# Ecosystem Considerations 2017

## Status of the Gulf of Alaska Marine Ecosystem

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November 13, 2017
North Pacific Fishery Management Council
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# Western Gulf of Alaska 2017 Report Card

- The Gulf of Alaska in 2017 remained **characterized by warm conditions** although conditions have moderated since the extreme heat wave of 2014–2016. The **PDO remains in a positive pattern but with lower amplitude**.
- The **freshwater runoff into the GOA appears to have been greater than normal during the fall of 2016 and somewhat less than normal in summer 2017**, with implications for the baroclinic component of the Alaska Coastal Current.
- **Mesozooplankton biomass measured by the continuous plankton recorder** has often shown a largely biennial trend, however biomass **remained greater than average in 2014 – 2016**. 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** which have shown lower than expected marine survival for the 2015 and 2016 outmigration year classes.
- **Copepod community size remained small for the fourth consecutive year**. The prevalence of small copepods fits predictions of warm conditions favoring small copepods. This suggests that **planktivorous predators may have had to work harder to fill nutritional needs from the numerous, but small, prey items**.
- Bottom trawl **survey biomass of motile epifauna** was **below its long-term mean for the first time since 2001**. The increase from 1987 to 2001 was driven by hermit crabs and brittle stars, which continue to dominate the biomass. Octopus catches, which were record high in 2015, declined to a low not seen since 1990.
- Trends in capelin as sampled by seabirds and groundfish have indicated that **capelin were abundant from 2008 to 2013, but declined in during the warm years of 2015–2016**. Their apparent **abundance coincided with the period of cold water temperatures** in the Gulf of Alaska. Preliminary reports suggest that predators were again foraging on capelin in 2017.
- **Fish apex predator biomass during 2017 bottom trawl surveys was at its lowest level in the 30 year time series**, and the recent 5 year mean is below the long-term average. **The trend is driven primarily by Pacific cod and arrowtooth flounder** which were both at the lowest abundance in the survey time series. Pacific halibut and arrowtooth flounder have shown a general decline since their peak survey biomasses in 2003. **Pacific cod has continued to decline from a peak survey biomass in 2009**.
- **Black-legged kittiwakes had moderate reproductive success in 2017** 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. In general, fish-eating seabirds had less successful reproduction in 2017 than mixed fish and plankton-eating seabird species.
- Modelled estimates of **western Gulf of Alaska Steller sea lion non-pups counts were approaching the long-term in 2016**, suggesting conditions had been favorable for sea lions in this area. However, preliminary estimates show a decline in the number of pups from 2015 to 2017 and declines in the number of non-pups in the Cook Inlet, Kodiak, and Semidi area.
- Human populations in the small (<1500 people) fishing communities in the western Gulf of Alaska **have remained stable as a whole since 2000**.

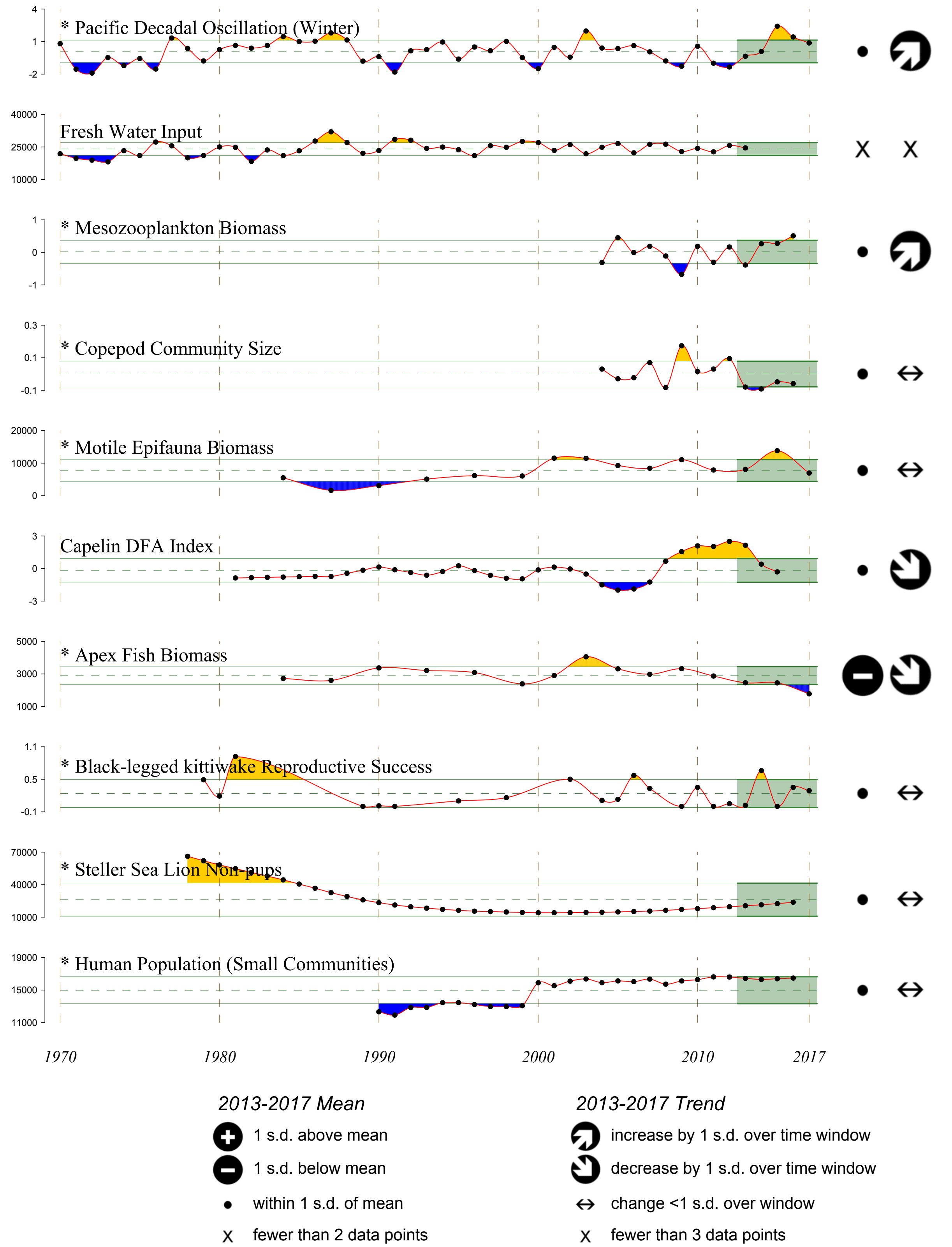


Figure 1: Western Gulf of Alaska ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2017.

# Eastern Gulf of Alaska 2017 Report Card

- The Gulf of Alaska in 2017 remained **characterized by warm conditions** although conditions have moderated since the extreme heat wave of 2014–2016. The **neutral El Niño of last winter has lessened, and La Niña conditions are slightly more favored that neutral for next winter**.
- The **sub-arctic front was farther south than usual**, which was consistent with surface currents. Strong winter winds from the north impelled the PAPA trajectory index to its most southerly latitude since the late 1930s. This represented a substantial change from the northerly surface current pattern during the previous three winters.
- Total **zooplankton density in Icy Strait increased in 2016 relative to the previous three years** but remained lower than the peak values in 2006–2009. Zooplankton were numerically dominated by gastropods and small copepods, while large copepod and euphausiid densities remained below average.
- Also in Icy Strait, the **increase in large and decrease in small copepod abundances in 2016 relative to the previous year** resulted in an increase in copepod community size. However, the low abundances of all copepods **does not indicate substantially improved foraging conditions for planktivorous predators**.
- Bottom trawl **survey biomass of motile epifauna is typically dominated by brittle stars and a group composed of sea urchins, sand dollars and sea cucumbers**. Record catches of hermit crabs influenced the peak biomass estimate in 2013. Catches of many of the more dominant members of this foraging guild were low in 2015. Brittle stars and miscellaneous crabs were the most abundant in 2017.
- A **decrease in estimated total mature herring biomass in southeastern Alaska has been observed since the peak in 2011**. Modeling indicates that the declines in biomass may be related to lower survival.
- Bottom-trawl survey **fish apex predator biomass is currently below its 30-year mean**, following a peak in 2015. **The trend is driven primarily by arrowtooth flounder** which caught in great numbers in 2015. Pacific halibut and sablefish, the next most abundant species in this foraging guild have shown variable but generally stable trends in recent surveys. Pacific cod were at their lowest abundance in the time series in 2017, but had been at their highest relative abundance in 2015.
- **Growth rates of piscivorous rhinoceros auklet chicks were anomalously low in 2015 and 2016**, 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 through 2015**. However, preliminary estimates suggest that non-pup counts declined 12% in 2017 relative to 2015. This unusual recent decline in a long-increasing stock may indicate adverse responses to the marine heat wave of recent years.
- Human populations in the small (<1500 people) fishing communities in the eastern Gulf of Alaska **have remained stable in recent years** following a gradual decline since peak population counts in the mid-1990s.

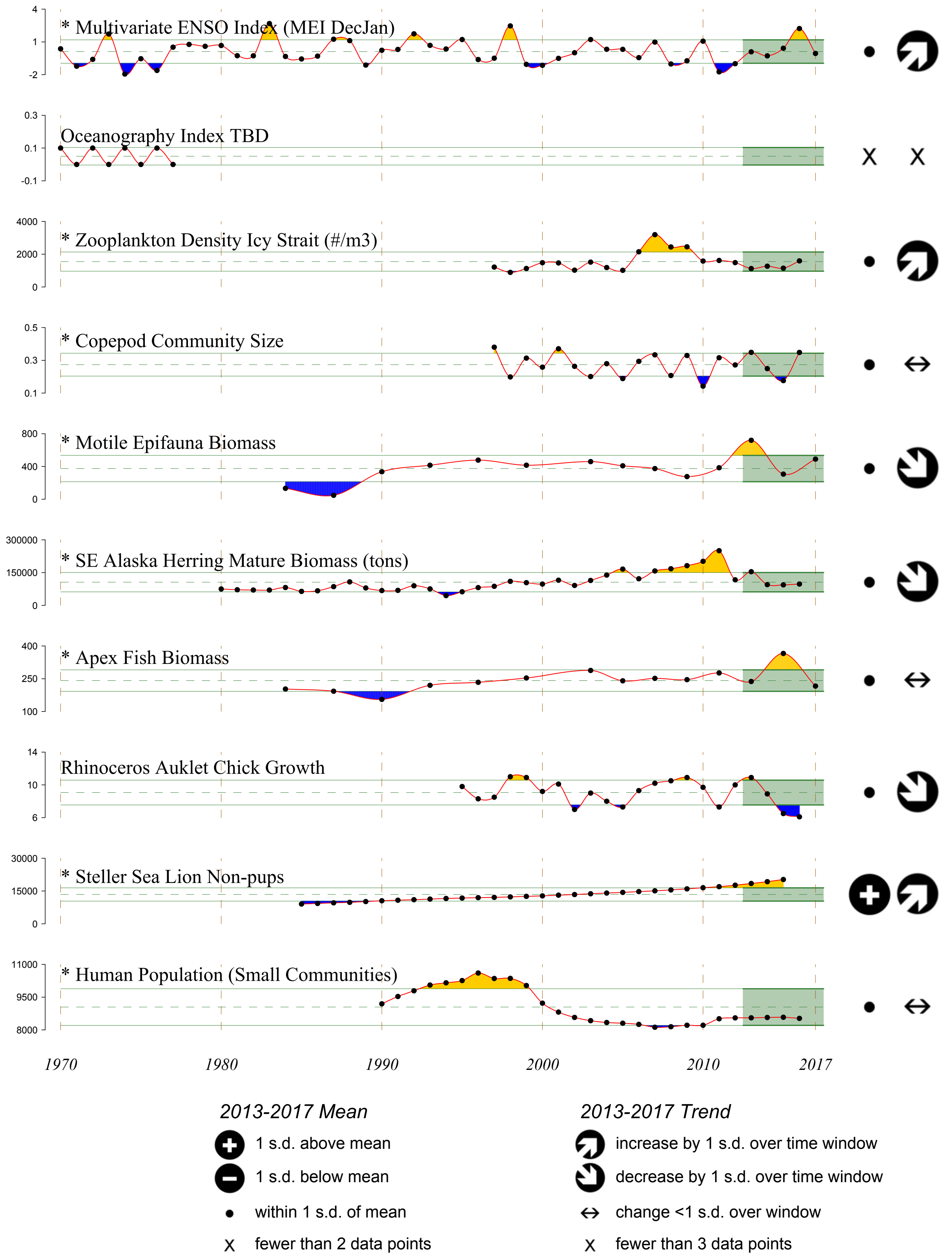


Figure 2: Eastern Gulf of Alaska ecosystem assessment indicators; see text for descriptions. One potential indicator is yet to be determined (TBD). * indicates time series updated in 2017.

# Executive Summary of Recent Trends in the Gulf of Alaska

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

## Physical and Environmental Trends

### North Pacific

- The North Pacific atmosphere-ocean climate system was in a more moderate state during 2016–2017 than during the previous two years (p. 61).
- In particular, the warm sea surface temperature anomalies associated with the extreme marine heat wave of 2014–2016 moderated (p. 56).
- A weak La Niña developed during winter 2016–2017 along with a weaker than normal Aleutian Low (p. 61).
- The Pacific Decadal Oscillation remains positive but with lower amplitude than in recent past years (p. 61).
- The winter of 2016–2017 included a large positive value for the North Pacific Index (NPI). While this sign of the NPI represents a typical atmospheric response to La Niña, its magnitude was disproportionately large considering the weak amplitude of La Niña in late 2016 (p. 61).
- The North Pacific Gyre Oscillation (NPGO) mostly declined from a small positive value in early 2016 to a small negative value in early 2017, implying that flows in the Alaska Current portion of the Subarctic Gyre and the California Current weakened slightly (p. 61).
- Climate models used for seasonal weather predictions indicate neutral to weak La Niña conditions for the winter of 2017–2018 (p. 63).
- A continuation of warm sea surface temperatures across most of the North Pacific is predicted through the end of the year. The magnitude of the anomalies is projected to be greatest in the western Bering Sea, followed by slight cooling in the eastern Bering Sea, Gulf of Alaska, and nearshore waters of the Pacific Northwest during spring 2018 (p. 63).

### Gulf of Alaska

- The weather of the coastal GOA was generally warmer than normal during the past year with the exception of winter 2016–2017, during which air temperatures were near normal (p. 56).

- The coastal wind anomalies were upwelling favorable during the winter (p. 56).
- The freshwater runoff into the GOA appears to have been greater than normal during the fall of 2016 and somewhat less than normal in summer 2017, with implications for the baroclinic component of the Alaska Coastal Current (p. 56).
- A prominent eddy formed near Yakutat in January 2016, leading to eddy kinetic energy levels in the northern Gulf of Alaska during spring 2016 were the highest recorded. Thus, phytoplankton biomass was likely not confined to the shelf and cross-shelf transport of heat, salinity and nutrients was likely strong (p. 65).
- Relatively weak eddy kinetic energy was observed in both the northern Gulf of Alaska and south of Kodiak during spring 2017 (p. 65).
- The sub-arctic front was farther south than usual, which is consistent with the surface currents shown in the Papa Trajectory Index (p. 67).
- The PAPA Trajectory Index recorded its southernmost latitude since the late 1930s. Strong winter winds pushed the drifter track to the south east, in contrast to the north easterly direction of the past three years (p. 67).
- Water temperatures during the 2017 bottom trawl survey were slightly cooler compared to 2015 but still among the warmer years in the record. The 2017 GOA thermal profile shared characteristics of the other warm survey years (i.e., 2003, 2005, and 2015) and contrasts with the cooler survey years (e.g., 2007–2013). The warmest water did not penetrate as deeply into the upper 100 m in 2017 (p. 70).
- Freshwater temperatures in Auke Creek were above average during 2016 and average during during 2017 relative to the long term 1980–2017 average (p. 75).
- Auke Creek water depths were higher than average during March-April and August, and lower than average May–July during 2017 (p. 75).
- Sea surface temperatures in Icy Strait were $\sim$0.5°C below the 20-year time series average (p. 92).
- Sea temperatures on the Eastern Gulf of Alaska shelf at the surface and at the average mixed layer depth were cooler in 2017 than 2016 (p. 90).

## Ecosystem Trends

- In the Alaskan Shelf region sampled by the continuous plankton recorder, diatom abundance anomalies were very low in 2016, representing a substantial decline relative to the previous six years (p. 80).
- In the same region, copepod community size anomalies remained negative for the fourth year (2013–2016), while mesozooplankton biomass anomalies were positive (and highest) for the third consecutive year (p. 80).
- Based on rapid zooplankton assessments in spring and summer 2017 in the western Gulf of Alaska, large copepod abundances in 2017 appeared to be higher than 2015 and similar in magnitude to the long-term estimates from Line 8 (p. 83).
- In the same surveys, small copepods were abundant throughout the sampling area in spring, and their abundances increased during summer. 2017 values were similar to the long-term estimates (p. 83).
- There were two types of surveys that sampled euphuasiids in the western Gulf of Alaska during 2017. There was a decline in acoustically-determined euphausiid abundance during summer 2017 relative to the previous survey in 2015, to a low value similar to 2003 (p. 87). In the rapid zooplankton assessment, euphausiid abundances appeared to be much higher than historical estimates in spring and much higher than 2015 in particular (p. 83).

- Comprehensive zooplankton analysis from the eastern Gulf of Alaska showed patchy distribution of species during 2017 with 40% of the total biomass to Cnidarian (nearshore) and Tunicates (basin) (p. 94).
- Zooplankton density in Icy Strait increased in 2016 relative to the previous three years but remained lower than the peak values in 2006–2009. Zooplankton were numerically dominated by gastropods and small copepods, while large copepod and euphausiid densities remained below average (p. 92).
- The bottom trawl survey shows very few trends in total jellyfish abundance across time, with most of the trends being consistent within regions (p. 101).
- Diversity and abundance of jellyfish community during the EGOA summer survey increased in 2017 with a shift away from single-species dominate (*Phacellophora*) observed in 2016 (p. 101).
- ADF&G survey biomass of Pacific herring in southeast Alaska in 2016 continued the decline from the peak in 2011. All but Sitka herring stocks were at the lowest level in the time series, 1980–2016 (p. 127).
- Neither sand lance nor capelin were prevalent during 2013–2016 in forage fish sampled by seabirds at Middleton Island. Instead, mytophids and salmon increased in frequency (p. 112).
- The 2017 summer young-of-year sablefish-targeted trawl survey caught very few sablefish (2017 year class) within the survey grid, but caught more opportunistically near Kayak Island. *Sebastes* spp. catches in 2017 were similar to 2016.
- The 2017 summer eastern Gulf of Alaska shelf surface trawl survey biomass estimates for juvenile were low for squid, juvenile Pacific cod, juvenile walleye pollock, and juvenile rockfish, but high for juvenile arrowtooth flounder. Biomass estimates for juvenile salmon were lowest on record for juvenile Chinook salmon and juvenile coho salmon, low for juvenile pink and sockeye salmon, and moderate for juvenile chum salmon (p. 124, 116, and 120)
- At the Auke Creek weir, the marine survival of wild coho salmon for the 2016 smolt year was lowest the on record for age-1 for the 38 year time series (p. 133).
- Marine survival of wild pink salmon for the 2016 smolt year was below average but above average over the last 5 years (p. 131).
- Fish CPUE in Icy Strait was the lowest on record for juvenile salmon, low for capelin, larval pollock, adult pollock, moderate for immature Chinook salmon, and high for adult chum salmon and herring in 2017 relative to 1997-2016 (p. 130).
- Above average recruitment of sablefish to age-2 in 2018 (69 million) is expected based on warm late summer sea temperatures and high chlorophyll *a* values in Icy Strait waters of northern southeast Alaska during 2016 (p. 144).
- In 2017 groundfish condition was below average for all species except Pacific cod. Northern rockfish and arrowtooth flounder had the lowest condition on record, and Pacific Ocean perch and southern rock sole were the second lowest on record (p. 135).
- In the Gulf of Alaska, there continues to be no significant trends in the distribution of rockfish with depth, temperature and position. The stability of the distribution indicates that each of the species occupy a fairly specific depth distribution. As temperatures rise and fall around the mean, the depth distribution does not change, indicating that the rockfish are not changing their habitat or distribution to maintain a constant temperature (p. 147).
- 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 2016 from the years of record high catches occurring from 2002 to 2005 (p. 139).

- Below average anomaly values for arrowtooth flounder and flathead sole were recorded again in 2016 for both inshore and offshore areas; along with walleye pollock and Pacific cod. Pacific halibut and skates were above in both areas, while Tanner crab was above average only in the offshore area (p. 139).
- Total CPUE in both the eastern and western GOA bottom trawl survery decreased from recent high values to their lowest (west) and second lowest (east) value in 2017. Species that showed the largest absolute declines in biomass since 2013 included walleye pollock, Pacific cod, arrowtooth flounder and northern rockfish in the western GOA; and arrowtooth flounder, shortraker rockfish, Pacific cod and spiny dogfish in the eastern GOA (p. 158).
- 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. 160).
- Few "mushy" halibut were reported during the 2017 fishing season relative to the previous few years, possibly indicating improved foraging conditions for halibut (p. 163).
- *Ichthyophonus*, a non-specific fungus-like protozoan fish parasite, has caused epizootic events among economically important fish stocks including herring and salmon. Current research has found no indication of high intensity infections or clinically diseased individuals, supporting the hypothesis that under typical conditions, *Ichthyophonus* can occur at high infection prevalence with concomitant low infection intensities (p. 163).
- Several fish-eating seabirds had unusually low reproductive success in 2017. Common murres, which showed rare widespread reproductive failure in 2015–2016, generally had better colony attendance and fledging rates in 2017 but still the number of birds breeding was low. Black-legged kittiwakes and storm-petrels (which consume a mix of fish and invertebrates) showed fledging rates within 1 SD of the mean, as did planktivorous auklets ( p. 152).
- Humpback whale calving and juvenile return rates in Glacier Bay and Icy Strait have declined substantially in recent years. An anomalously low crude birth rate is expected for 2017. These changes in calving and juvenile return rates may be related to recent changes in whale prey availability and/or quality, which may in turn be negatively affecting maternal body condition and therefore reproductive success and/or overall juvenile survival (p. 154).
- Observations of humpback whales throughout Prince William Sound and southeast Alaska suggest that there is a long-term trend in humpback whales in Gulf of Alaska that may be related to prey. If prey is limiting and humpback whale populations have fully recovered to carrying capacity, there is potential for top-down forcing on forage species and competition with fish, other marine mammals, and seabirds (p. 156).

# Fishing and Human Dimensions Trends

- Discard rates of groundfish in the Gulf of Alaska increased from <10% in 2015 to >11% in 2016 for the fixed gear sector; remained low, fluctuating between 1-3%, for the pollock trawl sector since 1998; and generally declined over the last ten years to a low of 8% in 2015 and 2016 for the non-pollock trawl sector (p. 165).
- Non-target species catch of Schyphozoan jellies, primarily captured in the pollock fishery, was highest in 2016 relative to 2011–2016. Sea stars comprise 90% of the catch of assorted invertebrates. They are primarily captured in the Pacific cod and halibut fisheries. Catch of structural epifauna has trended upward since 2012. These are mostly sea anemones caught in the flatfish, Pacific cod, and sablefish fisheries (p. 169).

- Stock Composition of Chinook salmon bycatch in the Gulf of Alaska trawl fisheries has been relatively stable from 2012–2015. British Columbia stocks dominate the bycatch, and West Coast U.S. stocks either similar to British Columbia stocks, or less, in most years. The 2015 stock composition included Chinook salmon from British Columbia (51%), West Coast U.S. (32%), coastal southeast Alaska (14%), and northwest Gulf of Alaska (3%) (p. 170).
- Estimated numbers of seabird caught incidentally in the groundfish fisheries decreased from 876 to 626 from 2015 to 2016 primarily due to a reduction in bycatch by 43% for black-footed albatross, 48% for gull, 100% for cormorant, and 43% for unidentified birds. No cormorant, other alcid, auklets, or unidentified albatross were caught (p. 173).
- At present, no GOA groundfish stock or stock complex is subjected to overfishing, and no GOA groundfish stock or stock complex is considered to be overfished or to be approaching an overfished condition (p. 177).
- Landings (pounds) to characterize commercial seafood production decreased from 2015 to 2016 primarily due to a reduction in salmonid landings, then apex predators, and motile epifauna. Increases in landing occurred in pelagic and benthic foragers (p. 182).
- Halibut and salmon (94% sockeye) subsistence harvest trends increased slightly from 2013 to 2014. However, over a longer period, 2005 to 2014, trends show roughly a 30% decline in halibut harvest and 40% increase in salmon harvest for subsistence (p. 183).
- Economic values of 5 functional groups (apex predators, benthic foragers, motile epifauna, pelagic foragers, and salmonids) show a decline in real ex-vessel value overall in all groups, a decline in the real first-wholesale value in all groups except benthic foragers and motile epifauna, and an increase of roughly 20% in the ratio of first-wholesale to total catch unit value for groups combined from 2015 to 2016 (p. 187).
- Saltwater recreational fishing participation included almost 1 million days fished and an increase from approximately 375,000 to 390,000 saltwater anglers from 2014 to 2015 (p. 191).
- The trend in unemployment as an indicator of community viability increased in 2016 relative to 2015 and was slightly higher 4.8% than the national unemployment rates of 4.6% in 2016 (p. 194).
- Trends in human populations from 2010 to 2016 indicate a 4.17% increase for Alaska, 2.98% increase for Gulf of Alaska communities including Anchorage, and a 3.98% increase for Gulf of Alaska communities not including Anchorage (p. 196).
- School enrollment has remained fairly stable recently, showing a slight decrease for larger schools with 500-4,500 students. Smaller schools had more variable enrollment year-to-year and an overall downward trend. As of 2017, 27 schools have enrollment under 30 students, and 12 schools have enrollments under 15 students, and 7 schools were closed (p. 199).

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

### December 2016 SSC Comments

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

In this year's reports, a standardized summary of the Rapid Zooplankton Assessments are provided for both the eastern Bering Sea and Gulf of Alaska. In addition, the RZA estimates are shown in context of historical time series of abundance for large copepods, small copepods, and euphausiids. Another improvement to the RZA analysis is an estimation of abundance, as opposed to proportional catches. In the Western Gulf of Alaska Report Card, we include copepod community size composition from the Continuous Plankton Recorder. New this year for the Eastern Gulf of Alaska, we include the proportion of large calanoid copepod in relation to all calanoid copepods, from data in the Ferguson et al. contribution p. 92, to represent changes in copepod community size.

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

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

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

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

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

The below information is provided from the Marine Mammal Laboratory:

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

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

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

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

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

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

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

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

7. Employment
8. Socio-Cultural

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

***Gulf of Alaska*** *The GOA Ecosystem Considerations chapter has undergone considerable improvement in recent years, though the Editor and the SSC acknowledge that it is still a work in progress. As mentioned previously, the GOA report card has now been split into two regions (western and eastern) based on feedback from a workshop with the GOA IERP principal investigators. The SSC notes that the ecology of the two subregions is quite different, and supports this division, which is already recognized in some groundfish assessments. Some indicators have not yet been finalized for the eastern GOA report card. The SSC looks forward to continued development of these region-specific indicators.*

We continue to expand the Gulf of Alaska report, which features several new indicator contributions this year. This includes temperature and salinity at GAK1, two on zooplankton, a spring larval pollock assessment, two on forage fish, squid, salmon, seabirds, two on humpback whales, and six related to socio-economics. In addition, we continue to emphasize the division between the East and West GOA at 144°W. Not all contributions follow this division, but when a majority do, we plan to reorganize the report to emphasize the two regions. At present within each subsection, West GOA contributions are presented first, followed by East GOA.

*Capelin abundance (Report card): This suggests that capelin were more abundant in the cold years. Did their numbers change that quickly, or did they change their distribution, making them less available to the birds?*

The capelin indicator last year showed a common trend of capelin sampled at depth by groundfish as well as by seabirds, so changes in capelin were not related solely to moving out of range of foraging seabirds. Groundfish diets were not available at the time of report completion, so the next update of this indicator will be in 2018.

*Zooplankton Indices: It would be of value to examine the relationships between the abundance of large and small zooplankton, and whether there is a tie to water temperature. What are the ecological mechanisms behind the observed dynamics?*

In the Ferguson contribution from 2016, the total zooplankton density and temperature show a weak negative correlation in Icy Strait. However, this relationship was not significant, and both positive and negative monthly anomalies occurred in warm and cold years ($r = -0.362$, $P = 0.328$). Relationships are currently in flux with the perpetually increasing Icy Strait 20-m integrated sea temperature and the evident decline in the density of both large and small copepods. Densities of euphausiids are showing an increasing response to the warming temperatures, which could be trophically beneficial for many planktivores. The mechanisms driving variation in Icy Strait zooplankton is being studied as part of a Masters degree by Emily Fergusson (AFSC Juneau) at the University of Alaska Fairbanks School of Fisheries and Ocean Sciences in Juneau. She currently considers that advection, freshwater inflow, temperature, and salinity all play a role in the variation in zooplankton.

*Salp abundance increased again (p. 29): This is an important observation that might portend a new* *food web structure inimical to commercially important fish. Is there information on how nutritious salps are?*

Salp is a low nutrient food source. Among holoplankton, the mean soluble protein content of salp (*Salpa fusiformis*) (0.1 mg/ml) was low relative to the cnidarians (0.1–18 mg/ml), cyanobacteria (29–48 mg/ml), chaetognaths (10.9 mg/ml), and squid paste (34.5 mg/ml) (Bullard and Hay 2002). Protein content correlates significantly and positively with lipid and carbohydrate content in gelatinous zooplankton (R2 = 0.71, 0.34; P =0.001, 0.040 (derived from Bailey et al. 1995). Salp had low nutritional values (0 .2% protein, 1.0% fat, 0.43 kJ/g) in the Mediterranean waters (Cardona et al. 2012).

Bailey, T. G., M. J. Youngbluth, and G. P. Owen. 1995. Chemical composition and metabolic rates of gelatinous zooplankton from midwater and benthic boundary layer environments off Cape Hatteras, North Carolina, USA. Mar. Ecol. Prog. Ser. 122:121134. Bullard, S. G. and M. E. Hay. Palatability of marine macro-holoplankton: Nematocysts, nutritional quality, and chemistry as defense against consumers. Limnology and Oceanography: 47(5): 1456-1467. Cardona, L., De Quevedo, I.., Borrell, A. and Aguilar, A., 2012. Massive consumption of gelatinous plankton by Mediterranean apex predators. PloS one, 7(3), p.e31329.

*Capelin indicators (P.31): It might be useful to present the data from the seabird diets and the fish diets separately so that one can understand if the index shifts whether the shift is primarily in capelin availability in surface waters or at depth.*

The contribution of seabirds versus fish diets to the observed trend can be seen in the loadings. Rhinoceros auklet, Pacific cod, black-legged kittiwakes, and Pacific halibut all contributed significantly to this trend, so we believe that the trend is robust to the type of sampler. As explained above, the next update to this indicator will be in 2018.

*Ocean Station Papa (p. 39): This report, while excellent, seems too detailed and too retrospective. A shorter report focused on the current situation and its relationship to the time series might be more appropriate. Coloring the modeled tracks for warm and cold years could be of value for understanding the implications of the trajectories. Figures 12 and 13 (p. 53, 54): It would be useful to have some indication of the variances around the means.*

The author has been unable to find a definitive annual list of warm and cold years in the GOA, but we hope to update this figure with colors in 2018.

*Herring (p. 73): This is a very nice, helpful summary.*

The author made a concerted effort to shorten their contribution based on previous SSC request.

*Human population declines in GOA (p. 134): The statement that the declines are due to declining fish stocks seems problematic. This is not what the stock assessments show. Is this population decline really driven by increases in efficiency or changes in product mix?*

This type of statement is not included in the current population contribution.

# Introduction

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

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

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

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

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

[1] The Arctic report is under development

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

| Objective | Indicators |
|---|---|
| Stability | • Species richness and diversity (p. 160)<br>• Fish stock sustainability index ( p. 177) |
| Biomass | • Abundance and distribution of jellyfish (p. 101, p. 101)<br>• Abundance and distribution of forage fish, groundfish, and salmon (p. 109, p. 112, p. 112, p. 116, p. 120, p. 124, p. 127, p. 130 )<br>• Fish and invertebrate CPUE (p. 139, p. 149, p. 158)<br>• Salmon survival indices (p. 131, p. 133) |
| Productivity | • Ichthyoplankton (p. 107)<br>• Zooplankton (p. 80, p. 83, p. 87, p. 90, p. 92, p. 94, p. 92)<br>• Groundfish condition (p. 135)<br>• Groundfish recruitment predictions (Sablefish: p. 144)<br>• Seabird reproductive activity (p. 152)<br>• Humpback whale calf production (p. 154) |
| Trophic Structure | • See Report Card indicators (Figures 1, 1) |
| Habitat | • Structural epifauna (p. 78) |
| Climate & Oceanography | • North Pacific climate conditions (p. 56, p. 57, p. 65, p. 67, p. 70, p. 74, p. 75),<br>• Climate Indices (p. 61), and<br>• Projections (p. 63) |
| Bycatch Reduction | • Groundfish discards (p. 165)<br>• Non-target species catch (p. 169, p. 170)<br>• Seabird bycatch (p. 173) |
| Seafood production | • Commercial landings (p. 182)<br>• Subsistence trends (p. 183) |
| Profits | • Ex-vessel value, first-wholesale value, and unit ratio value (p. 187) |
| Recreation | • Number of recreational anglers and fishing days (p. 191) |
| Employment | • Unemployment trends (p. 194) |
| Social-Cultural | • LEO Network (p. 38)<br>• Trends in human population ( p. 196)<br>• School enrollment (p. 199) |

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

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

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

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

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

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

1. Track ecosystem-based management efforts and their efficacy

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

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

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

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

This report represents much of the first three steps in Alaska's IEA: defining ecosystem goals, developing indicators, and assessing the ecosystems (Figure 3). The primary stakeholders in this case are the North Pacific Fishery Management Council. Research and development of risk analyses and management strategies is ongoing and will be referenced or included as possible.

It was requested that contributors to the Ecosystem Considerations report provide actual time series data or make it available electronically. Many of the timeseries 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`


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

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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**Last updated: October 2017**

## Introduction

The primary intent of this assessment is to summarize and synthesize climate, biological, and fishing effects on the shelf and slope regions of the Gulf of Alaska (GOA) from an ecosystem perspective and to provide where possible an assessment of the possible future effects of climate and fishing on ecosystem structure and function. The Ecosystem Considerations reports associated with the AFSC's Groundfish Stock Assessment and Fishery Evaluation (SAFE) report provides the historical perspective on 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 ecosystem status to provide ecosystem context within which fisheries quota-setting decisions are made. The overall goal of the synthesis is to provide a narrative of the current ecosystem state in the context of history and future changes.

## Hot Topics

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

## Pyrosomes seen for first time in Gulf of Alaska research surveys

Researchers observed *Pyrosoma atlanticum* (Figure 4) in three types of Alaska fish surveys this year — NOAA's acoustic, surface and bottom trawl surveys. Fishermen first reported seeing the organisms when trolling for salmon off Sitka, AK in February.

Pyrosomes are pelagic tunicates that typically form tube-like colonies and can approach four meters in length, but colonies are most commonly only several cm in length. Their name means "fire-house", due to the brightly bioluminescence of the colonies at times. Pyrosomes can produce flashes of light visible up to 100 meters in clear water. The tube-like colonies are made up on 100's or 1,000's of individual organisms called zooids, which reproduce sexually and asexually. Asexual reproduction of pyrosomes provide them with the ability to form massive blooms under favorable conditions. The creatures typically live in tropical waters around the world, occasionally emerging a little farther north in sub-tropical waters. *Pyrosoma atlanticum* is the most common and widespread of all species of pyrosomes.

Pyrosomes were frequently encountered during AFSC fish surveys during the winter and summer of 2017 (Figure 5). Until this year, pyrosomes had never been detected in the Gulf of Alaska during any of AFSCs acoustic, surface trawl, or bottom trawl surveys, the latter of which has been conducted since 1984. Pyrosomes were first observed during the AFSC's winter acoustic survey for walleye pollock in the Gulf of Alaska in March when between 1 and 104 were caught in midwater trawl sets conducted off of the Kenai Peninsula and Kodiak. Pyrosomes were caught again during the July surface trawl survey conducted both on and offshore of the shelf between Yakutat and Sitka. The AFSC bottom trawl survey observed pyrosomes from mid-July to early August along the shelf from Icy Bay to Dixon Entrance. The June–August summer acoustic survey for walleye pollock again detected pyrosomes with midwater trawls as far west as Chirikof Island to just west of Icy Bay. Pyrosomes were also observed in the stomachs of sablefish and in some rockfishes.

*Contributed by Wayne Palsson, Jim Murphy, and Patrick Ressler*

Figure 4: An example of a *Pyrosoma atlanticum* zooid observed during NOAA fisheries surveys in the Gulf of Alaska during 2017. Photo credit: AFSC

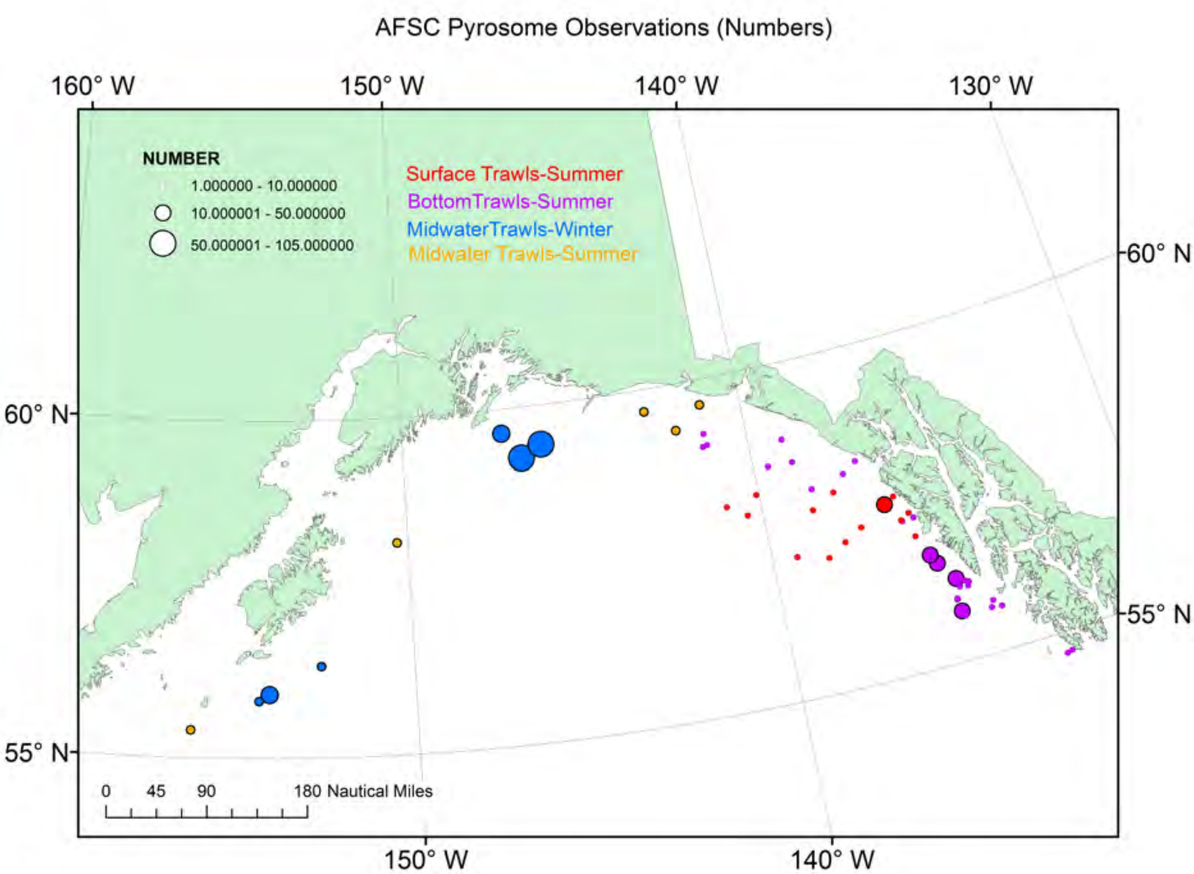


Figure 5: Map of *Pyrosoma atlanticum* observations during NOAA fisheries surveys in the Gulf of Alaska during 2017. Map created by Wayne Palsson

## LEO Network

The NMFS AFSC is interested in documenting and learning from citizen science observations that may be incorporated into future Ecosystem Status Reports (ESRs). We have identified the LEO Network as a potential platform for tracking these observations (Figure 6). We are seeking Council input on the utilization of this network to gather citizen science observations on marine environment changes for future ESRs. Other citizen science efforts exist in Alaska, but to our knowledge these efforts are mostly project specific (e.g., bird spotting and identification) or community specific.

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

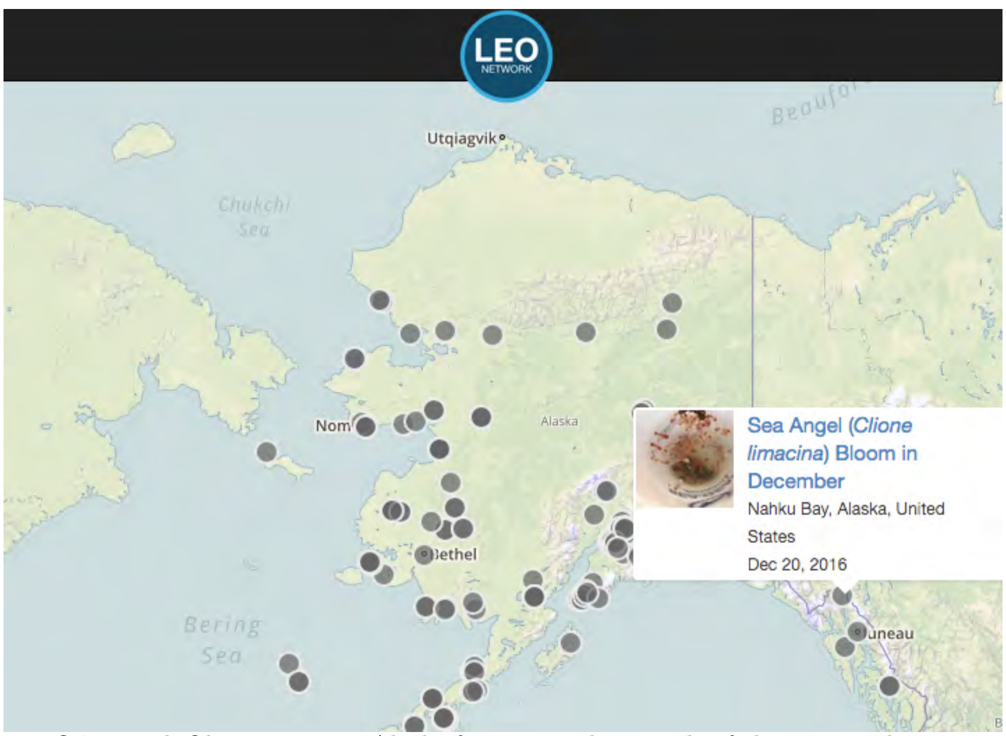


Figure 6: LEO Network Observations in Alaska for 2016 with example of observation description, source: `https://www.leonetwork.org`.

A preliminary analysis of 2016 LEO Network observations in the GOA indicates the following frequency of observations by category (Figure 7). These categories are based on initial analysis of the 53 total observations in 2016 in the GOA and are not limited to the marine environment. The categories are also based on observations for the Eastern Bering Sea ecosystem, which are described in that ESR; therefore, not all categories have observations in the GOA. This figure is being included as an example of the types of observations that are made on the LEO Network, and future utilization of LEO Network observations for ESRs would be highly refined. The observations in Figure 7 were made in 20 total communities.

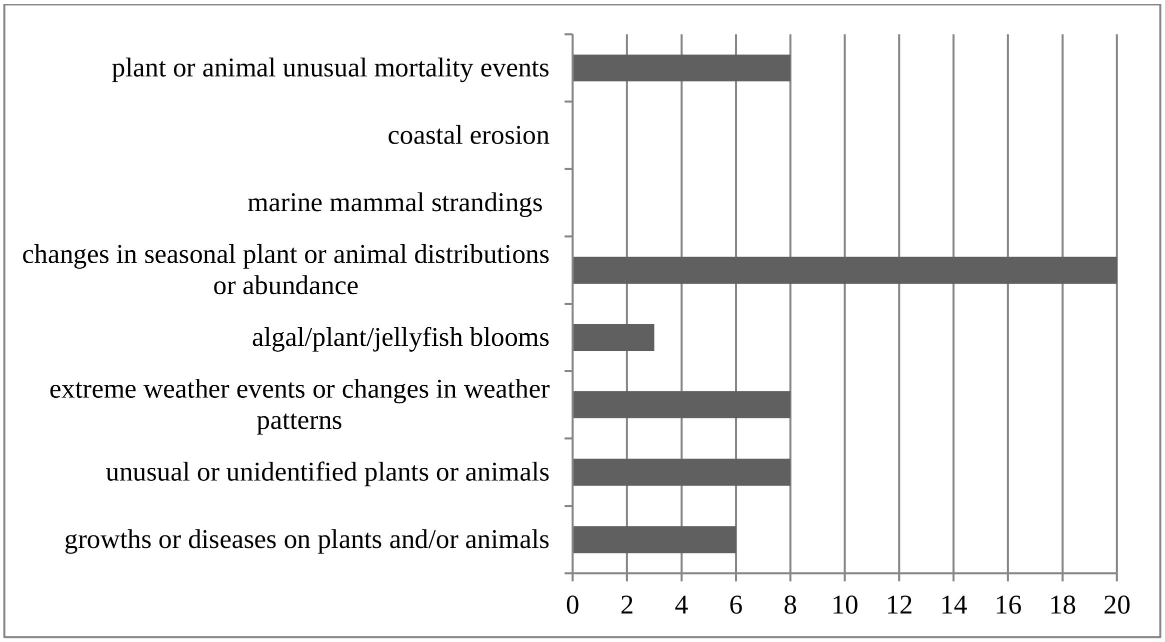


Figure 7: Distribution of 2016 LEO Network Observations in GOA communities.

With the permission of ANTHC, future reports could employ qualitative content analysis techniques to systematically categorize observations by ecosystem. These categories would be mutually exclusive and exhaustive and pertain to the marine environment. An alternative to this approach would be the development of LEO Network \projects" specific to Alaska marine ecosystems (e.g., Eastern Bering Sea, Aleutian Islands, Gulf of Alaska, and Arctic) under which LEO Network participants could categorize their observations and NMFS staff could pull in and track relevant observations. Alaska State agencies, non-pro t organizations, universities, and U.S. federal agencies have developed projects on the network to track observations specific to their area of interest, e.g., weather events, sh pathology, subsistence harvests, etc. Similarly, the National Weather Service has developed an extreme weather-tracking program called \Storm Spotters" for citizens to report severe weather, and such events identified on the LEO Network are forwarded to this NWS Program.

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

*Contributed by Marysia Szymkowiak*

# Gulf of Alaska Ecosystem Assessment

We present separate Western and Eastern Gulf of Alaska Report Cards to highlight inherent differences in ecosystem structure and function between the eastern and western ecoregions.

The Gulf of Alaska (GOA) 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 GOA. Thus, local effects of ecosystem drivers may swamp basin-wide signals. With this in mind, ecosystem indicators were selected to best reflect the complexity of the GOA. Although there are many more people living in both large and small communities throughout the GOA relative to the Aleutian Islands or eastern Bering Sea, the complexity of the system requires a high-degree of local understanding to disentangle broad-scale patterns from local processes. Thus while the GOA Integrated Research Project in addition to ongoing studies are increasing understanding of the GOA ecosystem, we still consider the Gulf of Alaska to be ecosystem data-moderate relative to the Aleutian Islands (data-poor) and eastern Bering Sea (data-rich). However, as with the Aleutian Islands report cards, the division of the GOA report card into separate ecoregions highlights data gaps. For example, comparable forage fish indicators are not available for both regions. Also, while fresh water input is considered informative for the west, a comparable oceanographic indicator remains to be selected for the east. In this edition, we include a new copepod community size indicator and revised foraging guild biomasses, stellar sea lions, and human population indicators. These are described below. 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
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 at this station since December, 1970. The GAK 1 discharge time series is a 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.

Although the GAK 1 time series has been used as a measure of freshwater discharge in the past, salinity 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 become available from outputs of a new, high resolution discharge hindcast model by David Hill at Oregon State University. This improved discharge model uses a snowpack model, elevations, reanalysis precipitation, and streamflow routing to estimate freshwater discharge and is tuned against USGS discharge measurements. The 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 future editions of this report (Seth Danielson, pers. comm.).

**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 western GOA. In the 2016 report, this indicator included the entire survey area.

**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*). This indicator will be updated in the 2018 report and biennially thereafter, as there is a lag in identifying fish diets following the biennial bottom trawl survey.

**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. In the 2016 report, this indicator included the entire survey area but now represents only the portion that is west of 44°W.

**Black-legged kittiwake reproductive success** Black-legged kittiwakes are common surface-foraging, piscivorous seabirds that nest in the GOA. Reproductive success is defined as the proportion of nest sites with fledged chicks from the total nest sites that 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 GOA. This region includes the GOA portion of the western Distinct Population Segment (known as the west, central and east GOA).

**Human population** The combined populations of small (∼1500 people) fishing communities west of 144°W are used to represent human population trends in communities with ties to the marine environment. A description of how these communities are selected can be found in the Human Populations contribution, p. 196.

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 by zooplankton density (number per $m^3$) as captured by 333-$\mu$m bongo net samples during summer months in Icy Strait.

**Copepod Community size** The ratio of large calanoid copepods to total large and small calanoid copepods as sampled in Icy Strait is used to represent copepod community size.

**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 GOA. These values are summarized for the eastern region, where survey efforts vary among years.

**Southeast Alaska mature herring biomass** Herring is used to represent forage fish trends in the eastern GOA 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. These values are summarized for the eastern region, where survey efforts vary among years.

**Rhinoceros auklet chick growth rate** Mean growth rates of rhinoceros auklet chicks at St. Lazaria Island. Reproductive success is difficult to determine for these burrow-nesting seabirds because they are sensitive to disturbance. Data are only included for chicks that were measured at least three times during the linear phase of growth; chicks that did not exhibit linear growth were excluded. Data are collected by the Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service. The colony was not monitored in 2017.

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

**Human population** The combined populations of small (∼1500 people) fishing communities east of 144°W are used to represent human population trends in communities with ties to the marine environment. A description of how these communities are selected can be found in the Human Populations contribution, p. 196.

## Recap of the 2016 Ecosystem State

*Some ecosystem indicators are updated to the current year (2017), while others can only be updated to the previous year (or earlier) due to the nature of the data collected, sample processing, or modelling efforts. Therefore, some of the "new" updates in each Ecosystem Considerations Report reflect information from the previous year. This year for the first time we include a complete summary of the ecosystem status of the GOA during 2016 that includes information from both previous and current indicators. The next section (Current conditions: 2017) provides, also for the first time, separate summaries of the 2017 ecosystem state for the western and eastern GOA based on indicators updated this year. We plan to continue developing the ecosystem assessments with this ecoregional focus in future editions.*

The 2016 environmental state in the GOA reflected the continuance of the anomalously warm water that first appeared in late 2013/early 2014. This began as the "Warm Blob" in the NE Pacific and evolved afterward, related in part to sea level pressure and wind anomalies. Temperatures at GAK1 during 2016 were the warmest on record since 1970. In the 2015/2016 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 was consistent with the poleward surface currents shown in the Papa Trajectory Index. The 2016 surface current pattern itself was very similar to those of 2012, 2014, and 2015. The coastal wind anomalies were generally downwelling favorable during winter and spring of 2016 due to the pattern of winds from the northwest, but switched to more upwelling favorable during the summer. 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 since 2014, indicating warmer than normal sea surface temperatures along the west coast of North America. The El Niño of the previous winter faded, and the neutral state that was forecasted for winter 2016/2017 held. The NPGO approached a neutral state, indicating normal flows in the Alaska Current portion of the Subarctic Gyre. Sea surface temperature projections indicated that the warm conditions were likely to remain through the upcoming winter. However, the observed SSTs were generally cooler than predicted in the NE Pacific. The models simulated too-little moderation of the pre-existing warm anomalies in the GOA and Bering Sea, and also under-predicted the amount of cooling in the waters offshore of the Pacific Northwest. Nevertheless, the models did reproduce the overall patterns in anomalous SST that were observed, even in the longer-range projections.

Many biological indicators suggested that there was poor productivity in the GOA in 2016. There were some signs of improvement relative to 2015, but these were limited to some increases in total zooplankton abundance, abundant juvenile salmon and young of year forage fish, age-4 (2012 year class) pollock growth during spring, lower seabird bycatch, and the absence of large bird die-offs at the end of summer (in the GOA). However, small copepod community size, the presence of southern species and salps during eastern GOA surveys, declines in groundfish catch rates in Barnabus Gully, occurrence of "mushy" halibut syndrome, poor seabird and humpback whale reproduction, and the second year of greater than average whale strandings point to the general low productivity of 2016.

Common murres experienced complete reproductive failure at nearly all monitored colonies in the GOA in 2016. 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 USFWS 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. USFWS biologists hypothesized 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 suggested 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.

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. In addition, high cyamid lice appeared to be increasingly prevalent on humpback whales, possible further indication of poor foraging conditions for whales resulting in poor body condition. The crude birth rate of humpback whales in Glacier Bay was the lowest on record, which began in 1985, only one mother/calf pair of which both appeared to be abnormally thin.

The NOAA summer bottom trawl survey is conducted biennially during odd-numbered years over a large part of the GOA shelf, so there were no data to report for 2016. 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 they both generally declined. Both species increased in the NOAA and ADF&G survey in 2015 relative to 2013 suggesting that 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. With the addition of 2016 ADF&G survey data this year, we note that all but halibut declined from 2015 to 2016. Of particular note, Pacific cod continued to decline from a 2013 peak catch rate to the lowest observed in 2016.

There were a few reports of "mushy" halibut syndrome in 2016, although the reporting of this condition is anecdotal and may not accurately represent the true prevalence. 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 winter 2015/2016 and early spring 2016, 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 remains uncertain 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 predominantly small zooplankton observed in fall 2015 and during 2016 summer surveys.

New human dimensions indicators added in this 2017 Report provide information on the 2016 status of human economic and social well-being. Landings reflect commercial economic production in the region; salmon and apex predator landings have been stable, while landings of pelagic foragers have been increasing since 2012 due to an increase in Total Allowable Catch for pollock. Subsistence use permits for salmon, primarily sockeye, have continued a generally increasing trend. Recreational salt water fishing has remained stable The population in the GOA has remained relatively stable as a whole with some variability in the smaller communities. School enrollment has generally decreased in the mid- to smaller schools, and some small rural communities have experienced school closures. Meanwhile, unemployment in the GOA is lower than state and national rates overall. Taken as a whole, these data suggest stability in these measures of human dimensions in the GOA, at least within the short time scales of these assessments. Future refinement of and research into this suite of indicators may inform more subtle but important trends.

## Impacts of the Marine Heat Wave on the Gulf of Alaska Ecosystem, including Pacific Cod

With the end of the marine heat wave that began during early 2014 and persisted through 2016, we can begin to assess some of the immediate and cumulative ecosystem responses across multiple ecosystem components and metrics. There are increasing lines of evidence that in temperate/sub-arctic ecosystems such as the GOA and eastern Bering Sea, anomalously warm water, and in particular, consecutive years of warm water patterns, can have an overall negative effect on ecosystem productivity. While there are winners and losers, warm water patterns can lead to bottom-up forcing that favors smaller and less-lipid rich zooplankton which in turn increases steps in food chains and decreases trophic transfer efficiency. Predator response to environmental and trophic changes can be rapid or slow and varies with natural history and adaptive capacity. For example, mobile species can shift their distributions to more favorable habitat via changes in depth or horizontal distance, while sessile organisms may exhibit temperature-driven physiological changes in growth or condition. As such some predator indicators will rapidly reflect environmental change with little lag, such as within-season shifts in fish distribution (e.g., presence of southern species in surveys), while other signals may manifest over multiple years (e.g., changes in production). Bottom-up forcing can also be tracked through factors affecting recruitment; some which can be expected to show rapid responses (e.g., age-0 fish abundance and survival) and others longer-term lagged responses (e.g., recruitment to a fish stock). An additional general response to warm waters patterns is through the effect of increased temperature on the metabolic demands of ectothermic (cold-blooded) organisms such as fish, who, all else being equal, need to eat more as their metabolism increases with temperature up to a critical point at which thermal stress and lethargy lead to a lack of foraging, loss off tissue, and eventually mortality. Thus, it is reasonable to presume that changes in temperature could lead to changes in top-down (i.e., predation) forcing and shifts in food-web structure.

The marine heat wave of 2014–2016 in the Northeast Pacific was unusual in the magnitude of temperatures across the system, the persistence of warm water through the winters, and the depth to which warming extended (Bond et al 2015). Given that predation is a major structuring pressure in the Gulf of Alaska ecosystem (Gaichas et al. 2015), we hypothesize that the extent and persistence in warm temperatures was sufficient to cause increases in metabolic demands in ectothermic fish such that prey was limiting through both (1) bottom-up forced decrease in lower-trophic prey availability and quality (ie., smaller zooplankton) and (2) through competition with fish, bird, and mammal predators with overlapping diets. We focus on Pacific cod to explore this possibility (see Gulf of Alaska 2017 Pacific Cod Stock Assessment for additional detail), using data from the AFSC bottom-trawl survey and Resource Ecology and Ecosystem Modelling (REEM) Food Habits Lab.

Metabolic demand of ectothermic fish like Pacific cod is largely a function of thermal experience and tends to increase exponentially with increasing temperatures. Fish can minimize metabolic costs through behaviors such as movement to thermally optimal temperatures, or can increase consumption of food energy to meet increasing metabolic demands. The former requires access to thermally optimal temperatures, which may have been impacted by the recent marine heat wave. The latter requires sufficient access to abundant or high energy prey resources. Thus, if either is limiting, metabolic costs may exceed energetic consumption and decreases in growth or increases in mortality will occur.

In fact, for Pacific cod in the GOA during the anomalously warm years of 2014–2016, prey demand was elevated above long-term mean estimates, and peaked in 2016, according to adult bioenergetic model estimates of relative energetic demand (Figure 8). Based on water temperatures at preferred depth, metabolic demand was greatest for 10 cm fish and >40 cm fish but lowest for 30 cm fish (Figure 8). Bioenergetic model estimates of Pacific cod growth and respiration also suggest poor thermal conditions for growth in 1998 (following the record El Niño of 1997/98) and 2016 (top panel Figure 9) that were driven by high metabolic demand during those years (bottom panel, Figure 9). Prey energetic demand based on mean energy densities and annual shifts in diet composition show moderate changes in diet energy density over time, with highest cumulative diet energy densities in 2013, which occurred at the end of a 7 year cold temperature stanza in the GOA, and slightly lower values in 2015 near the long-term mean (Figure 10). Stomach fullness of Pacific cod sampled from the GOA summer bottom trawl survey was lowest to date in 2015 (Figure 11), and diet composition varied from previous years, with a 47.8% drop in *Chionoecetes bairdi* relative to previous years (Figures 11 and 12) and an absence of capelin which had been abundant, particularly in smaller Pacific cod, during 2011 and 2013. The proportion of *C. bairdi* in the diets of 40–80 cm cod dropped from the long-term mean of about 14% to 7% in 2015 (Figure 13).

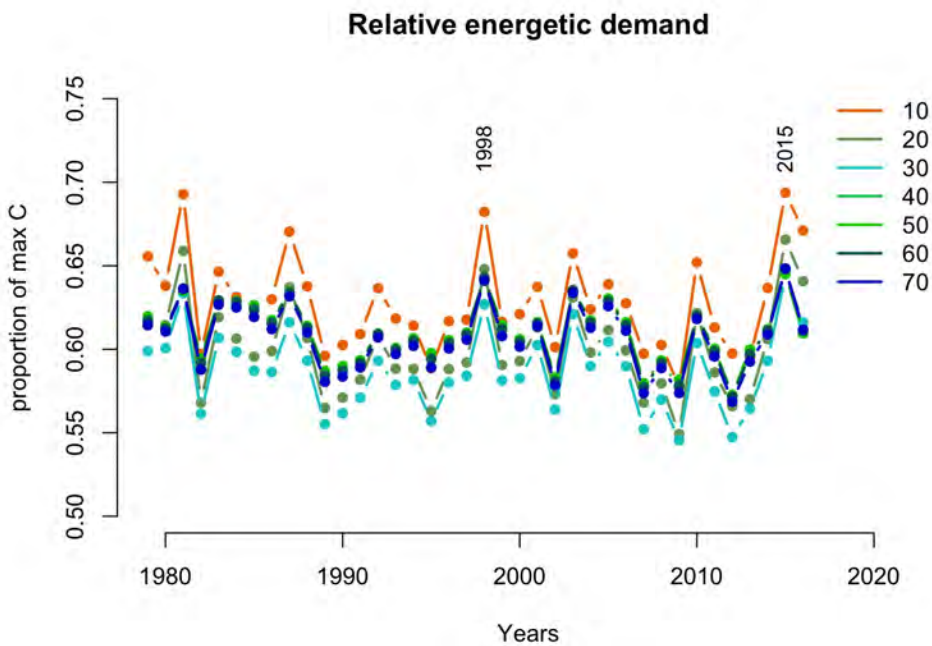


Figure 8: Relative energetic demand for Pacific cod of 10-70 cm FL based on the adult bioenergetic model for Pacific cod (Holsman and Aydin, 2015) and CSFR age-specific depth-preference corrected water temperatures (Barbeaux, unpublished data).

