessel counts before and after 2003 may not be directly comparable due to changes in fishery monitoring and reporting methods. The CAS, implemented in 2003 for in-season monitoring of groundfish catch, registers the Federal Fisheries Permit number of catcher vessels delivering to motherships and shoreside processors, thus giving a more complete accounting of participating vessels than the previous blend system. The increase in 2003 in hook and line/jig vessel counts, in particular, is likely attributable this change.

Factors influencing observed trends: Participation in groundfish fisheries off Alaska since the early 1990s has been driven by a number of interacting factors. These include fluctuations in market conditions, stock levels, and allowable catch quotas; the availability of fishing opportunities in alternative fisheries; and the introduction of management measures intended to address issues such as bycatch, protected species, and overcapitalization.

Participation in Bering Sea pot cod fisheries increased beginning in the mid-1990s as BSAI crab harvesters sought opportunities outside declining king and Tanner crab fisheries.

The trawl pollock fleet in the Bering Sea has contracted significantly since implementation of the American Fisheries Act of 1998 (AFA). Intended to help end the race for fish and reduce capacity in the BSAI pollock fishery, the AFA provides for a vessel buyback program, fixed allocations between sectors, and coordination of catch within harvest cooperatives. Participation in the AFA fishery declined from 140 to 113 vessels in the first year of cooperative fishing for all sectors (2000) and in the last 5 years has stabilized at around 100 vessels.

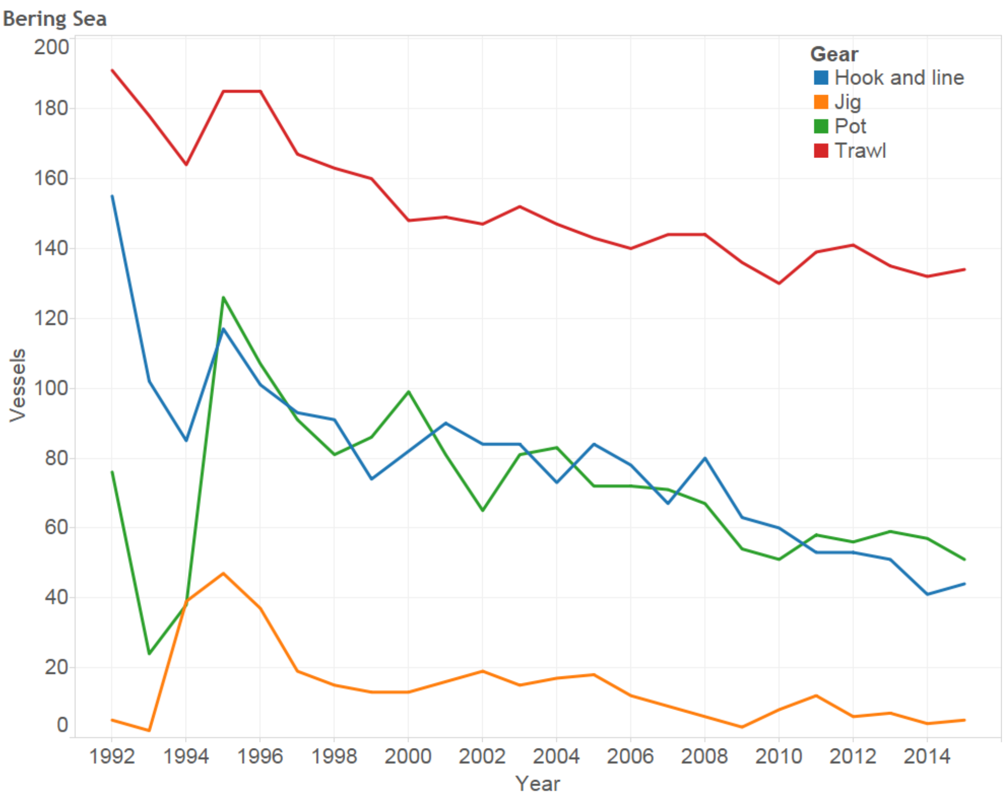

Figure 104: Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1992-2015.

In all LMEs, the fixed gear Sablefish fishery experienced significant consolidation upon transitioning from open access to individual fishing quota (IFQ)-based management in 1995. In the Bering Sea IFQ Sablefish fishery, participation by hook and line vessels has declined gradually since implementation of the program (from 64 vessels in 1995 to 11 in 2015). Pot fishing for IFQ Sablefish increased beginning in 2000 in response to depredation of longline catch by killer whales, though catch and participation have leveled off in recent years.

