Ecosystem Considerations 2015

Status of Alaska's Marine Ecosystems

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Bering Sea, Aleutian Islands, and Gulf of Alaska

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Eastern Bering Sea 2015 Report Card

- The **eastern Bering Sea in 2015 was characterized by warm conditions** that were first seen in 2014, and continued through the winter, during which the **PDO reached the highest winter value seen** in the record extending back to 1900.
- The extent of **sea ice during winter was reduced, as was as the size of the cold pool of bottom water** relative to the long term mean during the summer.
- While there was no acoustic survey of euphausiids during summer, rough counts of zooplankton during spring indicated that **small copepods were more prevalent than either lipid-rich large copepods or euphausiids**.
- **Jellyfish remained abundant** during summer, following a new peak fall biomass recorded in 2014.
- **Survey biomass of motile epifauna has been above its long-term mean** since 2010, with no trend in the past 5 years. There has been a unimodal increase in brittle stars since 1989 and for sea urchins, sea cucumbers and sand dollars since 2004-2005.
- **Survey biomass of benthic foragers decreased substantially in 2015, which contributed to the change in their previously stable recent trend to negative.** Recent declines could possibly be related to the consecutive years of springtime drift patterns that have been linked with poor recruitment of flatfish.
- **Survey biomass of pelagic foragers has increased steadily** since 2009 and is currently above its 30-year mean. While this is primarily driven by the **increase in walleye pollock** from its historical low in the survey in 2009, it is also a result of **increases in capelin during the cold years**, which have remained high during the past two warm years.
- **Fish apex predator survey biomass is currently above its 30-year mean**, although the increasing trend seen in recent years has leveled off. **The increase from below average values in 2009** back towards the long term mean is driven primarily by increases in Pacific cod from low levels in the early 2000s.
- **The multivariate seabird breeding index is below the long term mean**, indicating that seabirds bred later and less successfully in 2015. This suggests that **foraging conditions were not favorable for piscivorous seabirds**, a hypothesis further supported by large numbers of dead, emaciated birds observed at sea.
- **Northern fur seal pup production for St. Paul Island remained low** in 2014, indicating that fewer pups were produced in 2014 than during the year of the last survey in 2012.
- The maximum potential **area of seafloor habitat disturbed by trawl gear has remained stable since 2011**.

