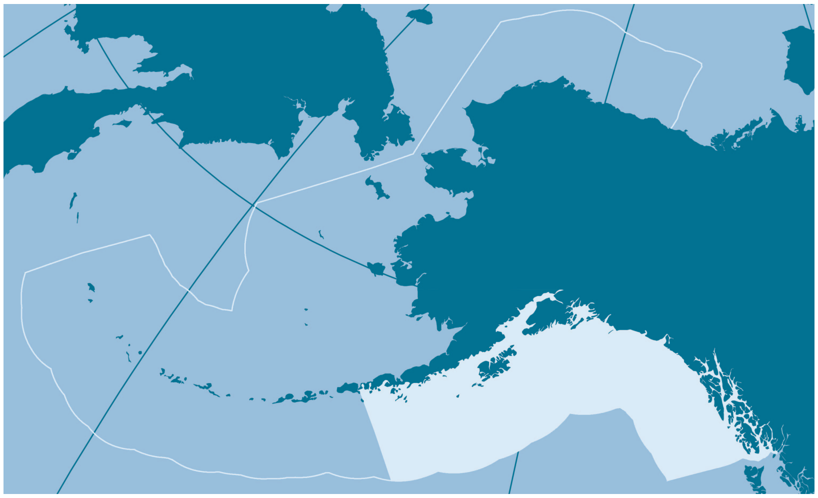
Ecosystem Considerations 2016

Status of the
Gulf of Alaska Marine Ecosystem



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Western Gulf of Alaska 2016 Report Card

- The Gulf of Alaska in 2016 was **characterized by warm conditions** that were first seen in 2014, and have continued as reflected in the **positive PDO pattern**. Anomalously warm conditions are expected to continue through the winter.
- **Fresh water input as estimated at the GAK1 station has been variable** over the long time series. The most recent data indicate an increasing trend.
- **Mesozooplankton biomass measured by the continuous plankton recorder has shown a largely biennial trend since 2009**, however biomass remained greater than average in 2015. Biomass trends can be influenced by ecosystem conditions and mean size of the community. This suggests that prey availability for planktivorous fish, seabirds, and mammals has been variable recently. The biennial patterns suggests a **possible link with biennially varying planktivorous pink salmon abundance**.
- **Copepod community size has been declining in recent years**. The prevalence of small copepods during 2015 fits predictions of warm conditions favoring small copepods. This suggests that **less lipid-rich prey were available to planktivorous predators**.
- **Survey biomass of motile epifauna** has been **above its long-term mean** since 2001. The increase from 1987 to 2001 was driven by hermit crabs and brittle stars, which dominate the biomass. Since 2001 their biomass has been stable. Record catches of octopus influenced the increased estimate in 2015.
- Trends in capelin as sampled by seabirds and groundfish have indicated that **capelin were abundant from 2008 to 2013, but have declined in the past two years**. This pattern **coincides with the period of cold water temperatures** in the Gulf of Alaska.
- **Fish apex predator survey biomass is currently below its 30-year mean**, although the declining trend seen in recent years has leveled off. **The trend is driven primarily by arrowtooth flounder** which, along with halibut, had been declining since 2005. Both increased slightly in 2015. It is unknown whether these increases were due to distributional shifts in the warm water. **Pacific cod has declined from a peak survey biomass in 2009**.
- **Black-legged kittiwakes had moderate reproductive success in 2016** at the Semedi Islands, in contrast to the complete failure in 2015 for kittiwakes as well as other seabird species. Their reproductive success is typically variable, presumably reflecting foraging conditions prior to the breeding season, during, or both.
- Modelled estimates of **western Gulf of Alaska Steller sea lion non-pups counts are above the long term mean and continuing to increase**, suggesting conditions are favorable for sea lions in the western Gulf.
- Human populations in the western Gulf of Alaska coastal towns of **Homer and Kodiak are above their 25 year mean**. Homer is the sole town with a steadily increasing trend. Kodiak saw declines until 2006 and has recovered slightly since then.

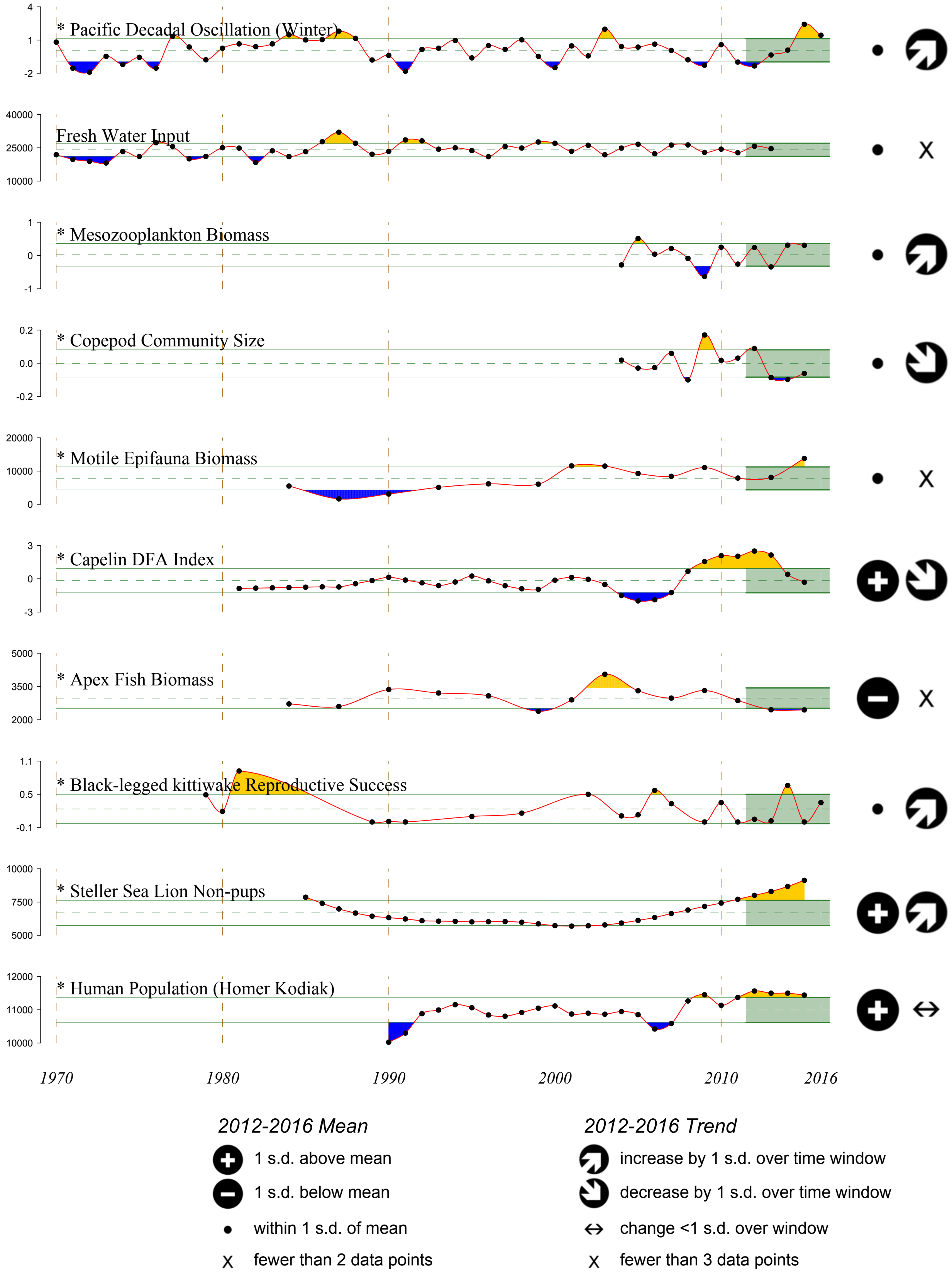

Figure 1: Western Gulf of Alaska ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2016.

Eastern Gulf of Alaska 2016 Report Card

- The Gulf of Alaska in 2016 was **characterized by warm conditions** that were first seen in 2014, and have generally continued since. The **strong El Niño of last winter has lessened, and near neutral conditions are expected for next winter**.
- The **sub-arctic front was farther north than usual**, which is consistent with the poleward surface currents seen in the past three years.
- Total **zooplankton density in Icy Strait has been anomalously low in the past three years**. Zooplankton density has declined since peak values in 2008 and 2009. This suggests that prey availability has been low for planktivorous fish, seabirds, and mammals.
- Also in Icy Strait, **large copepod abundance has declined** over the past five years and was particularly low in 2015. The prevalence of small copepods during 2014 fit predictions of warm conditions favoring small copepods, but small copepods also declined in 2015. This suggests that **less lipid-rich prey were available to planktivorous predators**.
- A **decrease in estimated total mature herring biomass in southeastern Alaska has been observed since the peak in 2011**, although the biomass has been above the long-term (1980-2015) median since 2002.
- **Growth rates of piscivorous rhinoceros auklet chicks were anomalously low in 2015**, suggesting that the adult birds were not able to find sufficient prey to support successful chick growth. This is in contrast to 2012 and 2013, when chick growth rates were above the long term average.
- Modelled estimates of eastern Gulf of Alaska **Steller sea lion non-pups counts are above the long term mean**, althought the rate of increase is slower than that for the western Gulf of Alaska.
- Human populations in the Gulf of Alaska coastal towns of **Yakutat and Sitka are around their 25-year mean**. The population of Yakutat has grown a gradually declining trend since a peak in 1997. Sitka has been increasing since that time, with two substantial declines in 2007 and 2015.

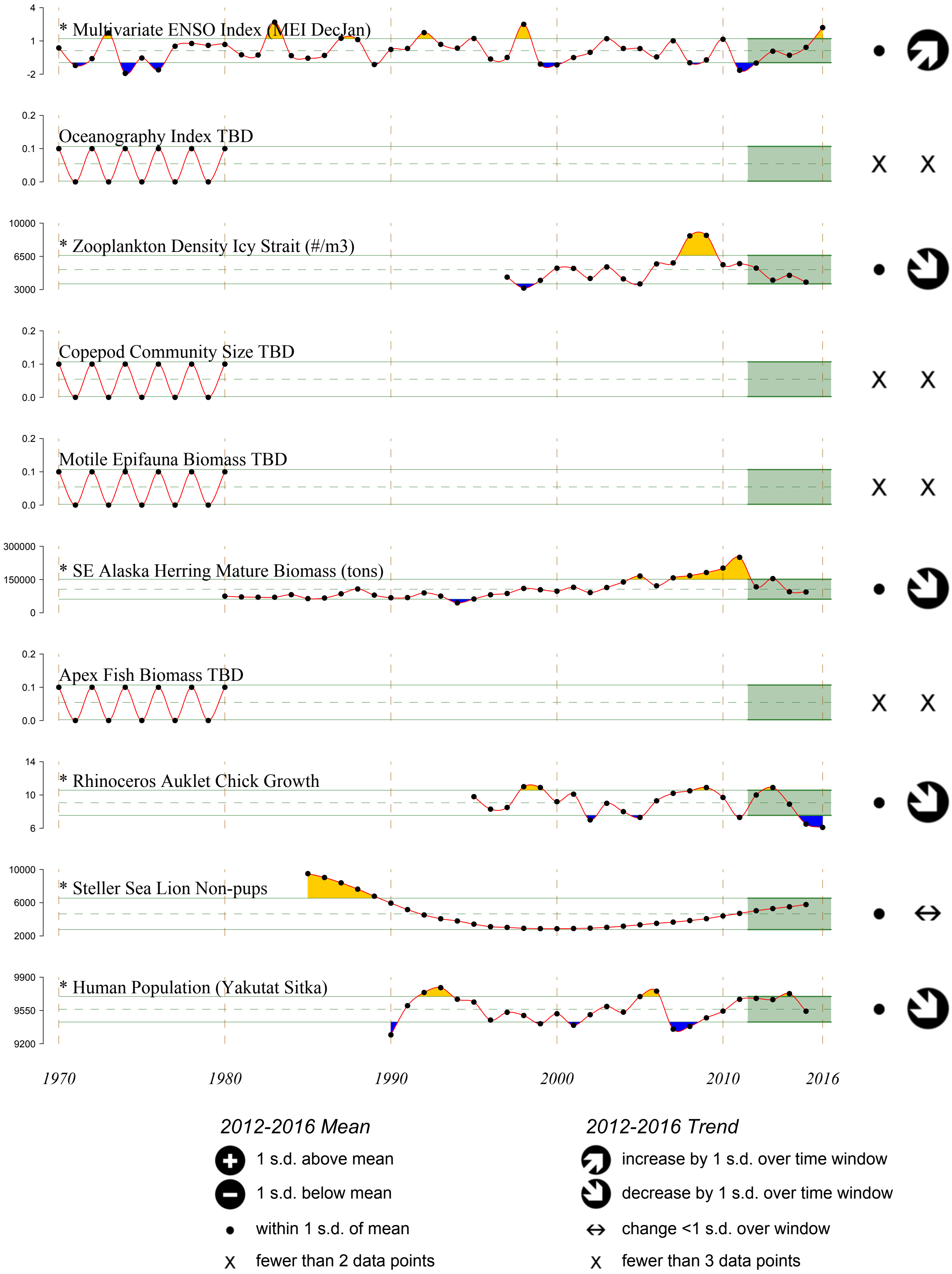

Figure 2: Eastern Gulf of Alaska ecosystem assessment indicators; see text for descriptions. Four potential indices are yet to be determined (TBD). * indicates time series updated in 2016.

Executive Summary of Recent Trends in the Gulf of Alaska

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

- 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. 38).
- A strong El Niño developed during winter 2015-2016 (p. 43).
- However, the climate models used for seasonal weather predictions are indicating borderline to weak La Niña conditions for the winter of 2016-17 (p. 45).
- The Pacific Decadal Oscillation (PDO) remained positive during the past year (p. 43).
- 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. 43).
- 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 Subarccic Gyre and the California Current strengthened to normal (p. 43).
- 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. 45).
- 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. 45).
- 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. 45).

Gulf of Alaska

- The coastal wind anomalies were generally downwelling favorable during winter and spring but switched to more upwelling favorable during the summer of 2016 (p. 38).
- The sub-arctic front was farther north than usual, which is consistent with the poleward surface currents shown in the Ocean Surface Currents – Papa Trajectory Index (p. 50).
- A prominent eddy formed near Yakutat in January 2016, leading to eddy kinetic energy (EKE) levels in the northern Gulf of Alaska during spring 2016 were very high (similar to 2002, the previous maximum). Thus, phytoplankton biomass was likely not confined to the shelf and cross-shelf transport of heat, salinity and nutrients was likely strong (p. 47).
- Relatively weak eddy kinetic energy was observed south of Kodiak during spring 2016 (p. 47).
- It now appears the filtered PAPA Trajectory Index has shifted back to northerly flow, which would indicate that the recent period of predominantly southern flow (mid-2000s to present) will have been the shortest and weakest in the time series (p. 50).

Ecosystem Trends

- In the Alaskan Shelf region sampled by the continuous plankton recorder, spring diatom abundances for the Alaskan Shelf were low, but increased by the summer and fall, leading to positive anomalies and suggesting a change in the ocean conditions mid-way through the year (p. 56).
- In the same region, copepod community size anomalies remained negative from 2013-2015, while mesozooplankton biomass anomalies were positive in 2014 and 2015 (p. 56).
- A new zooplankton indicator features a hindcast of data collected from Line 8 in Shelikof Strait from 1990-2012 to compare with current zooplankton rapid assessments. Trends in euphausiid, small copepod, and large copepod abundance has varied over the time period, but small copepod abundance was always higher than the other zooplankton (p. 60).
- A fall 2015 zooplankton rapid assessement was dominated by small copepods, similar to the spring 2015 survey. Large copepods were located in deep stations in Shelikof Strait, indicating that there were a few hotspots remaining in fall where successful foraging by juvenile pollock could occur (p. 62).
- Total Icy Strait zooplankton density was anomalously low during summer 2015, continuing a declining trend over the past five years (p. 64).
- Icy Strait zooplankton were numerically dominated by small and large calanoid copepods (p. 64).
- Jellyfish biomass during 2015 GOA IERP surveys decreased relative to the peak value observed in 2014. In contrast to jellyfish catches in the EBS, the GOA catches are more diverse, with *Aequorea* and *Chrysaora* as the top two geni (p. 67).
- The icthyoplankton abundance timeseries shows anomalously low abundances for most species in 2015. The abundance of pollock larvae in 2015 was the lowest observed, following the very high anomaly observed in 2013. Only northern lampfish and rockfish showed positive anomalies in 2015 (p. 69).
- A new forage fish indicator was developed that represents temporal trends in abundance of capelin and sand lance based on prey composition of various piscivorous seabird and groundfish species in the Gulf of Alaska. Capelin showed an increasing trend beginning in 2006 that declined begining in 2014. Sand lance declined in the early 1990s, but recovered by the end of the decade, but have declined again since 2000 (p. 71).
- Although the estimated total mature herring biomass in southeastern Alaska has been above the long-term (1980-2015) median of 92,595 tons since 2002, a decrease in biomass has been observed since the peak in 2011. The most notable drop in biomass was observed in Hoonah Sound (p. 74).

- In the Southeast/Yakutat region, the 2015 adult pink salmon return was the lowest odd-year return since 1997. In contrast, 2015 saw the largest Prince William Sound pink salmon harvest recorded. For 2016 ADF&G has forecasted a decrease in the total commercial salmon catch in Alaska, due to an expected decrease in the number of pink salmon, possibly due to poor overwintering condition and/or increased predation on juvenile pink salmon by southern predators (p. 79 and p. 84).
- Ecosystem indicators predict a pink salmon harvest in southeast Alaska of about 30 M fish, somewhat below the historical average. However, as of October 2016, harvests have been only 18 M fish (p. 84).
- The Southeast Alaska Coastal Monitoring project Chinook salmon index is the abundance estimate of ocean age-1 fish sampled in Icy Strait, lagged two years later to their ocean year of recruitment as ocean age-3 fish, the age when most reach legal size. Based on this index of ocean age-1 fish, there appears to be two strong Chinook salmon year classes emerging: one as ocean age-3 fish in 2013 and another two years later in 2015 (p. 88).
- Late summer chlorophyll a values in 2014 and 2015 were used to predict 19.7 million age-2 sablefish in 2016 (average) and below average recruitment of sablefish to age-2 (3.8 million) in 2017 (p. 91).
- Arrowtooth flounder, flathead sole, and other flatfish continue to dominate the biomass in the ADF&G trawl survey but not to the same degree as seen in previous surveys. A decrease in overall biomass is apparent from 2007 to 2015 from years of record high estimates seen from 2002 to 2005 (p. 94).
- In 2015, overall gadid catches have increased in offshore area of Barnabus Gully and decreased in the inshore areas of Kiliuda and Ugak Bays. Below average anomaly values for arrowtooth flounder and flathead sole were recorded again in 2015 for both inshore and offshore areas, while Pacific halibut and skates were above average only in the offshore stations. Pollock, Pacific cod, and Tanner crab anomaly values were all below average for both areas (p. 94).
- A new regime shift indicator based on 17 biological time series from the GOA shows three distinct trends, but none provide support for a recent regime shift (p. 99).
- Total CPUE in the western GOA bottom trawl survey has varied over time with lowest abundances estimated to have occurred in 1999 and 2001, but with no significant trend from 1993 to 2015. CPUE in the eastern GOA significantly increased over time (p. 102).
- Species richness and diversity are generally higher in the eastern Gulf of Alaska than in the western Gulf. Both richness and diversity tend to be highest along the shelf break and slope, with richness peaking at or just below the shelf break (200-300m), and diversity peaking deeper on the slope as well as in shallow water. Diversity in the eastern Gulf has been declining since 2007 (p. 105).
- Some "mushy" halibut were reported during the 2016 fishing season (p. 108).
- *Ichthyophonus*, a non-specific fungus-like protozoan fish parasite, has caused epizootic events among economically important fish stocks including herring and salmon. Recent research found that of the fish sampled in lower Cook Inlet, 23% had *Ichthyophonus* in 2012, and 29% had *Ichthyophonus* in 2013. However, findings did not support the hypothesis that reduced halibut size-at-age may be caused by *Ichthyophonus* (p. 108).

Fishing and Fisheries Trends

- The total catch of non-target species groups in commercial groundfish fisheries has been variable in the GOA. Catches of Scyphozoan jellyfish, structural epifauna, and assorted invertebrates all increased in 2015 relative to 2014, with the invertebrate catch (primarily sea stars) the highest in the time series (p. 110).
- The numbers of seabirds estimated to be bycaught in Gulf of Alaska fisheries in 2015 increased from that in 2014, but remained below the 2007-2014 average (p. 111).

- At present, 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. The only crab stock considered to be overfished is the Pribilof Islands blue king crab stock, which is in year 2 of a new rebuilding plan (p. 119).
- Annual surplus production trend is characterized by occasional 1-3 year periods of high surplus production that far exceed surplus production in most years. Recent peak years include 2001/02, 2007-09 and 2014 (p. 127).
- Total exploitation rates for the groundfish complex have ranged from 2.5-5.8% over the past few decades. Overall exploitation rates have been relatively stable with occasional peaks such as in 1998/99 and in 2014 (p. 127).
- The pattern of changes in the total number of vessels harvesting groundfish and the number of vessels using hook and line gear have been very similar since 1992. Numbers of hook and line vessels have steadily decreased, then have remained stable in the past three years. Trawl vessels have also decreased over time. Numbers of jig and pot vessels have varied, but with no overall trend (p. 130).
- Human populations within 25 miles of the coast in the Gulf of Alaska have increased steadily to 450,461 people total in 2015. However 43% of communities experience population declines between 1990 and 2015 (p. 132).
- Unemployment rates in the GOA, from 1990 to 2015, were lower than state and national rates with the exception of the year 2000 when the GOA unemployment rate was 4.5%; higher than the national rate of 4.0% (p. 132).

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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 3).

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, nontarget) 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

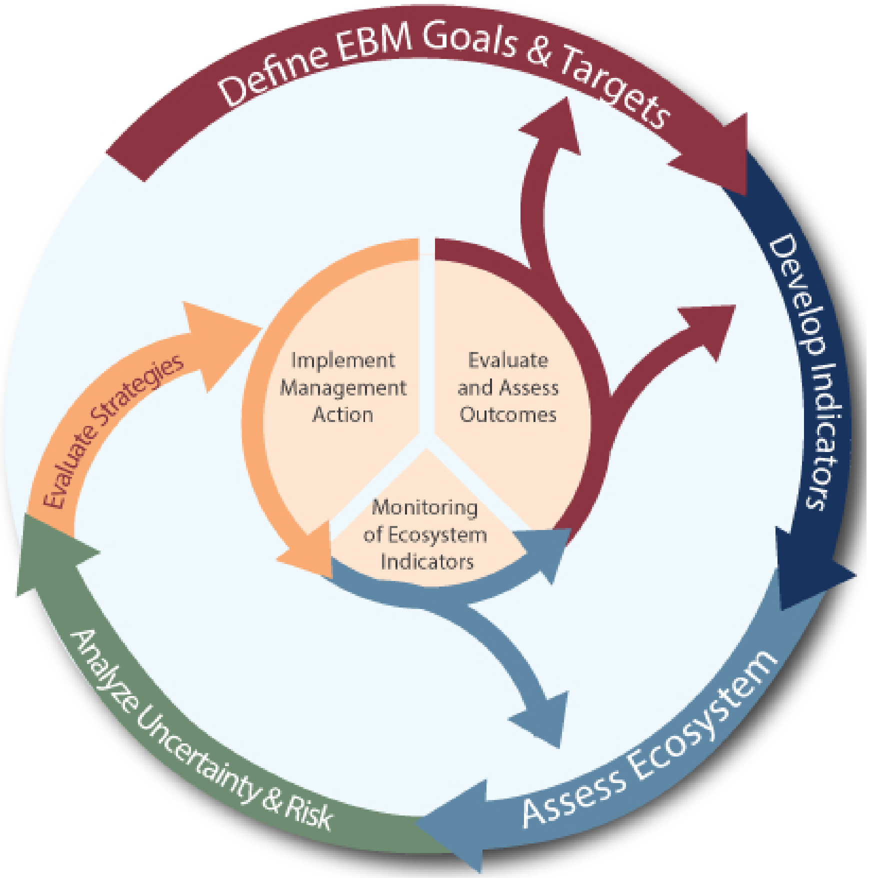

Figure 3: The IEA (integrated ecosystem assessment) process.

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 Gulf of Alaska (GOA) 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 ecosystems 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 states in the context of history and past and future climate.

Hot Topics

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

Newly observed pteropod and re-occurrence of high salp abundance in the Gulf of Alaska during 2016

The shell-less pteropod *Corolla ovata* was observed in for the first time in surface trawl samples were collected from inshore and offshore waters during the Gulf of Alaska (GOA) Assessment survey in 2016. Pteropods are efficient at feeding upon small particles which adhere to their mucus membrane. Salp abundance was also high in the eastern GOA during 2016. Most of the salps that were encountered belonged to the species *Salpa aspera*, which were also highly abundant in the GOA 2011. Salps are phytoplankton grazers and are capable of filtering a large volume of water proportional to their body size, can exhibit a high degree of predation pressure on phytoplankton, and thus have been referred to as the vacuum cleaners of the ocean. Primary production was extremely low in the eastern Gulf of Alaska during 2011, and most of the primary producers were small single celled phytoplankton. The biomass of large crustaceous zooplankton was also low. (Li et al., 2016) concluded that the combined effect of the northward transport of seed populations, rapid biomass increase through asexual reproduction, and the high filtration efficiency of salps contributed to atypically low chlorophyll*a*in the Gulf of Alaska during spring and summer of 2011. Preliminary observations from the 2016 GOA Assessment survey indicate that chlorophyll *a* concentrations are also low in 2016. The abundance of large crustaceous zooplankton also appeared to be low this year. Salps may be key players in structuring the base of the food web, particularly in years where northward transport is strong and may potentially serve as an indicator for poor production. *Contributed by Jamal Moss and Wess Strasburger*

Gulf of Alaska Ecosystem Assessment

We present separate Western and Eastern Gulf of Alaska Report Cards for the first time this year (Figures 1–2). The report cards follow the format of those for the eastern Bering Sea and Aleutian Islands. This associated ecosystem assessment defines the report card indicators, describes how they were selected, and provides a synthesis of the current state of the Gulf of Alaska ecosystem based on the report card indicators as well as other indicators.

The Gulf of Alaska is characterized by topographical complexity, including: islands; deep sea mounts; continental shelf interrupted by large gullies; and varied and massive coastline features such as the Cook Inlet, Prince William Sound, Copper River, and Cross Sound, which bring both freshwater and nutrients into the GOA. The topographical complexity leads to ecological complexity, such that species richness and diversity differ from the western to eastern Gulf of Alaska. Thus, local effects of ecosystem drivers may swamp basin-wide signals. With this in mind, our goal was to create a short list of ecosystem indicators that best reflect the complexity of the Gulf of Alaska. Although there are many more people living in both large and small communities throughout the Gulf of Alaska relative to the Aleutian Islands or eastern Bering Sea, we consider the Gulf of Alaska to be data-moderate relative to the Aleutian Islands (data-poor) and eastern Bering Sea (data-rich).

During 2014 and 2015, we used an online survey format to solicit opinions from ecosystem experts on the most appropriate indicators to include in the report card[2]. The purpose of this format was to increase the group size and diversity in GOA expertise of the participants in the indicator selection process by soliciting information online. In the past, we had broadened the expertise of the team developed to select the Aleutian Islands indicators relative to the eastern Bering Sea team based on comments from the Scientific and Statistical Committee of the North Pacific Fisheries Management Council. We hoped that by surveying a greater number of individuals than were involved with indicator selection for the eastern Bering Sea and Aleutian Islands, the survey results reflect broader expertise and an "equal voice" from all participants.

In early 2016, we reviewed and refined these indicators in conjunction with the NPRB-sponsored GOA IERP synthesis team workshop. 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 for the Gulf of Alaska regions west and east of 144°W. While the general indicator categories are similar between the two report cards, some individual indicators differ. For example, different climate indices were considered to be more influential in each region. However, as with the Aleutian Islands report card, the division of the report card into separate regions 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. We will continue to revise and update these indicators in future editions of this report.

Indicators

Top-ranked indicators were selected for each category: physical, plankton, benthic, forage fish, non-forage fish, seabirds, marine mammals, and humans. We include two physical and plankton indicators and one from each of the other categories where available. The indicators are defined below.

Western Gulf of Alaska

1. The winter Pacific Decadal Oscillation
2. Fresh water input
3. Mesozooplankton biomass
4. Copepod community size
5. Motile epifauna biomass
6. Capelin
7. Fish apex predator biomass
8. Black-legged kittiwake reproductive success

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[2] The survey was conducted under the requirements of the Paperwork Reduction Act.

9. Steller sea lion non-pup estimates
10. Human population

Winter Pacific Decadal Oscillation The leading mode of monthly sea surface temperature anomalies in the North Pacific Ocean, poleward of 20°N. The monthly mean global average SST anomalies are removed to separate this pattern of variability from any "global warming" signal that may be present in the data. The winter index is the average monthly values from November through March. Data from `http://research.jisao.washington.edu/pdo/PDO.latest`.

Fresh water input The GAK 1 oceanographic station is located at the mouth of Resurrection Bay near Seward. Temperature and salinity versus depth profiles have been taken there since December, 1970. Although the GAK 1 time series has been used as a measure of freshwater discharge in the past, the salinity there is affected by a number of factors, including wind mixing, evolution of stratification, and shelf advection. Thus, there is need for a better indicator, which may come available as a very high resolution discharge hindcast (Seth Danielson, pers. comm.).

The GAK 1 discharge time series is a very low-resolution "model" (estimate) of discharge that accounts for little more than monthly mean air temperatures over the GOA drainage basin, estimated precipitation, and some seasonal lags. The data are the annually-average monthly discharge value for each calendar year. There is a new, very high resolution discharge hind-cast model by David Hill at Oregon State University that uses a snowpack model, elevations, reanalysis precipitation and streamflow routing and is tuned against USGS discharge measurements. This model is at about 1 km resolution and provides hourly estimates all along the GOA coast. We hope use this model to improve this indicator in the next edition.

Mesozooplankton biomass Mesozooplankton biomass is estimated from taxon-specific abundance data collect from Continuous Plankton Recorders (CPRs). These have been deployed in the North Pacific routinely since 2000. The transect for the region known as the Alaska Shelf is sampled monthly (∼Apr-Sept) and presented here. Anomaly time series of each index are calculated as follows: a monthly mean value (geometric mean) was first calculated. Each sampled month was then compared to the mean of that month and an anomaly calculated (Log_{10}). The mean anomaly of all sampled months in each year was calculated to give an annual anomaly.

Copepod Community size Mean Copepod Community Size (Richardson et al., 2006) as sampled by Continuous Plankton Recorders is presented as an indicator of community composition. The methods used to calculate this indicator is listed above for mesozooplankton biomass.

Motile epifauna biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community of the Gulf of Alaska.

Capelin The common trend identified by Dynamic Factor Analysis of capelin in prey composition time series from various piscivorous seabird and groundfish species, considered to be "samplers" of the forage fish community. The capelin data are from seabird chick diets collected at breeding colonies during summer and from groundfish stomach contents collected biennially during summer bottom-trawl surveys. The data include the percent diet composition from tufted puffins (*Fratercula cirrhata*) and common murres (*Uria aalge*) at East Amatuli Island, Alaska (USFWS), the relative occurrence during June August in black-legged kittiwakes (*Rissa tridactyla*) and percent biomass from rhinocerous auklets (*Cerorhinca monocerata*) at Middleton Island (ISRC), and the number of capelin or sand lance per length of groundfish (year range; AFSC). The groundfish species included arrowtooth flounder (*Atherestes stomias*), Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), and walleye pollock (*Gadus chalcogramma*).

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

Black-legged kittiwake reproductive success Black-legged kittiwakes are common surface-foraging, piscivorous seabirds that nest in the Gulf of Alaska. Reproductive success is defined as the proportion of nest sites with fledged chicks from the total nest sites that had eggs laid. Reproductive success of this species is considered to be more sensitive to foraging conditions than that of common murres, another common seabird that has less variable reproductive success due to behaviors that can buffer the effects of poor food supply. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service.

Steller sea lion non-pup estimates The R package agTrend model was used to produce abundance estimates of Steller sea lions within the bounds of the Gulf of Alaska. This region includes the Gulf of Alaska portion of the western Distinct Population Segment.

Human population The combined populations of Homer and Kodiak are used to represent the health of the human communities closely associated with the marine ecosystem of the Gulf of Alaska. Data are from the Alaska Population Estimates by Borough, Census Area, City and Census Designated Place (CDP), 2000-2010, and 1990 - 2009, found at the Alaska State Labor Statistics `http://laborstats.alaska.gov/index.htm`. This indicator could be refined in the future to better represent the human populations that are directly influenced by fishing and/or ecosystem state. Attributes of an improved indicator include representation of trends in rural communities (that can be swamped by signals from larger communities), responsiveness to environmental changes, and availability at annual time scales.

Eastern Gulf of Alaska

1. The Multivariate ENSO Index (MEI)
2. Oceanographic index to be determined

3. Mesozooplankton biomass
4. Copepod community size
5. Motile epifauna biomass
6. Southeast Alaska mature herring biomass
7. Fish apex predator biomass
8. Rhinoceros auklet chick growth rates
9. Steller sea lion non-pup estimates
10. Human population

Multivariate ENSO Index (MEI) The MEI represents trends in the El Niño/La Niña Southern Oscillation. It is calculated from the first principal component of six variables observed over the tropical Pacific. These are: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. Data are from `http://www.esrl.noaa.gov/psd/enso/mei/table.html`.

Oceanographic index to be determined A suitable oceanographic index has yet to be selected. We hope to present one next year.

Mesozooplankton biomass Zooplankton biomass is represented byt zooplankton density (number per m^3) as captured by 333-μm bongo net samples during summer months in Icy Strait.

Copepod Community size A suitable community size index has yet to be determined. We hope to present one next year.

Motile epifauna biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The motile epifauna foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. This guild includes: eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs. This indicator is presented to reflect the trends in the benthic community of the Gulf of Alaska. However, summarizing these values for the eastern region, where survey efforts vary among years, was not finalized in time for this edition.

Southeast Alaska mature herring biomass Herring is used to represent forage fish trends in the eastern Gulf of Alaska region. Total mature herring biomass is estimated from nine primary sites for which regular assessments are conducted and probably account for the majority of the spawning biomass in southeastern Alaska in any given year.

Apex predator biomass The NOAA bottom trawl survey has been conducted triennially since 1984, and biennially since 2000. The apex predator foraging guild is calculated from the survey data modified by an ecopath-estimated catchability. Fish in this guild include: Pacific cod, arrowtooth flounder, halibut, sablefish, large sculpins, and skates. Marine mammals, seabirds, and some other fishes such as sharks are included as constant ecopath-estimated biomasses. However, summarizing these values for the eastern region, where survey efforts vary among years, was not finalized in time for this edition.

Rhinoceros auklet chick growth rate Mean growth rates of rhinoceros auklet chicks at St. Lazaria Island. Reproductive success is difficult to determine for these burrow-nesting seabirds because they are sensitive to disturbance. Data are only included for chicks that were measured at least three times during the linear phase of growth; chicks that did not exhibit linear growth were excluded. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service.

Steller sea lion non-pup estimates The R package agTrend model was used to produce abundance estimates of Steller sea lions within the bounds of the Gulf of Alaska. This region includes the eastern Distinct Population Segment.