Thus the increase in metabolic demand in 2015 has two important implications: (1) Pacific cod would have had to consume an additional 6-12% of prey per day ($g^{-1}d^{-1}$) over average ( i.e., based on mean estimates for years 1980-2014) to maintain growth and body condition, or (2) Pacific cod would have had to access energetic reserves leading to net body mass loss. The protracted warm conditions from 2014–2016 may have exceed both adaptive options, potentially leading to starvation and mortality. In addition, other ectothermic fish species would be expected to have similarly elevated metabolic demands during the warm conditions, increasing the potential for broad scale prey limitations. There a few lines of evidence to support this potential mechanism

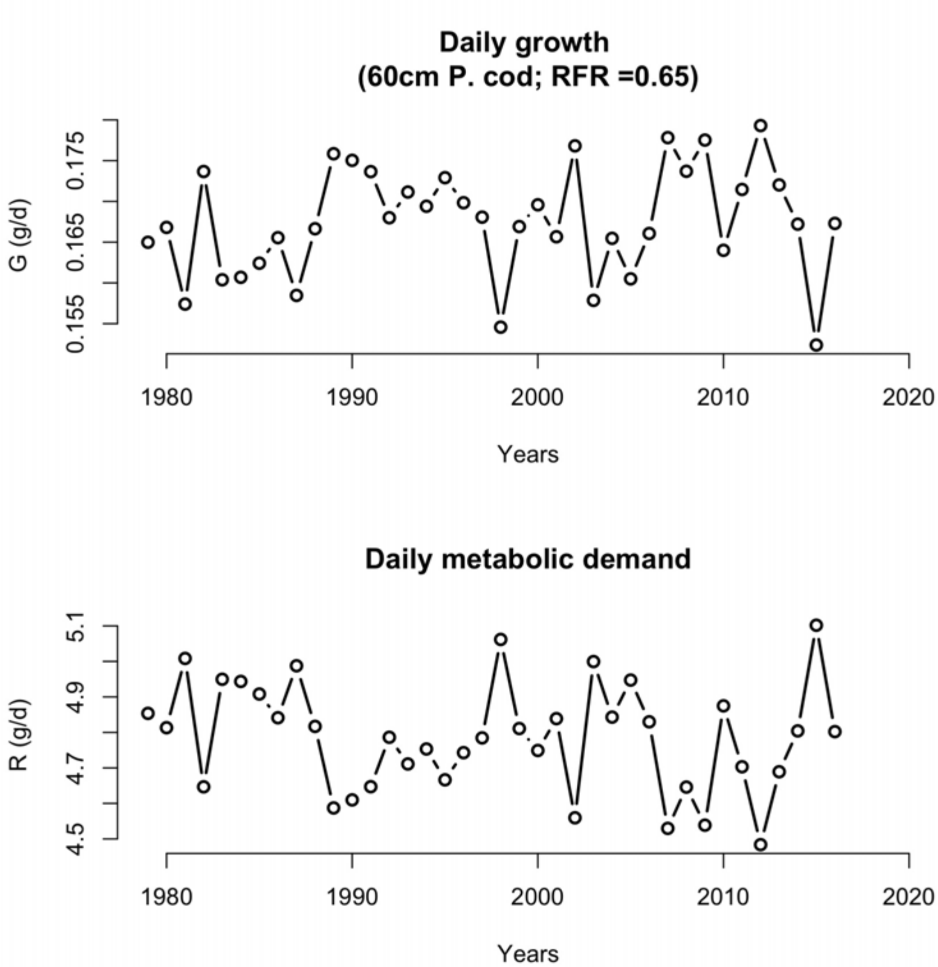


Figure 9: Daily model estimates of growth (top panel) and metabolic demand (bottom panel) based on the adult Pacific cod bioenergetics model (Holsman and Aydin, 2015), a fixed relative foraging rate (RFR) = 0.65 (across years), annual indices of GOA prey eenergy density, and an intermediate P. cod energy density of 3.7 kJ/g reported in Vollenweider et al. 2011.

for declines in Pacific cod abundance, including poor fish condition observed in 2015 (i.e., fish that were lighter than average for a given length; Zador et al. 2017), lowest potential growth based on mean relative foraging rates reported in Holsman and Aydin (2015; Figure 9 top), highest recorded metabolic demands in 2015 (Figure 9, bottom), below average diet energy density (lowest since 2007) based on diet composition of survey collected stomach samples (Figure 10), and reports in 2015–2016 of widespread reproductive failures and mortality events from starvation for bird and marine mammal predators that share prey resources with Pacific cod in the GOA. Also of important note is the potential absence of capelin (an important prey item) in the diets of Pacific cod from 2015 (Figure 11), and the overall lower mean stomach fullness for fish in 2015 (height of columns in Figure 11; note that these data are aggregated across the GOA). Considered collectively, these lines of evidence suggest that persistent anomalously warm conditions that extended from surface waters to depth, may have contributed to high mortality rates for juvenile and adult Pacific cod from the years 2014–2016. Additional analysis of these patterns is needed to further evaluate spatial differences in energetic demand and potential factors influencing Pacific cod survival across

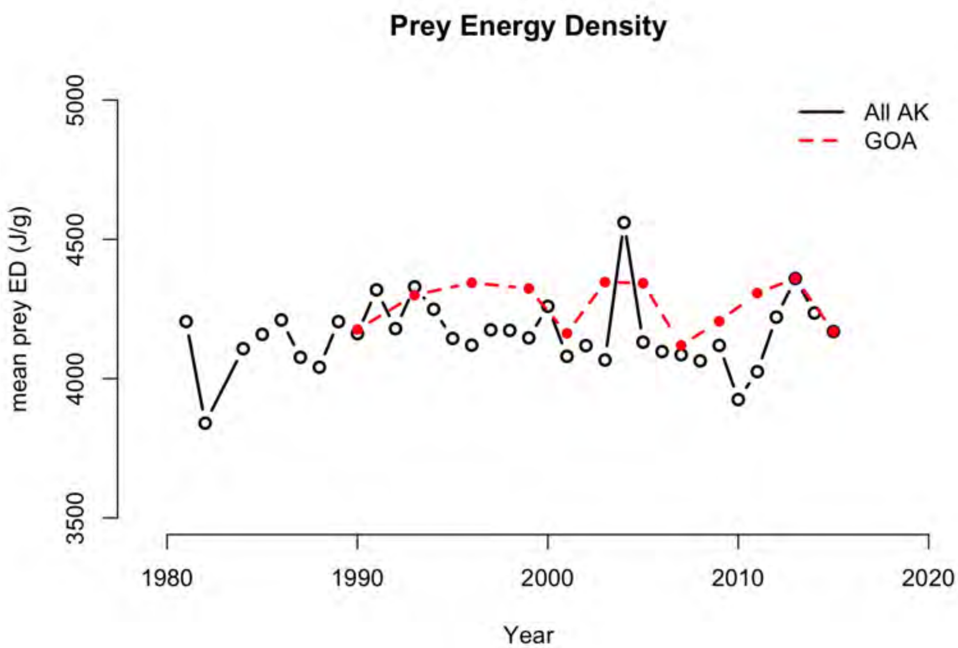


Figure 10: Average prey energy density based on mean energy density of prey items and diet composition from GOA Pacific cod stomach samples. Diet data from NOAA REEM Food Habits database.

the region.

Specific responses to the marine heat wave appears to have varied among the other abundant, ectothermic groundfish in the GOA such as walleye pollock, arrowtooth flounder, and Pacific halibut. While they would be expected to have similar metabolic responses to the increased temperature, inherent differences in life history and/or adaptive capacity may influenced how their responses manifested. For example, the relatively more pelagic and lower trophic (i.e., zooplankton) diet of walleye pollock may have been sufficient to maintain natural mortality rates. Arrowtooth flounder abundance has also declined in recent years, which may reflect similar stock-wide effects of increased metabolic demands and limiting prey resources. Additionally, as a major predator of young pollock, the decline in arrowtooth flounder may have decreased predatory pressure on pollock. While Pacific halibut stomachs were also lacking *C. bairdi* during 2015, their high migration and pelagic foraging capabilities may have been sufficient to buffer the effects of increased metabolic demands. Additional analysis is needed to further evaluate how various ecosystem components have responded to the heat wave.

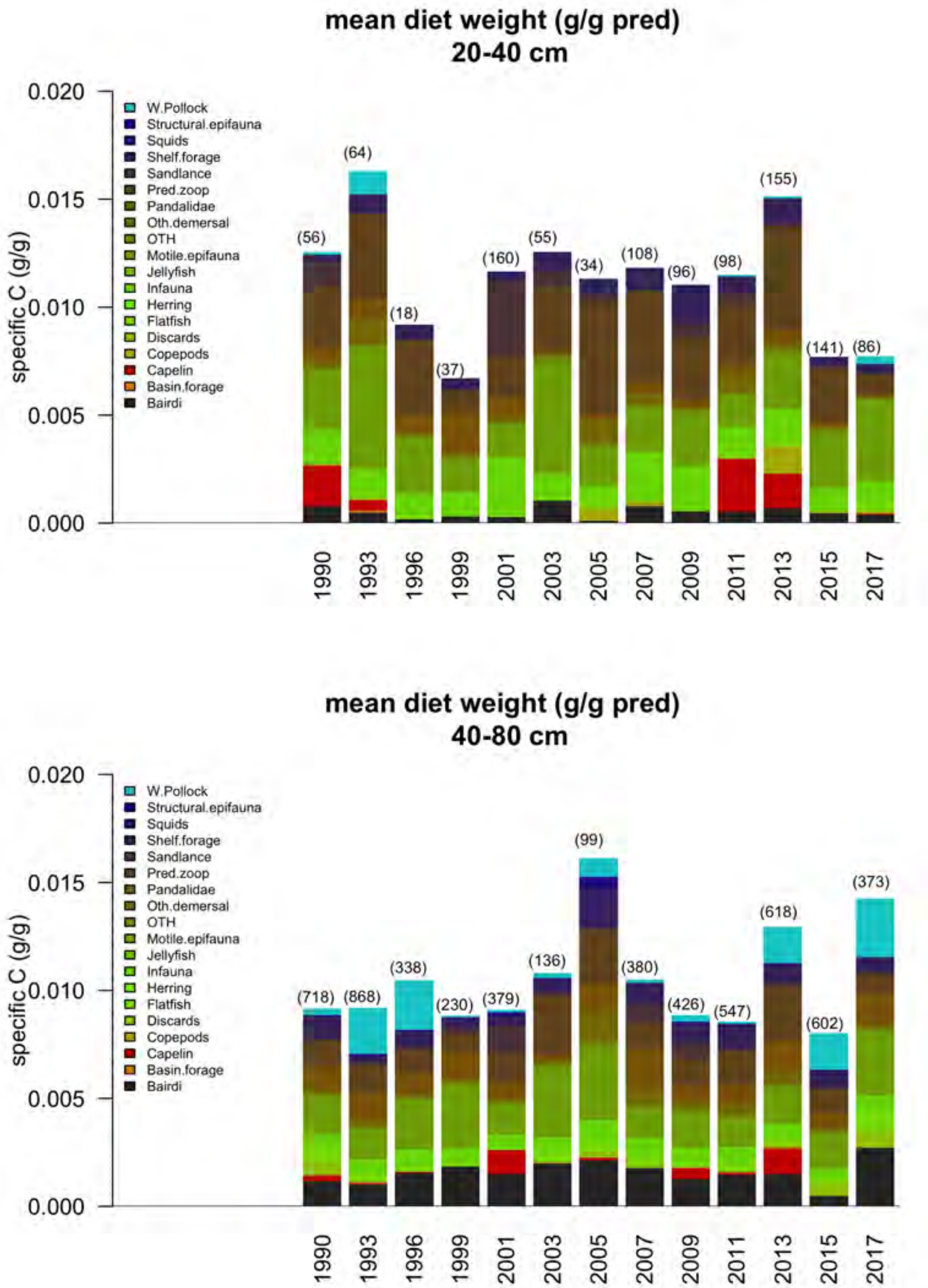


Figure 11: Specific weight (g prey/ g pred) of prey in the diets of GOA Pacific cod, averaged across all survey diet samples and fish sizes. Diet data from NOAA REEM Food Habits database.

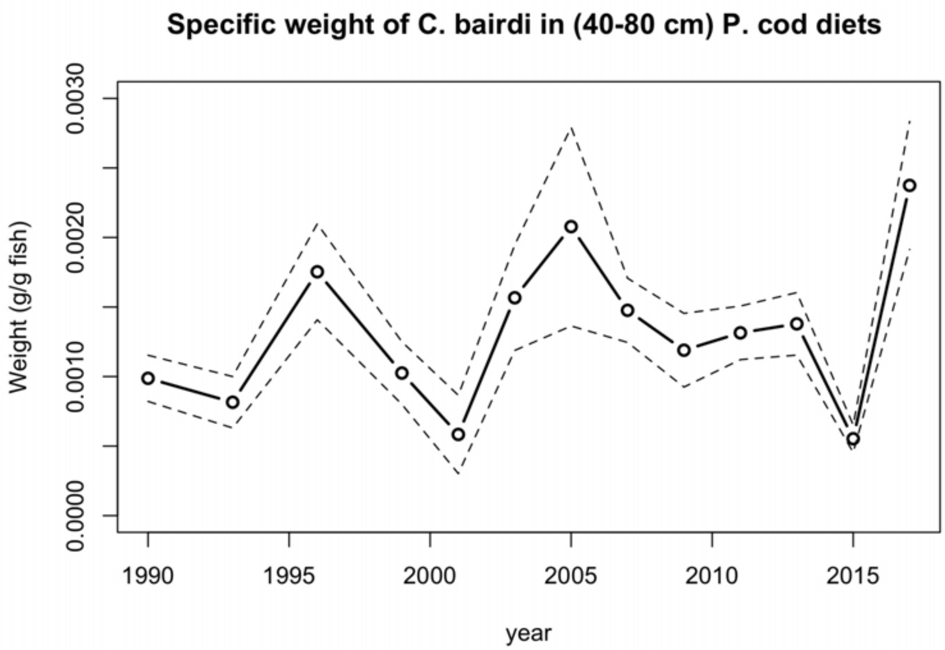


Figure 12: Specific weight (g prey/ g pred) of *Chionoecetes bairdi* in the diets of Pacific cod in the Gulf of Alaska, AK. Diet data from NOAA REEM Food Habits database.

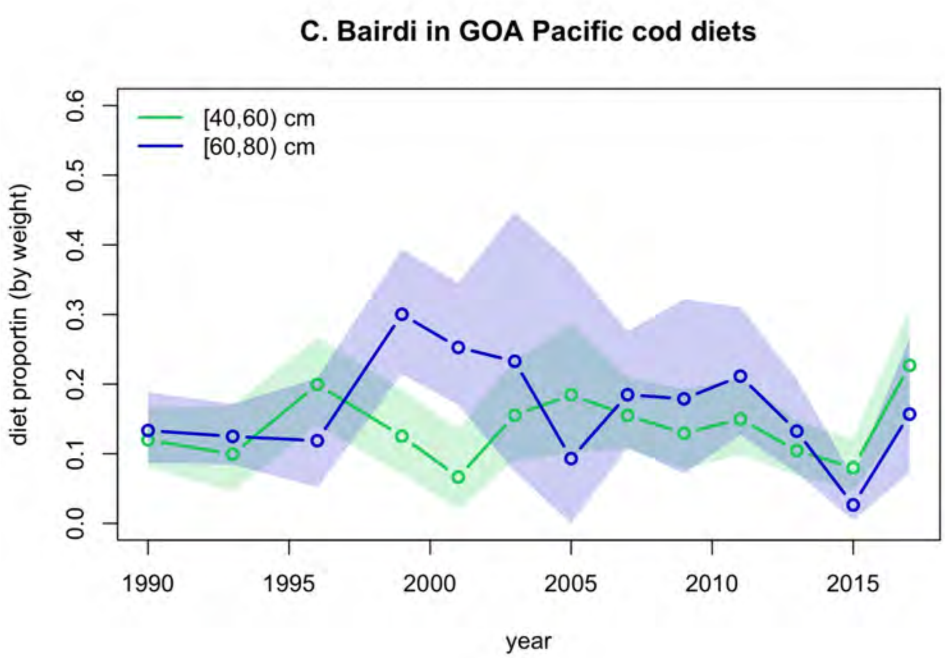


Figure 13: Proportion by weight of *Chionoecetes bairdi* in the diets of different size classess of Pacific cod in the Gulf of Alaska, AK. Diet data from NOAA REEM Food Habits.

## Current Environmental State – Western Gulf of Alaska

The North Pacific atmosphere-ocean climate system was in a more moderate state during 2016–2017 than during the previous two years. In particular, the warm sea surface temperature anomalies associated with the extreme marine heat wave of 2014–2016 moderated. A weak La Niña developed during winter 2016–2017 along with a weaker than normal Aleutian Low. The Pacific Decadal Oscillation remains positive but with lower amplitude than in recent past years. The weather of the coastal GOA was generally warmer than normal during the past year with the exception of winter 2016–17, during which air temperatures were near normal. The freshwater runoff into the GOA appears to have been greater than normal during the fall of 2016 and somewhat less than normal in summer 2017, with implications for the baroclinic component of the Alaska Coastal Current. The coastal wind anomalies were upwelling favorable during the winter. The sub-arctic front was farther south than last year. This is consistent with the surface currents shown in the Papa Trajectory Index, which has its southernmost extent since the 1930s, and suggests that there was reduced transport into the Alaska Current. Eddy kinetic energy has been low this past spring and summer, suggesting that phytoplankton was more tightly confined to the shelf. Water temperature profiles taken during the summer bottom-trawl survey showed slight overall cooling compared to 2015 but that it was still among the warmer years in the survey's record. Also, the warmest water did not penetrate as deeply into the upper 100 m as in 2015. Taken together, these suggest that the GOA continues to be warm but is returning to average conditions.

The rapid zooplankton assessment during spring and summer in the western GOA noted some hot spots of large copepods during spring, but the numbers of large copepods declined over the summer. Compared with historical estimates in Shelikof Straits, large copepod abundances were similar to the long-term mean and higher than they were in 2015, the year of the last survey. Small copepods were widespread in spring and increased in abundance in summer, with both values about equal to the long term mean. The smaller life-stages of euphausiids that are sampled in the rapid zooplankton assessment appeared to be more abundant compared to historical estimates and to the low estimates in 2015. This pattern was in contrast to the preliminary euphausiid abundance estimate from the acoustic survey, which samples larger juveniles and adults, and which found less euphausiid biomass in 2017 than in 2015.

Larval walleye pollock rough counts from the 2017 western GOA EcoFOCI survey were above average throughout the grid with few zero catches. This is in contrast to 2015 when the survey catches were far below average and often zero across the survey grid. The rough count abundance estimate indicates that larval walleye pollock abundance was similar to previous higher-abundance years (2000, 2006, 2010) although not as high as 2013. However, the distribution of the extremely abundant larval pollock in 2013, which did not materialize into a large year-class, was more concentrated to the west of the Shumagin Islands compared with the more widespread larval distribution this year. Late summer catches this year remained high, the second-highest in the record, and were concentrated through Shelikof Strait and east of Kodiak. Their distribution may have favored their survival over the summer.

Groundfish condition during the summer bottom-trawl surveys in 2015 was notable in that all species had below average body condition. Pacific cod condition was the lowest recorded. In 2017, all species but Pacific cod had below average body condition. Fish condition for arrowtooth flounder and northern rockfish were the lowest on record, indicating that foraging conditions for most species remained poor. Pacific cod diets, particularly in the larger sizes, contained large proportions of pollock and *C. bairdi* crab, which had been noticeably absent in 2015. The depth distribution of rockfish caught during the bottom trawl survey remained unchanged relative to previous years. Their mean distribution relative to temperature was lower than last year, reflecting the temperature difference in the water column.

Seabirds and marine mammals continued to do poorly overall in 2017 with some exceptions. Several fish-eating seabirds had unusually low reproductive success in 2017. In general, murres appear to have been negatively affected during the marine heat wave of the past few years, with widespread reproductive failures, die-offs, and low attendance at breeding colonies. Other species did not show broad-scale failures during this period; planktivorous seabirds were generally successful. Despite overall low reproductive success of murres in 2017, some improvement in murre attendance and fledging success may indicate some improvement in foraging conditions. In Glacier Bay, biologists only documented two mother-calf humpback whale pairs, which will likely be the second year in a row of anomalously low birth rates. In addition, one of the whale mothers in 2017 appeared to be abnormally thin, and the other lost her calf by mid-July. A preliminary look at finalized 2017 counts of steller sea lions indicates that there has been a significant decline in pup counts in the eastern and central GOA relative to 2015 (Sweeny and Fritz pers. comm). These are the first region-wide declines in western Steller sea lion pup counts that the NOAA Marine Mammal Lab has observed east of Samalga Pass since the overall stock decline ceased in the early 2000s. Pup counts had consistently increased at all rookeries in these 2 regions through 2013, and through 2015 at 8 of the 10. Whatever caused the substantial drop in pup counts observed in 2017 appears to have had the greatest impact in the Prince William Sound area and less impact to the west and east.

## Current Environmental State – Eastern Gulf of Alaska

Eastern GOA shelf waters were 2–3°C cooler in 2017 than we have seen for the last 3 years, although still within the range of a "warm" year. Within the archipelago of northern southeast Alaska, the top 10-m integrated temperatures were also about 2°C cooler in 2017 than in 2016 during July, and 0.5°C below the long term average (Fergusson). Overall there were near normal temperatures averaged over upper 100m, albeit they were warmer on the shelf and colder offshore. The intensity of stratification, and the shallowness of "deep" cold water offshore was notable. Average mixed layer water temperature was cooler than last year, confirming that the "Warm Blob" is dissipating.

The eastern GOA zooplankton community in oceanic waters contained a high biomass of tunicates (doliolids and salps), while the nearshore zooplankton biomasses consisted of a high number of small (<0.25 mm) juvenile shelled pteropods, *Limacina helicina*, at a single station. Some mixing of oceanic and shelf species assemblages occurred during July of 2017, likely resulting from weak horizontal density gradients and a weak Alaska Coastal Current. Zooplankton communities over the eastern GOA shelf were shaped by a freshwater plume emanating from the Alsek River, south of Yakutat. Offshore ichthyoplankton in the bongo was dominated by rockfish, snailfish, and fish eggs, with the occasional myctophid.

Observations from 2017 surveys targeting young-of-the-year (YOY) fish in the eastern GOA indicated low productivity of YOY groundfish, juvenile salmon, adult salmon, and squid with the exception of high YOY arrowtooth flounder and average juvenile chum salmon abundances. Relative to 2016, there was a continuation of low biomass of YOY Pacific cod, YOY pollock, and squid; a reduction in juvenile salmon biomass and YOY rockfish, and an increase in YOY arrowtooth flounder biomass. While a portion of the catch differences in 2016 and 2017 was possibly due to a change in trawl gear, some portion is likely to be the result of shift in prey fields and primary producers.

Inside archipelago waters of northern southeast Alaska, surface trawl surveys found few juvenile salmon, YOY groundfish, or forage fish, although there were moderate herring and high adult chum salmon catches. Large catches of adult chum salmon were consistent with large harvest rates of chum salmon in commercial fisheries around the state of Alaska.

Jellyfish biomass was dominated by *Ctenophora* and *Aequorea*. For the third continuous warm year, the biomass of large-bodied jellyfish *Chrysaora melanaster* was down, and this species failed to dominant catches as they have in the past. Overall, Ctenophores and Hydrozoans were the recent key players in GOA in terms of abundance. Shifts from large bodies to small bodied jellyfish may be due to shifts in water mass properties that shift distributions or a result of environmental forcing on growth and survival on the early life polyp stage on the benthos.

The YOY sablefish surface trawl survey catches indicated sparse abundances of sablefish ($n = 2$) and stable *Sebastes* spp. abundances ($n = 4{,}946$) in offshore waters during 2017 relative to catches during 2016 (sablefish $n = 2{,}202$, rockfish $n = 3891$). In 2017, juvenile sablefish were nearshore in the northern edge of the panhandle off of Kayak Island rather than offshore as in 2016. The survey adaptively sampled a nearby eddy and on the shelf between Baranof Island and Kayak Island where catches were sparse until reaching Kayak Island ($n \sim 700$). YOY groundfish, forage fish, and juvenile salmon body sizes were small in the nearshore eastern GOA during 2017.

In Auke Creek in 2016, the number of pink and coho salmon smolt outmigrants was low. These migrating smolts experienced warm creek temperatures and low water depths. Lack of snowfall and snowmelt contributed to warmer creek temperatures in 2016. The 2016 out migrants had the lowest marine survival of salmon returning to spawn for the 1980–2017 time series, with coho salmon experiencing the lowest marine survival on record. In contrast, pink salmon had average marine survival rates. Conditions for smolt outmigration improved in 2017 with cooler freshwater temperature (2°C) and deeper creek depths.

# Ecosystem Indicators

## Ecosystem Status Indicators

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

### Physical Environment

#### North Pacific Climate Overview

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**Last updated: August 2017**

**Summary:** *The state of the North Pacific atmosphere-ocean system during 2016–2017 featured the moderation of warm sea surface temperature (SST) anomalies associated with the extreme marine heat wave of 2014–16. The sea level pressure (SLP) anomaly patterns varied from season to season, with the most prominent perturbation occurring in winter 2016–17 when the Aleutian Low was much weaker than normal. This kind of anomaly has often been associated with the remote forcing by La Niña; the magnitude of the response was large relative to that of the tropical Pacific signal. The Pacific Decadal Oscillation (PDO) was positive during the past year, with an overall decline in amplitude. The climate models used for seasonal weather predictions are indicating that near-neutral ENSO conditions or a weak La Niña are most likely for the winter of 2017–18, while maintaining North Pacific SST anomalies in a weakly PDO-positive sense.*

**Regional Highlights:**

*West Coast of Lower 48.* This region experienced moderate upper ocean temperatures with the exception of Baja California, where relatively warm water prevailed. The winter of 2016–17 was wetter than normal along the entire west coast, with portions of Northern California receiving record amounts of precipitation. It was also quite chilly in the Pacific Northwest, where it was the coldest winter since 1992–93, and a full 5textsuperscriptoC colder than the record warm winter of 2014–15.

The end of winter snow pack was above normal for all of the Pacific coast states. The coastal wind anomalies were downwelling-favorable during the fall of 2016. Enhanced upwelling occurred along the northern and central California coast during late spring into summer 2017. Upwelling was also prominent at times along the coast of the Pacific Northwest, which, during August 2017, included relatively high near-surface chlorophyll concentrations; moored buoys indicated relatively cool water with low oxygen content below about 80 meters depth. Based on anecdotal accounts, there do not appear to have been as many unusual species sighted. An exception was during late spring into summer along the coast of the Pacific Northwest, where there were multiple sightings of large assemblages of pyrosomes, a gelatinous tunicate that are rarely found in such large numbers.

*Gulf of Alaska.* The weather of the coastal GOA was generally warmer than normal during the past year with the exception of winter 2016–17, during which air temperatures were near normal. The freshwater runoff into the GOA appears to have been greater than normal during the fall of 2016 and somewhat less than normal in summer 2017, with implications for the baroclinic component of the Alaska Coastal Current. The coastal wind anomalies were upwelling favorable during the winter. The sub-arctic front was farther south than last year, which is consistent with the surface currents shown in the Ocean Surface Currents–Papa Trajectory Index section (p. 67).

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

### Sea Surface Temperature and Sea Level Pressure Anomalies

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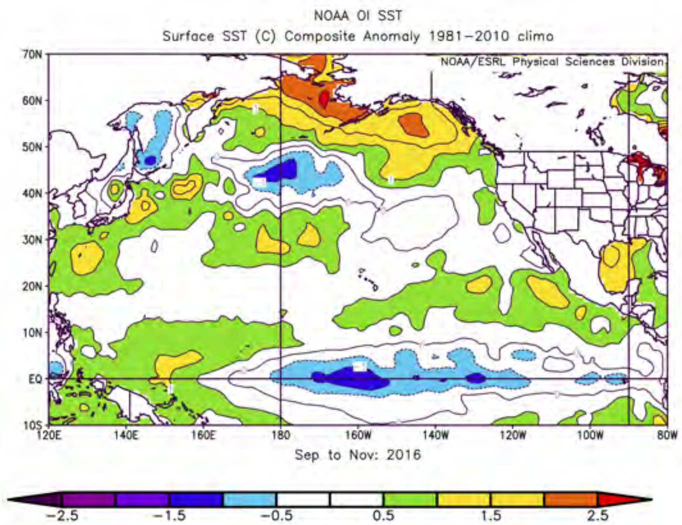
**Last updated: September 2017**

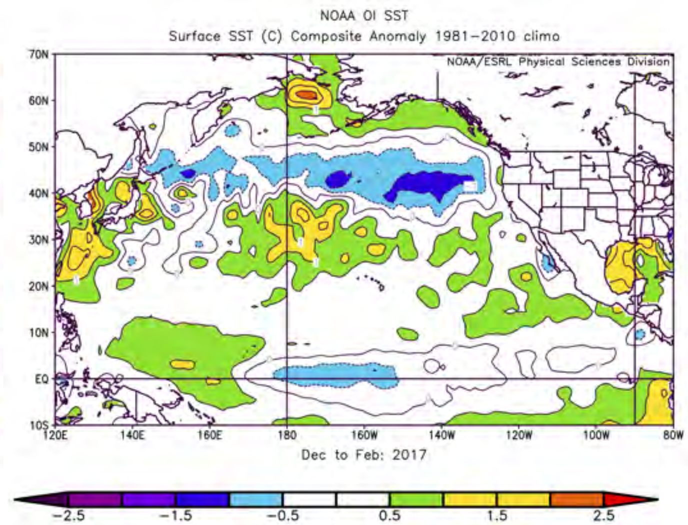
**Description of indices:** The state of the North Pacific climate from autumn 2016 through summer 2017 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981–2010.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

**Status and trends:** The eastern portion of the North Pacific ocean experienced during 2014–16 one of the most extreme marine heat waves in the observational record (Scannell et al., 2016); the interval summarized here can be considered a transition period between that event and a more climatologically normal SST distribution on the basin-scale. More detail on the evolution of the SST and SLP from a seasonal perspective is provided directly below.

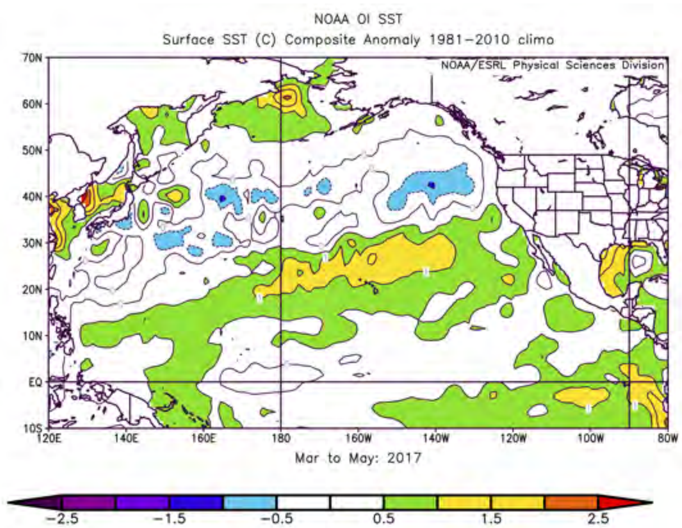
The SST in the North Pacific during the autumn (Sep–Nov) of 2016 (Figure 14a) was warmer than normal in the Gulf of Alaska (GOA) and much warmer than normal (>2$^o$C) in the northern and eastern Bering Sea. Most of the remainder of the North Pacific Ocean had SSTs that were near to slightly above normal, with the exception of a cold patch at the dateline between 40$^o$ and 50$^o$N. The SST anomalies in the tropical Pacific were positive in the west, and negative in the east, with the latter implying weak La Niña conditions. The pattern of anomalous SLP during autumn 2016 featured a pole of strongly negative anomalies over the western Bering Sea, and lower than normal SLP extending eastward to a secondary negative pole off the coast of the Pacific Northwest (Figure 15a). This SLP pattern implies wind anomalies from the west across the North Pacific between roughly 40$^o$ and 50$^o$N, causing enhanced cooling.



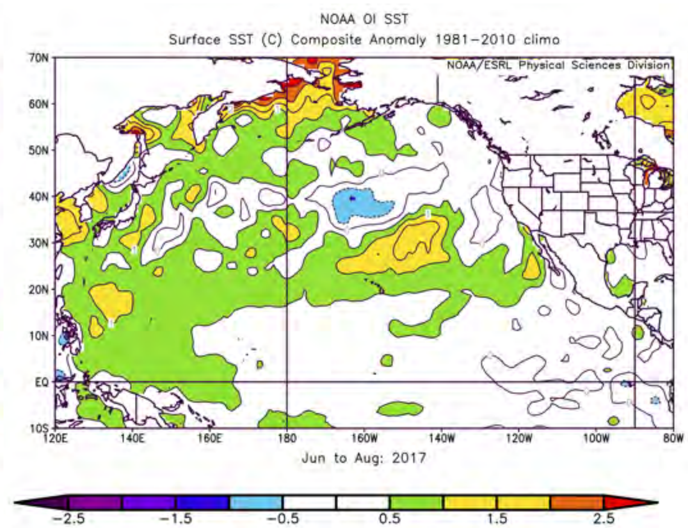

(a) Autumn




(b) Winter

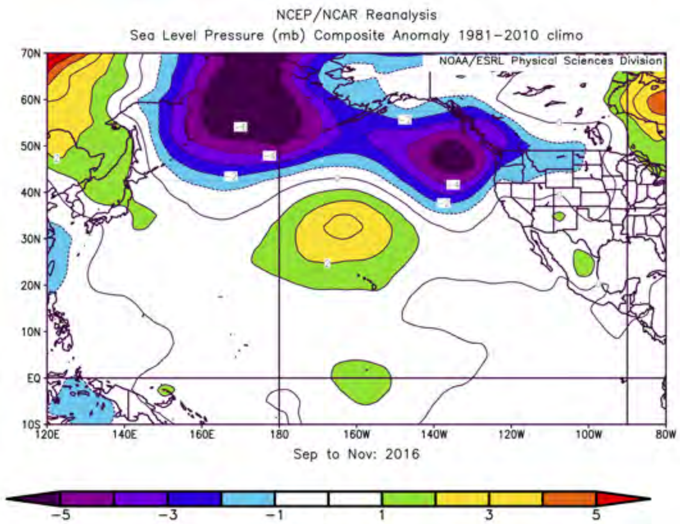



(c) Spring

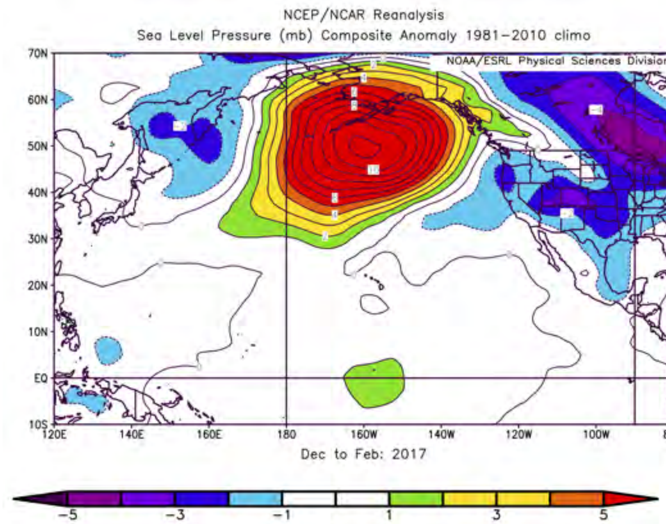



(d) Summer

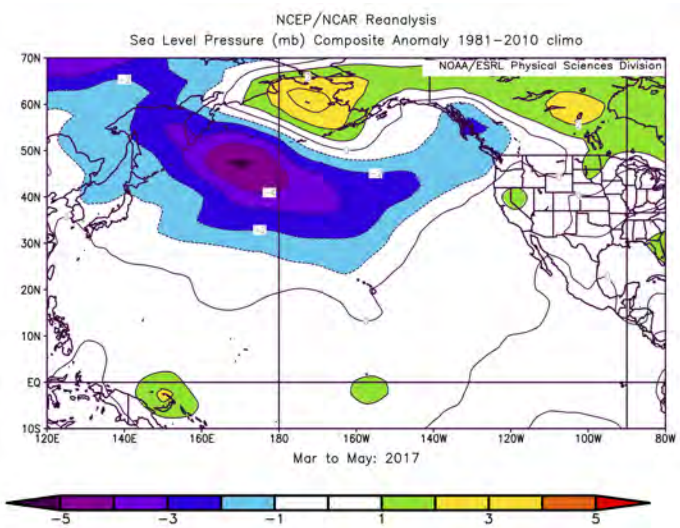
Figure 14: SST anomalies for autumn (September–November 2016), winter (December 2015–February 2017), spring (March–May 2017), and summer (June–August 2017).



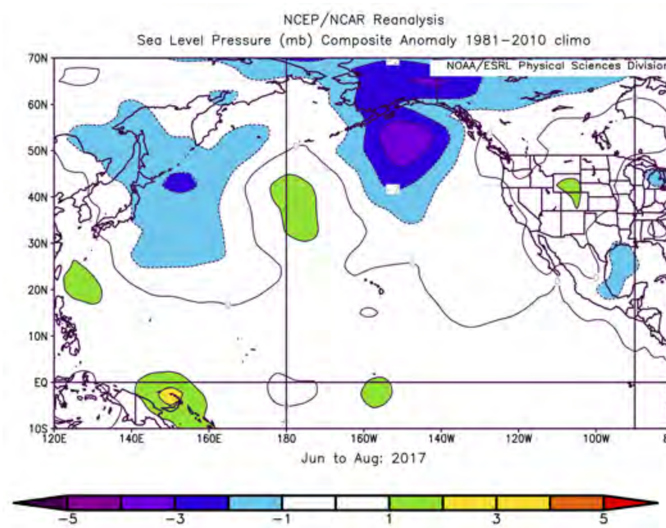

(a) Autumn




(b) Winter




(c) Spring




(d) Summer

Figure 15: SLP anomalies for autumn (September–November 2016), winter (December 2016–February 2017), spring (March–May 2017), and summer (June–August 2017).

The pattern of North Pacific SST during winter (Dec–Feb) of 2016–17 relative to the seasonal mean (Figure 14b) reflected cooling north of about 40°N relative to the previous fall season. This cooling was associated with anomalous winds out of the west across the middle latitudes of the North Pacific in fall, followed by anomalous winds during winter out of the west across the Bering Sea and out of the northwest in the GOA. The latter wind anomalies were due to a distribution of anomalous SLP during winter 2016–17 that featured much higher pressures than normal over a large portion of the eastern North Pacific, with a peak magnitude greater than 12 mb located south of the Alaska Peninsula (Figure 15b). This is the signature of a particularly weak Aleutian Low, and implies suppressed storminess for the southeastern Bering Sea and GOA. A weak Aleutian Low commonly occurs during La Niña, but as shown in Figure 14b, the SST anomalies in the central and eastern tropical Pacific were not much cooler than normal. It is not known why there appears to have been such a disproportionate response in the atmospheric circulation over the North Pacific. The anomalous northerly flow on the east side of the positive SLP anomaly south of Alaska resulted in the coldest winter for the Pacific Northwest since 1992–93; the region of lower than normal pressure along the west coast of the US was also accompanied by higher than normal precipitation.

The distribution of anomalous SST in the North Pacific during spring (Mar–May) of 2017 (Figure 14c) was similar to that during the previous winter season, with moderation in the magnitude of the anomalies north of 30°N and modest warming in the sub-tropical North Pacific. Moderate cooling occurred in the central North Pacific in the vicinity of 40°N, 170°W. The overall pattern projected on the positive phase of the Pacific Decadal Oscillation (PDO), but not as strongly as during the past two years. The SST anomalies in the tropical Pacific were of minor amplitude. The SLP anomaly pattern (Figure 15c) for spring 2017 featured a band of lower than normal pressure from eastern Siberia to a negative center south of the Aleutian Islands, with an eastward extension to British Columbia. Above-normal SLP resulted in suppressed storminess for the eastern Bering Sea. The atmospheric circulation in the northeast Pacific promoted relatively downwelling-favorable winds in the coastal GOA and wet weather in the Pacific Northwest.

The SST anomaly pattern in the North Pacific during summer (Jun–Aug) 2017 is shown in Figure 14d. It was warmer than normal north of 50°N, with the greatest positive anomalies of +2°C near Bering Strait into the southern Chukchi Sea. Warm SSTs were also present in a band between about 30° and 15°N across the entire North Pacific Ocean with the greatest anomalies located northeast of the Hawaiian Islands. Upper ocean temperatures in the tropical Pacific were quite close to their climatological norms. The distribution of anomalous SLP (Figure 15d) during summer 2017 included negative centers in the northwestern portion of the North Pacific basin and south of mainland Alaska straddling a region of slightly higher than normal SLP centered near 40°N and the dateline.

### Climate Indices

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**Last updated: September 2017**

**Description of indices:** Climate indices provide an alternative means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, Pacific Decadal Oscillation (PDO) index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO) and Arctic Oscillation (AO). The time series of these indices from 2007 into summer 2017 are plotted in Figure 16.

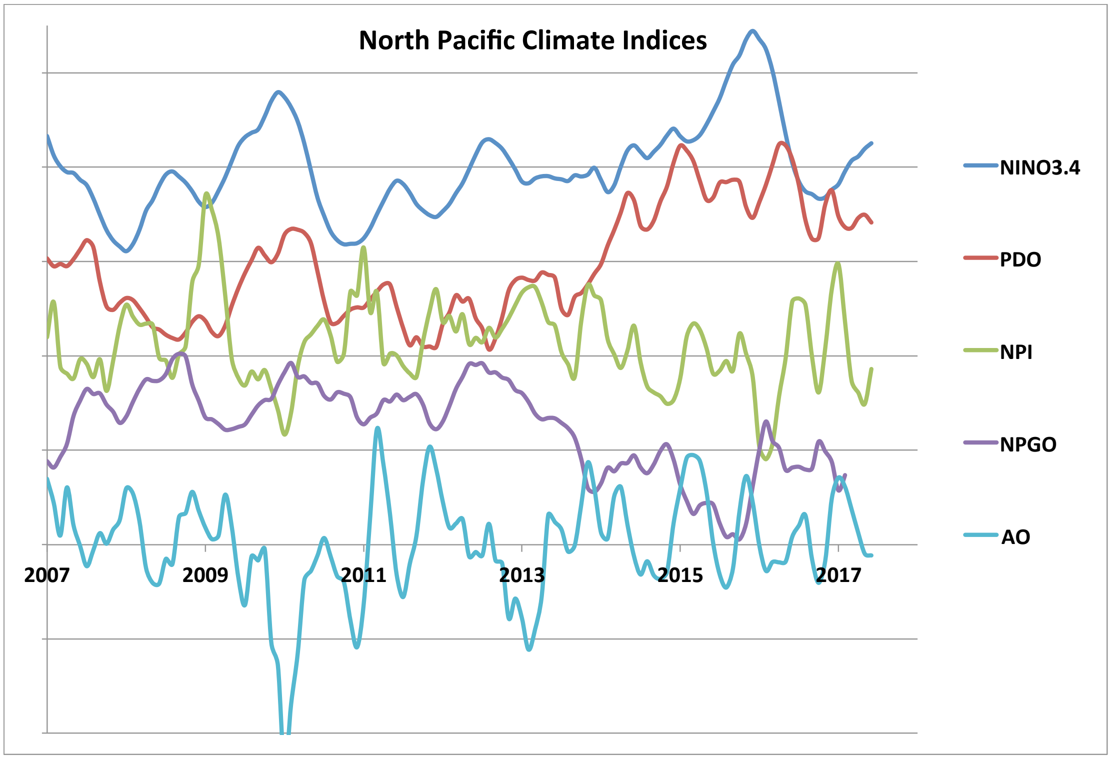


Figure 16: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized using a climatology based on the years of 1981–2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAAs Earth Systems Laboratory at `http://www.esrl.noaa.gov/psd/data/climateindices`.

**Status and trends:** The North Pacific atmosphere-ocean climate system, in an overall sense, was in a more moderate state during 2016–17 than during the previous two years. The NINO3.4 index ranged from slightly negative during late 2016 to slightly positive during spring of 2017, with little trend over the course of summer 2017 (Figure 16). This rather quiet state for the tropical Pacific is in contrast with the large swings that occurred in 2015–16. The PDO has been positive (indicating warmer than normal SST along the west coast of North America and cooler than normal in the central and western North Pacific) since early 2014. The magnitude of the PDO has generally decreased since early 2016. Much of this decline can probably be attributed to ENSO, and in particular the transition from a strong El Niño to a weak La Niña in 2016. The NPI was negative during the past fall and spring, implying a deeper than normal Aleutian Low, as indicated in Figures 15a and 15b. In contrast, the winter of 2016–17 included a large positive value for the NPI. While this sign of the NPI represents a typical atmospheric response to La Niña, its magnitude is disproportionately large considering the weak amplitude of La Niña in late 2016.

The NPGO mostly declined from a small positive value in early 2016 to a small negative value in early 2017. This index has been shown to be positively correlated with nitrate concentrations on Line P extending from Vancouver Island to Station P at 50°N, 145°W. The AO represents a measure of the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the Pacific and Atlantic Ocean at a latitude of roughly 45°N. It has a weakly positive correlation with sea ice extent in the Bering Sea. The AO was positive during the winter of 2016–17, perhaps contributing to the anomalously weak Aleutian Low (Figure 15b), and otherwise in a mostly neutral state on seasonal time scales since early 2016.

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

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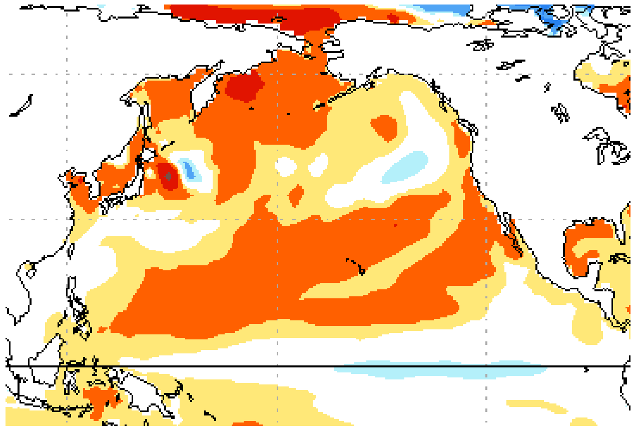
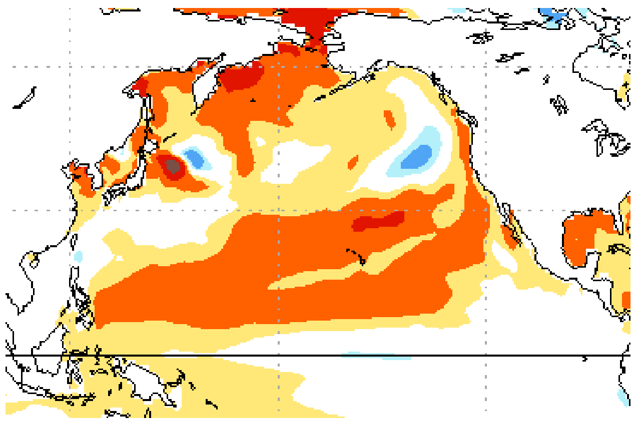
**Last updated: September 2017**

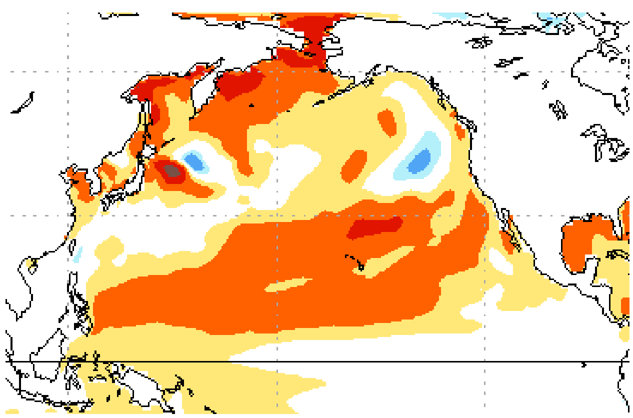
**Description of indicator:** Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 17. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.



(a) Months OND



(b) Months DJF



(c) Months FMA

Figure 17: Predicted SST anomalies from the NMME model for OND (1 month lead), DJF (3 month lead), and JFM (4 month lead) for the 2017–2018 season.

**Status and trends:** First, the projections from a year ago are reviewed qualitatively. The one-month lead forecast for Oct–Dec 2016 was quite accurate, which is not surprising in that the upper ocean has a great deal of thermal inertia, i.e., persistence, with the initial state being a primary determinant of near-term future conditions. This influence lessens with time and indeed for the period considered here, the longer-range (3-month and 5-month) forecasts were not as skillful.

The models as a group, as reflected in the ensemble averages, correctly predicted the signs and the magnitudes of the SST anomalies in the sub-tropical and tropical Pacific, with only minor discrepancies. The NMME forecasts at the 3-month and 5-month forecast horizons did not validate as well north of about 30°N, where the modeled SSTs were generally warmer than observed. The models simulated too-little moderation of the pre-existing warm anomalies in the GOA and Bering Sea, and also under-predicted the amount of cooling in the waters offshore of the Pacific Northwest. Nevertheless, the models did reproduce the overall patterns in anomalous SST that were observed, even in the longer-range projections; the positive skill in these forecasts discussed here (and found in other studies) suggest that the NMME SST output merits consideration.

These NMME forecasts of three-month average SST anomalies indicate a continuation of warm conditions across most of the North Pacific through the end of the year (Oct–Dec 2017) with a reduction in the longitudinal extent of cooler than normal temperatures offshore of the Pacific Northwest (Figure 17a). The magnitude of the positive anomalies is projected to be greatest (exceeding 1°C) in the western Bering Sea. Negative SST anomalies are projected in the central and eastern equatorial Pacific. It is uncertain whether they will remain weak enough to constitute neutral conditions or become strong enough to constitute La Niña. As of early September 2017, the probabilistic forecast provided by NOAA's Climate Prediction Center (CPC) in collaboration with the International Research Institute for Climate and Society (IRI) for the upcoming fall through winter indicates about a 40% chance of neutral conditions and a 55% chance of a weak La Niña. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2017–February 2018 (Figure 17b) and February–April 2018 (Figure 17c) with some slight cooling in the eastern Bering Sea, GOA, and nearshore waters of the Pacific Northwest.

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

### Eddies in the Gulf of Alaska

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**Last updated: August 2017**

**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), 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 18; 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 18). 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 18). By averaging EKE over regions c and d (see boxes in Figure 18), we obtain an index of energy associated with eddies in these regions (Figure 19). The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS) (`http://www.marine.copernicus.eu`).

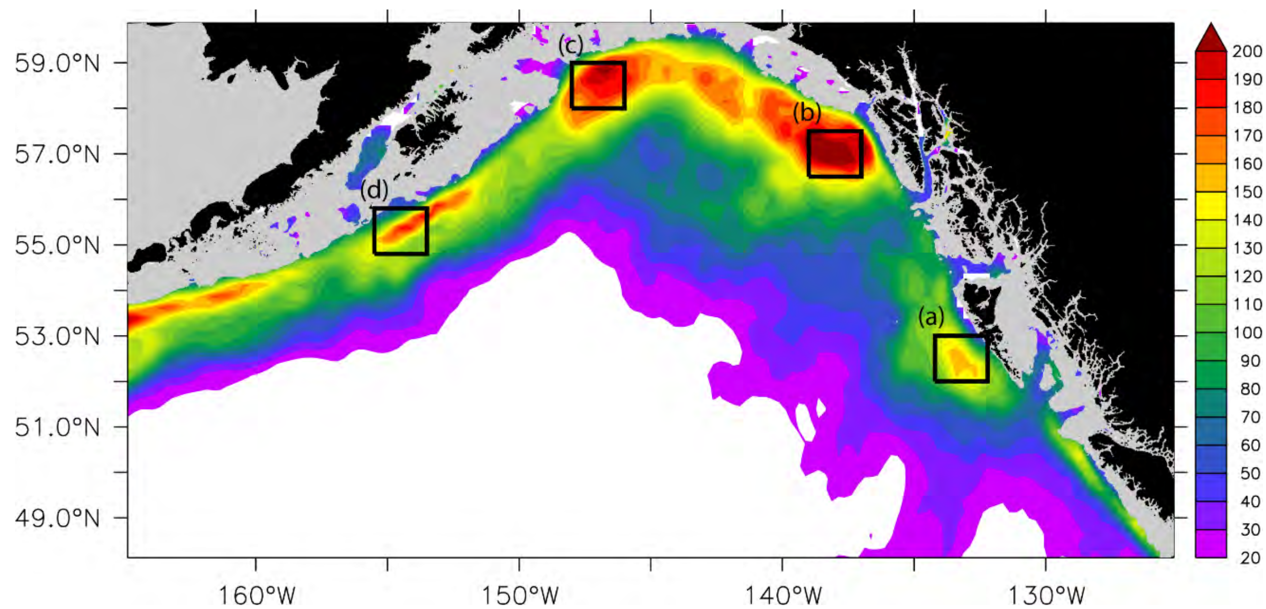


Figure 18: Eddy Kinetic Energy averaged over January 1993–December 2016 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 19.

**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. The highest EKE observed in region (c) occurred in 2016 when a strong persistent eddy remained in the region for multiple months. 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 was low in both regions in spring and summer 2017. The high EKE values in spring 2016 in region (c) were due to a strong eddy that formed near Yakutat in January 2016.

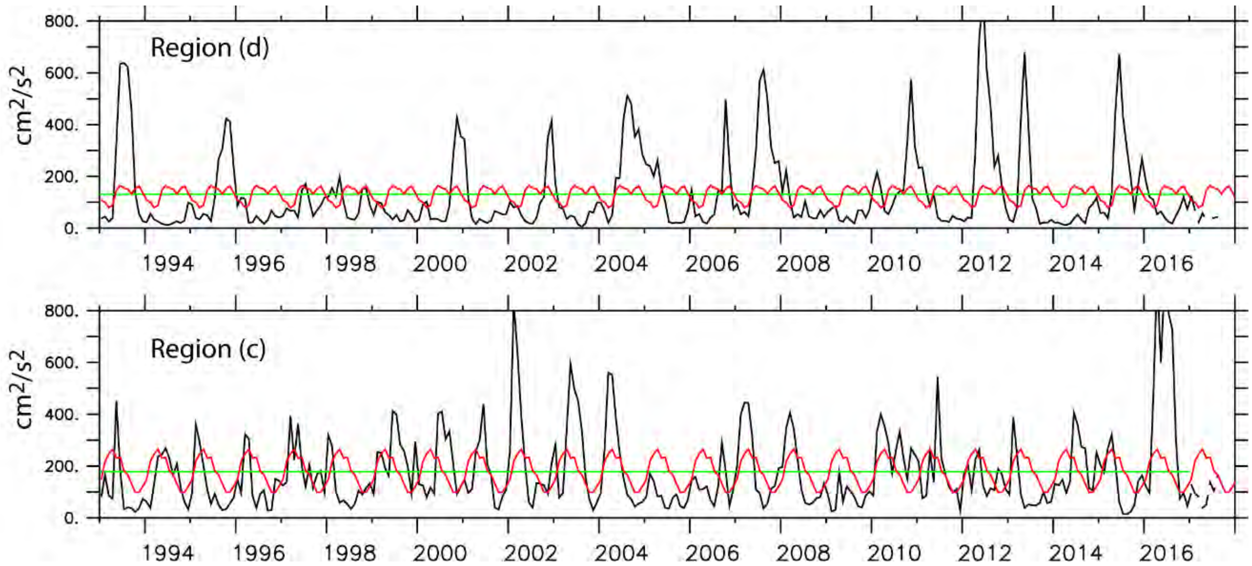


Figure 19: Eddy kinetic energy (cm$^2$ s$^{-2}$) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 18. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product), Red: seasonal cycle. Green (straight line): mean over entire time series.

**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 2017 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 2017 than in 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 2017**

**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 20). 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 2016 (trajectory endpoints years 1902–2017).

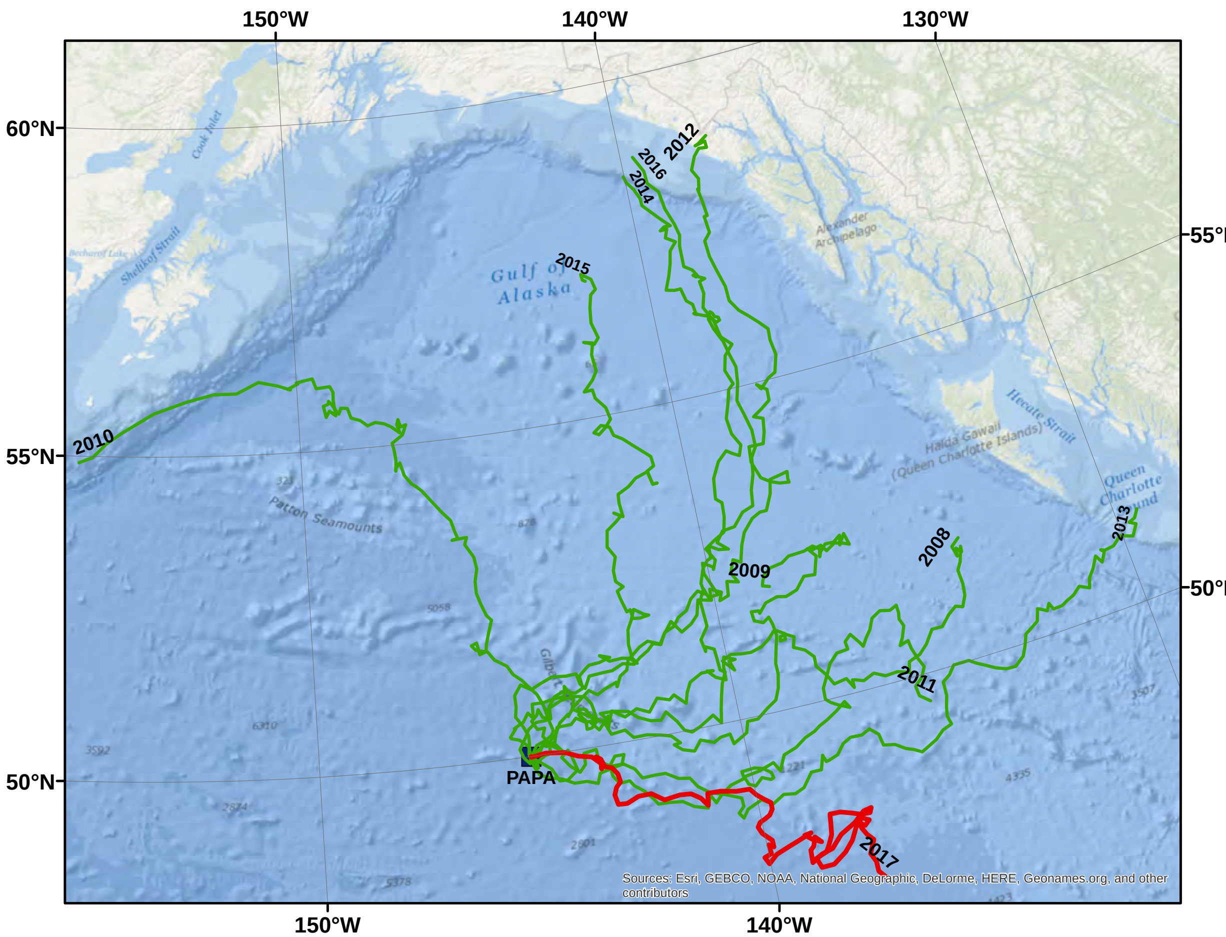


Figure 20: Simulated surface drifter trajectories for winters 2008–2017 (endpoint year). End points of 90-day trajectories for simulated surface drifters released on Dec. 1 of the previous year at Ocean Weather Station PAPA are labeled with the year of the endpoint (50°N, 145°W).

**Status and trends:** In general, the trajectories fan out northeastwardly toward the North American continent (Figure 20). The 2009/2010 trajectory was an exception and resulted in the westernmost trajectory endpoint for the entire set of model runs (1902–2017 endpoints). 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 trajectory for 2012/13 was notable as ending up the furthest east among trajectories in recent years, driven by very strong westerly anomalies in the northeast Pacific. The trajectories for 2013/14, 2014/15, and 2015/16 trajectories were very similar to that for 2011/12, although these did not reach quite as as far north as in 2011/12. These trajectories coincided with the development (2013/14) and continuation (2014/15, 2015/16) of the "Blob" of warm surface waters along the eastern Pacific coast and the return of the Pacific 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 opposite was true for the 2016/17 winter, however, and strong northerly winds pushed the drifter trajectory to its most southerly latitude since the late 1930s.

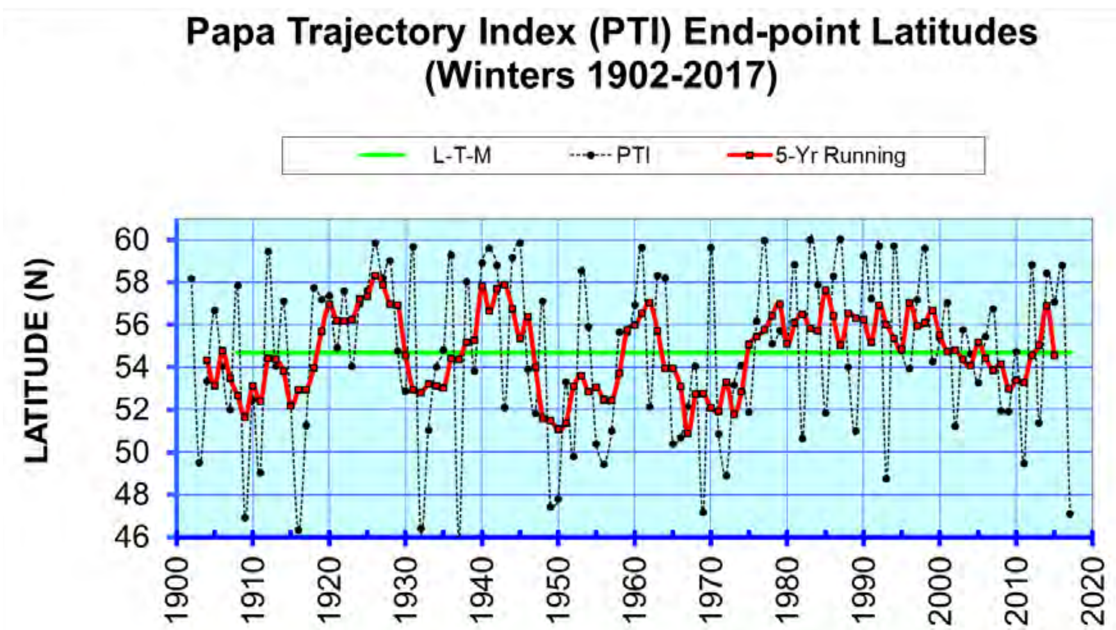


Figure 21: Annual, long-term mean (green line), and 5-year running mean (red line and squares) of the PAPA Trajectory Index time series (dotted black line and points) for 1902–2017 winters.

The PTI time series (Figure 21, 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 successive years.