Cooperative fishing in the non-AFA trawl catcher/processor sector since 2008 and in the BSAI freezer longline sector since 2010 has resulted in some consolidation within these fleets.

Implications: Monitoring the numbers of fishing vessels provides general measures of fishing effort, the level of capitalization in the fisheries, and the potential magnitude of effects on industry stakeholders caused by management decisions.

Trends in Human Population and Unemployment in the Bering Sea

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Last updated: September 2016

Description of indicator: Human population and unemployment, the social indices presented in this report, are significant factors in the Bering Sea (eastern and northern) ecoregions, and groundfish fishery management, as many communities in the region rely upon fisheries to support their economies and to meet subsistence and cultural needs. As with other areas neighboring the Arctic, population and unemployment are important indicators of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems (SES) research has demonstrated the importance of incorporating social variables in ecosystem management and monitoring, and these indices reflect aspects of the social (population) and economic (unemployment) settings of a SES (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 report summarizes trends in human population and unemployment rates over time in the eastern Bering Sea (EBS) and northern Bering Sea (NBS). For 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 this analysis comprise most of the population that resides along the coast. For the NBS, this includes communities of the Bethel Borough located 60 latitude and those of the Kusilvak and Nome Boroughs. The 58 NBS fishing communities included in this 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 Councils Bering Sea fishery programs, such as the Community Quota Entity program. Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990-2015 (ADLWD, 2016a). Unemployment data was also aggregated and weighted to account for varying community populations across Alaska Boroughs. Estimates are presented annually from 1990-2015 (ADLWD, 2016a).

Status and trends:

Eastern Bering Sea

As of 2015 the population of EBS communities was 10,304. The overall population increased steadily since 1880 with the greatest population increase of 44.2% occurring between 1950 and 1960 (Table 15 and Figure 105). This is consistent with 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 2015, the population of EBS increased 10.3% which was lower than State trends during this time period (34.1%). The much lower increase in the EBS is because population growth was highest in urban areas, such as Anchorage, where 40% of Alaskas population currently resides (ADLWD, 2016a,b).

Table 15: Eastern Bering Sea (EBS) and northern Bering Sea (NBS) population 1880-2015. Percent change rates are decadal until 2010.

Year	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2015
Alaska	33426	32052	63592	64356	55036	59278	72524	128643	226167	302583	401851	550043	626932	710231	737625
% Change	NA	-4.11	98.40	1.20	-14.48	7.71	22.35	77.38	75.81	33.79	32.81	36.88	13.98	13.29	3.86
EBS	1504	1022	1203	688	1279	1369	2292	3212	4633	5445	7428	9339	10383	10025	10304
% Change	NA	-32.05	17.71	-42.81	85.90	7.04	67.42	40.14	44.24	17.53	36.42	25.73	11.18	-3.45	2.78
NBS	3270	2043	20453	5201	4669	5688	7777	9490	14010	16569	20845	26157	30219	31600	33732
% Change	NA	-37.52	901.13	-74.57	-10.23	21.82	36.73	22.03	47.63	18.27	25.81	25.48	15.53	4.57	6.75

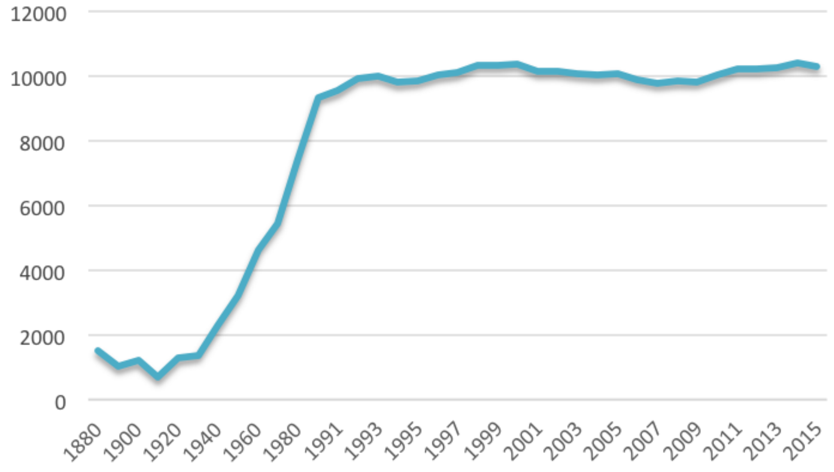

Figure 105: Eastern Bering Sea population.