Human population The combined populations of Yakutat and Sitka are used to represent the health of the human communities closely associated with the marine ecosystem of the Gulf of Alaska. Data are from the Alaska Population Estimates by Borough, Census Area, City and Census Designated Place (CDP), 2000-2010, and 1990 - 2009, found at the Alaska State Labor Statistics `http://laborstats.alaska.gov/index.htm`. This indicator could be refined in the future to better represent the human populations that are directly influenced by fishing and/or ecosystem state. Attributes of an improved indicator include representation of trends in rural communities (that can be swamped by signals from larger communities), responsiveness to environmental changes, and availability at annual time scales.

Current Environmental State

The current environmental state in the Gulf of Alaska reflects the continuance of the anomalously warm water present since late 2013/early 2014. This began as the warm “Blob” in the NE Pacific and has evolved since that time, related in part to sea level pressure and wind anomalies. This past winter, the western GOA experienced anomalous winds out of the northwest in association with extremely low sea level pressure. 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 Papa Trajectory Index. This 2016 surface current pattern itself was very similar to those of 2012 and 2014. This year, the coastal wind anomalies were generally downwelling favorable during winter and spring due to the pattern of winds from the northwest, 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.

The PDO has remained positive during the past two years, indicating warmer than normal sea surface temperatures along the west coast of North America. The El Niño of the last winter has faded, and a neutral state is forecasted for the upcoming winter. The NPGO has also approached a neutral state, indicating normal flows in the Alaska Current portion of the Subactic Gyre. Sea surface temperature projections indicate the warm conditions are likely to remain through the upcoming winter.

Many biological indicators suggest that there was poor productivity in the Gulf of Alaska in 2016. There are some signs of improvement relative to 2015, but these are limited to abundant juvenile salmon and young of year forage fish, age-4 (2012 year class) pollock growth during spring, and the absence of large bird and whale die-offs. However, low zooplankton abundances, the presence of southern species during surveys, occurrence of "mushy" halibut syndrome, and poor seabird reproduction point to the general low productivity of 2016.

Observations from the 2016 ABL surveys in the eastern Gulf of Alaska were similar to 2015 with the continuation of warm sea temperatures, low zooplankton biomass, large catches of juvenile salmon, and the presence of southern species (Moss and Strasburger, pers. comm.). The eastern Gulf of Alaska average upper 20-m sea temperatures for May-August were the warmest recorded for Icy Strait inside waters (1997-2016) and outside Gulf of Alaska continental shelf waters (1997-2004, 2010-2016) in the past 20 years. Eastern Gulf of Alaska nearshore survey observations included low zooplankton biomass, large numbers of gastropods (*Limacina helicina*), and high numbers of juvenile pink and chum salmon. Adult pink salmon returns were lower than expected, indicating poor ocean conditions or increased presence of predators. The eastern Gulf of Alaska shelf survey (2010-2016) observations included low crustacean biomass, high catches of salps, juvenile rockfish, market squid, and Pacific saury and relatively low catches of Pacific pomfret and age-0 pollock. Offshore, juvenile sablefish were eating juvenile rockfish and salps.

Humpback whales continued to experience unusual mortality events with at least 8 humpback whales killed by orcas (J. Moran, pers. comm.). Large whale entanglements were high (>20), possibly due to changes in foraging behavior. Whales were observed feeding more nearshore and on juvenile salmon than is typical.

There were a few reports of "mushy" halibut syndrome in 2016. The condition is considered a result of nutritional myopathy, and thus many be indicative of poor prey conditions for halibut. Also, the dominant year class of pollock (2012) was smaller than average during the past winter and early spring, but there appeared to be growth compensation over the following few months so that they were larger than expected by the summer (J. Bonney, pers. comm.). It currently unknown whether the pollock grew even less than expected during winter, then caught up? And/or was their spring growth rate greater than usual, indicating good feeding conditions? This would not be expected given the low abundance and predominantly small zooplankton observed since fall 2015 and during 2016 summer surveys.

Common murres experienced complete reproductive failure at nearly all monitored colonies in the Gulf of Alaska in 2016 (H. Renner, pers. comm.). This unprecedented event came after an unusually widespread and prolonged winter mortality event in 2015-2016 and was presumably linked to the anomalously warm conditions. At many colonies, zero to few murres attended nesting cliffs during the typical breeding period, which limited the ability of the U.S.F.W.S. biologists to detect population-level effects of the winter die-off. Colonies where murres attempted to breed in 2016 laid eggs later than normal, and many experienced high rates of predation. U.S.F.W.S. biologists hypothesize that the reproductive failure in murres resulted from poor body condition prior to the breeding season after multiple years of food stress. Forage fish work in PWS and Kachemak Bay during summer 2016 suggest that there were favorable conditions for young-of-the-year forage fish including sand lance, herring and pollock during summer 2016 (Y. Arimitsu, unpubl. data.). These fish, while abundant, are of lower energetic value than older age classes and they become available to predators later in the breeding season, compared to older age classes.

The NOAA summer bottom trawl survey is conducting biennially during odd-numbered years over a large part of the Gulf of Alaska shelf, so there are no new data to report. However, some catch patterns in this survey align closely with those of the annual bottom trawl survey conducted by ADF&G over a more restricted area, Barnabus Gully. For example, both arrowtooth flounder and Pacific halibut appear to have increased in abundance until approximately 2003, after which there has been a general declining pattern. With the addition of the 2015 ADF&G survey data this year, it is confirmed that both species increased in the NOAA and ADF&G survey in 2015 relative to 2013. Thus, the annual ADF&G survey may be able to provide some insight into groundfish patterns during even years when there are no NOAA bottom trawl surveys.

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

Contributed by Nick Bond (UW/JISAO))
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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 around 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 Papa Trajectory Index section (p. 50). 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 4 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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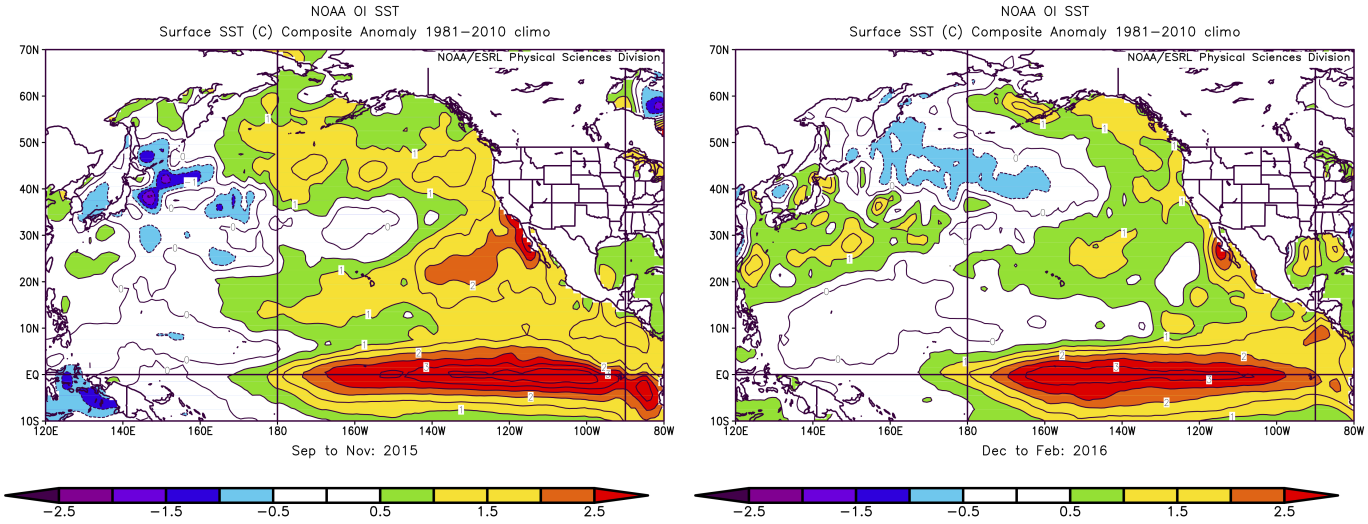
Last updated: August 2016

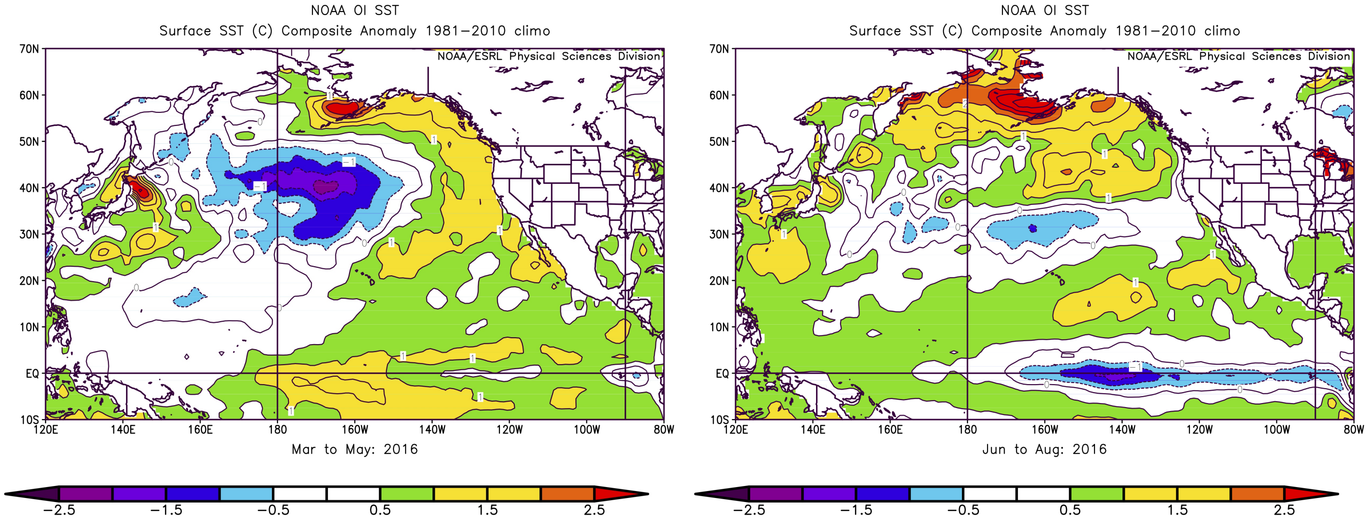
Description of indices: The state of the North Pacific climate from autumn 2015 through summer 2016 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981-2010. 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 4a) 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.

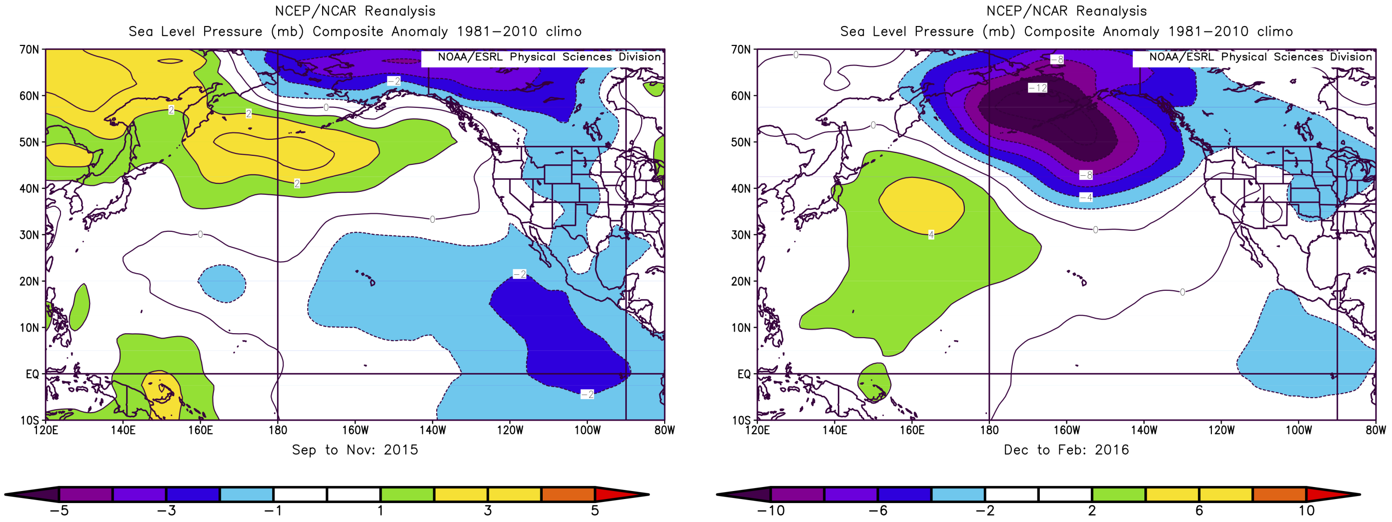


(a) Autumn (b) Winter

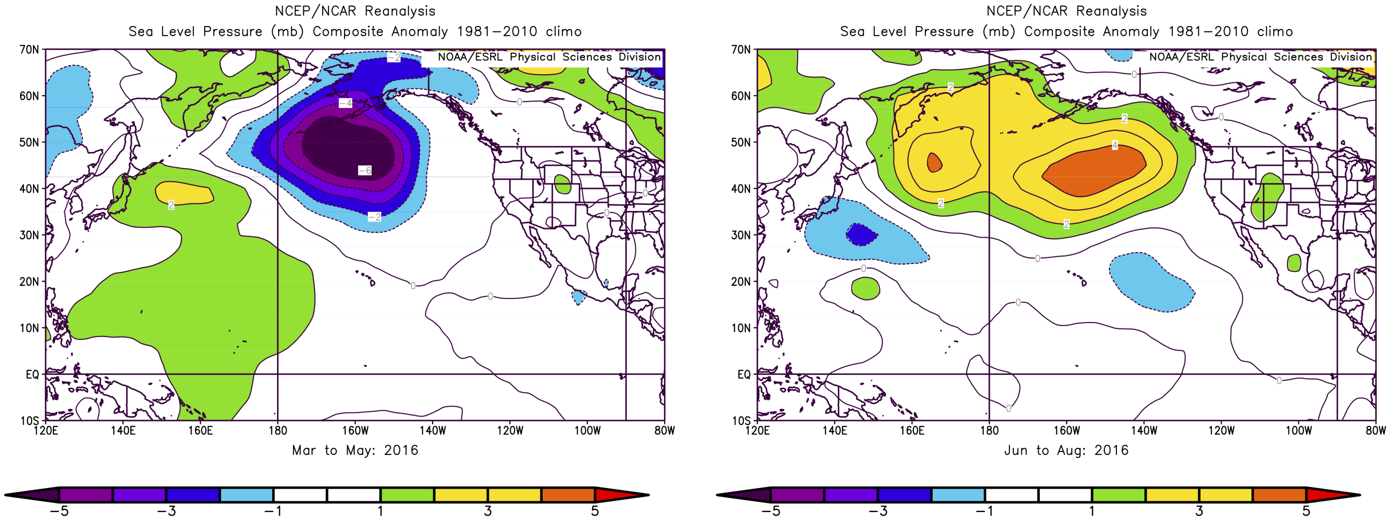


(c) Spring (d) Summer

Figure 4: SST anomolies for autumn (September-November 2015), winter (December 2015 -February 2016), spring (March - May 2016), and summer (June - August 2016).


NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Anomaly 1981–2010 climo

(a) Autumn (b) Winter


NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Anomaly 1981–2010 climo

(c) Spring (d) Summer

Figure 5: 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 4b) 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 5b). 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 4b) 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 4c) 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 5c) 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 4d. It was warmer than normal in the north, with especially positive anomalies region 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 5d) 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 4d. 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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Last updated: August 2016

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 6.

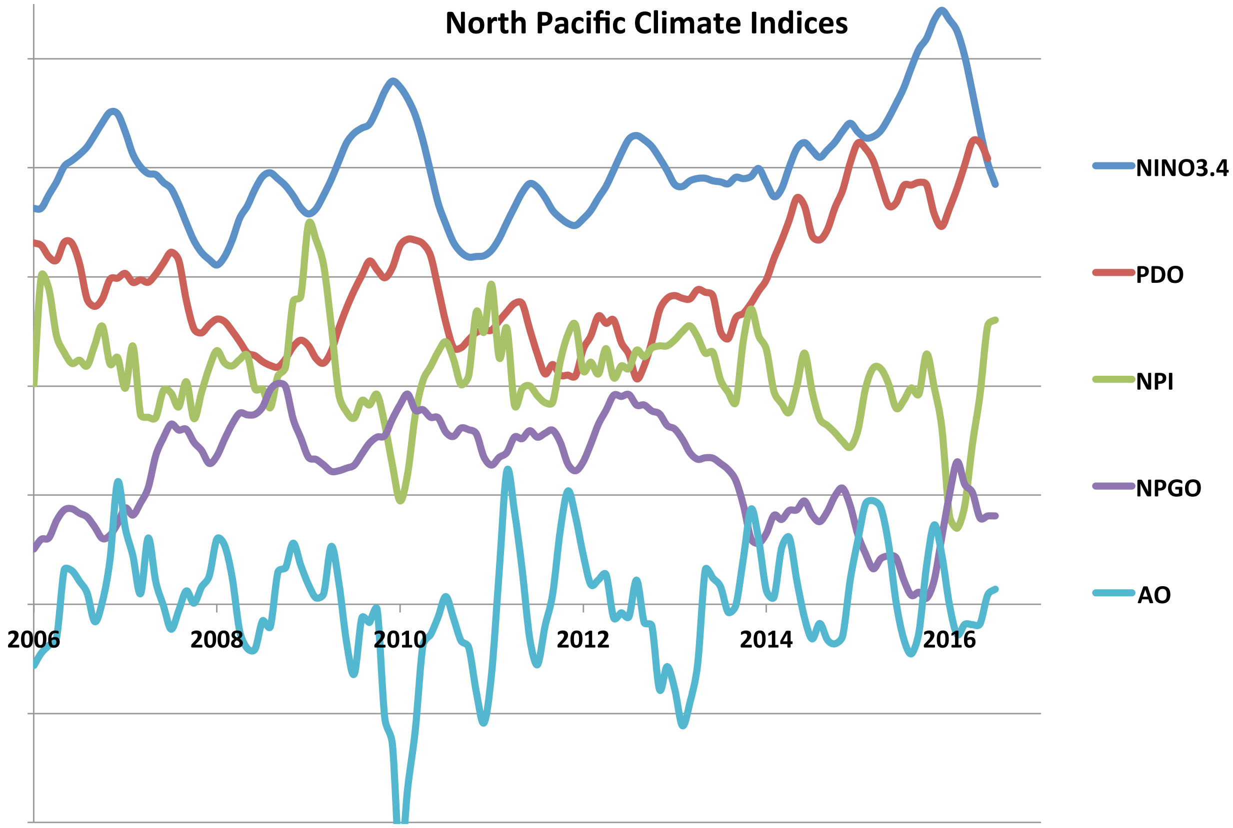

Figure 6: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 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 6. 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 4b and 5b). 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 2nd 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 and 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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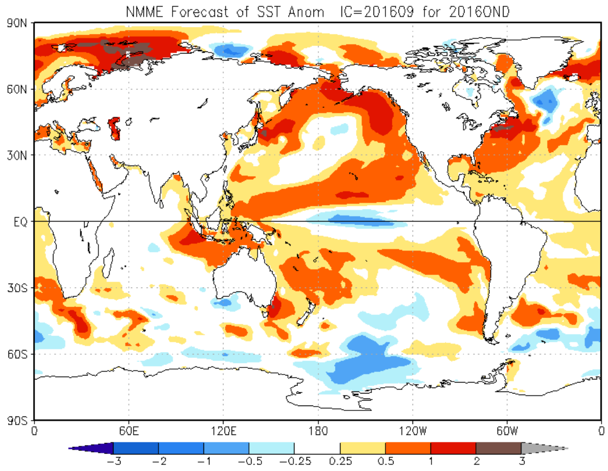
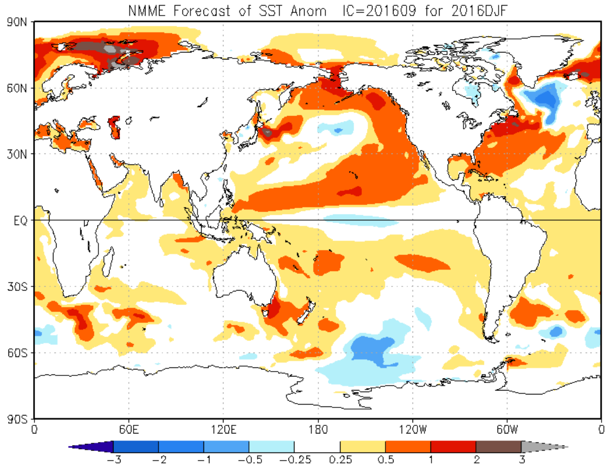
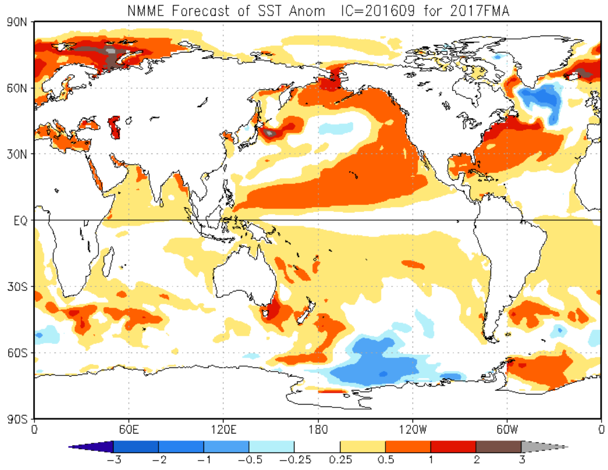
Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 7. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight models. The uncertainties 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 7: 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 7a). 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 7b) and February-April 2017 (Figure 7c) 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 7 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.

Eddies in the Gulf of Alaska

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Last updated: August 2016

Description of indicator: Eddies in the northern Gulf of Alaska have been shown to influence distributions of nutrients (Ladd et al., 2009, 2005; Ladd, 2007), phytoplankton (Brickley and Thomas, 2004), and ichthyoplankton (Atwood et al., 2010), and the foraging patterns of fur seals (Ream et al., 2005). Eddies propagating along the slope in the northern and western Gulf of Alaska are generally formed in the eastern Gulf in autumn or early winter (Okkonen et al., 2001) sometimes associated with gap winds from Cross Sound (Ladd and Cheng, 2016). Using altimetry data from 1993 to 2001, Okkonen et al. (2003) found that strong, persistent eddies occurred more often after 1997 than in the period from 1993 to 1997. Ladd et al. (2007) extended that analysis and found that, in the region near Kodiak Island (Figure 8; region c), eddy energy in the years 2002-2004 was the highest in the altimetry record.

Since 1992, a suite of satellite altimeters has been monitoring sea surface height. Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (merged TOPEX/Poseidon, ERS-1/2, Jason and Envisat; (Ducet et al., 2000), giving a measure of the mesoscale energy in the system. A map of eddy kinetic energy in the Gulf of Alaska averaged over the altimetry record (updated from Ladd et al. (2007)) shows four regions with local maxima (labeled a, b, c and d in Figure 8). The first two regions are associated with the formation of Haida (a) and Sitka (b) eddies. Eddies that move along the shelf-break often feed into the third and fourth high EKE regions (c and d; Figure 8). By averaging EKE over regions c and d (see boxes in Figure 8), we obtain an index of energy associated with eddies in these regions (Figure 9). The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS) (`http://www.marine.copernicus.eu`).

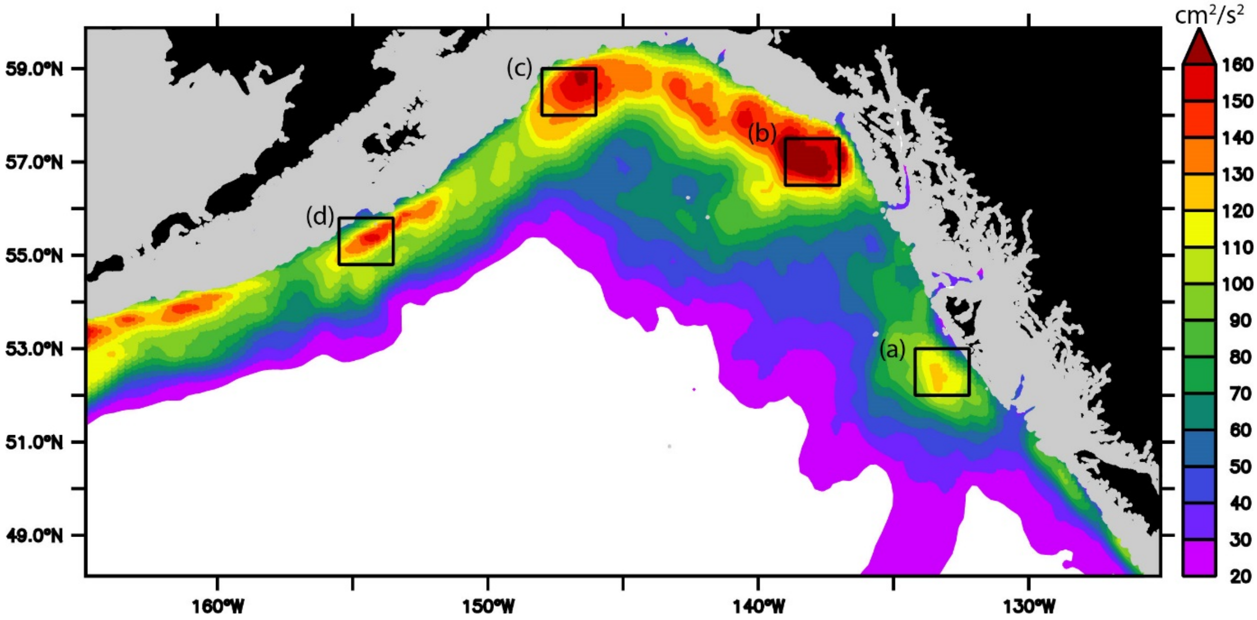

Figure 8: Eddy Kinetic Energy averaged over October 1993-October 2014 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 9.

Status and trends: The seasonal cycle of EKE averaged over the two regions (c and d) are out of phase with each other. Region (c) exhibits high EKE in the spring (March-May) and lower EKE in the autumn (September-November) while region (d) exhibits high EKE in the autumn and low EKE in the spring. EKE was particularly high in region (c) in 2002-2004 when three large persistent eddies passed through the region. In region (d), high EKE was observed in 1993, 1995, 2000, 2002, 2004, 2006, 2007, 2010, 2012, 2013, and 2015. Near-real-time data suggests that EKE

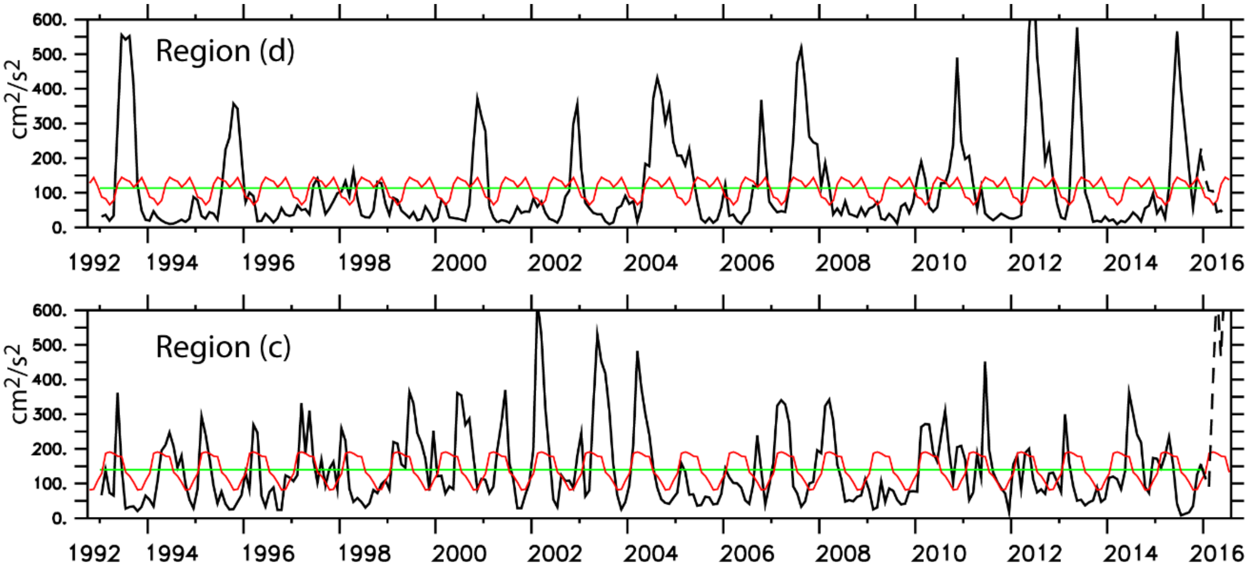

Figure 9: Eddy kinetic energy (cm^2 s^{-2}) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 8. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product), Red: seasonal cycle. Green (straight line): mean over entire time series.

was low in spring 2016 in region (d) while in region (c), EKE values were very high (similar to 2002, the previous maximum). The high EKE values in spring 2016 in region (c) were due to a strong eddy that formed near Yakutat in January 2016. 2016 EKE is calculated from near-real-time altimetry data which has lower quality than the delayed time data and may be revised.

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

Implications: EKE may have implications for the ecosystem. Phytoplankton biomass was probably more tightly confined to the shelf during 2009 due to the absence of eddies, while in 2007, 2010, 2012, 2013, and 2015 (region (d)), phytoplankton biomass likely extended farther off the shelf. In addition, cross-shelf transport of heat, salinity, and nutrients were probably weaker in 2009 than in 2007, 2010, 2012, 2013 and 2015 (or other years with large persistent eddies). Eddies sampled in 2002-2004 were found to contain different ichthyoplankton assemblages than surrounding slope and basin waters indicating that eddies along the slope may influence the distribution and survival of fish (Atwood et al., 2010). In addition, carbon isotope values suggest that cross-shelf exchange due to eddies may be important to the marine survival rate of pink salmon (Kline, 2010).

Ocean Surface Currents – Papa Trajectory Index

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Last updated: August 2016

Description of indicator: The PAPA Trajectory Index (PTI) provides an annual index of near-surface water movement variability, based on the trajectory of a simulated surface drifter released at Ocean Station PAPA (50°N, 145°W; Figure 10). The simulation for each year is conducted using the "Ocean Surface CURrent Simulator" (OSCURS; `http://las.pfeg.noaa.gov/oscurs`). Using daily gridded atmospheric pressure fields, OSCURS calculates the speed and direction of water movement at the ocean's surface at the location of a simulated surface drifter. It uses this information to update the position of the simulated drifter on a daily basis over a specified time period. For the index presented here, OSCURS was run for 90 days to simulate a surface drifter released at Ocean Station PAPA on December 1 for each year from 1901 to 2015 (trajectory endpoints years 1902-2016).

Status and trends: In general, the trajectories fan out northeastwardly toward the North American continent (Figure 10). The 2009/2010 trajectory was an exception and resulted in the westernmost trajectory endpoint for the entire set of model runs (1902-2016). This trajectory was, however, consistent with the atmospheric conditions that existed during the winter of 2009-2010 (N. Bond, U.W., pers. comm.). Under the influence of contemporaneous El Niño conditions, the Aleutian Low in the winter of 2009-2010 was anomalously deep and displaced to the southeast of its usual position in winter (Bond and Guy, 2010), resulting in anomalously high easterly (blowing west) wind anomalies north of Ocean Station PAPA. The 2011/2012 trajectory followed the general northeastwardly path of most drifters, but was notable because its ending latitude was the northernmost of all trajectories since 1994. The three most recent (2013/14, 2014/15, and 2015/16) trajectories were also very similar to that from 2011/12, although these did not reach quite as as far north as in 2011/12, while that for 2012/13 was notable as ending up the furthest east among trajectories in recent years. However, the ending latitude for 2012/2013 was only somewhat southerly of the average ending latitude for all trajectories (Figure 11) and certainly not atypical. This is consistent with the northeast Pacific wind forcing, which featured very strong westerly anomalies. The most recent trajectories coincided with the development (2013/14) and continuation (2014/15, 2015/2016) of a "Blob" of warm surface waters along the eastern Pacific coast and the return of the Pacfic Decadal Oscillation (PDO) to a warm, positive phase associated with winds from the south near the coast. The increased southerly winds contributed to well above-average sea surface temperatures in the Gulf of Alaska in 2015/16.

The PTI time series (Figure 11, black dotted line and points) indicates high interannual variation in the north/south component of drifter trajectories, with an average between-year change of >4° and a maximum change of greater than 13° (between 1931-1932). The change in the PTI between 2010/11 and 2011/12 was the largest since 1994, while the changes between 2011/12 and 2012/13, and between 2012/13 and 2013/14, represented reversals with slightly less, but diminishing, magnitude. Such swings, however, were not uncommon over the entire time series. The changes from 2013/14 to 2015/16 constituted a relatively rare event when the index changed very little over three

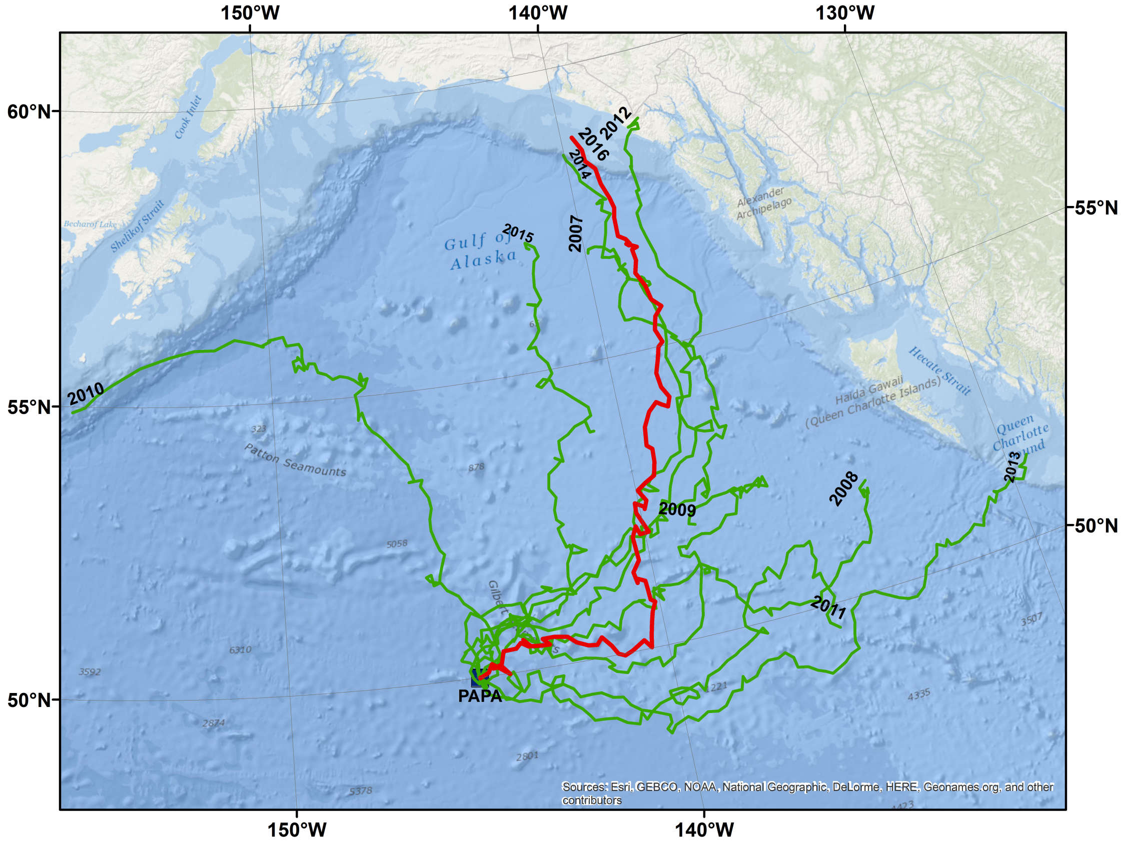

Figure 10: Simulated surface drifter trajectories for winters 2007-2016 (endpoint year). End points of 90-day trajectories for simulated surface drifters released on Dec. 1 of the previous year at Ocean Weather Station PAPA are labeled with the year of the endpoint (50°N, 145°W).

successive years.