Over the past century, the filtered (5-year running average) PTI has undergone four complete oscillations with distinct crossings of the mean, although the durations of the oscillations are not identical: 26 years (1904–1930), 17 years (1930–1947), 17 years (1947–1964), and 41 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 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 Alaskas heat budget. In addition, the PDO recently (July, 2014) shifted into a positive and warm phase, associated with warm SST anomalies 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 "warm" regime that began in 1977. Zooplankton production was positively affected after the 1977 regime shift (Brodeur and Ware, 1992), as were recruitment and survival of salmon and demersal fish species. Recruitment of rockfish (Pacific ocean perch) and flatfish (arrowtooth flounder, halibut, and flathead sole) also increased. However, shrimp and forage fish such as capelin were negatively affected by the 1977 shift (Anderson, 2003). The reduced availability of forage fish may have contributed to the decline in marine mammal and seabird populations observed after the 1977 shift (Piatt and Anderson, 1996).

### Gulf of Alaska Survey Bottom Trawl Temperature Analysis

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**Last updated: October 2017**

**Description of indicator:** Since 1993, water column temperatures have been routinely recorded during Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering Groundfish Assessment Program (RACE-GAP) GOA bottom trawl surveys using bathythermograph data loggers attached to the headrope of the bottom trawl net. In 2003, the SeaBird (SBE-39) microbathythermograph (Sea-Bird Electronics, Inc., Bellevue, WA) replaced the Brancker XL200 data logger (Richard Brancker Research, Ltd., Kanata, Ontario, Canada) which had been in use from 1993–2001 (Buckley et al., 2009). The analyses presented here combine these two types of bathythermic data; the downcast data from each RACE-GAP trawl haul were isolated and used to inform our models.

The spatial and temporal coverage of the GOA RACE-GAP summer bottom trawl surveys has varied from year to year. Starting dates have ranged from the middle of May to the first week in June, and survey end dates ranged from the third week in July to the first week in September. The number of vessels employed, the areal extent, and the maximum depth of the GOA survey have all varied between survey years (e.g., water temperatures were not collected from the eastern GOA in 1993 and 2001, stations in the deepest GOA stratum [700–1000 m] have been sampled in just 5 of the last 12 surveys). Additionally, there is the expectation of an overall warming trend for water temperatures collected as the summer advances and the bottom trawl survey progresses from the western GOA into southeast Alaska; this should be particularly pronounced in the upper layers of the water column.

To account for the spatio-temporal variation that were a consequence of the survey design we removed the effect of collection date on water temperature by standardizing all RACE-GAP GOA bottom trawl collection dates to a median survey date of July 10. We formulated a generalized additive model (GAM) to estimate the effects of collection date on temperature at depth across survey areas and years; the GAM accounted for 81% of the total deviance in the temperature data. The resulting model was used to predict water temperature on the median survey day at depth and station from survey trawl haul downcasts. Model residuals were added to the predicted median day temperature-at-depth to produce temperature anomaly estimates for each station and depth during each survey year. To facilitate visualization, these estimates were averaged over systematic depth bins in ½-degree longitude increments. Depth gradations were set finer in shallower depths (e.g., 5 m bins between 0 and 100 m, 10 m bins between 100 and 300 m) to capture the anticipated rapid water temperature changes in surface waters with increasing depth. To further stretch the color ramp and enhance the visual separation of the near-surface temperature anomalies (between $\sim 4$ and 10°C and $< 100$ m), predicted temperature anomalies $\geq 9.5$°C and $\leq 3.5$°C were fixed at 9.5 and 3.5°C (e.g., a 12.5°C temperature anomaly was recoded as 9.5°C for the graphic representation) and the y-axis (depth) was truncated (0–400 m) relative to the deepest depths sampled (ca. 1000 m).

**Status and trends:** The thermal profile suggests that conditions in 2017 may have been slightly cooler compared to 2015 but still among the warmer years in our record (Figure 22). The warmest water did not penetrate as deeply into the upper 100 m in 2017. The warmer anomalies from this summers survey ($\geq 7$°C) were generally constrained to depths $< 50$ m whereas similar temperature anomaly values in 2015 were common between 50 and 100 m. However, there appeared to be warmer water deeper in the central Gulf (200–300 m) in 2017 compared to 2015. In general, the 2017 GOA thermal profile shares characteristics of the other warm years in our record (i.e., 2003, 2005, and 2015) and contrasts with the cooler years we have observed (e.g., 2007–2013).

**Factors influencing observed trends:** Temperature data we collected during RACE-GAP bottom trawl surveys in the GOA represent a temporally brief and spatially constrained snapshot of water column conditions. In the data summarized in the figure, each temperature bin represents data that were collected over a relatively short time as the vessels moved through the area. It is difficult to draw general conclusions about longer term trends from this type of data, especially since these temperature observations can be affected by short term events such as storms, tidal currents, and changes in freshwater discharge. More persistent medium-term phenomena like seasonal changes in solar heat flux, El Niño Southern Oscillations, and shifts in the Alaska Coastal Current also play an important role in determining water column temperatures. In addition, the strength and persistence of eddies are believed to have a large impact on the transport of both heat and nutrients across the continental shelf in the GOA (Ladd et al., 2007). The data reported here depict the variation in water column temperatures observed amongst GOA bottom trawl survey years, but do not inform the mechanisms or processes driving these differences.

**Implications:** Water column temperatures influence the distribution, assemblage membership, abundance, and growth rates of phytoplankton and zooplankton species. Ichthyoplankton distribution and growth rates are also related to location of the warm core eddies that are a prominent feature of the central GOA (Atwood et al., 2010). Adult and juvenile fish distribution can also be influenced by water temperatures (Kotwicki and Lauth, 2013; Rooney et al., in press). Interannual differences in water column temperatures, their implications, and their possible effects on fish populations in the GOA require more study to be better understood.

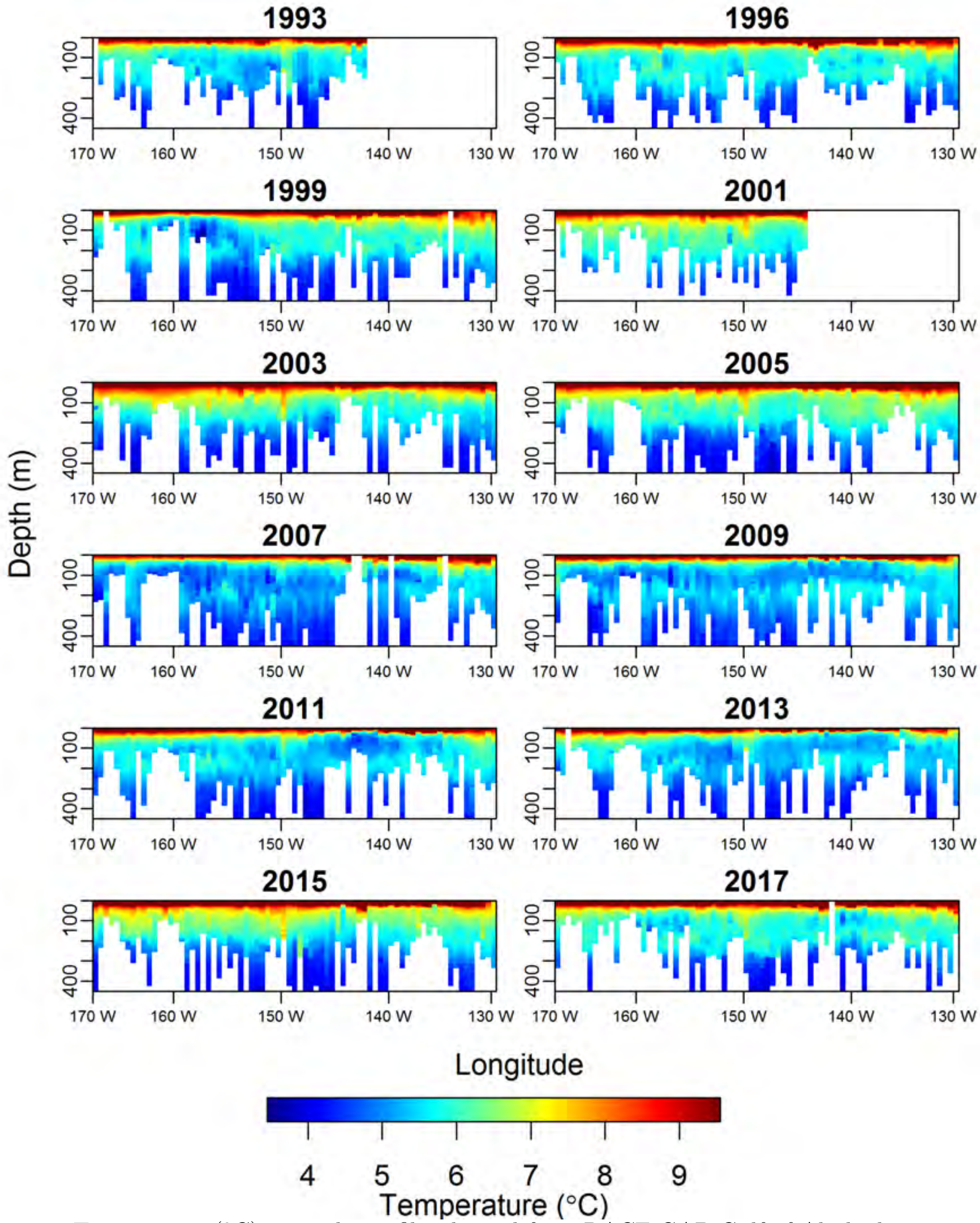


Figure 22: Temperature (°C) anomaly profiles derived from RACE-GAP Gulf of Alaska bottom trawl survey bathythermograph casts (1993–2017) and predicted from a generalized additive model at systematic depth increments and ½-degree longitude intervals; to visually enhance near-surface temperature changes, values $\leq 3.5$°C or $\geq 9.5$°C were fixed at 3.5 or 9.5°C and the y-axis (depth) was truncated at 400 m (relative to maximum collection depth ca 1000 m).

## Temperature and Salinity at GAK1

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**Last updated: September 2017**

**Description of indicator:** Temperature and salinity versus depth profiles have been taken since December 1970 at oceanographic station GAK1, located at the mouth of Resurrection Bay near Seward, Alaska. This 47-year time series is one of the longest running oceanographic time series in the North Pacific and the longest-running hydrographic profile dataset in Alaskan waters. The location is 59º 50.7' N, 149º 28.0' W and is located within the Alaska Coastal Current, so it is well "connected" with the shelf circulation. The sampling platform is normally R/V Little Dipper, a 28' coastal research vessel operated by the University of Alaskas Seward Marine Center.

The goal of the GAK1 project is to provide a long-term high-quality reference dataset for the coastal northern Gulf of Alaska that enables scientists, students, commercial and subsistence fishers and resource managers to better understand climatic and ecological conditions, their changes, and ramifications of change. Understanding, anticipating, and responding to change requires a stationary frame of reference in the form of long-term in situ observations. Such datasets are the best means to guide our assessments and interpretations of system variability. Untangling the relations between climatic and other drivers of change (e.g., oil spills or fishing regulations) similarly requires long reference time series. Environmental time series data can provide information valuable to the management of fish and shellfish populations and fisheries.

The GAK1 dataset is collected under the fundamental hypothesis that oceanic conditions are important to the physical and biological functioning of the Prince William Sound and Gulf of Alaska ecosystems. To that end, many dozens of papers have examined this hypothesis from numerous perspectives (for a comprehensive listing, see the GAK1 home page at `http://www.ims.uaf.edu/gak1/`). As the chemical and biological datasets begin to catch up (via quality of resolution, duration and frequency) to the physical measurements we expect that the insights gleaned through interdisciplinary analyses will grow in kind.

**Status and trends:** Year 2016 was the warmest on record for the GAK1 time series. Trends shown in Figure 23 are averages over 0–50 m depth and 200–250 m depth. Table 2 shows regression statistics for the period of record and for 2009–2016. The recent 2013–2016 warm interval was preceded by relatively cool temperatures over 2007–2012 and as a consequence the 2009–2016 analysis period shows an increasing trend that is an order of magnitude larger than the 1970–2016 interval. While salinity has declined in the past decade in both the near-surface and near-bottom, salinity over the entire time period has increase slightly in the near-bottom.

**Factors influencing observed trends:** The GAK1 record captures long-term (47-year) trends of warming throughout the water column, along with freshening in the 50 m closest to the surface and a slight salinization close to the seafloor. The observed warming is consistent with long-term climate trends of warming for the planet as a whole. Warming temperatures affect snow melt, net glacial ablation, coastal runoff, and by extension, these terrestrial discharges impact the surface salinity. The reasons for the near-seafloor salinity increases are presently unknown and are under investigation.

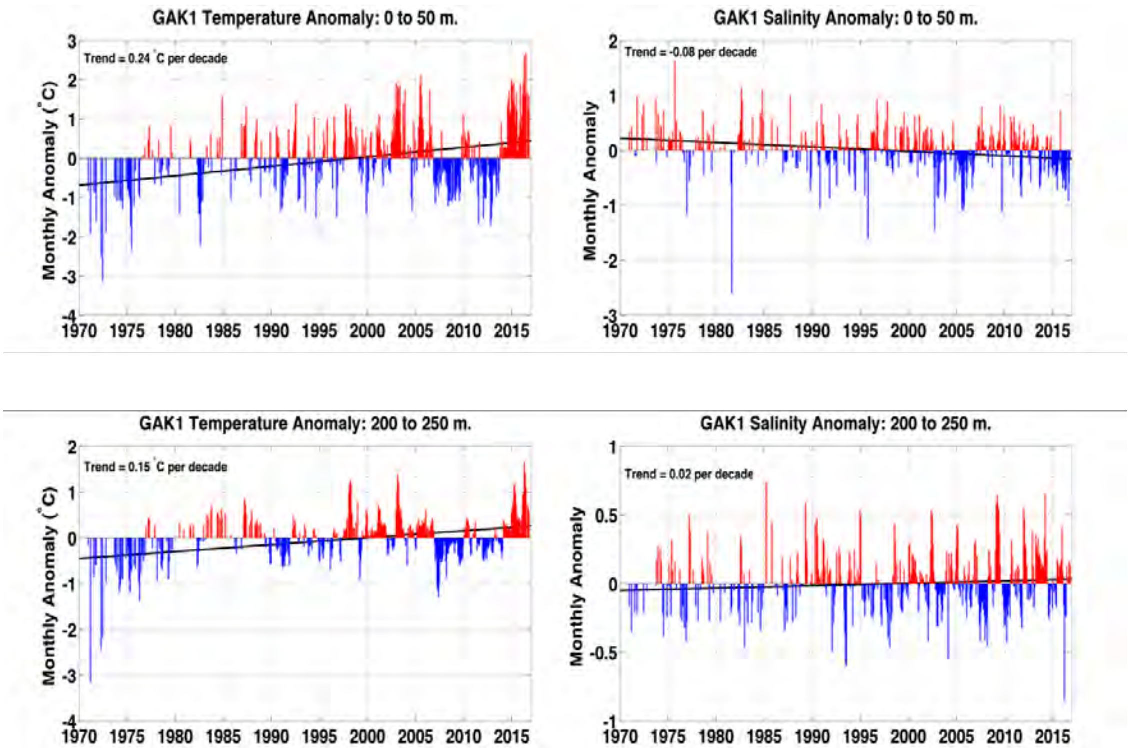


Figure 23: Plots of temperature (left) and salinity (right) monthly anomalies over 1970–2016. Black lines depict the least squares best-fit line to the data.

**Implications:** There are myriad consequences that may propagate through the ecosystem as a result of the observed temperature and salinity changes and many effects are difficult or impossible to anticipate. Some expected impacts include the following: 1. increasing coastal salinities could increase the along-shelf transport in the Alaska Coastal Current, altering the dispersal pathways and/or timing of water, heat, the coastal water chemical constituents, and plankton that are influenced by the coastal current; 2. warming will lead to increased metabolic rates and changes in biogeochemical cycling; 3. differential trends in the influence of temperature and salinity lead to increased levels of stratification on the Gulf of Alaska continental shelf; and 4. increasing stratification may alter (reduce) the transfer of nitrate from subsurface waters into the euphotic zone. The latter has implications for the amount of new production that the shelf may be able to sustain.

### Watershed Dynamics in the Auke Creek System, Southeast Alaska

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**Last updated: September 2017**

**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

Table 2: Regression statistics for temperature and salinity at GAK1 from 1970–2016.

| Parameter | Date range | Depth Range (m) | Number of samples | Trend (per decade) | Trend Confidence bounds | Correlation coefficient | p-value |
|---|---|---|---|---|---|---|---|
| Temperature (C) | 1970-2016 | 0-50 | 381 | 0.24 | +/- 0.068 | 0.11 | 1.07E-11 |
| Temperature (C) | 1970-2016 | 200-250 | 379 | 0.15 | +/- 0.040 | 0.13 | 1.08E-12 |
| Temperature (C) | 2009-2016 | 0-50 | 93 | 2.93 | +/- 0.704 | 0.43 | 1.05E-12 |
| Temperature (C) | 2009-2016 | 200-250 | 93 | 1.39 | +/- 0.322 | 0.45 | 2.31E-13 |
| Salinity | 1970-2016 | 0-50 | 381 | -0.08 | +/- 0.035 | 0.05 | 7.99E-06 |
| Salinity | 1970-2016 | 200-250 | 379 | 0.02 | +/- 0.019 | 0.01 | 6.53E-02 |
| Salinity | 2009-2016 | 0-50 | 93 | -0.78 | +/- 0.323 | 0.20 | 5.77E-06 |
| Salinity | 2009-2016 | 200-250 | 93 | -0.12 | +/- 0.233 | 0.01 | 3.10E-01 |

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-eight years of temperature data are available (1980–2017), and 12 years of creek height data (2006–2017). 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 11.6°C with an average temperature of 10.3°C from 1980–2017. The average temperature for 2016 was 11.5°C and 10.4°C for 2017. From 2006–2017, average yearly creek height varied from 21.6ft to 21.9ft, with an average of 21.7 ft. The average gauge height for 2017 was 21.6ft and 21.8ft for 2017. Historical trends and the most recent two years are shown for creek temperature (Figure 24) and gauge height (Figure 25).

**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-dominated to a rainfall-dominated watershed at Auke Creek (Shanley et al., 2015)(Figure 25). This lack of snowfall, and subsequent lack of snowmelt, contribute to warmer creek temperatures earlier in the year (Figure 24).

**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).

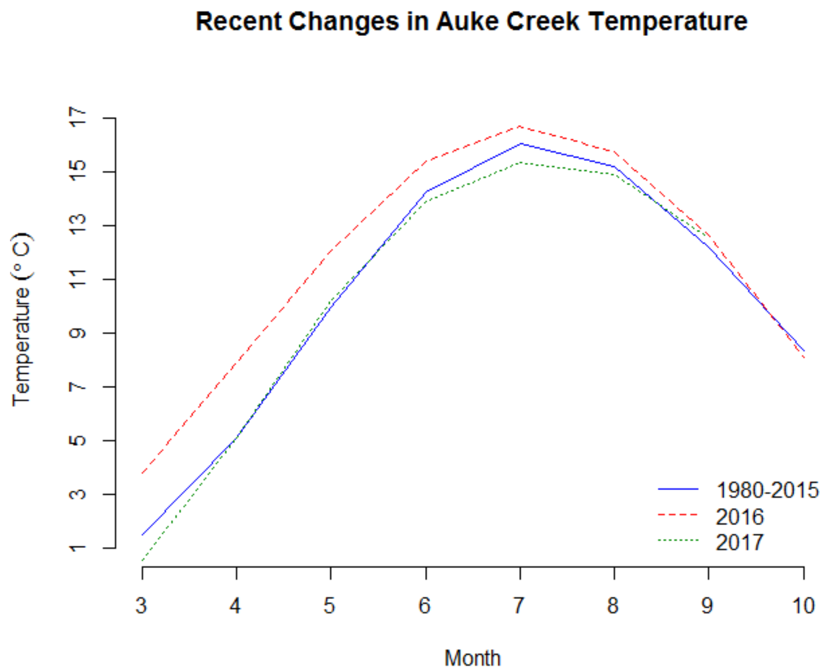


Figure 24: Auke Creek average temperature by months of operation for 1980–2015, 2016, and 2017.

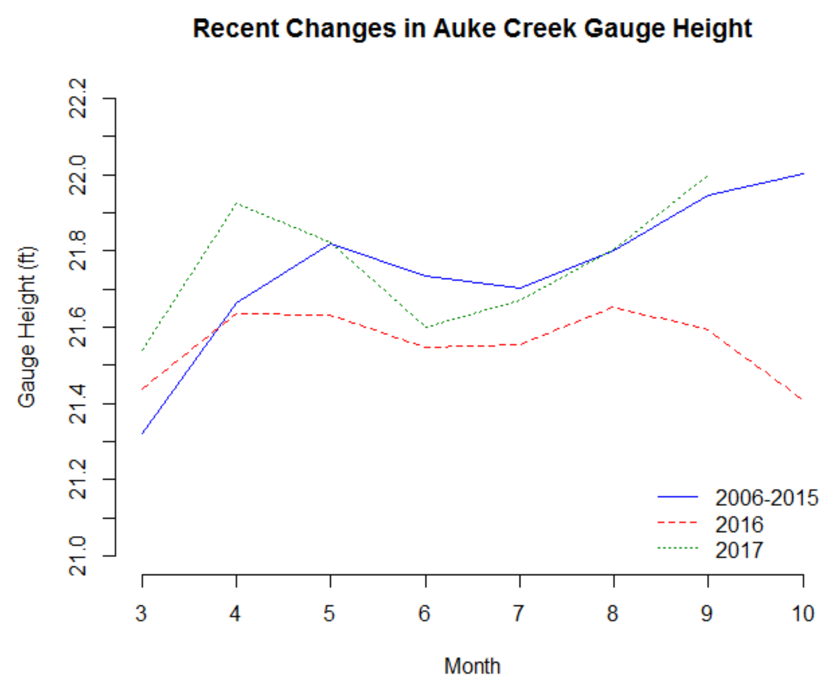


Figure 25: Auke Creek average gauge height by months of operation for 2006–2015, 2016, and 2017.

## Habitat

### Structural Epifauna – Gulf of Alaska

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**Last updated: October 2017**

**Description of indicator:** Structural epifauna groups considered to be Habitat Area of Particular Concern (HAPC) biota include sponges, corals (both hard and soft) and anemones. NOAA collects data on structural epifauna during the biennial RACE summer surveys in the Gulf of Alaska. For each species group, the catches for each year were scaled to the largest catch over the time series (which was arbitrarily scaled to a value of 100). The standard error (±1) was weighted proportionally to the CPUE to get a relative standard error. The percentage of positive catches in the survey bottom trawl hauls was also calculated.

**Status and trends:** A few general patterns are clearly discernible (Figure 26). Sponges are caught in about 50% of bottom trawl survey hauls in all areas of the GOA when combined across areas. This percentage has been increasing in the Yakutat (to about 30% of hauls) and Southeastern (to about 60% of hauls) regions. However, the CPUE is generally highest in the Shumagin area low to the east. Sponge CPUE has declined in the Kodiak area, while CPUE has remained fairly constant in the four other areas. Anemones are caught in low abundance in the eastern GOA, while they are common (occur in ∼50% of tows) at a relatively constant abundance in the Shumagin, Chirikof and Kodiak regions. Gorgonian corals show an opposite pattern, as they are in highest abundance in the southeastern GOA, although they are relatively uncommon in catches for all areas. The peak abundance occurred in 1999 in the eastern GOA, and catches have declined in recent surveys. The sea pen time series is dominated by large CPUEs in 2005 and 2015 in the Chirikof area, but they occur uncommonly in bottom trawl tows (< 10% occurrence). Stony coral catches are rare. Soft coral CPUE has been uniformly low with the exception of a large catch in the western GOA in the 1984 survey.

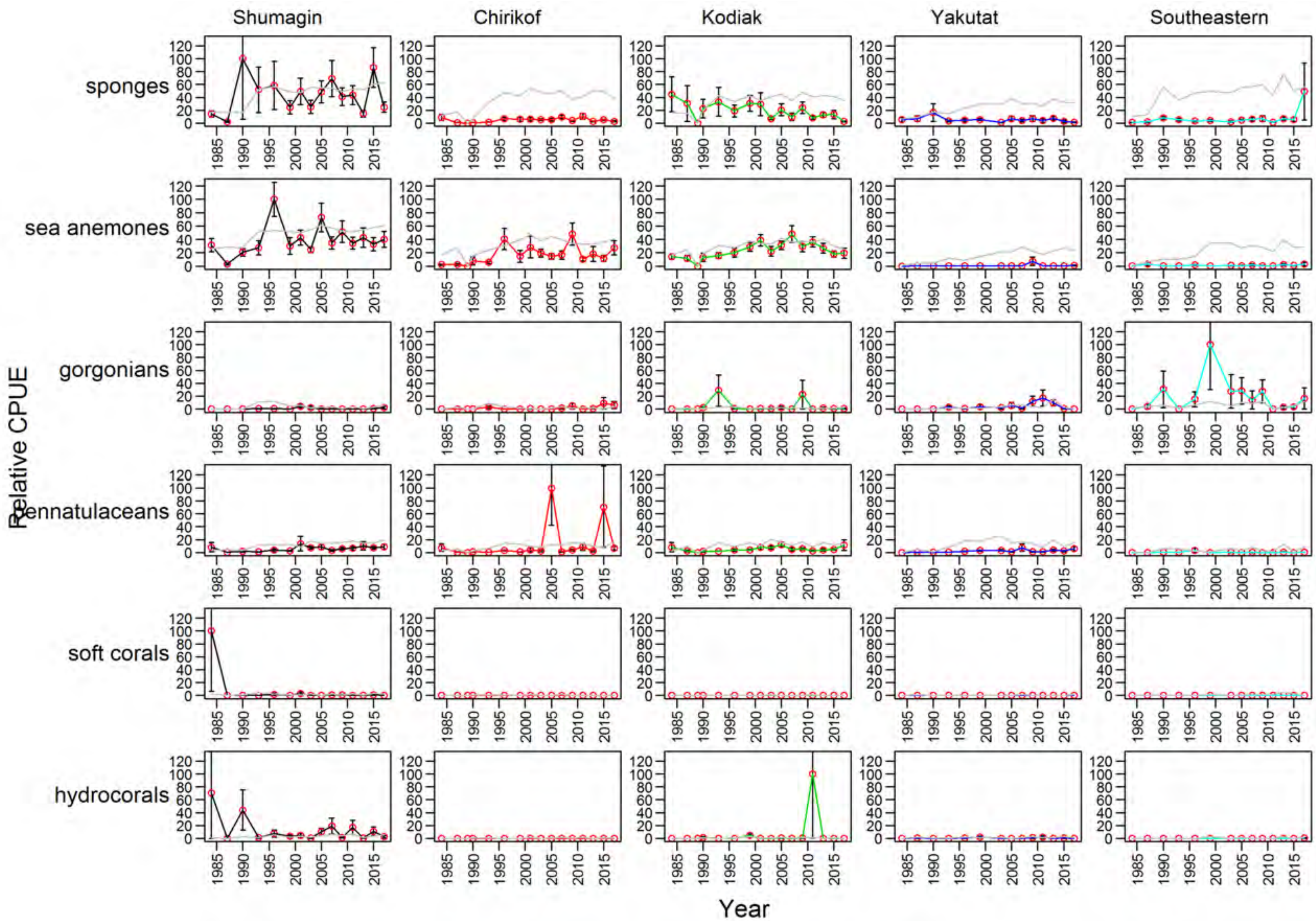


Figure 26: Mean CPUE of HAPC species groups by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2017. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

**Factors influencing observed trends:** The Gulf of Alaska survey does not sample any of these fauna well, so some caution is recommended in interpreting these trends in CPUE. Overall, most area-species combinations do not show trends in either catches or frequency of occurrence. However, the decline in sponge catches in the Kodiak area may indicate that sponges are decreasing here, whereas the increases in frequency of occurrence of sponges in the Yakutat and Southeastern areas may indicate an expansion of sponge populations.

**Implications:** Changes in structural epifauna CPUE may indicate changes in habitat, but at present no research has demonstrated definitive links. In future ecosystem contributions an overall biomass for these species groups for the Gulf of Alaska will be computed using geospatial methods. Preliminary results (Figure 27) show that overall coral and sponge biomass estimates have remained highly variable, but relatively constant throughout the history of the bottom trawl survey, whereas pennatulaceans seemed to peak in the 2005 survey before falling off and recovering to a high level in 2017. These are preliminary results and need further examination and exploration.

## 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. 80. 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 2016

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**Last updated: July 2017**

**Description of indicator:** Continuous Plankton Recorders (CPRs) have been deployed in the North Pacific routinely since 2000. Two transects are sampled seasonally, both originating in the Strait of Juan de Fuca, one sampled monthly (∼Apr–Sept) which terminates in Cook Inlet, the second sampled 3 times per year (in spring, summer and autumn) which follows a great circle route across the Pacific terminating in Asia. Several indicators are now routinely derived from the CPR data and updated annually. In this report we update three indices for three two regions (Figure 28); the abundance per sample of large diatoms (the CPR only retains large, hard-shelled phytoplankton so while a large proportion of the community is not sampled, the data are internally consistent and may reveal trends), mesozooplankton biomass (estimated from taxon-specific weights and abundance data) and mean Copepod Community Size (see Richardson et al., 2006 for details but essentially the length of an adult female of each species is used to represent that species and an average length of all copepods sampled calculated) as an indicator of community composition. Anomaly time series of each index have been calculated as follows: A monthly mean value for each

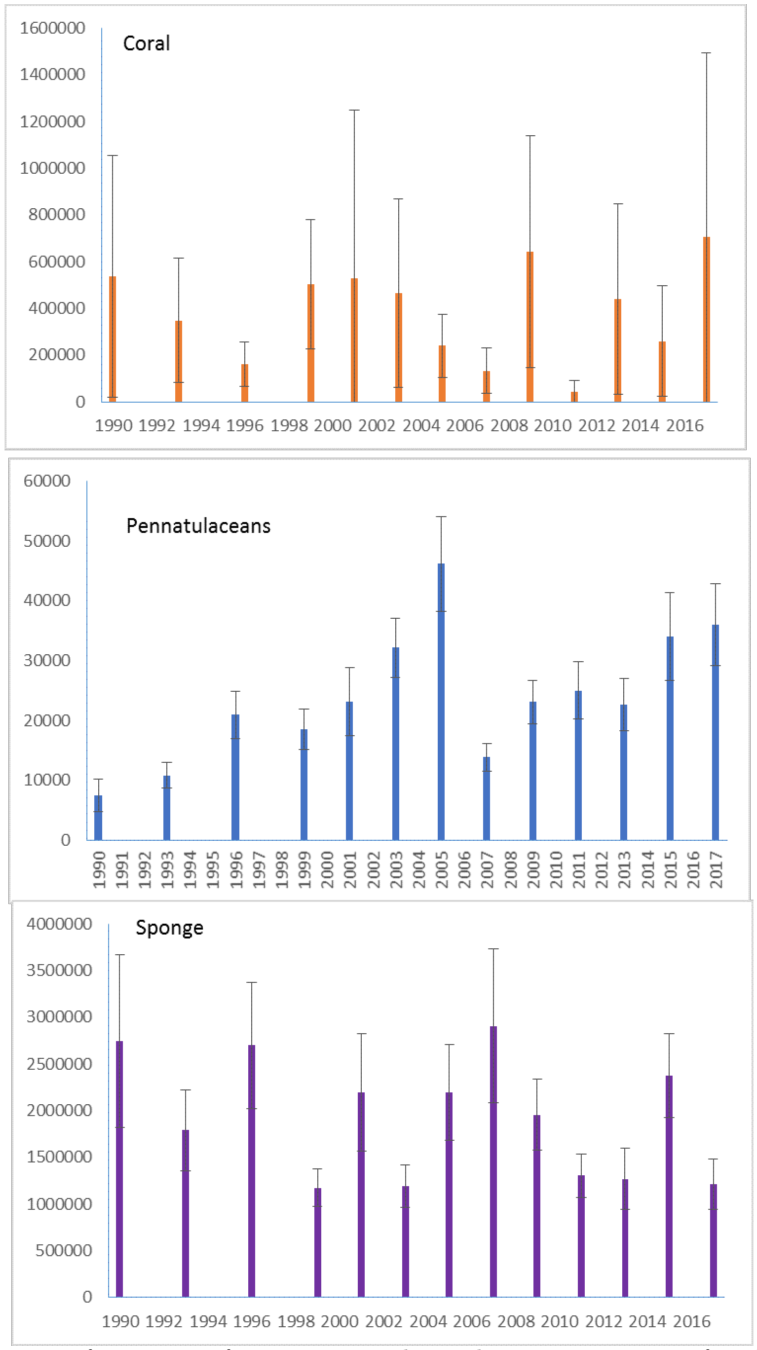


Figure 27: Time series of structure forming invertebrate biomass estimates for the Gulf of Alaska. Estimates (and standard deviations) were produced using a multispecies VAST model that included combined coral groups, combined pennatulaceans and combined sponge groups.

region is first calculated. Each sampled months mean is then compared to the long-term 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 the oceanic North-East Pacific and the Alaskan shelf SE of Cook Inlet (Figure 28). The oceanic NE Pacific region has the best sampling resolution as both transects intersect here. This region has been sampled up to 9 times per year with some months sampled twice. The Alaskan shelf region is sampled 5–6 times per year by the north-south transect.

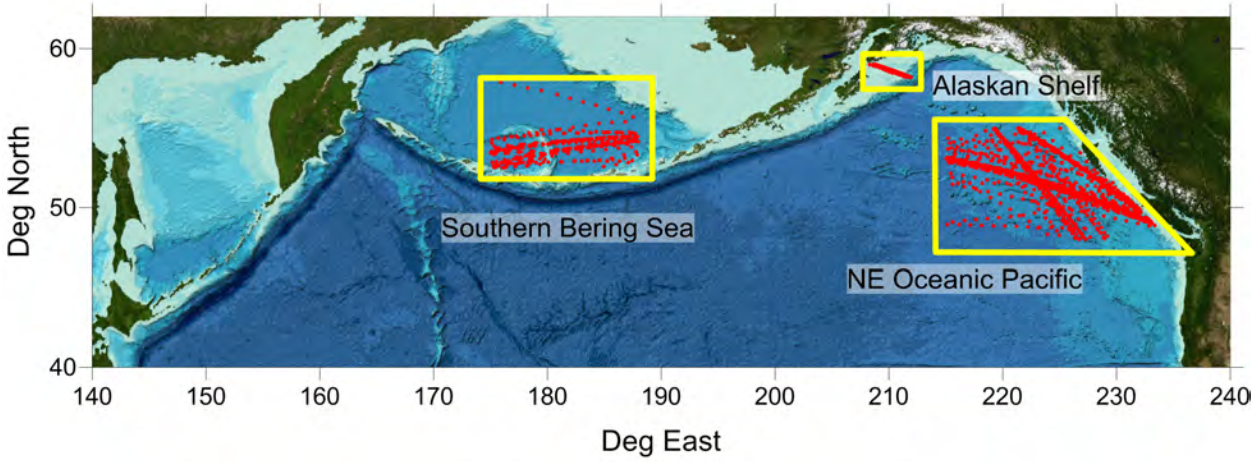


Figure 28: Boundaries of the regions described in this report. Dots indicate actual sample positions (note that for the Alaskan Shelf region the multiple (>50) transects overlay each other almost entirely). The Southern Bering Sea region is not discussed in this report.

**Status and trends:** Diatom abundance anomalies were very low on the Alaskan Shelf in 2016 (particularly in April and May) and lower than in 2015 in the oceanic NE Pacific (Figure 29). The mesozooplankton biomass anomaly was strongly positive on the Alaskan shelf, with positive anomalies in each sampled month. It was also positive overall for the NE Pacific region, although May and July values were slightly negative. The Copepod Community Size index saw negative anomalies for both the Alaskan Shelf and the NE Pacific regions meaning that the species were smaller then average. For the Alaskan Shelf region this was the $4^{th}$ consecutive year of negative anomalies and while the anomaly for the NE Pacific was not as low as in 2015, it was again negative.

**Factors influencing observed trends:** We have previously speculated that during the previous heat wave years of 2014–2015 nutrient conditions may have been poor since a higher than average contribution of smaller, pennate diatoms (that have an advantage over larger cells in low nutrient conditions) was evident in spring of those years in the Alaskan Shelf, as well as the NE Pacific region. This trend could have continued with even smaller cells present in 2016 that are not retained by the CPR. However, there was a very high zooplankton biomass in 2016 so it is also possible that the low numbers of larger diatoms was caused by high grazing pressure from zooplankton. Whatever the cause, the diatom anomaly in spring 2016 was the lowest of the time series so clearly something was unusual in the 2016 plankton community.

The negative anomalies for the Copepod Community Size Index for both the Alaska Shelf and NE Pacific regions are consistent with the warmer water favoring the smaller-bodied species which generally have a more southerly center to their distribution and are more abundant in warm years. They were very abundant in 2016, since biomass anomalies were positive while mean size was small.

**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

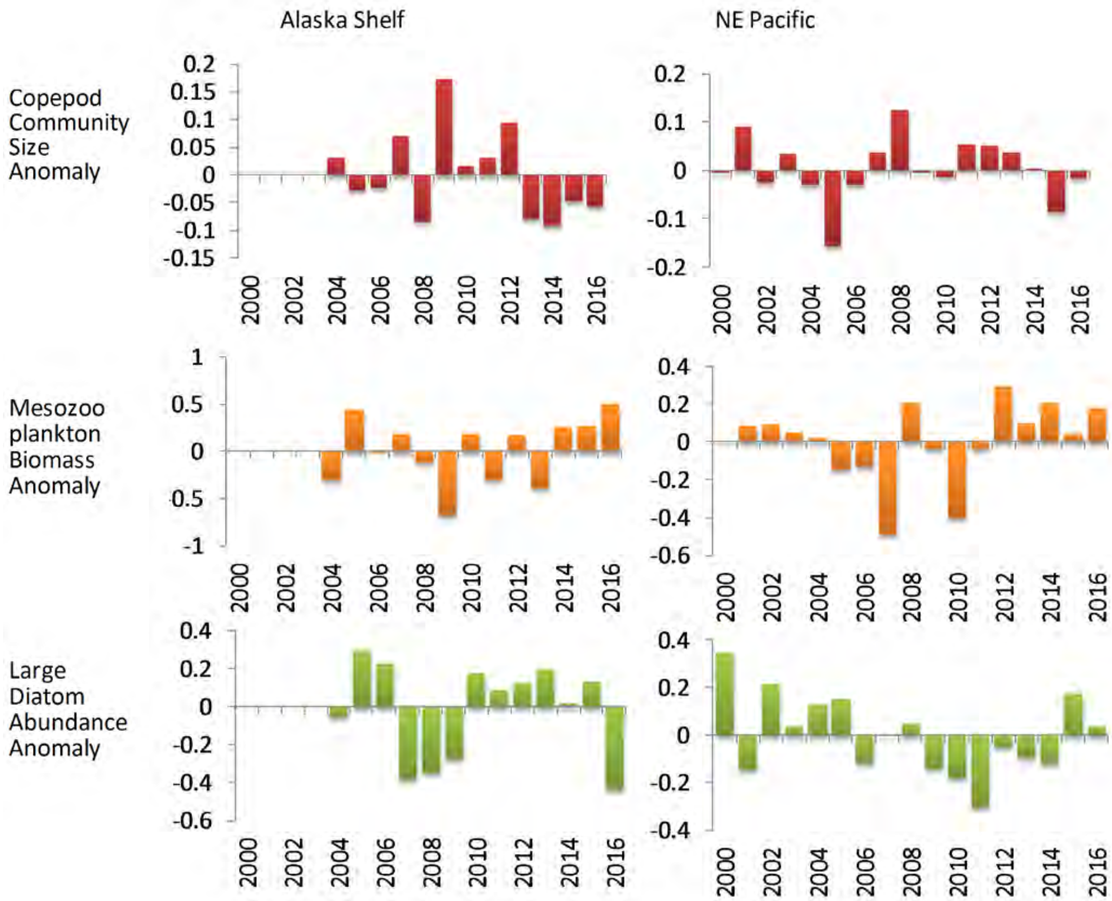


Figure 29: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for each region shown in (Figure 28). Note that sampling of this Alaskan Shelf region did not begin until 2004.

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, influences availability of prey to predators. For example, while mesozooplankton biomass anomalies were positive, the reduced average size of the copepod community suggests that the biomass was packaged into numerous, but small, prey items. This may require more work by predators to obtain their nutritional needs, and for the Alaskan Shelf region this is now a persistent feature occurring in 4 consecutive years.

### Rapid Zooplankton Assessment and Long-Term Time Series, Western Gulf of Alaska, Spring and Summer 2017

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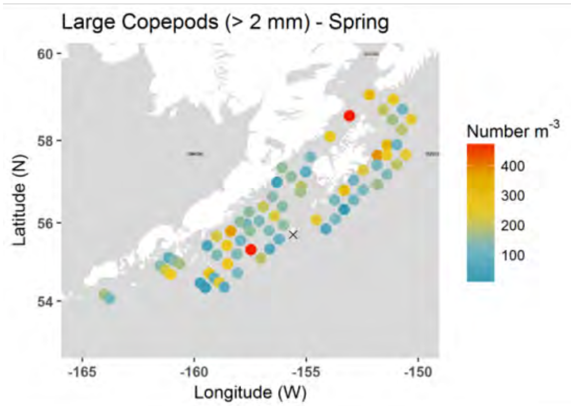
**Last updated: September 2017**

**Description of indicator:** In 2015, EcoFOCI implemented a method for an at sea Rapid Zooplankton Assessment (RZA) to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20/60 cm oblique bongo tows from 10 m from bottom or 300 m, whichever is shallower), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories are small copepods ($<$ 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp. and *Oithona* spp.), large copepods ($>$ 2mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids ($<$ 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 $\mu$m mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 $\mu$m mesh, 60 cm bongo net. In 2016, the method was refined and personnel counted a minimum of 100 organisms per sample at sea to improve zooplankton estimates. Other, rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1+ years post survey). The GOA RZA was conducted on two surveys: 1) from 12 May to 1 June 2017 (spring) and 2) from 19 Aug to 17 Sep 2017 (summer).

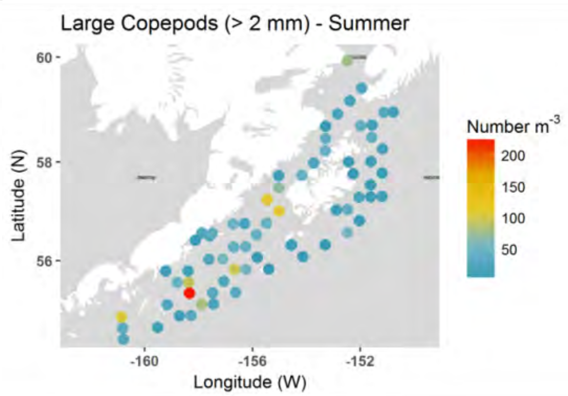
In order to provide comparison to yearly RZA data, a long-term time series was developed from archived data. The mean, annual abundance of each RZA category was plotted for "Line 8" (an area approximately bounded by 57.46–57.73°N and 154.67–155.30°W) in the Shelikof Strait, Gulf of Alaska from 1990–2011 and represented May/June sampling (spring). For summer, mean, annual abundance of each RZA category was plotted for the primary grid area southwest of Kodiak Island (an area approximately bounded by 54–58°N and 155–160°W) from 2000–2015 (where data were available) and represented Aug/Sep sampling.

**Status and trends:** Large copepods had high abundances in the SW area of the survey grid and near Kodiak Island in spring (Figure 30). Large copepod abundances declined in summer, and the SW area of the survey grid remained the area with the highest abundances (Figure 30). Compared to historical abundances of large copepods at Line 8, 2017 abundances appeared to be similar in magnitude to the long-term estimates and higher than 2015 (Figure 31). Small copepods were abundant throughout the sampling area in spring, and their abundances increased during summer (Figure 30). Small copepods showed very little interannual variability in spring and summer abundance, and 2017 values were similar to the long-term estimates (Figure 31). Euphausiid juvenile stages were abundant throughout the sampling region in spring and numbers reduced into summer (Figure 30). Euphausiid abundances appeared to be much higher than historical estimates in spring in general and 2015 in particular (Figure 31). Higher abundances of euphausiids were observed in summer of 2015 and 2017 compared to the most recent survey values (Figure 31).

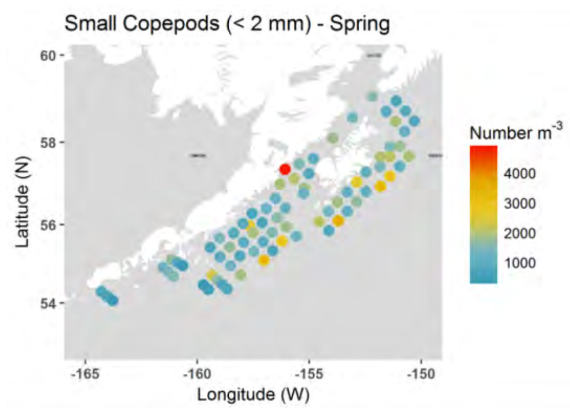
**Factors influencing observed trends:** Large copepods in spring include *Neocalanus cristatus* and *N. plumchrus/flemingeri*. These species enter diapause and disappear from the plankton in June, thus the decline of larger copepods into the summer (Figure 30) is partially explained by this life history event. The other large copepod species, *Calanus marshallae*, has been shown to increase in years with cold winters and a strong, spring phytoplankton bloom (Sousa et al., 2016). We observed evidence of a recent spring bloom and numerous *Calanus* copepodites during the spring survey, suggesting that winter conditions were favorable for *Calanus*. The long-term times-series of large and small copepods showed little variability in either spring or summer (Figure



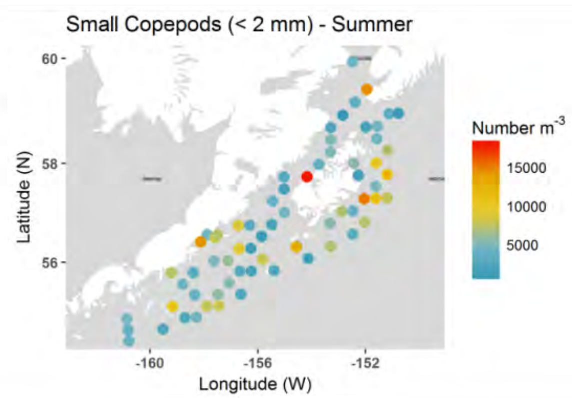

(a) Large Copepods–Spring



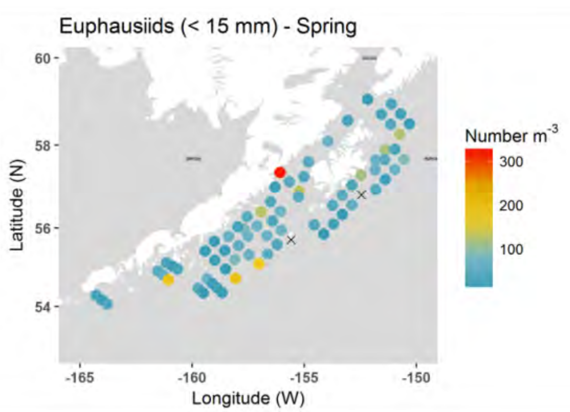

(b) Large Copepods–Summer



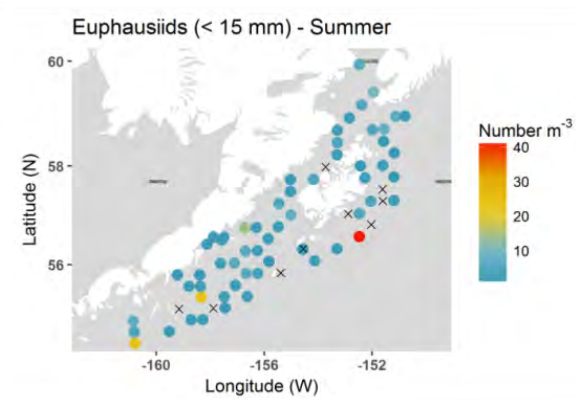

(c) Small Copepods–Spring




(d) Small Copepods–Summer




(e) Euphausiids–Spring




(f) Euphausiids–Summer

Figure 30: Maps show the spring (left) and summer (right) abundance of large copepods, small copepods, and euphausiid larvae/juveniles estimated by the rapid zooplankton assessment. Note all maps have a different abundance scales (No. $m^{-3}$). X indicates a sample with abundance of zero individuals $m^{-3}$.

31) and this is likely due to the combination of multiple species into one, representative category. Examination of individual species shows that variability among the individual species of smaller copepods does occur (unpub. data). We also observed large numbers of euphausiid early life history stages in spring (Figure 30). Sousa et al. (2016) also report the conditions that increased *Calanus* abundances also appeared to favor the euphausiid *Thysanoessa inermis*. The significant decline in

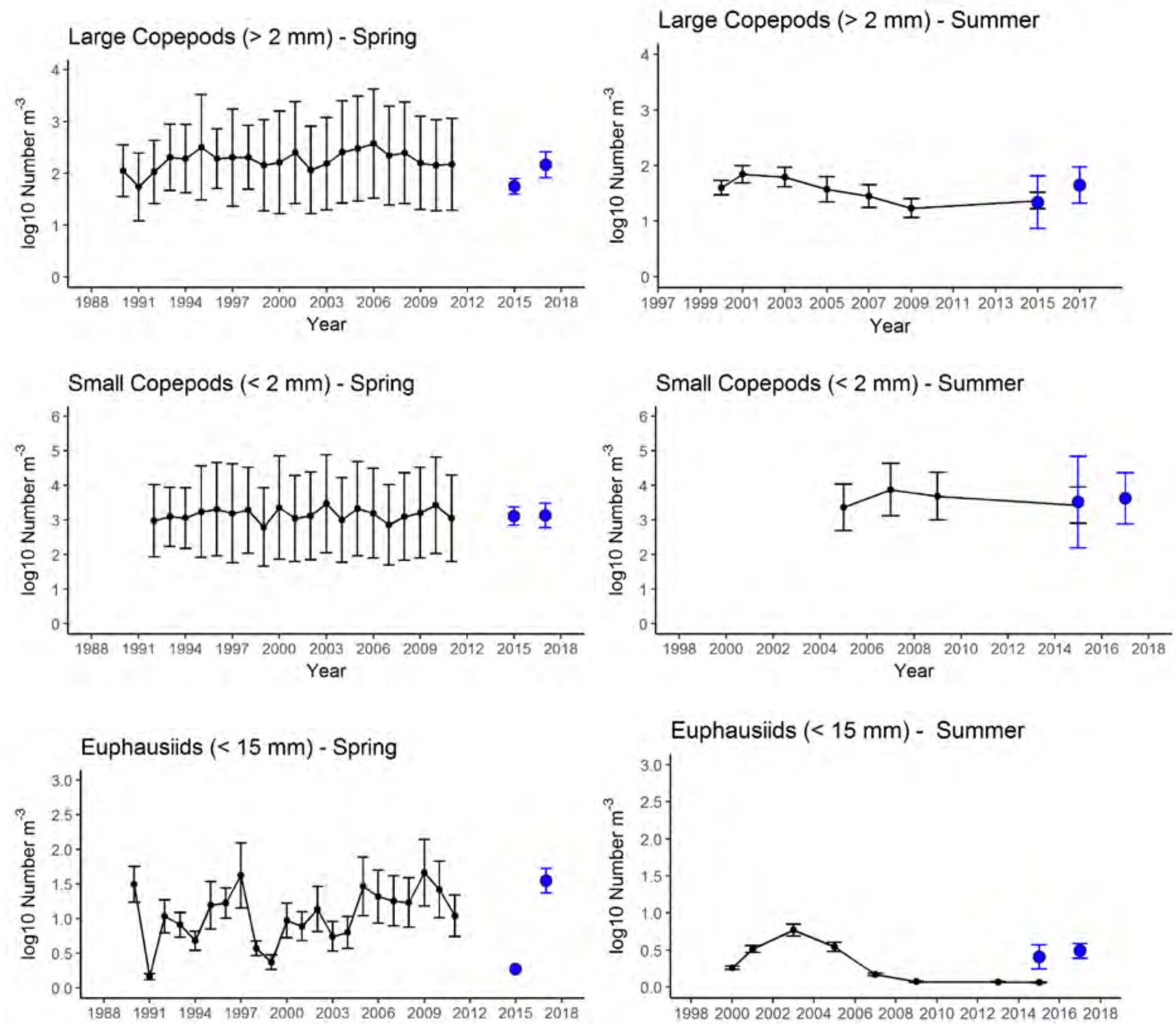



Figure 31: Spring (left) and summer (right), annual, mean abundance of large copepods, small copepods, and euphausiids in the Gulf of Alaska, FOCI sampling region. Black points and lines represent FOCI archived data from the Line 8 region, blue points represent RZA data from spring sampling across the Gulf of Alaska in 2015 and 2017. Error bars represent standard error of the mean.

euphausiid numbers during the summer (Figure 30) can be partially explained by the development of euphausiids resulting in larger sized individuals that can effectively avoid the 60 cm bongo net. Long-term variability in mesozooplankton in this region is thought to be driven by PDO and ENSO cycles (Sousa et al., 2016). However, the euphausiid variability does show some patterns over time (Figure 31). The drops in euphausiid abundance corresponded with positive phases of the PDO (Figure 31) as suggested by (Sousa et al., 2016). However, considerable local variability within a given year may mask these longer-term trends in abundance.

**Implications:** Zooplankton are an important prey base for larval and small juvenile pollock in spring. The increase in abundance of copepods and their presence at nearly all stations indicates significant secondary production present in the ecosystem during spring of 2017, particularly when compared to 2015 estimates (Figure 31). Furthermore, the higher abundances of early stage euphausiids present could bode well for higher abundances in fall when juvenile pollock diets shift to a primarily euphausiid-based diet prior to overwintering.

### Gulf of Alaska Euphausiid ("krill") Acoustic Survey

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**Last updated: October 2017**

**Description of indicator:** The Gulf of Alaska survey of the abundance and distribution of euphausiids ("krill", principally *Thysanoessa* spp.) has been developed (Simonsen et al., 2016) based on methods used by Ressler et al. (2012) in the Bering Sea. The survey incorporates both acoustic and Methot trawl data from summer Gulf of Alaska acoustic-trawl surveys for pollock conducted in 2003, 2005, 2011, and biennially since 2013 by NOAA-AFSC. Acoustic backscatter per unit area ($s_A$ at 120 kHz, $m^2$ $nmi^{-2}$) classified as euphausiids was integrated over the water column and then across the surveyed area to produce an annual estimate of acoustic abundance ($s_A$ * area, proportional to the total abundance of euphausiids). Approximate 95% confidence intervals on these estimates were computed from geostatistical estimates of relative estimation error (Petitgas, 1993). Though surveys since 2013 have covered the shelf from the Islands of Four Mountains to Yakutat (Figure 32), the index reported here is limited to areas around Kodiak that have been consistently sampled in all years of the time series (Figure 33). Net collections from euphausiid scattering layers in 2011, 2013, and 2015 have been numerically dominated by euphausiids and show that *Thysanoessa inermis*, *T. spinifera*, and *Euphausia pacifica* with average length ∼19 mm are the most commonly encountered species (Simonsen et al. 2016, Ressler unpublished data). Additional sampling during the summer 2017 survey was conducted in support of an NPRB-funded project focused upon measuring acoustic properties of and improving survey techniques for euphausiids (#1501, "How many krill are there in the eastern Bering Sea and Gulf of Alaska?", PIs Warren, Ressler, Harvey, Gibson, underway through 2019).

**Status and trends:** Results indicate that highest abundance of euphausiids in the time series was observed in 2011 and the lowest in 2003 (Figure 34). There was a decline in 2017 relative to the previous survey in 2015, to a value similar to 2003. Barnabas Trough appears to be a local hotspot (Figures 32, 33), as observed in previous surveys (Simonsen et al., 2016). Final species and length composition from summer 2017 Methot trawls are not yet available. *These data are preliminary and will change.*

**Factors influencing observed trends:** Factors controlling annual changes in euphausiid abundance are not well understood; possible candidates include bottom-up forcing by temperature and food supply, and top-down control through predation (Hunt et al., 2016). When factors including temperature, pollock abundance, primary production, and spatial location have been considered in spatially-explicit multiple regression models, increases in euphausiid abundance have been strongly correlated with cold temperatures in the eastern Bering Sea (Ressler et al., 2014), but not in the GOA (Simonsen et al., 2016). Euphausiid abundance is not strongly correlated with the abundance of pollock (a major predator) in statistical models of observations from either system.

**Implications:** The results presented here suggest a lower level of euphausiid prey availability in summer 2017. Euphausiids are a key prey species for fish species of both ecological and economic

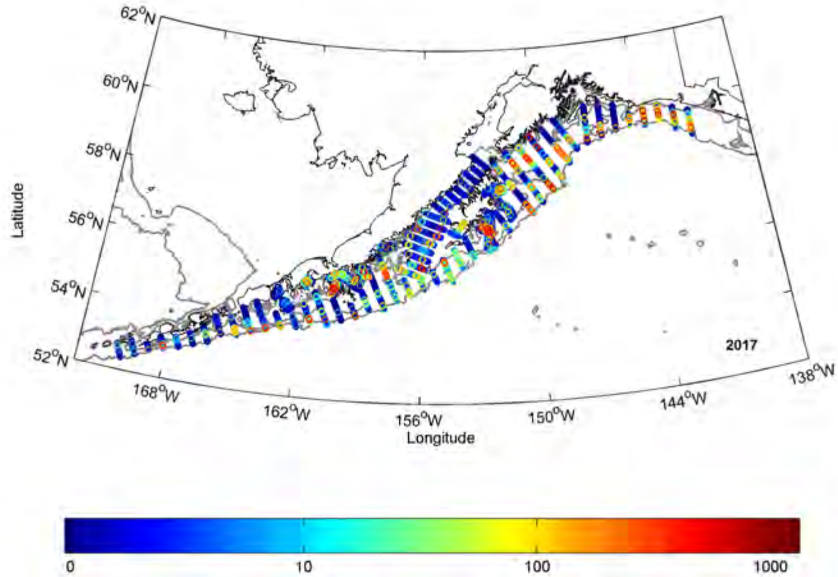


Figure 32: Spatial distribution of acoustic backscatter density ($s_A$ at 120 kHz, $m^2$ $nmi^{-2}$) attributed to euphausiids in consistently sampled areas in the entire GOA survey area during the 2017 Gulf of Alaska summer acoustic-trawl survey.

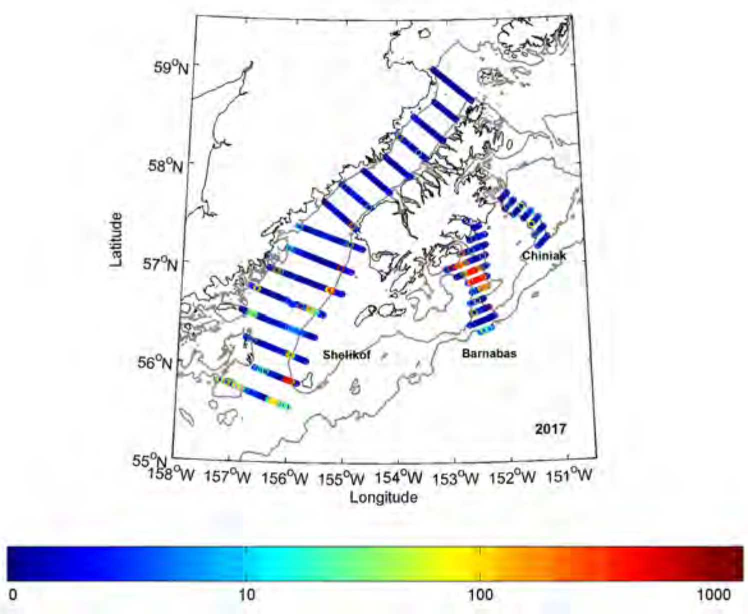


Figure 33: Spatial distribution of acoustic backscatter density ($s_A$ at 120 kHz, $m^2$ $nmi^{-2}$) attributed to euphausiids in the consistently sampled areas around Kodiak Island (Shelikof Strait, Barnabas Trough, and Chiniak Trough) during the 2017 Gulf of Alaska summer acoustic-trawl survey.

importance in the Gulf of Alaska, including walleye pollock (*Gadus chalcogrammus*), Pacific Ocean perch (*Sebastes alutus*), arrowtooth flounder (*Atheresthes stomias*), capelin (*Mallotus villosus*),

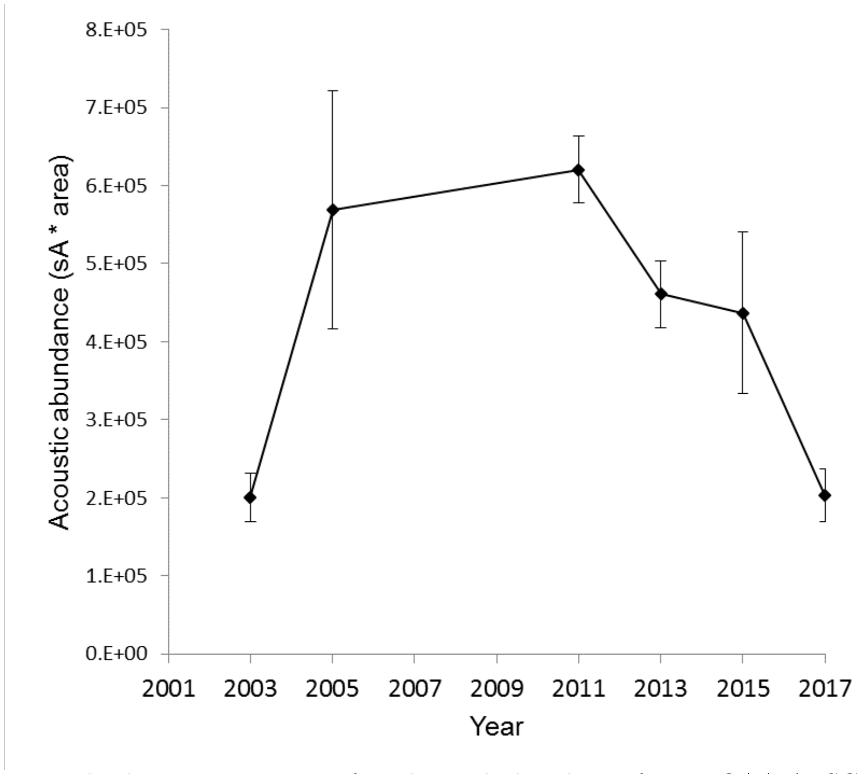


Figure 34: Acoustic backscatter estimate of euphausiid abundance from NOAA-AFSC Gulf of Alaska summer acoustic-trawl survey. Error bars are approximate 95% confidence intervals computed from geostatistical estimates of relative estimation error (Petitgas, 1993).

eulachon (*Thaleichthys pacificus*), and as well as many species of seabirds and marine mammals.