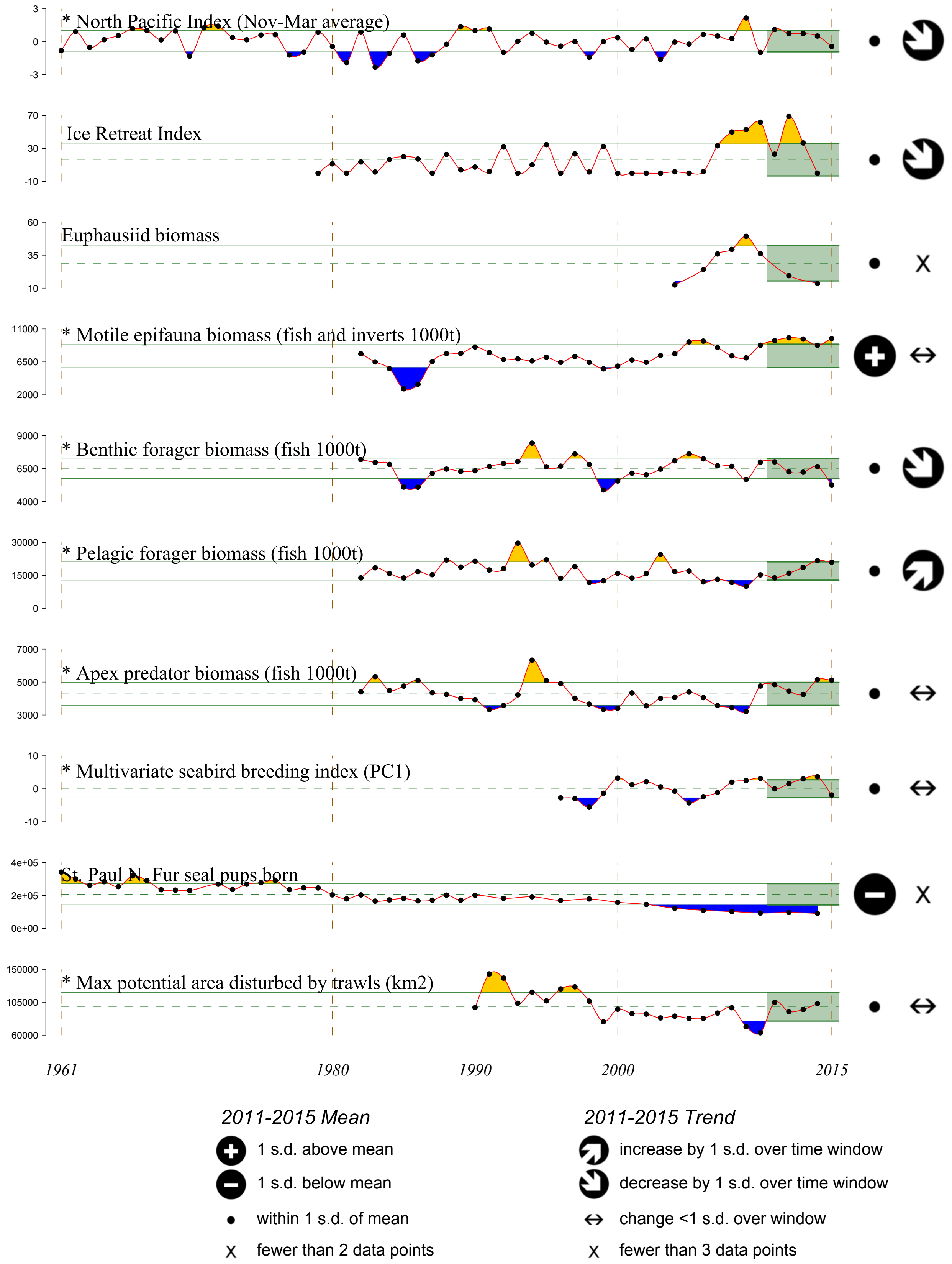

Figure 1: Eastern Bering Sea ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2015.

Aleutian Islands 2015 Report Card

Region-wide

- The state of the North Pacific atmosphere-ocean system during 2014-2015 featured the **continuance of strongly positive SST anomalies** that began in 2013-2014.
- The NPI was negative during the fall and early winter, implying a strong and often displaced Aleutian Low. The generally **negative values of the NPI are consistent with the positive trend in the PDO**.
- Some of the **abnormally warm water that developed in the NE Pacific during early 2014 appears to have made it to the Aleutians and through the eastern Aleutian passes** into the Bering Sea, presumably during the winter when the local winds were favorable for northward transports.
- During the period from fall 2014 to summer 2015, **upper ocean temperature anomalies** in the western Aleutians **cooled from above normal to near normal**. These anomalies remained generally above normal along the arc of the eastern Aleutian Islands
- In general, **schools in the Aleutian Islands have shown no recent trends in enrollment**, possibly indicating that communities with year-round residents that experience direct interactions with the ecosystem through residential and subsistence activites are stable.

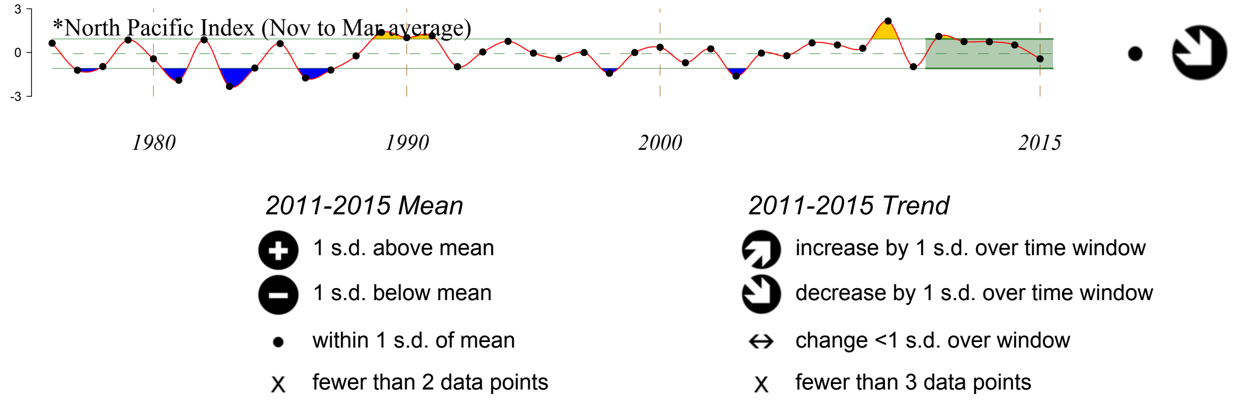

Figure 2: The winter North Pacific Index time series. * indicates time series updated in 2015.

Western Aleutian Islands Ecoregion

- While the reproductive success of planktivorous least auklets declined in 2015, that of crested auklets increased from the low level seen in 2014. Crested auklets rely more on euphausiids than the copepod-specialist least auklets, thus **we can speculate that copepod availability was poor in 2015**.
- Forage fish trends as indicated in tufted puffin chick meals have varied over the long term. In general, sand lance have been absent since 2010, and age-0 gadids uncommon. The **number of hexagrammids (likely age-0 Atka mackerel) declined relative to the past two years, possibly indicating poor recruitment**.
- Steller **sea lions remain below their long-term mean** in this ecoregion, although there has been no significant trend in the past 5 years. The 2014 counts were the lowest in the time series.