Using a 5-year running mean boxcar filter to smooth the raw PTI reveals multidecadal-scale oscillations in the north/south component of the drift trajectories (Figure 11, red line and squares), with amplitudes over 7° latitude. Over the past century, the filtered PTI has undergone four complete oscillations with distinct crossings of the mean, although the durations of the oscillations are not identical: 27 years (1904-1930), 18 years (1930-1947), 18 years (1947-1964), and 42 years (1964-2005). The filtered index indicates that a shift occurred in the mid 2000s to predominantly southerly anomalous flow following a 20+ year period of predominantly northerly anomalous flow. This was indicative of a return to conditions (at least in terms of surface drift) similar to those prior to the 1977 environmental regime shift. This part of the cycle apparently ended rather quickly, however, as it now appears the filtered PTI has crossed the mean in the opposite direction. The recent period of predominantly southern flow has been the shortest and weakest in the time series.

Factors influencing observed trends: Filtered PTI values greater than the long-term mean are

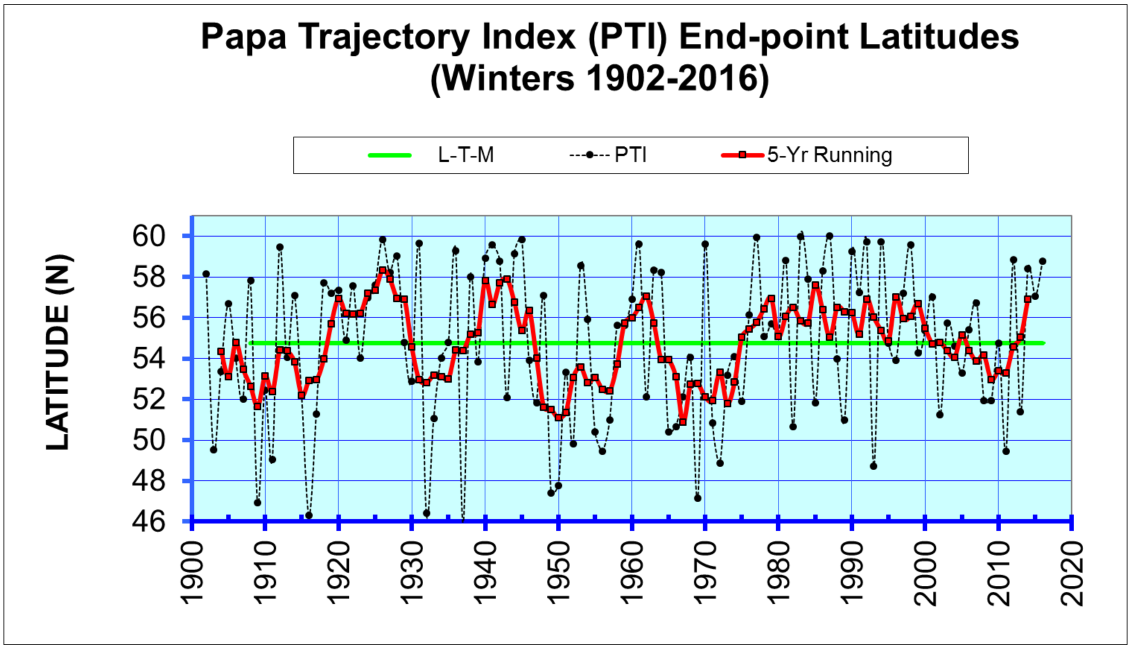

Figure 11: Annual, long-term mean (green line), and 5-year running mean (red line and squares) of the PAPA Trajectory Index time-series (dotted black line and points) for 1902-2015.

indicative of increased transport and/or a northerly shift in the Alaska Current, which transports warm water northward along the west coast of Canada and southeast Alaska from the south and consequently plays a major role in the Gulf of Alaska's heat budget. In addition, the PDO recently (July, 2014) shifted into a positive and warm phase, associated with warm SST anaomlies near the coast in the eastern Pacific and low sea level pressures over the North Pacific, the latter of which contributes to southerly winds and northerly flows. Individual trajectories also reflect interannual variability in regional (northeast Pacific) wind patterns.

Implications: The year-to-year variability in near-surface water movements in the North Pacific Ocean has been shown to have important effects on the survival of walleye pollock (*Gadus chalcogrammus*) by affecting its spatial overlap with predators (Wespestad et al., 2000), as well as to influence recruitment success of winter spawning flatfish in the eastern Bering Sea (EBS; Wilderbuer et al. (2002)). Interdecadal changes in the PTI reflect changes in ocean climate that appear to have widespread impacts on biological variability at multiple trophic levels (King, 2005). There is strong evidence that the productivity and possibly the carrying capacity of the Alaska Gyre and of the continental shelf were enhanced during the recent "warm" regime that began in 1977. Zooplankton production was positively affected after the 1977 regime shift (Brodeur and Ware, 1992). Recruitment and survival of salmon and demersal fish species also improved after 1977. Recruitment of rockfish (Pacific ocean perch) and flatfish (arrowtooth flounder, halibut, and flathead sole) increased. However, shrimp and forage fish such as capelin were negatively affected by the 1977 shift (Anderson, 2003). The reduced availability of forage fish may have been related to the decline in marine mammal and seabird populations observed after the 1977 shift (Piatt and Anderson, 1996).

Although the PTI was smaller than the mean in both 2010/11 and 2012/13, it was substantially larger than the mean in both 2011/12 and 2013/14-2015/16. The short period of negative PTI (southward trajectory anomalies) that began in earnest in the late 2000s appears to have ended. The trajectory for 2012/13 indicated the potential for southeast Alaska to experience an influx of open ocean type organisms at the lower trophic levels in 2013, as well as a southward shift in the "boundary" between sub-arctic and sub-tropical species. The trajectories for 2013/14-2015/16 indicate a northward shift in the "boundary" between sub-arctic and sub-tropical species, as well as a relative absence of open ocean type organisms at the lower trophic levels in southeast Alaska.

Gulf of Alaska Survey Bottom Trawl Temperature Analysis

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Gulf of Alaska surveys are conducted every other year. See archives for the latest report.

Watershed Dynamics in the Auke Creek System, Southeast Alaska

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Last updated: September 2016

Description of indicator: The Auke Creek Research Station has been in permanent operation since 1980 and provides a unique opportunity to study migratory salmonids due to the operation of a weir capable of the near-perfect capture of all migrating juvenile and adult salmon. In addition to the capture of migrating individuals, daily recordings of environmental variables are also collected. These variables include: creek temperature, and creek height. Creek temperature is collected using an in-creek probe that records temperature on an hourly basis and is located 25 meters upstream of the weir structure. Creek height is recorded using a staff gauge that is permanently installed directly downstream of the weir structure and approximately 7 meters above the average low tide line. Thirty six years of temperature data are available (1980 2016), and 10 years of creek height data (2006 2016). These variables provide a valuable addition to the fisheries data collected at the Auke Creek Research Station.

Status and trends: The historical trends of yearly average creek temperature in Auke Creek varies from 8.6°C to 12.4°C with an average temperature of 10.31°C from 1980 - 2016. The average temperature for 2015 was 9.0°C and 12.4°C for 2016. From 2006 - 2016, average yearly creek height varied from 21.6ft to 21.9ft, with an average of 21.7 ft. The average gauge height for 2015 was 21.7ft and 21.6ft for 2016. Historical trends and the most recent two years are shown for creek temperature (Figure 12) and height (Figure 13).

Factors influencing observed trends: The trends that we are observing in the Auke Creek watershed provide further evidence for the rapid climatic change that has been documented in this system. Due to recent fluctuations in winter snowfall, we are seeing shifts from a snowmelt-

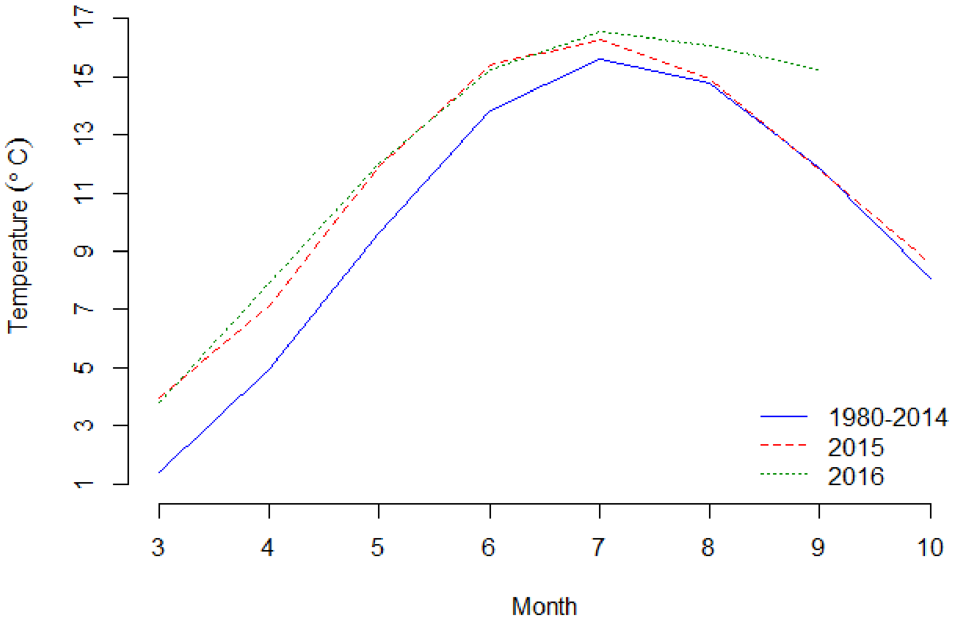

Figure 12: : Auke Creek average temperature by months of operation for 1980-2014, 2015, and 2016.

dominated to a rainfall-dominated watershed at Auke Creek (Shanley et al., 2015)(Figure 13). This lack of snowfall, and subsequent lack of snowmelt, contribute to warmer creek temperatures earlier in the year (Figure 12).

Implications: These changes in stream conditions and climate have been shown to have influence on the median migration date of juvenile and adult salmon in Auke Creek (Kovach et al., 2013). Additionally, changes in time of entry to the marine environment can effect marine survival (Weitkamp et al., 2011). Both of these can have impacts on groundfish and salmon productivity as juvenile salmon serve as an important food source in the early marine environment. (Landingham et al., 1998; Sturdevant et al., 2009, 2012). Additionally, shifts in the timing and magnitude of freshwater and associated nutrient input directly affects processes in the nearshore marine environment (e.g. salinity and temperature).

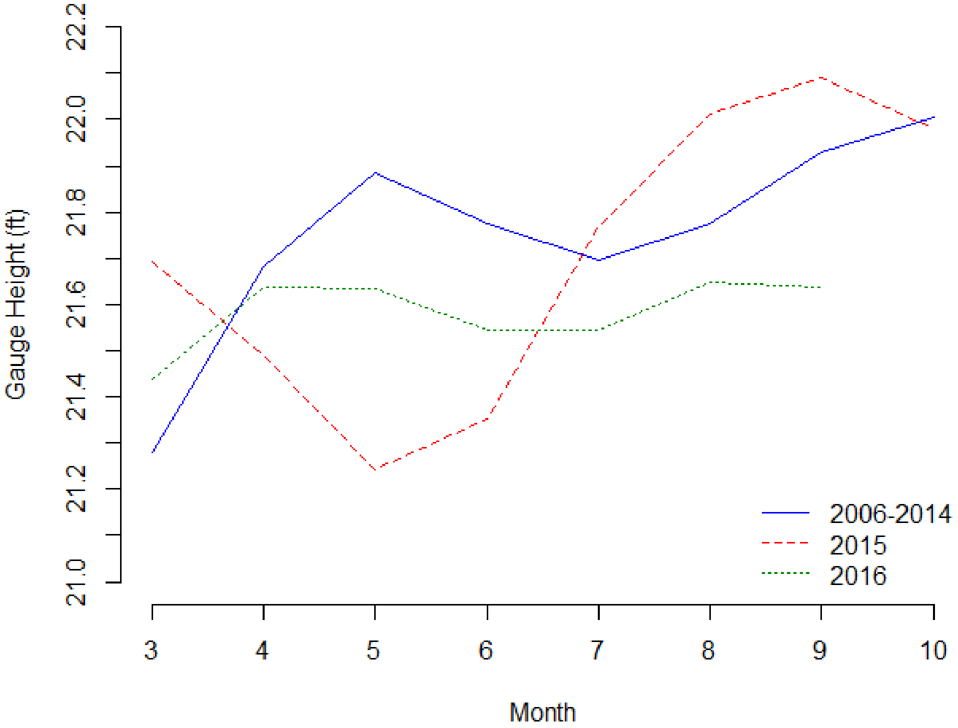

Figure 13: Auke Creek average gauge height by months of operation for 2006-2014, 2015, and 2016.

Habitat

Structural Epifauna – Gulf of Alaska

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Last updated: October 2015

Gulf of Alaska surveys are conducted every other year. See archives for the latest report.

Primary Production

There are no updates to primary production indicators in this year's report, except for the diatom trends in the Continuous Plankton Recorder contribution by Batten (p. 56. See the appendix for a list of indicators not updated, and see the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.php`

Zooplankton

Continuous Plankton Recorder Data from the Northeast Pacific: Lower Trophic Levels in 2015

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Last updated: July 2016

Editor's note: This contribution is presented in its entirety, which includes information about the Bering Sea. The portion focusing on the Bering Sea is also presented in Ecosystem Considerations 2016: Status of the Aleutian Islands Marine Ecosystem.

Description of indicator: Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. Two transects are sampled seasonally, both originating in the Strait of Juan de Fuca. One is sampled monthly (∼Apr-Sept) and terminates in Cook Inlet; the second is sampled 3 times per year and follows a great circle route across the Pacific, terminating in Japan. Several indicators are now routinely derived from the CPR data and updated annually. In this report we update three indices for three regions (Figure 14); large diatoms (the CPR only retains large, hard-shelled phytoplankton so while a large proportion of the community is not sampled, the data are internally consistent and may reveal trends), mesozooplankton biomass (estimated from taxon-specific weights and abundance data) and mean Copepod Community Size (Richardson et al., 2006) as an indicator of community composition. Anomaly time series of each index have been calculated as follows: a monthly mean value (geometric mean) is first calculated. Each sampled month is then compared to the mean of that month and an anomaly calculated

(Log_{10}). The mean anomaly of all sampled months in each year is calculated to give an annual anomaly.

The indices are calculated for three regions; the oceanic North-East Pacific, the Alaskan shelf SE of Cook Inlet, and the deep waters of the southern Bering Sea (Figure 14). The oceanic NE Pacific region has the best temporal sampling resolution as both transects intersect here. This region has been sampled up to 9 times per year with some months sampled twice. The southern Bering Sea is sampled only 3 times per year by the east-west transect while the Alaskan shelf region is sampled 5-6 times per year by the north-south transect. Note that in 2015 the Bering Sea region was only sampled in the fall owing to a ship change in the spring so that the transect was cancelled, and a severe storm in the summer causing the ship to divert south away from the region.

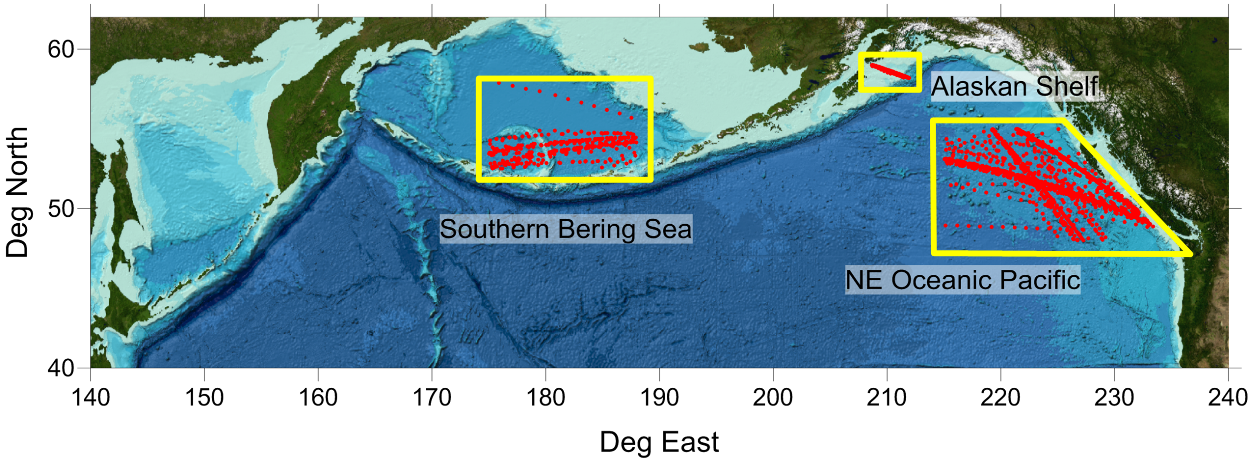

Figure 14: Boundaries of the three regions described in this report. Dots indicate actual sample positions (note that for the Alaskan Shelf region the multiple (>50) transects overlay each other almost entirely).

Status and trends: Ocean conditions in 2015 were warm across much of the north Pacific, with strongly positive values of the Pacific Decadal Oscillation (PDO) through the year, and continued influence from the warm Blob first noted in 2014 (Bond et al., 2015) plus a strong El Niño that developed during the year. The lower trophic level indices showed some similarities to what was reported for 2014, driven largely by the warmth (Figure 15).

Diatom abundance anomalies were higher in 2015 on the Alaskan shelf and the oceanic region than they were in 2014. However, spring abundances were still low, and it was increased abundances later in the year which caused the overall anomalies to be more positive.

The Copepod Community Size index saw negative anomalies for all three regions. While the Alaska Shelf region had seen a bias towards smaller species since 2013, this was the first year since 2010 that the oceanic NE Pacific region had shown a negative anomaly. The Bering Sea data are only represented by the fall sampling but 2015 values were the smallest since 2009 at this time of year.

The mesozooplankton biomass anomalies were neutral in the oceanic NE Pacific region and Bering Sea region. For the Alaskan shelf region the value was quite high and similar to that of 2014, but it was the late summer/fall values that were unusually high with spring and summer values near average.

Factors influencing observed trends: Spring diatom abundances for the Alaskan Shelf and oceanic NE Pacific regions were low, and these communities contained a higher than usual proportion of pennate-type taxa. These taxa generally do better in lower nutrient conditions as their high surface area to volume ratio facilitates nutrient uptake compared to centric taxa. Diatom numbers had increased by the summer and fall, leading to positive anomalies in both regions and suggesting a change in the ocean conditions mid-way through the year.

The negative anomalies for the Copepod Community Size Index are consistent with the warmer water favoring the smaller-bodied species which generally have a more southerly center to their distribution. It is interesting that on the shelf this switch to smaller species occurred in 2013 when the warmth first became apparent, while in the oceanic region it was not until 2015 that the anomaly became negative. Abundance of zooplankton organisms was generally higher than average so that biomass anomalies remained neutral despite smaller organisms.

Implications: Each of these variables is important to the way that ocean climate variability is passed though the phytoplankton to zooplankton and up to higher trophic levels. Changes in community composition (e.g. abundance and composition of large diatoms, prey size as indexed by mean copepod community size) may reflect changes in the nutritional quality of the organism to their predators. Changes in abundance or biomass, together with size, influence availability of prey to predators. For example, while mesozooplankton biomass anomalies remained neutral or positive, the reduced average size of the copepod community suggests that the biomass was packaged into numerous, but smaller, prey items. This may require more work by predators to obtain their nutritional needs.

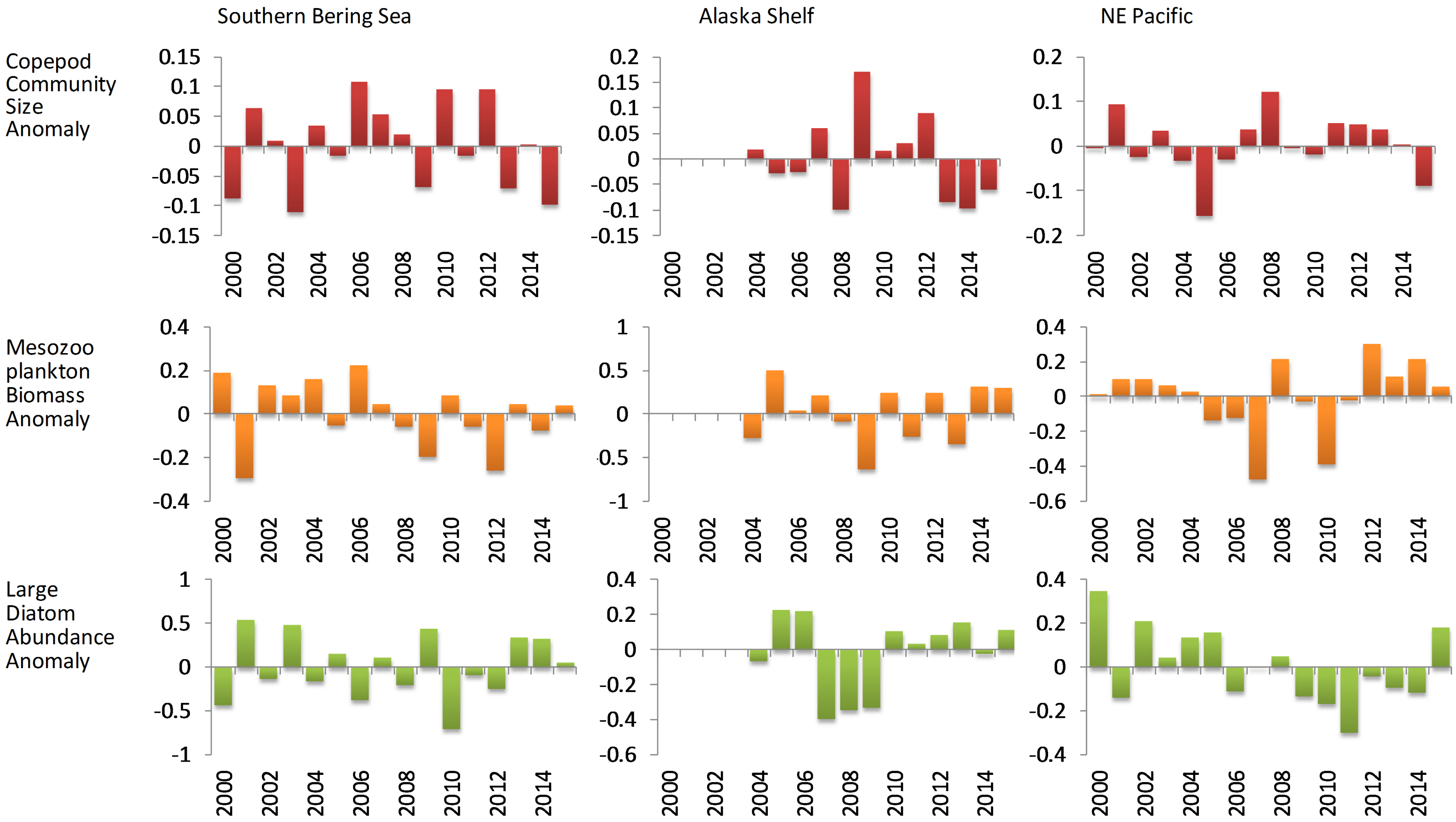

Figure 15: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for each region shown in (Figure 14). Note that sampling of this Alaskan Shelf region did not begin until 2004.

Gulf of Alaska Zooplankton Rapid Assessment Time-Series Hindcast

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Last updated: July 2016

Description of indicator: Zooplankton records from "Line 8" (an area bounded by 57.46-57.73N and 154.675-155.300W) in the Shelikof Strait, Gulf of Alaska were compiled from 1990-2012. 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 2000, 2003, and 2009 along "Line 8". 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 of Ferm (see p. 62). 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. 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 from abundances samples during May was plotted. The month of May has been consistently sampled across all years.

Status and trends: Euphausiid abundance was high during the first two years (1993, 1994) of the data record prior to a decline (Figure 16). Abundance remained similar until a steep drop in 2005. The low abundances of Euphausiids persisted for one more year before increasing in 2007-2008 and then declined in 2010. Large copepod abundance was variable in the early part of the data record, but interestingly declined during the two years that Euphausiid abundance was high. Large copepod abundance rebounded in 1995, but steadily declined each year until the end of the decade. Abundance remained at near 1999 levels until a sharp rise in 2004 with a peak in 2006. Abundance remained high before declining in 2010. Small copepod abundance was always higher than Euphausiid or large copepod abundance. Small copepod abundances were lower in the early 1990s and peaked in the latter half of that decade prior to a sharp decline in 1999. Abundance values rebounded in the early 2000s and remained high with the exception of 2007, when numbers dipped to levels similar to the late 1990s.

Factors influencing observed trends: Zooplankton dynamics in the northern Gulf of Alaska are complicated by a variety of factors, including temperature, currents, and biological factors such as predation and competition (Coyle et al., 2013). Temperature is likely the largest driver of long-term trends in observed abundances in the Gulf of Alaska and is linked to the Pacific Decadal Oscillation (Sousa et al., 2016). Negative phases of the PDO are correlated to colder waters and positive phases are correlated to warmer waters in the northern Gulf of Alaska (Sousa et al., 2016). The PDO had several identified phases during the data record: 1) positive from 1992-1998; 2) negative from 1998-2002; 3) positive from 2002-2007; and 4) negative from 2007-2012. During the initial, positive PDO phase, warmer waters resulted in a decline in Euphausiids, variability among the large copepods, and an increase in the small copepods (Figure 16). Moving forward in time, euphausiids increased during negative PDO phases (colder waters) and declined in positive PDO

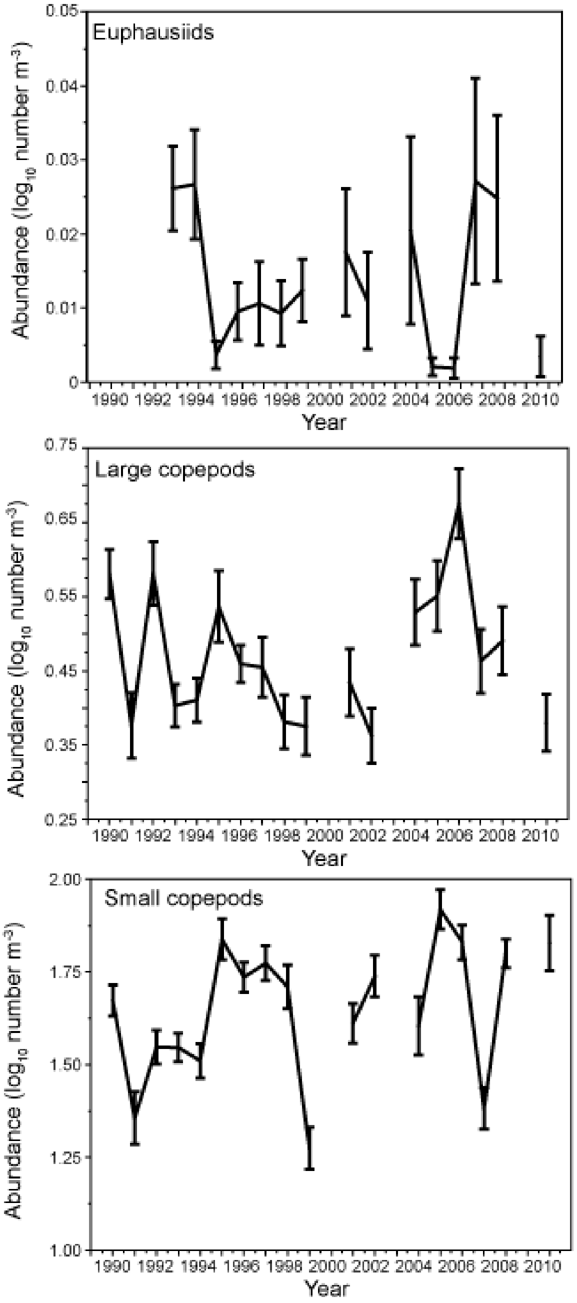

Figure 16: Annual mean abundance (log^{10} abundance (number m^{-3}) of Euphausiids, Large (>2 mm) and Small (<2 mm) copepods at “Line 8”in the Shelikof Strait. Error bars represent standard error of the mean.

phases (warmer waters; Figure 16). Post-1999, large and small copepods appeared synchronous, declining during negative phases (colder waters) and increasing during positive phases (warmer waters). The exception was post-2007 when small copepod abundances remained high.

Implications: Euphausiids and large copepods represent important components of diets for the early life history stages of commercially important fish species. They are rich in storage lipids and are energetically more dense compared to other dietary options, such as the more abundant small copepod species. Declines in the relative abundance of these zooplankton will impact growth and survival of fish. Small copepods also comprise an important fraction of fish diets; however, they are less rich in lipids and may have a lower impact on fish survival to recruitment.

Fall Gulf of Alaska Zooplankton Rapid Assessment

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Last updated: August 2016

Description of indicator: In 2015 EcoFOCI implemented a method for an at sea zooplankton community rapid assessment (ZRA) to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20 / 60 cm oblique bongo tows to 10m off bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories chosen are ecologically important and appear to be highly influenced by cold and warm years. The categories are small copepods, large copepods, and euphausiids. Small copepods are $\leq$2mm total length and include species such as *Pseudocalanus* spp. Large copepods are those greater than 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 (added in fall 2015) were counted from the 503μm 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 505 μm 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. Detailed information on these taxa are provided after in-lab processing protocols have been followed (1+ years post survey).

Status and trends: The fall GOA ZRA was conducted on two surveys during August 9 to September 1, 2015. The assessment was performed at 25 stations; fewer than in spring. The fall survey was dominated by small copepods; this was similar to the spring survey. Pockets of large copepods were present within the deeper Shelikof Straight stations and those off the Kenai Peninsula. The highest proportions of large copepods were located near the eastern edge of Shelikof Straight, with 24.1%, and diminished moving west along Kodiak Island (Figure17). Eight stations had proportions of large copepods near zero. Euphausiid proportions were at or near zero for all stations and chaetognaths were only present at one station. Only five of the gridded stations were sampled in both spring and fall and the change in percent from spring to fall was calculated (Table **??**). On average there was a 4.1% decrease in the proportion of large copepods, an 8.9% increase in small copepods, no change in Euphausiids, and a 7.8% decrease in chaetognaths. Stations D and E showed the largest shift in zooplankton proportions from spring, where small copepods nearly replaced all large copepods and chaetognaths.

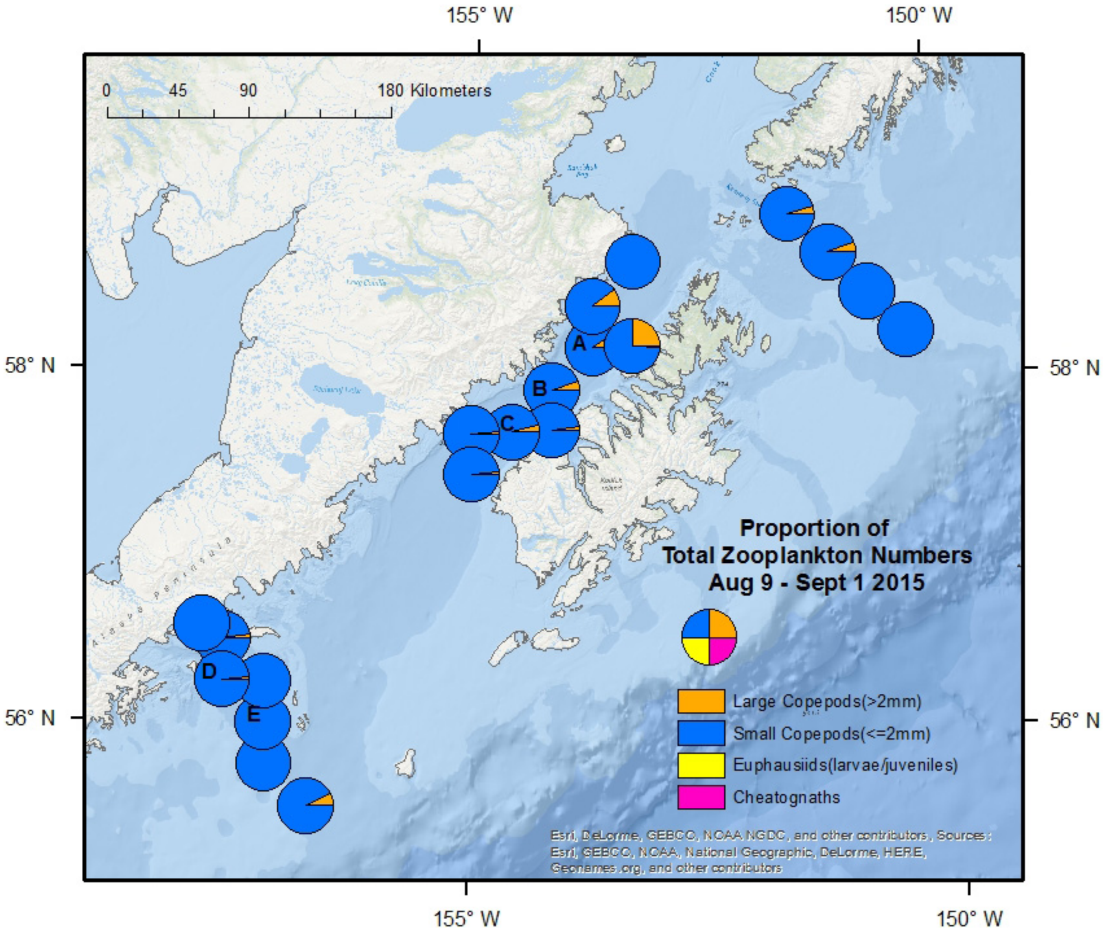

Figure 17: Map of fall ZRA stations. Pie charts at each sampling location show the proportion of four zooplankton categories. Stations labeled A-E are grid stations sampled in both spring and fall. The highest proportions of large copepods are located east of Station A.

Factors influencing observed trends: The shifts in the zooplankton proportions from spring to fall are consistent with seasonal changes in assemblage structure. Certain species of large oceanic copepods such as *Neocalanus flemingeri* and *N. plumchrus* would have been present in the spring but by fall would have moved off the shelf to overwinter, leaving only the neritic species *Calanus marshallae*. Chaetognaths were only present at the station with the largest proportion of large copepods. Chaetognaths predate on large copepods and are possibly following their primary prey off the shelf. The seasonal decrease in the proportion of large copepods and chaetognaths can explain the increase in proportion of small copepods. Large copepods present in the fall were located at deep stations within Shelikof Strait. These are most likely *C. marshallae* which will remain in those locations at depth to overwinter. Higher proportions of large copepods within the deeper stations at the eastern edge of Shelikof Strait might be influenced by nutrients brought in by fall upwelling events (Stabeno et al., 2004). Fall nutrient input can produce phytoplankton blooms prolonging the feeding season of large copepods making them high quality prey for juvenile forage fish.