## Rapid Zooplankton Assessment, Eastern Gulf of Alaska, Summer 2017

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**Last updated: October 2017**

**Description of indicator:** In 2015, EcoFOCI implemented a method for an at sea Rapid Zooplankton Assessment (RZA) to provide leading indicator information on zooplankton composition in Alaskas Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20/60 cm oblique bongo tows from 10m from bottom or 200 m, if bottom depth was >200 m), provides preliminary estimates of zooplankton abundance and community structure. Coarse species categories were assessed using standard zooplankton sorting methods (Harris et al., 2005). The categories were small copepods (< 2 mm; example species: *Acartia* spp., *Pseudocalanus* spp., and *Oithona* spp.), large copepods (> 2mm; example species: *Calanus* spp. and *Neocalanus* spp.), and euphausiids (< 15 mm; example species: *Thysanoessa* spp.). Small copepods were counted from the 153 $\mu$m mesh, 20 cm bongo net. Large copepods and euphausiids were counted from the 505 $\mu$m mesh, 60 cm bongo net. The method was refined in 2016, and personnel counted a minimum of 100 organisms per sample to improve zooplankton estimates. Other, less abundant zooplankton taxa were present but were not sampled effectively with this method. Detailed information on these taxa is provided after in-lab processing protocols have been followed (1+ years post survey). The eastern Gulf of Alaska was sampled from July 2 to July 25, 2017.

**Status and trends:** This is the first year that the RZA has been performed on the eastern Gulf of Alaska Assessment survey. No information on trends in zooplankton abundance are available across years. However, we are able to provide a snap-shot of the large and small copepod and euphausiid (<15 mm) community in the eastern GOA during July. Large copepod abundance peaked in the coastal areas off Chichagof and Baranof Islands. They were also generally more abundant over the continental shelf and less abundant over continental slope and basin waters (Figure 35). Small copepod abundance decreased within the southern portion of the survey grid, especially in areas stretching from the coast to 80 nm offshore. Small copepod abundance peaked at survey stations located on the northern shelf (Figure 36). Euphausiids were most abundant at coastal nearshore stations (Figure 37). High catches at nearshore stations may have been due in part to shallow depths where the net was sampling closer to the substrate relative to deeper stations located further from shore.

**Factors influencing observed trends:** Large copepod species (e.g., *Neocalanus* spp.) enter diapause (descend) and become less abundant in zooplankton samples by June. Two hundred meters was the maximum depth sampled, and large copepods residing at slope and offshore stations would not be captured. The increase in large copepod abundance over nearshore stations (Figure 35) may thus be due to sampling, as gear was deployed to just above the bottom (stations <200 m) and may be more likely to sample copepods in or entering diapause. Another important large copepod species, *Calanus marshallae/glacialis*, is generally more abundant in years with cold winters and a strong spring phytoplankton bloom (Sousa et al., 2016). The EcoFOCI program observed evidence of a strong spring bloom and numerous *Calanus* spp. copepodites in the western Gulf of Alaska, spring 2017. This evidence suggests that winter conditions were favorable for *Calanus* spp.

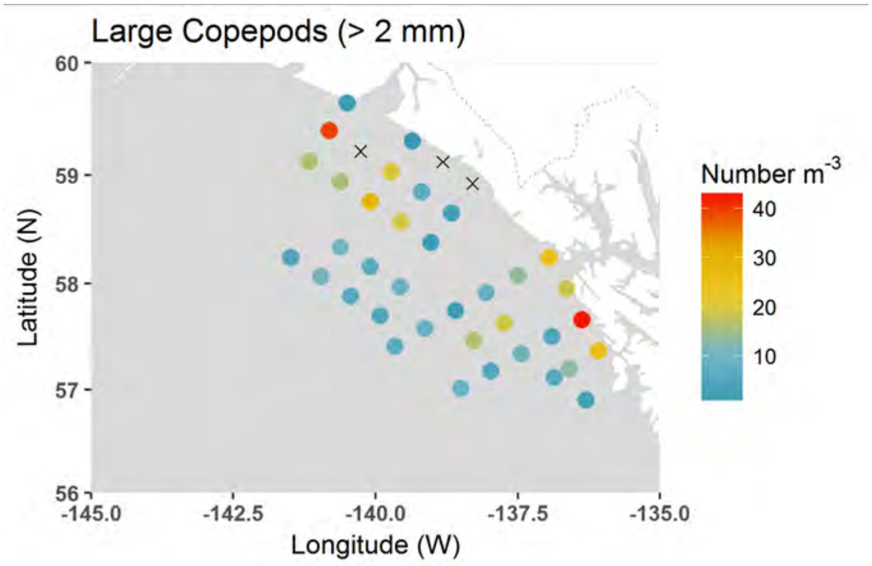


Figure 35: Map showing the summer (July) mean abundance (No. $m^{-3}$) of large copepods estimated by the rapid zooplankton assessment in the eastern GOA during 2017. X indicates a sample with abundance of zero individuals per $m^{-3}$.

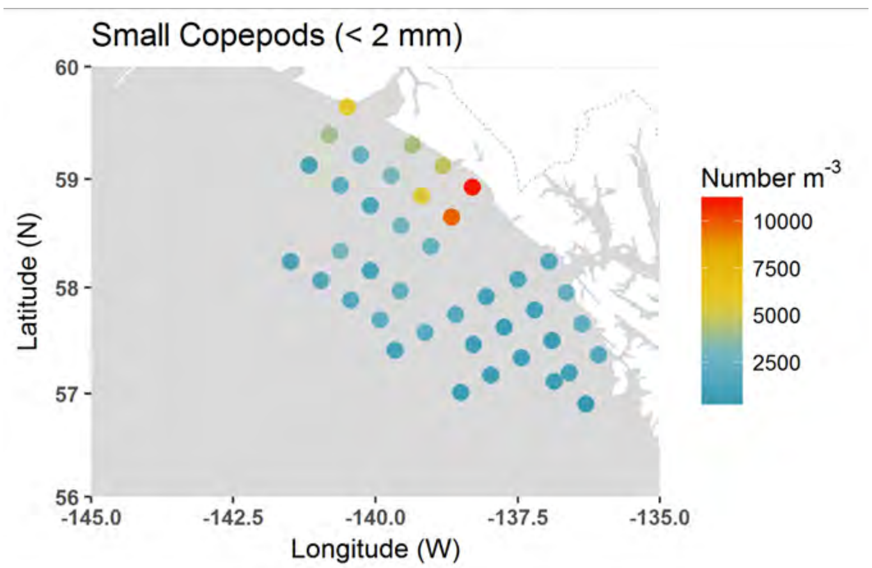


Figure 36: Map showing the summer (July) mean abundance (No. $m^{-3}$) of small copepods estimated by the rapid zooplankton assessment in the eastern GOA during 2017. X indicates a sample with abundance of zero individuals per $m^{-3}$.

Copepod and euphausiid abundances in the eastern GOA were lower than those in the western GOA (p. 83). Large copepod densities in the western GOA during late summer typically ranged within 50 individuals $m^{-3}$ (hereafter $Im^{-3}$), whereas large copepod densities in the eastern GOA typically ranged between 10–20 $Im^{-3}$. Small copepod densities in the western GOA ranged from 5,000–15,000 $Im^{-3}$, whereas in the eastern GOA they typically ranged from 2,500–7,500 $Im^{-3}$. Euphausiid

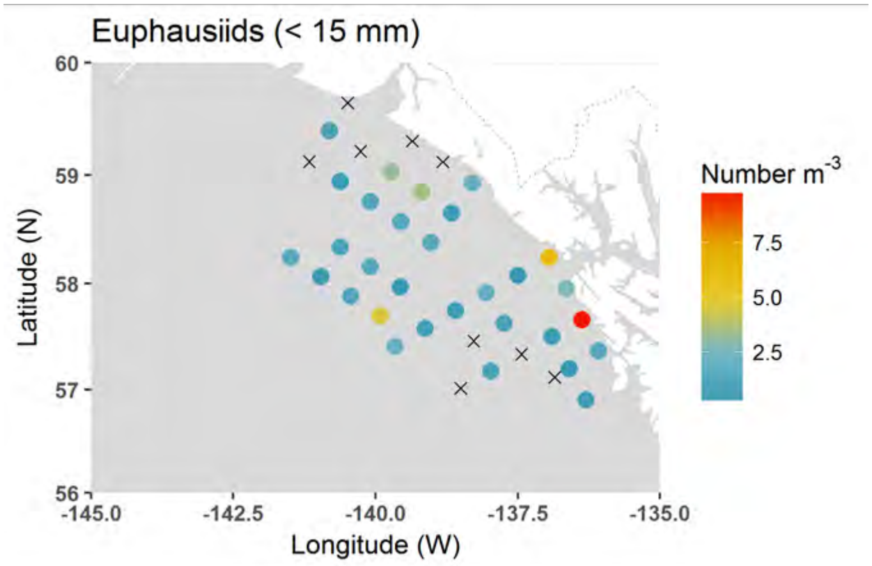


Figure 37: Map showing the summer (July) mean abundance (No. m$^{-3}$) of euphausiids estimated by the rapid zooplankton assessment in the eastern GOA during 2017. X indicates a sample with abundance of zero individuals per m$^{-3}$.

densities in the eastern GOA ranged from 2.5–7.5 Im$^{-3}$ whereas those in the western GOA ranged from 10–40 Im$^{-3}$.

**Implications:** Zooplankton are an important prey base for age-0 and juvenile marine fish and some species of juvenile salmon. Increased abundance of copepods and euphausiids over the shelf and at coastal locations (within 3 miles from shore) likely served to benefit juvenile fishes and salmon inhabiting coastal waters during summer 2017.

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

Contributed by Emily Fergusson, Joseph Orsi, and Andrew Gray, Auke Bay Laboratories Division, Alaska Fisheries Science Center, NOAA Fisheries
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**Last updated: August 2017**

**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 2016 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-$\mu$m 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 and ecologically important forage fish in SEAK.

**Status and trends:** The ISTI shows the annual temperature trend identifying warm and cool years, with 11 years warmer and 9 years cooler than the average (9.4°C). Overall, the ISTIs ranged from 8.3°C to 10.6°C, and anomalies did not exceed ±1.2°C (Figure 38). The ISTI in 2016 was anomalously warm by approximately 1.2°C, which made it the highest ISTI observed over the 20 year time series.

The zooplankton density shows the trend in zooplankton abundance and also reflects the health of this important lower trophic level community. Overall, the long-term mean zooplankton density ranged from 891 to 3,192 organisms per $m^3$ (Figure 39). The 2016 total density of zooplankton showed an increased from the 2015 density and was above average as the 6th highest measure in the 20-year time series. For all years, total zooplankton density and temperature were not significantly correlated, with positive and negative monthly anomalies occurring in both warm and cold years ($r = 0.11$, $P = 0.64$).

Overall, the zooplankton community was numerically dominated by gastropods ($\leq$ 36%) and small calanoid copepods ($\leq$ 2.5 mm length; $\leq$ 35% composition). Three other taxa, important in fish diets (Sturdevant et al. 2012; Fergusson et al. 2013), contributed to the community in smaller percentages (large calanoid copepods ($>$ 2.5 mm), $\leq$ 19%; hyperiid amphipods, $\leq$ 3%; and euphausiids, $\leq$ 1%). For 2016, densities of hyperiid amphipods and gastropods were anomalously high, showing a clear increase from the 2015 densities, furthermore, the densities of the hyperiids and gastropods are the 2nd and 1st highest densities, respectively, over the time series. Large calanoid copepods also showed an increase from 2015 densities but were still below the 20-year mean density. Euphausiid and small calanoid densities both declined from 2015 densities. The shifts in densities between species is indicative of differential responses to the drastic increase in the ISTI.

**Factors influencing observed trends:** Subarctic zooplankton typically follow seasonal cycles of abundance, however as indicated here, responses to climate change may be species-specific. These species-specific differences may be 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 ISTI may not adequately explain shifts in abundance and composition of these prey fields, particularly at broader 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 increase in the density of some of the zooplankton groups. Likewise, the densities of euphausiids and small calanoid copepods are showing an opposite decreasing response to the warming temperatures, which could be trophically consequential for many planktivores. Additionally, shifts in the developmental timing of the zooplankton could lead to mismatched timing of favorable prey fields for planktivorous fish. These indices may help to explain climate-related variation in prey

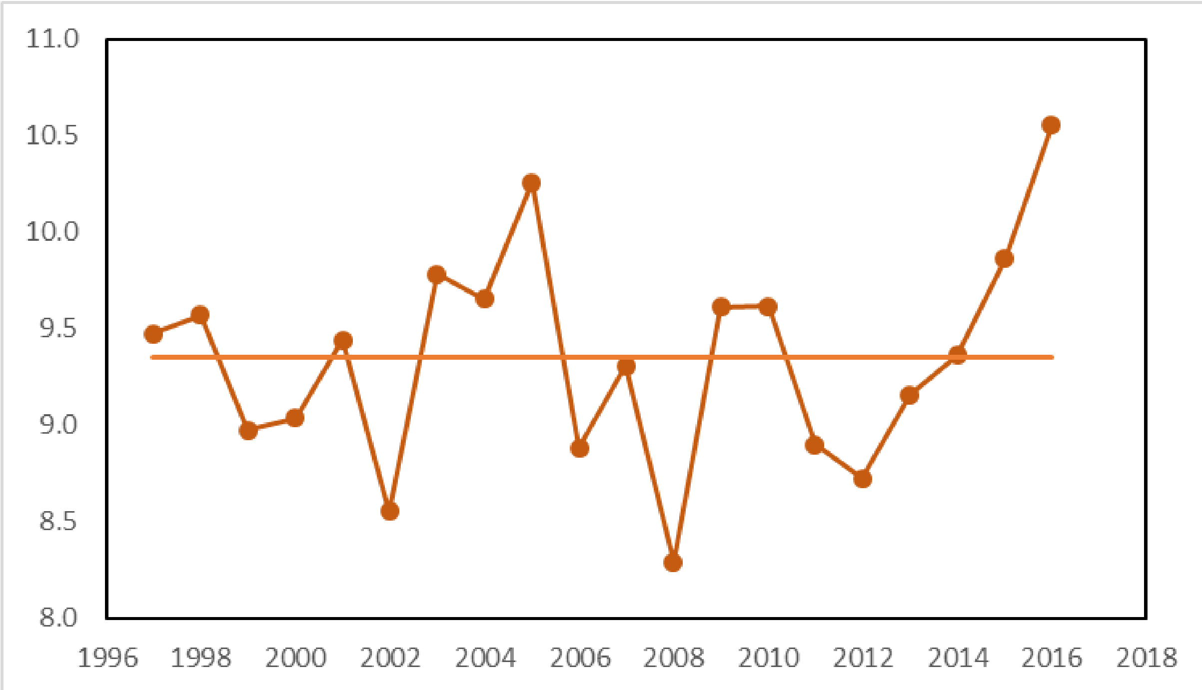


Figure 38: Mean annual Icy Strait Temperature Index (ISTI, °C, 20-m integrated water column, May-August) and 20-year mean ISTI (dashed line), for the northern region of SEAK from the Southeast Coastal Monitoring project time series, 1997–2016

fields across the diverse range of fish communities (Sturdevant et al., 2012; Fergusson et al., 2013), which may directly or indirectly affect fish growth and recruitment (Beamish et al., 2004, 2012; Coyle et al., 2011).

### Spatial trends in the biomass of mesozooplankton in waters of the eastern Gulf of Alaska during July 2017

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**Last updated: September 2017**

**Description of indicator:** Fisheries oceanography surveys were conducted by AFSC in the eastern Gulf of Alaska during July, 2010–2017. In 2017, we developed new indicators of zooplankton biomass in collaboration with the University of Alaska Fairbanks using 2017 data that will allow us to compare estimated total biomass for select zooplankton species in the future. A zooplankton net tow (60 cm bongo, 505 $\mu$m mesh) was used to collect mesozooplankton at each station. A Seabird Electronics FastCat (49) was mounted above the bongo net to provide real time depth, temperature, and salinity data. Casts were to "bottom" (5–10 m from bottom) or 200 m (if bottom depths were >200 m). Calibrated General Oceanics flowmeters were mounted inside the mouth of

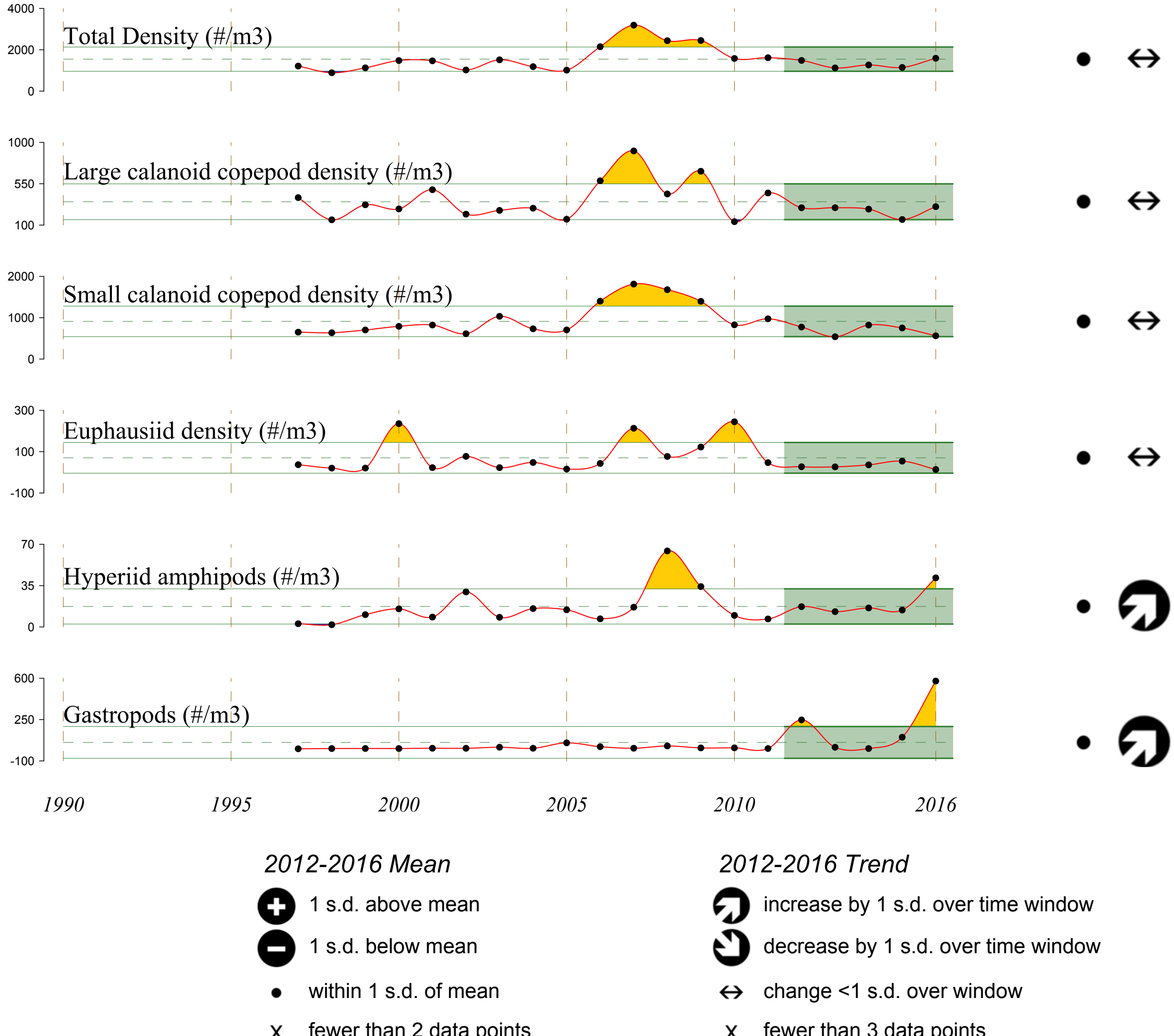


Figure 39: Average annual zooplankton density anomalies for the northern region of SEAK from the Southeast Coastal Monitoring project time series 1997–2016. Annual densities are composed of zooplankton samples collected monthly from May to August in Icy Strait. No samples were available for August 2006 or May 2007.

the nets to measure volume filtered. Volume estimates from flowmeters were compared with volumes estimates from the distance towed at each station to ensure net clogging was not a significant factor. All samples were preserved in 5% formalin, buffered with seawater for later processing.

In the laboratory, each mesozooplankton sample was poured into a sorting tray and large organisms, such as shrimp and jellyfish, were removed and counted. The sample then was sequentially split using a Folsom splitter until the smallest subsample contained approximately 200 specimens of the most abundant taxa. All taxa in the smallest subsamples were identified, staged, counted, and weighed. Each larger subsample was examined to identify, count, and weigh the larger, less abundant taxa. Blotted wet weights for each taxa and stage were determined as outlined in earlier papers (Coyle et al., 2008, 2011). The coefficient of variation in the average wet weight was computed for each species. If the coefficient of variation for any given taxon and stage changed by less than 5% when additional weights were taken from subsequent samples, a mean wet weight was calculated, and wet weights were no longer measured for that taxon. The wet weight biomass for all subsequent samples was estimated by multiplying the specimen count by the mean wet weight. Multi-year (since 1997) average individual weights obtained from the Seward Line were applied to rare taxa. In practice, only calanoid copepods had consistent wet weights after weighing each taxon and stage in about 10–15 samples. Therefore, wet weights on chaetognaths, decapod larvae, and other larger and soft-bodied taxa were measured and recorded for each sample. Wet weight measurements were done on a Cahn Electrobalance or Mettler top loading balance, depending on the size of the animal. All animals in the samples were identified to the lowest taxonomic category possible. Copepodite stages were identified and recorded. Biomass values by station were computed for each species in mg $m^{-3}$. In order to produce this volume of data within 2 months of the end of the survey, only data from the 60 cm bongo is being considered, and approximately every other station was processed.

The depth of the pycnocline was computed for each station by locating the depth where dt/dz was at a maximum ($\sigma$t = density - 1000, kg $m^{-3}$; z = depth, m). The mean water-column temperature above and below the pycnocline were then computed. Interpolation of physical and biological values over the sampling area was done using kriging subroutines in SURFER 12 (Golden Software).

**Status and trends:** The 2017 eastern Gulf of Alaska shelf sea surface (12–14°C) and bottom (6–10°C) temperatures during July were above average for the survey area since 2014 (Figure 40). Salinity values ranged from 26–35 in the surface and 32–33 near the benthos (Figure 40). A freshwater plume emanated from the Alsek River, south of Yakutat (Figure 1). Total zooplankton biomass (Figure 41) had two large peaks, one oceanic and one over the shelf. The oceanic peak was due to a very high biomass of tunicates (salps, Figure 41), while the nearshore biomass peak was due to the shelled pteropod, *Limacina helicina* (Figure 3). Approximately 40% of the total zooplankton biomass was Cnidaria and Tunicata (hydrozoan jellyfish and salps) (Figure 42). The largest proportion of cnidarian (hydrozoan jellyfish; Figure 42) biomass was within and bordering the freshwater body near the Alsek River. Other selected zooplankton species were influenced by salinity above the pycnocline, with increased biomass in offshore and shelf areas along with intrusions of oceanic water (Figures 43, 44, 45).

**Factors influencing observed trends:** Similar to previous work in the Gulf of Alaska (Coyle and Pinchuk, 2003), salinity appears to be the largest factor influencing distribution and biomass in the mesozooplankton community in the eastern Gulf of Alaska. Nearshore communities over the northern portion of the grid were shaped by a freshwater plume emanating from the Alsek River, south of Yakutat. Additionally, a lack of frontal structure and the ability of certain species to rapidly react to temperature and salinity differences appear to have shaped the zooplankton community in July of 2017. Some mixing of oceanic and shelf species assemblages occurred during July of 2017 and was likely due to a lack of an oceanic front (Mundy, 2005), and a weak Alaska Coastal Current.

Asexual reproduction in hydrozoan jellyfishes and salps has been documented to increase under warmer or warming conditions (Purcell, 2005). In addition, we have qualitatively observed a large increase in the abundance and prevalence of pelagic tunicates (salps and doliolids) during the summer season in the past few years. Trawl samples (and other anecdotal evidence) indicate high numbers of pyrosomes and gymnosomes since 2014. This is likely due to seeding events from offshore

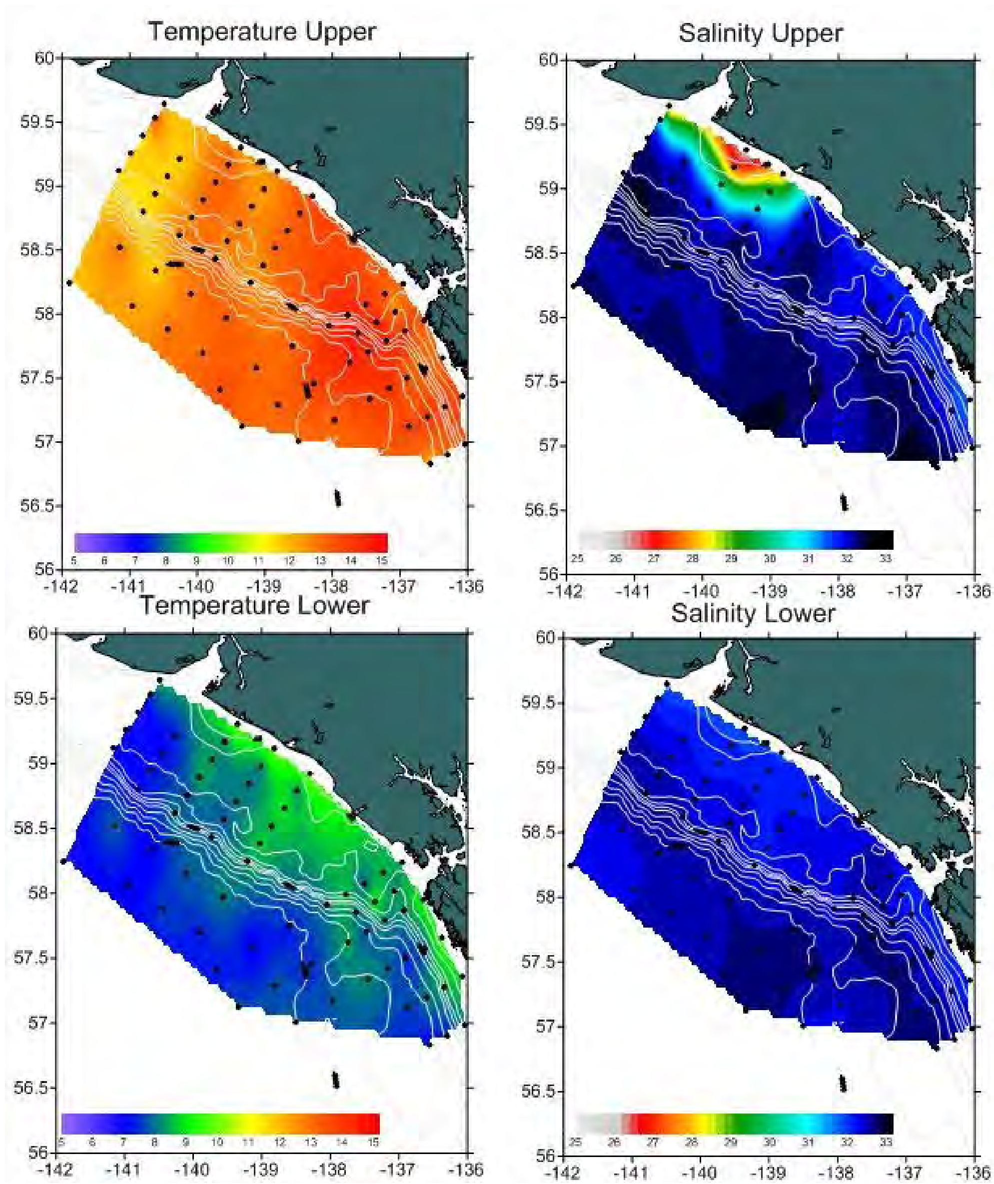

Figure 40: Physical properties above and below the pycnocline in the eastern Gulf of Alaska, July 2017. Temperatures are reported in degrees Celsius, salinity units are PSU.

during the "Warm Blob" (Bond et al., 2015) or from further south (Li et al., 2016).

**Implications:** Given the prevalence of gelatinous zooplankton in 2017, there is a high potential for the removal of a large fraction of primary productivity from the pelagic ecosystem (Li et al., 2016). As an example of critical species abundance reduction, the average abundance per cubic meter for *Calanus marshallae* in 2012 was nearly 500% more than the average abundance in 2017. Abundance of *C. marshallae* in 2012 was regularly above 100 individuals per cubic meter, 22 of 32 stations processed in 2017 had an abundance of less than 10 individuals per cubic meter. Removal of the base of the food chain has large implications for zooplankton, fish, seabirds, and marine mammals. The catch of juvenile salmon and age-0 marine groundfish in surface waters during this July 2017 survey was very low. The low pelagic fish catches were in part possibly due to a

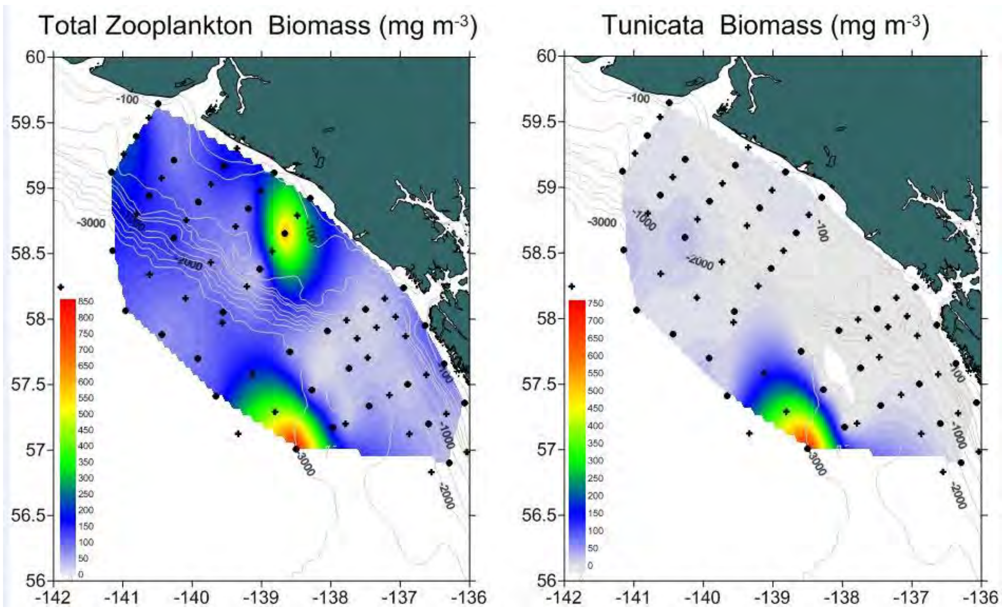


Figure 41: Kriging surface of biomass for total zooplankton and tunicates (salps) in the eastern Gulf of Alaska, July 2017. Circle points were processed in the lab.

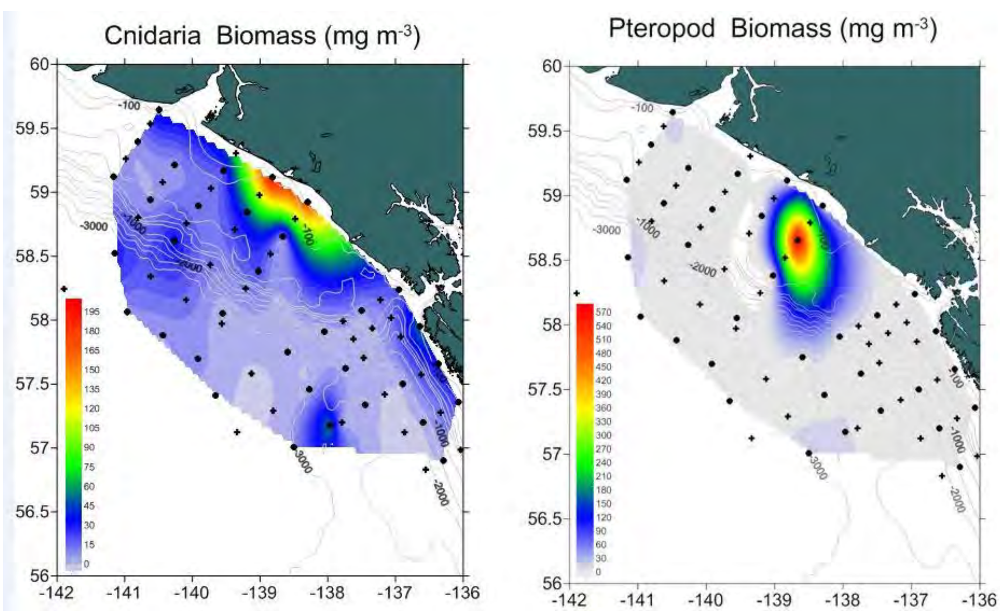


Figure 42: Kriging surface of biomass for Cnidarians (hydrozoan jellyfish) and all pteropods in the eastern Gulf of Alaska, July 2017.

changes in trawl gear in 2017, and/or the result of shifts in prey fields and primary producers. In addition, gelatinous zooplankton are highly efficient filter feeders that shunt pelagic production to the benthos via fecal pellets and dead falls (Richardson et al., 2009) and may stimulate production and growth of benthic species.

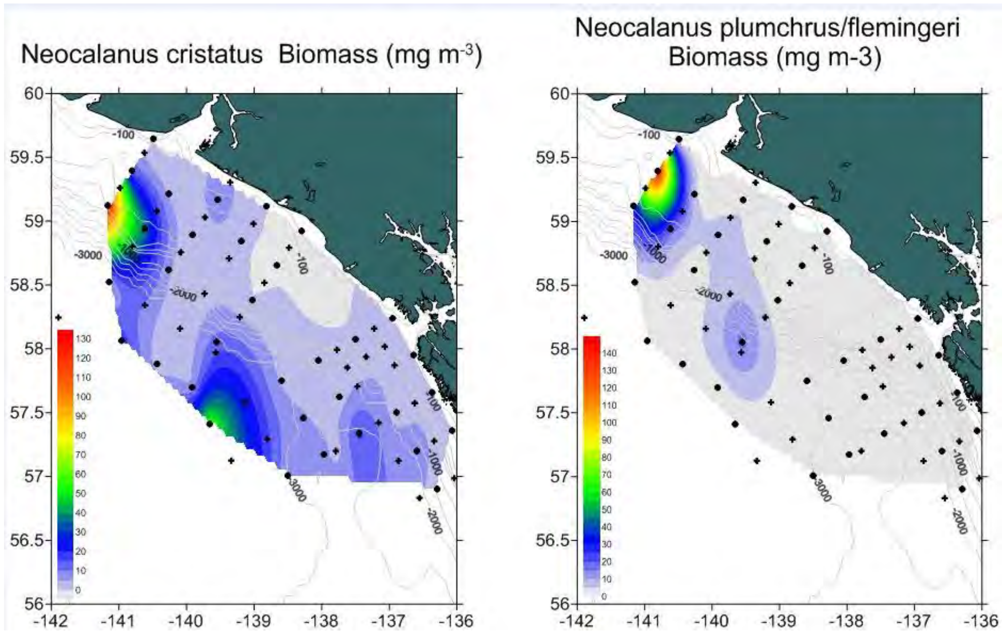


Figure 43: Kriging surface of biomass for *Neocalanus cristatus* and *Neocalanus plumchrus/flemengeri* in the eastern Gulf of Alaska, July 2017.

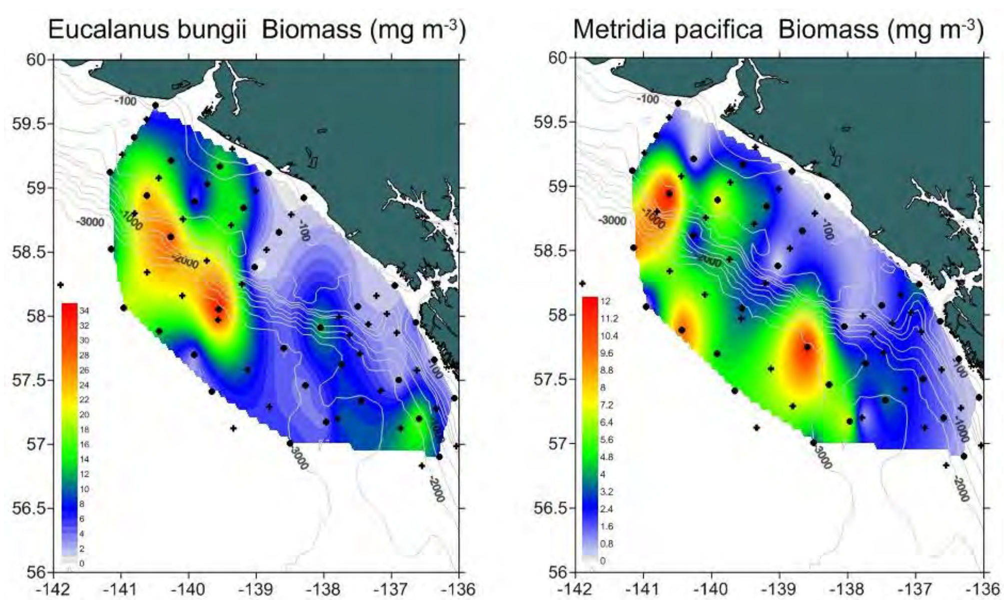


Figure 44: Kriging surface of biomass for *Eucalanus bungii* and *Metridia pacifica* in the eastern Gulf of Alaska, July 2017.

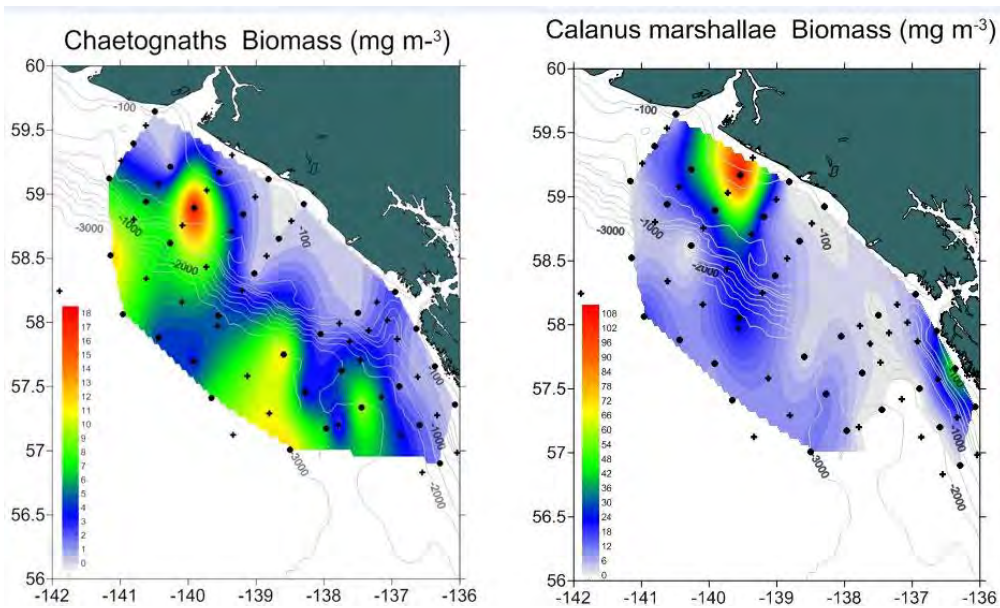


Figure 45: Kriging surface of biomass for Chaetognaths and *Calanus marshallae* in the eastern Gulf of Alaska, July 2017.

## Jellyfish

### Jellyfish – Gulf of Alaska Bottom Trawl Survey

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**Last updated: October 2017**

**Description of indicator:** RACE bottom trawl surveys in the Gulf of Alaska (GOA) are designed primarily to assess populations of commercially important fish and invertebrates. However many other species are identified, weighed and counted during the course of these surveys and these data may provide a measure of relative abundance for some of these species. For jellyfish, the catches for each year were scaled to the largest catch over the time series (which was arbitrarily scaled to a value of 100). The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The percentage of positive catches in the survey bottom trawl hauls was also calculated.

**Status and trends:** Jellyfish mean catch per unit effort (CPUE) is typically higher in the Kodiak region than in other areas (Figure 46). The frequency of occurrence in trawl catches is generally high across all areas, except the Shumagins, but has been variable. Jellyfish catches in the western GOA (Chirikof and Shumagin areas) have been uniformly low. Jellyfish catch in the Kodiak area decreased from peaks during the 2013 and 2015 surveys. Jellyfish catches in the eastern GOA (Yakutat and Southeastern areas) have been low.

**Factors influencing observed trends:** Jellyfish are probably not sampled well by the gear due to their fragility and potential for catch in the mid-water during net deployment or retrieval. Therefore jellyfish encountered in small numbers which may or may not reflect their true abundance in the GOA. The fishing gear used aboard the Japanese vessels that participated in all GOA surveys prior to 1990 was very different from the gear used by all vessels since. This gear difference almost certainly affected the catch rates for jellyfish.

**Implications:** GOA survey results show very few trends in jellyfish abundance across time, with most of the trends being consistent within regions.

### Spatial and Temporal Trends in the Abundance and Distribution of Jellyfish in the Eastern Gulf of Alaska During Summer, 2011–2017

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**Last updated: October 2016**

**Description of indicator:** Pelagic jellyfish were sampled using a rope trawl towed in the upper 20 m of the eastern Gulf of Alaska during the Alaska Fisheries Science Center's Gulf of Alaska Assessment Survey, 2011–2017. Stations were approximately 10 nautical miles apart and a trawl was towed for approximately 30 minutes. Area swept was estimated from horizontal net opening

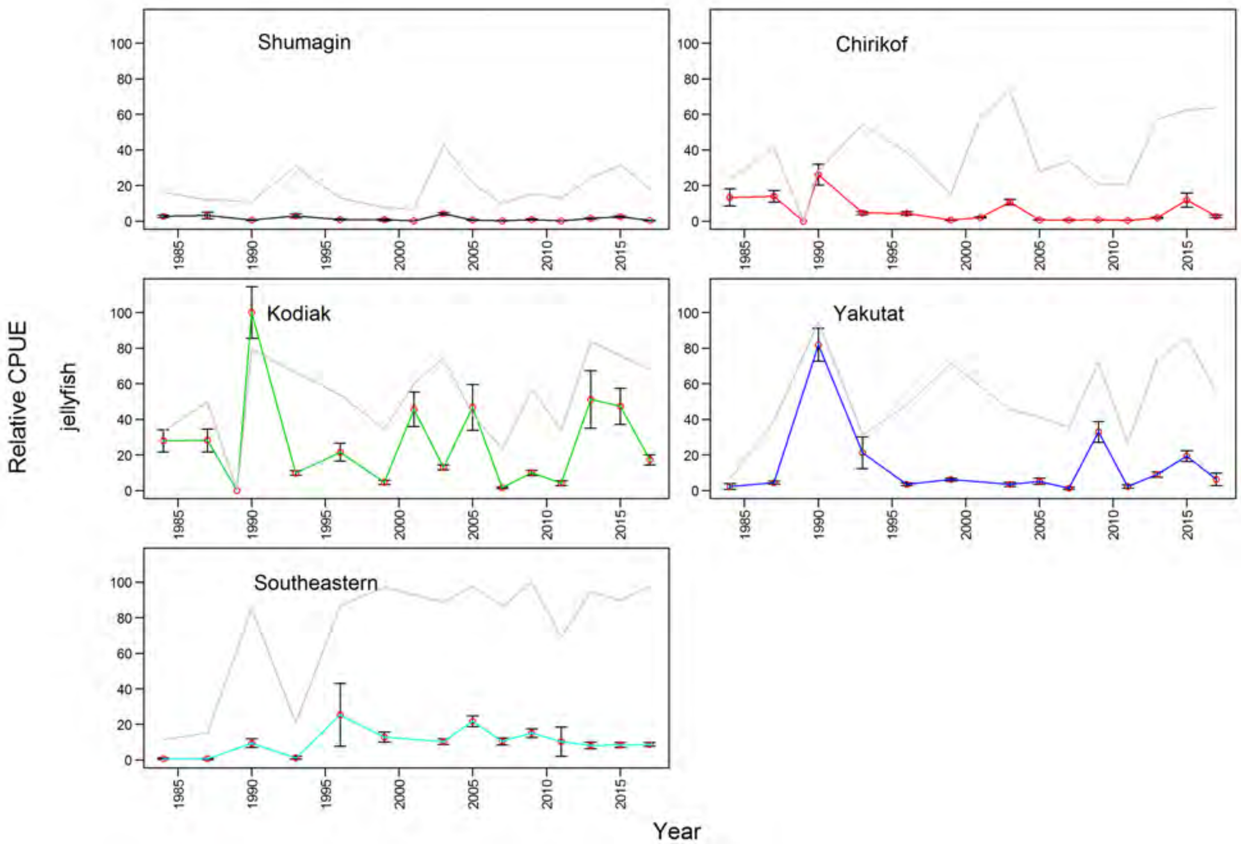


Figure 46: Relative mean CPUE of jellyfish species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2017. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

and distance towed.

Jellyfish catch was estimated in kilograms. Jellyfish distribution, abundance, and densities in these areas were estimated using geostatistical modeling methods (Thorson et al., 2015). All jellyfish medusae caught in the surface trawl (top 20 m of the water column) were sorted by species and subsampled for bell diameter and wet weight. Several gelatinous species were encountered with the surface trawl, the most common identifiably retained are: *Aequorea* sp., *Aurelia* sp., *Chrysaora melanaster*, Ctenophora (*Hormiphora* sp., *Pleurobrachia bachei*, *Beroe* sp.), *Cyanea capillata*, *Phacellocephora camtschatica*, and *Staurophora mertensii*. Biomass was calculated for each species and compared across species, and oceanographic domain in the eastern Gulf of Alaska. In 2017 a gear change was implemented, the Cantrawl was replaced with a Nordic 264 trawl net. For specific details on this gear change please reference cruise report (Strasburger et al. in review).

Abundance and distribution (center of gravity and area occupied) were estimated for each jellyfish species using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 0.99.896 and R software version 3.3.0 (R Core Team 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015); Thorson and Kristensen (2016); Thorson et al. (2016*a*,*b*) to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 100 knots. Parameter estimates were within the upper and lower bounds.

**Status and trends:** Total biomass of jellyfish in the EGOA survey area was low during the cold years (2011–2013) and high during the warm years (2014–2017) with the exception of 2016 (Figure 47). The trend in biomass was dominated by *Aequorea*. Temporal trends in the estimated abundance of jellyfish indicated a recent increase in the productivity of smaller body-sized jellyfish (*Aequorea*, *Ctenophora*) and a decrease in the typically dominant larger jellyfish (*Chrysaora*). *Cyanea* and *Phacellophora* have also increased recently in the eastern Gulf of Alaska. The large body-sized jellyfish *Chrysaora melanaster* seems to be without favor in the Gulf of Alaska ecosystem and fails to dominant currently as they have in the past and in other ecosystems. Overall, *Ctenophora* and *Aequorea* seem to be the recent key players in Gulf of Alaska in terms of abundance

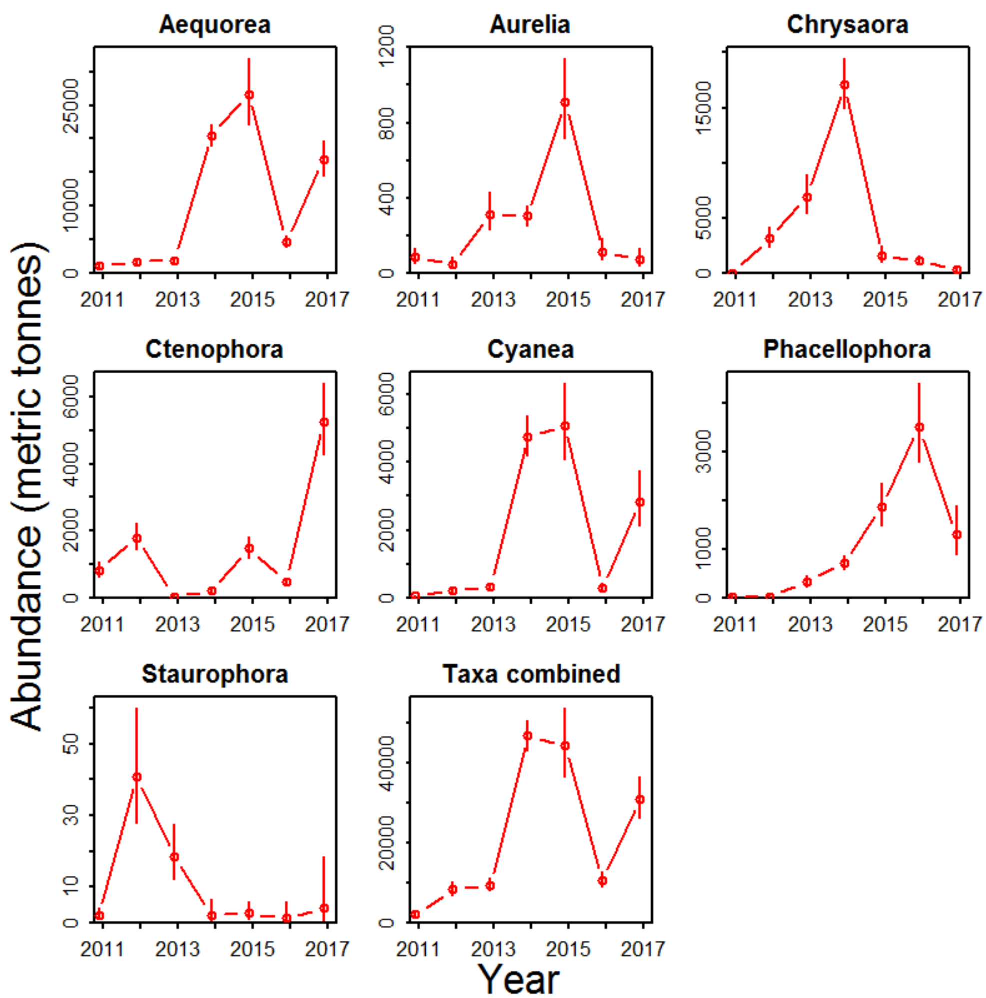


Figure 47: Index of abundance (metric tonnes) ±1 standard deviation for jellyfish in the eastern Gulf of Alaska during late summer, 2011–2017.

Distribution of jellyfish varied among species and years. Yearly distributions throughout the sample grid for all species have been patchy and highly variable. Center of gravity plots indicate no warm and cold year trend in the distribution of jellyfish (Figure 48). Latitudinal (N-S) distribution was farther north during 2017 for *Aequorea*, *Ctenophora*, and *Phacellophora*, and slightly farther south for *Aurelia*, *Chrysaora*, and *Staurophora*, and no different for *Cyanea* relative to 2016. Longitudinal distribution was oriented farther east for *Aequorea*, *Aurelia*, *Chrysaora*, and *Staurophora*, and farther west for *Ctenophora*, *Cyanea*, and *Phacellophora* in 2017 relative to 2016. According to the estimated area occupied, the distribution was contracted for *Aequorea*, *Chrysaora*, *Phacellophora*, and *Staurophora*, and slightly expanded for *Aurelia*, *Ctenophora*, and *Cyanea* during 2017 relative to 2016 (Figure 49).

**Factors influencing observed trends:** Shifts in abundance from single-body, large-sized jellyfish during cold years to multiple, smaller-sized species during warm years indicate that there could be a shift to multiple taxa in the future during warm stanzas. There is not enough eastern Gulf of Alaska data to determine if this is the trend. The cause for the shifts in biomass and distribution do not seem to rely solely on physical ocean factors (temperature and salinity). These shifts could also be a result of environmental forcing earlier in the growing season or during an earlier life history stage (polyp), which may influence large medusae biomasses and abundances (Purcell et al., 2009). The rise in Ctenophore catches could possibly be related to the change in gear but gear effects have not been determined at this time.

**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).

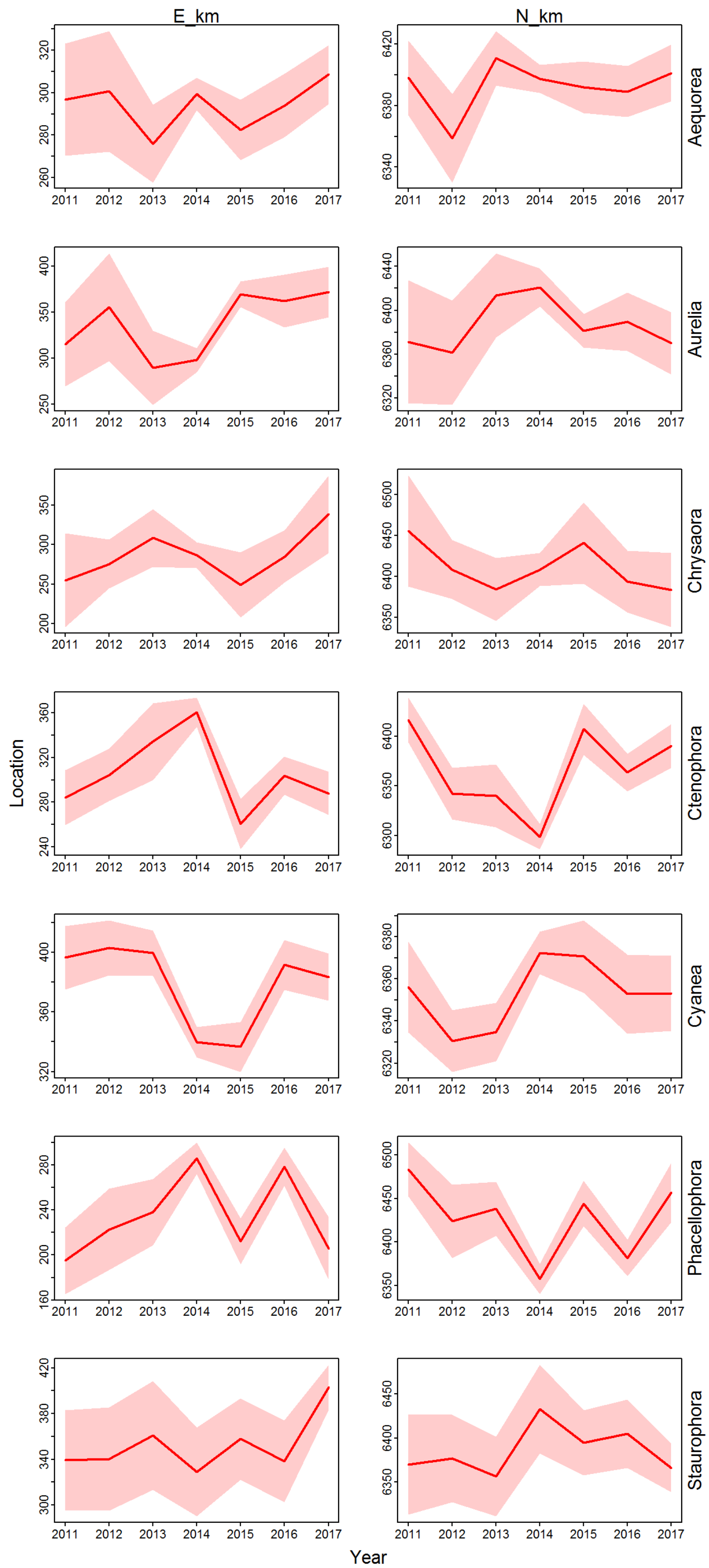


Figure 48: Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution plus/minus 1 standard deviation in UTM (km) for jellyfish on the eastern Gulf of Alaska during summer, 2011–2017.

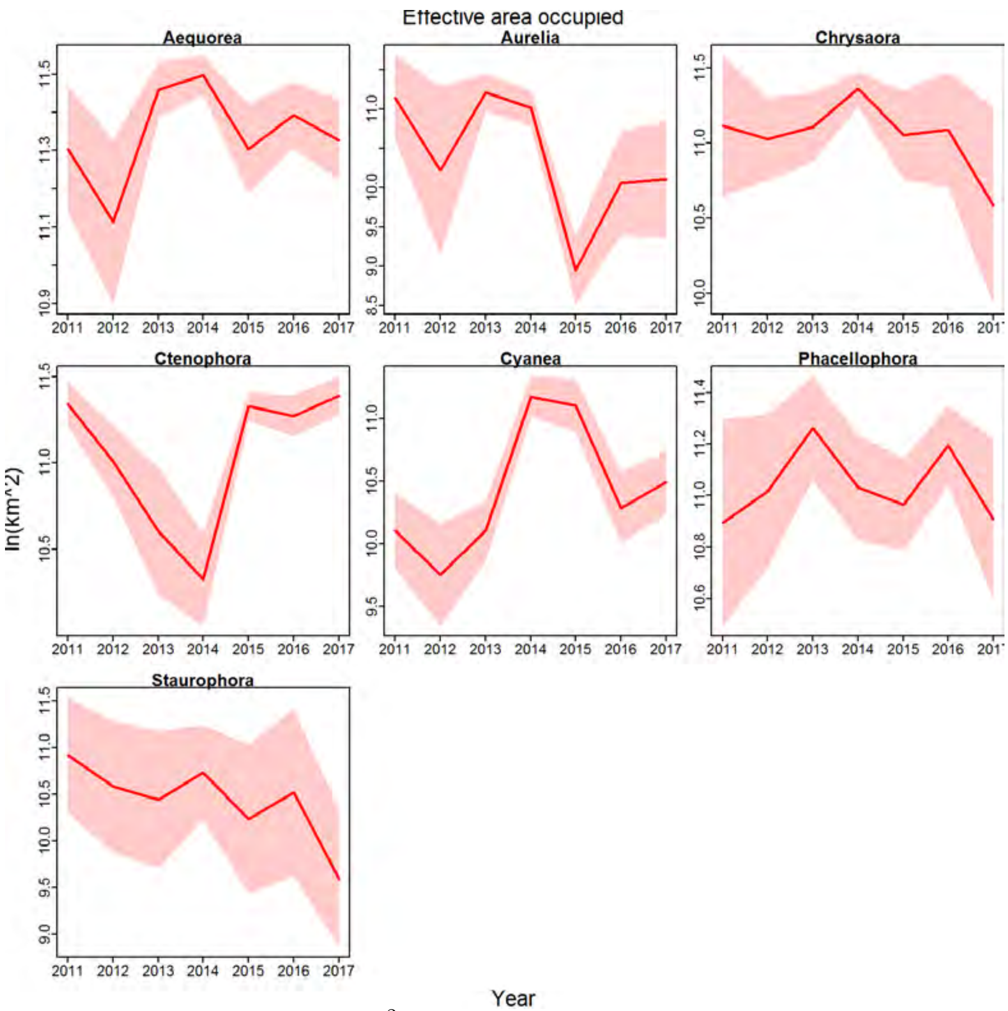


Figure 49: Effective area occupied ($\ln(km^2)$) indicating range expansion/contraction plus/minus 1 standard deviation for jellyfish in the eastern Gulf of Alaska during summer, 2011–2017.

## Ichthyoplankton

### Larval Walleye Pollock Assessment in the Gulf of Alaska, Spring 2017

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**Last updated: August 2017**

**Description of indicator:** The 2017 EcoFOCI spring larval survey was conducted from May 11 to June 2. A total of 267 stations were sampled using the 60 cm bongo with 0.505 mm mesh. From the 60 cm bongos, net 1 was preserved in 1.5% formaldehyde for later identification, quantification, and length measurement of all larval fish species. Net 2 was used to acquire a rough count of larval pollock while at sea to determine a rough estimate of abundance and geographic distribution. Rough counts were acquired by pouring the codend contents into a 4-liter beaker and removing a 10% subsample for sorting. If the larval pollock count was below 10, then the entire codend was sorted. The larval samples removed from net 2 were preserved in alcohol to determine age, growth, hatch date distributions, prey estimates, and condition by cell cycle analysis. The 20/60 bongo array with 0.153/0.505 mm mesh was used every other survey line to identify and quantify relative zooplankton abundance available for larval fish. A Sea-Bird FastCat was used in conjunction with the bongos to acquire temperature and salinity profiles. Argos satellite-tracked drifters drogued at 40 meters were released east of Kennedy Entrance and between the Semidi Islands and Chirikof Island (both areas of high larval pollock counts) to assess current strength and direction of larval transport.

A time series of larval walleye pollock abundance has been developed using quantitative laboratory counts of samples from the spring larval survey from 1981–2015 (Rogers and Mier, 2016; Doyle et al., 2009); however, these data are not available until approximately 12 months after the survey. At-sea rough counts of larval walleye pollock provide a rapid indicator of larval abundance, and a time series was constructed for larval rough counts using the same methodology as for laboratory-based counts. Comparison of abundance estimates using at-sea rough counts and laboratory counts from 2000–2015 indicate a strong correlation (r = 0.99). At-sea rough counts are only available for walleye pollock.

**Status and trends:** Larval walleye pollock rough counts from the 2017 western Gulf of Alaska survey were above average throughout the grid with few zero catches (Figure 50). This is in contrast to 2015 when catches were far below average and often zero across the survey grid (Dougherty, 2015). The rough-count abundance estimate indicates that larval walleye pollock abundance was similar to previous high-abundance years (2000, 2006, 2010) although not as high as 2013 (Figure 51).