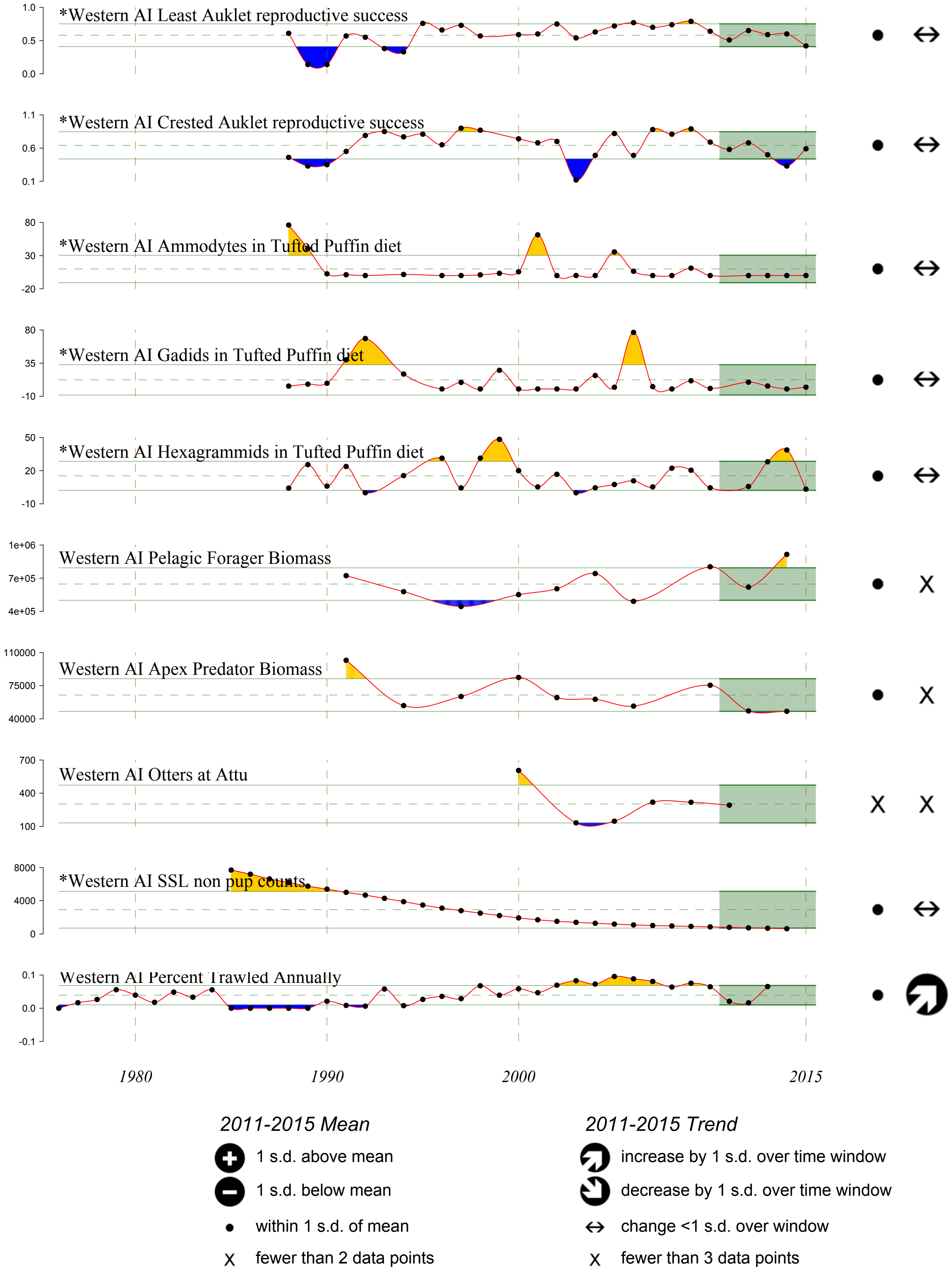

Figure 3: Western Aleutian Islands ecoregion indicators. * indicates time series updated in 2015. See Figure 2 for legend.

Central Aleutian Islands Ecoregion

- **Counts of non-pup Steller sea lions remain below the long term mean** although there is no significant trend in the past 5 years.
- **School enrollment has shown no trend** in recent years, following a decline since peak enrollment in 2000, and potentially indicating stability in the residential communities.