Implications: One of the major factors that influence survival of juvenile pollock through their

Table 2: The change in proportion from spring to fall within each zooplankton category at the five gridded stations A-E. Shows seasonal change to a small copepod dominated system in the fall.

	A	B	C	D	E	Avg.
Large Copepods	+2.3	-0.6	-0.2	-14.8	-7.4	-4.1
Small Copepods	-2.3	+3.0	+2.4	+32.1	+9.4	+8.9
Euphausiids	+0.1	+0.2	0.0	0.0	0.0	+0.1
Chaetognaths	-6.8	-5.0	-4.0	-15.8	-7.4	-7.8

first winter is fall foraging success. Foraging success depends on the juveniles matching high quality prey locations. By fall, significant portions of the large copepod community have already moved off the shelf to overwinter. Successful juvenile pollock will need to match locations where these large energy rich copepods, most likely *Calanus marshallae*, are located. The GOA ZRA shows there are a few hot spots remaining in fall where successful foraging could occur.

Long-term Zooplankton and Temperature Trends in Icy Strait, Southeast Alaska

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Last updated: August 2016

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

This report presents 2015 annual values of temperature and zooplankton in relation to the long-term trends in Icy Strait. The Icy Strait Temperature Index (ISTI, °C) is the average temperature of the upper 20-m integrated water column. Zooplankton density (number per m^3) was computed from 333-μm bongo net samples ($\leq$200 m depth) (Orsi et al., 2004; Park et al., 2004). Temperature and zooplankton anomalies were computed as deviations from the long-term annual mean values. The temperature and zooplankton measures were used to describe the nearshore environment utilized by many commercially important forage fish in SEAK.

Status and trends: The ISTI shows the annual temperature trend identifying warm and cool years, with 10 years warmer and 9 years cooler than average (9.4 °C, Figure 18). Overall, the ISTIs ranged from 8.3 °C to 10.3 °C, and anomalies did not exceed ±1.1 °C. The ISTI in 2015 was anomalously warm by approximately 0.5 °C relative to the mean of the time series.

The long-term mean zooplankton density ranged from 3,160 to 8,711 organisms per m^3 and compared to the time series, the 2015 total density of zooplankton was anomalously low (Figure 18). Total zooplankton density and temperature show a weak negative correlation. However, this relationship was not significant, and both positive and negative monthly anomalies occurred in warm and cold years ($r = -0.362$, $P = 0.328$).

Overall, the zooplankton community was numerically dominated by calanoid copepods and included small ($\leq$2.5 mm length; $\leq$60% composition) and large species (>2.5 mm; $\leq$22% composition). Three other taxa, important in fish diets (Sturdevant et al. 2012; Fergusson et al. 2013), contributed to the community in small percentages (euphausiids, $\leq$4%; gastropods, $\leq$3%; and hyperiid amphipods, $\leq$1%). For 2015, densities of large and small calanoid copepods and hyperiid amphipods were anomalously low showing a decline from the 2014 densities (Figure 18). Euphausiids were also anomalously low but have been increasing since 2012. Gastropods were the only zooplankton group with an anomalously high density value, the second highest anomaly for gastropods in the time series. In past years, small and large calanoid copepods typically had inverse monthly composition anomalies that indicated differential responses to changes in season and temperature. However, both of these species have shown similar decreases in density, which coincides with the increase in the ISTIs.

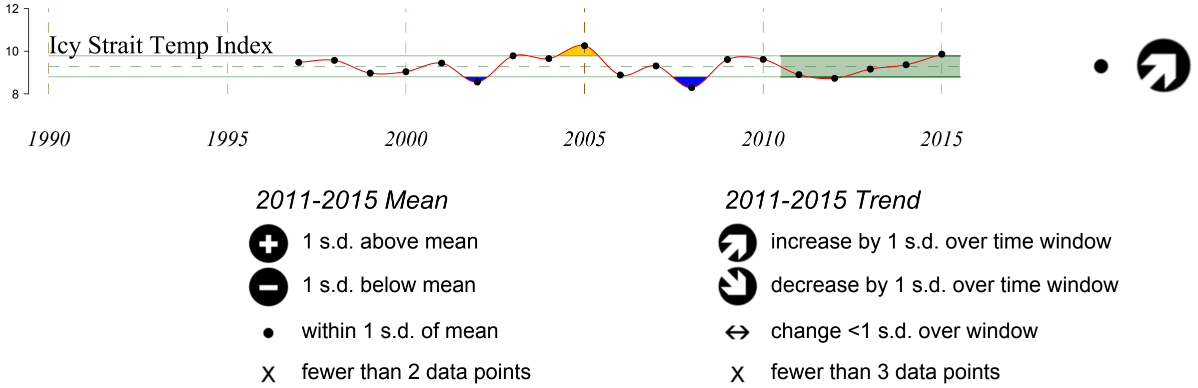

Figure 18: Mean annual Icy Strait Temperature Index (ISTI, °C, 20-m integrated water column, May-August) and 19-year mean ISTI (dashed line), for the northern region of SEAK from the Southeast Coastal Monitoring project time series, 1997-2015

Factors influencing observed trends: Subarctic zooplankton typically follow seasonal cycles of abundance and responses to climate change may be species-specific based on life history, seasonal timing cues, physiology, and environmental parameters other than temperature (Mackas et al., 2012), and these responses could depend on the monthly timing, magnitude, and duration of temperature anomalies in warm or cold years. Therefore, the simple ISTI may not explain shifts in abundance and composition of these prey fields, particularly at broad taxonomic scales. To more accurately reflect critical trophic interactions with respect to climate change, an analysis at the species level would be needed and should include a prey quality measure, such as % lipid.

Implications: Climate change can have broad impacts on key trophic linkages in marine ecosystems by changing relationships of the biophysical environment with seasonal abundance, composition, timing, and utilization of prey (Mackas et al., 2004, 2012; Coyle et al., 2011). Our results suggest that such relationships are currently in flux with the perpetually increasing ISTIs and the evident decline in the density of both large and small copepods. Likewise, the densities of euphausiids are showing an opposite increasing response to the warming temperatures, which could be trophically beneficial for many planktivores. Additionally, shifts in the developmental timing of the zooplankton could lead to mismatched timing of prey fields for planktivorous fish. These indices may help to explain climate-related variation in prey fields for diverse fish communities (Sturde-

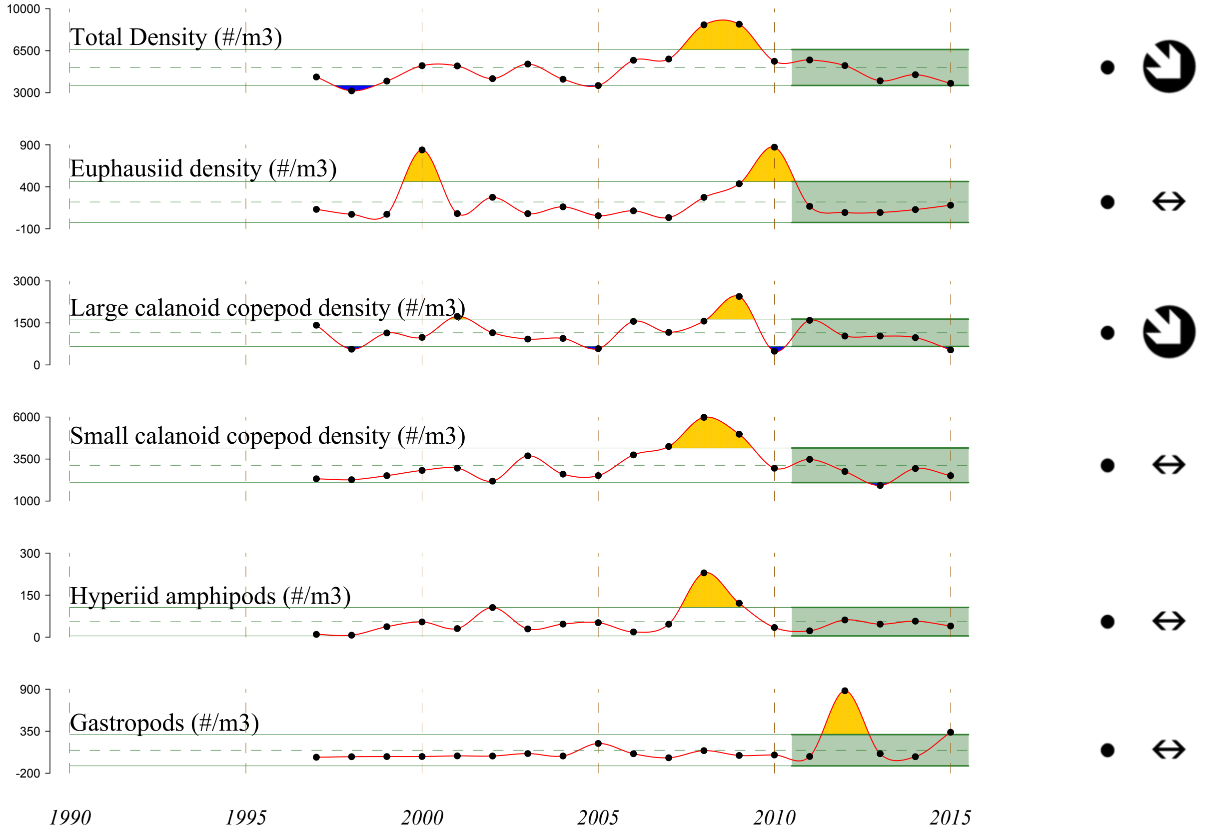

Figure 19: Average annual zooplankton density anomalies for the northern region of SEAK from the Southeast Coastal Monitoring project time series 1997-2015. Annual densities are composed of zooplankton samples collected monthly from May to August in Icy Strait. No samples were available for August 2006 or May 2007.

vant et al., 2012; Fergusson et al., 2013) which may directly or indirectly affect fish production and recruitment (Beamish et al., 2004, 2012; Coyle et al., 2011).

Jellyfish

Jellyfish - Gulf of Alaska Bottom Trawl Survey

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Last updated: October 2015

Gulf of Alaska surveys are conducted every other year. See archives for the latest report.

Trends in Jellyfish and Gelatinous Zooplankton Bycatch from the Gulf of Alaska Project Survey

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Last updated: October 2016

Description of indicator: Jellyfish sampling was incorporated during the Gulf of Alaska Project starting in 2011 and continued through 2016. All jellyfish medusae caught in the surface trawl (top 18-20 m of the water column) were sorted by species and subsampled for bell diameter and wet weight. Eight species are commonly caught with the surface trawl (Can-trawl net with a 1.2 cm mesh liner in the cod-end) in the eastern Gulf of Alaska (GOA): *Aequorea* sp., *Chrysaora* spp., *Cyanea capillata*, *Aurelia labiata*, *Phacellocephora camtschatica*, *Hormiphora* sp., *Staurophora mertensi* and *Salpa* spp. Biomass was calculated for each species and compared across genus.

Status and trends: The biomass in 2014 was the largest for the five years of collected jellyfish catch data (Figure 20). This significant increase was consistent with the southeastern Bering Sea in 2014 which documented the largest catches on record for the Bering Aleutian Salmon International Surveys (BASIS) surveys (see Ecosystem Considerations for the Eastern Bering Sea report). *Aequorea* and *Chrysaora* are the top two genera in terms of catch and abundance observed in the eastern GOA for the five years of data (Figure 21). In 2015 *Aequorea* sp. was still one of the highest recorded in terms of catch where as *Chrysaora* spp. was recorded at its lowest levels since sampling began 5 years ago. One striking difference with the GOA survey data is the diversity in species seen versus the Bering BASIS surveys which have been single species dominant by *Chrysaora melanaster* for almost a decade.

Factors influencing observed trends: Factors causing changes in biomass, abundance and distributions are largely unknown. Little information has been documented on trends in macro jellyfish in general in the GOA.

Implications: Significant increases in jellyfish biomass may redirect energy pathways, causing disruption to eastern Gulf of Alaska foodwebs by increased jellyfish predation pressure on zooplankton and larval fish, which could result in limiting carbon transfer to higher trophic levels (Condon et al., 2011).

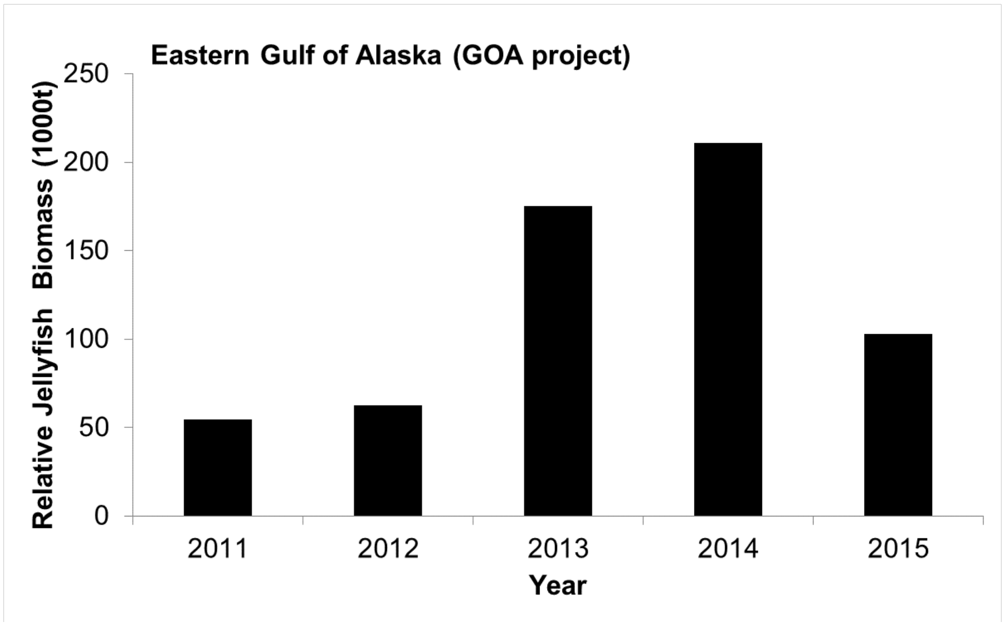

Figure 20: Total annual jellyfish biomass (1000 t) for eastern Gulf of Alaska region. Includes combined species caught in surface trawls in the Gulf of Alaska during June-August. Biomass was calculated using average effort per survey area by year.

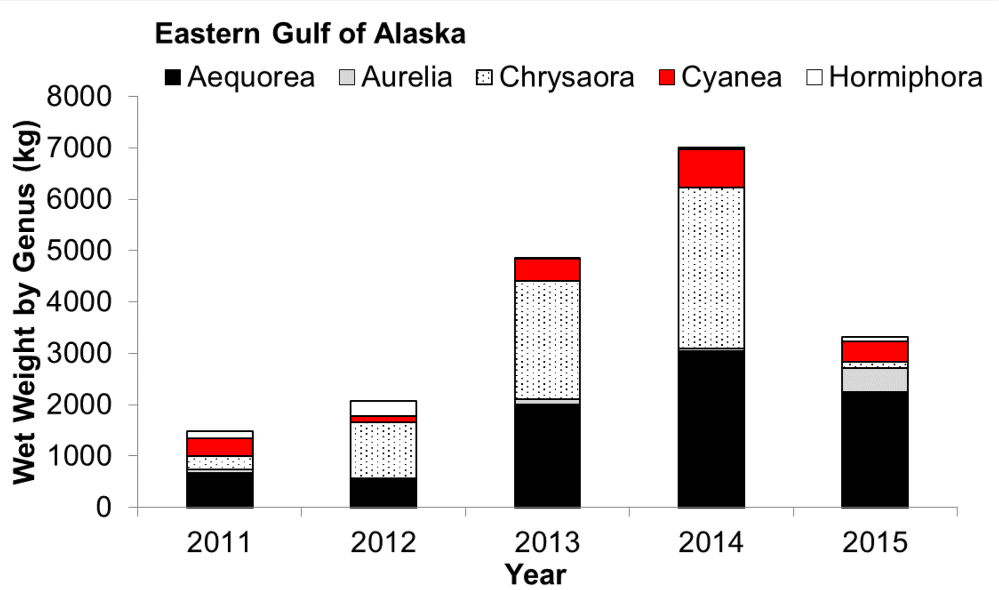

Figure 21: The Gulf of Alaska Project total surface trawl catch (wet weight) by genus for 2011-2016 during July-August. Chosen genus was based on the top four most encountered species during the survey

Ichthyplankton

Gulf of Alaska Ichthyoplankton Abundance Indices 1981-2015

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Last updated: August 2016

Description of indicator: The Alaska Fisheries Science Centers (AFSC) Ecosystems and Fisheries Oceanography Coordinated Investigations Program (EcoFOCI) has been sampling ichthyoplankton in the Gulf of Alaska (GOA) from 1972 to the present, with annual sampling from 1981-2011 and biennial sampling thereafter. The primary sampling gear used for these collections is a 60-cm bongo sampler fitted with 333 or 505-μm mesh nets. Oblique tows are carried out mostly from 100 m depth to the surface or from 10 m off bottom in shallower water (Matarese et al., 2003, Ichthyoplankton Information System `http://access.afsc.noaa.gov/ichthyo/index.php`). Historical distribution of sampling effort extends from the coastal area to the east of Prince William Sound southwestward along the Alaska Peninsula to Umnak Island, covering coastal, shelf and adjacent deep water, but has been most intense in the vicinity of Shelikof Strait and Sea Valley during mid-May through early June (Figure 22). From this area and time, a subset of data has been developed into time-series of ichthyoplankton species abundance (after Doyle et al., 2009)) for the 12 most abundant larval taxa in the GOA, including commercially and ecologically important species (Figure 23).

Status and trends: In relation to the previous three decades of observations, 2015 was an anomalous year for most species. For walleye pollock, larval abundance was the lowest ever observed, following a very high positive anomaly in 2013. Pacific cod, flathead sole, northern rock sole, and Pacific sand lance also had record low abundances in 2015, and starry flounder and Pacific halibut showed strong negative anomalies. Only two taxa showed positive anomalies in 2015: northern lampfish and rockfish. Rockfish, which are not identified to species, continued their steep upward trend, which started in 2007 and accelerated in 2011 and 2013.

Factors influencing observed trends: The warm "Blob" in the Gulf of Alaska in 2014 and 2015 appears to have had wide-ranging consequences for the marine ecosystem (Zador, 2015). Our data suggest that the anomalous warm conditions corresponded to extreme low abundances of larvae for many species, although the mechanism underlying such a response is still being investigated. Possibilities include a mismatch of prey availability with the period of larval first-feeding, low quality prey resources, advection of larvae out of preferred shelf habitats, or thermal stress. Investigation into these mechanisms is continuing.

Previous work has explored trends in abundance of these species in relation to atmospheric and oceanographic conditions on both the ocean basin and local scales (Doyle et al., 2009; Doyle and Mier, 2012). Similarities in response to environmental forcing were apparent among species that display similarities in patterns of early life history exposure to the environment (Doyle et al., 2009). For instance, years of high abundance for the late winter to early spring shelf spawners Pacific cod, walleye pollock, and northern rock sole were associated with cooler winters and enhanced alongshore

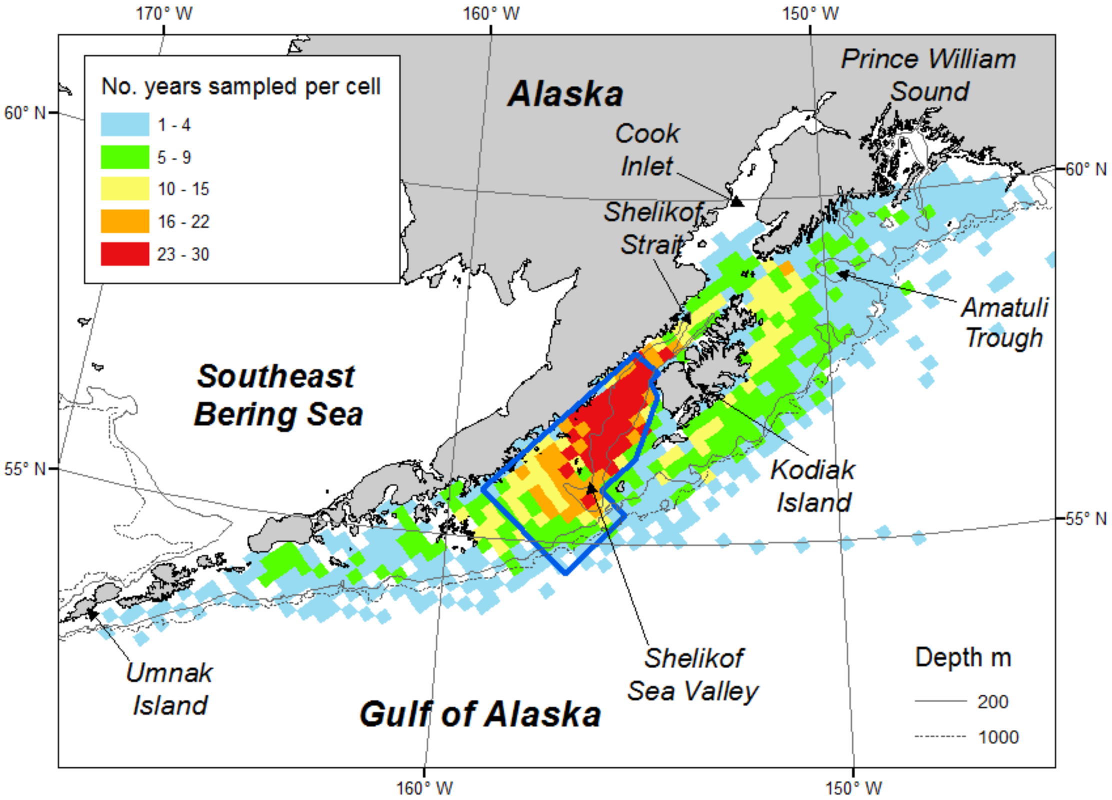

Figure 22: Distribution of historical ichthyoplankton sampling in the Gulf of Alaska by NOAA's Alaska Fisheries Science Center using a 60 cm frame bongo net. Sampling effort is illustrated by the number of years where sampling occurred in each 20km^2 grid cell over these years. A late spring time-series of mean abundance of ichthyoplankton species has been developed for the years 1981-2015, from collections in the polygonal area outlined in blue where sampling has been most consistent during mid-May through early June.

winds during spring. High larval abundance for spring-summer spawning rockfish species and southern rock sole seemed to be favored by warmer spring temperatures later in the time-series. Observations in 2015 continued to support these patterns of common responses for species with similar early life history exposure, as well as generally low abundance for those species favored by cooler conditions and high abundance for those favored by warm conditions.

Implications: If the abundance patterns hold, our data suggest a wide-spread recruitment failure for walleye pollock, Pacific cod, and other commercially important species in 2015, with implications for fisheries, as well as foraging opportunities for seabirds and marine mammals. Subsequent surveys have confirmed a small 2015 year class for walleye pollock (Wilson 2015; Ressler preliminary results). Icthyoplankton surveys can provide early-warning indicators for ecosystem conditions and recruitment patterns in marine fishes. While mortality during later life stages is clearly important, poor conditions during the first few weeks and months of life can already determine the potential for a large year class, emphasizing the importance of studying processes affecting mortality and abundance of early life history stages.

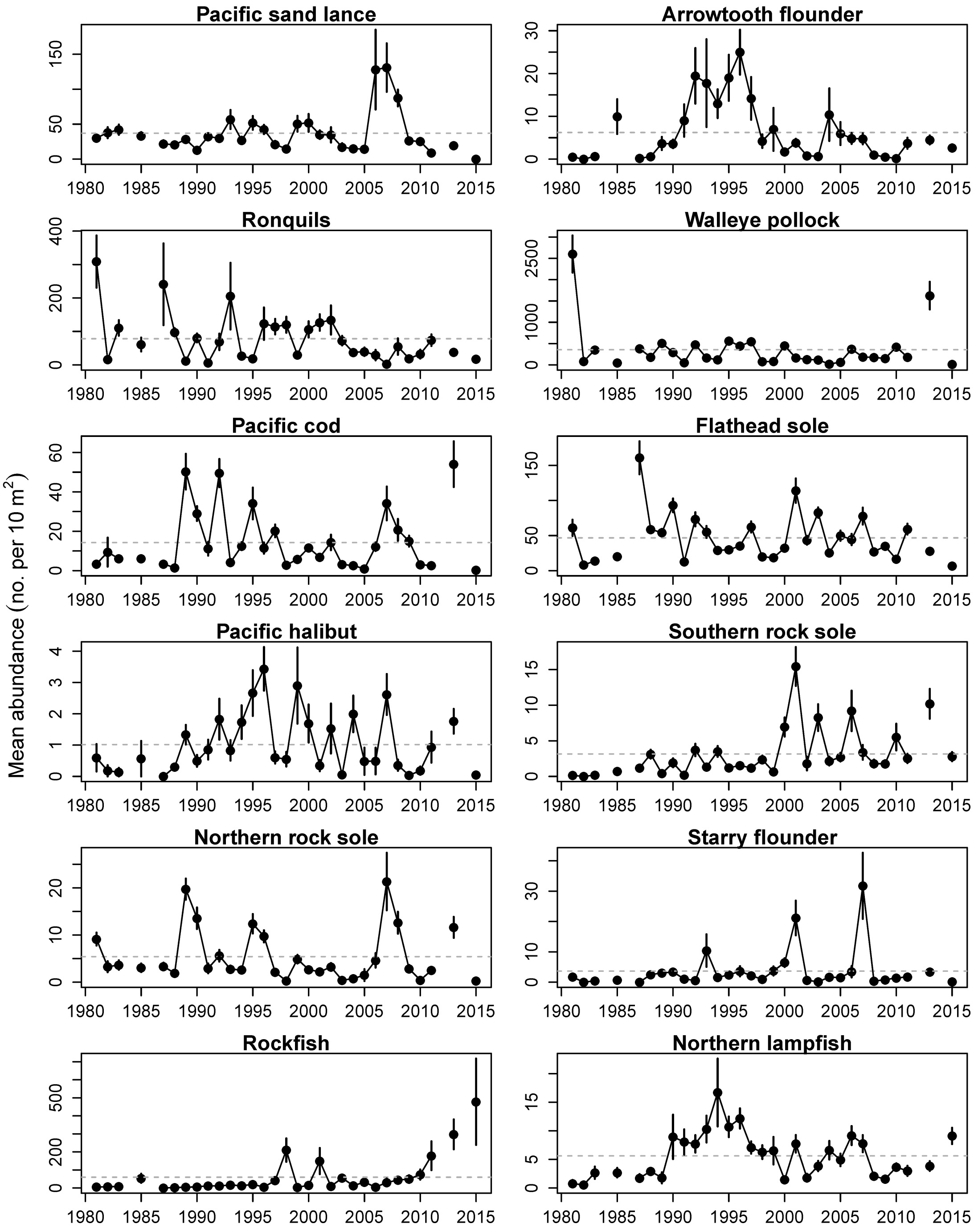

Figure 23: Interannual variation in late spring larval fish abundance in the Gulf of Alaska. The larval abundance index is expressed as the mean abundance (no. 10 m^{-2}), and the long-term mean is indicated by the dashed line. Error bars show ± 1 SE. No data are available for 1984, 1986, 2012, or 2014.

Forage Fish

Capelin and Sand Lance Indicators for the Gulf of Alaska

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Description of indicator: We produced indices representing temporal trends in abundance of capelin (*Mallotus villosus*) and sand lance (*Ammodytes personatus*) based on prey composition of various piscivorous seabird and groundfish species in the Gulf of Alaska. We considered that the seabirds and groundfish were "samplers" of the forage fish community, and that common trends among predators with varying foraging strategies would reflect true trends in relative abundance. Time series of capelin and sand lance data from each type of sampler were analyzed using dynamic factor analysis (DFA). DFA is similar to a PCA in that it reduces multiple datasets into fewer common trends, but is designed for time series data. The resulting factors in the best fit models for each forage fish species were considered to represent common trends in relative forage fish abundance. The forage fish data are from seabird chick diets collected at breeding colonies during summer and from groundfish stomach contents collected biennially during summer bottom-trawl surveys. The data include the percent diet composition from tufted puffins (*Fratercula cirrhata*) and common murres (*Uria aalge*) at East Amatuli Island, Alaska (USFWS), the relative occurrence during June August in black-legged kittiwakes (*Rissa tridactyla*) and percent biomass from rhinocerous auklets (*Cerorhinca monocerata*) at Middleton Island (ISRC), and the number of capelin or sand lance per length of groundfish (year range; AFSC). The groundfish species included arrowtooth flounder (*Atherestes stomias*), Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), and walleye pollock (*Gadus chalcogrammus*).

All data were standardized to a mean of zero and standard deviation of 1. The best model was determined by the lowest AICc value (Zuur et al., 2003) among models with variable R-matrix formats and number of common (hidden) trends. Variables which loaded strongly onto the trend (absolute values over 0.2) were considered to be influential. To detect possible regime shifts, a sequential F-test was conducted on the DFA trend of the best model using SRSD software (Rodionov, 2015). The target significance level was set to 0.05, the proposed regime length of 15 years, and a Huber weight parameter equal to 6. The IP4 method for red-noise estimation was selected, with a subsample length set to 5 years.

Status and trends: The best model for the capelin time series had an R-matrix structure of same variances and same covariances, and with one trend (Table 3). The best model for the sand lance time series had an R-matrix with different variances and covariances, and with one trend (Table 4). This model was substantially better than the next best model, as seen by the large difference between the delta.AICc values.

The trend produced by the DFA for capelin was at a minimum around 2005 and a maximum around 2010. Shortly after 2010 the trend decreases until the end of the time series (Figure 24). Four of the variables load strongly and positively onto the trend produced by the DFA. These include rhinoceros auklets, Pacific cod, black-legged kittiwake, and Pacific halibut. The sequential F-test detected a regime shift in the positive direction in the year 2008.

The trend produced by the DFA for sand lance drops greatly in the early 1990s, recovering by the end of the decade, and then consistently decreasing for the remainder of the time series (Figure 25). Five of the eight time series loaded strongly (loading>0.2) onto the trend. These time series included tufted puffins, rhinoceros auklets, black-legged kittiwakes, arrowtooth flounder, and Pacific

Table 3: AICc values for models with variations in the R-matrix and number of hidden trends for capelin.

R	m	logLik	delta.AICc	Ak.wt.SB	Ak.wt.SB.cum
equalvarcov	1	-168.0507	0	0.7979	0.7979
diagonal and equal	1	-170.8806	3.31986	0.1517	0.9497
diagonal and unequal	1	-163.3875	5.56003	0.0495	0.9992
equalvarcov	2	-166.2540	13.92497	0.0008	0.9999
diagonal and unequal	2	-160.9362	20.09618	3.45E-05	1
diagonal and equal	2	-170.7081	20.20115	3.28E-05	1
equalvarcov	3	-167.3520	32.92766	5.65E-08	1
diagonal and equal	3	-170.1280	35.55139	1.52E-08	1
unconstrained	1	-131.7202	38.53570	3.42E-09	1
diagonal and unequal	3	-160.8011	38.59077	3.33E-09	1
equalvarcov	4	-167.3519	48.41455	2.45E-11	1
diagonal and equal	4	-170.1280	50.75138	7.61E-12	1
diagonal and unequal	4	-161.6044	57.58973	2.49E-13	1
equalvarcov	5	-167.3519	61.91917	2.86E-14	1
diagonal and equal	5	-170.1280	63.99495	1.01E-14	1
unconstrained	2	-128.4043	66.38531	3.07E-15	1
diagonal and unequal	5	-161.9013	73.42991	9.05E-17	1
unconstrained	3	-135.4893	115.23394	7.57E-26	1
unconstrained	4	-131.3803	140.45600	2.53E-31	1
unconstrained	5	-144.9810	198.05727	7.84E-44	1

halibut. The sequential F-test also detected a regime shift in a negative direction in 2008.

Factors influencing observed trends: Hatch (2013) suggested that a regime shift from predominantly warm conditions to cold conditions occurred in 2008, resulting in changes in diet and productivity of kittiwakes at Middleton Island. We use the same kittiwake diet data in this analysis, with the addition of years 2012-1015. Thus, the timing of this regime shift is further corroborated by the inclusion of data from other seabirds and groundfish, with varying foraging strategies and collected over a broad scale in the western Gulf of Alaska. Both capelin and sand lance DFAs selected a single trend as the best model, supporting the notion that these trends represents overall abundance trends as experienced by the different "samplers". Hatch (2013) detected positive correlations between the summer PDO (Jun-Aug) and capelin in kittiwake diets and chick production, and posited that a continuation of the ∼60 year ocean and atmospheric conditions after 2008 would be favorable for kittiwakes. Water column temperatures as recorded during NOAAs bottom trawl survey showed cooler conditions from 2007–2013. The appearance of anomalously warm water, the Blob, in 2014 and continuation through 2015 ended this cold period. Capelin abundance appears to have responded negatively to this shift to warm conditions, as expected. In addition the PAPA Trajectory Index (this doc, p. 50), which showed predominantly northerly flow following the 1977 regime shift through the mid-2000s, appears to show a shift to more southerly flow from the mid-2000s to about 2014. This short period of southerly flow coincides with the recent period of cold temperatures, and indicates the potential for a return to mid-1970s to mid-2000s conditions, with increased transport and/or a northerly shift in the Alaska Current.

Implications: Combining data from multiple, imperfect types of forage fish samplers is a promising

Table 4: AICc values for models with variations in the R-matrix and number of hidden trends for sand lance.

R	m	logLik	delta.AICc	Ak.wt.SB	Ak.wt.SB.cum
unconstrained	1	-91.3833	0	0.997917	0.9979
diagonal and unequal	1	-145.7807	12.4845	0.001941	0.9999
diagonal and unequal	2	-139.3097	18.9814	7.54E-05	0.9999
equalvarcov	1	-157.0866	20.2100	4.08E-05	1
diagonal and equal	1	-158.7713	21.2395	2.44E-05	1
equalvarcov	2	-152.1467	27.8486	8.95E-07	1
diagonal and equal	2	-154.4577	29.8385	3.31E-07	1
equalvarcov	3	-147.9192	36.2004	1.37E-08	1
diagonal and unequal	3	-139.0844	37.2954	7.95E-09	1
diagonal and equal	3	-150.7833	39.0000	3.39E-09	1
unconstrained	2	-95.6127	42.9403	4.73E-10	1
diagonal and equal	4	-146.8889	46.4112	8.34E-11	1
equalvarcov	4	-146.1278	48.1045	3.58E-11	1
equalvarcov	5	-143.7312	56.8159	4.59E-13	1
diagonal and equal	5	-147.1088	60.0946	8.91E-14	1
diagonal and unequal	4	-143.0189	62.5570	2.60E-14	1
diagonal and unequal	5	-138.5866	68.9386	1.07E-15	1
unconstrained	3	-101.7889	89.9714	2.90E-20	1
unconstrained	5	-91.3434	132.9202	1.37E-29	1
unconstrained	4	-108.9503	137.7341	1.23E-30	1

way to determine trends in ecologically-important, yet difficult to monitor forage fish. The DFAs can be expanded to include net and acoustic sampling data and further, alternative samplers. The trends detected here for capelin and sandlance indicate that capelin increased during a recent period of cold conditions from 2007-2013 and that sandlance appear to be at long term low. Current low trends in both forage fish suggest lower availability of these species to a variety of forage fish predators.