Despite the general population trend in the EBS (based on aggregated data), 41% of communities experienced population decline between 1990 and 2015. For example, Portage Creek had a population of 5 in 1990, it increased to 45 in 2003, and was reduced to 1 in 2015 (an 80% decrease between 1990 and 2015). The communities of South Naknek, Saint Paul, Nelson Lagoon, and King Salmon experienced population declines ranging from 44% to 54% during this time period. Also, Indigenous Americans comprise up to 82% of the population of small communities in remote areas and more Native Americans reside in Alaska than any U.S. state (Goldsmith et al., 2004). As of 2014, 15% of Alaska's population was Alaska Native or American Indian (ADLWD, 2016b) and as of 2015, 75.7% of the population in the EBS identified as Native American alone or 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), yet the majority of population growth that has occurred in Alaska is of the Caucasian demographic (ADLWD, 2016b).

Unemployment rates in the EBS, between 1990 and 2015, were lower than State and national rates (Figure 106, Figure 107). The unemployment rate in the EBS was lowest in 1990 (1.6%) and highest in 2014 (3.6%), 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 of all regions (central Aleutian Islands had the lowest).

Northern Bering Sea

As of 2015 the population of NBS communities was 33,732. 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 15 and Figure 108). The latter increase is consistent with 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 2015, the population of NBS increased 29.0% which was lower than State trends during this time period (34.1%). There was lower increase in the NBS because population growth was highest in urban areas, such as Anchorage, where 40% of Alaskas population currently resides (ADLWD, 2016a,b).

The population of communities in the NBS has remained relatively stable. Only 19% of NBS communities experienced population decline between 1990 and 2015. Diomede and Shageluk lost

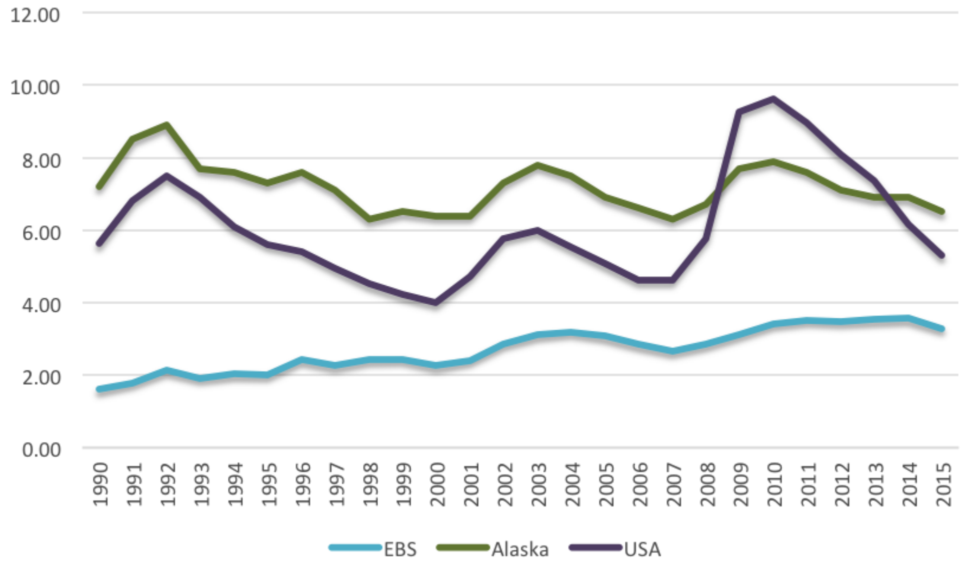

Figure 106: Unemployment rates for EBS, Alaska, and USA.