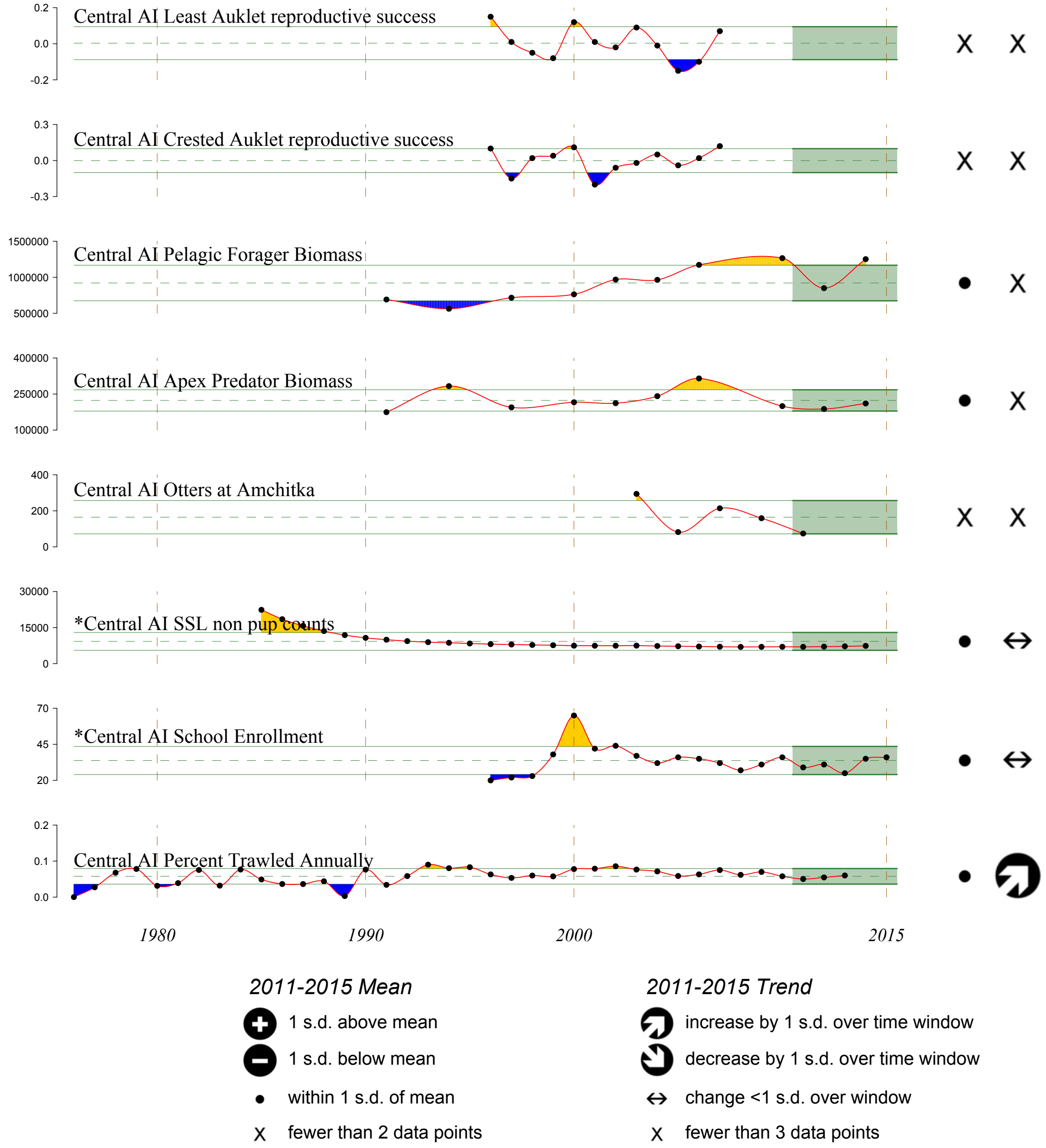

Figure 4: Central Aleutian Islands ecoregion indicators. * indicates time series updated in 2015. See Figure 2 for legend.

Eastern Aleutian Islands Ecoregion

- Relative abundances of **gadids and *Ammodytes*** in prey brought back to feed puffin chicks **have shown opposite trends, although both declined in recent years. Age-0 gadids were uncommon in 2015** Chick-provisioning patterns suggest puffins are responding to changes in forage fish availability.
- In contrast to the other ecoregions, **non-pup counts of Steller sea lions remained high** during the last count in 2014. Counts were largely stable through the 1990s, but increased at a rate of 3% per year between 2000 and 2008.
- **School enrollment has shown no trend in the past five years**, despite peak enrollment in 2014. These numbers suggest communities are stable in the eastern ecoregion communities.