Herring

Southeastern Alaska Herring

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Last updated: August 2016

Description of indicator: Pacific herring (*Clupea pallasi*) populations in southeastern Alaska are monitored by the Alaska Department of Fish and Game, primarily through stock assessments that combine spawn indices with age and size information have been conducted annually for nine spawning areas in southeastern Alaska for most years since 1980. The magnitude and regularity

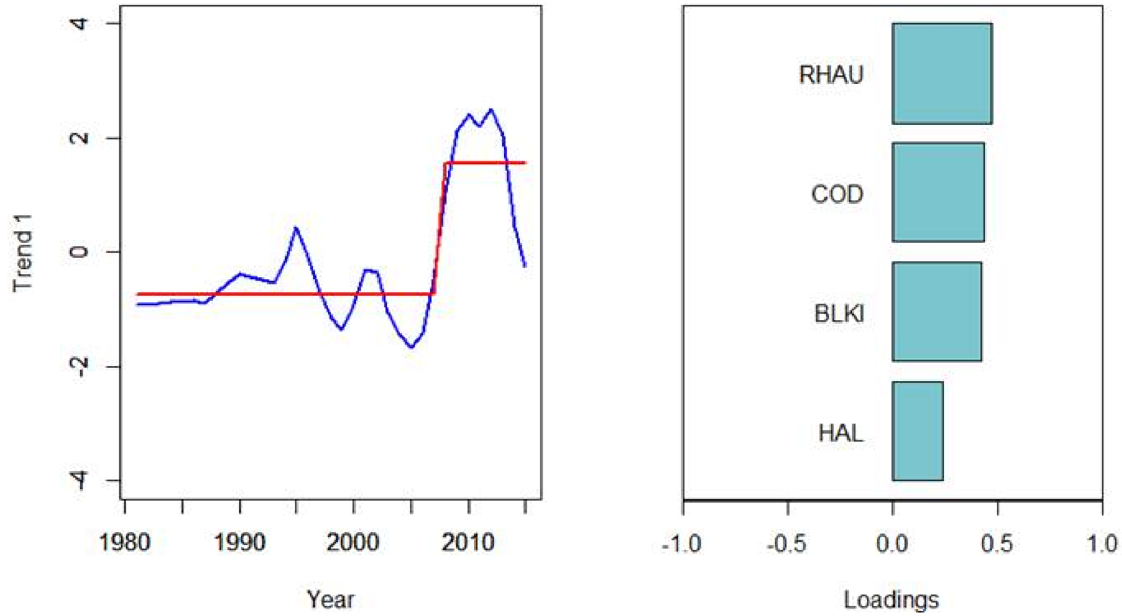

Figure 24: Capelin trend output is shown on the left plot and time series with a loading absolute value over 0.2 is depicted in the plot to the right. The red line on the left plot indicated the regime shift time series results.

of spawning in these areas has chiefly determined whether stock assessment surveys, and thus potential commercial harvest opportunity, at these locations have been warrented during the last 30 years. Although spawning occurs at other locales throughout southeastern Alaska, little or no stock assessment activity occurs at these locations other than occassional and opportunistic aerial surveys to document the miles of spawn along shoreline. Spawning at the nine primary sites for which regular assessments are conducted probably accounts for the majority of the spawning biomass in southeastern Alaska in any given year.

Status and trends: Herring spawning biomass estimates among spawning areas in southeastern Alaska often change markedly from year to year, rarely exhibiting consistent, monotonic trends. Over the period 1980 through 2015, some stocks have generally undergone increasing trends (Sitka Sound, Craig, Seymour Canal, Hoonah Sound), while others have declined (Kah Shakes/Cat Island, Lynn Canal not shown in figures), and yet others have exhibited no obvious trend (West Behm Canal, Hobart Bay/Port Houghton, Tenakee Inlet, Ernest Sound).

Although the estimated total mature herring biomass in southeastern Alaska has been at or above the long-term (1980-2015)median of 92,595 tons since 2002 (2015 total is 93,910 tons), a decrease in biomass has been observed since peaking around 2011 (Figure 26). The most dramatic drop in biomass has been observed in Hoonah Sound where the mature biomass dropped from 14,664 tons to 412 tons over a two year period, and continues to be at a very low level. It is apparent that the herring population in southeastern Alaska has come down from a period of higher productivity during about 2005-2011, with mature biomass in the region showing a downward tradjectory from 2011 through 2015 (Figure 26). The herring biomass in Sitka Sound continues to be by far the highest in the region. Since 1980, herring biomass near Sitka has contributed between 37% and 72% (median of 58%) of the total estimated annual mature biomass among the nine surveyed spawning locations, and represented 71% of the 2015 estimated total southeastern Alaska mature biomass.

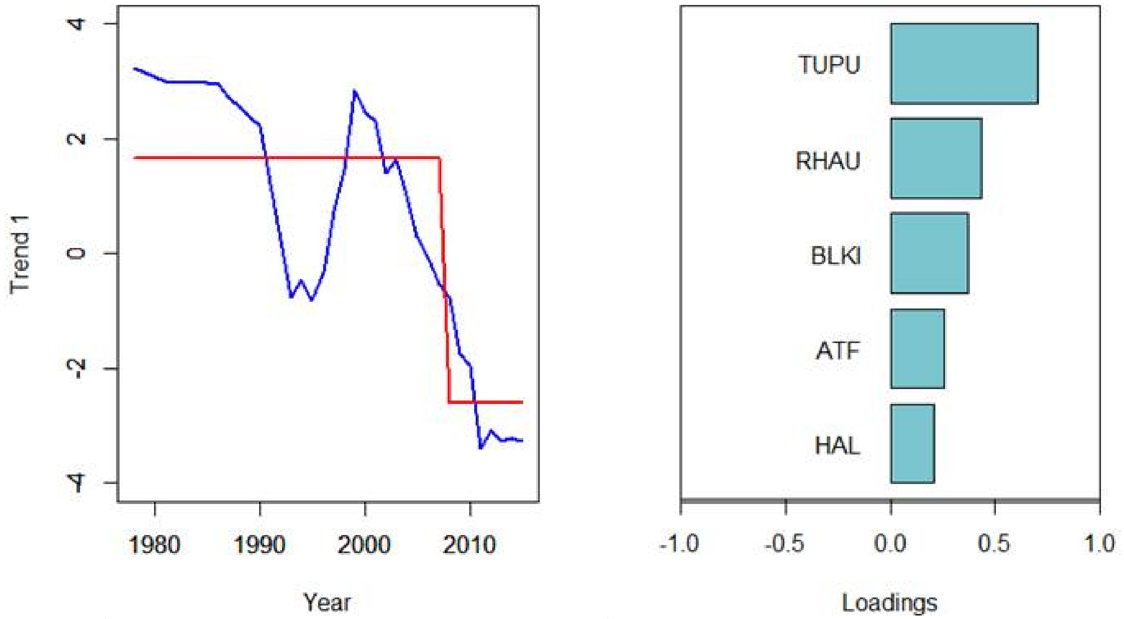

Figure 25: Sand lance trend output is shown on the left plot and time series with an absolute loadings value over 0.2 is shown in the plot to the right. The red line on the left plot indicates the regime shift time series results.

Excluding the Sitka biomass, the southeastern Alaska herring biomass in 2015 was estimated to be below the median (40,997 tons over 1980-2015) for the second year in a row (Figure 26).

Factors influencing observed trends: The generally increasing long-term trends of biomass observed for many herring stocks in southeastern Alaska, particularly over the last decade, are thought to be at least partially a result of higher survival rates among adult age classes. Age-structure analysis (ASA) modeling of several herring stocks in the region suggests that changes in survival during the late 1990s are partially responsible for the observed increasing and high herring abundance levels. For example, for the Sitka stock, during the period 1980-1998, survival has been estimated to be 58%, while for the period 1999-2015 survival is estimated at 76%. These shifts in survival coincide with time periods of change in ocean conditions, as indexed by the Pacific Decadal Oscillation (PDO) (predominately positive phase in the former and predominantly negative phase during the latter time periods).

There has been some speculation about the extent to which commercial harvests may have contributed to marked declines in estimated abundance and/or localized changes in herring spawning sites in some areas of southeastern Alaska, notably Revillagigedo Channel (Kah Shakes/Cat Island), located in the southernmost part of southeastern Alaska, and Lynn Canal, located in the northernmost part of southeastern Alaska. In the Revillagigedo Channel area, significant spawning and fisheries have occurred at Annette Island Reserve, a site outside the management jurisdiction of the State of Alaska and from which limited data are gathered by the department. Although spawning activity at the Kah Shakes and Cat Island sites (also within the Revillagigedo Channel area) has declined within the last decade, this decline may be at least partially attributable to a shift of herring spawning grounds to within the Annette Island Reserve. In 2015, a substantial increase in spawning was documented in state waters, and a substantial decrease in spawning was

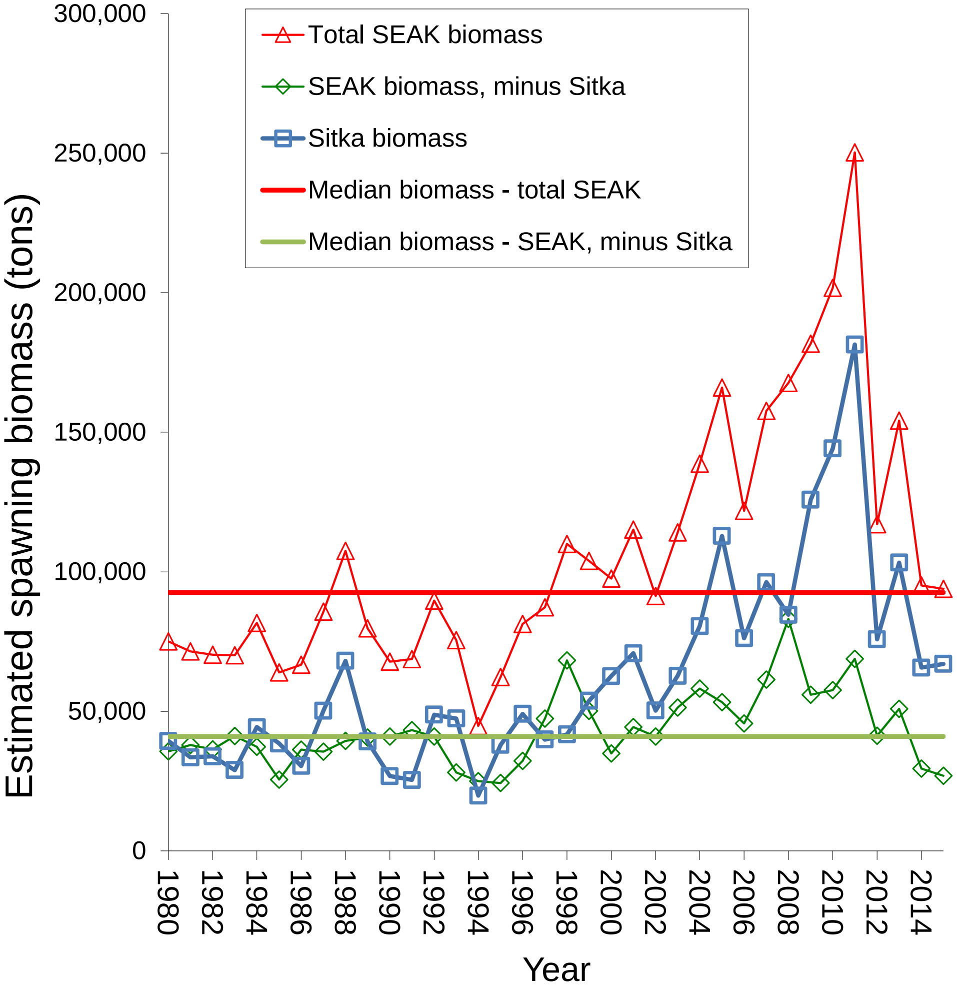

Figure 26: Estimated combined annual mature herring biomass (including and excluding Sitka) at major southeastern Alaska (SEAK) spawning areas, 1980-2015.

observed in Annette Island waters, suggesting another shift in herring spawning grounds. In the Lynn Canal area, the herring spawning population collapsed in the early 1980s, and has been at a low level for most years since. However, in the most recent decade there have been indications of increasing spawning biomass, although consistent surveys of spawning biomass have only been conducted in recent years. Reasons for the population decline in this area are unknown but possibilities include commercial harvest, increased predation by marine mammals and fish, and shoreline development on or near spawning grounds.

Implications: The harvest rate policy in southeastern Alaska allows for harvest rates ranging from 10 to 20% of the forecasted spawning biomass when the forecast is above a minimum threshold biomass. The rate of harvest depends upon the ratio of forecast to threshold (the more the forecast exceeds the threshold, the higher the harvest rate). Consequently, catch limits have varied in direct proportion to forecasted biomass. The lower abundance of mature herring observed at some spawning areas will likely reduce commercial harvest opportunity in the region due to lower guideline harvest levels. However, the short life-span of herring and the natural volatility of stock levels, particularly of smaller-sized stocks, make it difficult to speculate on long-term fishery implications. The relationship between PDO phase and herring survival suggests that survival may decline if the PDO shifts to a positive (i.e. warm) phase, however this is an area that requires further research.

Salmon

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 Gulf of Alaska, and takes a closer look at a stock that could be informative from an ecosystem perspective, Prince William Sound pink 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; they are sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*).

Status and trends: *Statewide* Catches from directed fisheries on the five salmon species have fluctuated over the last 35-40 years (Figure 27), 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.

Gulf of Alaska In the Southeast/Yakutat region, 2015 salmon harvests totaled 50.6 million, which was 92% of the recent 10-year average harvest and 124% of the long-term average harvest. Pink salmon comprised 69% of the total number of salmon harvested in 2015. Since 2006 pink salmon returns have followed a cycle of strong odd years and weak even years and that pattern continued in 2015; however, the 2015 pink salmon return is the lowest odd-year return since 1997.

In the Southeast/Yakutat region, the harvest of Chinook salmon and sockeye salmon were both above their long-term average harvests and recent 10-year average harvests. The coho salmon harvest of 2.1 million was less than both the long-term average harvest and the recent 10-year average. In contrast, the harvest of 11.5 million chum salmon in the Southeast/Yakutat region was 115% the recent 10-year average harvest and 199% the long-term average.

In the Kodiak management area the 2015 sockeye salmon commercial harvest was below forecast but was 141% the recent 10-year average. The 2015 pink salmon harvest was well above the 10-year

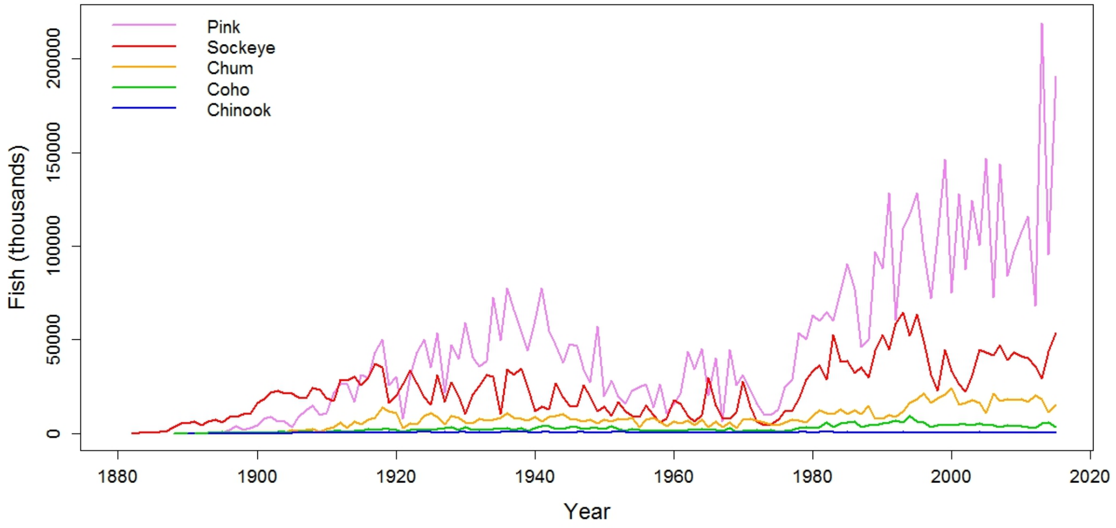

Figure 27: Alaska historical commercial salmon catches, 2016 values are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.)

average harvest and was the third largest ever in the Kodiak management area.

In the Prince William Sound Area of the Central region, the 2015 total commercial salmon harvest was 103.47 million fish, of which 97.32 million were pink salmon. The commercial common property fishery harvest of 90.1 million pink salmon is the largest Prince William Sound pink salmon harvest recorded (Figure 28). The catch of other salmon species in the Prince William Sound Area included 3.39 million sockeye, 2.51 million chum, 227,000 coho, and 23,400 Chinook. Historically, pink salmon catches increased in the late 1970s to the mid-1990s and have generally remained high in all regions in the last decade (Figure 27).

Factors influencing observed trends: Pink salmon is the most abundant Pacific salmonid species. While both natural and hatchery populations return to Prince William Sound, a large majority of the returning fish are hatchery fish, upwards of up to one half billion are released from four hatcheries (Kline et al., 2008). Pink salmon have an abbreviated life cycle, consisting of three phases 1) brood year, 2) early marine year, and 3) return year (Kline et al., 2008).

Pink salmon run strength is established during early marine residence and may be influenced by diet and food availability (Cooney and Willette 1997). Survival rates of Alaska pink salmon are positively related to sea surface temperatures and may reflect increased availability of zooplankton prey during periods with warmer surface temperatures (Mueter et al., 2002).

Implications: Salmon have important influences on Alaska marine ecosystems through interactions with marine food webs as predators on lower trophic levels and as prey for other species such as Steller sea lions. In years of great abundance, salmon may exploit prey resources more efficiently than their competitors, affecting the body condition, growth, and survival of competitors (Ruggerone et al., 2003; Toge et al., 2011; Kaga et al., 2013). A negative relationship between seabird reproductive success and years of high pink salmon abundance has recently been demonstrated Springer and van Vliet (2014). Directed salmon fisheries are economically important for the state

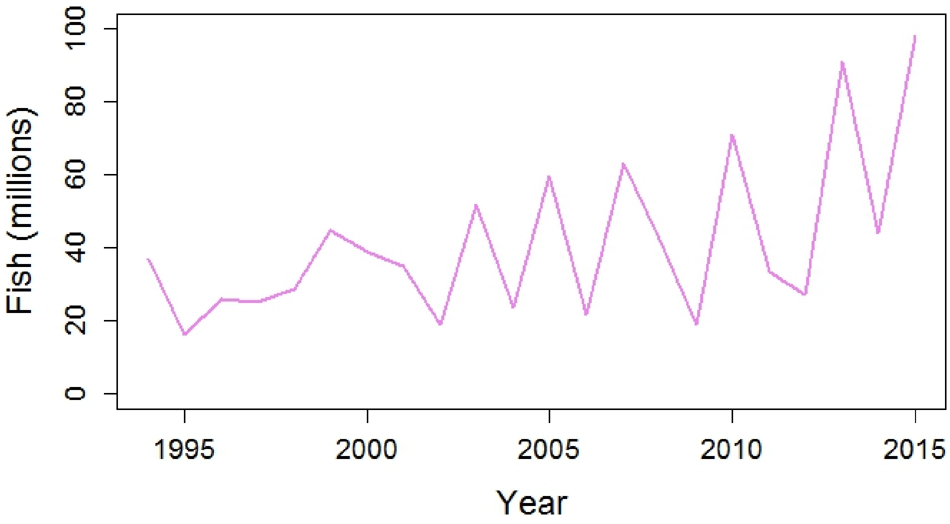

Figure 28: The Prince William Sound commercial harvest of pink salmon from 1994 through 2015. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.

of Alaska. The trend in total salmon catch in recent decades has been for generally strong harvests, despite annual fluctuations.

Marine Survival Index for Pink Salmon from Auke Creek, Southeast Alaska

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Last updated: September 2016

Description of indicator: The time series of marine survival estimates for wild Pink salmon from the Auke Creek Research Station in Southeast Alaska is the longest-running continuous series available in the North Pacific. The Auke Creek weir structure facilitates near-complete capture of all migrating pink fry and returning adults, and is the only weir capable of such on a wild system in the North Pacific. Marine survival is estimated as the number of adults (escapement) per fry. While no stock-specific harvest information is available for Auke Creek pink salmon, and there are possible influences of straying and intertidal production downstream of the weir structure, the precision of this long-term dataset is still unmatched and the series an excellent choice for model input relating to nearshore and gulf-wide productivity. The index is presented by fry outmigration year.

Status and trends: The historical trend shows marine survival of wild pink salmon from Auke Creek varies from 1.2% to 53.3%, with an average survival of 11.3% from ocean entry years 1980-

2015 (Figure 29). Marine survival for 2015 was 4.7% and overall survival averaged 18.6% over the last 5 years and 14.8% over the last 10 years.

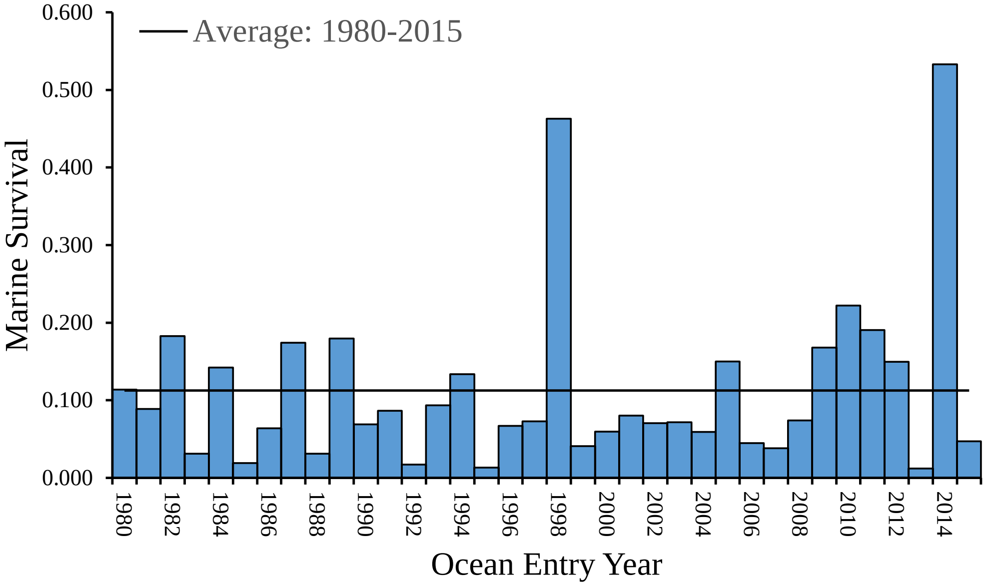

Figure 29: Auke Creek pink salmon marine survival indices showing total marine survival

Factors influencing observed trends: Factors that have influenced these observed trends include: migration timing, fishery effort and timing, predation, growth rates, maintained genetic variation, and stream conditions. Within the Auke Creek system, a system undergoing rapid climatic change, climate-induced phenological shifts have been shown to influence the trend of earlier migration of both the early and late run of pink adults, as well as, juvenile fry migration (Kovach et al. 2013b, Shanley et al. 2015). The effect of fishing pressure on pink salmon has some obvious effects on marine survival, as well as, unapparent impacts including decreases in body weight, variations in length, increases in earlier-maturing fish, and increases in heterozygosity at PGM (Hard et al. 2008).

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

Implications: The marine survival of Auke Creek pink salmon is related to large-scale ocean productivity indices and to important rearing habitats of many southeast Alaska groundfish species. The marine survival of indices of Auke Creek pink salmon provide trends that allow for the examination of annual variation in habitat quality of rearing areas and general ocean conditions and productivity. Due to the one ocean year life history of pink salmon, we are able to use their marine survival as a proxy for the general state of the Gulf of Alaska. Additionally, as pink fry are such a numerous food resource in southeast Alaska, their abundance and rate of predation allow for insights into the groundfish fisheries. Pink fry have been shown to be an important food resource for juvenile sablefish, making up a large percentage of their diet (Sturdevant et al. 2009, 2012). The growth and marine survival of Auke Creek pink salmon provide valuable proxies for Gulf of Alaska and southeast Alaska productivity, as well as, the overwintering survival and recruitment of sablefish.

Marine Survival Index for Coho Salmon from Auke Creek, Southeast Alaska

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Last updated: September 2016

Description of indicator: The time series of marine survival estimates for wild coho salmon from the Auke Creek Weir in Southeast Alaska is the most precise and longest-running continuous series available in the North Pacific. Auke Bay Laboratory began monitoring wild coho salmon survival in 1980. All coho salmon smolts leaving the Auke Lake watershed have been counted, subsampled for age and length, and injected with coded wire tags (CWT). Research studies over the last 36 years have captured and sampled virtually all migrating wild juvenile and adult coho salmon. These migrating fish included those with both 1 and 2 freshwater annuli and 0 or 1 ocean annuli. Marine survival is estimated as the number of adults (harvest plus escapement) per smolt. The index is presented by smolt (outmigration) year. The precision of the survival estimate was high due to 100% marking and sampling fractions that minimized the variance in the survival estimate and made the series an excellent choice for model input relating to nearshore and gulf-wide productivity. It is the only continuous marine survival and scale data set in the North Pacific that recovers all returning age classes of wild, CWT coho salmon as ocean age 0 and 1

Status and trends: The historical trend shows marine survival of wild coho salmon from Auke Creek varies from 11.7% to 47.8%, with an average survival of 24.1% from smolt years 1980-2014 (Figure 1; top panel). Marine survival for 2014 was 17.0% and overall survival averaged 19.2% over the last 5 years and 20.0% over the last 10 years. The survival index for ocean age-1 coho varies from 9.4% to 36.6% from smolt years 1980-2014 (Figure 1; middle panel) and for ocean age-0 coho varies from 1.1% to 11.2% from smolt years 1980-2015, with 2015 being the lowest on record (Figure 1; bottom panel). Return data for 2016 returns are included, despite the fact that the run may not be completely finished. These data are included because the marine survival for ocean age-1 coho at Auke Creek will likely be the lowest on record at ∼5.0% (marine survival was at 5.0% as of 28 September 2016, with recent fishery and escapement counts indicating that a minimum amount of fish likely remain at large).

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

Implications: The marine survival index of coho salmon at Auke Creek is related to ocean productivity indices and to important rearing habitats shared by groundfish species. The trends in coho salmon marine indices from Auke Creek provide a unique opportunity to examine annual variation in habitat rearing areas and conditions because ocean age-0 coho adults occupy only nearshore and strait habitats prior to returning to the creek. Ocean age-0 coho leave freshwater in May through June and return in August through October, the same time sablefish are moving from offshore to nearshore habitats. In contrast, ocean age-1 coho salmon occupy those nearshore habitats for only a short time before entering the Gulf of Alaska and making a long migratory loop. They return to the nearshore habitats on their way to spawning grounds after the first winter that age-0 sablefish spend in nearshore habitats. The relative growth and survival of ocean age-0 and age-1 coho salmon from Auke Creek may provide important proxies for productivity, overwintering survival of sablefish, and recruitment of sablefish to age-1.

Forecasting Pink Salmon Harvest in Southeast Alaska

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Description of indicator: Over the past decade, researchers from the Alaska Fisheries Science Centers (AFSC) Southeast Alaska Coastal Monitoring (SECM) Project have used ecosystem indicators to provide valuable pre-season pink salmon (*Oncorhynchus gorbuscha*) forecast information to salmon resource stakeholders of Southeast Alaska (SEAK). These SECM pre-season forecast models of pink salmon harvest were developed to: 1) help fishery managers achieve sustainable fisheries, 2) meet pre-season planning needs of resource stakeholders of the commercial fishing industry, and 3) gain a better understand of mechanisms related to salmon production in the Gulf of Alaska large marine ecosystem in a changing climate.

To develop the pre-season pink salmon forecast, ecosystem metrics were obtained from stations sampled in the vicinity of Icy Strait (58°N, 135°W) by SECM research in coastal SEAK (Orsi et al., 2015). This locality is the principal northern seaward exit route for migrating juvenile salmon through SEAK to the GOA. Pink salmon are the most abundant of the salmon species and also rapidly migrate seaward after leaving the nearshore littoral zone as emigrating fry, where mortality can be high and variable. The same stations have been sampled systematically over the past 20 years in a monthly sequential approach from May to August. Salmon that exit this migration corridor are comprised predominately of stocks originating from SEAK whose compositions shift over time based on origin information from coded-wire tags and thermally induced ototlith marks.

Temporally, oceanographic sampling has occurred in May, June, July, and August, whereas surface trawling (0-20 m depth) for epipelagic fish species is conducted in the latter three months.

The ecosystem indicators used for pre-season pink salmon forecast models consist of juvenile pink salmon abundance during trawl surveys and other associated biophysical metrics. The primary forecast model used is a step-wise regression of juvenile pink salmon abundance (trawl CPUE) in summer (June or July) compared to harvest the ensuing year (Wertheimer et al. 2014). Additional explanatory ecosystem variables in this regression model are used some years to better explain residual error in the relationship. A secondary complementary model uses a summed ranked approach of a broad suite of six ecosystem metrics, all significantly ($p<0.05$) correlated with harvest over the prior 18 year SECM time series: CPUE measures (two), peak migration month, pink salmon relative catch composition, predation impact index, and the summer North Pacific Index.

Status and trends: Based on ecosystem metrics, the pink salmon harvest to SEAK in 2016 is forecasted to be around 30 M fish, somewhat below the historical average. This below average forecast is actually moderate when considering the recent lower abundance of the even year pink salmon harvests in 2006, 2008, 2010, and 2012 (Figure 30). Of all the large basin scale physical ecosystem metrics considered to influence SEAK pink salmon production, only the North Pacific Index (NPI, summer) was significantly correlated with harvest over the recent 19-yr time series, the remaining five significant ecosystem metrics were biological (juvenile pink salmon abundance, distribution, timing, and depredation, Figure 31).

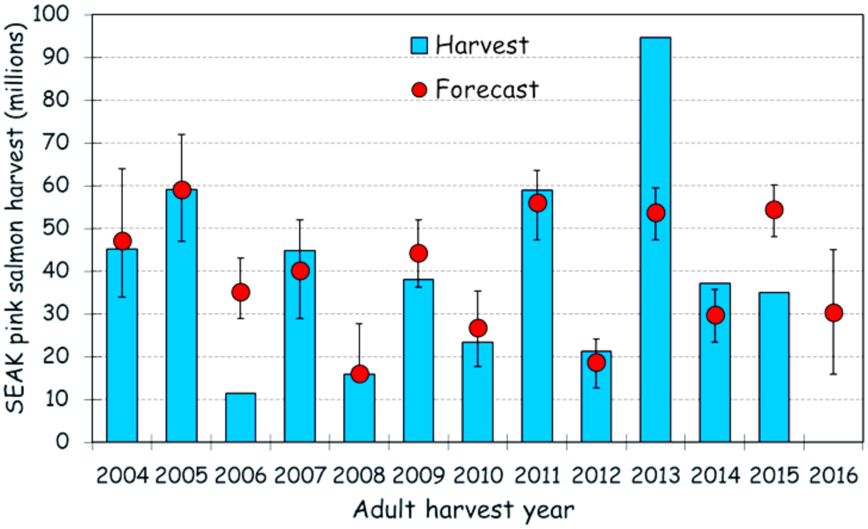
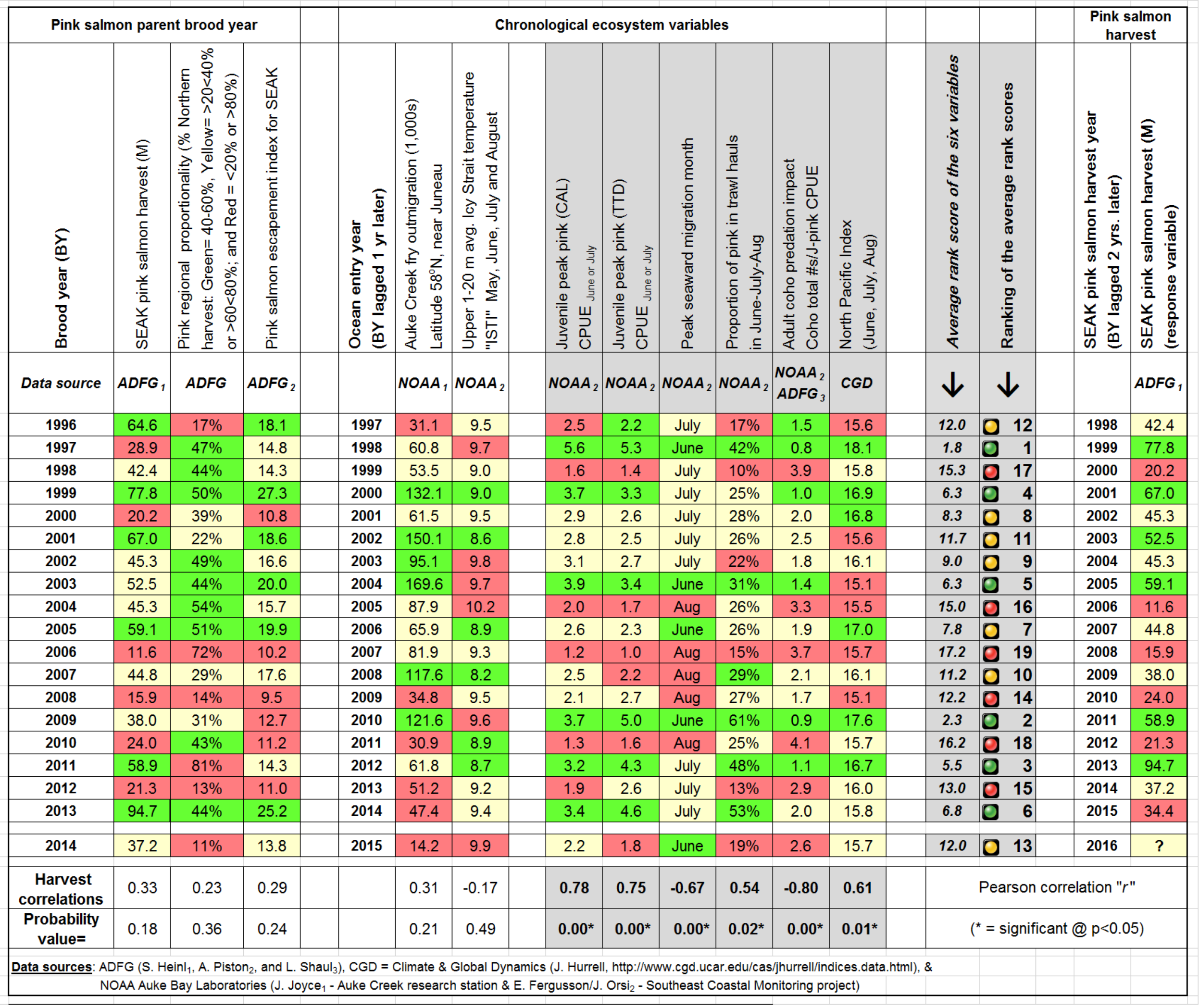


Figure 30: Previous SECM pink salmon pre-season forecast model predictions (with 80% confidence intervals) and actual SEAK harvests over the past 12 years. Harvest data from the SEAK pink salmon fishery still incomplete for 2016, and 2016 SECM surveys are still ongoing for the 2017 forecast.