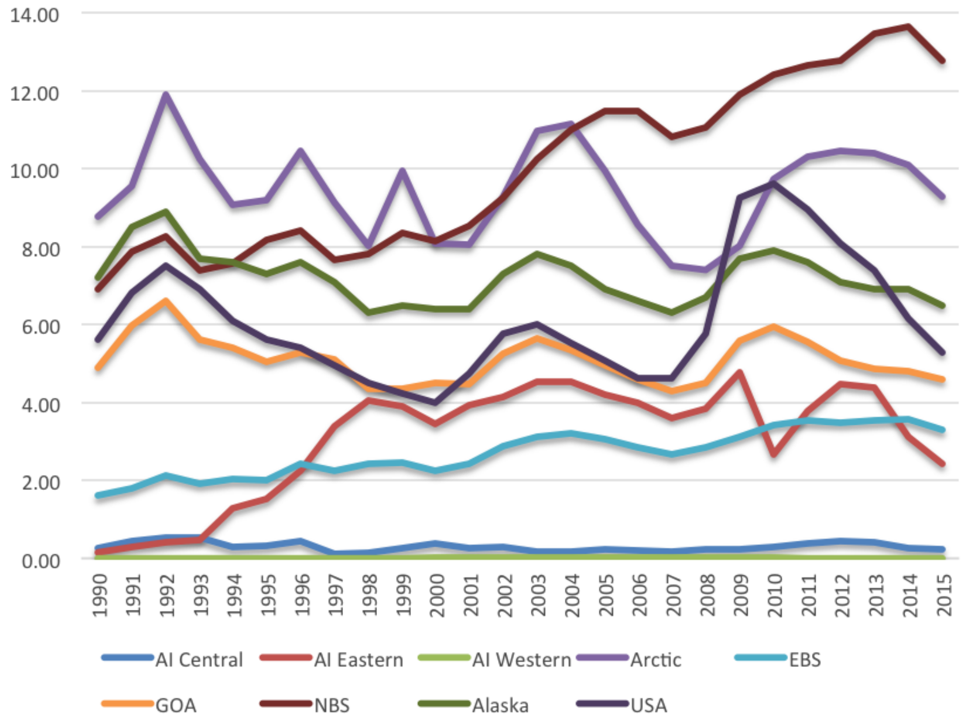

Figure 107: Unemployment rates for all regions, Alaska, and USA.

between 47-49% of their populations during this time period. Many NBS communities are small and/or remote. Indigenous Americans comprise up to 82% of the population of small communities in remote areas and more Native Americans reside in Alaska than any U.S. state (Goldsmith et al., 2004). As of 2014, 15% of Alaskas population was Alaska Native or American Indian (ADLWD,

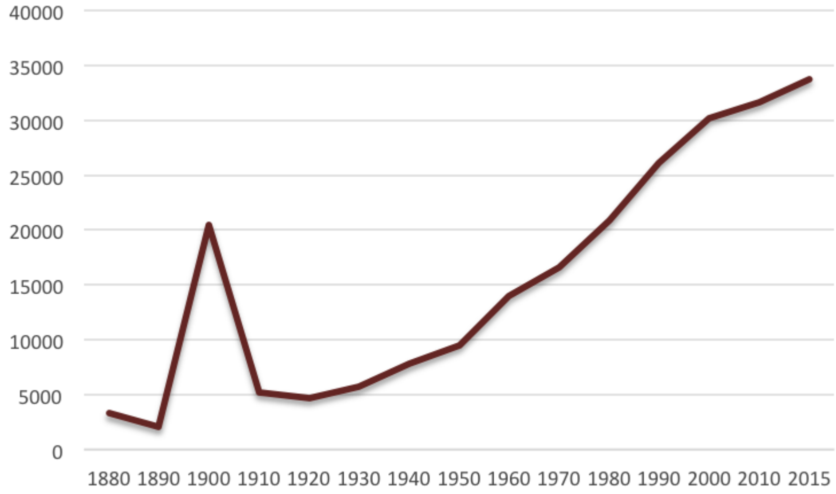

Figure 108: Northern Bering Sea population.

2016b) and as of 2015, 90.2% of the population in the NBS identified as Native American alone or combination with another race (DCCED, 2016). There has been increased migration of Alaska Natives from rural to urban areas (Goldsmith et al., 2004; Williams, 2004), yet the majority of population growth that has occurred in Alaska is of the Caucasian demographic (ADLWD, 2016b).

Unemployment rates in the NBS, between 1990 and 2015, were higher than State and national rates (Figure 109, Figure 107). 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 Artic region had periods of higher unemployment than the EBS until the year 2000, and between 2002 and 2004.