**Factors influencing observed trends:** All larval pollock caught were observed to be in excellent condition and feeding well. A rapid zooplankton assessment (RZA) was conducted at sea to determine prey quality and abundance (see Ferm et al., p. 83). Results suggest good conditions for pollock larvae and juvenile production. Temperature at 40 meters (larval pollock residence) ranged between 4–6°C, which is closer to the expected temperature range for late May in comparison to 2015. The Argos satellite-tracked drifter released east of Kennedy Entrance quickly entered

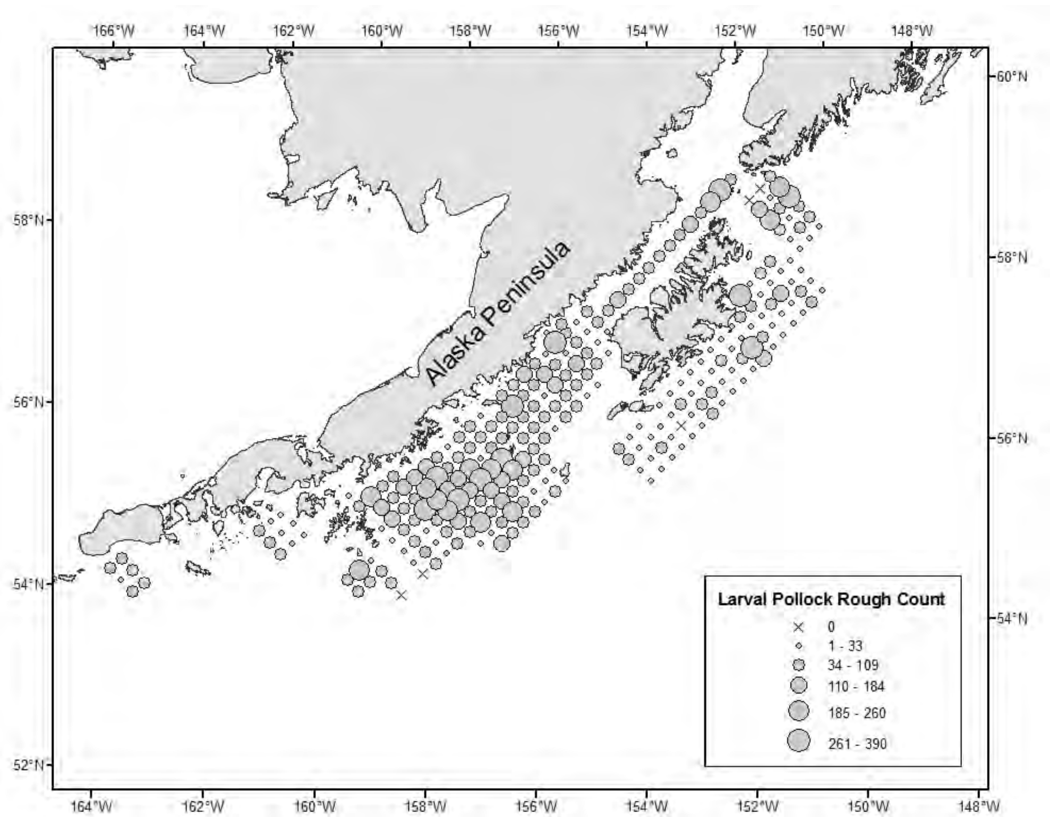


Figure 50: At-sea rough counts of larval walleye pollock on the EcoFOCI Spring Survey, DY17-05. Counts are uncorrected for effort.

Shelikof Strait and is currently traveling along the Alaska Peninsula between Sutwik Island and the Shumagin Islands. The drifter released between Chirikof Island and the Semidi Islands. has traveled inland to the Alaska Peninsula past the Shumagin Islands and is moving towards Pavlof Bay. The data from the drifter tracks will be useful to determine if mixing of larval pollock from geographically separated spawning stocks is occurring (i.e. Shelikof and Shumagin Islands).

**Implications:** Observed high abundance of larval walleye pollock indicates good survival through the first critical bottleneck period for walleye pollock. This suggests that the ecosystem has returned to a more productive state after the 2014–2016 warm anomaly. Juvenile walleye pollock are an important prey species in the Gulf of Alaska. Whether 2017 will be a strong year-class for the walleye pollock fishery remains to be seen, as high mortality at later stages can reduce even strong larval and juvenile cohorts, as was seen in 2013.

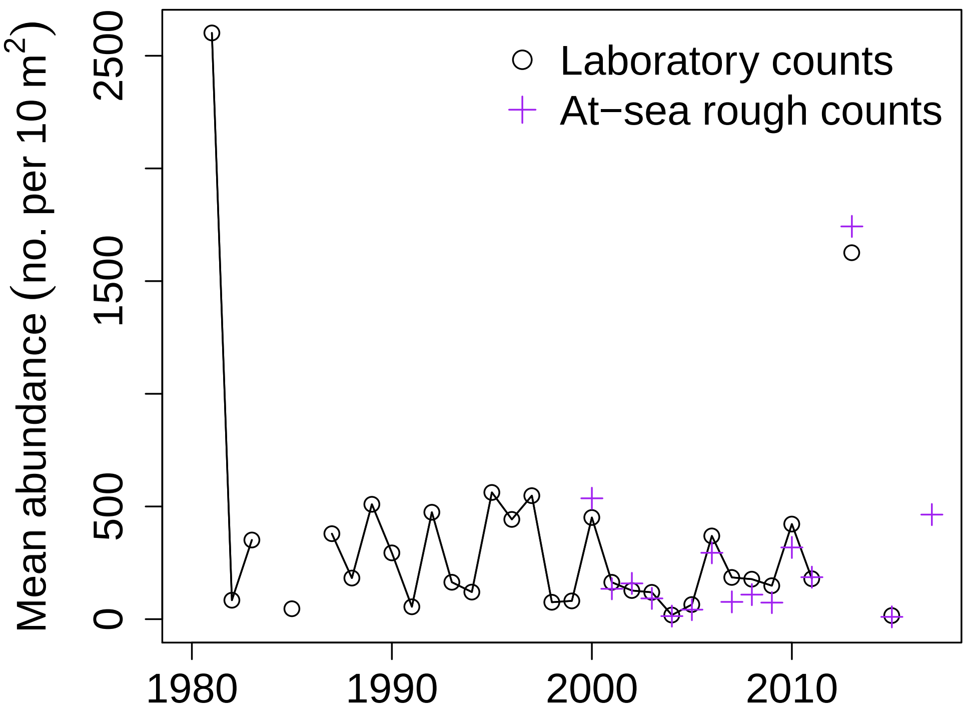


Figure 51: Estimated abundance of larval walleye pollock based on quantitative laboratory-based counts (1981–2015) and at-sea rough counts (2000–2017).

## Forage Fish and Squid

### Small Neritic Fishes in Coastal Marine Ecosystems: Late-Summer Conditions in the Western Gulf of Alaska

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**Last updated: September 2017**

**Description of indicator:** The Ecosystems & Fisheries Oceanography Coordinated Investigations (EcoFOCI) Program monitors and researches small neritic fishes to improve our understanding and management of the Gulf of Alaska ecosystem and fisheries. Small neritic fishes include the juvenile stages of economically and ecologically important species (e.g., walleye pollock, Pacific cod, Pacific ocean perch and other rockfishes, sablefish, and arrowtooth flounder). They also include species managed exclusively as forage fishes (e.g., capelin and eulachon) that support the fishes, seabirds, and marine mammals that characterize the piscivore-dominated GOA ecosystem. Longstanding objectives of EcoFOCI late-summer field work in the western Gulf of Alaska are to extend a time series of age-0 walleye pollock abundance estimates, monitor the neritic environment including zooplankton and abiotic conditions, and collect samples for research (e.g., trophic and spatial ecology, bioenergetics, age and growth).

During 21 August–15 September, the NOAA vessel *Oscar Dyson* sampled the western Gulf of Alaska from Cook Inlet to the Shumagin Islands, including Shelikof Strait, the east side of Kodiak Island, and spanning the shelf out to the shelf break. The survey grid west of the Shumagin Islands was truncated due to weather. At each of 130 stations, water temperature and salinity were profiled and zooplankton samples were collected with 20 cm (153 $\mu$m mesh) and 60-cm (505 $\mu$m mesh) bongos towed obliquely through the upper 200 m of the water column (see p.83). Target fishes were collected using a Stauffer trawl (aka anchovy trawl) equipped with a small-mesh (2x3 mm) codend liner towed obliquely to a maximum depth of 200 m.

Time series of abundance for age-0 pollock and for capelin were constructed based on catches from late-summer surveys since 2000 (only odd years since 2001) for the consistently sampled region between Kodiak Island and the Shumagin Islands (Figure 52). Mean catch per unit area was calculated using an area-weighted mean. Due to significant differences in catches of capelin during day versus night, mean CPUE for the night stations only is also shown.

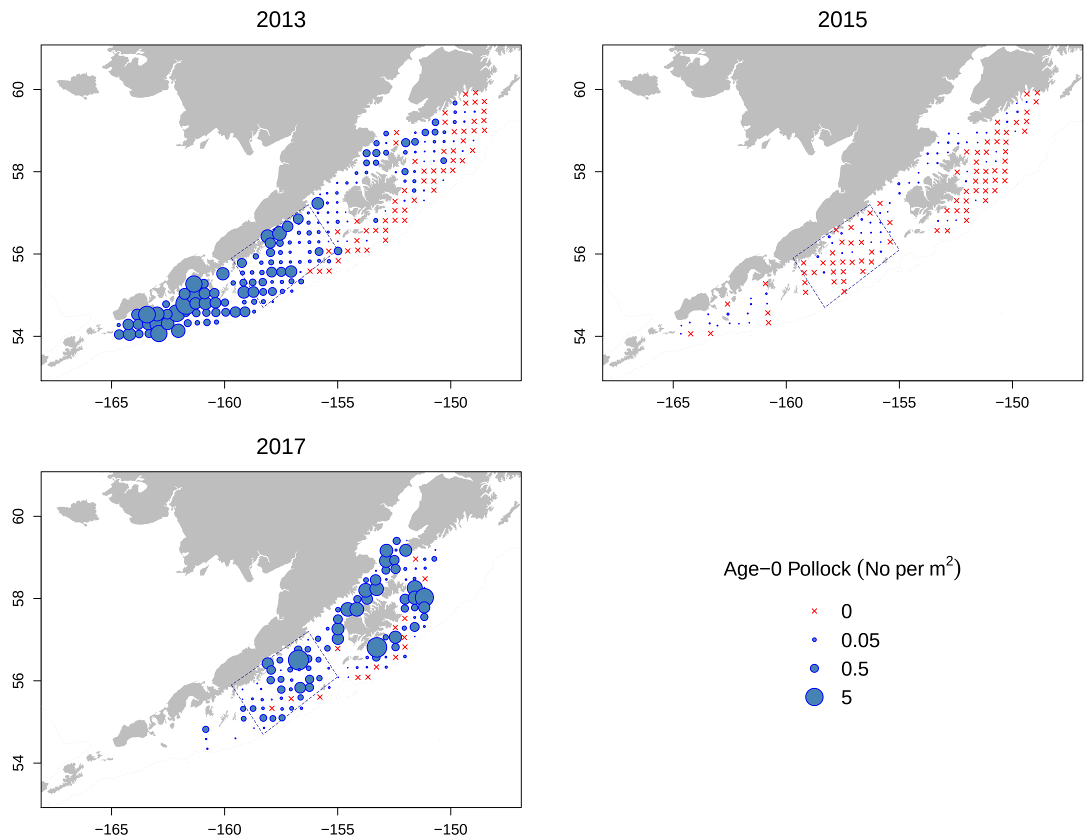


Figure 52: Catches of age-0 walleye pollock in the EcoFOCI late-summer small-mesh trawl survey for 2013, 2015, and 2017. The area in the blue dashed box indicates the region most consistently sampled since 2000 and includes the stations used to develop CPUE time series.

**Status and trends:** Catches of age-0 pollock were particularly high through Shelikof Strait and to the east of Kodiak Island (Figure 52). The mean CPUE estimate for 2017, which does not include the stations near Kodiak, suggests the second highest abundance of age-0 pollock in our time series

(Figure 53), averaging 380,000 age-0 pollock per square kilometer (0.38 fish/m$^2$). Pollock densities tapered off towards the Shumagin Islands in the southwest. This spatial distribution is in contrast to a previous high abundance year (2013) when catches were highest southwest of the Shumagin Islands. Capelin abundance remained low in 2017, continuing a trend of low abundance since 2011. However, note that no sampling occurred in even years and the time series estimate does not include catches from near Kodiak, where capelin catches are typically higher.

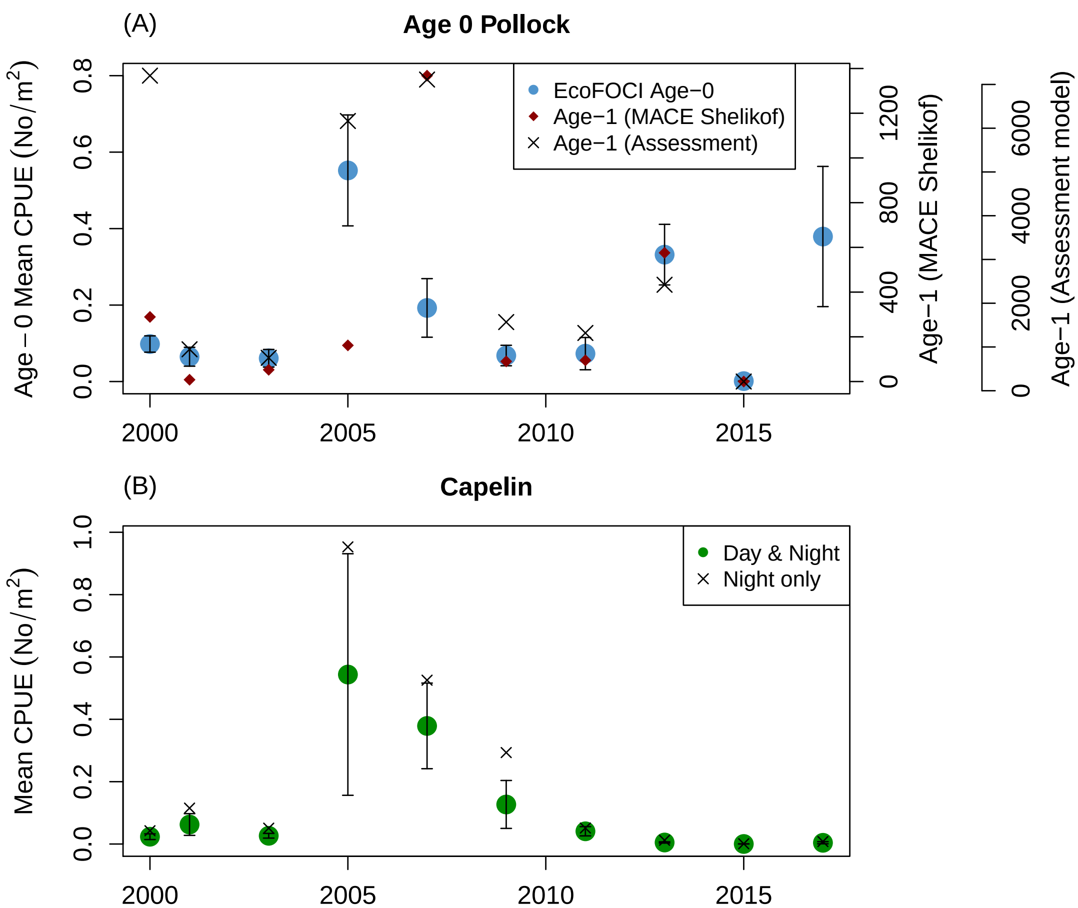


Figure 53: Catches of age-0 walleye pollock in the EcoFOCI late-summer small-mesh trawl survey for 2013, 2015, and 2017. The area in the blue dashed box indicates the region most consistently sampled since 2000 and includes the stations used to develop CPUE time series.

**Factors influencing observed trends:** The abundance of age-0 pollock in late summer reflects the number of surviving larvae from spawning in the spring and survival processes through the summer. In spring of 2017, catches of larval pollock were high (Dougherty and Rogers, p.107), and a rapid assessment of zooplankton in late summer (Ferm et al., p.83) suggested high abundance of euphausiids and large copepods, preferred prey for pollock. The observed spatial distribution of pollock may result from transport processes and/or reflect production from different spawning groups. Investigations into factors driving changes in the spatial distribution and abundance of capelin and juvenile pollock are underway.

**Implications:** Capelin and young-of-year pollock are key forage fish species in the Gulf of Alaska, providing prey for seabirds, fishes, and mammals. This late-summer survey also provides an assessment of the abundance, size, and condition of young-of-year pollock before entering their first winter, giving an early indicator of potential year class strength. Strong catches of juvenile pollock, together with previously observed high larval abundance, suggest a return to productive conditions in the Gulf of Alaska following the "Blob" warm anomaly in 2014–2016.

### Capelin and Sand Lance Indicators for the Gulf of Alaska

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**Last updated: August 2016**
This will be updated in 2018.

### Seabird-Derived Forage Fish Indicators from Middleton Island

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**Last updated: August 2017**

**Description of indicator:** Time series of seabird and forage fish monitoring at Middleton Island in the north-central Gulf of Alaska are among the longest available from any Alaska location. Being situated near the continental shelf edge (lat 59.4375, lon -146.3277), Middletons seabirds sample both neritic habitat and deep ocean waters beyond the shelf break. Consequently, certain species of ecological concern (myctophids) and/or economic concern (0-age group sablefish) figure prominently in seabird diets at Middleton, unlike anywhere else these prey and their seabird predators might be monitored.

In most years since 2000, regurgitated food samples have been collected from adult and/or nestling black-legged kittiwakes (*Rissa tridactyla*) during all months April through August. From an evaluation of alternate methods of analyzing and reporting diet results, the preferred metric for kittiwakes is prey relative occurrence (Hatch, 2013), for which the relevant sample units are numbers of identified prey types in a given sample. Rhinoceros auklet (*Cerorhinca monocerata*) diets are monitored by collecting bill-loads from chick-provisioning adults, usually once or twice a week from early July through early or mid-August. Since 1978, more than 100 kg of auklet prey samples have been collected on Middleton, and auklet diet monitoring provides our single best indicator of forage fish dynamics in the region.

**Status and trends:** On average, Middleton kittiwakes take about equal amounts of Pacific sand lance, capelin, and invertebrates, with lesser amounts of herring, sablefish, salmon, and myctophids, depending on stage of the season. The juxtaposition of time series for kittiwakes and rhinoceros auklets since 1978 (Figure 54) shows general agreement between a sustained decline of sand lance and, beginning in 2007, the emergence of capelin as a dominant forage species. In the last 4 years, however, when neither sand lance nor capelin were prevalent, the diets of surface-feeding kittiwakes and diving auklets diverged in respect to prey-switching to alternate species such as mytophids and salmon.

Auklet data plotted separately by prey type highlight the interannual dynamics of individual species (Figure 55). By all appearances, sand lance were the overwhelmingly dominant forage species in the northern Gulf in the late 1970s through the early 1980s. Following a period of reduced availability in the mid 1990s, sand lance made a strong comeback by the end of that decade. However, sand lance steadily declined in importance after 2000 and for the most part have contributed little to seabird diets since 2008. However, the appearance of about 30% sand lance in the auklet diet in 2016 and 2017 is consistent with a known association of sand lance with warm-water conditions (Hatch, 2013). Pacific herring seem also to have benefited from recent warm surface conditions prevalent in the region

**Factors influencing observed trends:** Seabird diets at Middleton reflect ecosystem shifts in the Gulf of Alaska. This includes specific events recorded and widely discussed in the ecological literature such as the notable shift from "warm" (positive Pacific Decadal Oscillation, PDO) conditions to cold (negative PDO) conditions around 1999–2000 (Greene, 2002; Peterson et al., 2003; Batten and Welch, 2004), a similar but stronger and more persistent shift in 2008 (Hatch, 2013), and a widely reported warm-water anomaly that has dominated the system since late winter 2013 (Bond et al., 2015)). A salient finding during a recent, anomalous warm-water event has been the virtual disappearance of capelin from the kittiwake diet on Middleton, following 6 prior years when capelin were predominant (Figure 54). An apparent trade-off between Pacific sand lance (warm conditions) and capelin (cold conditions) may be a benchmark of the forage fish community in the region.

**Implications:** Seabird diets provide further evidence that capelin disappeared in the ecosystem during the recent warm years. Chick diets at Middleton may be informative for sablefish studies. In 2017, the Alaska Fisheries Science Center will begin using specimens from seabird diet sampling at Middleton for phenology and growth studies of first-year sablefish, which are difficult to sample directly. Seabird diet indicators are potentially applicable to other management concerns in the region, including Pacific herring stocks, which crashed and have not recovered after the Exxon-Valdez Oil Spill in 1989, and year-class strengths of pink and chum salmon, which appear regularly in Middleton seabird diets.

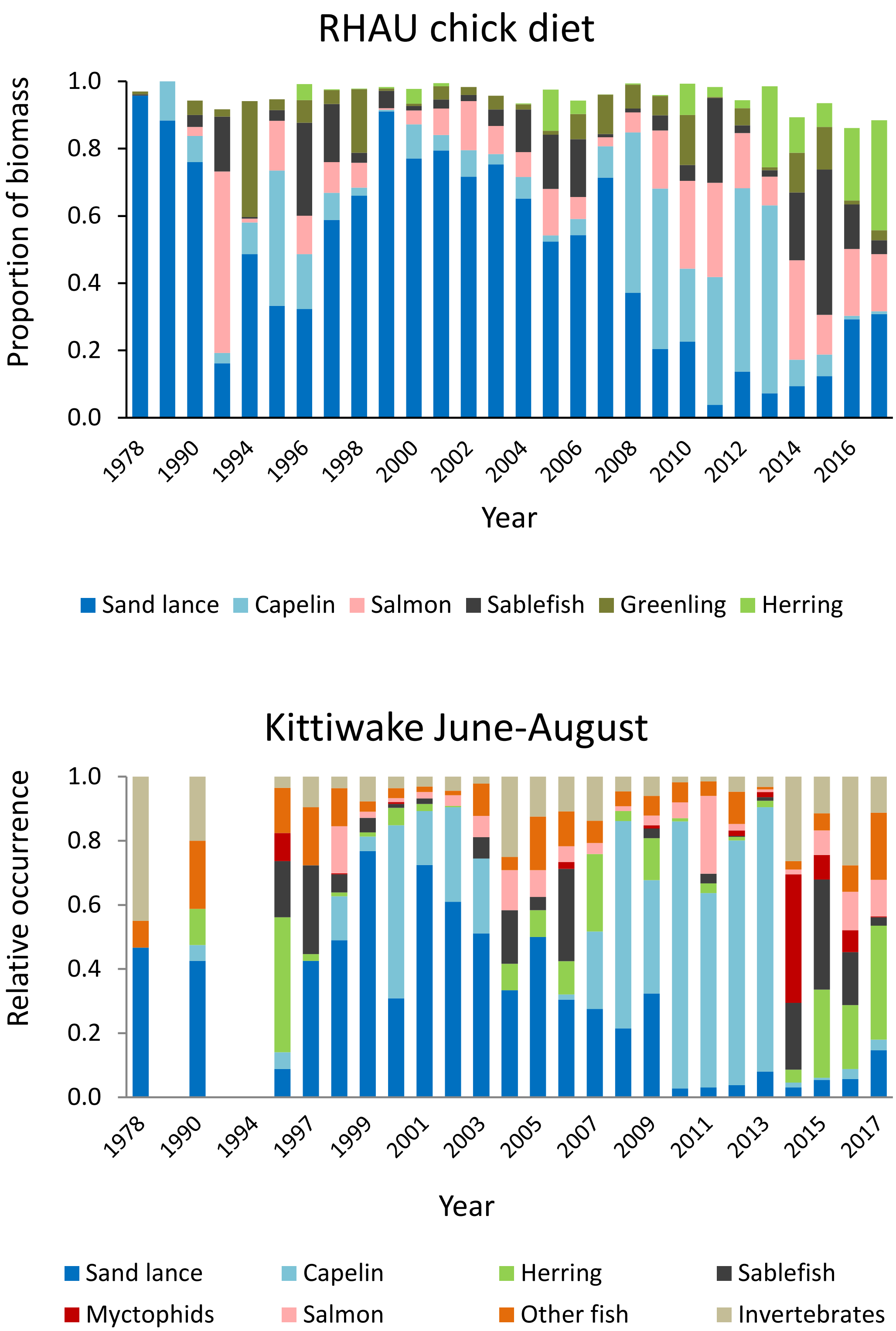


Figure 54: Interannual variation in diet composition of chick-rearing rhinoceros auklets on Middleton Island, 1978–2017, with a similar time series for black-legged kittiwakes (lower panel) for comparison.

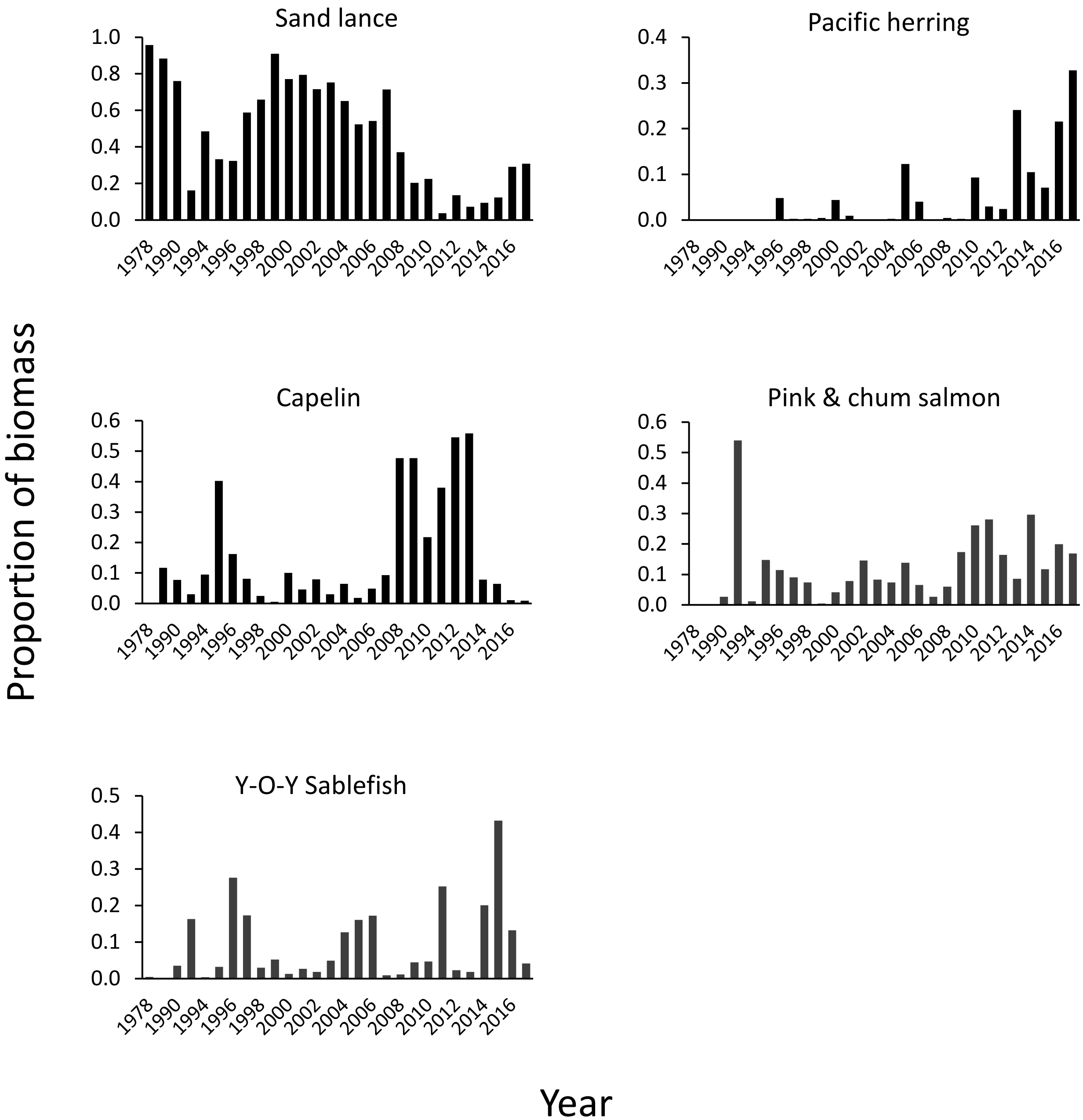


Figure 55: Prey species occurrence in the nestling diet of rhinoceros auklets on Middleton Island from 1978–2017.

### Spatial and temporal trends in the abundance and distribution of YOY groundfish in pelagic waters of the eastern Gulf of Alaska during summer, 2010–2017

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**Last updated: October 2017**

**Description of indicator:** Pelagic fish were sampled using a rope trawl towed in the upper 20 m during the Alaska Fisheries Science Center's eastern Gulf of Alaska Assessment Survey, summer 2010–2017. Stations were approximately 10 nautical miles apart and hauls were standardized to approximately 30 minutes. Area swept was estimated from horizontal net opening and distance towed. The Nordic 264 trawl was used in 2010 and 2017, and a CanTrawl 400/601 was used in 2011–2016.

Fish catch was estimated in kilograms. Young-of-the-year (YOY) marine fish weight was estimated by multiplying the grand mean weight in a given year by the number captured at a station. Four YOY groundfish species were captured in the trawl, including: Pacific cod, walleye pollock, arrowtooth flounder, and rockfish (Sebastes spp.).

Abundance and distribution (center of gravity and area occupied) were estimated using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*). This package generates a standardized geostatistical index, used for estimating abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 100 knots (100 prediction units). Parameter estimates were within the upper and lower bounds and final gradients were less than 0.0005. If no positive catches occurred for a species within a year, an artificial minimum value was inserted, allowing the model to run. It is important to note that no YOY Pacific cod were sampled in 2016. This resulted in very large confidence intervals on a low point. The overall trend is still what would be expected.

**Status and trends:** YOY biomass estimates indicate high levels of arrowtooth flounder, and low levels of Pacific cod, pollock, and rockfish in 2017. Temporal trends in the estimated abundance of these groundfish species indicated above average abundance of arrowtooth flounder in 2012, above average abundance of Pacific cod in 2014, above average abundance of pollock during 2014, and an above average abundance of rockfish in 2016 (Figure 1). In 2016, rockfish were the most abundant YOY marine fish species in 2016 followed by pollock, and arrowtooth flounder (Figure 56).

Distribution of groundfish in pelagic waters varied among species and years. Pacific cod were commonly predicted to be over the shelf (50–200 m bottom depth) and within 20 nm from shore. Pollock were more widely distributed, occupying shelf, slope, and basin domains (50–2000 m bottom depth). Rockfish were the most widely distributed species in the eastern Gulf of Alaska; occupying shelf, slope, and basin domains up to 100 nm from shore. Arrowtooth flounder were typically found offshore, with the exception of in 2012. In 2017, Pacific cod were found off of Yakutat Bay and Baranof Island, pollock were found north and offshore, arrowtooth flounder in the northern region of the survey area, and rockfish fairly evenly distributed across the shelf.

Center of gravity indicated that all species were distributed farther north in 2017. Pacific cod

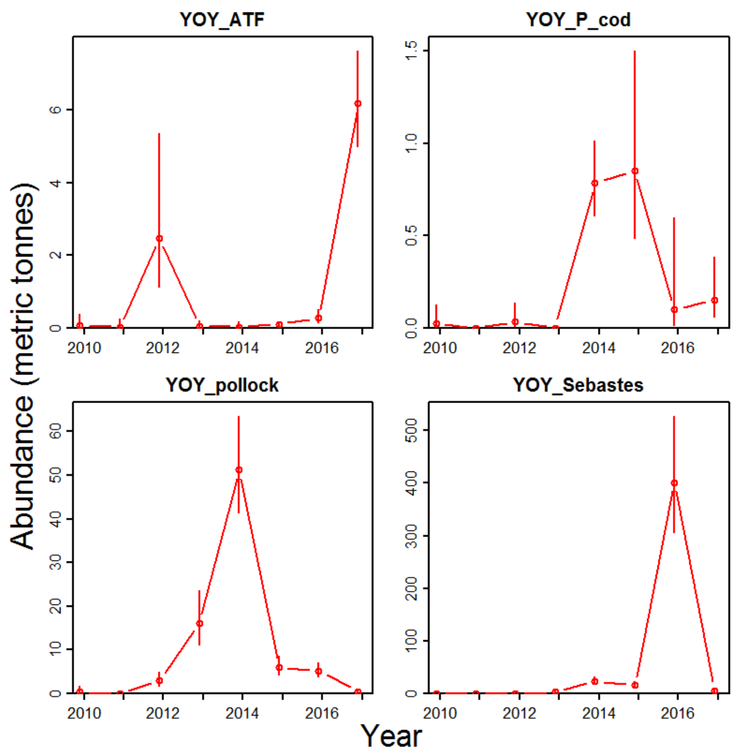


Figure 56: Index of abundance (metric tonnes) plus/minus 1 standard deviation for groundfish species in pelagic waters of the eastern Gulf of Alaska during summer, 2010–2017.

were distributed farther north during recent warm years (2014–2015), whereas pollock, arrowtooth flounder, and rockfish were not until 2017 (Figure 2). Range expansion or contraction occurred for all species in 2017 relative to 2016, except for pollock (Figure 3).

**Factors influencing observed trends:** Lower groundfish abundances in pelagic waters during 2017 are believed to be in response to poor primary production (Strom et al., 2016) and an increased abundance of salps (Li et al., 2016), which further reduced the amount of plankton available transfer energy to upper trophic levels. Piscivorous predators not common to the eastern Gulf of Alaska (e.g., Pacific pomfret) were present in the eastern Gulf of Alaska during 2014, and 2015, presumably in response to unprecedented warming in the eastern Pacific Ocean commonly referred to as the "Warm Blob" (Bond et al., 2015). Additional predation pressure by these warm water predators may have reduced the amount of YOY marine fish that would have otherwise been present.

**Implications:** Lower groundfish abundances in surface waters during 2017 indicate a change in productivity in pelagic waters that affected many species of YOY marine fish. Warm conditions during 2014 and 2015 appeared to initially benefit pollock and Pacific cod and in more recent years benefited arrowtooth flounder and rockfish. No Pacific cod were sampled during 2016. Additionally, Pacific cod were low for 2010–2013 year classes in the survey area, a period of cool temperatures.

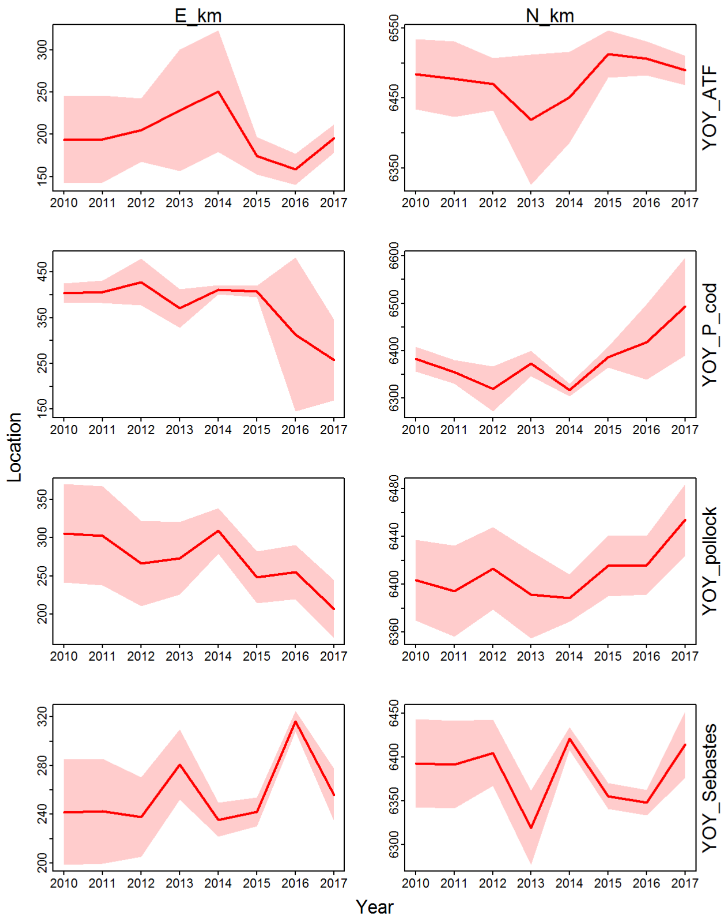


Figure 57: Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution plus/minus 1 standard deviation in UTM (km) for groundfish in pelagic waters of the eastern Gulf of Alaska during summer, 2010–2017.

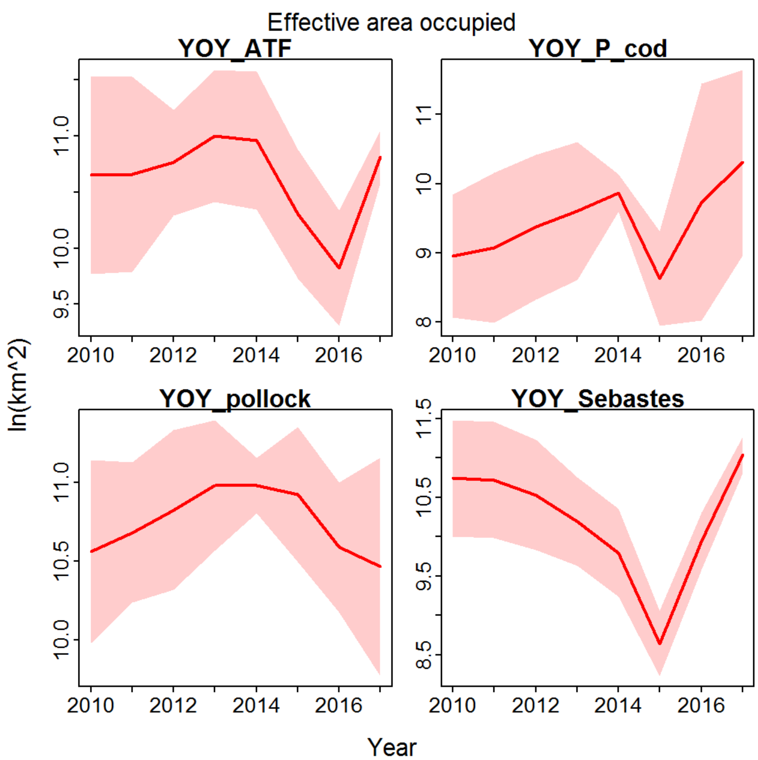


Figure 58: Effective area occupied ($\ln(\text{km}^2)$) indicating range expansion/contraction plus/minus 1 standard deviation for groundfish in pelagic waters of the eastern Gulf of Alaska during summer, 2010–2017.

## Spatial and Temporal Trends in the Abundance and Distribution of Juvenile Pacific Salmon in the Eastern Gulf of Alaska during Summer 2011–2017

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**Last updated: October 2017**

**Description of indicator:** Pelagic fish were sampled using a trawl net towed in the upper 20 m of the eastern Gulf of Alaska (EGOA) during the Alaska Fisheries Science Centers Gulf of Alaska Assessment Surveys during summer, 2010–2017. Stations were approximately 10 nautical miles apart and a trawl was towed for approximately 30 minutes. The area swept by the trawl was estimated from horizontal net opening and distance towed. Fish catch was estimated in kilograms. Juvenile salmon weight was estimated by multiplying the grand mean weight in a given year by the number captured at a station. A CanTrawl was used to sample fish during 2011–2016 and Nordic trawl was used to sample fish in 2017.

Abundance and distribution (center of gravity and area occupied) were estimated for juvenile Chinook (*Oncorhynchus tshawytscha*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 1.0.136 and R software version 3.3.0 (R Core Team 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015); Thorson and Kristensen (2016); Thorson et al. (2016*a*,*b*) to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 100 knots. Parameter estimates were within the upper and lower bounds and final gradients were less than 0.0005.

**Status and trends:** Temporal trends in the estimated biomass of juvenile salmon in the EGOA shelf survey area indicates a decrease in the productivity of juvenile salmon during 2017 (Figure 59). Abundances were low for Chinook, coho, pink, and sockeye salmon, and moderate for chum salmon. Both juvenile pink and chum salmon had an alternating year pattern with higher abundances in even-numbered years. Juvenile salmon were distributed nearshore in waters above the continental shelf. Juvenile salmon were distributed farther south and east in 2017 relative to 2016 (Figure 59). In 2017, area occupied was contracted for Chinook, coho, and sockeye, and expanded for pink and chum salmon (Figure 59).

**Factors influencing observed trends:** Lower abundances of juvenile salmon during 2017 was likely due to a combination of lower odd-brood year pink salmon production and due to the continuation of warm waters and low and patchy ocean productivity.

**Implications:** Recent decreases in the abundance of juvenile salmon in our survey area during summer implies a decline in conditions for growth and survival of salmon from southeast Alaska, British Columbia and the Pacific Northwest lakes and rivers and/or a change in the distribution of juvenile salmon into our survey area during July. The size of juvenile salmon in the surveys were also observed as smaller than usual. Juvenile indices may be an early indication for the numbers of returning adults to the region of origin.

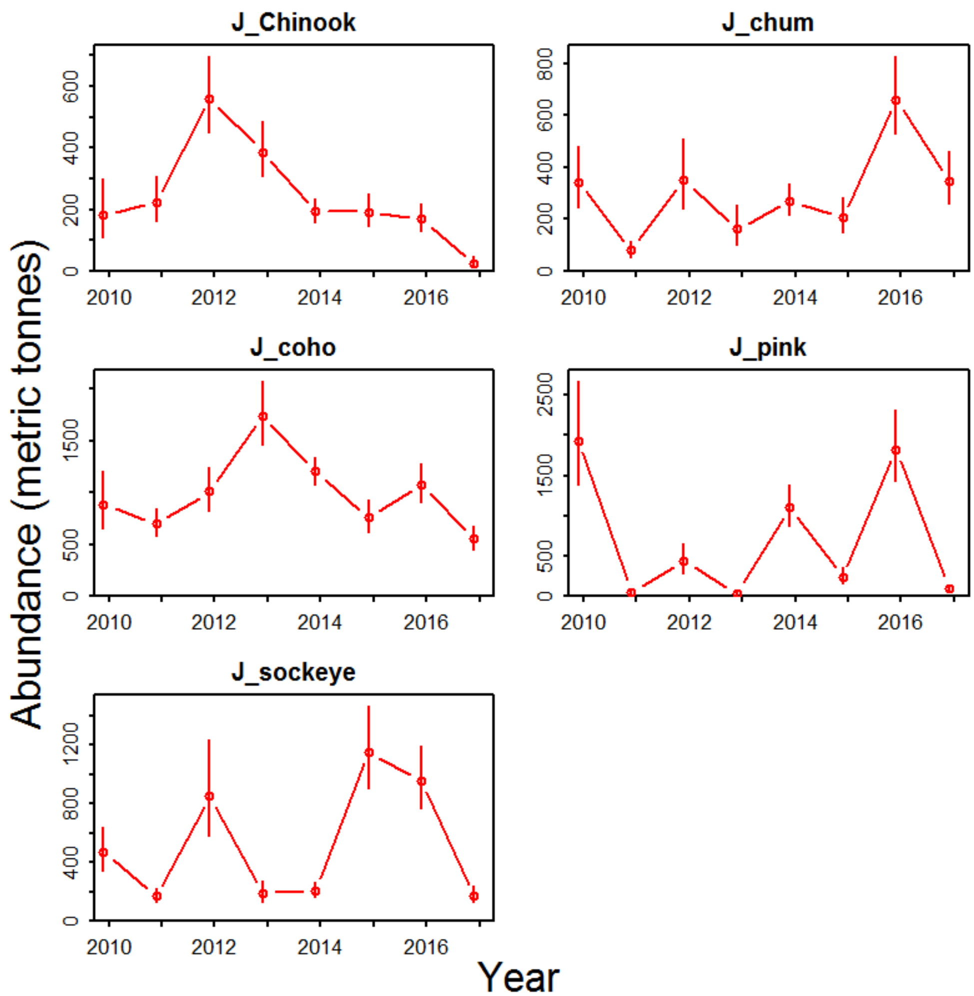


Figure 59: Index of abundance (metric tonnes) plus/minus 1 standard deviation for Pacific salmon in the eastern Gulf of Alaska during late summer, 2010–2017.


Figure 60: Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution plus/minus 1 standard deviation in UTM (km) for juvenile Pacific salmon on the eastern Gulf of Alaska during late summer, 2010–2017.

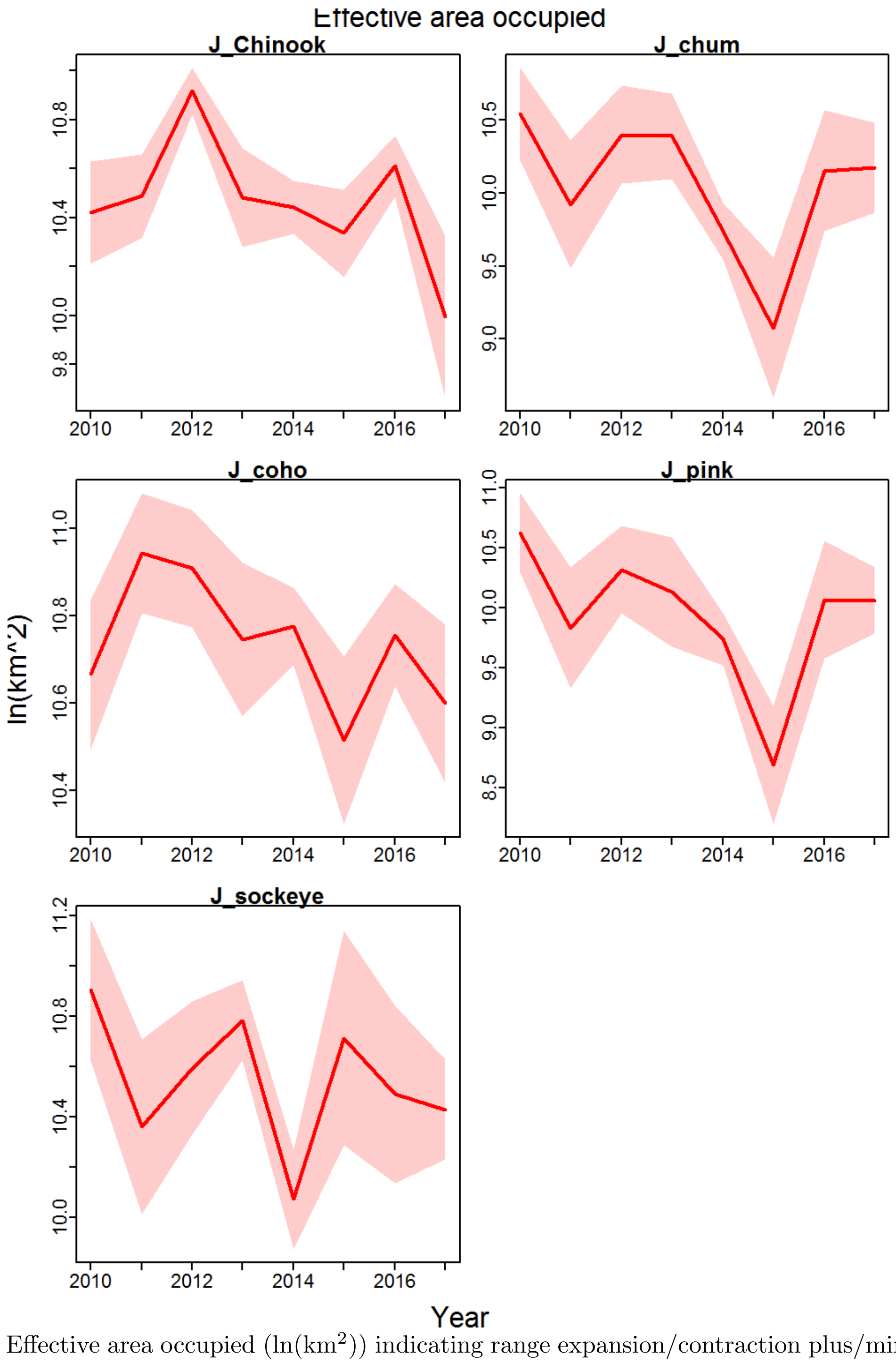


Figure 61: Effective area occupied ($\ln(\text{km}^2)$) indicating range expansion/contraction plus/minus 1 standard deviation for juvenile Pacific salmon on the eastern Gulf of Alaska during summer, 2010–2017.

### Spatial and Temporal Trends in the Abundance and Distribution of Squid in the Eastern Gulf of Alaska during Summer 2011–2017

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**Last updated: October 2017**

**Description of indicator:** Squid were sampled using a trawl net towed in the upper 20 m of the eastern Gulf of Alaska (EGOA) during the Alaska Fisheries Science Center's Gulf of Alaska Assessment Surveys during summer, 2011–2017. Stations were approximately 10 nautical miles apart and a trawl was towed for approximately 30 minutes at each station. A CanTrawl was used from 2011–2016 and a Nordic trawl in 2017. The area swept by the trawl was estimated from horizontal net opening and distance towed. Squid catch was estimated in kilograms by year and station. Squid weight at each station was estimated by multiplying the grand mean weight in a given year by the number captured at a station.

Abundance and distribution (center of gravity and area occupied) were estimated using the VAST package for multispecies version 1.1.0 (Thorson et al., 2015; Thorson and Kristensen, 2016; Thorson et al., 2016*a*,*b*) in RStudio version 1.0.136 and R software version 3.3.0 (R Core Team 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015, 2016*a*) to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 100 knots. Parameter estimates were within the upper and lower bounds and final gradients were less than 0.0005.

**Status and trends:** Squid were most abundant in the EGOA during 2014 (Figure 62). Temporal trends in squid abundances indicate that squid has steadily increased since 2011 with the exception of a large spike in abundance in 2014 and slight decline in 2017. Squid were distributed across the shelf but farther offshore during 2011–2015 and nearshore during 2016 and 2017 (Figure 63). Squid were distributed farther northwest during 2017 relative to 2016. During the 2014–2017 warm years, squid were generally distributed farther north relative to the prior cold years 2011–2013 (Figure 64). The area that squid occupied in the survey area declined over the 2011–2017 year period (Figure 65).

**Factors influencing observed trends:** Squid abundance was lowest during 2011 and may be correlated with poor primary production. Abundances of squid in the EGOA during 2014 may have been in response to unprecedented warming in the eastern Pacific Ocean and influx of the water mass referred to as the "Warm Blob" (Bond et al., 2015).

**Implications:** Predators not common to the eastern Gulf of Alaska were present in the EGOA during 2014, and 2015, presumably in response to the "Warm Blob" (Bond et al. 2015). We speculate that forage such as squid may have attracted predators to the EGOA shelf. Squid is a high energy prey item for marine species. The high abundances of squid in 2014 may had increased the quality and quantity of prey for predators and subsequent survival for species such as salmon. Good feeding conditions during the early marine and pre- and post-winter life stages of juvenile salmon is thought to improve body condition and survival of salmon to adulthood. The high abundances of squid in 2014 corresponded with the 2014 juvenile year for salmon that had higher

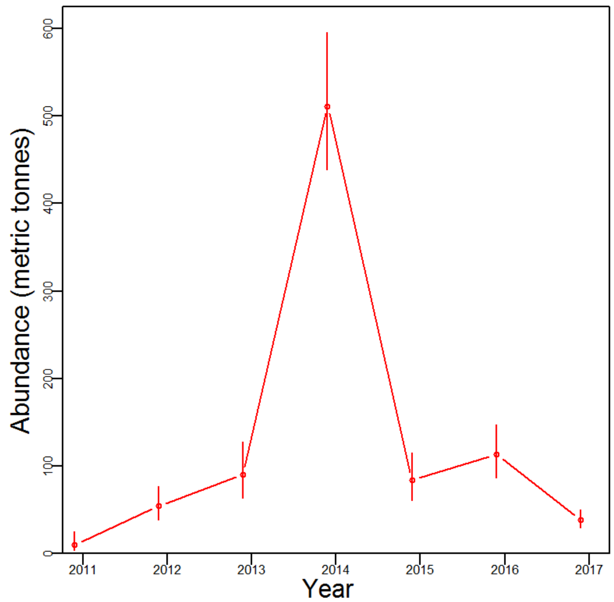


Figure 62: Index of abundance (metric tonnes) plus/minus 1 standard deviation for squid in the eastern Gulf of Alaska during late summer, 2011–2017.

returns of chum salmon (that typically mature after 3 winters in the ocean) to Alaska in 2017 and high returns of pink salmon (that mature after one winter in the ocean) to Alaska in 2015.

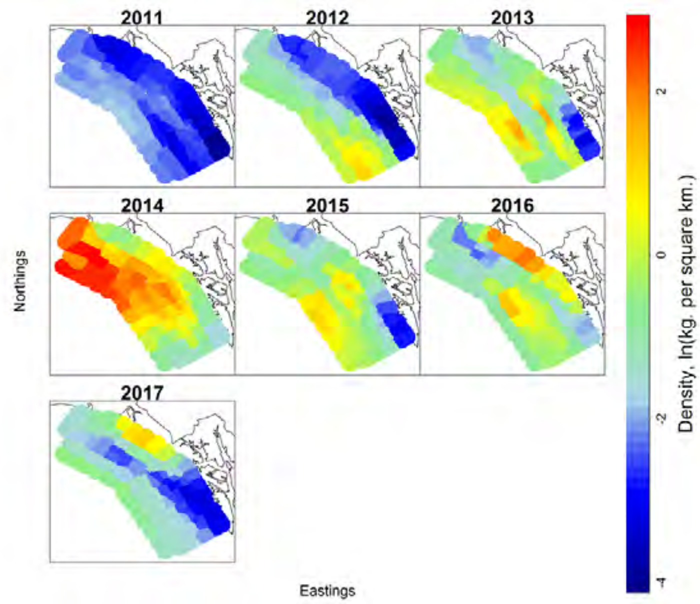


Figure 63: Predicted field densities of squid in the eastern Gulf of Alaska during summer, 2011–2017.

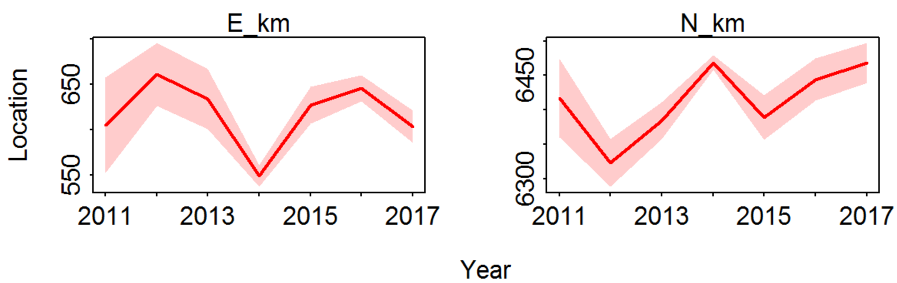


Figure 64: Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution plus/minus 1 standard deviation in UTM (km) for squid in the eastern Gulf of Alaska during summer, 2011–2017.

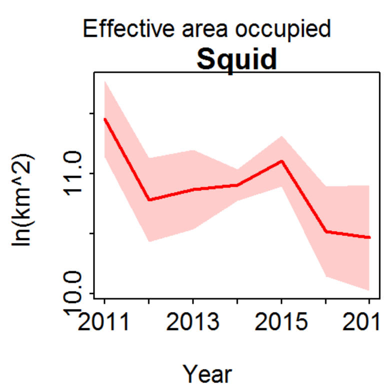


Figure 65: Effective area occupied ($\ln(km^2)$) indicating range expansion/contraction plus/minus 1 standard deviation for squid on the eastern Gulf of Alaska during summer, 2011–2017.

## Herring

### Southeastern Alaska Herring

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**Last updated: July 2017**

**Description of indicator:** Pacific herring (*Clupea pallasi*) stocks that reside in southeastern Alaskan waters are defined on a spawning area basis. In recent decades there have been about nine spawning areas where spawning events have typically been annual and meaningful in size relative to potential for commercial exploitation. These areas include Sitka Sound, Craig, Seymour Canal, Hoonah Sound Hobart Bay-Port Houghton, Tenakee Inlet, Ernest Sound, West Behm Canal, and Kah Shakes-Cat Island (Figure 66). Stock assessments have been conducted at these areas for most years since at least the 1980s by the Alaska Department of Fish and Game, primarily through modeling that relies on indices of egg deposition, age, and size (Hebert, 2017). Although spawning at these areas accounts for a large proportion of the spawning biomass in southeastern Alaska in any given year, other areas with more limited spawning also exist throughout southeastern Alaska. However, little or no stock assessment activity occurs at these minor locations other than occasional and opportunistic aerial surveys to document the miles of spawn along shoreline. The herring that spawn in all areas of Southeast Alaska are believed to be affected by the physical and chemical characteristics of Gulf of Alaska waters, though the spawning areas directly exposed to the open coast (Sitka Sound, Craig, Kah Shakes-Cat Island) may be affected the greatest or the most immediately.

**Status and trends:** Since peaking around the early 2010s, several stocks have decreased substantially. The current biomass level for Southeast Alaskan herring in aggregate is below the mean level over the base period 2009–2016 (Figure 67). This also holds true for every individual stock in the region. Biomass levels prior to the base period were also below the mean level of the base period, for both combined biomass and for most years of individual stocks. Biomass levels, both current and historical, are low relative to the base period because the base period partially coincides with the most productive period for herring in Southeast Alaska that has been documented since at least 1980. Although the two largest and most consistent stocks (Sitka Sound and Craig), have declined substantially from their peaks around 2011, they continue to be at levels above the thresholds necessary to allow commercial fisheries. Other, smaller stocks in the region have declined to much lower levels over the past few years and in some cases to small fractions of their peaks a few years ago (e.g., Hoonah Sound, Seymour Canal, Ernest Sound). Age-structured stock assessment modeling indicates that the decline can be attributed at least in part to lower survival rates over the past few years.

**Factors influencing observed trends:** The underlying cause for the recent decline in herring survival and biomass in the region remains unknown. Multiple plausible factors may be contributing, including increasing populations of predatory marine mammals, such as humpback whales and Stellar sea lions (Sigler et al., 2009; Muto et al.; Fritz et al., 2016), high levels of predatory fish such as salmon, or the recent shift to warmer sea surface temperatures as reflected in the PDO, which could affect herring prey or metabolism.

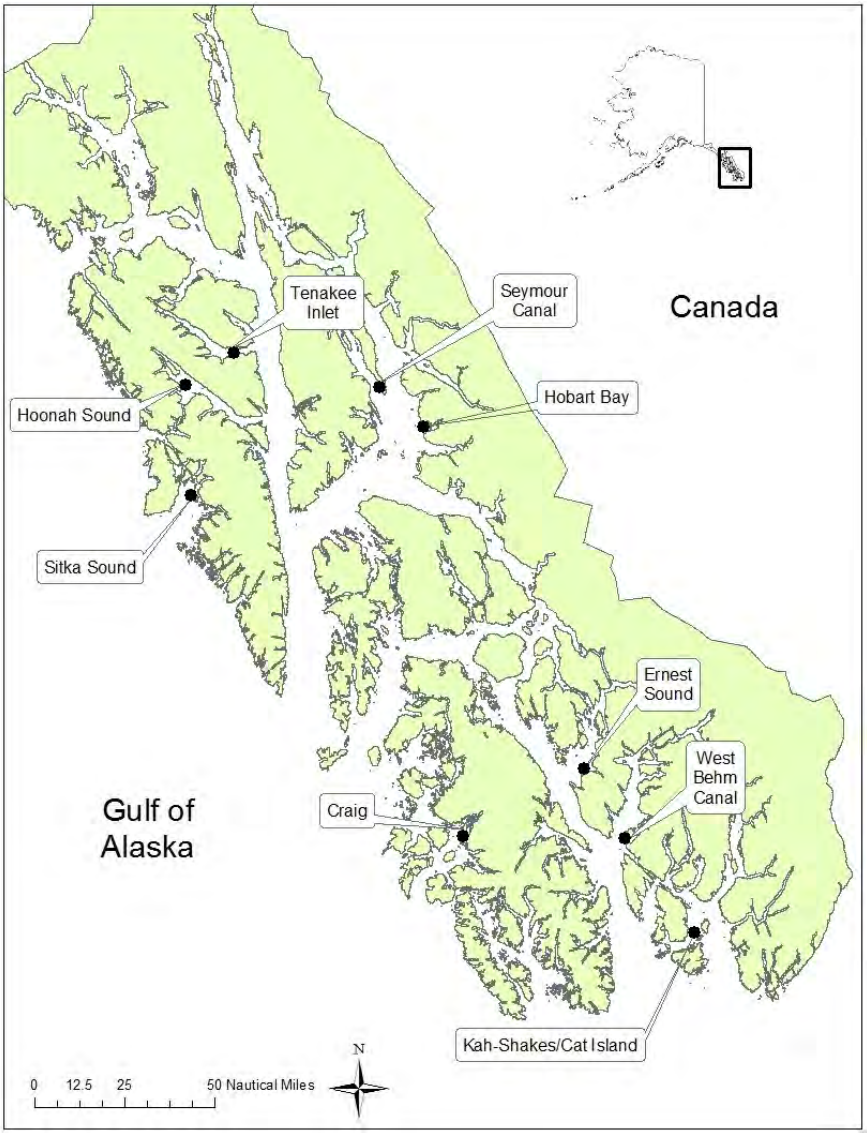


Figure 66: Location of nine important Pacific herring spawning locations in Southeast Alaska..

**Implications:** Although it is possible that lower abundance of herring in the region may have short-term deleterious effects on predators that rely on herring, there is not enough information about populations of other forage species to understand the broader net impact on predators. 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 implications to the ecosystem.