Given the ecosystem conditions and SECM metrics sampled in 2015, the two best SECM forecast models for the 2016 SEAK pink salmon harvest are shown below in Table 5. Each forecast model value has an 80% bootstrap confidence interval shown in parentheses. The 6 variable model is the best fit predictor for the relationship of the 18-year time series of SECM data parameters with subsequent SEAK pink salmon harvests from 1998 to 2015, based on the R^2 and AIC_c.

A chronological set of ecosystem metrics associated with SEAK adult pink harvest over the 19-year SECM time series are shown in Figure 32. Note that in addition to the CPUE metrics, four other



Pink salmon parent brood year				Chronological ecosystem variables											Pink salmon harvest	
Brood year (BY)	SEAK pink salmon harvest (M)	Pink regional proportionality (% Northern harvest: Green= 40-60%, Yellow= >20<40% or >60<80%; and Red = <20% or >80%)	Pink salmon escapement index for SEAK	**Ocean entry year (BY lagged 1 yr later)**	Auke Creek fry outmigration (1,000s) Latitude 58°N, near Juneau	Upper 1-20 m avg. Icy Strait temperature "ISTI" May, June, July and August	Juvenile peak pink (CAL) CPUE $_{\text{June or July}}$	Juvenile peak pink (TTD) CPUE $_{\text{June or July}}$	Peak seaward migration month	Proportion of pink in trawl hauls in June-July-Aug	Adult coho predation impact Coho total #s/J-pink CPUE	North Pacific Index (June, July, Aug)	***Average rank score of the six variables***	**Ranking of the average rank scores**	**SEAK pink salmon harvest year (BY lagged 2 yrs. later)**	**SEAK pink salmon harvest (M) (response variable)**
Data source	***ADFG*** $_1$	***ADFG***	***ADFG*** $_2$		***NOAA*** $_1$	***NOAA*** $_2$	***NOAA*** $_2$	***NOAA*** $_2$	***NOAA*** $_2$	***NOAA*** $_2$	***NOAA*** $_2$ ***ADFG*** $_3$	***CGD***	↓	↓		***ADFG*** $_1$
1996	64.6	17%	18.1	**1997**	31.1	9.5	2.5	2.2	July	17%	1.5	15.6	***12.0***	🟡 **12**	**1998**	42.4
1997	28.9	47%	14.8	**1998**	60.8	9.7	5.6	5.3	June	42%	0.8	18.1	***1.8***	🟢 **1**	**1999**	77.8
1998	42.4	44%	14.3	**1999**	53.5	9.0	1.6	1.4	July	10%	3.9	15.8	***15.3***	🔴 **17**	**2000**	20.2
1999	77.8	50%	27.3	**2000**	132.1	9.0	3.7	3.3	July	25%	1.0	16.9	***6.3***	🟢 **4**	**2001**	67.0
2000	20.2	39%	10.8	**2001**	61.5	9.5	2.9	2.6	July	28%	2.0	16.8	***8.3***	🟡 **8**	**2002**	45.3
2001	67.0	22%	18.6	**2002**	150.1	8.6	2.8	2.5	July	26%	2.5	15.6	***11.7***	🟡 **11**	**2003**	52.5
2002	45.3	49%	16.6	**2003**	95.1	9.8	3.1	2.7	July	22%	1.8	16.1	***9.0***	🟡 **9**	**2004**	45.3
2003	52.5	44%	20.0	**2004**	169.6	9.7	3.9	3.4	June	31%	1.4	15.1	***6.3***	🟢 **5**	**2005**	59.1
2004	45.3	54%	15.7	**2005**	87.9	10.2	2.0	1.7	Aug	26%	3.3	15.5	***15.0***	🔴 **16**	**2006**	11.6
2005	59.1	51%	19.9	**2006**	65.9	8.9	2.6	2.3	June	26%	1.9	17.0	***7.8***	🟡 **7**	**2007**	44.8
2006	11.6	72%	10.2	**2007**	81.9	9.3	1.2	1.0	Aug	15%	3.7	15.7	***17.2***	🔴 **19**	**2008**	15.9
2007	44.8	29%	17.6	**2008**	117.6	8.2	2.5	2.2	Aug	29%	2.1	16.1	***11.2***	🟡 **10**	**2009**	38.0
2008	15.9	14%	9.5	**2009**	34.8	9.5	2.1	2.7	Aug	27%	1.7	15.1	***12.2***	🔴 **14**	**2010**	24.0
2009	38.0	31%	12.7	**2010**	121.6	9.6	3.7	5.0	June	61%	0.9	17.6	***2.3***	🟢 **2**	**2011**	58.9
2010	24.0	43%	11.2	**2011**	30.9	8.9	1.3	1.6	Aug	25%	4.1	15.7	***16.2***	🔴 **18**	**2012**	21.3
2011	58.9	81%	14.3	**2012**	61.8	8.7	3.2	4.3	July	48%	1.1	16.7	***5.5***	🟢 **3**	**2013**	94.7
2012	21.3	13%	11.0	**2013**	51.2	9.2	1.9	2.6	July	13%	2.9	16.0	***13.0***	🔴 **15**	**2014**	37.2
2013	94.7	44%	25.2	**2014**	47.4	9.4	3.4	4.6	July	53%	2.0	15.8	***6.8***	🟢 **6**	**2015**	34.4
2014	37.2	11%	13.8	**2015**	14.2	9.9	2.2	1.8	June	19%	2.6	15.7	***12.0***	🟡 **13**	**2016**	**?**
Harvest correlations	0.33	0.23	0.29		0.31	-0.17	**0.78**	**0.75**	**-0.67**	**0.54**	**-0.80**	**0.61**	Pearson correlation "*r*"			
Probability value=	0.18	0.36	0.24		0.21	0.49	**0.00***	**0.00***	**0.00***	**0.02***	**0.00***	**0.01***	(* = significant @ p<0.05)			

Data sources: ADFG (S. Heinl$_1$, A. Piston$_2$, and L. Shaul$_3$), CGD = Climate & Global Dynamics (J. Hurrell, http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html), & NOAA Auke Bay Laboratories (J. Joyce$_1$ - Auke Creek research station & E. Fergusson/J. Orsi$_2$ - Southeast Coastal Monitoring project)

Figure 31: Matrix of ecosystem metrics considered for pink salmon forecasting. The ranges of values within each metric column are color-coded below, with the highest values in green, intermediate values in yellow, and the lowest values in red. The response variable of pink salmon harvest in Southeast Alaska (SEAK) is the right hand column and the grey column with stoplight colors shows the annual rank score by year.

variables are significantly correlated with harvest (Peak migration month, %pink in June-July trawl hauls, the North Pacific Index, and Adult coho predation impact). Additionally, this matrix shows that anomalously low (red: 2000, 2006, 2008, 2010 2012, 2015) or high (green: 1999, 2001, 2003, 2005, 2011, 2013) return years always flag 3-5 ecosystem indicators of the respective color signal in each row. For the 2016 forecast, however, there were six “red” ecosystem indicator flags, four “yellow” and one “green” ecosystem indicator flags.

Factors influencing observed trends: Pink salmon year-class success has varied widely in SEAK, with annual harvests ranging from 3 to 95 M fish since 1960 (ADFG 2015). Pink salmon are an ecologically and economically important resource in SEAK, and in 2013 reached a record harvest of 95 M fish valued at over $125 M. These returns also show decadal abundance trends and alternating odd-even year brood line dominance patterns. This variability may result from

Table 5: The two best SECM pink salmon forecast models for the 2016 Southeast Alaska pink salmon harvest.

SECM forecast models	Adj. R^2	AICc	P value	Prediction for 2016
Eco-rank + May_{temp} (6 variables)	78%	143.8	<0.001	30.4 M (16-45) M
Peak CPUE_{cal}+$\text{ISTI}_{\text{20m temp}}$ (2-parameter)	70%	149.4	<0.001	24.2 M

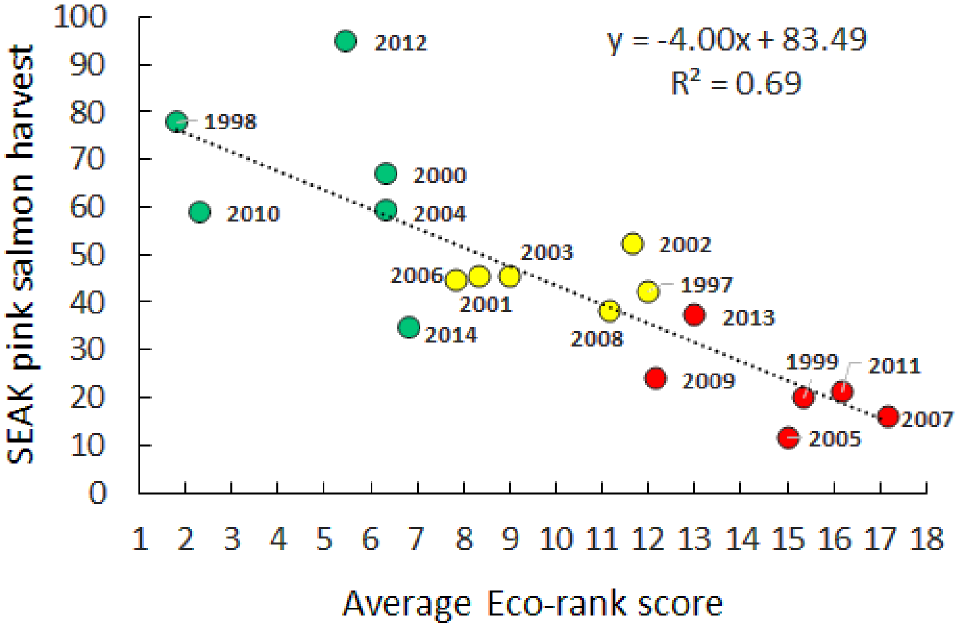


Figure 32: A complementary approach to forecasting pink salmon returns using a regression of the average ranks of the six significant ecosystem metrics and SEAK pink salmon harvest the ensuing year. Years next to data points correspond to the ocean entry year of the juvenile salmon. Average rank based on 2015 ecosystem metrics for the 2016 pink salmon forecast is 12.0 corresponding to a 37.1 M fish harvest. See Figure 31 for the average rank scores, ocean entry years, and pink salmon harvests used in this figure.

dynamic ocean conditions or ecological interactions that affect juvenile salmon or overwintering adults above the transition domain in the North Pacific. Additionally, pink salmon production in SEAK is predominately derived from >97% wild stocks of varied run timings that originate from >2,000 anadromous streams throughout the region (Piston and Heinl, 2013). Pink salmon in SEAK are a key stock group proposed for monitoring in the North Pacific (Orsi et al., 2014).

Alaska pink salmon stocks migrate over 2,000 km across the North Pacific Ocean in a little over a year. Consequently, Alaska pink salmon stocks spend a large portion of their life history in marine waters within the U.S. Exclusive Economic Zone (EEZ) and beyond the 200-mile EEZ of the coastal States north of 33°N in international waters (NPAFC, 2014). However, year class strength of this species is often set earlier, and further inshore of the EEZ, during their seaward migration phase as juveniles.

Implications: These ecosystem indicators in concert suggest a below average pink salmon harvest in 2016. By virtue of their high numerical abundance and annual biomass, pink salmon are a keystone species in the epipelagic waters of the GOA ecosystem. The short one-ocean winter lifespan of this species and wide ocean distribution makes pink salmon an ideal ecological indicator of changing ocean conditions from climatic shifts. Consequently, understanding factors affecting year class strength of pink salmon annual cycles may help identify important trophic dynamics in the GOA ecosystem that impact multiple species. Terrestrially, pink salmon also serve as an important conduit of marine derived nutrients to the temperate rainforests of coastal Alaska. Economically, pink salmon have been called the "bread and butter" fish of SEAK, and are represented by primarily wild stocks (>95%) from over 2,500 SEAK stream systems. This production base can contribute to an annual commercial SAEK harvest of upwards of 95 M fish, worth over $125 M ex-vessel value. Ecologically, this large 2013 harvest in SEAK represented a significant component in the GOA ecosystem, comprising 21% of the 643,779 metric tons of fish commercially harvested off Alaska in the GOA and adjacent coastal waters, and pink salmon from all regions representing 46% of the harvest.

Using Ecosystem Indicators to Develop a Chinook Salmon Abundance Index for Southeast Alaska

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Last updated: August 2015

Description of indicator: The Southeast Alaska Coastal Monitoring (SECM) project has a time series of ecosystem metrics in coastal Southeast Alaska (SEAK) and in the Gulf of Alaska (GOA) from annual surface trawl and oceanographic sampling over the past 19 years.

The SECM data for the Chinook salmon index was obtained from stations sampled in the vicinity of Icy Strait (58°N, 135°W)(Orsi et al., 2015). Ocean age-1 Chinook salmon were sampled from monthly surface trawl catches June-August, 1997-2010. This locality is the principal northern exit route for seaward migrating juvenile salmon through SEAK to the GOA. Based on coded-wire tag recoveries, Chinook salmon found in this migration corridor in fall and in the ensuing spring presumably wintering are predominately of SEAK origin. This suggests SEAK Chinook salmon smolts have a localized early marine residency pattern and a portion of then reside as older immature fish in Icy Strait, rather than heading directly seaward. As Chinook salmon grow and recruit into the Alaska legal size limit (71 cm total length), fish are harvested in commercial and recreational sport fisheries in SEAK under annual quotas established by the Chinook Technical Committee of the U.S./Canada Pacific Salmon Treaty (PSC 2014). Chinook salmon harvested off SEAK are predominately immature fish comprised of mixed stocks originating from SEAK southward. The quotas are allocated based on the estimated abundance of index populations from SEAK to Oregon. Chinook salmon over the AK legal size limit sampled in fisheries provide information on fish typically aged two or more ocean winters old (ocean age-2 to ocean age-5 fish), but not on younger ocean age-1 and ocean age-0 fish. These younger fish are however the primary age groups sampled annually in SECM surveys, and are mostly comprised of immature ocean age-1 fish in early summer and some juvenile (ocean age-0) fish in fall. Thus, a reporting of a SECM Chinook salmon index of ocean age-1 fish would give an outlook of ocean age-3 recruits to managers and stakeholders in SEAK and serve as a leading ecological indicator of year class strength a year or two prior to fishery recruitment.

Status and trends: As in most of Alaska, Chinook salmon returns to SEAK have been in decline for almost a decade. This trend is also apparent in the SECM Chinook salmon abundance index (Figure 33). Based on this index of ocean age 1 fish, there appears to be two strong Chinook salmon year classes emerging: one as ocean age-3 fish in 2013 and another two years later in 2015.

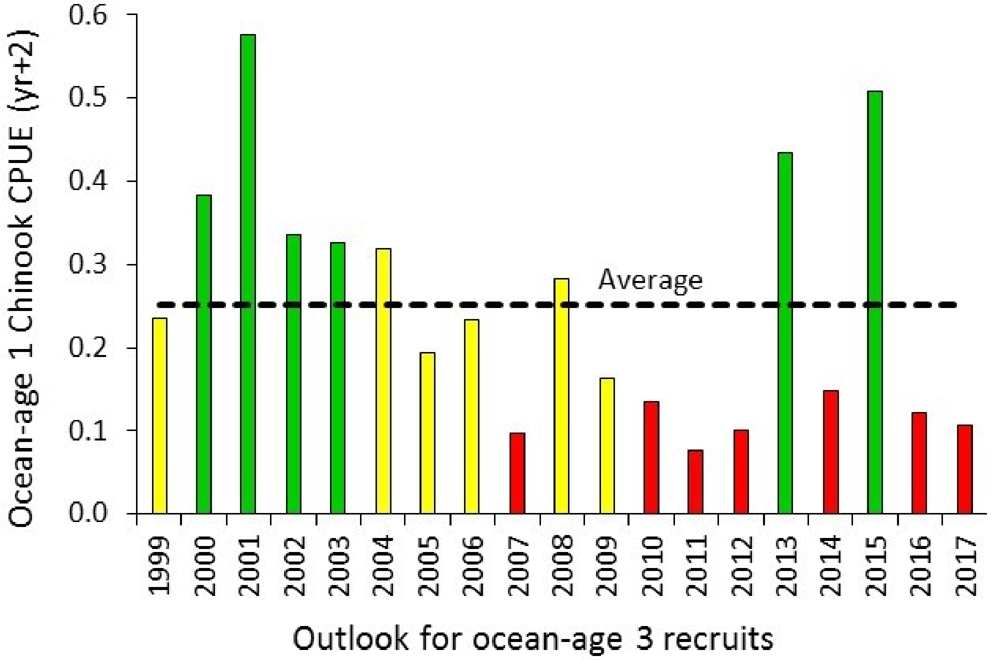

Figure 33: Outlook for ocean age-3 recruit Chinook salmon from the Southeast Alaska Coastal Montioring project. Recruit index estimate based on average LN(CPUE + 1) of ocean age-1 fish sampled in Icy Strait in June, July, and August lagged two years later to project ocean age-3 fish, 1999-2017. No trawling was conducted in June of 2009, so the index for 2011 was only based on the July-August average.

Factors influencing observed trends: Contrary to many of the assumptions of negative impacts of pink salmon on other species, in the case of these two strong year classes of Chinook, they coincide with the same ocean entry years of the high juvenile pink salmon abundances in 2010 and 2012. This suggests that both juvenile Chinook and pink salmon mutually benefited from favorable ocean conditions in 2010 and 2012, or the smaller, more abundant juvenile pink salmon proved to be a predator buffer to the larger Chinook salmon juveniles. Year class strength is often set inshore of the EEZ during juvenile Chinook salmon seaward migration phase or during the ensuing overwintering phase of immatures. Southeast Alaska Chinook salmon stocks in the Icy Strait study area have an initial localized marine distribution as juveniles, are present the ensuing spring and summer as immature fish, and appear to emigrate in the fall as older ocean age-1 fish. There is only a significant relationship between ocean age-1 Chinook salmon CPUE and brood year survival, in contrast to juvenile Chinook salmon CPUE. Abundance information on ocean age-1 fish in June has been significantly correlated to brood year survival of selected stocks of wild and hatchery Chinook salmon in SEAK (Orsi et al. 2013) and the summer abundance of ocean age-1 fish has also been

Table 6: Correlation matrix of combined Chinook salmon brood year survivals (hatchery and wild) and CPUE data of ocean age-0 and ocean age-1 Chinook salmon from monthly surface trawl sampling from the Southeast Alaska Coastal Monitoring project in the marine waters of Icy Strait, Alaska, June-August, 1997-2010. Asterisk denotes significant differences (uncorrected for multiple comparisons) at P-value < 0.05

	Average brood-year survival	CPUE ocean age-0
CPUE ocean age-0	0.26	
CPUE ocean age-1	0.67	-0.07

correlated with brood year survival (Figure 34, Table 6, Orsi et al. In Press).

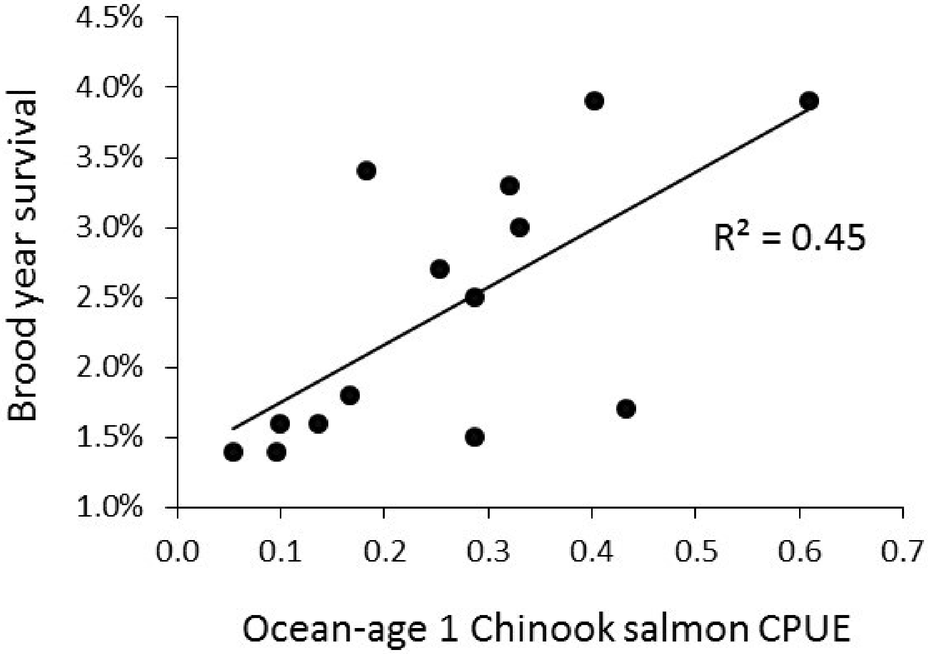

Figure 34: The relationship between ocean age-1 Chinook annual catch and average brood year survivals of Chinook salmon hatchery and wild stocks from the northern region of Southeast Alaska (Chilkat River, Taku River, DIPAC hatchery, and Hidden Falls hatchery)

Implications: In both 2016 and 2017 the recruitment outlook for ocean age-3 Chinook salmon to SEAK is poor. The CPUE of ocean age-1 Chinook salmon in summer has promise as a leading indicator of upcoming fishery recruitment strength two years later and may be a useful leading ecosystem indicator stock assessment tool for managers.

Groundfish

Southeast Coastal Monitoring Survey Indices and the Recruitment of Gulf of Alaska Sablefish

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Last updated: August 2016

Description of indicator: Biophysical indices from surveys and fisheries in 2014 and 2015 were used to predict the recruitment of sablefish to age-2 in 2016 and 2017 (Yasumiishi et al., 2015*b*). The southeast coastal monitoring project has an annual survey of oceanography and fish in inside and outside waters of northern southeast Alaska (Orsi et al. 2012). Oceanographic sampling included, but was not limited to, sea temperature and chlorophyll *a*. These data are available from documents published through the North Pacific Anadromous Fish Commission website from 1999 to 2012 (`www.npafc.org`) and from Emily Fergusson. An index for pink salmon survival was based on adult returns of pink salmon to southeast Alaska (Piston and Heinl, 2014). These oceanographic metrics may index sablefish recruitment, because sablefish use these waters as rearing habitat early in life (late age-0 to age-2). Estimates of age-2 sablefish abundance are from (Hanselman et al., 2013). We modeled age-2 sablefish recruitment estimates from 2001 to 2010 as a function of sea temperature, chlorophyll *a*, and pink salmon productivity during the age-0 stage for sablefish.

Status and trends: Based on a low chlorophyll *a* value in 2014 (3.73) and 2015 (1.12) we expect the abundance of 19.7 million age-2 sablefish in 2016 and below average at 3.8 million age-2 sablefish in 2017. We modeled age-2 sablefish recruitment estimates from 2001 to 2015 (Hanselman et al., 2015) as a function of sea temperature, chlorophyll *a*, and pink salmon productivity during the age-0 stage for sablefish. The model with the lowest Bayesian information critierion (112) described the stock assessment estimates of recruitment of sablefish to age-2 as a function of late August chlorophyll *a* during the age-0 stage (Figure 35; Table 7). A regression model indicated that chlorophyll a during the age-0 phase was positively and signficantly correlated with sablefish recruitment ($R^2 = 0.59$; p-value = 0.0008). Sea temperature and pink salmon productivity fell out of the model with the addition of 4 years of data to the 2016 model compared to the 2015 model (Yasumiishi et al., 2015*a*).

Factors influencing observed trends: Warmer sea temperatures were associated with high recruitment events in sablefish (Sigler and Zenger Jr., 1989). Higher chlorophyll *a* content in sea water during late summer indicate higher primary productivity and a possible late summer phytoplankton bloom. Higher pink salmon productivity, a co-occurring species in near-shore waters, was a positive predictor for sablefish recruitment to age-2. These conditions are assumed more favorable for age-0 sablefish, overwintering survival from age-0 to age-1, and overall survival to age-2.

Implications: Late summer chlorophyll a in 2014 and 2015 were used to predict the recruitment of Alaska sablefish to age-2 in 2016 and 2017. The model predicts 19.7 million age-2 sablefish in 2016 (average) and **below average recruitment of sablefish to age-2 at 3.8 million in 2017**.

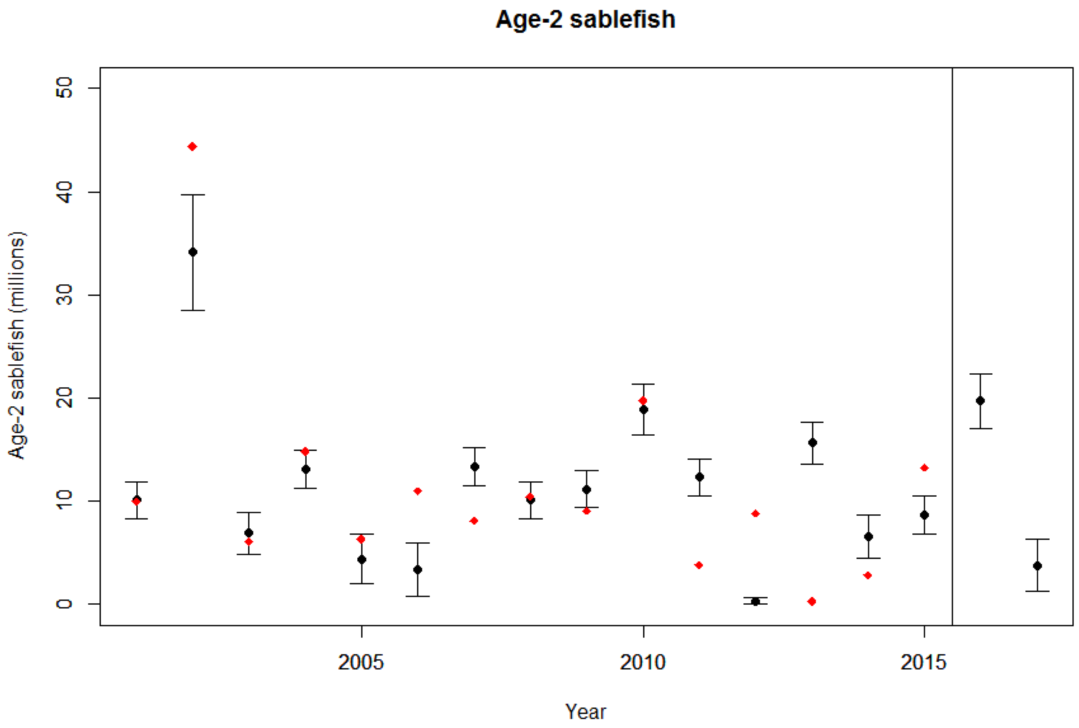

Figure 35: Stock assessment estatimes, model estimates, and the 2016 and 2017 prediction for age-2 Alaska sablefish. Stock assessment estimates of age-2 sablefish were modeled as a function of late August chlorophyll a levels in the waters of Icy Strait in northern southeast Alaska during the age-0 stage (t-2).

Table 7: Nearshore survey data fit to the stock assessment estimates of age-2 sablefish (millions of fish) from Hanselman et al. (2015). Table shows the 2016 model fitted (2001-2015), forecast (2016 and 2017) estimates and standard errors for age-2 sablefish, and the predictor variable (1999-2013).

Year	Stock assessment Estimates Sablefish (t)	Model Fitted and forecast estimates	Standard error	Predictor variable Chlorophyll a (t-2)
2001	9.98	9.96	2.24	2.15
2002	44.39	33.48	5.14	6.08
2003	6.07	6.85	1.81	1.63
2004	14.83	12.89	1.82	2.64
2005	6.33	4.4	2.1	1.22
2006	10.97	3.38	2.55	1.05
2007	8.09	13.13	2.61	2.68
2008	10.44	9.96	1.59	2.15
2009	9.09	11.04	2.46	2.33
2010	19.76	18.58	2.08	3.59
2011	3.84	12.18	2.01	2.52
2012	8.82	0.386	2.83	0.55
2013	0.29	15.4	2.21	3.06
2014	2.82	6.55	4.17	1.58
2015	13.26	8.86	1.7	1.92
2016		19.7	2.64	3.73
2017		3.79	2.49	1.12

Benthic Communities and Non-target Fish Species

ADF&G Gulf of Alaska Trawl Survey

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Last updated: August 2016

Description of indicator: The Alaska Department of Fish and Game conducts an annual trawl survey for crab and groundfish in Gulf of Alaska targeting areas of crab habitat around Kodiak Island, the Alaska Peninsula, and the Eastern Aleutian Islands (Spalinger, 2016). The survey uses a large mesh bottom trawl net. The smallest mesh size in the codend has a 3.2 cm stretch mesh liner, and thus does not sample juvenile fish (e.g., pollock sizes captured in 2014 ranged from 14-79 cm). While the survey covers a large portion of the central and western Gulf of Alaska, results from Kiliuda and Ugak Bays (inshore) and the immediately contiguous Barnabas Gully (offshore) (Figure 36) are generally representative of the survey results across the region. These areas have been surveyed annually since 1984, but the most consistent time series begins in 1988. In 2015, a total of 379 stations were sampled from June 12 through September 17. Using a method described by Link et al. (2002), standardized anomalies, a measure of departure from the mean, catch (kg) per distance towed (km), for the survey catches (kg/km towed) from Kiliuda and Ugak Bays, and Barnabas Gully were calculated and plotted by year for selected species (arrowtooth flounder *Atheresthes stomias*, flathead sole *Hippoglosoides elassodon*, Tanner crab *Chionoecetes bairdi*, Pacific cod *Gadus macrocephalus*, skates, walleye pollock *G. chalcogrammus*, and Pacific halibut *Hippoglossus stenolepis*) using the method described by Link et al. (2002) (Figure 37). Bottom temperatures for each haul have been recorded since 1990 (Figure 38).

Status and trends: Arrowtooth flounder, flathead sole, and other flatfish continue to dominate the catches in the ADF&G trawl survey, but not to the same degree as seen in previous surveys. A sharp decrease in overall biomass is apparent from 2007 to 2015 from years of record high catches seen from 2002 to 2005 (Figure 39).

Prior to the start of our standard trawl survey in 1988, Ugak Bay was the subject of an intensive seasonal trawl survey in 1976-1977 (Blackburn 1977). Today, the Ugak Bay species composition is markedly different than in 1976. Red king crabs Paralithodes camtschaticus were the main component of the catch in 1976-1977, but now are nearly non-existent. Flathead sole, skate, and gadid catch rates have all increased roughly 10-fold. While Pacific cod made up 88% and walleye pollock 10% of the gadid catch in 1976-1977, catch compositions have reversed in 2015 with Pacific cod making up 13% of catch and walleye pollock 86%.

In 2015, overall gadid catches have increased in offshore area of Barnabus Gully and decreased in the inshore areas of Kiliuda and Ugak Bays (Figure 39). Below average anomaly values for arrowtooth flounder and flathead sole were recorded again in 2015 for both inshore and offshore areas, while Pacific halibut and skates were above average only in the offshore stations (Figure 37). Pollock, Pacific cod, and Tanner crab anomaly values were all below average for both areas.

Temperature anomalies for both inshore, Kiliuda and Ugak Bays and offshore stations, Barnabas Gully, from 1990 to 2015, show periods of above average temperatures corresponding to the moder-

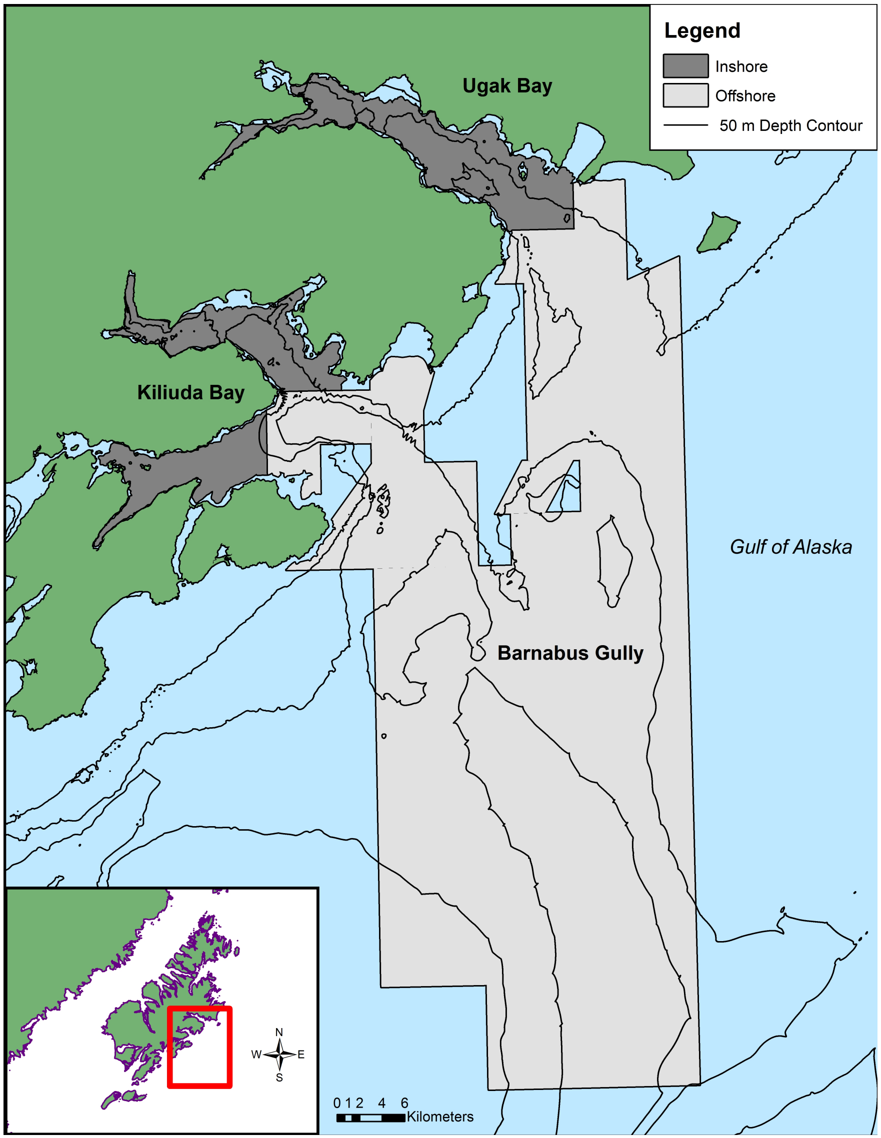

Figure 36: Kiliuda Bay, Ugak Bay, and Barnabus Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

ate and strong El Niño years (1997-1998; Figure 38; `http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml`). Cooler temperatures were apparent from 2011 to 2013, with temperatures markedly increasing in 2014 and 2015.