Factors influencing observed trends: Overall population increase between 1990 and 2015 in the EBS (10.3%) and NBS (29.0%) was consistent with, yet lower than, State trends (34.1%). Alaska has high rates of population turnover because of migration, and population growth has occurred mainly in urban areas (ADLWD, 2016b). 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, 2016b). In 2010, 61% of Alaska's population was born out of State (Rasmussen et al., 2015). In terms of natural growth, from 2013 to 2014 the birth rate in Alaska was 1.5 per 100 people which was higher than the national rate of 1.3. 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%). The estimated natural growth rates of the EBS had a range of 0.5-3.0% (ADLWD, 2016b). The Kusilvak census area had the highest birth rate of 3 births per 100 people (ADLWD, 2016b). In regard to migration, the net annual migration of both the EBS and NBS was very low (<0) since the region has among the lowest migration rates in the State (Williams, 2004; ADLWD, 2016b). The highest net migration occurs in the GOA region and the Matanuska-Susitna Borough has the highest growth rate in the State (ADLWD, 2016b).

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

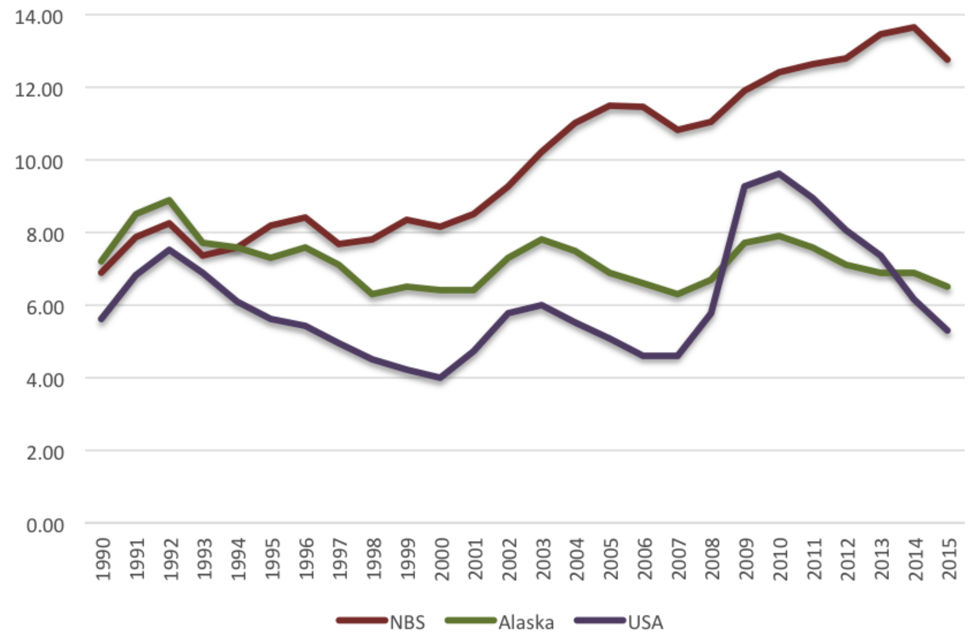

Figure 109: Unemployment rates for NBS, Alaska, and USA.

population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD, 2016b). 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 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. Factors that influence population shifts/migration include employment, retirement, educational choices, cost of living, climate, and quality of life (Donkersloot and Carothers, 2016).

Alaska State 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, 2016c)[2]. 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, 2016d). The EBS area had the second lowest unemployment rates between 1990 and 2015 (Figure 106, Figure 107). However, many EBS communities rely upon seasonal fisheries and construction opportunities for employment, and others seek employment in Dillingham (Himes-Cornell et al., 2013). The NBS area had the highest unemployment rates between 2004 and 2015 (Figure 109, Figure 107). Communities in the NBS region rely mainly upon seasonal employment and subsistence activity while year-round employment opportunities are sparse (Himes-Cornell et al., 2013).

Implications: Population shifts can affect pressures on fisheries resources, however inferences

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[2] For more detailed information see `http://live.laborstats.alaska.gov/pop/estimates/data/ex2.pdf`

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. In the EBS, 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). 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. Fisheries contribute to community vitality and efforts could be made to better engage NBS in fisheries. Changes in groundfish policy and management, such as increased regulations, may have implications for small communities and those of the Bering Sea Community Quota Entities. Also, with a large proportion of the Bering Sea populations 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).

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Appendix

Table 16: Summary of Alaska Fisheries Science Center surveys as of May 2016 and compiled by Jennifer Ferdinand and Mike Sigler.