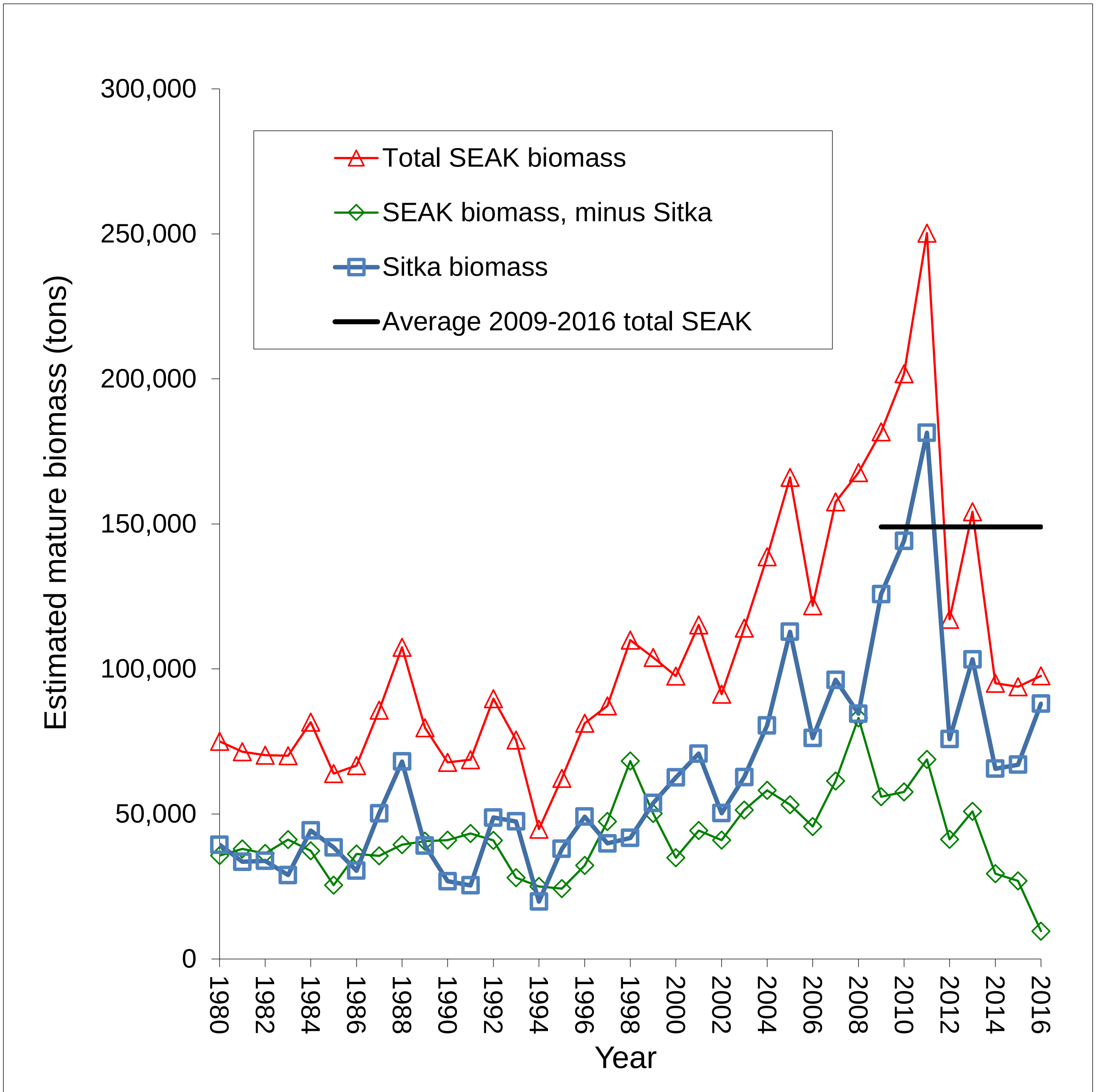


Figure 67: Estimated combined annual mature herring biomass (prefishery, including and excluding Sitka) at nine important southeastern Alaska spawning areas, 1980–2016. Black line indicates average of combined Southeast Alaska herring biomass during base period of 2009–2016.

## Salmon

### Salmon Trends in the Southeast Coastal Monitoring (SECM) Survey

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**Last updated: August 2017**

**Description of indicator:** The Southeast Coastal Monitoring (SECM) program has collected fish, zooplankton, and oceanographic samples in southeast Alaska since 1997 (Fergusson et al., 2013; Orsi et al., 2014, 2015). Sampling has been focused most consistently in Icy Strait, the primary northern migratory pathway to the Gulf of Alaska for juvenile salmon originating from over 2000 southeast Alaska streams and rivers. Research objectives of the SECM program are to provide insight into the production dynamics and early ocean ecology of Southeast Alaska salmon.

Surface trawls (0–20m) are used to sample epipelagic fish species, including all five commercial species of Pacific salmon (*Oncorhynchus* sp.) in southeast Alaska. Juvenile pink salmon (*O. gorbuscha*) are, on average, the most abundant species in the epipelagic habitat in SECM surveys. In addition to juvenile salmon, SECM surveys catch a suite of non-salmonid fish species, including occasional large numbers of walleye pollock (*Gadus chalcogrammus*), capelin (*Mallotus villosus*), and Pacific herring (*Clupea pallasii*). We provide summaries of the annual catch rates for the five salmon species (pink; coho *O. kisutch*; sockeye, *O. nerka*; chum, *O. keta*; and Chinook, *O. tshawytscha*).

**Status and trends:** In 2017, juvenile salmon catch rates were among the lowest of the time series for all five salmon species (Figure 68). Meanwhile, adult chum salmon catch rates continued an upward trend, though these rates remain nearly an order of magnitude lower than those of adult pink salmon.

**Factors influencing observed trends:** Ocean conditions in 2017 were preceded by several anomalously warm years. Warm ocean conditions are likely to have influenced recruitment patterns through multiple years of altered community structure and stock dynamics. We continue to seek relationships between observed trends and environmental covariates (e.g., sea surface temperature).

**Implications:** Understanding recruitment processes of fish stocks is an important aspect of managing fish stocks, particularly during periods of substantial climate change. Juvenile abundance and oceanographic data collected during SECM have provided reliable forecasts of pink salmon returns to Southeast Alaska (Orsi et al., 2015) and are used for pre-season fisheries management decisions in the purse seine and drift gillnet fisheries of Southeast Alaska (Wertheimer et al., 2015). By extending the application of SECM fish catches beyond pink salmon, we are poised to better resolve the relationships between other salmon species and ecosystem indicators that help to describe their production dynamics. Furthermore, as SECM surveys continue annually, they fill a valuable gap in data that occurs during off-years for the Gulf of Alaska Ecosystem Surveys.

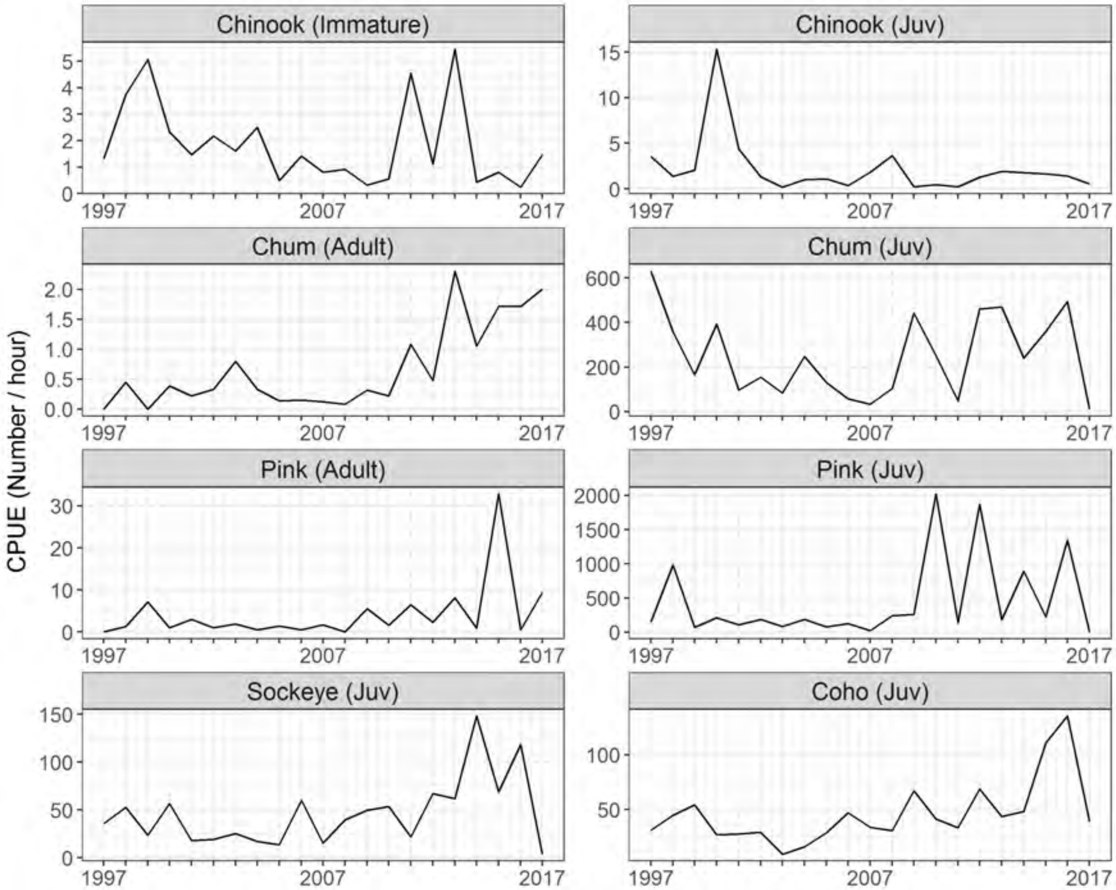


Figure 68: Time series of juvenile, immature (Chinook only), and adult salmon catch rates (number of fish per hour) during SECM surveys from 1997–2017.

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

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**Last updated: September 2017**

**Description of indicator:** The 1980–2016 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. The index is presented by fry outmigration year. 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 makes it an excellent choice for model input relating to nearshore and gulf-wide productivity.

**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 11.2% from ocean entry years 1980–2016 (Figure 69). Marine survival for the 2016 smolt year was 10.6% and overall survival averaged 16.9% over the last 5 years and 15.4% over the last 10 years.

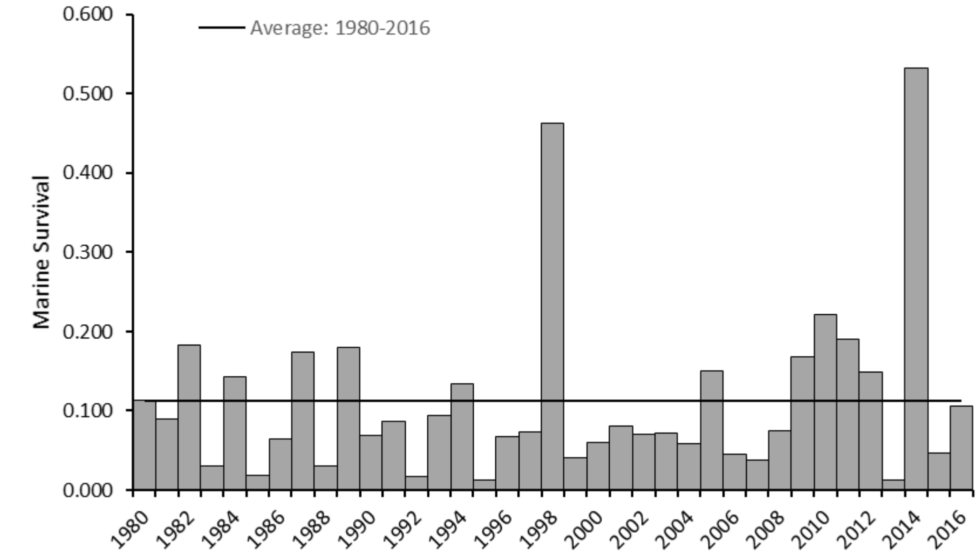


Figure 69: Auke Creek pink salmon marine survival indices showing total marine survival presented by fry outmigration year.

**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 due to their size (Parker 1971). During juvenile development, the local conditions of stream discharge and temperature are strong determinants of egg and fry survival. In addition, many of these influencing factors have been shown to have a genetic component that can strongly influence survival (Geiger et al. 1997, McGregor et al. 1998, Kovach et al. 2013a).

**Implications:** The low survival indices of the 2015 and 2016 outmigration year classes may indicate poor habitat quality, ocean conditions, and/or prey resources for predatory groundfish. 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 2017**

**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 Laboratories 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 5.1% to 47.8%, with an average survival of 23.7% from smolt years 1980–2015 (Figure 70; top panel). Marine survival for 2015 was the lowest on record at 5.1% and overall survival averaged 16.2% over the last 5 years and 17.9% over the last 10 years. The survival index for ocean age-1 coho varies from 3.9% to 36.6% from smolt years 1980–2015 (Figure 70; middle panel) and for ocean age-0 coho varies from 1.1% to 11.2% from smolt years 1980–2016, with 2015 being the lowest on record (Figure 70; bottom panel). Return data for 2017 returns are included, despite the fact that the run is not completely finished. These data are included because the marine survival for ocean age-1 coho at Auke Creek will likely again be near the lowest on record at ∼7.0% (marine survival was at 6.7% as of 26 September 2017, 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

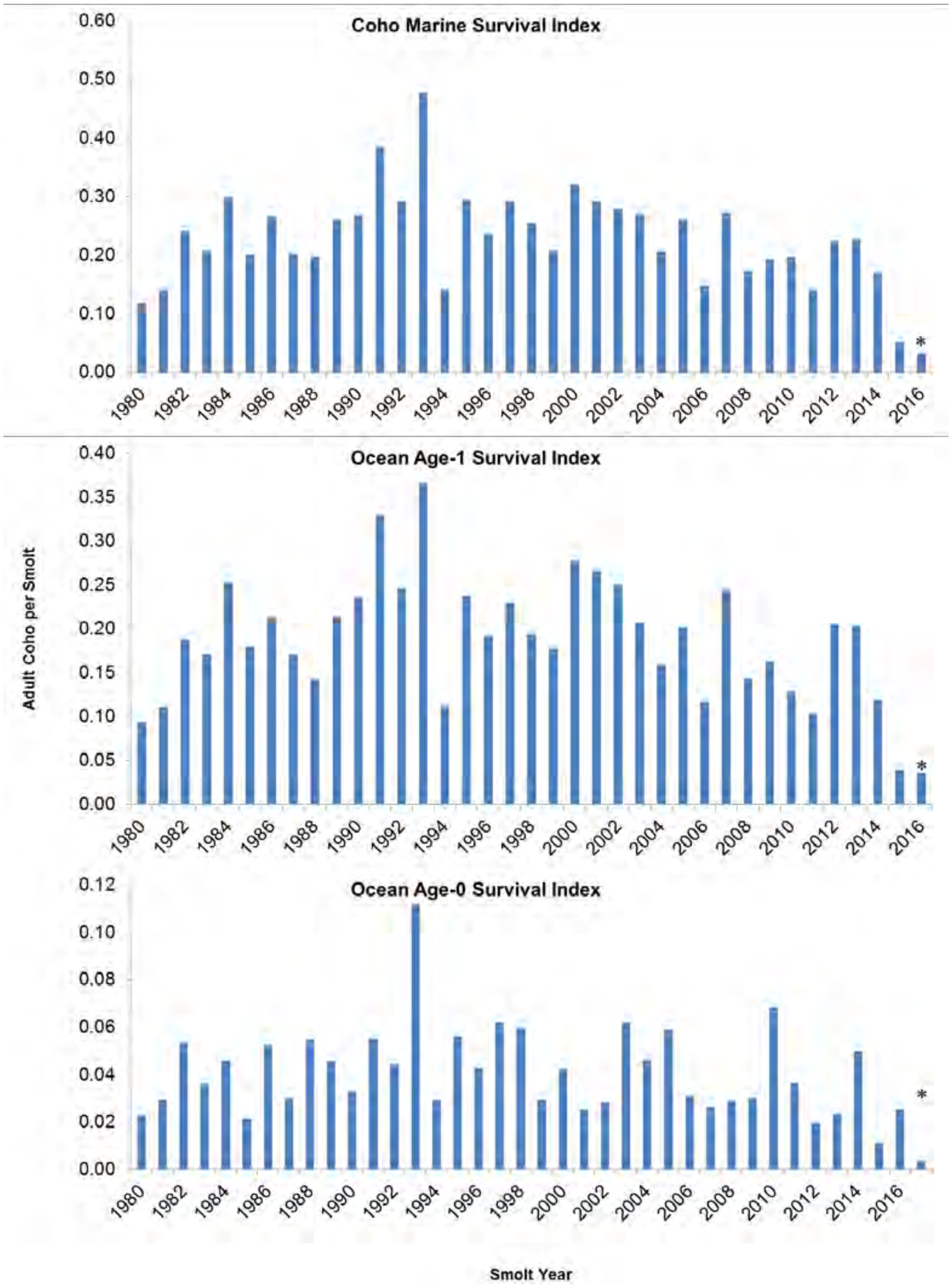


Figure 70: Auke Creek coho salmon marine survival indices showing total marine survival (ocean age-0 and age-1 harvest plus escapement; top panel), percentage of ocean age-1 coho per smolt (harvest plus escapement; middle panel), and percentage of ocean age-0 coho per smolt (escapement only; bottom panel) by smolt year. Return year 2017 data are denoted with an asterisk as these may change slightly by the end of the coho return.

(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 preliminary 2017 survival data indicate that recent conditions were not favorable for the Auke Creek coho. The trends in coho salmon marine survival 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.

## Groundfish

### Gulf of Alaska Groundfish Condition

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**Last updated: October 2015**

**Description of indicator:** Length-weight residuals are an indicator of somatic growth (Brodeur et al., 2004) and, therefore, a measure of fish condition. Fish condition is an indicator of how heavy a fish is per unit body length, and may be an indicator of ecosystem productivity. Positive length-weight residuals indicate fish are in better condition (i.e., heavier per unit length); whereas, negative residuals indicate fish are in poorer condition (i.e., lighter per unit length). Fish condition may affect fish growth and subsequent survival (Paul et al., 1997; Boldt and Haldorson, 2004). The AFSC Gulf of Alaska bottom trawl survey data were utilized to acquire lengths and weights of individual fish for walleye pollock, Pacific cod, arrowtooth flounder, southern rock sole, dusky rockfish, northern rockfish, and Pacific ocean perch. Only standard survey stations were included in analyses. Data were combined by INPFC area; Shumagin, Chirikof, Kodiak, Yakutat and Southeastern. Length-weight relationships for each of the seven species were estimated with a linear regression of log-transformed values over all years where data were available (during 1984–2017). Additionally, length-weight relationships for age 1+ walleye pollock (length from 100–250 mm) were also calculated independent from the adult life history stage. Predicted log-transformed weights were calculated and subtracted from measured log-transformed weights to calculate residuals for each fish. Length-weight residuals were averaged for the entire GOA and for the 5 INPFC areas sampled in the standard summer survey. Temporal and spatial patterns in residuals were examined.

**Status and trends:** Length-weight residuals varied over time for all species with a few notable patterns (Figure 71). Residuals for most species where there were data were positive in the first three years of the survey (1985–1990). The residuals have been mixed for all species since then, generally smaller and varying from year to year. Age-1 pollock have generally been at or near the mean condition since the 1990 survey (although 2017 was a negative condition year). In 2017 condition was below average for all species except Pacific cod. Fish condition for northern rockfish and arrowtooth flounder was the lowest on record and Pacific Ocean perch and southern rock sole were the second lowest on record. In general, for all species except the gadids there has been a general decrease in body condition since 1990.

Spatial trends in residuals were also apparent for some species (Figure 72). Most species were generally in better condition in the Kodiak area, especially southern rock sole. The southeastern area was an area where fish condition was generally worse than other areas of the GOA, except for northern rockfish. For Pacific Ocean perch, the Kodiak and Shumagin areas generally had positive length-weight residuals. Arrowtooth flounder and age-1 pollock are the only species with consistently higher residuals in the Yakutat area.

**Factors influencing observed trends:** One potential factor causing the observed temporal variability in length-weight residuals may be temperature and local production. The lack of consistent trends in any of the species and any of the areas suggests that local conditions that vary from year to year might be driving condition trends in the Gulf of Alaska.

Other factors that could affect length-weight residuals include survey sampling timing and fish migration. The date of the first length-weight data collected is generally in the beginning of June and the bottom trawl survey is conducted sequentially throughout the summer months from west to east. Therefore, it is impossible to separate the in-season time trend from the spatial trend in these data.

**Implications:** A fish's condition may have implications for its survival. For example, in Prince William Sound, the condition of herring prior to the winter may in part determine their survival (Paul and Paul 1999). The condition of Gulf of Alaska groundfish may partially contribute to their survival and recruitment. In the future, as years are added to the time series, the relationship between length-weight residuals and subsequent survival can be examined further. It is likely, however, that the relationship is more complex than a simple correlation. Also important to consider is that condition of all sizes of fish were examined and used to predict survival. Perhaps, it would be better to examine the condition of juvenile fish, not yet recruited to the fishery, or the condition of adult fish and correlations with survival. This work has not yet been done for the 2017 bottom trawl survey data, but we are preparing a manuscript describing the juvenile-adult condition correlation and further splitting of juvenile and adult fishes and anticipate including it in the 2018 ecosystem contributions.

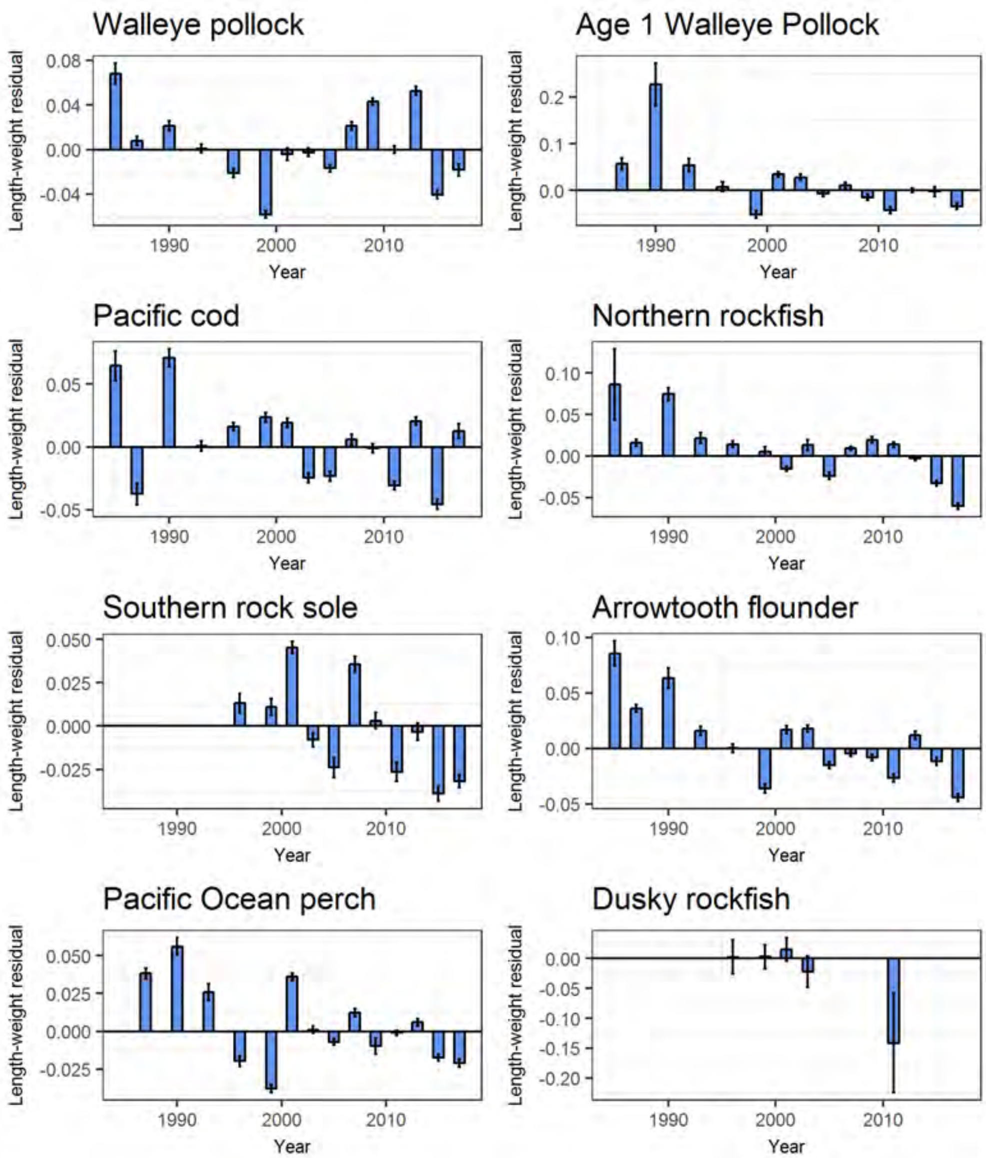


Figure 71: Length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985–2017.

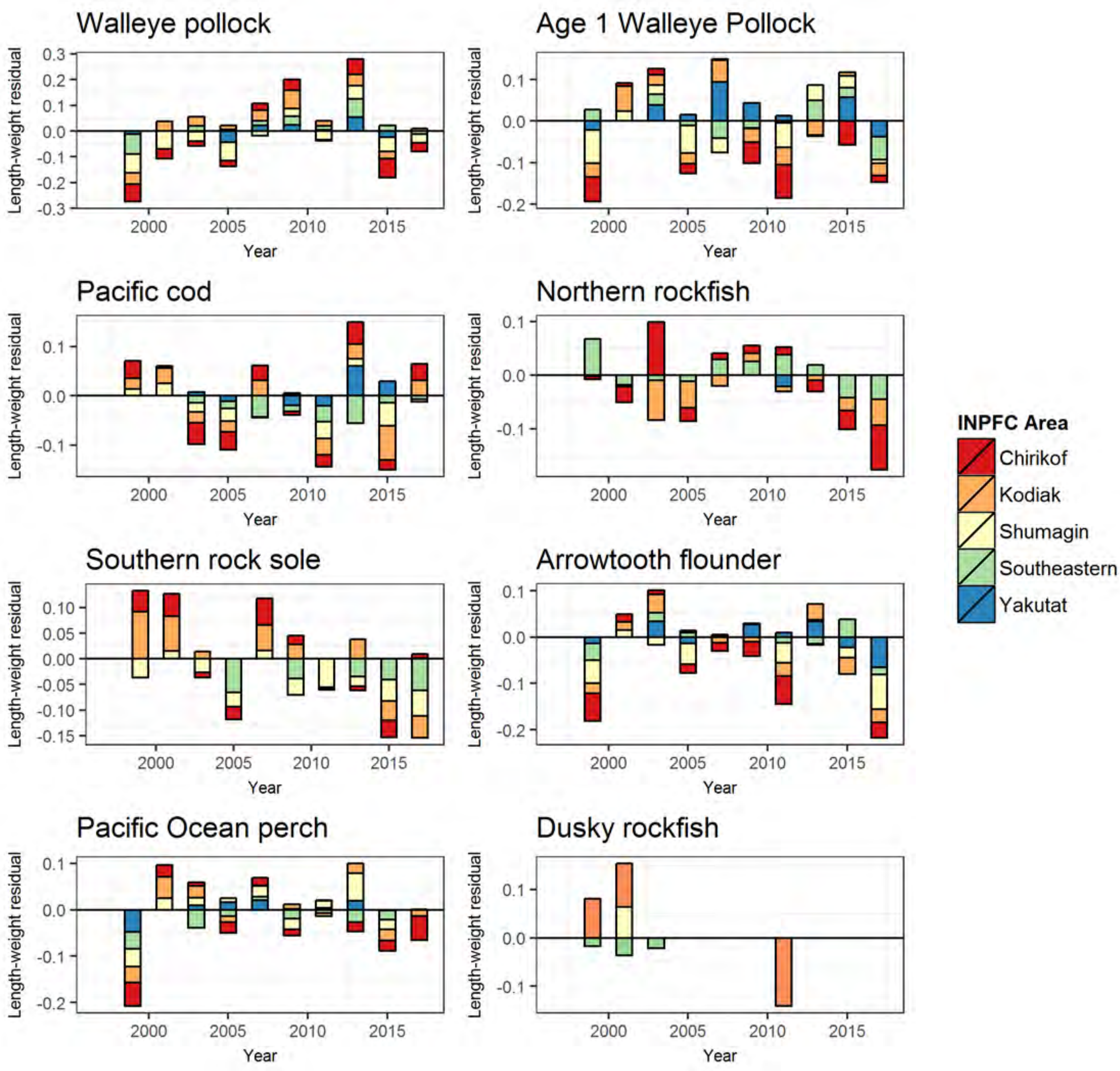


Figure 72: Length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985–2017, by INPFC area.

### ADF&G Gulf of Alaska Trawl Survey

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**Last updated: August 2017**

**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 *In press*). Parts of these areas have been surveyed annually since 1984, but the most consistent time series begins in 1988. In 2016, a total of 377 stations was sampled from June 9 through September 2. 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) are generally representative of the survey results across the region (Figure 73). The trawl survey uses a 400-mesh eastern otter trawl constructed with stretch mesh ranging from 10.2 cm in the body, decreasing to 3.2 cm in the codend. Constructed ideally to sample crab, it can also reliably sample a range of fish species and sizes, ranging from 15 cm to adult sizes, but occasionally capturing fish as small as 7 cm for some species. The survey catches (mt/km) from Kiliuda and Ugak Bays and Barnabas Gully were summarized by year for selected species groups (Figure 74). Using a method described by (Link et al., 2002), standardized anomalies, a measure of departure from the mean catch (kg) per distance towed (km), were also calculated for selected species; arrowtooth flounder *Atheresthes stomias*, flathead sole *Hippoglosoides elassodon*, Tanner crab *Chionoecetes bairdi*, Pacific cod *Gadus macrocephalus*, skates, walleye pollock *G. chalcogrammus* and Pacific halibut *Hippoglossus stenolepis* (Figure 75). Temperature anomalies were calculated using average bottom temperatures recorded for each haul from 1990 to present (Figure 76).

**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 2016 from the years of record high catches occurring from 2002 to 2005 (Figure 74).

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 2016 with Pacific cod making up 12% of catch and walleye pollock 87%. In 2016, overall gadid catches have slightly increased in the inshore areas of Kiliuda and Ugak Bays, but have decreased in the offshore area of Barnabus Gully (Figure 74).

Below average anomaly values for arrowtooth flounder and flathead sole were recorded again in 2016 for both inshore and offshore areas; along with walleye pollock and Pacific cod (Figure 75). Pacific halibut and skates were above in both areas, while Tanner crab was above average only in the offshore area.

Temperature anomalies for both inshore and offshore stations show significant increases in the last

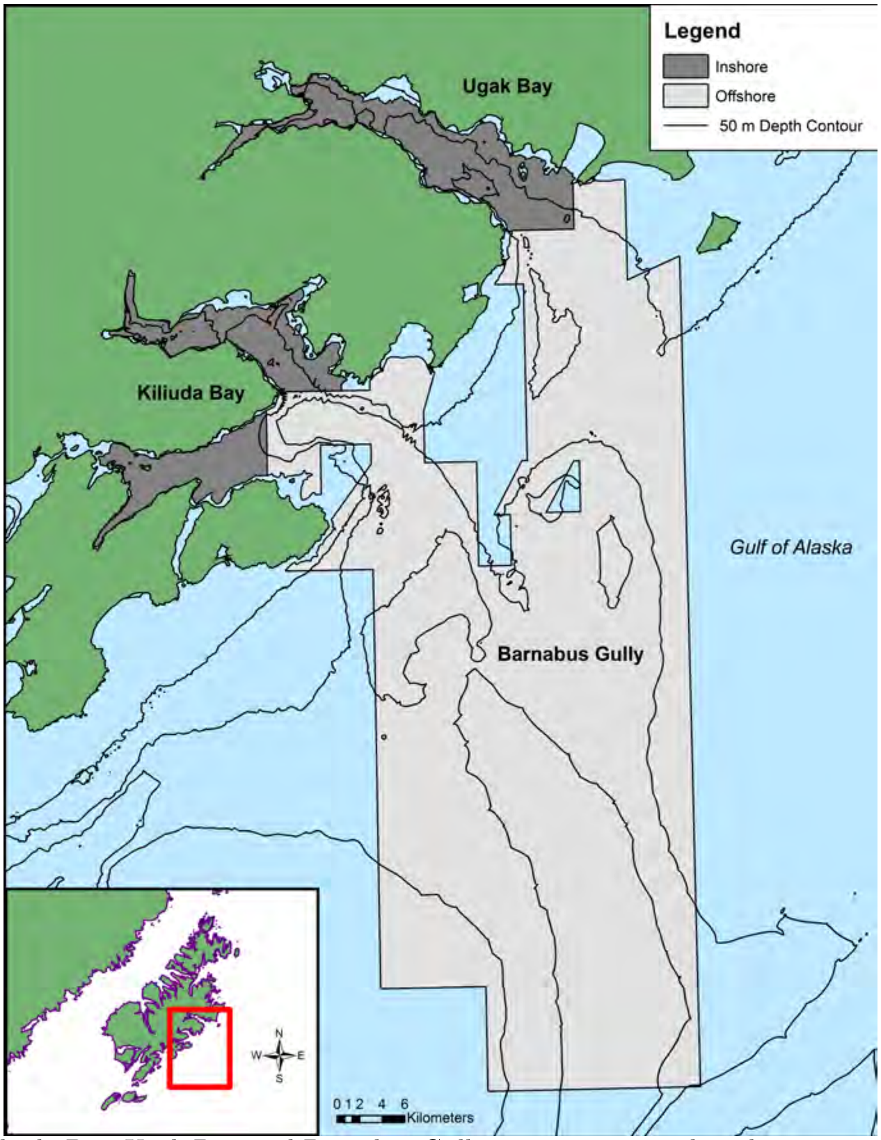


Figure 73: Kiliuda Bay, Ugak Bay, and Barnabus Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

3 years, from a previous period of below average temperatures (2011–2013) to highest average temperatures ever recorded in 2016 (Figure 76). The higher than average temperature years frequently occur during moderate and strong El Niño years (`http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml`).

**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 74) 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

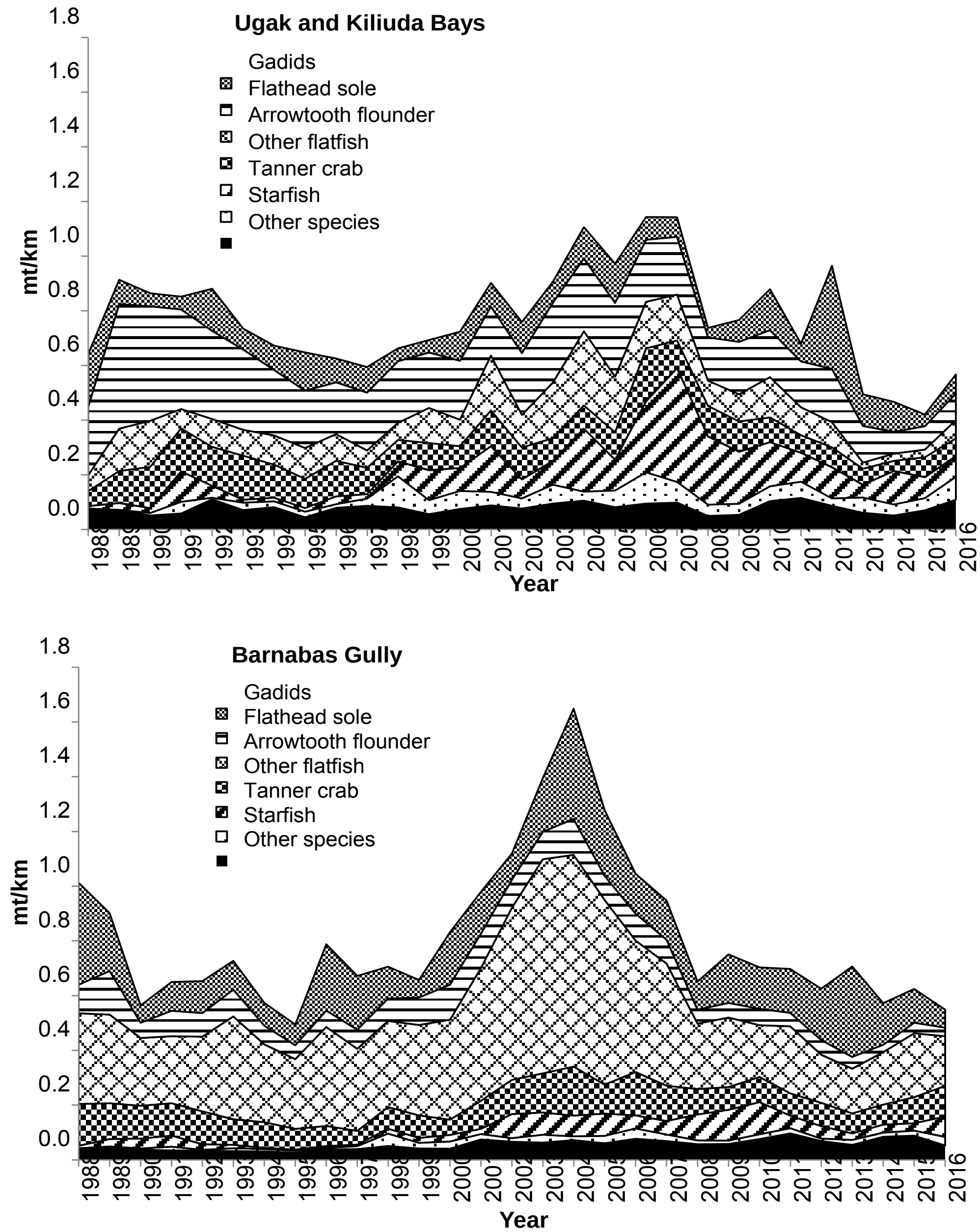


Figure 74: Total catch per km towed (mt/km) of selected species from Barnabus Gully and Kiliuda and Ugak Bay survey areas off the east side of Kodiak Island, 1987–2016

indicate a possible lag in response to changing environmental conditions or some other factors may 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. Monitoring these trends is an important process used in establishing harvest levels for state water fisheries. These survey data are used

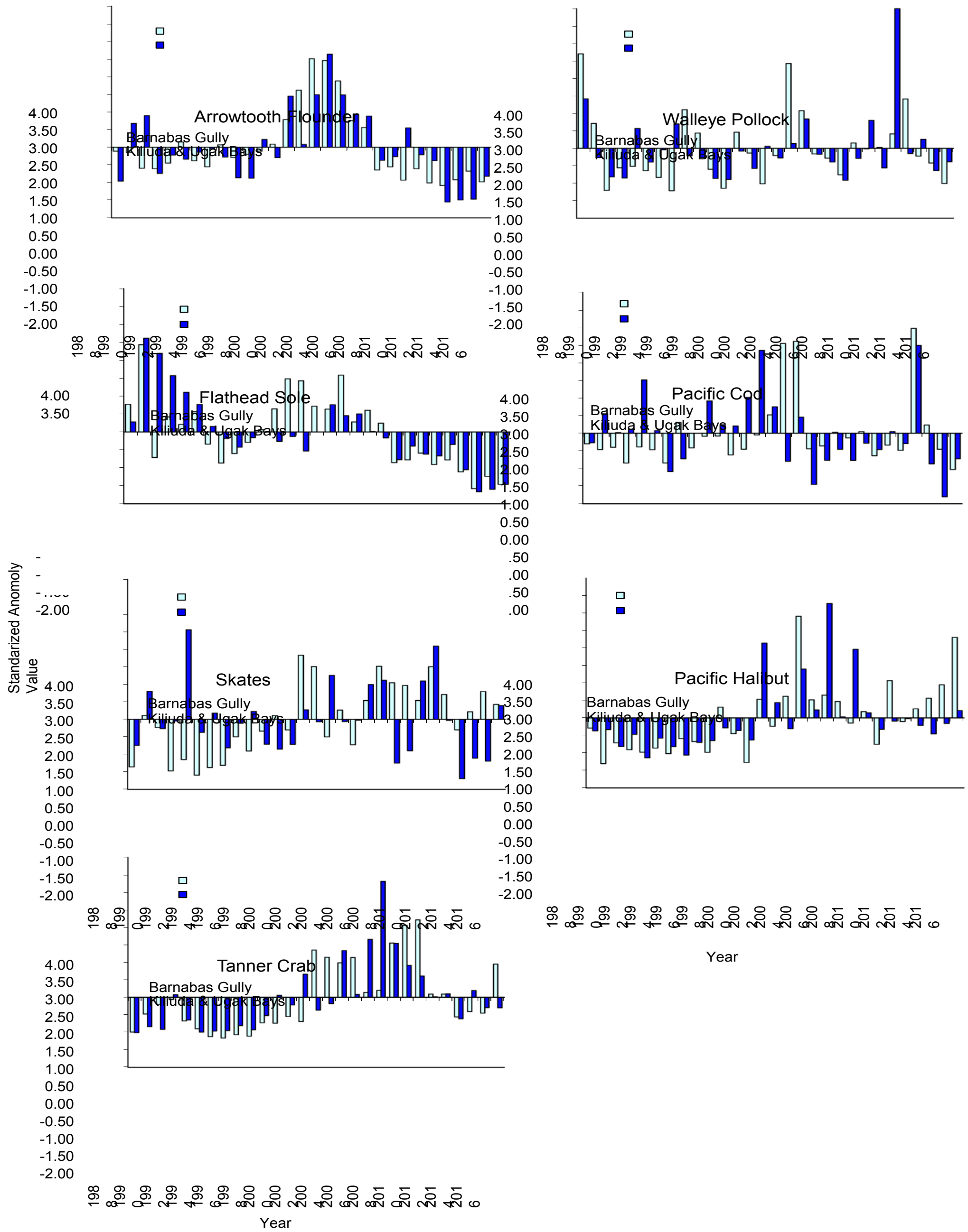


Figure 75: A comparison of standardized anomaly values, based on catch (kg) per distance towed (km) for selected species caught from 1988 to 2016 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

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.

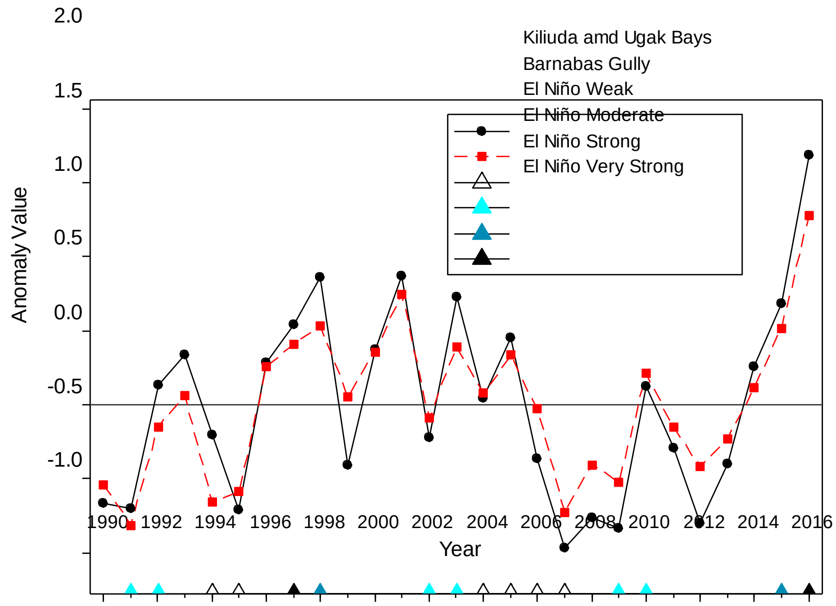


Figure 76: Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2016, with corresponding El Niño years represented.

### Recruitment Predictions for Sablefish in Southeast Alaska

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**Last updated: August 2017**

**Description of indicator:** Biophysical indices from surveys in 2016 and salmon returns in 2017 were used to predict the recruitment of sablefish to age-2 in 2017 and 2018 (Yasumiishi et al., 2015). Biophysical indices were collected during the southeast coastal monitoring (SECM) survey. The SECM survey has an annual survey of oceanography and fish in inside and outside waters of northern southeast Alaska since 1997 (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 at the Alaska Fisheries Science Center in Juneau, Alaska. 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:** We modeled age-2 sablefish recruitment estimates from 2001 to 2016 (Hanselman et al., 2016) as a function of sea temperatures during 1999–2014, chlorophyll *a* during 1999–2014, and adult pink salmon returns in 2000–2015. The model with the lowest Bayesian information criterion (108) described the stock assessment estimates of age-2 sablefish abundance as a function of late August maximum chlorophyll *a* during the age-0 stage, late August maximum sea temperature during the age-0 stage, and pink salmon returns during the age-1 life stage of these sablefish (Figure 77; Table 3). A regression model indicated positive coefficient for the predictor variables chlorophyll a, sea temperature, and pink salmon returns were positively in the sablefish model ($R^2 = 0.767$, Adjusted $R^2 = 0.708$, F-statistic: 13.15 on 3 and 12 DF, p-value: 0.0004).

Based on 2016 environmental data, the high levels of 10.83 chlorophyll a (10.83), warm waters (13.4°C) and good forecast for pink salmon returns (43 million) in 2017, we predict above average abundance of age-2 sablefish (68 million) in 2018 (2016 year class). Based on 2017 environmental data, low chlorophyll a (1.12) in 2015, average sea temperatures (12°C), and low pink salmon returns in 2016 (17,820,985), we predict below average abundance of age-2 sablefish in 2017 for the 2015 year class.

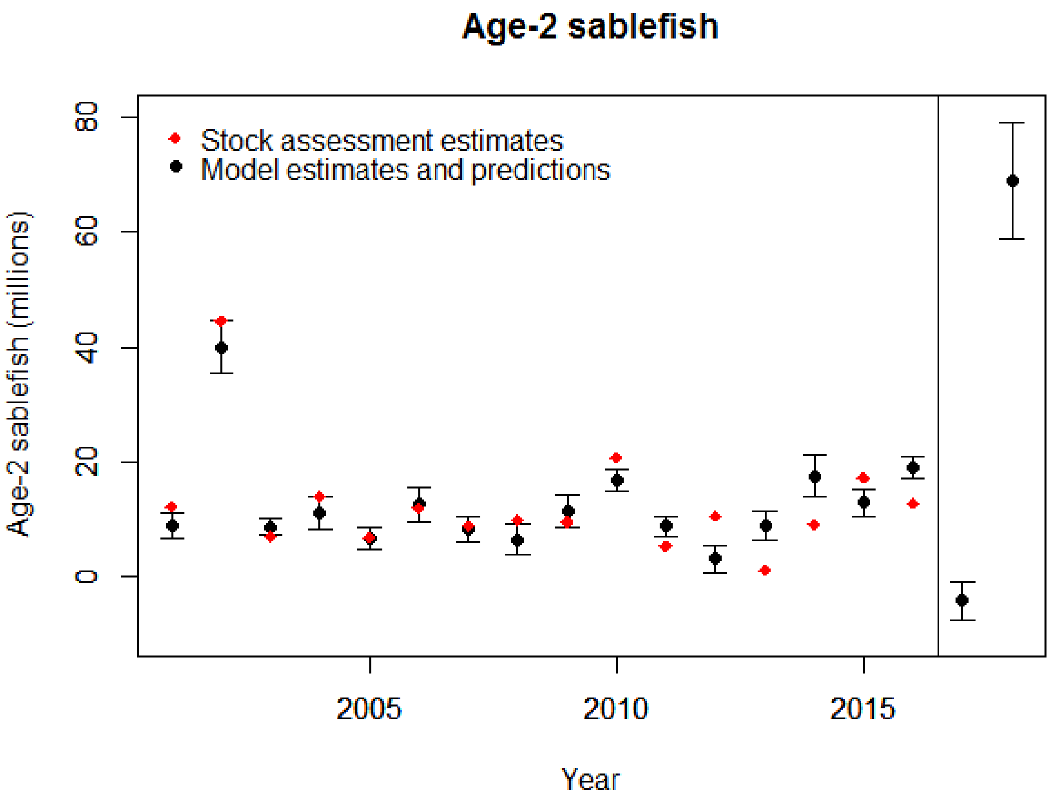


Figure 77: Stock assessment estimates, model estimates, and the 2017 and 2018 prediction for age-2 Alaska sablefish. Stock assessment estimates of age-2 sablefish were modeled as a function of late August chlorophyll *a* levels and late August sea temperatures in the waters of Icy Strait in northern southeast Alaska during the age-0 stage ($t$-2), and the returns of age-1 pink salmon ($t$-1). These predictors are indicators for the conditions experiences by age-0 sablefish. Stock assessment estimates of age-2 sablefish abundances are from Table 3.14 in Hanselman et al. (2016).

Table 3: Nearshore survey data fit to the stock assessment estimates of age-2 sablefish (millions of fish) from Hanselman et al. (2016). Table shows the 2017 model fitted (2001–2016) and forecast (2017, 2018) estimates and standard errors for age-2 sablefish, and the predictor variable from 1999–2015 used to estimate (2001–2016) and predict (2017, 2018) the stock assessment estimates of age-2 sablefish. Values in bold indicate predicted values based on the 2017 Model and environmental indices from 2016 and 2017.

| | Stock Assessment | Model | | | | |
|---|---|---|---|---|---|---|
| | Estimates | Fitted and forecast | | Predictor variables | | |
| Year | Sablefish (t) | Estimates | Standard error | Chlorophyll a (t-2) | Sea temperature (t-2) | Pink salmon (t-1) |
| 2001 | 12.2 | 8.95 | 2.067 | 2.15 | 13.4 | 31,009,547 |
| 2002 | 44.5 | 40 | 4.56 | 6.08 | 12 | 85,654,226 |
| 2003 | 7.1 | 8.79 | 1.55 | 1.63 | 12.8 | 61,929,924 |
| 2004 | 14 | 11.16 | 2.72 | 2.64 | 10.7 | 72,431,623 |
| 2005 | 6.8 | 6.77 | 1.81 | 1.22 | 13.1 | 60,965,661 |
| 2006 | 12 | 12.61 | 2.94 | 1.05 | 14.5 | 79,033,917 |
| 2007 | 8.9 | 8.38 | 2.25 | 2.68 | 12.5 | 21,848,850 |
| 2008 | 9.9 | 6.56 | 2.75 | 2.15 | 10.8 | 62,435,599 |
| 2009 | 9.6 | 11.54 | 2.8 | 2.33 | 14.2 | 25,406,377 |
| 2010 | 20.7 | 16.84 | 1.88 | 3.59 | 11.7 | 50,695,114 |
| 2011 | 5.4 | 8.91 | 1.78 | 2.52 | 12.3 | 35,196,281 |
| 2012 | 10.6 | 3.13 | 2.51 | 0.55 | 12.7 | 73,123,947 |
| 2013 | 1.2 | 8.86 | 2.51 | 3.06 | 11.2 | 32,320,595 |
| 2014 | 9.2 | 17.63 | 3.58 | 1.58 | 12.7 | 119,898,191 |
| 2015 | 17.2 | 12.98 | 2.33 | 1.92 | 14.2 | 50,944,432 |
| 2016 | 12.9 | 19.07 | 1.94 | 3.73 | 12.4 | 46,306,393 |
| 2017 | | **-4.11** | **3.3** | 1.12 | 12 | 17,820,985 |
| 2018 | | **68.72** | **10.08** | 10.83 | 13.4 | 43,000,000 |

**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:** Our 2017 model indicates that we should expect a weak 2015 year class and a strong 2016 year class of sablefish.

### Distribution of Rockfish Species in Gulf of Alaska Trawl Surveys

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**Last updated: October 2017**

**Description of indicator:** In a previous analysis of rockfish from 14 bottom trawl surveys in the Gulf of Alaska and Aleutian Islands (Rooper, 2008), five species assemblages were defined based on similarities in their distributions along geographical position, depth, and temperature gradients. The 180 m and 275 m depth contours were major divisions between assemblages inhabiting the shelf, shelf break, and lower continental slope. Another noticeable division was between species centered in southeastern Alaska and those found in the northern Gulf of Alaska and Aleutian Islands.

In this time series, the mean-weighted distributions of six rockfish (*Sebastes* spp.) species along the three environmental gradients (depth, temperature, and position) were calculated for the Gulf of Alaska. A weighted mean value for each environmental variable was computed for each survey as:

$$Mean = \frac{\sum(f_i x_i)}{\sum f_i},$$

where $f_i$ is the CPUE of each rockfish species group in tow $i$ and $x_i$ is the value of the environmental variable at tow $i$. The weighted standard error ($SE$) was then computed as:

$$SE = \frac{\sqrt{\frac{(\sum(f_i x_i^2)) - ((\sum f_i) * mean^2)}{(\sum f_i) - 1}}}{\sqrt{n}},$$

where $n$ is the number of tows with positive catches. Details of the calculations and analyses can be found in Rooper (2008). These indices monitor the distributions of major components of the rockfish fisheries along these environmental gradients to detect changes or trends in rockfish distribution.

**Status and trends:** In the Gulf of Alaska, there continues to be no significant trends in the distribution of rockfish with depth, temperature and position (Figure 78). This is in contrast to some of the earlier years in which the indicator was calculated. The distribution of rockfish species in the bottom trawl surveys appears to have stabilized for the Gulf of Alaska.

**Factors causing observed trends:** In the Gulf of Alaska, the stability of the distribution indicates that each of the species occupy a fairly specific depth distribution. This is seen in the flat line time series of distribution across depths and the variability in temperature. As temperatures rise and fall around the mean, the depth distribution does not change, indicating that the rockfish are not changing their habitat or distribution to maintain a constant temperature.

**Implications:** The trends in the mean-weighted distributions of rockfish should continue to be monitored, with special attention to potential causes of the shift in depth and position distributions of rockfish, especially as they relate to changing temperatures.

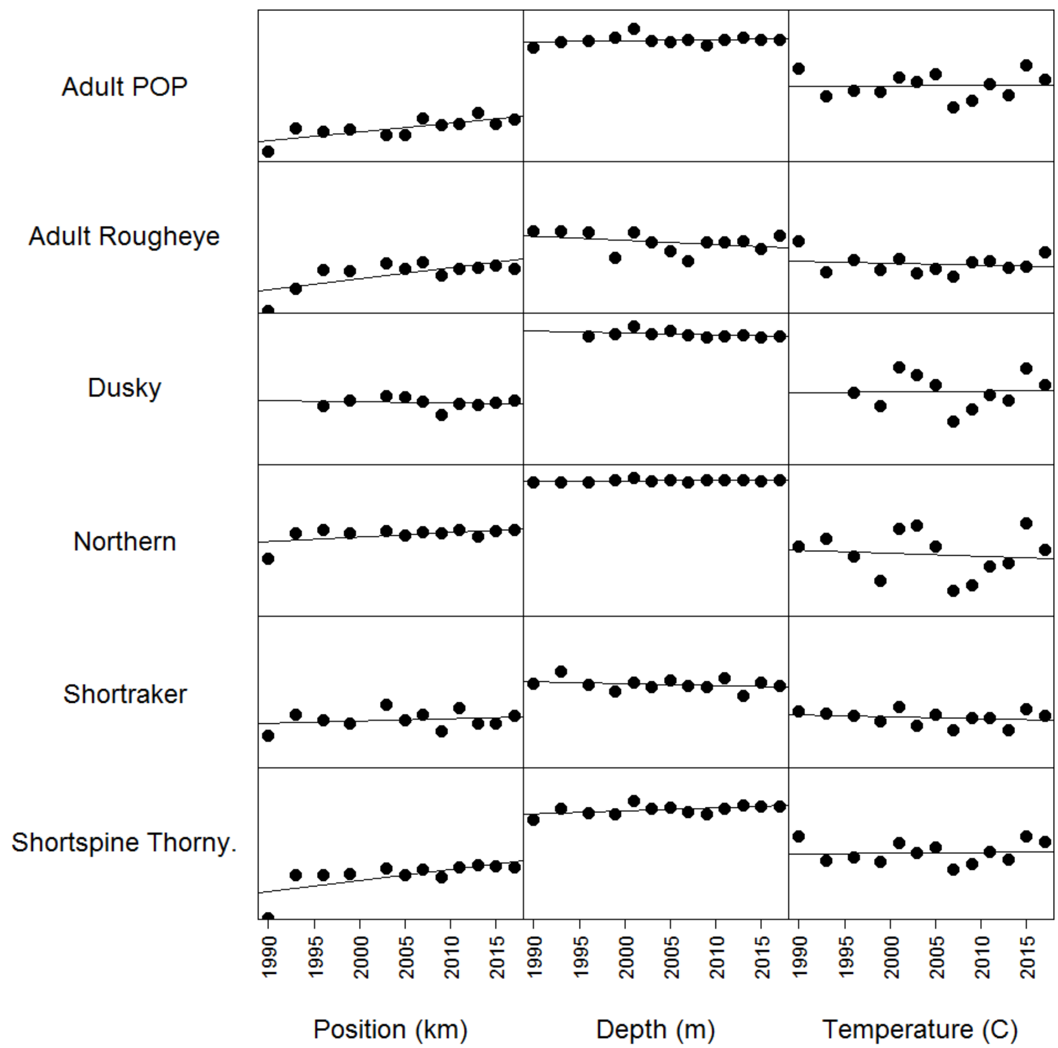


Figure 78: Plots of mean weighted (by catch per unit effort) distributions of six rockfish species-groups along three environmental variables in the Gulf of Alaska. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance from Hinchinbrook Island, Alaska, with positive values west of this central point in the trawl surveys and negative values in southeastward. Asterisk indicates significant trend over the time series.

## Benthic Communities and Non-target Fish Species

### Miscellaneous Species – Gulf of Alaska Bottom Trawl Survey

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**Last updated: October 2017**

**Description of indicator:** RACE bottom trawl surveys in the Gulf of Alaska (GOA) are designed primarily to assess populations of commercially important fish and invertebrates. However many other species are identified, weighed and counted during the course of these surveys, and these data may provide a measure of relative abundance for some of these species. For each species group, the catches for each year were scaled to the largest catch over the time series (which was arbitrarily scaled to a value of 100). The standard error (+/- 1) was weighted proportionally to the CPUE to get a relative standard error. The percentage of positive catches in the survey bottom trawl hauls was also calculated.

**Status and trends:** Echinoderm catches have been highest in the Kodiak and Chirikof regions of the GOA, and they are consistently captured in ∼80% of bottom trawl hauls in all areas (Figure 79. Echinoderms have been declining in both of these areas over the last few surveys. Shrimp CPUE has been increasing in the Kodiak and Chirikof areas over the last few surveys, while remaining fairly constant and low in the other areas. Eelpout CPUE has been variable, with peak abundances occurring in 1993, 2001 and 2009 in the Shumagin area, 2003 and 2013–2015 in the central GOA (Kodiak and Chirikof areas) and peak catches after 1999 in the eastern GOA. Poacher CPUEs peaked in 1993 and 2015 in the Shumagin area. Poachers have been uniformly in low abundance in the Chirikof, Yakutat and Southeastern areas and have been variable, but somewhat higher in the Kodiak areas.

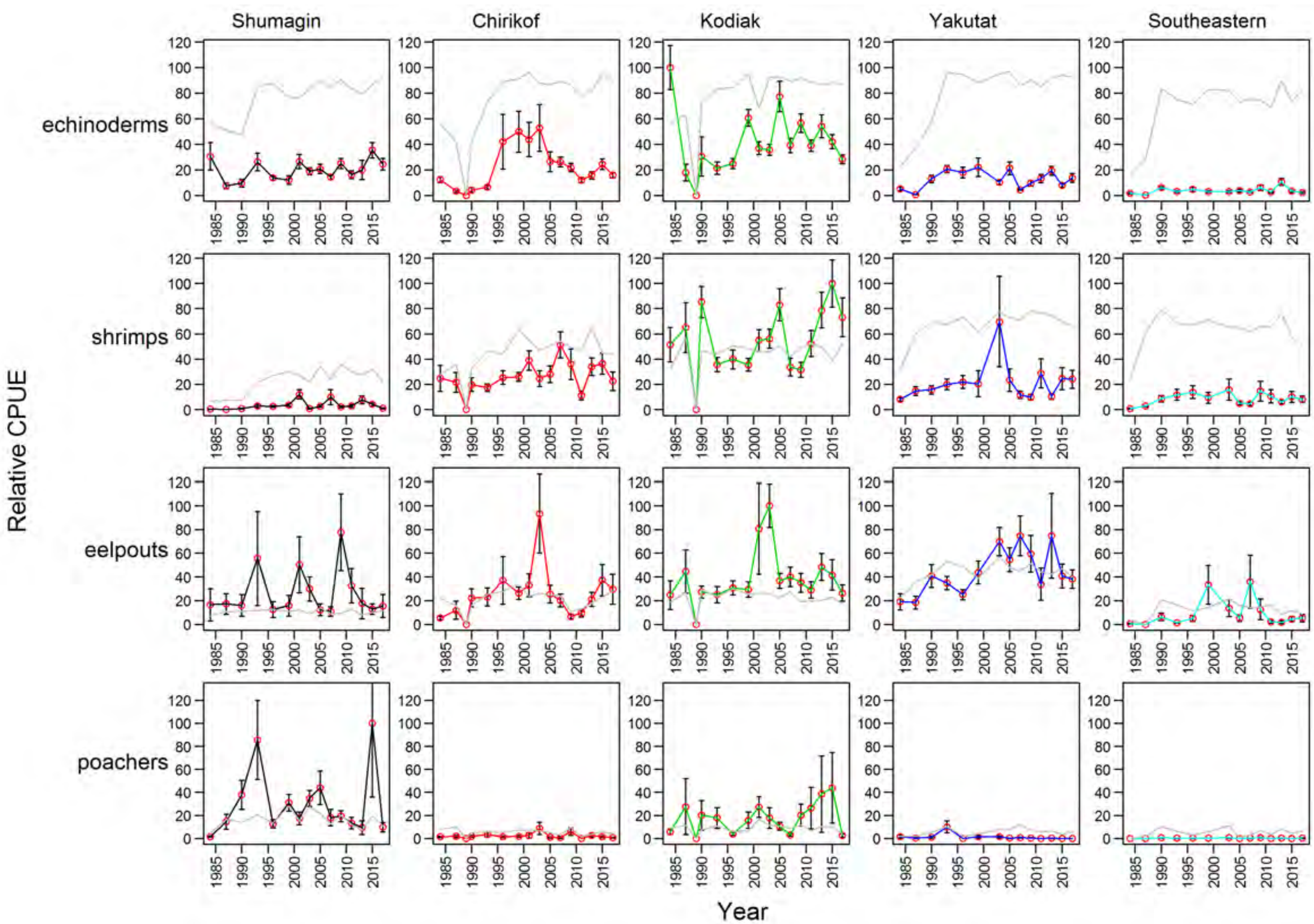


Figure 79: Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2017. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

**Factors influencing observed trends:** Many of these species are not sampled well by the gear or occur in areas that are not well sampled by the survey (hard, rough areas, mid-water etc.) and are therefore encountered in small numbers which may or may not reflect their true abundance in the GOA. The fishing gear used aboard the Japanese vessels that participated in all GOA surveys prior to 1990 was very different from the gear used by all vessels since. This gear difference almost certainly affected the catch rates for some of these species groups.

**Implications:** The trends in other species in the bottom trawl survey do not appear consistent over time, with the possible exception of decreases in recent echinoderm catches.

## Seabirds

### Seabird Monitoring Summary for the Western Gulf of Alaska

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**Last updated: October 2017**

**Description of indicator:** The Alaska Maritime National Wildlife has monitored seabirds at colonies around Alaska in most years since the early- to mid-1970's. Time series of annual breeding success and phenology (and other parameters) are available from over a dozen species at eight Refuge sites in the Gulf of Alaska, Aleutian Islands, and Bering and Chukchi Seas. Monitored colonies in the Gulf of Alaska include Aiktak (in Unimak Pass), Chowiet (Semidi Islands), East Amatuli (Barren Islands), and St. Lazaria (Southeast Alaska; not monitored in 2017) islands. Reproductive success is defined as the proportion of nest sites with eggs (or just eggs for murres that do not build nests) that fledged a chick.