Factors influencing observed trends: It appears that significant changes in volume and composition of the catches on the east side of Kodiak are occurring, but it is unknown to what extent predation, environmental changes, and fishing effort are contributing. The lower overall catch from 1993 to 1999 (Figure 39) may be a reflection of the greater frequency of El Niño events on overall production while the period of less frequent El Niño events, 2000 to 2003, corresponds to years of increasing production and corresponding catches. Lower than average temperatures have been recorded from 2006 to 2009 along with decreasing overall abundances in 2008 and 2009. This may indicate a possible lag in response to changing environmental conditions or some other factors may

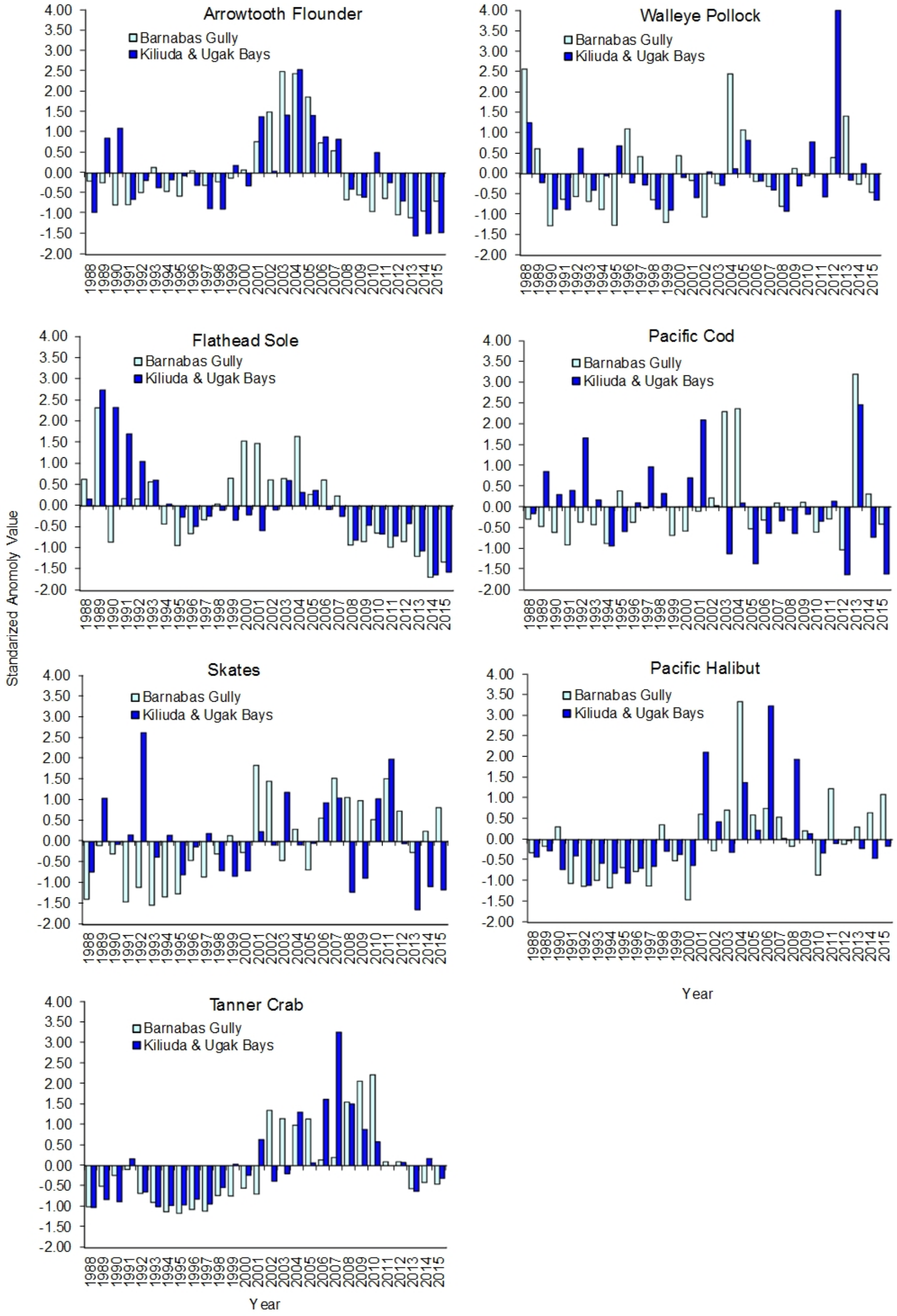

Figure 37: A comparison of standardized anomaly values based on catch (kg) per distance towed (km) for selected species caught from 1988-2015 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

be affecting abundance that are not yet apparent.

Implications: Although trends in abundance in the trawl survey appear to be influenced by major oceanographic events such as El Niño, local environmental changes, predation, movements, and fishery effects may influence species specific abundances and need to be studied further. Monitoring

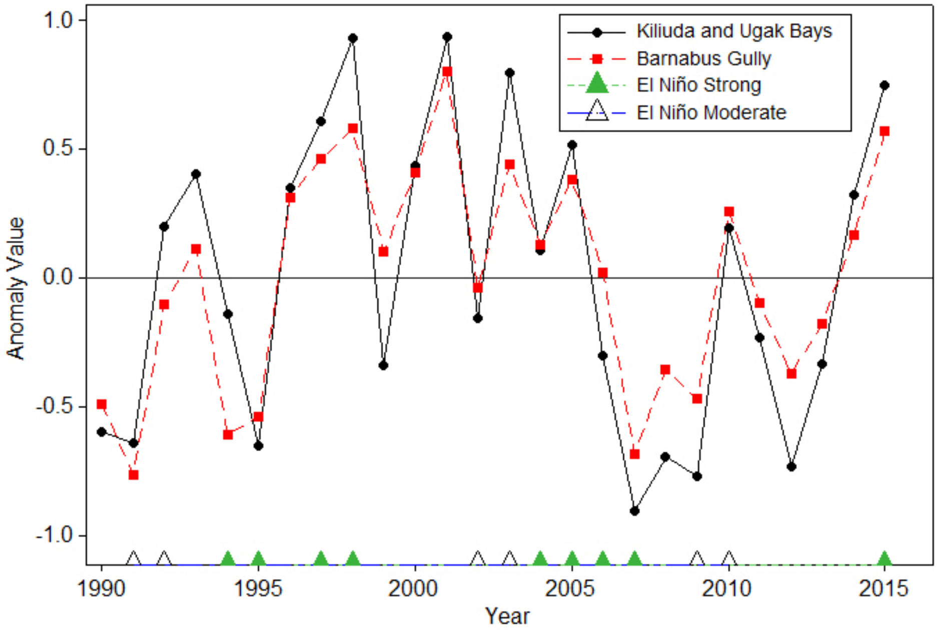

Figure 38: Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2015, with corresponding El Niño years represented.

these trends is an important process used in establishing harvest levels for state water fisheries. These survey data are used to establish guideline harvest levels of state managed fisheries and supply abundance estimates of the nearshore component of other groundfish species such as Pacific cod and pollock. Decreases in species abundance will most likely be reflected in decreased guideline harvest levels.

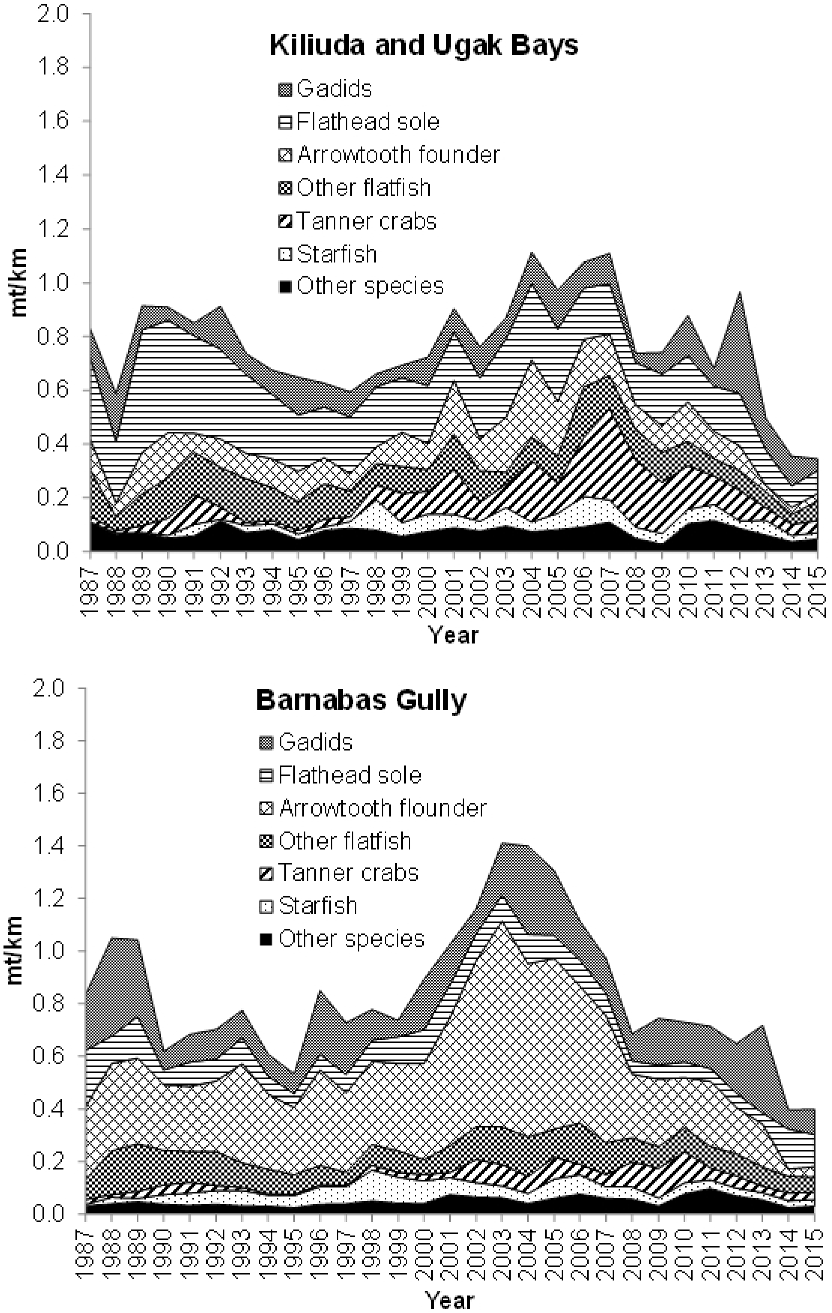

Figure 39: Total catch per km towed (mt/km) of selected species from Barnabus Gully and Kiliuda and Ugak Bay survey areas off the east side of Kodiak Island, 1987 to 2015.

Seabirds

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

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 (2015) Alaska Marine Mammal stock assessment was released in June 2016 and can be downloaded at `http://www.nmfs.noaa.gov/pr/sars/region.htm`.

There are no updates to marine mammal 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 or Community Indicators

Regime Shift Indicator Update for the Gulf of Alaska

Contributed by Madisyn Frandsen and Stephani Zador, Resource Ecology and Fishery Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: August 2016

Description of indicator: A dynamic factor analysis (DFA) was performed using 17 biological time series for the Gulf of Alaska, first used by Hare and Mantua (2000), and later updated by Litzow and Mueter (2014). In previous years, this analysis was performed with Principal Components Analysis (PCA). DFA is similar to a PCA in that it reduces multiple datasets into fewer common trends, but is designed for time series data (Zuur et al., 2003). Salmon commercial salmon catch data, provided by ADF&G (Byerly et al., 1999), was lagged to account for the year of ocean entry (Litzow and Mueter, 2014)). All data series, except for the CPUE time series, were log-transformed. 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 IPHC. A description of each biological time series used is provided in Table 8.

The number of trends to be used was determined by looking at the lowest AICc of various combinations of the covariance matrix, R, and number of hidden trends, m (Zuur et al., 2003). A varimax rotation was conducted on the results in order to maximize the variance between the time series

Table 8: Description of Gulf of Alaska biological 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	Type	Description
GOA Shrimp catch	I	Mean CPUE [Proportion (by weight)] of shrimp (Pandalidae) in annual small-mesh survey catches.
GOA sablefish recruitment	G	Recruitment of age-2 Anoplopoma fimbria by year class, log transformed
GOA Pacific halibut recruitment	G	Recruitment of age-8 Hippoglossus stenolepis, log transformed
GOA Pacific Ocean perch recruitment	G	Recruitment of age-2 Pacific Ocean perch by year class, log-transformed
GOA Pollock recruitment	G	Recruitment of age-2 walleye pollock by year class, log-transformed
GOA Pacific cod recruitment	G	Recruitment of age-0 Pacific cod by year class, log-transformed.
GOA arrowtooth flounder recruitment	G	Recruitment of age-3 arrowtooth flounder by year class, log-transformed
C. Alaska Chinook salmon catch	S	Commercial catch in Chignik, Kodiak, Cook Inlet, Prince William Sound management areas, log-transformed and lagged 3 years
C. Alaska chum salmon catch	S	Commercial catch, log-transformed and lagged 3 years
C. Alaska coho salmon catch	S	Commercial catch, log-transformed and lagged 1 years
C. Alaska pink salmon catch	S	Commercial catch, log-transformed and lagged 1 years
C. Alaska sockeye salmon catch	S	Commercial catch, log-transformed and lagged 2 years
SE Alaska Chinook salmon catch	S	Commercial catch in Southeast and Yakutat management areas, log-transformed and lagged 3 years
SE Alaska chum salmon catch	S	Commercial catch, log-transformed and lagged 3 years
SE Alaska coho salmon catch	S	Commercial catch, log-transformed and lagged 1 years
SE Alaska pink salmon catch	S	Commercial catch, log-transformed and lagged 1 years
SE Alaska sockeye salmon catch	S	Commercial catch, log-transformed and lagged 2 years

loadings for better interpretation (Holmes et al., 2014). A sequential F-test analysis was conducted, using Regime Shift Detection Software (SRSD), on the DFA and PCA results to determine 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 Gulf of Alaska has three trends, and an R-matrix with different variances and covariances, to represent the time series for the region (Table 9). The time series which loaded strongly (loading >|0.2|) onto the first trend included shrimp, which loaded positively, and central Alaska sockeye, Chinook and coho salmon, and southeastern Alaska sockeye salmon, which all loaded negatively. Trend 2 best described southeastern Alaska chum salmon, halibut, pollock, and central Alaska pink salmon, which all load positively. Trend 3 did not have any variables that loaded >|0.2|. Figure 40 shows all the time series which load strongly onto each trend produced by the DFA.

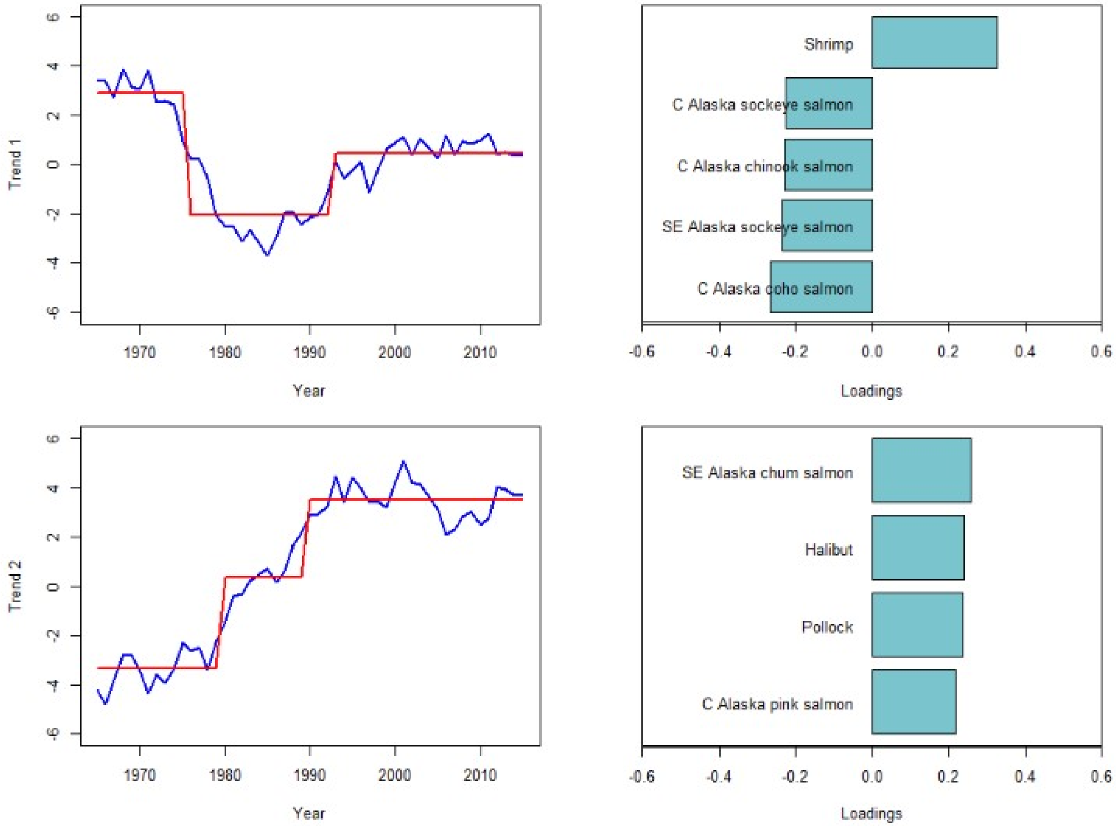

Figure 40: Trends and loadings of time series for the Gulf of Alaska region. The red line on the left plots represents the SRSD values, while the blue is the calculated DFA trend. The bar plots on the right depict the time series which load most strongly onto each trend (loading >|0.2|).

The first trend decreases sharply in 1976, then increases slightly in 1993. Trend 2 seems to be increasing continuously from 1965 to the present, taking a short dip in the late 2000s. The results of the sequential F-test are shown in Figure 40 for the Gulf of Alaska. The regimes for each of the trends produced by the DFA are depicted by the red line in the left-hand plots. Two regime shifts were detected for both trends. Trend 1 had shifts occurring in 1976 and 1993. The second trend

Table 9: Gulf of Alaska DFA model selection results.

R	m	logLik	delta.AICc	Ak.wt	Ak.wt.cum
unconstrained	3	-91.9	0	0.81	0.81
unconstrained	4	-67.3	3.0	0.19	1.00
unconstrained	5	-48.5	16.0	0.00	1.00
unconstrained	2	-144.6	52.2	0.00	1.00
unconstrained	1	-190.5	90.2	0.00	1.00
diagonal and unequal	5	-471.5	425.8	0.00	1.00
diagonal and unequal	4	-548.2	546.4	0.00	1.00
diagonal and unequal	3	-589.8	595.5	0.00	1.00
equalvarcov	5	-651.0	747.0	0.00	1.00
diagonal and unequal	2	-683.5	747.9	0.00	1.00
diagonal and equal	5	-653.5	749.4	0.00	1.00
equalvarcov	4	-676.4	766.3	0.00	1.00
diagonal and equal	4	-679.8	770.7	0.00	1.00
equalvarcov	3	-725.6	832.1	0.00	1.00
diagonal and equal	3	-726.9	832.5	0.00	1.00
equalvarcov	2	-769.9	887.0	0.00	1.00
diagonal and equal	2	-779.0	903.1	0.00	1.00
diagonal and unequal	1	-790.5	926.1	0.00	1.00
equalvarcov	1	-836.3	985.5	0.00	1.00
diagonal and equal	1	-845.9	1002.7	0.00	1.00

had a shift occur in 1980, and another in 1990.

Factors influencing observed trends: The well-documented regime shift in the late 1970s was linked with a broad scale change in climate such as depicted by the Pacific Decadal Oscillation (Hare and Mantua, 2000; Piatt and Anderson, 1996). The 1990 and 1993 shifts documented here occurred during a time of sequential El Niño or neutral years and positive PDO phase, which may indicate a response to ocean climate. However, the shifts shown in Trends 1 and 2 are in opposite direction, indicating a shift toward values before the late 70s shift in Trend 1 and farther away in Trend 2. Factors causing these trends are currently unknown.

Implications: The DFA does not provide support for a recent regime shift.

Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys in the Gulf of Alaska, 1993-2015

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Last updated: August 2016

Description of indicator: This index provides a measure of the overall biomass of benthic, demersal, and semi-demersal fish and invertebrate species. We obtained catch-per-unit-effort (CPUE in kg ha^{-1}) of fish and major invertebrate taxa for each successful haul completed during standardized bottom trawl surveys on the Gulf of Alaska shelf (GOA), 1993-2015. Total CPUE for each haul was computed as the sum of the CPUEs of all fish and invertebrate taxa. To obtain an index of average CPUE by year, we modeled log-transformed total CPUE (N = 6333 and 1561 hauls in the western and eastern GOA, respectively) as smooth functions of depth, alongshore distance and sampling stratum with year-specific intercepts using Generalized Additive Models following (Mueter et al., 2002). Hauls were weighted based on the area represented by each stratum. To avoid biases due to gear and vessel issues, data prior to the 1993 survey was not included in the analysis.

Status and trends: Total log(CPUE) in the western GOA varied over time with lowest abundances estimated to have occurred in 1999 and 2001, but with no significant trend from 1993 to 2015. CPUE in the eastern GOA significantly increased over time (Figure 41, Simple linear regression, t=3.102, p=0.0146).

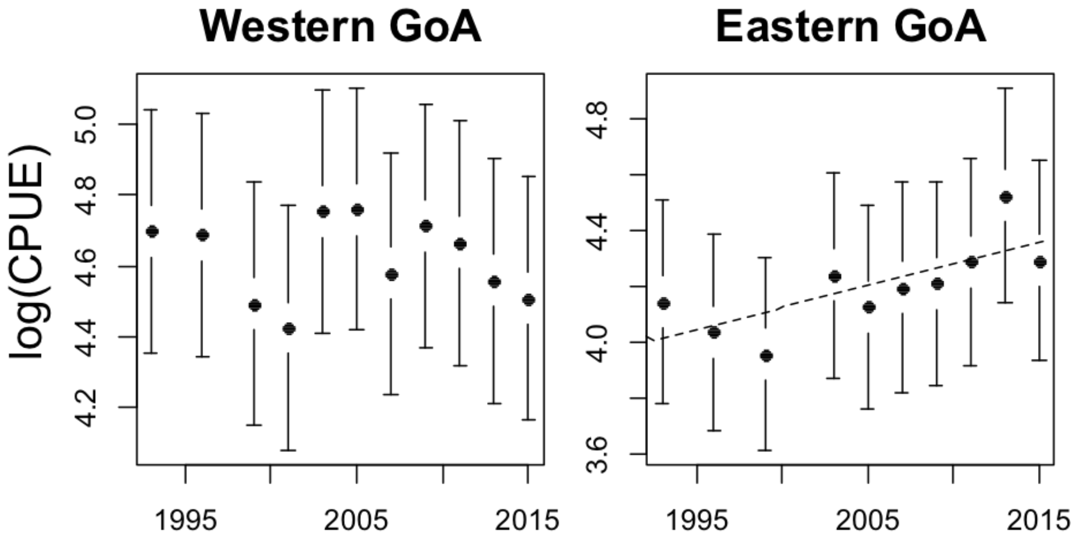

Figure 41: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from in the western Gulf of Alaska (west of 147° W) by survey year with approximate 95% confidence intervals. Estimates were adjusted for differences in depth and sampling locations (alongshore distance) among years. Linear trend in eastern GOA based on least squares regression (t = 3.102, p = 0.0146).

Factors influencing observed trends: Commercially harvested species account for over 70% 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. Increases in CPUE in the GOA between 1999/2001 and 2003 were largely due to a substantial increase in the abundance of arrowtooth flounder, which accounted for 43% of the total survey biomass in 2003 in the western GOA. The significant increase in total CPUE in the eastern GOA was associated with increases in arrowtooth flounder, several rockfish species, Pacific hake, and spiny dogfish.

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 or has increased over recent decades.

Average Local Species Richness and Diversity of the Gulf of Alaska 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 western (wGOA) and eastern Gulf of Alaska (eGOA). 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 Gulf of Alaska were based on 76 fish and common invertebrate taxa that have been consistently identified since the early 1990s. Indices were computed following (Mueter et al., 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) and depth with year-specific intercepts. In addition to trends in the indices over time, we mapped average spatial patterns for each index across the survey region.

Status and trends: Richness and diversity were generally higher in the eastern Gulf of Alaska than in the western Gulf with, on average, 2-3 additional species per haul in the east (Figure 42). Richness has been relatively stable in the western Gulf with relatively low richness in recent years. Local species richness in the eastern Gulf increased substantially in 2013, but declined again in 2015. Diversity in the eGOA has been declining since 2007 (Figure 42). Both richness and diversity tend to be highest along the shelf break and slope (Figure 43), with richness peaking at or just below the shelf break (200-300m), and diversity peaking deeper on the slope, as well as in shallow water ($<$ 100m).

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. 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 42) and spatial patterns (Figure 43) in species diversity differ from those in species richness. Diversity typically increases with species richness and decreases when the abundance of dominant species increases. For example, the decreasing trend in diversity in the eGOA since 2007 appears to be due to an increase in the abundance and dominance of a few species, including arrowtooth flounder, walleye pollock and Pacific ocean perch. The unusual increase in local species richness in the eastern GOA in 2013 appears to have resulted from increased catches of a number of fish and invertebrate species, including walleye pollock, several Sebastes species, skates, grenadiers, sea stars and others.

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

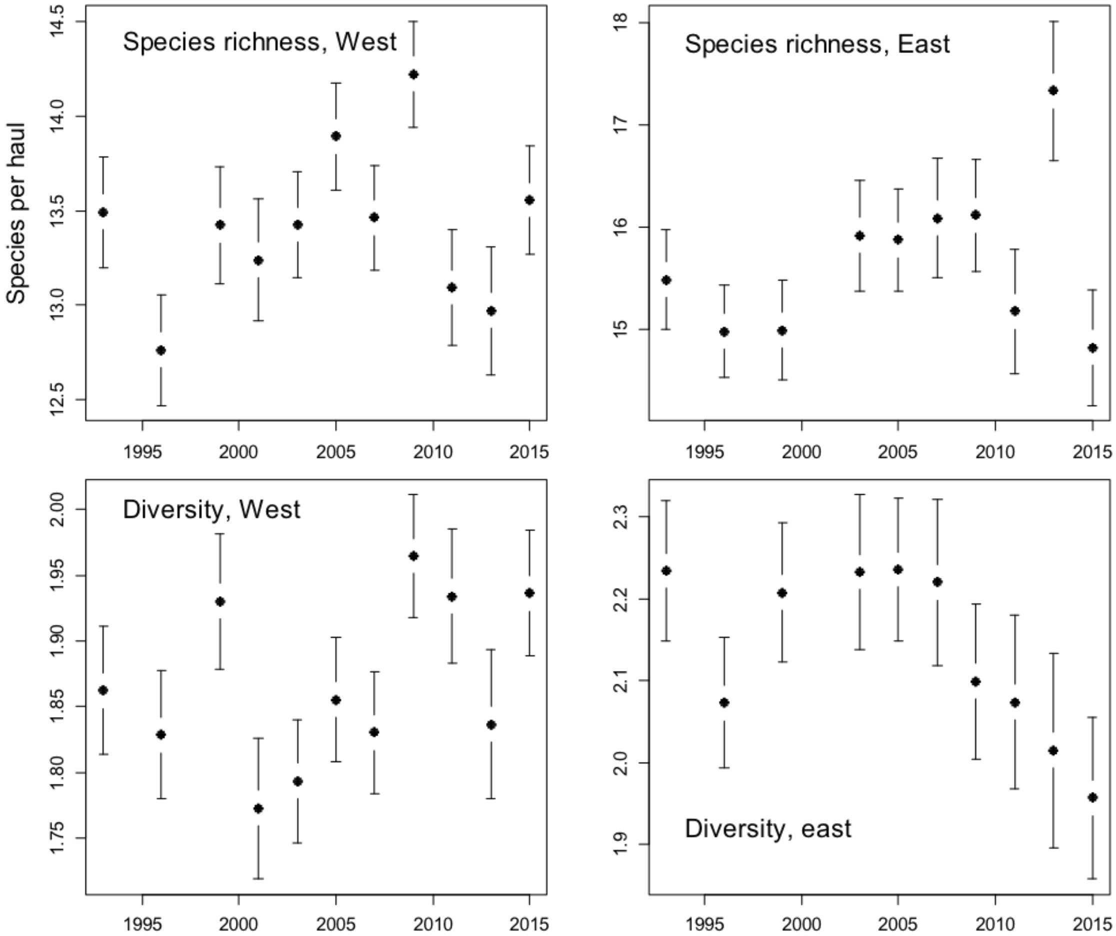

Figure 42: Model-based annual averages of species richness (average number of species per haul, top panels) and species diversity (Shannon index, bottom panels), 1993-2015, for the Western (left) and Eastern (right) Gulf of Alaska based on 76 fish and invertebrate taxa collected by standard bottom trawl surveys with 95% pointwise confidence intervals. Model means were adjusted for differences in depth, date of sampling, and geographic location.

or functional groups (McCann, 2000). To our knowledge, such a link has not been established for marine fish communities.

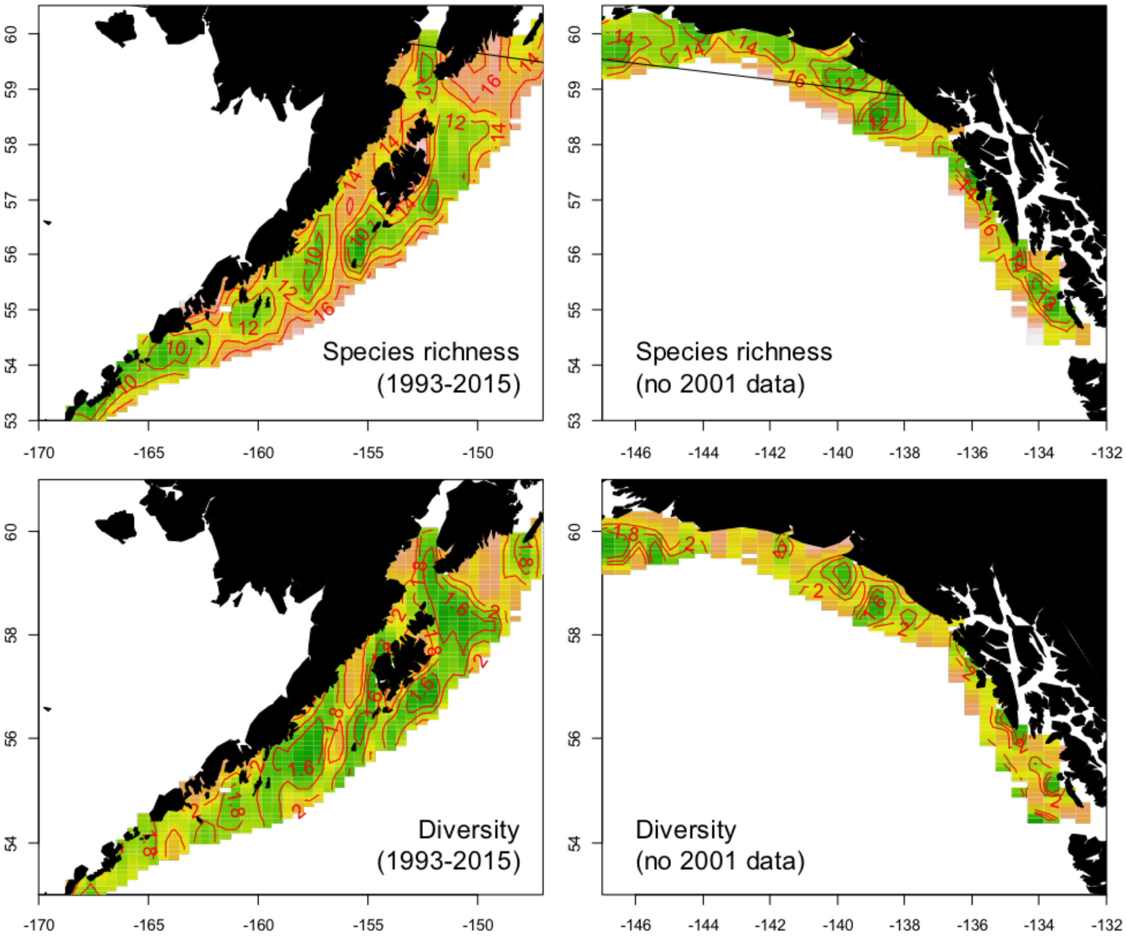

Figure 43: Average spatial patterns in local species richness (species per haul, top panels) and Shannon diversity (bottom panels) for the Western (left) and Eastern (right) Gulf of Alaska.

Disease Ecology Indicators

"Mushy" Halibut Syndrome Occurrence

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Last updated: October 2016

Description of indicator: The condition was first detected in Gulf of Alaska halibut in 1998. Increased prevalence occurred in 2005, 2011, and 2012. It is most often observed in smaller halibut of 15-20 lbs in the Cook Inlet area, but has also been noted in Kodiak, Seward, and Yakutat. Alaska Department of Fish and Game (ADF&G) describes the typical condition consisting of fish having large areas of body muscle that are abnormally opaque and flaccid or jelly-like. The overall body condition of these fish is usually poor, and often they are released because of the potential inferior meat quality.

Status and trends: ADF&G received a few reports of "mushy" halibut during the 2015 sport fishing season (`http://www.adfg.alaska.gov/sf/fishingreports/`).

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

Implications: The recurrence in "mushy" halibut, particularly relative to its absence in 2013 and 2014, may indicate that foraging conditions for young halibut were less favorable during the past year.

Ichthyophonus Parasite

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Last updated: September 2016

Description of indicator: *Ichthyophonus*, a non-specific fungus-like protozoan fish parasite, has caused epizootic events among economically important fish stocks including herring and salmon. The parasite has been documented in over 100 fish species, and infection can result in reduced growth, stamina, and overall fish health. In some cases, individuals show external symptoms including black papules, white nodules on heart tissue, muscle ulcers, and roughening of the skin.

Status and trends: In 2014, the FAST Lab examined prevalence and load of the parasite *Ichthyophonus* in Pacific halibut (*Hippoglossus stenolepis*), and found that of the fish sampled in lower Cook Inlet, 23% (71/315) had *Ichthyophonus* in 2012, and 29% (73/248) had *Ichthyophonus* in 2013 (Grenier 2014). The 2014 FAST Lab study found that the parasite infected heart tissues, was never found in liver, spleen, or kidney tissues, and was more prevalent in older fish. A Pepsin digestion assay was developed to assess the degree of the infection and found that load varied widely among infected fish with 6 to 1,245 *Ichthyophonus schizonts* per gram of heart tissue.

Factors influencing observed trends: Findings did not support the hypothesis that reduced size-at-age may be caused by Ichthyophonus.

Implications: This project lays important methodological groundwork for the expansion of groundfish fitness research to the Bering Sea Aleutian Islands and Gulf of AK. Current FAST Lab research is investigating *Ichthyophonus* prevalence in three Alaskan fish species, Pacific halibut, Pacific cod (*Gadus macrocephalus*), and Alaska pollock (*Gadus chalcogrammus*), in three Alaskan port towns (Homer, Seward, and Whittier). This work employs a length-based sampling design as well as the use of bioelectric impedance analysis (BIA) to allow assessment of *Ichthyophonus* impacts on fish condition, and also considers size-at-age, host immune response (histolopathological methods), parasite load (qPCR), and changes in heart mass. As with our earlier research, we are working cooperatively with the ADF&G port sampling program and the charter halibut fleets.

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 Non-Target Species Catch

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Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the Eastern Bering Sea (EBS), Gulf of Alaska (GOA) and Aleutian Islands (AI) ecosystems. In previous years we included the catch of “other” species, “non-specified” species, and forage fish in this contribution. However, stock assessments have now been developed or are under development for all groups in the “other species” category (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), some of the species in the “non-specified” group (giant grenadier, other grenadiers), and forage fish (e.g., capelin, eulachon, Pacific sand lance, etc.), therefore we no longer include trends for these species/groups here (see AFSC stock assessment website at `http://www.afsc.noaa.gov/refm/stocks/assessments.htm`). Invertebrate species associated with habitat areas of particular concern, previously known as HAPC biota (seapens/whips, sponges, anemones, corals, and tunicates) are now referred to as structural epifauna. Starting with the 2013 Ecosystem Considerations Report, the three categories of non-target species we continue to track here are:

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

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

Status and trends: The catch of Scyphozoan jellyfish in the GOA has been variable from 2003-2015, with years of high catch preceded or followed by years of reduced catch (Figure 44). Scyphozoan jellies are primarily caught in the pollock fishery. The catch of structural epifauna in the GOA has been variable, but generally low in comparison to the EBS and AI. Sea anemones comprise the majority of the structural epifauna catch, and they are caught primarily in the flatfish and Pacific cod fisheries. The catch of assorted invertebrates in the GOA has been variable and shown little trend. Sea stars are caught primarily in the Pacific cod and flatfish fisheries and have dominated the assorted invertebrate catch, accounting for more than 90% of the total in each year. The catch of assorted invertebrates in 2015 increased 69% from 2014, and was the highest over the time period 2003-2015.