Project name (short)	Start year	Survey frequency	Purpose	Comments
Spring ecosystem survey, Gulf of Alaska	1985	biennial; parts of this survey date back to 1972	Fisheries oceanography	
Spring ecosystem survey, southeastern Bering Sea	1995	biennial	Fisheries oceanography	
Late summer ecosystem survey, southeastern Bering Sea	2001	biennial	Fisheries oceanography	Funding uncertain each year
Southeast Alaska Coastal Monitoring	1995	annual	Fisheries oceanography	
Late summer ecosystem survey, Gulf of Alaska	2012	biennial	Fisheries oceanography	Funding uncertain each year
Moorings, Bering Sea	1995	annual	Oceanography	
Moorings, Gulf of Alaska	1995	annual	Oceanography	
Bottom trawl survey, southeastern Bering Sea	1982	annual	Stock assessment	
GOA/EBS/AI Longline Stock Assessment Survey	1988	annual	Stock assessment	
Bottom trawl survey, Gulf of Alaska	1987	biennial	Stock assessment	
Bottom trawl survey, Aleutian Islands	1992	biennial	Stock assessment	
Bottom trawl survey, Bering Sea slope	2002	intermittent	Stock assessment	
Acoustic survey, southeastern Bering Sea	2004	biennial		
Acoustic survey, Gulf of Alaska	2010	biennial	Stock assessment	
Acoustic survey, Gulf of Alaska, pre-spawning, Shelikof	1991	annual	Stock assessment	
Acoustic survey, Gulf of Alaska, pre-spawning, Shumagin/Sanak	2009	annual	Stock assessment	

Project name (short)	Start year	Survey frequency	Purpose	Comments
Acoustic survey, Bogoslof	1988-2007	annual; now biennial (see below)	Stock assessment	
Acoustic survey, Bogoslof	2009	biennial	Stock assessment	
Humpback whale predator/prey	2011	annual	special project	
Yukon chinook	2014	annual	special project	
Deepwater Rockfish Tagging	2014	annual	special project	
Sablefish and Deepwater Rockfish Maturity	2014	annual	special project	
Fishing Technology Studies to Reduce Bycatch and Habitat Effects of Fishing		intermittent	special project	
Arctic Aerial Calibration Experiments	2015	BOEM & Navy-funded; one-time	marine mammal	
Foraging ecology and health of adult female Steller sea lions	2010	annually (when possible)	marine mammal	
Ice-associated seal ecology	2005	intermittent; every 1-2 years	marine mammal	
Northern fur seal population studies at Bogoslof Island	1980	3-5 years	marine mammal	
Steller sea lion vital rate and pup health studies	mid-1980s	annual	marine mammal	
Steller sea lion vital rates studies in the Gulf of Alaska	mid-1980s	annual; marking stopped in 2005	marine mammal	
Steller sea lion vital rates studies in western and central Aleutian Islands	2011	mark animals biennially; conduct observations annually	marine mammal	
Harbor seal tagging in the western Aleutians	2014	annual	marine mammal	
Ice-associated seal aerial surveys	2012	biennial	marine mammal	
Harbor seal aerial surveys	1990s	annual	marine mammal	
Cook Inlet beluga aerial surveys	mid-1990s	annual; changed to biennial in 2013	marine mammal	
CHAOZ, CHAOZ-X (Chukchi Sea Acoustics, Oceanography, and Zooplankton)	2010	BOEM-funded; annual	marine mammal	
ASAMM	2008	BOEM-funded; annual	marine mammal	
Steller sea lion pup counts	1961	biennial	marine mammal	
Steller sea lion non-pup counts	1904	annual (some years inconsistent)	marine mammal	

Project name (short)	Start year	Survey frequency	Purpose	Comments
Southeast Alaska cetacean survey	mid-1990s	annual	marine mammal	
Arctic Coastal Ecosystem Survey and Shelf Habitat and Ecology of Fish and Zooplankton	2013-2014	one-time	ecosystem assessment	
North Pacific Domestic Fishery Observer Data	1986	continuous	catch accounting	
Gulf of Alaska small-mesh survey (ADF&G and NMFS)	1953	annual, discontinued	ecosystem assessment and shrimp biomass	
Arctic Integrated Ecosystem Survey	2012	intermittent	ecosystem assssment	
Beaufort Sea fish and shellfish survey	2008	one-time	ecosystem assssment	