**Status and trends:** Several fish-eating seabirds had unusually low reproductive success in 2017. At Chowiet Island in the Semidis, this included tufted and horned (not shown) puffins (Figure 80). Common murres, which showed rare widespread reproductive failure in 2015–2016, generally had better colony attendance and fledging rates in 2017 but still the number of birds breeding was low. In 2017, tufted puffin productivity was >1 standard deviation (SD) below the long term mean at all monitored sites except at East Amatuli (where they were observed carrying large amounts of capelin). Black-legged kittiwakes and storm-petrels (which consume a mix of fish and invertebrates) showed fledging rates within 1 SD of the mean, as did planktivorous auklets. Timing of breeding was within typical ranges for most species (although horned puffins and ancient murrelets were early at Aiktak and murres and kittiwakes were late at East Amatuli).

**Factors influencing observed trends:** In general, murres appear to have been negatively affected during the marine heat wave of the past few years, with widespread reproductive failures, die-offs, and low attendance at breeding colonies. Other species did not show broad-scale failures during this period; planktivorous seabirds were generally successful. Despite overall low reproductive success of murres in 2017, some improvement in murre attendance and fledging success may reflect environmental changes returning back to more neutral conditions (see Bond, p. 56).

**Implications:** Reproductive activity of central-place foraging seabirds can reflect ecosystem conditions at multiple spatial and temporal scales. For piscivorous species that feed at higher trophic levels, continued reduced reproductive success may indicate that the ecosystem has not yet shifted back from warm conditions and/or there is a lagged response of the prey. However, the improvement in attendance and minimal reproductive activity among murres during 2017 indicates some improvement in foraging conditions for those species.

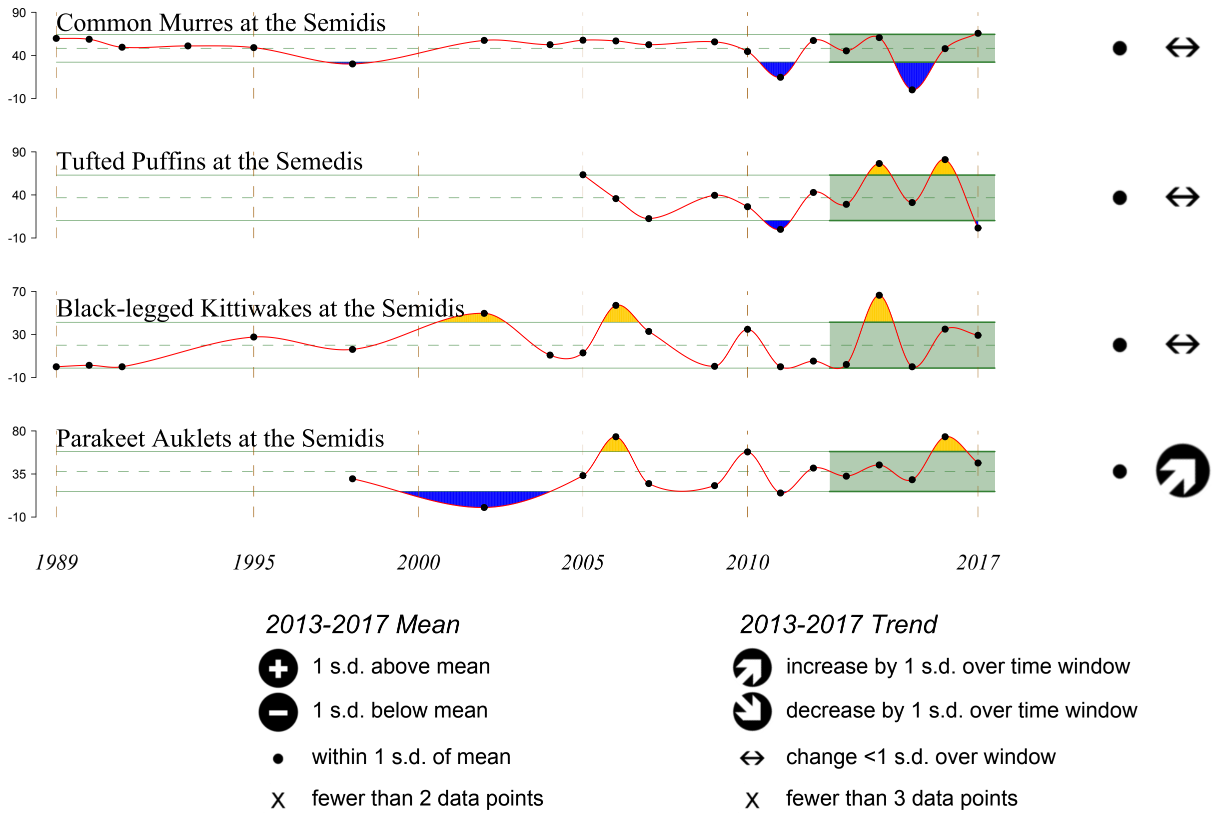


Figure 80: Summary of reproductive success for select seabird species at Chowiet Island in the Semidis.

## Marine Mammals

### Humpback Whale Calving and Juvenile Return Rates in Glacier Bay and Icy Strait

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**Last updated: September 2017**

**Description of indicator:** From 1985–2017, we used consistent methods and levels of effort to monitor humpback whales annually from June 1–August 31 in Glacier Bay and Icy Strait (Gabriele et al., 2017). We calculated the crude birth rate as an annual index of reproduction by dividing the number of calves by the total whale count each year. We also documented the return and recruitment of calves into the population as juveniles. Humpback whales and groundfish target the same lipid-rich prey (i.e., forage fish and euphausiids) and trends in humpback whale reproductive success and juvenile survival may indicate changes in prey availability and/or quality in the eastern Gulf of Alaska.

**Status and trends:** There is mounting evidence that humpback whale calving and juvenile return rates in Glacier Bay and Icy Strait have declined substantially in recent years. In 1985–2013, we observed 2–21 calves per year (mean = 9.3) and a crude birth rate ranging 3.3%–18.2% (Figure 81). Females almost always remained with their calves for the entire summer although we documented a missing calf in eight cases over the 1985–2013 time period, with no more than one case per year (Neilson et al., 2015). In 2014, an unprecedented number of calves (n = 5) went missing between early August and late October (Neilson et al., 2015) and none of the remaining calves (n = 9) have been resighted in subsequent years. In 2015, we documented relatively few calves (n = 5) (Neilson and Gabriele, 2016) and none have been resighted. In 2016, we documented only one mother/calf pair (both appeared to be abnormally thin), which led to the lowest crude birth rate (0.6%) since monitoring began in 1985 (Neilson et al. 2017) (Figure 81). In 2017, we documented only two mother-calf pairs, which we expect will lead to an anomalously low crude birth rate for the second year in a row (the total whale count for 2017 is pending data analysis). Furthermore, one of the mothers in 2017 appeared to be abnormally thin and the other lost her calf by mid-July.

Humpback whales that summer in southeastern Alaska exhibit strong maternally-directed site fidelity that has driven population growth over time (Pierszalowski et al., 2016). We did not document any one or two-year-old whales in 2016 and we observed very few small whales in 2017. Out of 29 calves that we documented in the study area from 2013–2015, only two individuals (7%) are known to have survived to be juveniles in the study. While the mean age at which calves return to the study area is 3.2 years (Gabriele et al., 2017) and juvenile whales can be difficult to track and photo-identify based on their small size and often erratic behavior, it is notable that before 2016, the last time we documented no one- or two-year-old whales in the study area was 2003 (Figure 82).

**Factors influencing observed trends:** We hypothesize that these changes in calving and juvenile return rates may be related to recent changes in whale prey availability and/or quality, which may in turn be negatively affecting maternal body condition and therefore reproductive success and/or overall juvenile survival (Bradford et al., 2012; Fuentes et al., 2016; Seyboth et al., 2016). This

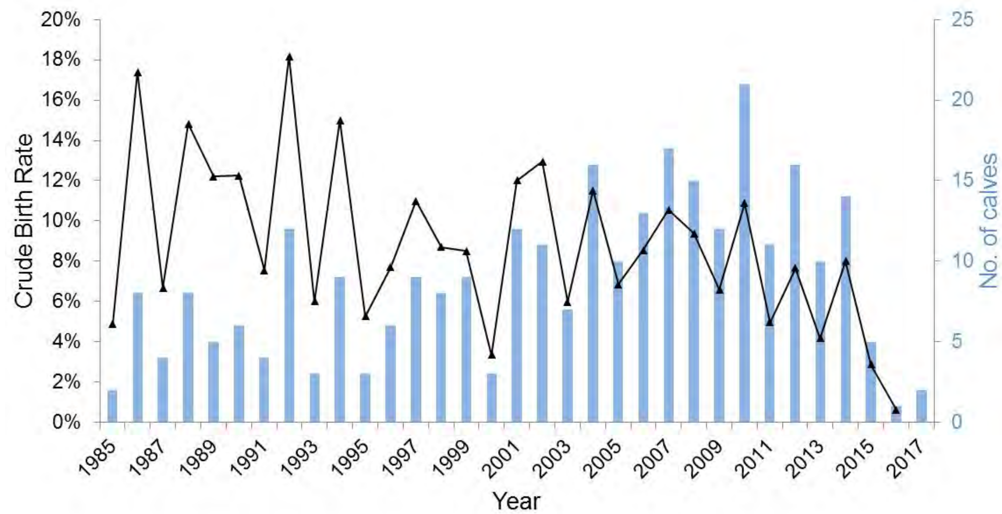


Figure 81: Crude birth rate (black line) (1985–2016) and annual number of calves (blue bars) (1985–2017) in Glacier Bay-Icy Strait.

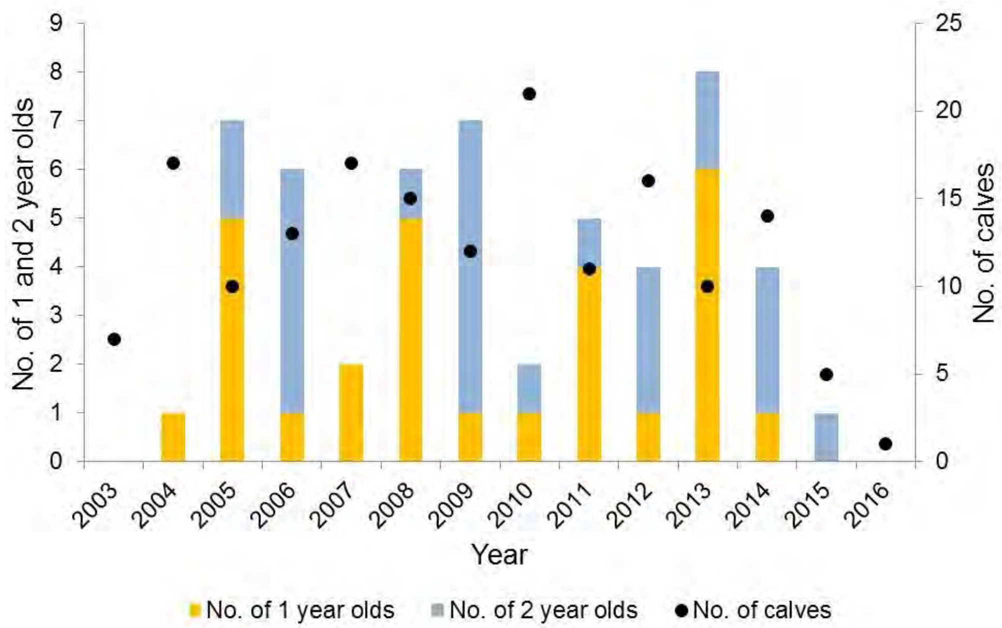


Figure 82: Number of calves, one- and two-year-old whales documented annually in Glacier Bay-Icy Strait, 2003–2016.

hypothesis is supported by observed declines in the body condition of humpback whales throughout northern Southeast Alaska in recent years (see Moran et al. this report).

**Implications:** Recruitment from local populations (vs. immigration from outside populations) has been a key driver of humpback whale population growth over the past 30 years in Glacier Bay and Icy Strait (Pierszalowski et al., 2016), therefore sustained declines in calving and/or recruitment will have long-term effects on the humpback whale population in this area. If humpback whales are currently food-limited in northern Southeast Alaska, this might indicate that groundfish (which prey on the same species) may also be food-limited.

### Summer Survey of Population Level Indices for Southeast Alaska Humpback Whales

Contributed by John Moran[1]1, Christine Gabriele, Janet Nielson, Heidi Pearson, Andy Szabo, Steve Lewis, Janice Straley, Jennifer Cedarleaf
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**Last updated: October 2017**

**Description of indicator:** Humpback whale populations have been monitored by various organizations in Northern Southeast Alaska since the 1970. The Survey of Population Level Indices for Southeast Alaska Humpback (SPLISH) survey assessed trends in abundance, calf production, spatial and temporal distribution, prey composition, and body condition for humpback whales in Northern Southeast Alaska during 2016 and 2017 (data from 2017 are not yet available). The 2016 results can be compared to earlier studies to produce a decadal-scale time series (Straley et al., 2009; Calambokidis et al., 2008; Hendrix et al., 2012; Dahlheim et al., 2009; Neilson et al., 2017). For this report, we include the total number of juvenile/adult whales and calves estimated for Frederick Sound, Stephens Passage, Glacier Bay, and Icy Strait.

**Status and trends:** The total number of whales has increased each decade. Crude birth rates were highest in 1986 and lowest in 2016. Calf numbers in 2017 are expected to be similar to 2016 or lower. There has been a recent decrease in observed body condition (not shown). There is also anecdotal evidence that whales have shifted the distribution to the continental shelf from inside water such as SEAK and Prince William Sound, possibly to feed on euphausiids.

During September in Prince William Sound, lower numbers of humpback whales and marine birds were observed along with a record low biomass of herring, and low numbers of other forage fish and krill relative to previous years. This was our 7th fall survey, with the lowest number of whales since the project began in 2007 (Table 4). Increased effort and excellent conditions while surveying known whale/herring hot spots failed to locate any concentrations of humpbacks or prey.

**Factors influencing observed trends:** Potential causes for observed trends and current status include: recent abnormally warm water in the Gulf of Alaska, which has been linked to decreasing primary production/ forage species; humpback whale populations approaching carrying capacity; or a shift in whale distribution (i.e. offshore to better feeding grounds).

Regarding the Prince William Sound survey, the decline in whales mirrors the decline in herring within the Sound. The PWS herring biomass had been hovering around 20,000 tonnes in since 1993. In 2015 it dropped to 8000 tonnes and continued to decline in 2016 and 2017 to 3000–3500 tonnes (pers. comm. Scott Pegau). Mile days of spawn have dropped from a range of 150 miles prior to the spill, to about 50 miles in the "re-set" level of the 90s and 2000s, to a downward spiral of 36 mile days in the El Niño year of 2014, to 17 mile days in the "Blob" year of 2015, and to 9 mile days in 2016, and 9 mile days in 2017. These levels are unprecedented, and not capable of supporting the predator levels of previous years.

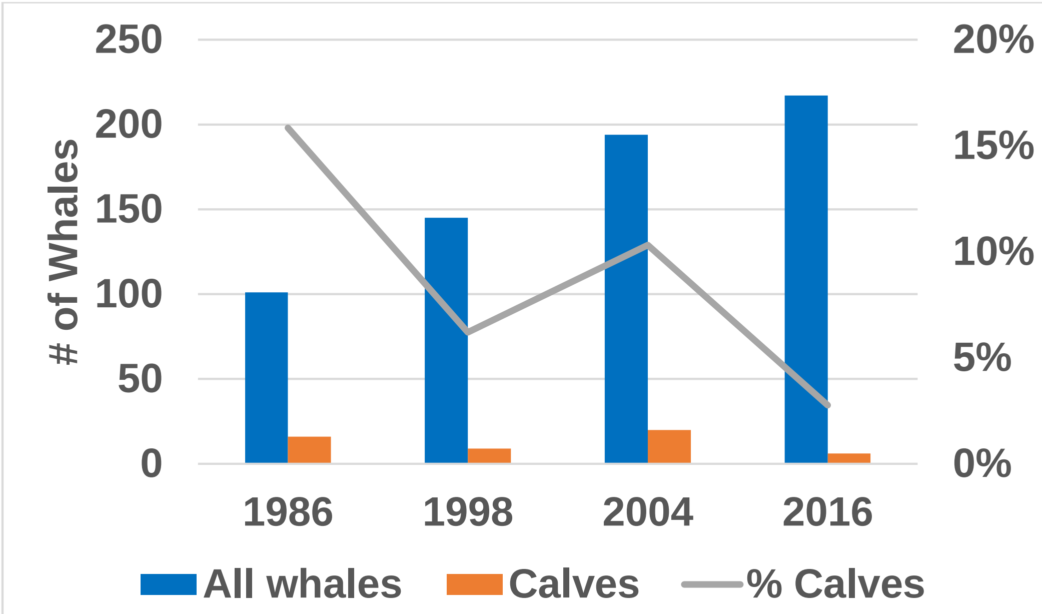


Figure 83: Total numbers of humpback whales, calves and crude birth rate in Frederick Sound, Stephens Passage, Glacier Bay, and Icy Strait.

Table 4: Index of PWS humpback whale abundance in PWS. * Note that the 2007 survey did not cover Montague Entrance, an area known for the highest concentration of whales and herring within the Sound in September.

| Month/year | Counts of whales | Nautical miles | Encounter rate Whale/NM |
|---|---|---|---|
| Sep 2007* | 24 | 370 | 0.06 |
| Sep 2008 | 71 | 412 | 0.17 |
| Oct 2011 | 62 | 441 | 0.14 |
| Sep 2012 | 81 | 444 | 0.18 |
| Sep 2013 | 113 | 355 | 0.32 |
| Sep 2014 | 181 | 427 | 0.42 |
| Sep 2017 | 12 | 543 | 0.02 |

**Implications:** These observations suggest that there is a long-term trend in humpback whales in Gulf of Alaska that may be related to prey. If prey is limiting and humpback whale populations have fully recovered to carrying capacity, there is potential for top-down forcing on forage species (Moran et al., 2017; Straley et al., 2017) and competition with fish, other marine mammals, and seabirds. Monitoring humpback whale indicators may be useful in assessing productivity in the eastern GOA (i.e. shifts in whale distribution may reflect shifts in prey; changes in body condition and calf production may indicate changes in prey abundance or availability). Since there is significant prey overlap between humpback whales and many ground fish species, these data may be useful for a coarse evaluation of ground fish forage.

## Ecosystem or Community Indicators

### Aggregated Catch-Per-Unit-Effort of Fish and Invertebrates in Bottom Trawl Surveys in the Gulf of Alaska, 1993–2017

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**Last updated: October 2017**

**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), 1993–2017. 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 (west of 147°W) 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 both the eastern and western GOA decreased from recent high values to their lowest (west) and second lowest (east) value in 2017 (Figure 84). There was no significant long-term trend over time from 1993 to 2017 in either region, but total CPUE decreased significantly by 30–40% since 2009 and 2013, respectively, in the eastern and western GOA. The decrease in CPUE was widespread among species, affecting commercial and non-commercial species. Species that showed the largest absolute declines in biomass since 2013 included walleye pollock, Pacific cod, arrowtooth flounder and northern rockfish in the western GOA; and arrowtooth flounder, shortraker rockfish, Pacific cod and spiny dogfish in the eastern GOA.

**Factors influencing observed trends:** Commercially harvested species account for over 70% of total 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. Substantial declines in many species in recent years may be associated with the unusual warm conditions in the GOA in 2014–2016, which appeared to affect prey availability and were associated with unusual mortality events in seabirds and marine mammals.

**Implications:** This indicator can help address concerns about maintaining adequate prey for upper trophic level species and other ecosystem components. A sharp drop in total biomass of demersal fish and invertebrates affecting commercial and non-commercial species, suggests poor availability of zooplankton prey for these species and a reduced prey base for upper trophic level species following the 2014/15 warm event.

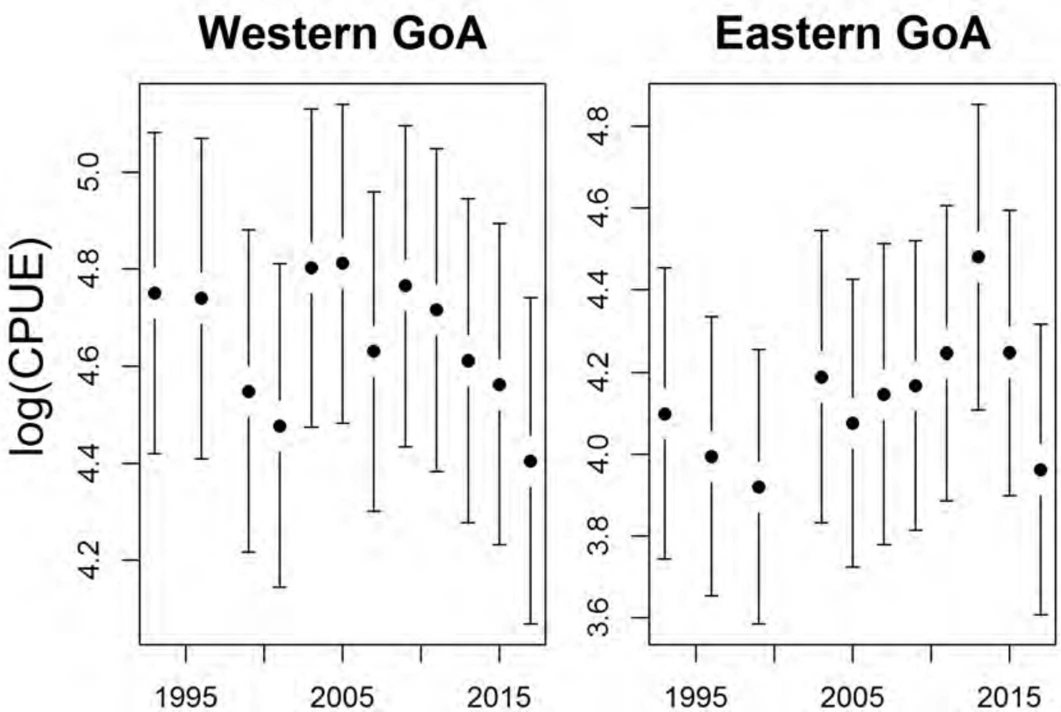


Figure 84: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from in the western (west of 147°W) and eastern Gulf of Alaska by survey year with approximate 95% confidence intervals. Estimates were adjusted for differences in depth and sampling locations (alongshore distance) among years. No sampling in the eastern Gulf of Alaska in 2001.

### Average Local Species Richness and Diversity of the Gulf of Alaska Groundfish Community

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**Last updated: October 2017**

**Description of indicator:** Indices of local species richness and diversity are based on standard bottom trawl surveys in the western (WGOA; west of 147°W) 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 EGOA than in the WGOA with, on average, 2–3 additional species per haul in the east (Figure 85). Richness and diversity have been relatively stable in the western Gulf with slightly higher local richness in the 2015/17 surveys compared to the 2011/13 surveys. Local species richness in the eastern Gulf increased substantially in 2013, declined by more than 2 species per haul in 2015 and increased somewhat in 2017. Diversity in the EGOA had been declining since 2007 but increased in the most recent survey associated with the increase in local richness (Figure 85). Both richness and diversity tend to be highest along the shelf break and slope (Figure 86), with richness peaking at or just below the shelf break (200–300m), and diversity peaking deeper on the slope (300m+), as well as in some shallow water regions ($< 100$m). Notably, both richness and diversity are high off the Kenai Peninsula.

**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 85) and spatial patterns (Figure 86) 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 EGOA 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. The increase in richness and diversity in 2017 reflects reduced dominance of many of these species and possibly a more even distribution across space.

**Implications:** There is evidence from many systems that diversity is associated with ecosystem

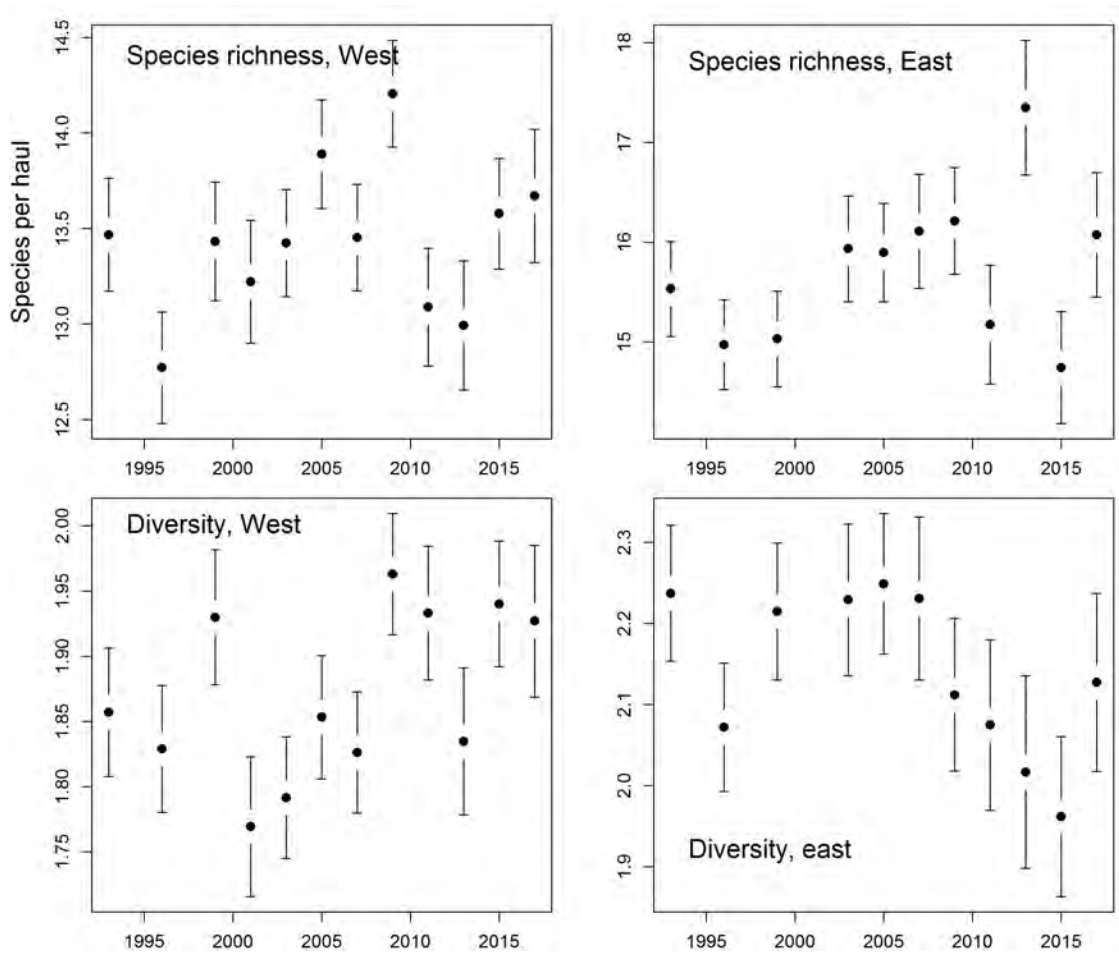


Figure 85: Model-based annual averages of species richness (average number of species per haul, top panels) and species diversity (Shannon index, bottom panels), 1993–2017, for the Western (left) and Eastern (right) Gulf of Alaska based on, respectively, 74 and 73 fish and invertebrate taxa collected by standard bottom trawl surveys with 95% pointwise confidence intervals. Model means were adjusted for differences in depth, date of sampling, and geographic location.

stability, which depends on differential responses to environmental variability by different species or functional groups (McCann, 2000). To my knowledge, such a link has not been established for marine fish communities.

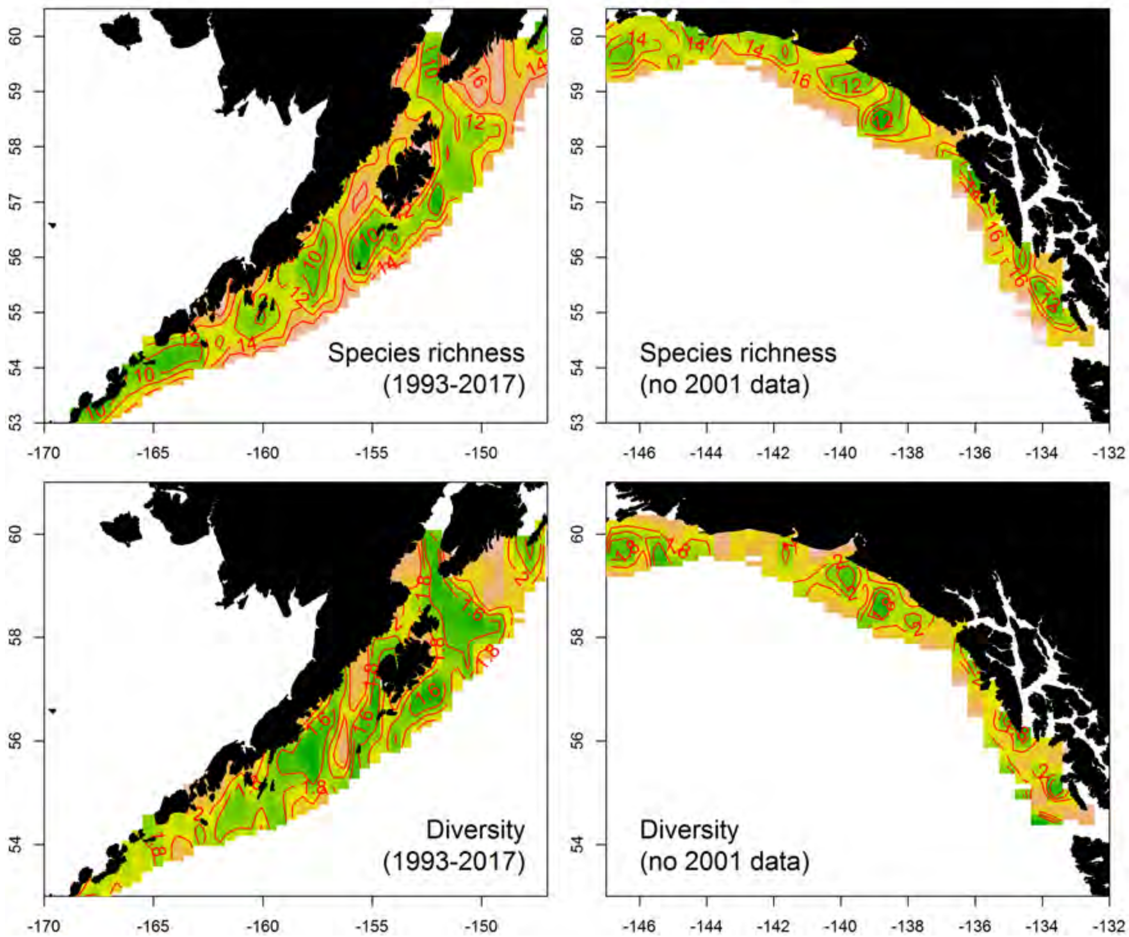


Figure 86: Average spatial patterns in local species richness (species per haul, top panels) and Shannon diversity (bottom panels) for the Western (left) and Eastern (right) Gulf of Alaska.

## 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, while it was apparently absent in 2013 and 2014. 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. Incidence of mushy halibut is reported opportunistically in recreational fishing reports, but may not represent true trends.

**Status and trends:** ADF&G post samplers have reported relatively few “mushy” halibut during the 2017 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 relatively few reports of “mushy” halibut, particularly relative to its recent prevalence in 2015 and 2016, may indicate that foraging conditions for young halibut were more favorable during the past year. However, reporting is opportunistic and may not reflect true prevalence.

### Ichthyophonus Parasite

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**Last updated: August 2017**

**Description of indicator:** *Ichthyophonus* (spp.) is a globally distributed mesomycetozoan fish parasite, which has caused epizootic events among economically important fish stocks, including herring and salmon. The parasite has been documented in at least 145 fish species, and infection can result in reduced growth, stamina, and overall health. In some cases, individuals show gross clinical signs including black papules, white nodules on heart tissue, muscle ulcers, and roughening of the skin. The FAST Lab has conducted *Ichthyophonus* surveys since 2011 that have focused on common sport-caught fishes throughout the marine waters of southcentral Alaska.

Current work is focused on surveying *Ichthyophonus* prevalence in Pacific halibut for 2017 in Homer. This work uses a fish length-based sampling design and also examines physiological components to gain more information on how the parasite affects halibut condition. Bioelectric impedance analysis (BIA) and Fultons Condition Factor (K) are being used to assess muscle condition and length/weight ratio. In addition, host immune response to the parasite is being measured by histolopathological methods, and qPCR is being used to quantify parasite load. As with our earlier research, we are working cooperatively with the ADF&G port sampling program and the charter halibut fleets.

**Status and trends:** Initial work in August of 2011 resulted in the first documentation of natural Ichthyophonus infections in lingcod (*Ophiodon elongates*), yelloweye rockfish (*Sebastes ruberrimus*) and Pacific cod (*Gadus macrocephalus*), along with the expansion of the geographic range of Ichthyophonus in black rockfish (*Sebastes melanops*) northward to include southcentral Alaska (Harris et al., InReview).

Subsequent work has focused on Pacific halibut (*Hippoglossus stenolepis*) in Homer, Alaska. The most recent survey was performed in 2016, and found 57% prevalence (n=335). Previous surveys reported 26% (n=126, 2011), 29% (n=248, 2012) and 23% (n=315, 2013)(Grenier, 2014).

**Factors influencing observed trends:** The 2012 and 2013 FAST Lab Pacific halibut research 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 infection, and found that load varied widely among infected fish with 6 to 1,245 *Ichthyophonus schizonts* per gram of heart tissue. Findings did not support the hypothesis that reduced halibut size-at-age may be caused by *Ichthyophonus*.

**Implications:** This research has found no indication of high intensity infections or clinically diseased individuals. These results support the hypothesis that under typical conditions, *Ichthyophonus* can occur at high infection prevalence with concomitant low infection intensities. This project lays important methodological groundwork for the expansion of groundfish condition research to the Bering Sea, Aleutian Islands and Gulf of Alaska.

# Fishing and Human Dimensions Indicators

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

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

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

## Maintaining Diversity: Discards and Non-Target Catch

### Time Trends in Groundfish Discards

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**Last updated: September 2017**

**Description of indicator:** Estimates of groundfish discards for 1993–2002 are sourced from NMFS Alaska Regions blend data, while estimates for 2003 and later come from the Alaska Region's Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards. Discard rates as shown in Figure 87 below are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area-gear-target sector. Where rates are described below for species or species groups, they represent the total discarded weight of the species/species group divided by the total catch weight of the species/species group for the relevant area-gear-target sector. These estimates include only catch of Fishery Management Plan (FMP)-managed groundfish species on FMP-managed groundfish targets: not included are groundfish discards in the halibut fishery and discards of non-FMP groundfish species, such as forage fish and species managed under prohibited species catch limits.

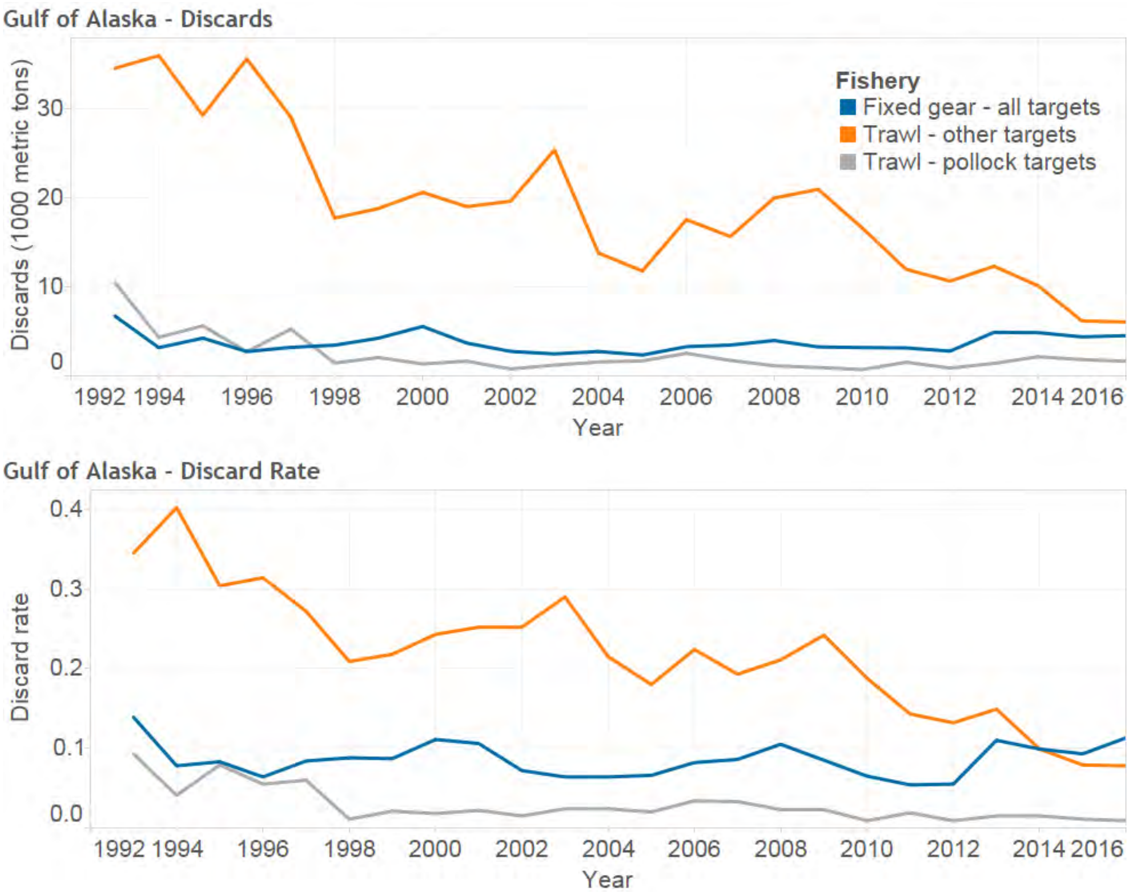


Figure 87: Total biomass and percent of total catch biomass of managed groundfish discarded in the fixed gear, pollock trawl, and non-pollock trawl sectors, 1993–2016 (Includes only catch counted against federal Total Allowable Catches).

**Status and trends:** Since 1993 discard rates of groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in both pollock and non-pollock trawl fisheries in the Gulf of Alaska (GOA)(Figure 87). One exception is in the GOA fixed gear sector, where rates have varied between a low of 6% in 2012 and a high of 14% in 1993 and have trended upward since 2012 following a downward decline during the preceding 4 year period. In the non-pollock trawl sector, discard rates dropped from 40% in 1994 to 21% in 1998, trended upwards from 1998 to 2003, and have generally declined over the last ten years to a low of 8% in 2015 and 2016. Discard rates in the GOA pollock trawl sectors declined from over 10% in 1993 to about 1% in 1998 and have since fluctuated between 1% and 3%.

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

- Limited access privilege programs (LAPPs) that reduce economic discards by removing the race for fish

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

In the Gulf of Alaska ecosystem management and conservation measures aimed at reducing bycatch have contributed to an overall decline in groundfish discards over time. Pollock roe stripping, wherein harvesters extract only the highest value pollock product and discard all of the remaining fish, was prohibited in 1991. In 1997 arrowtooth flounder was added as a basis species for retention of pollock and Pacific cod, and in 1998 full retention requirements for pollock and cod were implemented for all vessels fishing for groundfish, leading to overall declines in pollock and cod discards in the GOA. Additional retention requirements went into effect in 2003 for shallow-water flatfish species across the entire GOA and in 2004 for demersal shelf rockfish in the Southeast Outside district of the Eastern Gulf. Under the GOA groundfish FMP, fisheries with discard rates over 5% for shallow-water flatfish are subject to annual review by the North Pacific Council. Reductions in flatfish discards account for most of the general decline in discards and discard rates for the non-pollock trawl sector.

Implementation of the Pacific Halibut and Sablefish Individual Fishing Quota (IFQ) Program in 1995 led to an overall decline in groundfish discards in the GOA longline sablefish fishery. The IFQ program includes a number of measures to minimize discards of both target and bycatch species. Retention of sablefish and halibut is required as long as the harvester has IFQ catch quota available, which restricts the practice of high grading (discard of lower quality fish). Additionally, all Pacific cod and rockfish must be retained when IFQ halibut or sablefish are on board, subject to other regulations.

Another LAPP, the Central Gulf of Alaska Rockfish Program, rationalizes allocations of rockfish species targeted with trawl gear in the Central GOA (northern rockfish, Pacific ocean perch, and dusky rockfish) along with species harvested incidentally in the fishery (Pacific cod, rougheye rockfish, shortraker rockfish, and sablefish). Vessels fishing in cooperatives with Rockfish Program quota are prohibited from discarding catch of rationalized species. Discards and discard rates of sablefish and rockfish across the entire GOA non-pollock trawl sector have generally declined since the Rockfish Program was piloted in 2007.

In recent years the species historically comprising the "other groundfish" assemblage (skate, sculpin, shark, squid, octopus) have overtaken flatfish as the largest source of discards in the GOA. Most discards of these species currently occur in the longline fishery, although greater observer coverage on smaller hook and line vessels beginning in 2013 likely accounts for some of the recent increase in fixed gear sector discards. Retention rates for skate and octopus have fluctuated over time, in part due to changing market conditions for these species. Interest in retention of skates and directed fishing for skates (despite their management under "bycatch-only" status beginning in 2005) resulted in annual overages of longnose and big skate TACs from 2007 to 2013. Discards of skate have increased since 2012 as NMFS has taken action to prevent such overages, including regulatory discard requirements for big skate in the Central GOA, imposed at progressively earlier dates from 2013 to 2015, and, in 2016, a reduction in the MRA for GOA skates from 20% to 5%.

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

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

### Time Trends in Non-Target Species Catch

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**Description of indicator:** We monitor the catch of non-target species in groundfish fisheries in the Gulf of Alaska (GOA). 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 Fishery Management Plan areas. Catch since 2003 has been estimated using the Alaska Region's Catch Accounting System. This sampling and estimation process does result in uncertainty in catches, which is greater when observer coverage is lower and for species encountered rarely in the catch.

The catch of non-target species/groups from the GOA includes the reporting areas 610, 620, 630, 640, 649, 650, and 659 (https://alaskafisheries.noaa.gov/sites/default/files/fig3.pdf). Within reporting area 610, the GOA and Aleutian Islands (AI) Large Marine Ecosystems are divided at 164°W. Non-target species caught east of 164°W is within the GOA LME and the catch west of 164°W is within the AI LME.

**Status and trends:** The catch of Scyphozoan jellies in the GOA has been variable from 2011–2016, with the highest catch in 2016 (Figure 88). Other years of elevated catch were 2012 and 2015 and were preceded by years of reduced catch. Scyphozoan jellies are primarily caught in the pollock fishery. The catch of structural epifauna in the GOA dropped slightly from 2011 to 2012 and has generally trended upward since. Sea anemones comprise the majority of the structural epifauna catch and they are primarily caught in the flatfish, Pacific cod, and sablefish fisheries. The catch of assorted invertebrates in the GOA has been variable and shown little trend. Sea stars dominate the assorted invertebrate catch, accounting for more than 90% of the total assorted invertebrate catch in each year. Sea stars are caught primarily in the Pacific cod and halibut fisheries. The catch of assorted invertebrates in 2015 increased 69% from 2014, and was the highest over the time period 2011–2016. In 2016 the catch of assorted invertebrates dropped back down to nearly the 2014 level.

**Factors influencing observed trends:** The catch of non-target species may change if fisheries change, or ecosystems change, or both. Because non-target species catch is unregulated and unintended, if there have been no large-scale changes in fishery management in a particular ecosystem, then large-scale signals in the non-target catch may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both. Fluctuations in the abundance of jellyfish are influenced by a suite of biophysical factors affecting the survival, reproduction, and growth of jellies including temperature, wind-mixing, ocean currents, and prey abundance (Purcell, 2005; Brodeur et al., 2008).

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

### Stock Compositions of Chinook Salmon Bycatch in Gulf of Alaska Trawl Fisheries

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**Last updated: August 2017**

**Description of indicator:** Chinook salmon (*Oncorhynchus tshawytscha*) is a highly migratory species that is caught as bycatch in trawl fisheries in the Bering Sea and the Gulf of Alaska (Schnaittacher and Narita, 2013). This economically and culturally valuable species is designated as prohibited species catch, with a suite of bycatch mitigation measures, including hard caps that can result in fishery closures (Stram and Ianelli, 2014). Chinook caught in the Gulf of Alaska originate from as far south as Oregon and as far north as the Yukon River, so identifying sources of Chinook caught as bycatch is critical for conservation and management of domestic and transboundary stocks.

Observers from the North Pacific Groundfish Observer Program monitor at least 30% of the trips targeting walleye pollock (*Gadus chalcogrammus*) in the Gulf of Alaska each year, and during these trips, they enumerate all Chinook bycatch. Among these, they sample ∼10% of the total estimated Chinook bycatch for genetic analysis. The Genetics Program at the Auke Bay Laboratories analyzes

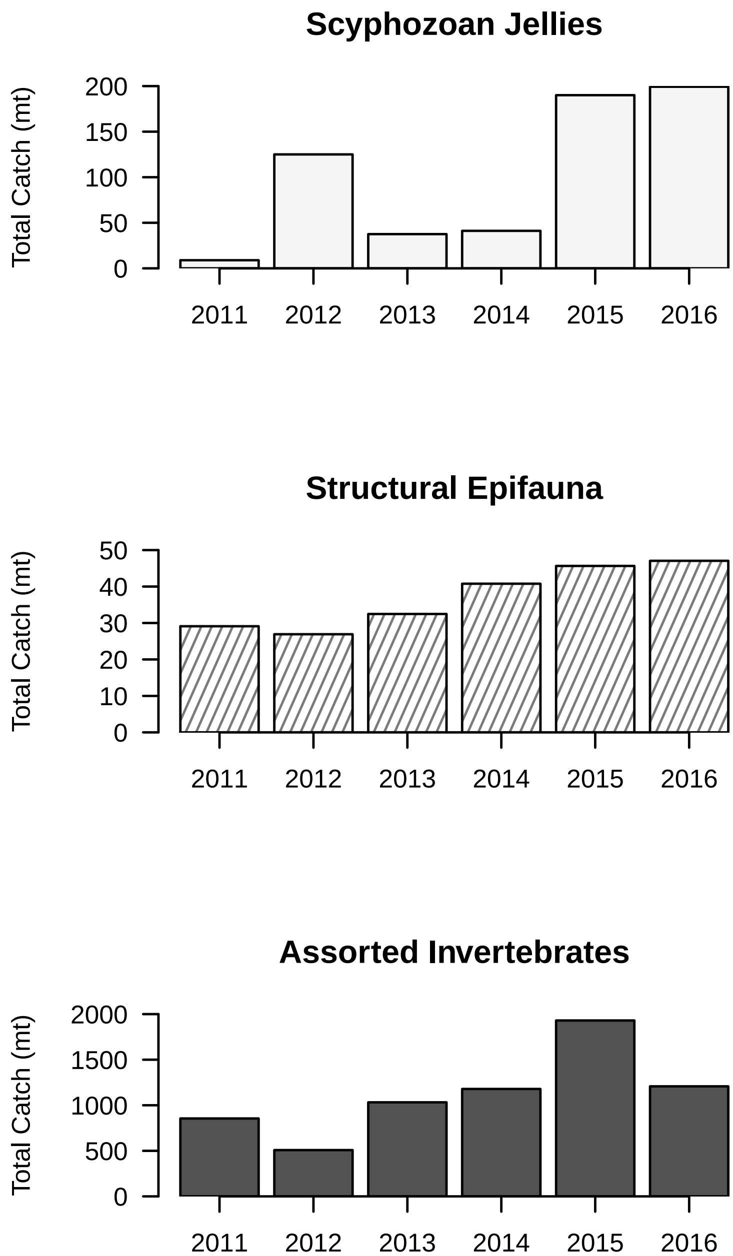


Figure 88: Total catch of non-target species (tons) in the GOA groundfish fisheries (2003–2016). Note the different y-axis scales between species groups.

Chinook bycatch samples for genetic stock identification (Guthrie III et al., 2017), apportioning catches to clusters of geographic regions (West Coast U.S., British Columbia, Coastal Southeast Alaska, Copper River, Northeast Gulf of Alaska, Northwest Gulf of Alaska, North Alaska Peninsula, Coastal Western Alaska, Middle Yukon River, Upper Yukon River, and Russia). As an indicator, we present the proportional composition of the bycatch by each of these stock complexes, or clusters.

**Status and trends:** Stock composition has been relatively stable during the short duration of this time series, with British Columbia stocks dominating the bycatch, and West Coast U.S. stocks either similar to British Columbia stocks, or less, in most years (Figure 89). Coastal Southeast Alaska and Northwest Gulf of Alaska stocks typically represent substantially less of the bycatch while the remainder of stocks were negligible.

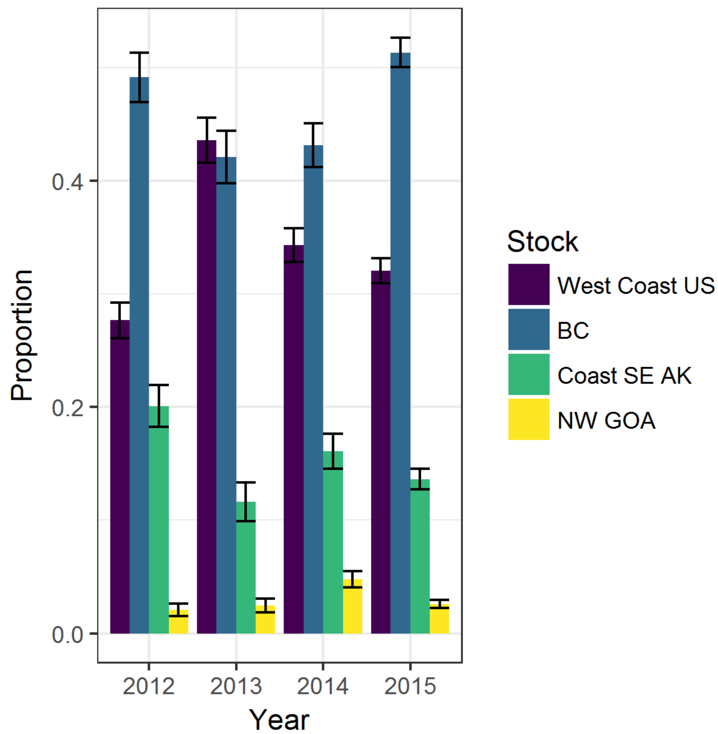


Figure 89: Stock composition of Chinook salmon bycatch in pollock trawl fisheries in the Gulf of Alaska.

Data have only been collected in a reproducible and consistent fashion for a few years, so a description of trends is fairly limited at this point. However, as we move forward, these data establish a baseline with which to compare changes in the future.

**Factors influencing observed trends:** Two primary factors dictate the observed trends in genetic stock composition of trawl fishery bycatch in the Gulf of Alaska. First, British Columbia and West Coast U.S. systems produce orders of magnitude more Chinook each year than Alaskan systems, yielding the much greater proportion of these stocks. Second, the timing of the fisheries may also drive some of the observed signals. British Columbia and West Coast U.S. stocks have both spring and fall runs of Chinook, which may lead to the presence of greater overlap with trawl fisheries in the Gulf of Alaska, as compared to Alaskan stocks which are dominated by a spring out-migration of smolts, reducing periods of potential overlap with trawl fleets.

**Implications:** Understanding the dynamics of Chinook bycatch in trawl fisheries is critical to groundfish management because Chinook represent a prohibited species catch that can drive fisher behavior and lead to significant economic impacts on the fleet. The coarse spatial resolution of the regional clusters makes it difficult to resolve the impacts of Chinook bycatch on any particular stock, as has been done in the Bering Sea (Ianelli et al., 2012). However, despite the coarse resolution, changes in the relative compositions from year to year may serve as an indicator of altered dynamics in the fishery interaction with Chinook. A shift in compositions could be indicative of a change in timing of either Chinook migration patterns or fishing patterns, both of which could be related to environmental changes. Alternatively, a change in genetic stock structure could be indicative of a change in population dynamics (e.g., higher or lower juvenile mortality) of a particular stock, altered production scales or schedules, or the recovery or failure of dominant regional runs. Any such factors could affect groundfish fleets or salmon fisheries and may warrant further investigation.

### Seabird Bycatch Estimates for Groundfish Fisheries in the Gulf of Alaska, 2007–2016

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**Last updated: August 2017**

**Description of indicator:** This report provides estimates of the numbers of seabirds caught as 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 2016. Estimates of seabird bycatch from earlier years using different methods are not included here. Fishing gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic trawl. These numbers do not apply to gillnet, seine, or troll fisheries. Data collection on the Pacific halibut longline fishery began in 2013 with the restructured observer program, although some small amounts of halibut fishery information were collected in years previous when an operator had both halibut and sablefish individual fishing quota (those previous years of halibut data, from 2007–2012, are not included in the data presented in this report).

Estimates are based on two sources of information, (1) data provided by NMFS-certified fishery observers deployed to vessels and floating or shoreside processing plants (AFSC, 2011), and (2) industry reports of catch and production. The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2014, 2010). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. 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; and changes in the landing or at-sea production reports where data entry errors were found.

**Status and trends:** The numbers of seabirds estimated to be caught incidentally in Gulf of Alaska fisheries in 2016 decreased from that in 2015 by 29%, and was below the 2007–2015 average of 1114 by 44% (Table 5). Black-footed albatross, northern fulmars, and gulls were the most common species group bycaught. In 2016, the number of northern fulmars increased by 126% compared to 2015 but remained below the 2007–2015 average of 451 by 56%. However, the number of black-footed albatross and gulls decreased compared to 2015. Fewer black-footed albatross were caught in 2016 than the three previous years (2013–2015) and were below the 2007–2015 average of 223. In fact, the numbers of all albatrosses estimated to be caught incidentally in the Gulf of Alaska, eastern Bering Sea, and Aleutian Islands fisheries in 2016 were less than those in 2015 (Figure 90) and below their respective 2007–2015 averages. The estimated numbers of albatrosses caught incidentally in the Gulf of Alaska is more than in the eastern Bering Sea and the Aleutian Islands, as has been the case in all years in this time series (Figure 91). In the Gulf of Alaska fisheries, shearwaters were the only species or species group to see a percentage increase in 2016 when compared to the 2007–2015 average. The estimated numbers of birds caught incidentally in the Gulf of Alaska falls between that in the eastern Bering Sea and the Aleutian Islands, as has been the case in all but two years in this time series (Figure 91).

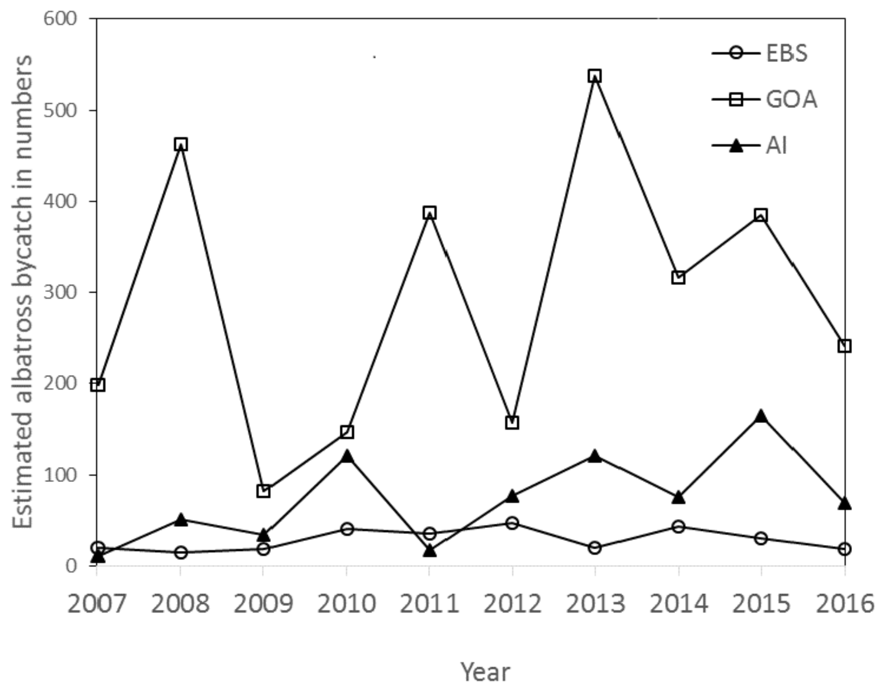


Figure 90: Total estimated albatross bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007 to 2016.

**Factors influencing observed trends:** There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. For example, a marked decline in overall numbers of birds caught after 2002 reflected the increased use of seabird mitigation devices. A large portion of the freezer longline fleet adopted these measures in 2002, followed by regulation requiring them for the rest of the fleet beginning in February 2004. Since 2002, seabird bycatch estimates have varied annually but have not returned to the level seen prior to the use of seabird mitigation devices. Since 2004, work has continued on developing new and refining existing mitigation gear (Dietrich and Melvin, 2008).

The longline fleet has traditionally been responsible for about 90% of the overall seabird bycatch in Alaska, as determined from the data sources noted above. However, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates are biased low (Fitzgerald et al., in prep). For example, this study shows that the 2010 estimate of trawl-related seabird mortality is 823, while

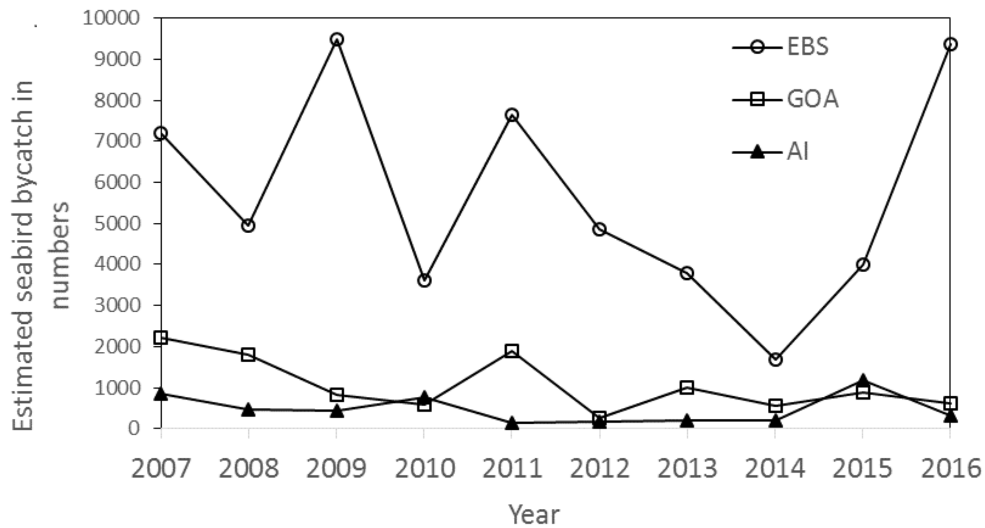


Figure 91: Total estimated seabird bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007 to 2016.

the additional observed mortalities (not included in this estimate and not expanded to the fleet) were 112. Observers now record the additional mortalities they see on trawl vessels and the AFSC Seabird Program has contracted an analyst to work on how these additional numbers can be folded into an overall estimate. The challenge to further reduce seabird bycatch is great given the rare nature of the event. For example, Dietrich and Fitzgerald (2010) found in an analysis of 35,270 longline sets from 2004 to 2007 that the most predominant species, northern fulmar, only occurred in 2.5% of all sets. Albatross, a focal species for conservation efforts, occurred in less than 0.1% of sets. However, given the vast size of the fishery, the total bycatch can add up to hundreds of albatross or thousands of fulmars (Table 5)

**Implications:** There was a slight decrease in seabirds caught incidentally in the Gulf of Alaska in 2016 relative to the year before, whereas the changes were relatively larger in the Aleutian Islands and in the eastern Bering Sea. These differences many reflect localized differences 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 ecosystem and lower productivity in the Gulf of Alaska. During the "Blob" years of 2014–2016, incidental catch in the Gulf of Alaska has remained relatively constant compared to earlier years (in contrast to the eastern Bering Sea).

It is difficult to determine how seabird bycatch numbers and trends are linked to changes in ecosystem components because seabird mitigation gear is used in the longline fleet. There does appear to be a link between poor ocean conditions and the peak bycatch years, on a species-group basis. Fishermen have noted in some years that the birds appear "starved" and attack baited longline gear more aggressively. In 2014 seabird bycatch off Alaska was at relatively low levels (driven by lower northern fulmar and gull bycatch) but albatross numbers were the highest at any time between 2002 and 2016. This could indicate poor ocean conditions in the North Pacific as albatross traveled from the Hawaiian Islands to Alaska. Broad changes in overall seabird bycatch, up to 5,750 birds per year, occurred between 2007 and 2016. This probably indicates changes in food availability rather than drastic changes in how well the fleet employs mitigation gear. A focused investigation

Table 5: Estimated seabird bycatch in Gulf of Alaska groundfish fisheries for all gear types, 2007 through 2016. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

| Species Group | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|
| Unidentified Albatross | 17 | 0 | 0 | 0 | 10 | 0 | 28 | 0 | 0 | 0 |
| Black-footed Albatross | 182 | 295 | 51 | 62 | 215 | 141 | 436 | 284 | 344 | 198 |
| Laysan Albatross | 0 | 168 | 31 | 84 | 163 | 17 | 73 | 33 | 42 | 44 |
| Northern Fulmar | 1466 | 893 | 236 | 175 | 875 | 19 | 257 | 51 | 88 | 197 |
| Shearwaters | 32 | 0 | 0 | 0 | 61 | 0 | 57 | 0 | 6 | 20 |
| Gull | 461 | 183 | 320 | 279 | 554 | 51 | 135 | 157 | 286 | 149 |
| Auklets | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 50 | 0 |
| Other Alcid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39 | 0 | 0 |
| Cormorant | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 0 |
| Unidentified | 48 | 274 | 188 | 0 | 9 | 33 | 7 | 0 | 33 | 19 |
| Grand Total | 2206 | 1813 | 827 | 600 | 1886 | 260 | 994 | 569 | 876 | 626 |

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

There are no updated or new indicators in this section this year.

## 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 2017**

**Description of indicator:** The Fish Stock Sustainability Index (FSSI) is a performance measure for the sustainability of fish stocks selected for their importance to commercial and recreational fisheries (`http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`). The FSSI will increase as overfishing is ended and stocks rebuild to the level that provides maximum sustainable yield. The FSSI is calculated by awarding points for each fish stock based on the following rules:

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

The maximum score for each stock is 4.

In the Alaska Region, there are 36 FSSI stocks and an overall FSSI of 144 would be achieved if every stock scored the maximum value, 4. Over time, the number of stocks included in the FSSI has changed as stocks have been added and removed from Fishery Management Plans (FMPs). Prior to 2015 there were 35 FSSI stocks and maximum possible score of 140. To keep FSSI scores for Alaska comparable across years we report the total Alaska FSSI as a percentage of the maximum possible score (i.e., 100%). Additionally, there are 29 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement. None of the non-FSSI stocks are known to be overfished, approaching an overfished condition, or subject to overfishing. For more information on non-FSSI stocks see the Status of U.S. Fisheries webpage.