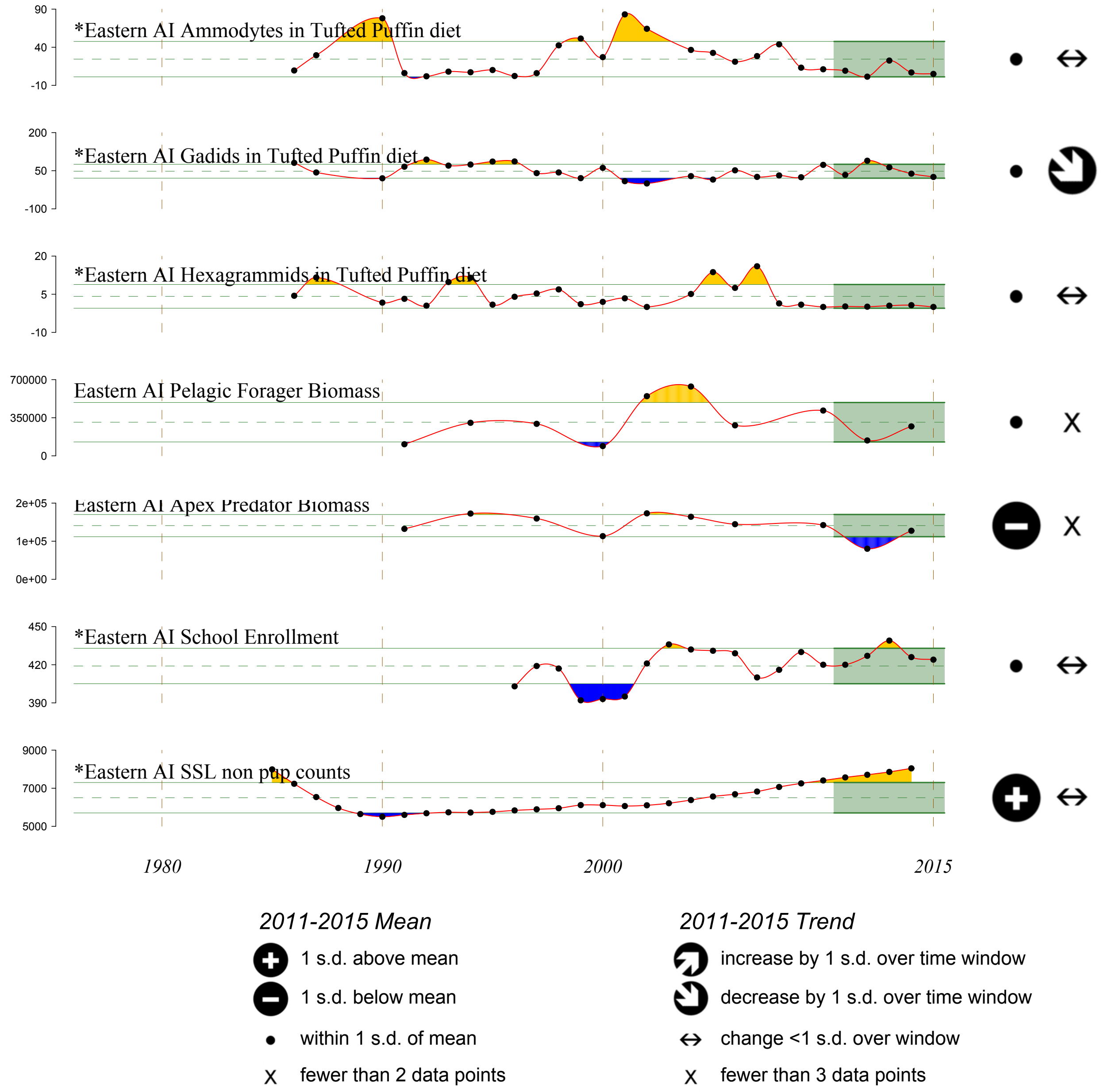

Figure 5: Eastern Aleutian Islands ecoregion indicators. * indicates time series updated in 2015. See Figure 2 for legend.

Gulf of Alaska 2015 Report Card

- The Gulf of Alaska in 2015 was **characterized by warm conditions** that were first seen in 2014, and continued through the winter, during which **the PDO reached the highest winter value seen** in the record extending back to 1900.
- **Fresh water input as estimated at the GAK1 station has been variable** over the long time series. The most recent data indicate an increasing trend.
- **Mesozooplankton biomass measured by the continuous plankton recorder has shown a biennial trend since 2009**, with higher biomass recorded during even-number years. Biomass trends can be influenced by ecosystem conditions and mean size of the community. This suggests that prey availability for planktivorous fish, seabirds, and mammals has been variable recently. The biennial patterns suggests a **possible link with biennially varying planktivorous pink salmon abundance**.
- **Copepod community size has been declining in recent years**. The prevalence of small copepods during 2014 fits predictions of warm conditions favoring small copepods. This suggests that **less lipid-rich prey were available to planktivorous predators**.
- **Survey biomass of motile epifauna** has been **above its long-term mean** since 2001. The increase from 1987 to 2001 was driven by hermit crabs and brittle stars, which dominate the biomass. Since 2001 their biomass has been stable. Record catches of octopus influenced the increased estimate in 2015.
- **Trends in capelin captured by tufted puffins at the Barren Islands have been variable** in the 20 year time series. **Capelin comprised the majority of chick diets in 2000 and were generally abundant from 2003 - 2008, but have been at or below the mean since that time**. It is unknown whether these trends reflect capelin abundance or prey preferences of the puffins.
- **Fish apex predator survey biomass is currently below its 30-year mean**, although the declining trend seen in recent years has leveled off. **The trend is driven primarily by arrowtooth flounder** which, along with halibut, had been declining since 2005. Both increased slightly in 2015. It is unknown whether these increases were due to distributional shifts in the warm water. **Pacific cod has declined from a peak survey biomass in 2009**.
- With the exception of 2014, **black-legged kittiwake reproductive success has been poor** in the Semedi Islands, indicating that conditions were not favorable for these surface-foraging piscivorous seabirds. This may reflect poor conditions prior to the breeding season, during, or both.
- Modelled estimates of total Gulf of Alaska **Steller sea lion non-pups counts are approaching the long term mean**. This slowly increasing pattern since 2000 reflects the combination of increasing trends in the eastern population with declining trends in the western popoulation.
- Human populations in the Gulf of Alaska coastal towns of **Homer, Kodiak, Sitka, and Yakutat are above their 25 year mean**. Homer is the sole town with a steadily increasing trend. Kodiak saw declines until 2006 and has recovered slightly since then.