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 jellies including temperature, sea ice phenology, wind-mixing, ocean currents, and prey abundance (Brodeur et al., 2008).

Implications: The catch of structural epifauna and assorted invertebrates in all three ecosystems is very low compared with the catch of target species. Structural epifauna 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 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 (PurcellSturdevant2001), and additionally, jellyfish may prey upon the early life history stages (eggs and larvae) of fishes (Purcell and Arai, 2001; Robinson et al., 2014).

Seabird Bycatch Estimates for Groundfish Fisheries in the Gulf of Alaska, 2007-2015

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Description of indicator: This report provides estimates of the numbers of seabirds caught as

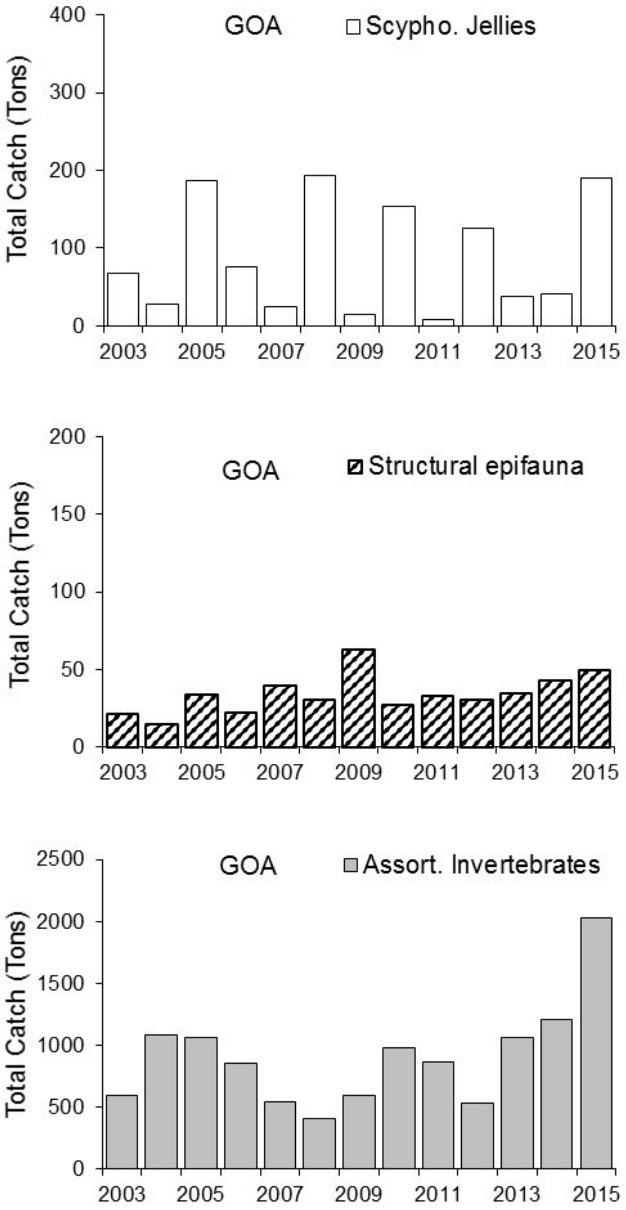

Figure 44: Total catch of non-target species (tons) in the GOA groundfish fisheries (2003-2015). Note the different y-axis scales between species groups.

bycatch in commercial groundfish fisheries operating in federal waters in the Gulf of Alaska 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.

Table 10: **Estimated** seabird bycatch in Gulf of Alaska 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	17	0	0	0	10	0	28	0	0
Black-footed Albatross	180	273	49	62	215	141	432	269	350
Laysan Albatross	0	168	89	84	163	17	69	32	41
Northern Fulmar	1439	870	602	174	874	19	260	51	88
Shearwaters	31	0	0	0	61	0	56	0	5
Cormorant	0	0	0	0	0	0	0	0	28
Gull	560	182	366	279	615	50	136	157	287
Auklets	0	0	0	0	0	0	0	6	49
Other Alcid	0	0	0	0	0	0	0	39	0
Unidentified	48	266	187	0	9	33	7	0	34
Grand Total	2275	1759	1292	600	1946	260	988	553	883

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 bycaught in Gulf of Alaska fisheries in 2015 increased from that in 2014, but remained below the 2007-2014 average of 1209 (Table 10). Black-footed albatross and gulls were the most common species group bycaught. This marked the third year in a row that greater than average black-footed albatross were bycaught. Few Northern fulmars were caught, relative to the numbers from 2007-2011. More cormorants and auklets were caught in 2015 than in any other year since the time series began in 2007. The estimated numbers of birds bycaught in the Aleutians exceeded that in the Gulf of Alaska, which typically has a greater number of estimated bycaught birds (Figure 45).

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

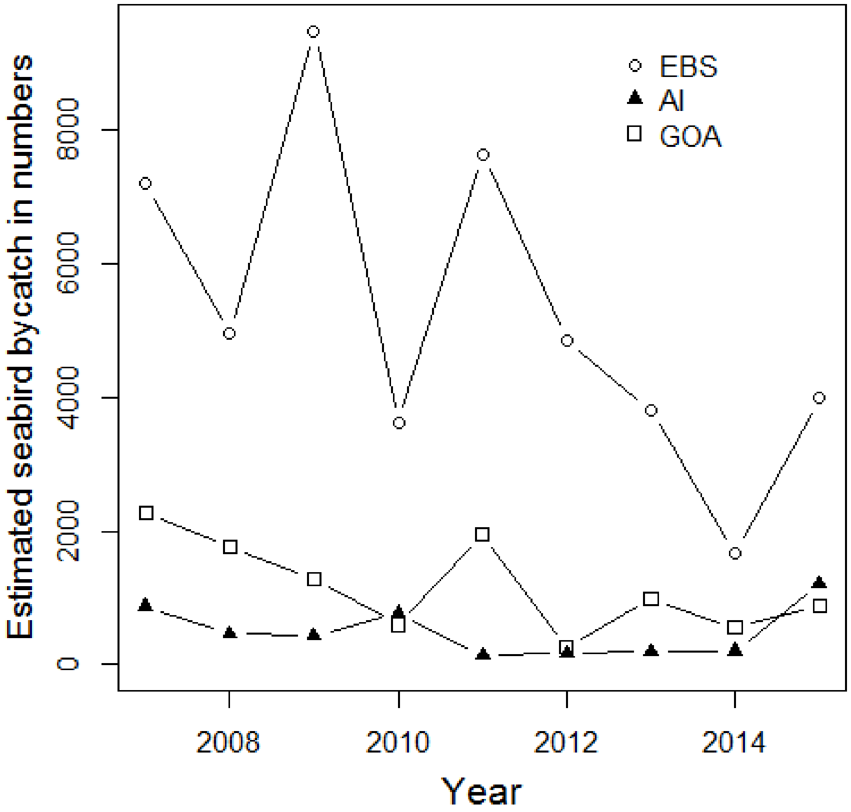

Figure 45: Total estimated seabird bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007 to 2015.

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 10).

Implications: While there was only a slight increase in seabirds bycaught in 2015 relative to the year before, increases was 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

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

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Last updated: October 2016

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 46, Table 11). 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.

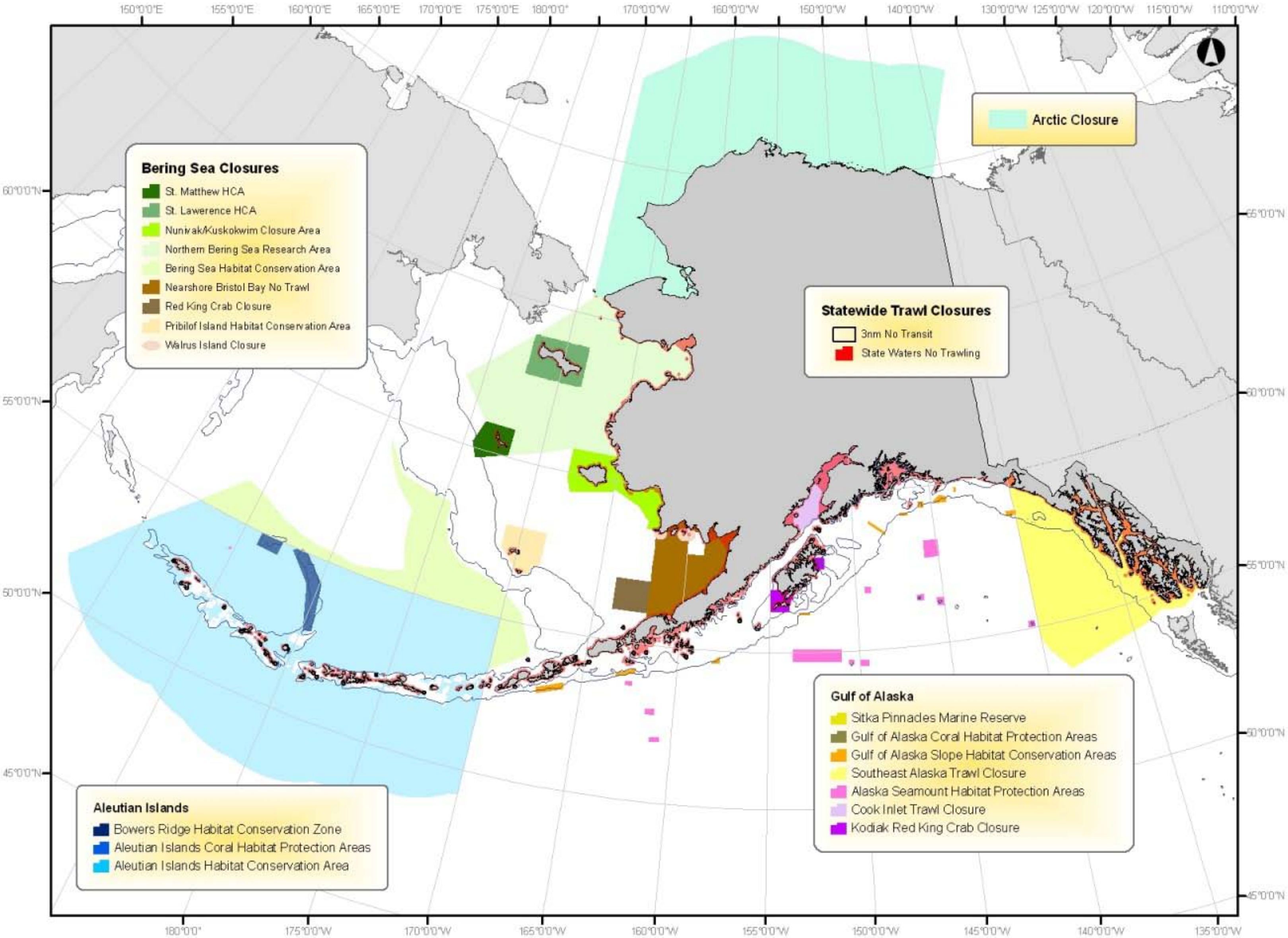

Figure 46: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Table 11: Groundfish trawl closure areas, 1995-2009. License Limitation Program (LLP); Habitat Conservation Area (HCA); Habitat conservation zone (HCZ).

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. Federal waters in Marmot Bay are closed year round to vessels fishing with nonpelagic trawl. 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`

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:

1. Stock has known status determinations:
   (a) overfishing = 0.5
   (b) overfished = 0.5
2. Fishing mortality rate is below the "overfishing" level defined for the stock = 1.0

Table 12: 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	N/A	Yes	No	Unk	Undef	
NPFMC	FSSI	36	0	36	0	0	0	1	32	3	0	0
NPFMC	NonFSSI	29	0	29	0	0	0	0	3	26	0	0
	Total	65	0	65	1	0	0	1	35	29	0	0

3. Biomass is above the "overfished" level defined for the stock = 1.0
4. Biomass is at or above 80% of the biomass that produces maximum sustainable yield (B_{MSY}) = 1.0 (this point is in addition to the point awarded for being above the "overfished" level)

The maximum score for each stock is 4.

In the Alaska Region, there are 36 FSSI stocks and an overall FSSI of 144 would be achieved if every stock scored the maximum value, 4 (Tables 12 and 13). Over time, the number of stocks included in the FSSI has changed as stocks have been added and removed from Fishery Management Plans (FMPs). Prior to 2015 there were 35 FSSI stocks and maximum possible score of 140. To keep FSSI scores for Alaska comparable across years we report the total Alaska FSSI as a percentage of the maximum possible score (i.e., 100%). Additionally, there are 29 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement (Tables 12 and 14).

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 12). 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 13). 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 47).

Factors influencing observed trends: One point was lost from last year 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)

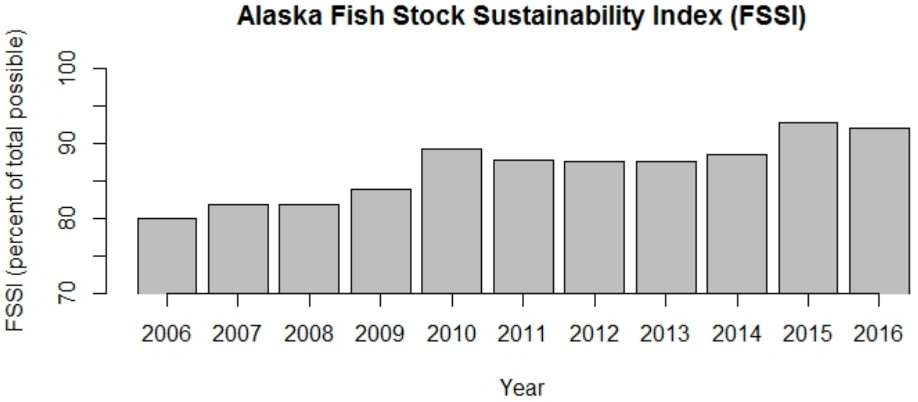

Figure 47: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2016. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 on it is 144. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

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 13: 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 13: 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 13, 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 thershallow-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 14: 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, Gulf of Alaska

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Description of indices: Total annual surplus production (ASP) of 12 groundfish on the Gulf of Alaska (GOA) shelf from 1978-2014 was estimated by summing annual production across major commercial groundfish stocks for which assessments were available (Table 15). These species represent at least 75% 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 15: Species included in computing annual surplus production in the Bering Sea and Gulf of Alaska.

Stocks
Walleye Pollock (*Gadus chalcogrammus*)
Pacific Cod (*Gadus macrocephalus*)
Arrowtooth Flounder (*Atheresthes stomias*)
Northern Rock Sole (*Lepidopsetta polyxystra*)
Southern Rock Sole (*L.bilineata*)
Flathead Sole (*Hippoglossoides spp.*)
Dover Sole (*Microstomus pacificus*)
Pacific Ocean Perch (*Sebastes alutus*)
Northern Rockfish (*S. polyspinus*)
Blackspotted Rockfish (*S. melanostictus*)
Dusky rockfish (*S. ciliatus*)
sablefish (*Anoplopoma fimbria*)

Status and trends: The resulting indices suggest high interannual variability in groundfish production in the GOA (Figure 48), with very high ASP in 1979/1980 associated with a number of strong recruitment events for multiple groundfish species after the 1976/77 oceanographic regime shift. ASP was lowest (including negative ASP) in the early 1980s and the early- to mid-1990s. The time series is characterized by occasional 1-3 year periods of high (> 400,000 t) surplus production that far exceed surplus production of 200,000 t or less in most years. Recent peak years include 2001/02, 2007-09 and 2014. Total exploitation rates for the groundfish complex ranged from 2.5 5.8% in the GOA (Figure 48). Overall exploitation rates were relatively stable since over recent decades with occasional peaks such as in 1998/99 and in 2014.

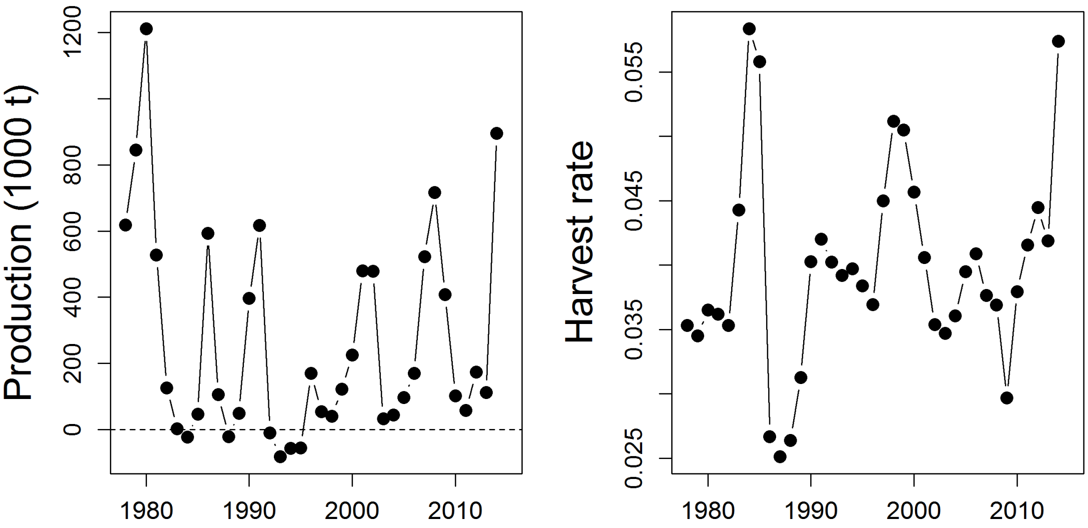

Figure 48: Total annual surplus production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska, and total harvest rate (total catch / beginning-of-year biomass, each summed across all major groundfish species).

Factors causing trends: Annual Surplus Production is an estimate of the sum of new growth and recruitment minus deaths from natural mortality (i.e. mortality from all non-fishery sources) during a given year. It is highest during periods of increasing total biomass (e.g. 2001-03, 2007-2010) and lowest during periods of decreasing biomass (e.g. 1992-95, 2003-06). 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 BMSY, which is the case for many species in the GOA management area. Exploitation rates are primarily determined by management and reflect a relatively precautionary management regime with rates that have mostly averaged less than 5% for the total groundfish complex. Low overall exploitation rates are largely a result of the fact that arrowtooth flounder dominate biomass in the GOA and have very low exploitation rates.

Implications: Under certain assumptions, aggregate surplus production can provide an estimate of the long-term maximum sustainable yield of these groundfish complexes (Mueter and Megrey 2006, Figure 49). 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 49). The estimated maximum sustainable yield for the groundfish complex (12 species) was 334,000 t.

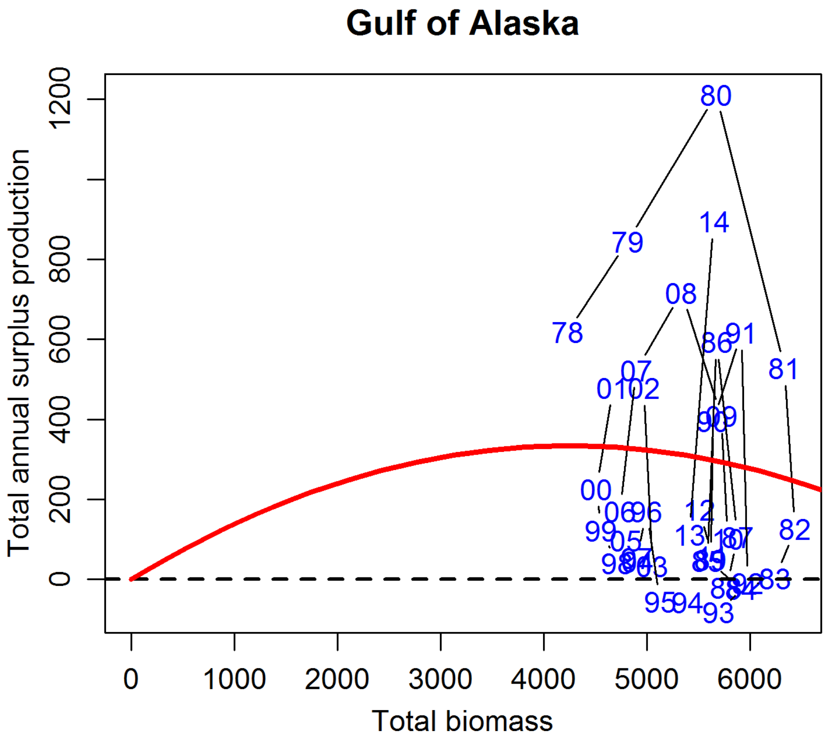

Figure 49: Estimated annual aggregated surplus production against total biomass of major commercial species with fitted Graham-Schaefer curve. Units on both axes are in 1000 t.

Humans as Part of Ecosystems

Groundfish Fleet Composition

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Last updated: September 2016

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 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: Figure 50 shows the number of vessels by gear type in the Gulf of Alaska. The total number of vessels participating in federally-managed fisheries Alaska-wide 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.

Vessel counts before and after 2003 may not be directly comparable due to changes in fishery monitoring and reporting methods. The Catch Accounting System (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.

Gulf of Alaska

- Trawl vessels in the Gulf of Alaska primarily comprise vessels fishing for pollock and/or cod. Participation by trawl vessels declined gradually from 228 vessels in 1995 to 94 in 2006; vessel counts since then have fluctuated between 80 to 90 vessels annually.
- Counts of sablefish hook and line vessels declined from over 1,000 in 1994 to 656 in 1995, the first year of management under the IFQ program. Participation levels post-IFQ implementation have declined steadily to just under 300 vessels in the last several years.
- Opportunities for entry level harvesters may help account for increased participation by jig

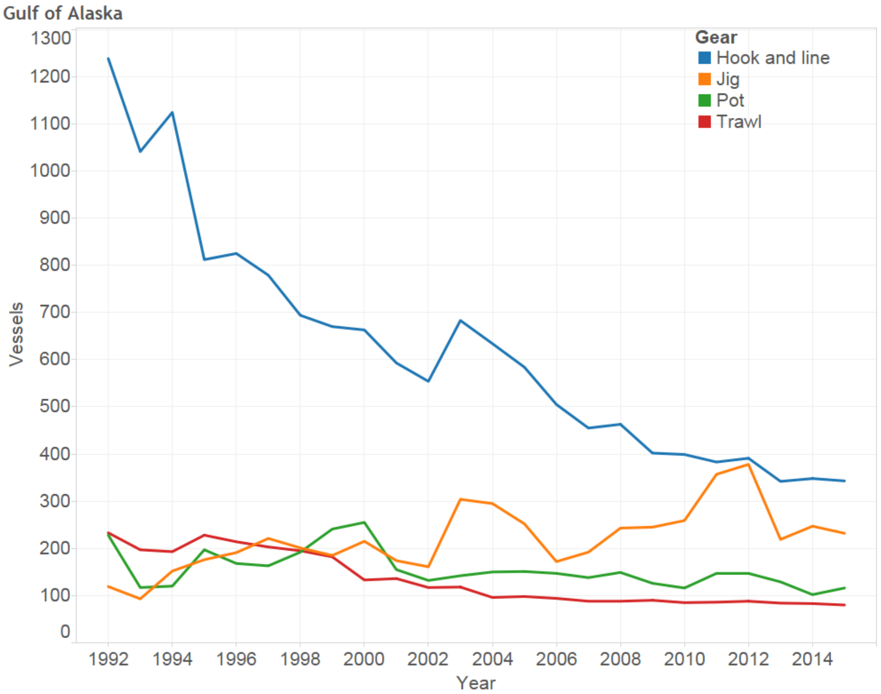

Figure 50: Number of vessels participating in the groundfish fisheries in the Gulf of Alaska by gear type, 1994-2014.

vessels in recent years. These include the Central Gulf of Alaska Rockfish Pilot Program (implemented in 2007 and superseded by the Rockfish Program in 2012), which allocated quota for rockfish primary species to an entry level longline sector; and, in 2011, Amendment 86 to the GOA Groundfish FMP, which exempts jig vessels from LLP licensing requirements in the Western and Central Gulf.

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 Gulf of Alaska

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Description of indicator: Human population and unemployment, the social indices presented in this report, are significant factors in the Gulf of Alaska (GOA) ecoregion, 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 Gulf of Alaska (GOA) (including Southeast Alaska, Cook Inlet, and Prince William Sound). The 98 GOA fishing communities included in analysis comprise most of the population that resides along Gulf of Alaska coast. Communities were included if they are within 25 miles of the coast, and/or based on their historical involvement in Gulf of Alaska fisheries, or if they were included in one of the North Pacific Fishery Management Councils GOA fishery programs, such as the Community Quota Entity program. Also, as of 2015 there was no population data for several communities that were previously included in this report. They were not included in analysis because of insufficient data, however, they are mentioned below. 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: As of 2015 the population of GOA was 450,461 or 151,553 excluding Anchorage. The overall population of GOA communities has increased steadily since 1880 with the greatest population increase of 194.2% occurring between 1950 and 1960 (Table 16 and Figures fig.santosgoats,fig.santosgoacompare). This figure includes Anchorage, the largest major city of Alaska, where the majority of population increase has occurred and where 40% of Alaskas population currently resides (ADLWD 2016a). With Anchorage excluded, the greatest population increase of 46.1% occurred between 1980 and 1990 in the GOA (decadal increments). 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 GOA and Alaska State. Between 1990 and 2015, the population of GOA increased 31.5% (30.4% excluding Anchorage) which is consistent with, yet lower than, State trends during this time period (34.1%).

Despite the general population trend in the GOA (based on aggregated data), 43% of communities experienced population decline between 1990 and 2015. The communities of Annette Island, Cube

Table 16: Gulf of Alaska (GOA) population 1880-2015. Percent change rates are decadal until 2010.

Year	Alaska	% change	GOA	% change	GOA excluding Anchorage	GOA % change excluding Anchorage
1880	33426		3151		3151	
1890	32052	-4.11	7469	137.04	7469	137.04
1900	63592	98.4	10499	40.57	10499	40.57
1910	64356	1.2	13394	27.57	13394	27.57
1920	55036	-14.48	17208	28.48	15352	14.62
1930	59278	7.71	21633	25.71	19356	26.08
1940	72524	22.35	29213	35.04	25718	32.87
1950	128643	77.38	41960	43.63	30706	19.39
1960	226167	75.81	123456	194.22	40623	32.3
1970	302583	33.79	181414	46.95	56872	40
1980	401851	32.81	253961	39.99	79530	39.84
1990	550043	36.88	342521	34.87	116183	46.09
2000	626932	13.98	400222	16.85	139939	20.45
2010	710231	13.29	437413	9.29	145587	4.04
2015	737625	3.86	450461	2.98	151553	4.1

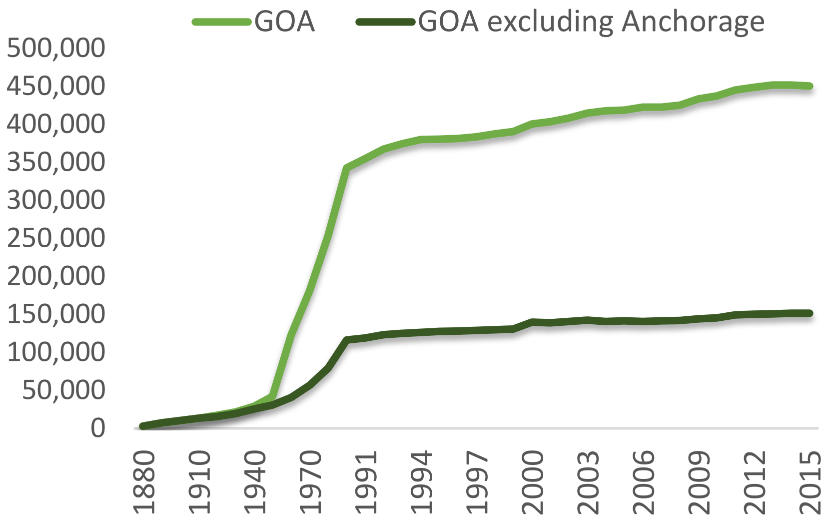

Figure 51: GOA population.

Cove, Meyers Chuck, and Hobart Bay had no population data as of 2010 and were not included in this report. 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 2016b) and as of 2015, 28% of the population in the GOA 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) and the majority of population growth that has occurred in Alaska and the GOA is of the Caucasian demographic

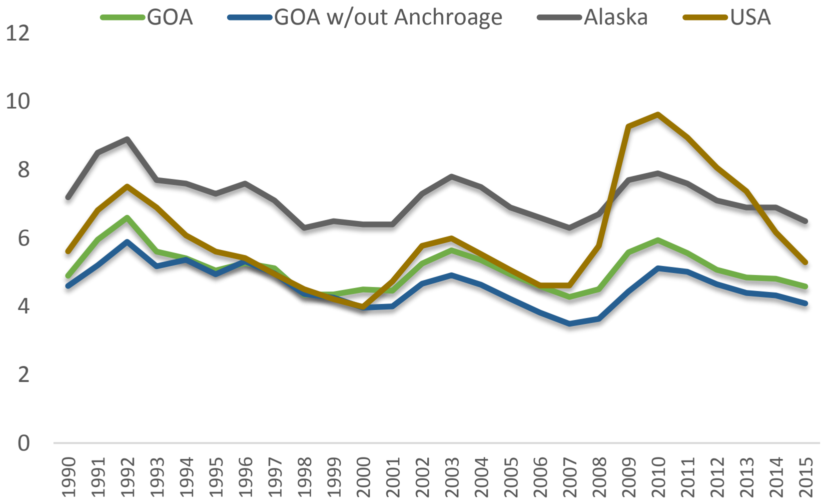

Figure 52: Unemployment rates for GOA, Alaska, and USA.

(ADLWD 2016b).

Unemployment rates in the GOA, from 1990 to 2015, were lower than State and national rates (Figure 53) with the exception of the year 2000 when the GOA unemployment rate was 4.5%; higher than the national rate of 4.0%. However, if Anchorage is excluded, GOA had a slightly lower rate of 3.97%. Overall, the GOA employment rate including Anchorage is higher than when Anchorage is excluded with the exception of the years 1994-1998 where the rates are almost equal. GOA unemployment rates reflect State and national trends overall as unemployment was highest in 1992, and peaked in 2003 and 2010.

Factors influencing observed trends: Overall population increase in GOA between 1990 and 2015 (31.5%) was consistent with 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 Alaskas 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%), and the natural growth rates of the GOA had a range of 0.0- 1.5% (ADLWD 2016b). In regard to migration, 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 and the GOA region are the result of changes in resource extraction and military activity (Williams 2004). Historically, the gold rush of the late 19th century doubled the States population by 1900, and later WWII activity and oil development fueled the population growth (ADLWD 2016b). However, certain areas have experienced population shifts at various periods, particularly those with military bases. For example, the population of Kodiak declined in the 1990s because of Coast Guard cut-backs (Williams 2006). The fishing industry

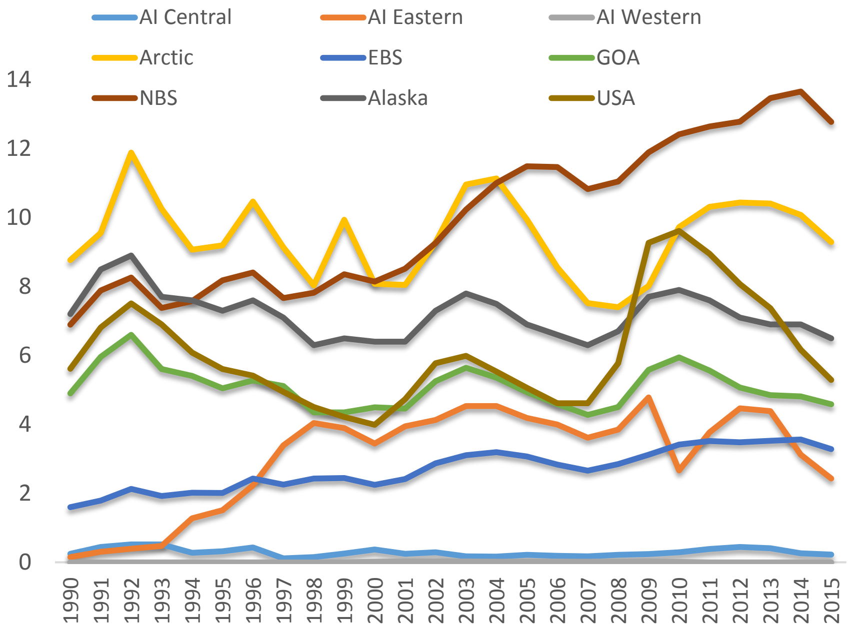

Figure 53: Unemployment rates for all regions, Alaska, and USA.

also influences community population. Kodiak and the Aleutian Islands have the most transient populations because of the seafood processing industry (Williams 2004). Some GOA communities that experienced fishery permit loss subsequently experienced population decline (Donkersloot and Carothers 2016). Also, reduction of jobs in the lumber industry have caused population decrease. For example, the Whitestone Logging Camp population fluctuated from 164 to 0 between 1990 and 2006, increased to 17 in 2010, then decreased to zero in subsequent years up to 2015 (ADLWD. 2016a). 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 peak occurred following completion of the pipeline, during the oil bust of the late 1980s, and during the great recession of 2007-2009 (ADLWD 2016c) . However, during the great recession, Alaskas employment decreased only 0.4% whereas the national drop was 4.3% partly because of the jobs provided by the oil industry (ADLWD 2016d). With the oil industry headquarters mainly located in Anchorage, the GOA region would be most impacted by job loss in the industry. The GOA region had the second highest unemployment rates (Arctic region had highest) between 1990 and 2015 (Figure 3). In the GOA, seafood processing is a major contributor of jobs, despite being mainly comprised of low-wage, non-resident labor, and declines in fish stocks in recent years have reduced the number of available jobs (ADLWD 2016d).

Implications: Population shifts can affect pressures on fisheries resources, however inferences about human impacts on resources should account for economic shifts and global market demand for seafood and other extractive resources of the ecoregion. As stated earlier, the majority of population increases in the GOA are due to increased net migration rather than natural increase, and it has mainly occurred in urban areas as populations in many small communities are declining. Fisheries contribute to community vitality of the GOA 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). Many larger communities of the GOA region are highly engaged in fisheries and depend upon fish processing industries to support their economies, such as in Kodiak, with both a resident and transient labor force. Changes in groundfish policy and management, such as increased regulations, may have implications for GOA community economies in both remote and urban areas.

With a large concentration of Alaskas population in Anchorage, it has become the major hub for goods and services, trade, and travel. Services such as medical, business and technology support and entertainment attract people to the area seeking services, and employment and education opportunities. The population growth of Anchorage has also contributed to sprawl into the Matanuska-Susitna valley. According to the U.S. Census Bureau of 2010, the population density of the Matanuska-Susitna borough was 3.6, whereas the State as a whole was 1.2. This regional growth has increased regional hunting and fishing pressures, recreational demand, and reduced available agricultural land because of high speculative land values (Fischer 1976). Rapid development of the Matanuska-Susitna valley may have impacts on the local watersheds fish stocks and habitat, which should be monitored over time.

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Appendix

Table 17: Summary of Alaska Fisheries Science Center surveys as of May 2016 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	