Within the GOA region there are 14 FSSI stocks. The assessment for sablefish is based on aggregated data from the GOA and BSAI regions. In previous FSSI contributions, the sablefish FSSI

Table 6: Summary of status for GOA FSSI stocks managed under federal fishery management plans, updated through June 2017.

| GOA FSSI (14 stocks) | Yes | No | Unk | Undef | N/A |
|---|---|---|---|---|---|
| Overfishing | 0 | 14 | 0 | 0 | 0 |
| Overfished | 0 | 12 | 2 | 0 | 0 |
| Approaching Overfished Condition | 0 | 12 | 2 | 0 | 0 |

score was included among BSAI species. Starting with this years contribution sablefish has been removed from the BSAI contribution and is now included in the GOA FSSI.

**Status and trends:** As of June 30, 2017, 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 6).

The current overall Alaska FSSI is 132.5 out of a possible 144, or 92%, based on updates through June 2017 and is unchanged from last year (Figure 92). The overall Alaska FSSI has generally trended upwards from 80% in 2006 to 92% in 2017. The GOA FSSI is 51 out of a maximum possible 56 (Table 6). Two and a half points are deducted from both the Demersal Shelf Rockfish Complex and the Thornyhead Rockfish complex for unknown status determinations and not estimating B/BMSY. Since 2006 the GOA FSSI has been generally steady, increasing from 90% in 2006 up to 91% in 2017 (Figure 93). There were minor drops in the FSSI in 2008–2009 and again in 2012–2013. In 2008 and 2009 a point was lost each year for B/BMSY walleye pollock in the western/central GOA dropping below 0.8. In 2009 an additional 2.5 points were lost for the Rex sole stock having unknown status determinations and for not estimating B/BMSY. In 2012 and 2013 2.5 points were lost for having unknown status determinations and not estimating B/BMSY for the deep water flatfish complex.

**Factors influencing observed trends:** The overall Alaska FSSI and the GOA FSSI is unchanged from last year. 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 for these groups are because the overfished status determinations are not defined and it is therefore unknown if the biomass is above the overfished level or if biomass is at or above 80% of BMSY.

**Implications:** The majority of Alaska groundfish fisheries appear to be sustainably managed, including GOA groundfish fisheries. Until the overfished status determinations are defined for the Demersal Shelf Rockfish complex and the Thornyhead Rockfish complex, it will be unknown whether these stocks are overfished or approaching an overfished condition.

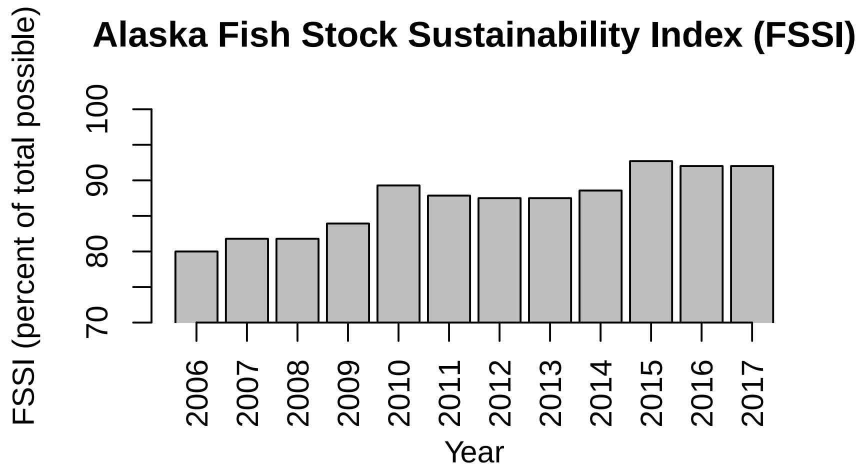


Figure 92: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2017. The maximum possible FSSI is 140 for 2006 to 2014, and from 2015 on it is 144. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

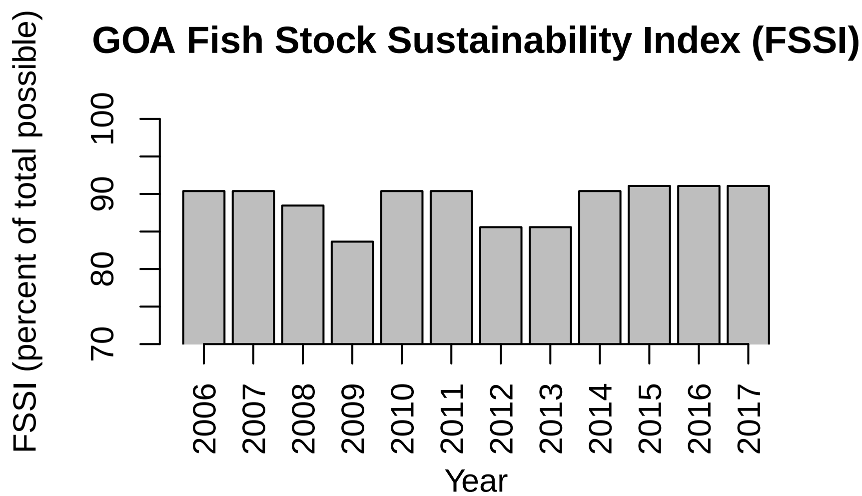


Figure 93: The trend in FSSI from 2006 through 2017 for the GOA region as a percentage of the maximum possible FSSI. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Table 6: 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 | 3.38 | 4 |
| GOA Flathead sole | No | No | No | N/A | N/A | 2.55 | 4 |
| GOA Blackspotted and Rougheye Rockfish complex[a] | No | No | No | N/A | N/A | 1.92 | 4 |
| GOA Deepwater Flatfish Complex[b] | No | No | No | N/A | N/A | 2.43 | 4 |
| GOA Shallow Water Flatfish Complex[c] | No | No | No | N/A | N/A | 2.02 | 4 |
| GOA Demersal Shelf Rockfish Complex[d] | No | Unknown | Unknown | N/A | N/A | not estimated | 1.5 |
| GOA Dusky Rockfish | No | No | No | N/A | N/A | 1.46 | 4 |
| GOA Thornyhead Rockfish Complex[e] | No | Unknown | Unknown | N/A | N/A | not estimated | 1.5 |
| Northern rockfish - Western / Central GOA | No | No | No | N/A | N/A | 1.28 | 4 |
| GOA Pacific cod | No | No | No | N/A | N/A | 1.32 | 4 |
| GOA Pacific Ocean perch | No | No | No | N/A | N/A | 1.57 | 4 |
| GOA Rex sole | No | No | No | N/A | N/A | 2.20 | 4 |
| Walleye pollock - Western / Central GOA | No | No | No | N/A | N/A | 0.93 | 4 |
| GOA BSAI Sablefish[f] | No | No | No | N/A | N/A | 1.02 | 4 |

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

(a) 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.

(b) 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.

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

(d) 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.

(e) 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.

(f) 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.

## Seafood Production

### Economic Indicators in the Gulf of Alaska Ecosystem – Landings

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**Description of indicator:** Landings are a baseline metric for characterizing commercial economic production in the Gulf of Alaska. Landings are the retained catch of fish, calculated as in Fissel et al. (2016), and plotted here by functional group. While many species comprise a functional group, it is the handful of species that fishermen target that dominate the economic metrics in each group. The primary target species in the apex predators functional group are Pacific cod, Pacific halibut, sablefish, and arrowtooth flounder. The primary target species in the pelagic foragers functional group are walleye pollock, Pacific ocean perch, northern rockfish and dusky rockfish. The primary species caught in the benthic foragers functional group are flathead sole, and rex sole. The primary target species in the salmonid functional group are chinook, sockeye, and pink salmon. The primary species caught in the motile epifauna functional group are tanner and dungeness crab. Because of significant differences in the relative scale of landings across functional group landings are plotted on a log scale.

**Status and trends:** Landings in the Gulf of Alaska are primarily comprised of catch from three functional groups: salmon, pelagic foragers, and apex predators (Figure 94). Salmon landings display a stable cycle driven by large returning year classes in odd years. The primary species landed within the pelagic forager functional group is pollock, whose landings have been fairly stable until 2012 when they began to increase with the Total Allowable Catch (TAC). Pacific ocean perch, northern rockfish and dusky rockfish are also caught in significant quantities in the Gulf of Alaska, but landings are roughly one half to one fifth the volume of pollock landings. Within the apex predator functional group, Pacific cod, arrowtooth flounder, halibut and sablefish all have significant target fisheries. Landings have been stable for the apex predator functional group as a whole, but the distribution of landings across species within this group has changed over time. Halibut and sablefish landings have declined significantly over roughly the last decade. Pacific cod landings decreased in 2016, a trend which is expected to continue through 2018. Relative to the preceding three functional groups, benthic forager and motile epifauna are caught in significantly smaller quantities. Rex sole and flathead sole have target fisheries and total landings are well below the annual TACs for these species. State managed fisheries exist for tanner and dungeness crab. Landings of both of these functional groups have remained fairly stable over time.

**Factors influencing observed trends:** For species with limiting TACs, trends in landing follows that of the TACs. The decline in halibut and sablefish landings follows the conservation reductions in the TAC. Pacific cod landings are also determined by the TAC, which had been significantly higher since 2010 than before, until the decrease in 2016.

**Implications:** Landings depict one aspect of the raw stresses from harvesting imposed on the

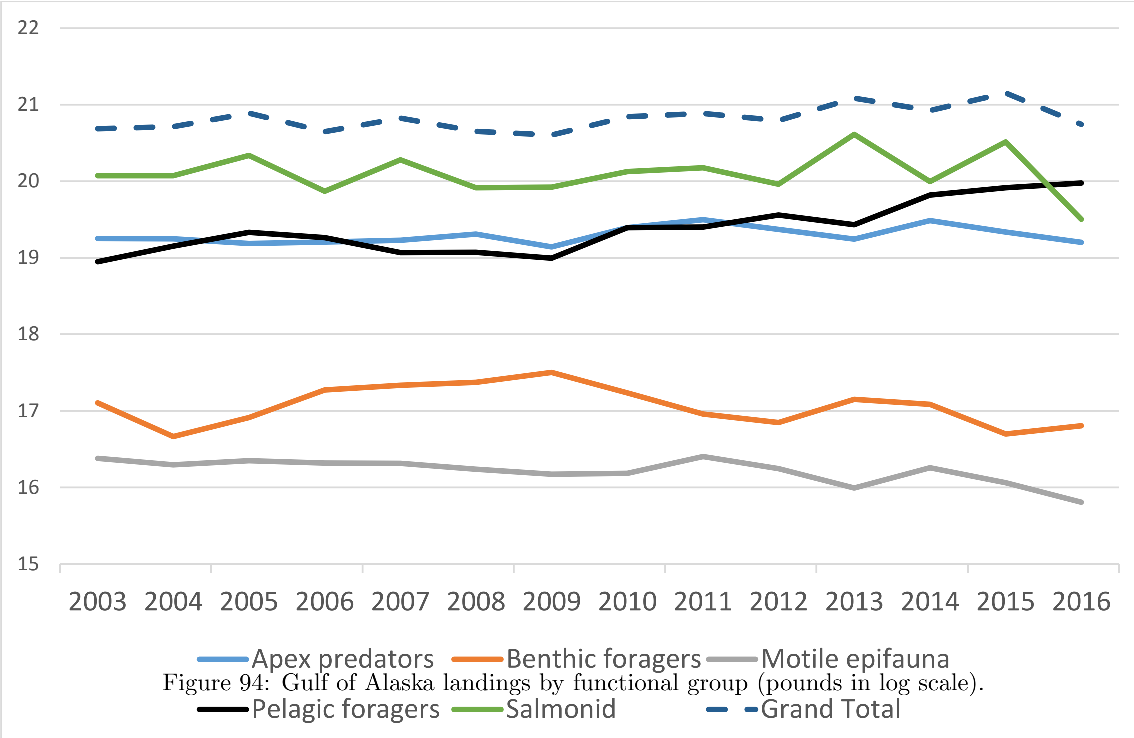


Figure 94: Gulf of Alaska landings by functional group (pounds in log scale).

Gulf of Alaska ecosystem's functional group through fishing. This information can be useful in identifying areas where harvesting may be impacting different functional groups in times where the functional groups within the ecosystem might be constrained. Salmonids have on average been the largest functional group landed over this period, followed by apex predators and pelagic foragers which have been roughly equivalent over time but have experienced some divergence in recent years with pelagic foragers being the largest component of landings in 2016. Relative to other functional groups, benthic foragers and motile epifauna make up a smaller share of total landings in the Gulf of Alaska. Monitoring the trends in landings stratified by ecosystem functional group provides insight on the fishing related stresses on ecosystems. The ultimate impact that these stresses have on the ecosystem cannot be discerned from these metrics alone and must be viewed within the context of what the ecosystem can provide.

**Halibut and Salmon Subsistence Trends in the Gulf of Alaska**

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**Description of indicator:** Subsistence uses of wild resources are defined as "noncommercial, customary and traditional uses" for a variety purposes including, nutritional, trade, and cultural purposes (ADF&G, http://www.adfg.alaska.gov). Following the IPHC and NMFS regulations in 2003, the subsistence halibut fishery allows the use of halibut by rural residents and members of federally-recognized Alaska native tribes for non-commercial use, for food, or customary trade (Gilroy). Subsistence fishery harvests produces an average of 155 pounds of food per person per year in rural Alaska. In the GOA, all five salmon species are important subsistence fisheries, as well as halibut, shellfish, and other finfish (ADF; Fall et al., 2017). In addition to subsistence, the Gulf of Alaska also supports personal-use fisheries. For these reasons, subsistence harvests of two focal species, salmon and halibut, were considered informative.

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

**Status and trends:** Records indicate a significant increase in household subsistence use permits in the GOA for salmon along with an increase in total salmon harvest (Figure 95). The vast majority of total harvest is sockeye salmon. In 2014, 94% of personal-use salmon harvested was sockeye salmon. The harvest data for other salmon species is less consistent (Figure 96). The data reflect a downward trend in Chinook harvest Alaska-wide, while Coho and chum salmon show considerable variation in harvest rates. The historical average since 1994 is 940,444 salmon, with the 2014 harvest estimated at 932,596 fish. Approximately half of state-wide subsistence sockeye harvests (47%) took place in GOA communities (Fall et al., 2017). In 2014, 728,225 salmon were harvested from personal-use fisheries, with 404,867 fish (56%) harvested from the Kenai River dip net fishery. Personal-use harvests have increased in the GOA since 1994, largely due to increased harvests in the Upper Cook Inlet dip net fisheries (Fall et al., 2017).

According to the Alaska Department of Fish and Game, statewide subsistence halibut harvest (in pounds) declined between the years 2004 to 2012, with a slight uptick in 2014 (Figure 95). There were approximately 4,506 subsistence fishermen throughout Alaska who harvested an estimated 40,698 halibut in 2014. In comparison, the IPHC estimated that the total halibut harvest in Alaska in 2014 was 33,804 million pounds, with total subsistence harvests representing 2.3% of the total harvest. Subsistence halibut are largely harvested in GOA communities. The data illustrate 56% of the subsistence halibut harvest occurred in Area 2C (Southeast Alaska), and 32% in Area 3A (Southcentral Alaska). Research indicates that Kodiak and Sitka regions have the largest subsistence halibut harvests (Fall and Lemons, 2016). Setline gear is most commonly used (71%) while 29 percent of harvests are conducted with hand-operated gear.

**Factors influencing observed trends:** The reasons for the decline in subsistence halibut harvest are complex, and in large part related to participation in the survey and methodology (Fall and Lemons, 2015). Due to budgetary constraints, data collection efforts were reduced in size and scope, which is consistent with the decrease in reported harvests, suggesting that some of the decrease in halibut harvest is a result of a lower participation in the survey. In certain regulatory areas, there is a downturn in renewal of Halibut permits (SHARCs) after the initial rise in participation after the start of the SHARC program (Fall and Lemons, 2015). Postal survey methodology differed in some regions. The decrease could suggest survey fatigue. In 2014, an effort was made to follow up with non-participants to complete the survey, increasing the reported harvest estimates. After the fieldwork, concerns were raised in certain areas about the decrease in available harvest, suggesting

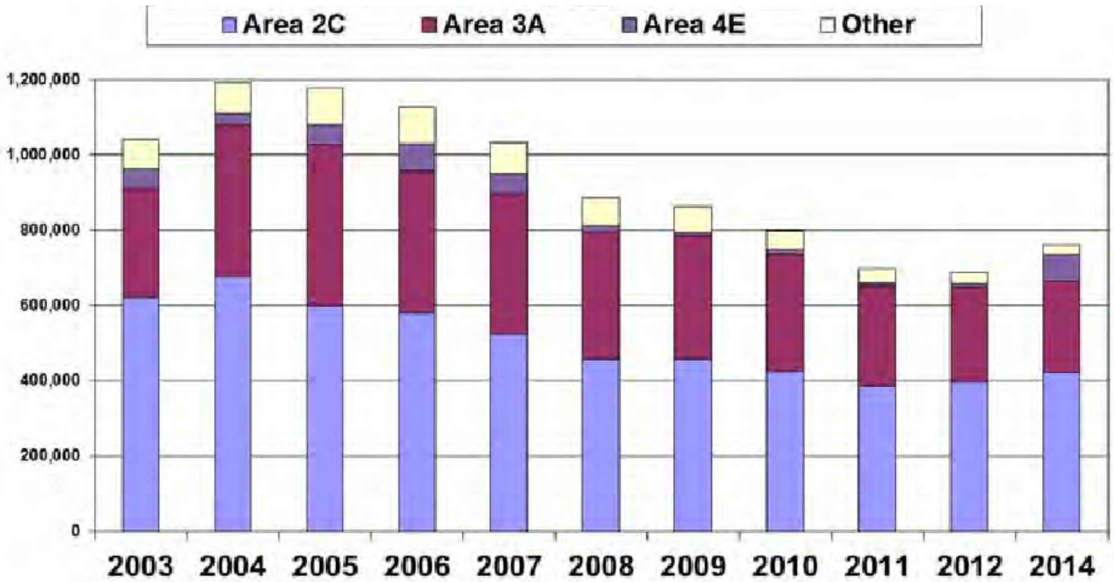


Figure 95: Estimated Subsistence Harvests of Halibut in Alaska, 2003–2012 and 2014 (lbs. net weight) by Area. Area 2C is Southeast Alaska, Area 3A is Central Gulf of Alaska (Kodiak to Cape Spencer), and Area 4E is the middle and inner domain of the eastern Bering Sea. Source: Fall and Lemons 2016.

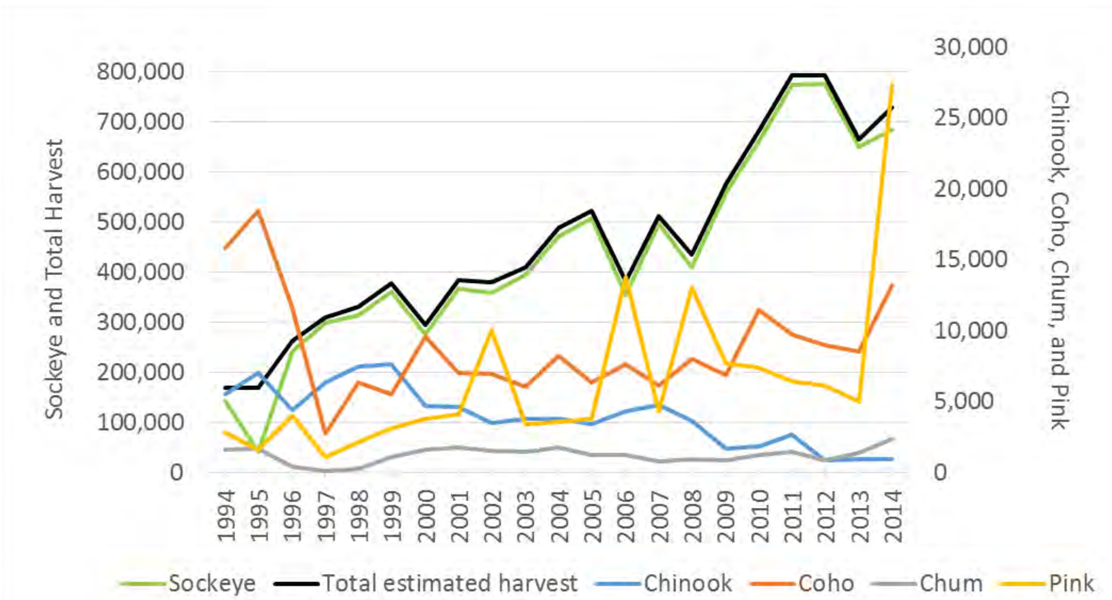


Figure 96: Household subsistence use permits and total salmon harvests in the Gulf of Alaska, 1994–2014.

one cause may be bycatch from commercial cod fishing.

**Implications:** Subsistence fishing and hunting represent a major source of food security and cultural identity for rural Alaskans. Rural households rely on subsistence resources to supplement food during the winter when other sources of food may be unavailable or prohibitively expensive

(Loring and Gerlach, 2009). In addition, gathering of subsistence resources represents a way of life to many rural Alaskans that connects them to their land, heritage and establishes community bonds of sharing and networking (Picou et al., 1992). The decline in halibut subsistence may indicate increased vulnerability for subsistence communities.

## Profits

### Economic Indicators in the Gulf of Alaska Ecosystem – Value and Unit Value

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**Last updated: October 2017**

**Description of indicator:** Three metrics are used to characterize economic value in an ecosystem context for the Gulf of Alaska: ex-vessel value, first-wholesale value, and ratio of first-wholesale value to total catch. Ex-vessel value is the un-processed value of the retained catch. Ex-vessel value can informally be thought of as the revenue that fishermen receive from the catch. First-wholesale value is the revenue from the catch after primary processing by a processor. First-wholesale value is thus a more comprehensive measure of value to the fishing industry as it includes ex-vessel value as well as the value-added revenue from processing which goes to processing sector. The first-wholesale value to total catch unit value is the ratio of value to biomass extracted as a result of commercial fish harvesting. The measure of biomass included in this index includes retained catch, discards, and prohibited species catch. This metric answers the question: "how much revenue is the fishing industry receiving per-unit biomass extracted from the ecosystem?"

The first two metrics are plotted by functional group. While many species comprise a functional group, it is the handful of species that fishermen target that dominate the economic metrics in each group. The primary target species in the apex predator functional group are Pacific cod, Pacific halibut, sablefish, and arrowtooth. The primary target species in the pelagic forager functional group are walleye pollock, Pacific ocean perch, northern rockfish and dusky rockfish. The primary species caught in the benthic forager functional group are flathead sole, and rex sole. The primary target species in the salmonid functional group are Chinook, sockeye, and pink salmon. The primary species caught in the motile epifauna functional group are tanner and dungeness crab. Because of significant differences in the relative scale of value across functional group value is plotted in logs. Ex-vessel value and first-wholesale value have been adjusted for inflation using the GDP chain-type deflator.

**Status and trends:** Ex-vessel value is the revenue from landings, so trends in ex-vessel value and landings are closely connected. Ex-vessel value is highest in the salmon and apex predator functional groups (Figure 97). Ex-vessel revenues have remained fairly stable over time but have been lower since 2013 as the relative share of landings have shifted away from the more highly priced sablefish and halibut species towards the more moderately priced Pacific cod. Despite large catch volumes pollock prices are comparatively lower than apex predators or salmon. A combination of catch and price increases account for the increasing trend in up to 2012. Since 2013 depressed pollock prices have resulted in flat or decreasing revenue despite increased landings. Changes in benthic forager flatfish revenues have largely tracked changes in landings of rex sole and flathead sole. Value in the motile epifauna group has generally increased with crab ex-vessel prices.

First-wholesale value is the revenue from the sale of processed fish. Some fish, in particular pollock

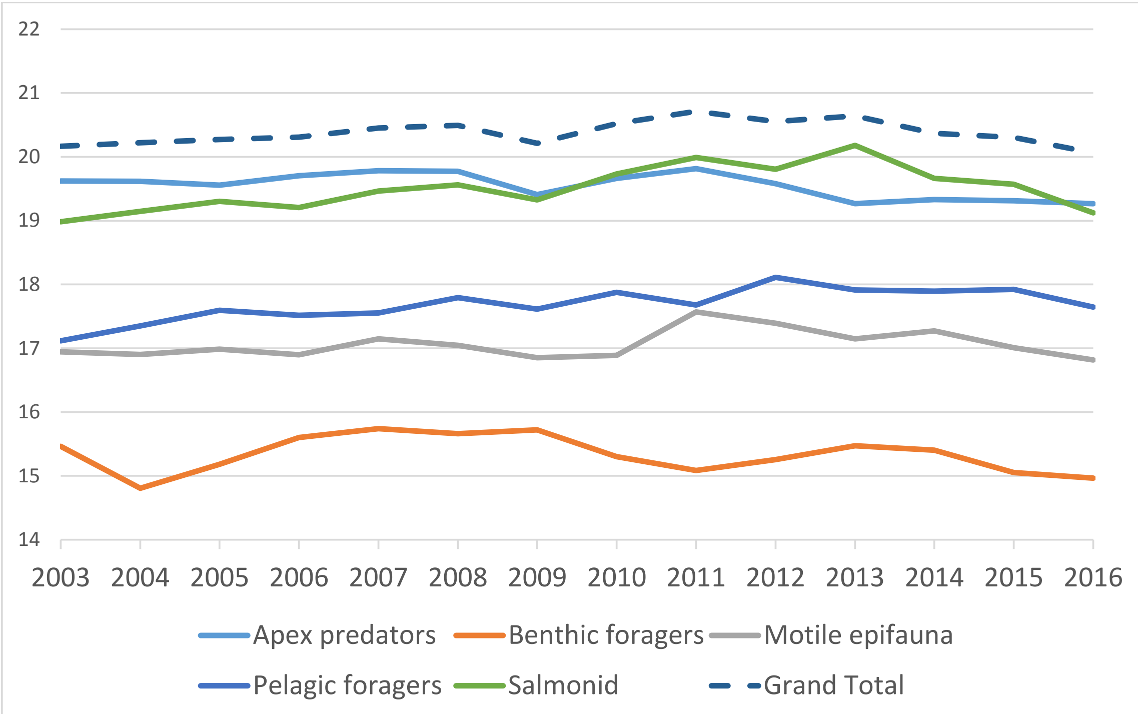


Figure 97: Gulf of Alaska real ex-vessel value by functional group (2016 dollars logged).

and Pacific cod, are processed in a numerous product forms which can influence the generation of revenue by the processing sector. First-wholesale was generally increasing for each of the functional groups up to about 2008–2010 with stable or increasing landings and gradually increasing prices (Figure 98). After 2010, variation in landings or in prices have had differential impacts. Over the long-term both salmon prices and revenue show an increasing trend. First-wholesale value in the apex predator group decreased with Pacific cod prices in 2009 and declined after 2011. The value of the pelagic forager group shows a gradual increasing trend up to 2012 when prices for pollock decreased with high global pollock supply. Benthic forager first-wholesale value has remained fairly stable and changes in value largely reflect changes in landings. First-wholesale value in the motile epifauna group has remained fairly stable, as crab prices increased through 2012, dipped in 2013–2014 and have been increasing through 2016.

The first-wholesale to total catch unit value is analogous to a volumetrically weighted average price across functional groups which is inclusive of discards. However, discards represent a relatively small fraction of total catch. Because of the comparatively larger value of salmon and apex predators the unit value index is more heavily weighted towards these groups. The unit value index increased from 2003–2008 with generally increasing prices across all functional groups (Figure 99). After 2008 shifts in the relative share of landings from halibut and sablefish to the more moderately-priced cod resulted in a decrease in the average price of the apex predator group. Salmon prices continued to rise through 2012. The net effect of these changes is that the trend in the aggregate unit value index leveled out from 2009–2012. Pollock prices fell somewhat starting in 2013. Apex predator prices continued to decline after 2013.

**Factors influencing observed trends:** Sablefish and halibut are high valued whitefish, and price increases resulting from the reduced supply of these species have helped to offset the impact on

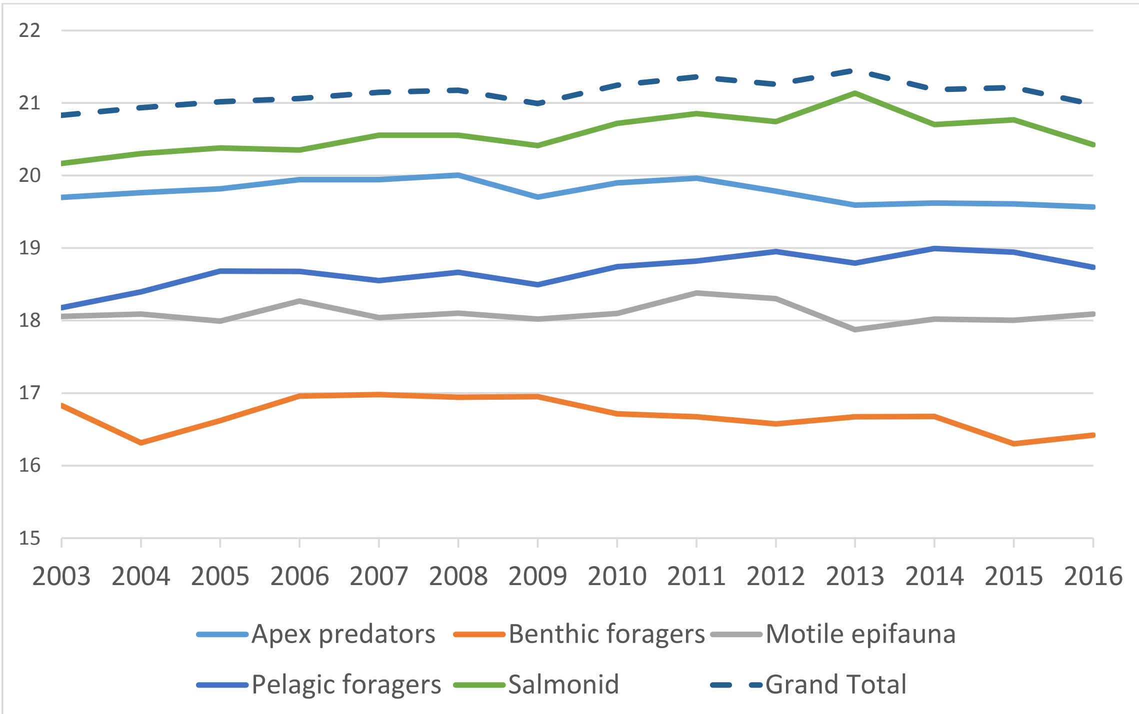


Figure 98: Gulf of Alaska real first-wholesale value by functional group (2016 dollars logged).

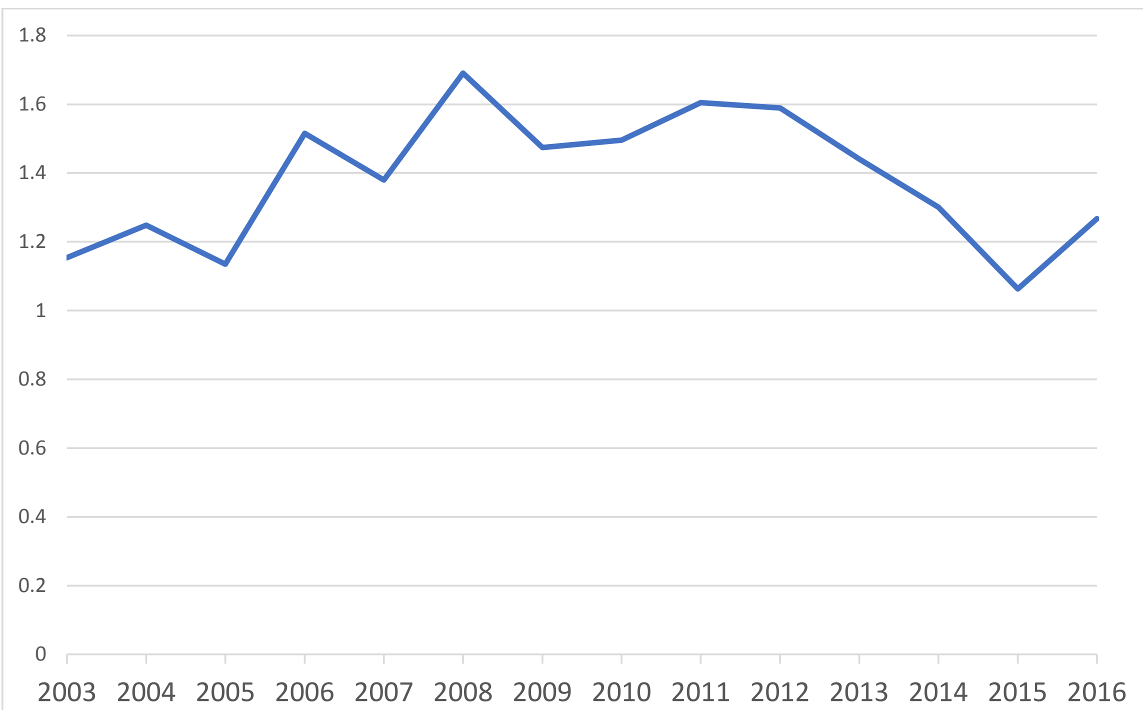


Figure 99: Real first-wholesale to total catch unit value in the Gulf of Alaska (2016 dollars).

revenues from reduced landings. Differences in the relative level of the indices between the landings and ex-vessel value in Figure 1 reflects differences in the average prices of the species that make up the functional group. Hence, landings of benthic forager flatfish may be larger than those of the motile epifauna group, but motile epifauna ex-vessel value is higher because it commands a higher price. Ex-vessel prices are influenced by a multitude of potential factors including demand for processed products, the volume of supply (both from the fishery and globally), the first-wholesale price, inflation, fishing costs, and bargaining power between processors and fishermen. However, annual variation in the ex-vessel prices tends to be smaller than variations in catch and short to medium term variation in the landings and ex-vessel revenue indices appear similar.

Level shifts in the relative location of the first-wholesale indices compared to the ex-vessel indices are influenced by differences in the amount and types of value-added processing in each functional group. Salmon first-wholesale prices are affected by the annual cycles in landings and tend to display a counter-cyclic relationship with lower prices when landings volumes are high and higher prices when volumes are low. This relationship tends to smooth out revenues over time. Declines since 2011 are largely the result of a shift in the relative share of landings from the more highly priced sablefish and halibut species towards the more moderately priced Pacific cod.

Significant global pollock supply contributed to the decline in pollock prices starting in 2013. The decline in apex predator prices after 2013 occurred with shifts in catch composition. These features combined with volatility in salmon prices account for the decreasing unit value trend since 2012.

**Implications:** The economic metrics displayed here provide perspective on how the human component of the ecosystem feeds off of and receives value from the Gulf of Alaska and the fish species within that ecosystem. Ex-vessel and first-wholesale value metrics area measure of the ultimate value from the raw resources extracted and how humans add value to the harvest for their own uses. While salmon and apex predators are relatively equally important to the ex-vessel sector, the salmonid functional group makes up a larger share of first-wholesale revenue. Pelagic foragers also make up a relatively similar share of landings as apex predators, but are substantially lower in terms of ex-vessel and first-wholesale revenue due to their high volume and relatively low prices. Situations in which the value of a functional group is decreasing but catches are increasing indicate that the per-unit value of additional catch to humans is declining. This information can be useful in identifying areas where fishing effort could be reallocated across functional groups in times where the functional groups within the ecosystem might be constrained while maintaining value to the human component of the ecosystem. Monitoring the economic trends stratified by ecosystem functional group provides insight on the fishing related stresses on ecosystems and the economic factors that influence observed fishing patterns. The ultimate impact that these stresses have on the ecosystem cannot be discerned from these metrics alone and must be viewed within the context of what the ecosystem can provide.

## Recreation

### Saltwater Recreational Fishing Participation in the Gulf of Alaska: Number of Anglers and Fishing Days

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**Last updated: August 2017**

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

**Status and trends:** In the GOA the total number of days fished in saltwater has increased since the early 1980s when almost a half million fishing days were taken (Figure 100). Annual saltwater fishing days reached its peak in 1995 at about 1.06 million fishing days. In recent years the annual number of fishing days has been just shy of 1 million. The annual number of saltwater anglers fishing in the GOA has fluctuated since the mid-1990s between 350,000 and 442,000 anglers (Figure 101). Since 2009, the annual number of saltwater anglers has generally been below 400,000.


Figure 100: The total number of days fished in saltwater in the Gulf of Alaska.

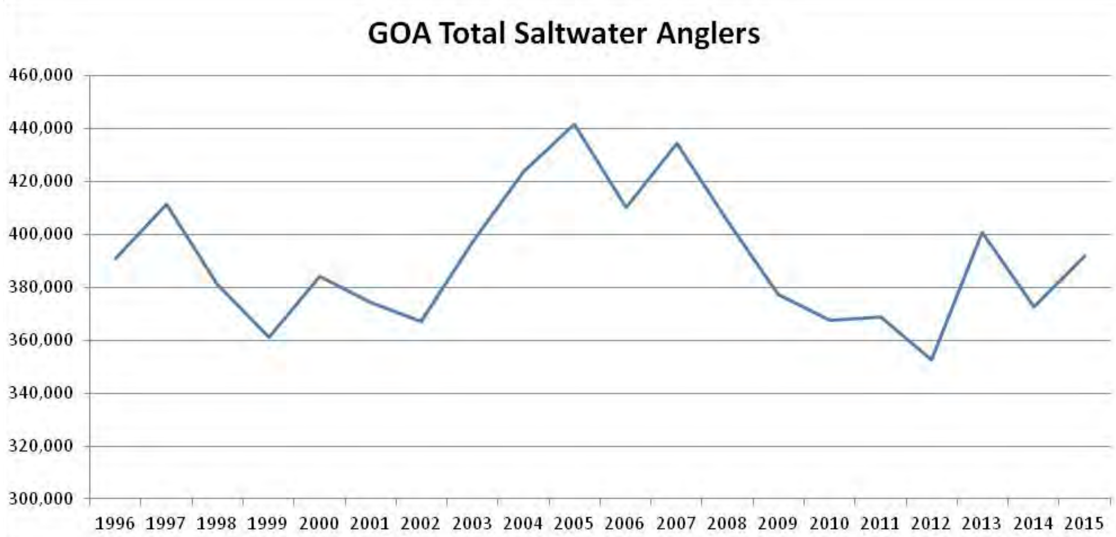


Figure 101: The number of saltwater anglers in the Gulf of Alaska.

**Factors influencing observed trends:** Saltwater recreational fishing participation in Alaska is influenced by a number of factors, including fishing regulations for target species, social and economic factors affecting the angler and the angler's household, and expected fishing conditions (e.g., stock size, timing and size of runs, weather, etc.). Pacific halibut and Pacific salmon (Chinook, coho, chum, sockeye, and pink salmon) are the most common target species, with other species less frequently being the principal target but being caught on trips targeting these species. Fishing regulations for these fish influence decisions about whether or not to fish, where to fish, what species to fish for, and by what means to fish (e.g., unguided or guided fishing).

Fishing regulations in the Pacific halibut sport fishery were first established in 1973, but have changed significantly over the years in the GOA (Meyer, 2010). Starting in 2007, more restrictive bag and size limit regulations were imposed for halibut caught on charter boat fishing trips in Southeast Alaska (74 Federal Register 21194). Beginning in 2014, Southcentral Alaska charter boat anglers began facing the same types of charter-specific bag and size limit and other restrictions (see `https://alaskafisheries.noaa.gov/fisheries/2c-3a-halibut-regs`). Under the Halibut Catch Sharing Plan (CSP), which went into effect during 2014, the management tools used to regulate harvest of Pacific halibut in the recreational sport sector are evaluated annually (79 Federal Register 13906).

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

Macroeconomic factors such as economy-wide recessions likely affect participation patterns in saltwater fishing in Alaska. Due to the expense of traveling to and from Alaska, it is likely that during times of economic hardship, there will be fewer non-resident saltwater anglers, resulting in fewer trips and days fished. Dips in annual saltwater fishing days and number of anglers during the period 2001 and 2002 and the period 2008 and 2012 can be seen, which may be a result of the brief 2001

Recession and the Great Recession (that began at the end of 2007). The increasing trend in the numbers of anglers and fishing days in recent years (2013–2015) may be related to an improving national economy. Population growth in Alaska and the U.S. may also impact fishing trends. While conditions in the larger state, national, and international economy are likely to explain some of the observed trends, the statistics generally reflect micro-level decisions made by individual anglers (Lew and Larson, 2011, 2012, 2015).

**Implications:** Monitoring the number of saltwater anglers and fishing days provides a general measure of fishing effort and participation in the saltwater sport fishery and can reflect changes in ecosystem conditions, target stock status, management, economic factors, demographic trends, and other economic, social, and cultural factors. Alaska is well-known for its sport fishing opportunities and draws anglers both from within and from outside Alaska. Saltwater recreational fishing can be a non-trivial source of extraction of several species (including Pacific halibut, Pacific salmon, and rockfish). Studies have indicated saltwater fishing in Alaska is valuable to anglers (Lew and Larson, 2011, 2012, 2015) and contributes to the economy by creating jobs and generating sales to fishing and non-fishing businesses and income to households (Lovell et al., 2013). Although there has been some variation over the past 15 years in annual fishing days and total saltwater anglers, the overall trends in recent years appear to be relatively stable. Thus, without significant changes in the ecological, economic, management, or socio-cultural factors that are likely to influence GOA-level participation in saltwater recreational fishing, it is likely that saltwater recreational fishing will remain at or near currently observed levels.

## Employment

### Trends in Unemployment in the Gulf of Alaska

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**Last updated: September 2017**

**Description of indicator:** Unemployment is a significant factor in the Gulf of Alaska (GOA) ecosystem, as it is an important indicator of community viability (Rasmussen et al., 2015). Advancements in socio-ecological systems research has demonstrated the importance of incorporating social variables in ecosystem management and monitoring, and unemployment reflects economic settings of a socio-ecological system (Turner et al., 2003; Ostrom, 2007).

This section summarizes trends in unemployment rates over time in the Gulf of Alaska (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. Unemployment data were aggregated and weighted to account for varying community populations across Alaska Boroughs. Estimates are presented annually from 1990–2017 (ADLWD, 2017). Population was calculated by aggregating community level data between 1890 and 1990 (DCCED, 2016) and annually from 1990–2015 (ADLWD, 2017).

**Status and trends:** Unemployment rates in the GOA from 1990 to 2016 were lower than state and national rates overall (Figure 102) with one exception in 2000 when the GOA unemployment rate was 4.5%, which was higher than the national rate of 4.0%. As of 2016, the GOA unemployment rate was slightly higher than the national rate (4.80 and 4.60 respectively). Spanning the years of 1990 to 2016 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. The unemployment rate in GOA communities increased from 4.59% in 2015 to 4.80% in 2016.

**Factors influencing observed trends:** Alaska has experienced several boom and bust economic cycles. Peaks in employment occurred during the construction of the Alaska pipeline in the 1970s and oil boom of the 1980s. In contrast, unemployment peaked following completion of the pipeline, during the oil bust of the late 1980s, and during the great recession of 2007–2009 (ADLWD, 2016*a*). However, during the great recession, Alaskas employment decreased only 0.4%, whereas the national drop was 4.3%, in part because of the jobs provided by the oil industry (ADLWD, 2016*b*). 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 102). In the GOA, seafood processing is a major contributor of jobs, despite being mainly comprised of low-wage, non-resident labor (ADLWD, 2016*a*).

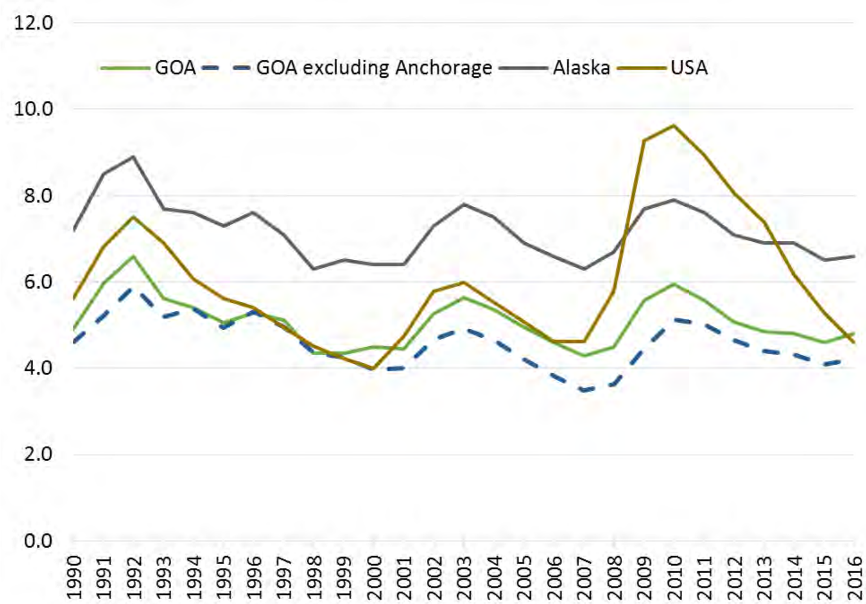


Figure 102: Unemployment rates for GOA, Alaska and USA

**Implications:** 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 may have implications for GOA community economies in both remote and urban areas.

## Socio-Cultural Dimensions

### Trends in Human Population in the Gulf of Alaska

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**Last updated: September 2017**

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

This section summarizes trends in human population over time in the 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 summing community level data at decadal scales from 1890–1990 (DCCED, 2016) and annually from 1990–2016 (ADLWD, 2017).

**Status and trends:** As of 2016 the population of GOA was 456,556 or 157,519 excluding Anchorage. The population of small communities (population less than 1,500) was 26,000. The population of all GOA communities has increased steadily since 1880 with the greatest population increase of 194.2% occurring between 1950 and 1960 (Table 7). 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 (ADLWD2017a). With Anchorage excluded, and for small communities, the greatest population increase of 50.2% 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 2016, the population of GOA increased 32.0% (31.8% excluding Anchorage) which is consistent with, yet lower than, state trends across this time period (34.5%)(Figure 103).

Despite the general population trend in the GOA as a whole, 41.2% of communities experienced population decline between 1990 and 2016. The communities of Hobart Bay, Annette, Meyers Chuck and Cube Cove had no population data as of 2010. Communities of Ivanof Bay, Elfin Cove, Karluk, Pelican City, Point Baker, and Cold Bay also had decreases in population ranging from

Table 7: Gulf of Alaska (GOA) population 1880–2016. Percent change rates are decadal until 2010.

| Year | Alaska | % change | GOA | % change | GOA excluding Anchorage | GOA % change excluding Anchorage |
|---|---|---|---|---|---|---|
| 1880 | 33,426 | | 3,151 | | 3,151 | |
| 1890 | 32,052 | -4.11 | 7,469 | 137.04 | 7,469 | 137.04 |
| 1900 | 63,592 | 98.40 | 10,499 | 40.57 | 10,499 | 40.57 |
| 1910 | 64,356 | 1.20 | 13,394 | 27.57 | 13,394 | 27.57 |
| 1920 | 55,036 | -14.48 | 17,208 | 28.48 | 15,352 | 14.62 |
| 1930 | 59,278 | 7.71 | 21,633 | 25.71 | 19,356 | 26.08 |
| 1940 | 72,524 | 22.35 | 29,213 | 35.04 | 25,718 | 32.87 |
| 1950 | 128,643 | 77.38 | 41,960 | 43.63 | 30,706 | 19.39 |
| 1960 | 226,167 | 75.81 | 123,456 | 194.22 | 40,623 | 32.30 |
| 1970 | 302,583 | 33.79 | 181,414 | 46.95 | 56,872 | 40.00 |
| 1980 | 401,851 | 32.81 | 253,961 | 39.99 | 79,530 | 39.84 |
| 1990 | 550,043 | 36.88 | 342,521 | 34.87 | 116,183 | 46.09 |
| 2000 | 626,932 | 13.98 | 400,222 | 16.85 | 139,939 | 20.45 |
| 2010 | 710,231 | 13.29 | 437,413 | 9.29 | 145,587 | 4.04 |
| 2016 | 739,828 | 4.17 | 456,556 | 2.98 | 157,519 | 3.96 |

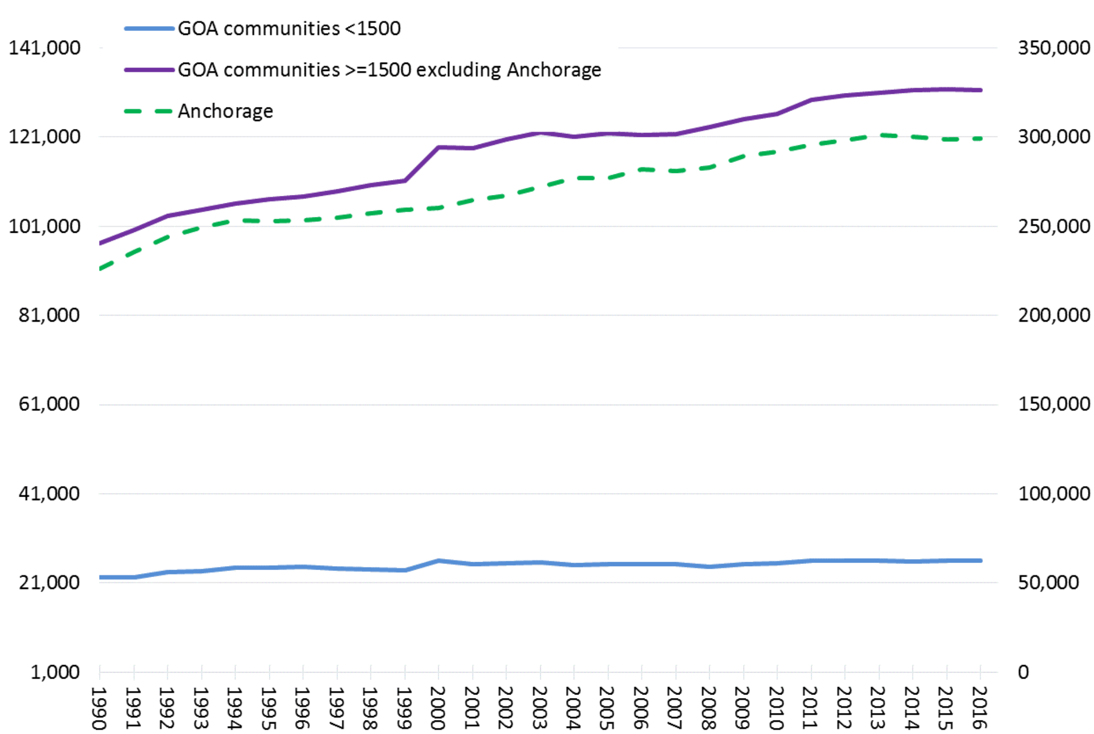


Figure 103: Gulf of Alaska population 1990–2016. Anchorage is presented on the second (right) axis.

60.1% to 80.0%. In contrast, the community of Kalifornsky experience a population increase of over 2,900% during this time period.

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 Native American (ADLWD, 2016*c*), 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). The majority of population growth that has occurred in Alaska and the GOA is of the Caucasian demographic (ADLWD, 2016*c*).

**Factors influencing observed trends:** Overall population increase in GOA between 1990 and 2016 (31.8%) was consistent with state trends (34.5%). Alaska has high rates of population turnover because of migration, and population growth has occurred mainly in urban areas (ADLWD, 2016*c*). The main factors that affect population growth are natural increase (births minus deaths) and migration, with the latter being the most unpredictable aspect of population change (Williams, 2004; ADLWD, 2016*c*). In 2010, 61% of Alaskas population was born out of state (Rasmussen et al. 2015). In terms of natural growth, from 2010 to 2014 the average annual birth rate in Alaska was 1.6 per 100 people which was higher than the national rate of 1.3 (ADLWD, 2016*c*). From 2010–2014 the Aleutian chain and Southeast Alaska had the lowest natural increase (0.0–1.0%) whereas the Northern Bering Sea area had the highest (1.5–3.0%). The natural growth rates of the GOA had a range of 0.0–1.5% (ADLWD, 2016*c*). The the GOA region has the highest net migration in the state, and the Matanuska-Susitna Borough has the highest growth rate (ADLWD, 2016*c*).

Population trends in Alaska 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 (ADLWD2016c). 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 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 and was zero in subsequent years (ADLWD, 2017).

**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 they have mainly occurred in urban areas as populations in many small communities are declining. Fisheries contribute to community vitality of the GOA. 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.

### Trends in School Enrollment in the Gulf of Alaska

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

Public school enrollment was analyzed in the Gulf of Alaska (GOA) by borough and community level in order to examine broader regional trends as well as the social and economic vitality of individual rural communities. Fishing communities were defined as in Lavoie p. 196. Enrollment statistics for K-12 grades by school and region were compiled for the years 1996–2014 from The National Center for Educational Statistics (`https://nces.ed.gov/ccd/elsi/tableGenerator.aspx`). More recent enrollment data were available for years 2014–2017 from the Alaska Department of Education and Early Development (`http://www.eed.state.ak.us/stats/`). Current school locations and names were verified using the EPA EJ mapping tool (`https://ejscreen.epa.gov/mapper/`). Municipalities or boroughs with enrollment over 4,500 were excluded from the analysis in order to avoid skewing the results (these included were the Matanuska-Susitna Borough, Juneau Borough, and Anchorage Municipality).

**Status and trends:** School enrollment patterns vary considerably in the GOA by rural and urban areas and by population of the municipality. Within municipalities where school enrollment is over 500 students, school enrollment remains fairly stable, showing a general slight decrease in enrollment. Overall, there is a general decrease in enrollment. The exception to this is Kenai City which has an increase in enrollment from 1424 students in 1996 to 1787 students in 2017, an increase of 26 percent. In contrast school enrollment in Homer decreased nearly 50 percent among those schools with over 500 students with 2302 students in 1996 and 1186 in currently (Figure 104).

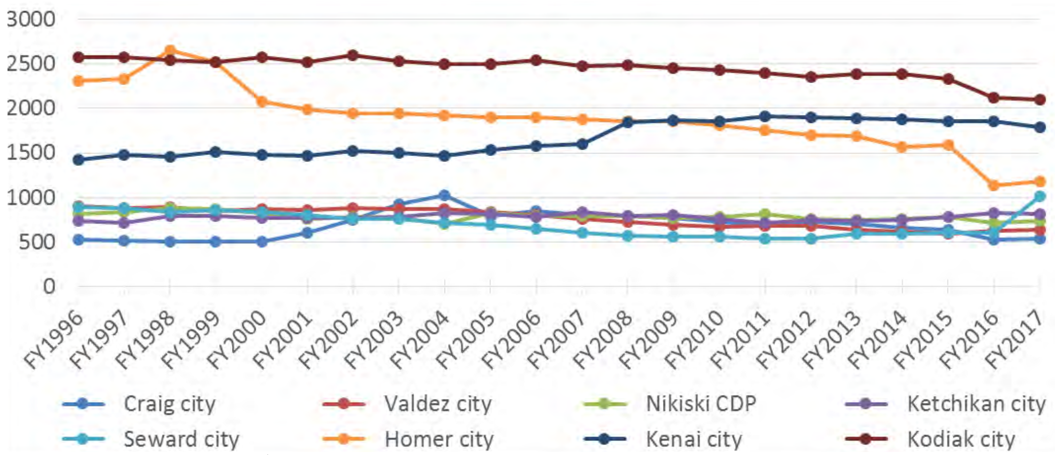

Figure 104: GOA fishing community schools with enrollment over 500 students.

In municipalities with school enrollment between 100 and 500 students, there is a downward trend for several schools including Hoonah City which decreased 60 percent, from 273 students to 109 students since 1996, and Petersburg City and Angoon City, which both decreased 50% (Figure 105).

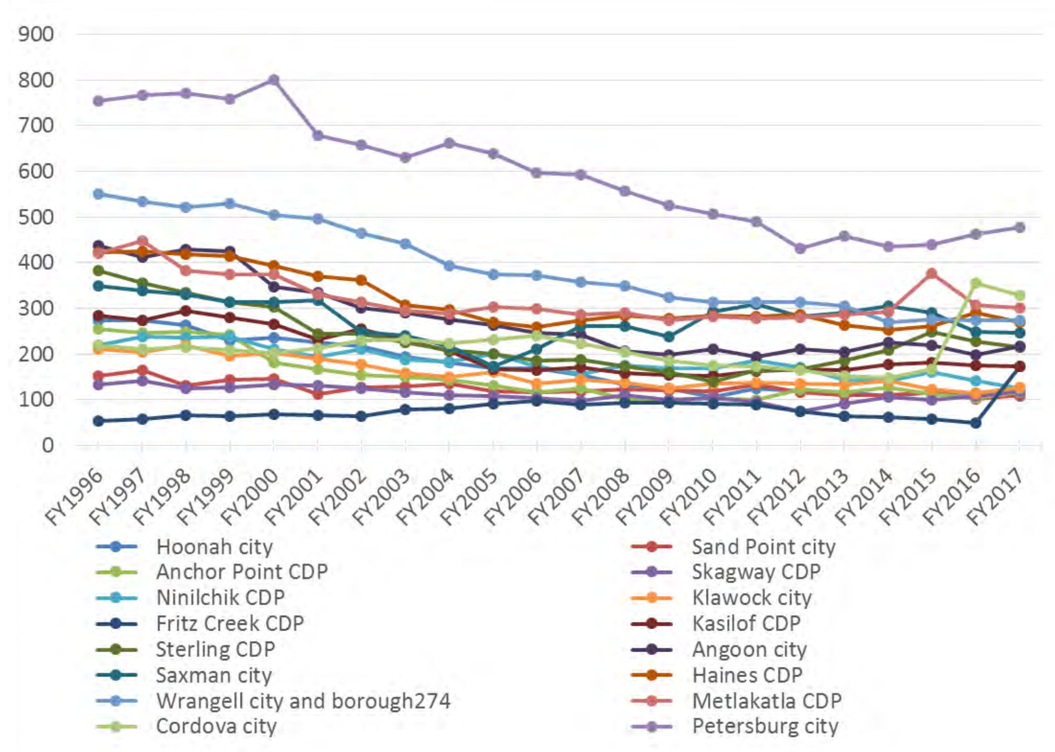


Figure 105: GOA fishing community schools with enrollment between 500 and 100 students.

A majority of schools have enrollment under 100 students. Schools in smaller communities tend to have more variable enrollment trends. To illustrate, Figure 106 depicts Kodiak Island Borough

Table 8: GOA fishing community schools with enrollment of 30 or fewer students.

| Status | Previously open now closed | ≤15 students | 16–30 students |
|---|---|---|---|
| Number of Schools | 7 | 12 | 14 |
| | Cube Cove CDP<br>Elfin Cove CDP<br>Edna Bay city<br>Ivanof Bay CDP<br>Meyers Chuck CDP<br>Port Protection CDP<br>Tenakee Springs city | Chenega CDP<br>Chignik city<br>Chignik Lagoon CDP<br>Hyder CDP<br>Karluk CDP<br>Kasaan city<br>Klukwan CDP<br>Moose Pass CDP<br>Pelican city<br>Perryville CDP<br>Port Alexander city<br>Port Lions city | Chignik Lake CDP<br>Coffman Cove city<br>Cooper Landing CDP<br>Hope CDP<br>Larsen Bay city<br>Tatitlek CDP<br>Whale Pass CDP<br>Tyonek CDP<br>Old Harbor city<br>Akhiok city<br>Chiniak CDP<br>Ouzinkie city<br>Hollis CDP<br>Naukati Bay CDP |

schools, with enrollments currently ranging from10 to 29. There is some fluctuation in enrollment, but an overall downward trend. Two schools dropped in enrollment forcing periodic school closures. The Karluk School first opened in 2001 with 10 students, closed in 2003, and re-opened in 2006 with 10. Chiniak School closed in 2009 when enrollment dipped below the 10 student threshold, and re-opening in 2011. As of 2017, 27 schools have enrollment under 30, and 12 schools have enrollments under 15 students (Table 8).

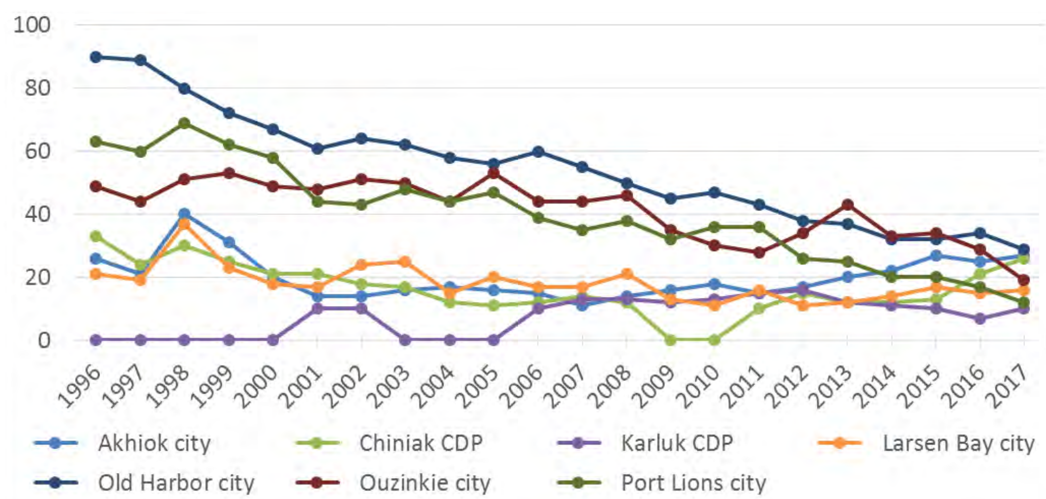

Figure 106: School enrollment in the Kodiak Island Borough.

**Factors influencing observed trends:** The GOA ecoregion varies substantially in population and community structure and vitality. The GOA holds several larger municipalities, with larger school enrollment, compared to other regions of Alaska. As people migrate to other areas, populations increase in adjacent communities. It is possible that enrollment may shift to the larger communities as more convenient schools open. However other factors must be considered including existing infrastructure such as functional ports, airports, or medical facilities to provide support for a viable community structure. Those schools with enrollment under 30 students experience the greatest uncertainty in terms of educational stability. With greater fluctuation in school enrollment, rural area schools are particularly vulnerable to closure and possible community disruption. The reasons for decreasing enrollment likely involve complex social and economic drivers including migratory patterns, resource availability, and employment. Additional research into the specific reasons for diminishing school enrollment in rural areas, as well as the impacts on these communities would inform and benefit management decisions.

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

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