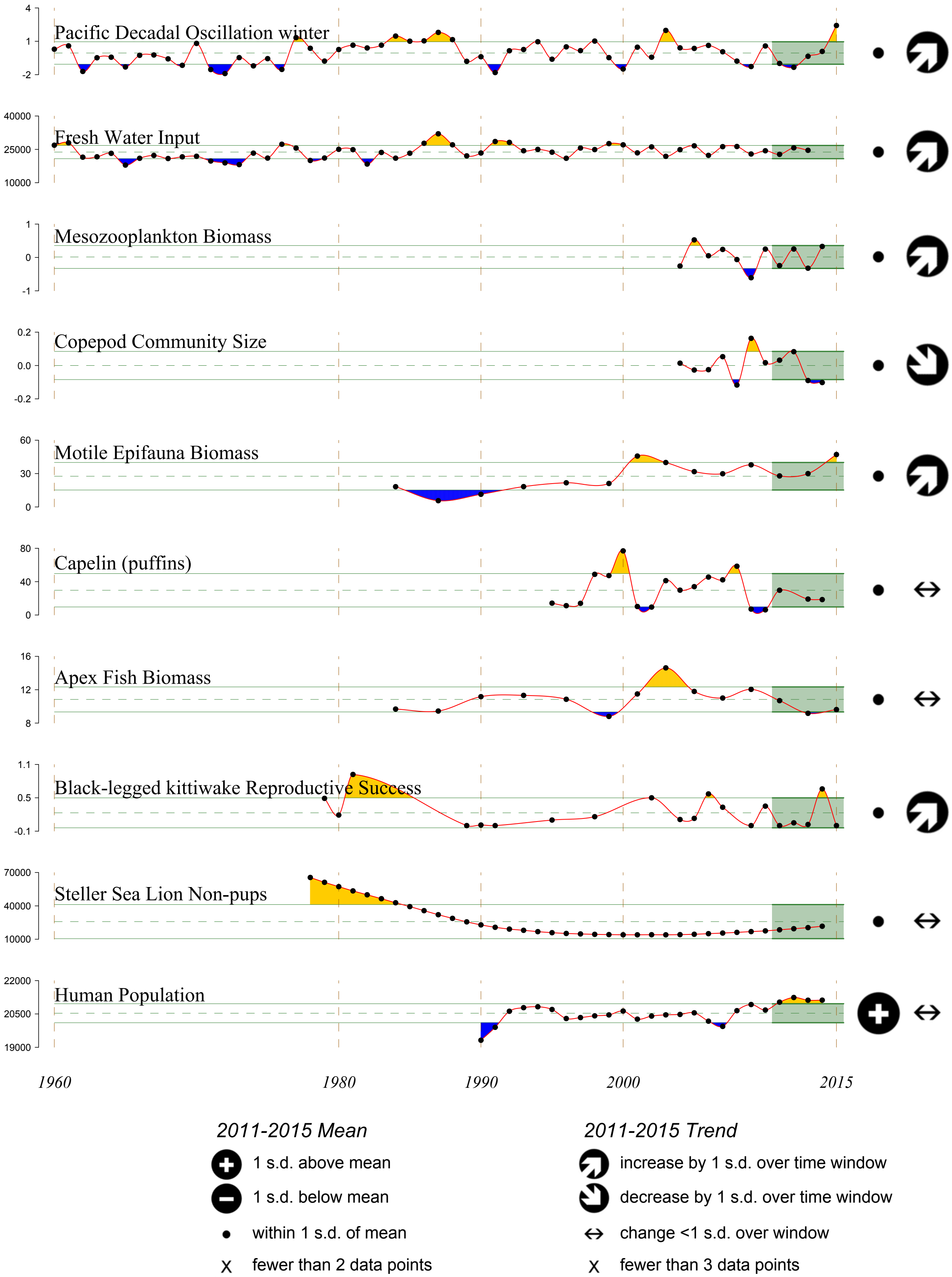

Figure 6: Eastern Bering Sea ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2015.

Executive Summary of Recent Trends

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

Physical and Environmental Trends

- The state of the North Pacific atmosphere-ocean system during 2014-2015 featured the continuance of strongly positive SST anomalies that began in 2013-2014 (p. 90).
- The sea surface temperature patterns can be attributed to the seasonal mean sea level pressure and wind anomalies such as the cyclonic wind anomalies in the central Gulf of Alaska in fall 2014 and winter 2015, with a reversal to anticyclonic flow in the following spring and summer of 2015 (p. 90).
- The Pacific Decadal Oscillation (PDO) was positive during the past year, especially so during the winter months, and the North Pacific Gyre Oscillation (NPGO) was moderately negative. Both climate indices maintained their transitions in sign from the year before (p. 95).
- Anomalously positive sea surface temperatures are predicted throughout much of the north east Pacific during the upcoming winter (p. 97).
- The climate models used for seasonal weather predictions are indicating strong El Niño conditions for the winter of 2015-16, and its usual impacts on the mid-latitude atmospheric circulation, which should serve to maintain a positive state for the PDO (p. 97).

Arctic

- The timing of the onset of ice in the Chukchi and coastal portion of the Beaufort Sea during fall 2014 was comparable to that of most recent years (p. 90).
- Air temperatures were systematically higher than normal from fall 2014 through spring 2015. It remained relatively warm in the Chukchi Sea through the summer of 2015, but temperatures were near normal in the Beaufort Sea where the ice was slow to retreat with a band of ice just off the coast east of Barrow that persisted through late summer (p. 90).
- The average September Arctic sea ice extent for 2015 was the fourth lowest in the satellite record. The seasonal daily minimum ice extent of 4.41 million square kilometers was likely set on September 11th (p. 99).

Eastern Bering Sea

- The warm year of 2015 followed the warm year of 2014 in breaking the unusual sequence of seven years with cold winter-spring temperatures (2007-2013), following the seven warm temperature years (2000-2006) (p. 99).
- Sea ice maximum extent was reduced (p. 90 and 99).
- Anomalous warming was particularly prominent during spring 2015 (p. 90).
- November through June 2015 near surface air temperature anomalies in the southeastern Bering Sea were +3°C, compared to +2°C in 2014 and in contrast to 2013 at -2.5°C and 2012 at -3°C (p. 99).
- The summer cold pool during 2014 was mostly restricted to north of 60°N (p. 99).
- Summer was characterized by a return to long term climatological air temperatures with a typical amount of storminess (p. 90 and 99).
- Time series of temperature and salinities above and below the mixed layer depth show spatial and temporal variation among the BSIERP regions of the eastern Bering Sea (p. 107).
- The mixed layer depth was shallow in 2014 (p. 107).
- The 2015 springtime drift patterns on the southern Eastern Bering Sea shelf appear to be consistent with years of good recruitment for northern rock sole, arrowtooth flounder and flathead sole, following three years (2012-2014) of wind patterns that were not consistent with strong recruitment (p. 110).

Aleutian Islands

- Some of the abnormally warm water that developed in the NE Pacific during early 2014 appears to have made it to the Aleutians and through the eastern Aleutian passes into the Bering Sea, presumably during the winter when the local winds were favorable for northward transports (p. 90).
- During the period from fall 2014 to summer 2015, upper ocean temperature anomalies in the western Aleutians cooled from above normal to near normal. These anomalies remained general above normal along the arc of the eastern Aleutian Islands and Alaska Peninsula (p. 90).
- Eddy energy in the region was low from the fall 2012 through July 2015, indicating that average volume, heat, salt, and nutrient fluxes through Amukta Pass were likely smaller during the this time (p. 112).

Gulf of Alaska

- The upper ocean in this region was fresher than usual with a relatively strong pycnocline (p. 90).
- The coastal winds were upwelling favorable in an anomalous sense, which helped maintain relatively normal SST along the coast as compared with the much warmer than normal water offshore (p. 90).
- The sub-arctic front was farther north than usual, which is consistent with the poleward surface currents shown in the Ocean Surface Currents - Papa Trajectory Index (p. 116).
- Eddy Kinetic Energy (EKE) levels in the western Gulf of Alaska were particularly weak in summer of 2014. Thus, phytoplankton biomass were likely more tightly confined to the shelf in those years and cross-shelf transport of heat, salinity and nutrients were probably weak (p. 114).
- In the northern Gulf, relatively high eddy kinetic energy was observed in the summer of 2014 (p. 114).
- It now appears the filtered PAPA Trajectory Index may shift back to northerly flow, which would indicate that the recent period of predominantly southern flow (mid-2000s to present) will have been the shortest and weakest in the time series (p. 116).

Ecosystem Trends

Eastern Bering Sea

- EcoFOCI implemented a new spring zooplankton rapid assessment to provide within-year preliminary estimates of zooplankton abundance and community structure. Zooplankton are sorted and enumerated within coarse categories: small copepods, large copepods, and euphausiids (p. 126).
- Small copepods made up the majority of plankton at four of six stations; large copepods and juvenile euphausiids were more abundant near the ice edge (p. 126).
- Continuous plankton recorder observations indicated that the 2014 copepod community size was average in the southern Bering Sea regions; however, mesozooplankton biomass was below average and large diatom abundance remained above average for the second year(p. 137).
- Jellyfish biomass during fall 2014 BASIS surveys in the north remained consistent with a slight increase to previous years. The biomass in the south was the highest year on record for the 11 years of this survey. The dominant species in terms of biomass and abundance remained *C. melanaster* (p. 141).
- In 2015, aerial surveys of Togiak District herring recorded 228,022 tons, which is approximately the most recent 10-year average and 131% of the 20-year average (p. 151).
- The 2014 Bristol Bay sockeye salmon run of 41.1 million fish was 55% above the preseason forecast of 26.6 million, and was 19% above the recent 20-year average (1994-2013) of 34.7 million. Chinook salmon abundance in the Arctic-Yukon-Kuskokwim region has been declining since 2007 and no commercial periods targeting Chinook salmon were allowed in the Yukon Area during the 2014 summer season (p. 157.
- Young of year pollock energy density increased from values near 3.63 kJ/g in 2003 to 5.26 kJ/g in 2010. In 2014 the average energy content was intermediate (9.75 kJ/fish); thus the model predicts an intermediate level of recruits per spawner in 2017 (p. 171).
- For the 2003-2010 year classes of pollock, a positive significant linear relationship was found between mean abundances of large zooplankton at year t (when pollock were age-0), and age-3 pollock abundance at year t+3. A strong relationship was also observed for large zooplankton and age-3 pollock abundance (t+3)/ spawner biomass (t). These results suggest that increases in the availability of large zooplankton prey during the first year at sea were favorable for age-0 pollock survival and recruitment into the fishery at age-3.
- The 2015 Temperature Change (TC) index value was above the long term average, therefore slightly above average numbers of pollock are expected to survive to age-3 in 2015. In the future, the TC values in 2015 indicate an expected below average abundance of age-3 pollock in 2017 (p. 174).
- Below average age-1 pollock recruitment is expected in 2015 based on 2014 biophysical indices indicating below average ocean productivity (chum salmon growth), warm spring sea temperatures (less favorable), and above average predator abundances (pink salmon) (p. 177).
- A new indicator reports trends in age-1 total mortality for pollock, cod, and arrowtooth flounder based on residual mortality inputs and model estimates of annual predation mortality produced from the multi-species statistical catch-at-age assessment model known as CEATTLE. Age-1 natural mortality (i.e., M1+M2) for pollock, cod and arrowtooth flounder was highest between 1980-2000 and has been marginally lower in the last 20 years. Predation by arrowtooth flounder has exceeded cannibalism as the largest source of predation mortality of age-1 pollock since 2007 (p. 179).
- Groundfish length-weight residuals (a measure of fish condition) have varied over time for all species with a few notable patterns. There has been a distinct negative trend in Pacific cod since a peak value in 2003. Age 1 walleye pollock and older walleye pollock are not well correlated in most years. Length-weight residuals for all species were lower in 2015 than in 2014 indicating smaller weight at length. Spatial trends in residuals were also apparent for some species (p. 182)

- New early warning indicators are designed to detect an increased risk of a tipping point to an alternate state in a population or community. Results of three types of early warning indicators are consistent with declining community resilience during the cold period, and recovered resilience with warming in 2014 (p. 209).
- Total trawl survey CPUE in the EBS shows an apparent long-term increase from 1982-2005, followed by a decrease from 2005 to 2009 increase in 2010-2013, and a substantial increase in 2014 to the highest oberved value in the time series. Recent changes in CPUE in the EBS have been most pronounced on the middle-shelf, which is occupied by the cold pool during cold years. Higher CPUEs on the middle shelf during the 2001-2005 warm period appeared to be related to the increasing colonization of this area by subarctic demersal species (p. 211).
- Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2014. Richness tends to be highest along the 100 m isobath, while diversity tends to be highest on the middle shelf (p. 214).
- Both the latitudinal and depth distribution of the demersal community on the eastern Bering Sea shelf show strong directional trends over the last three decades, indicating significant distributional shifts to the north and into shallower waters. On average, there was a gradual shift to the north from 2001 to 2005, which reversed as temperatures cooled after 2006. From 2009 through 2014, the average center of gravity temporarily has shifted between deeper and shallower waters (SW-NE axis) and in 2014 was further NE and shallower than in most years (p. 218).

Aleutian Islands

- The distributions of rougheye rockfish, shortspine thornyhead, and shortraker rockfish have been shallower in the most recent surveys of the Aleutian Islands (last surveyed in 2014). Northern rockfish have shown a significant trend in their mean-weighted distribution towards the Western Aleutians. Mean-weighted temperature distributions for all rockfish species were stable within about 1°C over the entire time series, although since 2000 the mean-weighted temperature distributions have decreased for most species (0.1 - 0.5°C)(p. 191).

Gulf of Alaska

- EcoFOCI implemented a new spring zooplankton rapid assessment to provide within-year preliminary estimates of zooplankton abundance and community structure. Zooplankton are sorted and enumerated within coarse categories: small copepods, large copepods, and euphausiids (p. 127).
- Small copepods were more abundant than large copepods or euphausiids. Large copepods were more abundant east of the Shumagin Islands. Euphausiids were more abundant on the southeastern side of Kodiak (p. 127).
- The highest overall abundance of euphausiids observed during the summer acoustic survey was in 2011, with lowest euphausiid abundance in 2003. There was a small decline in 2015 relative to 2013 (p. 128).
- Total Icy Strait zooplankton density was anomalously low for all months during the 2014 summer survey. Density anomalies were mostly negative from 1997-2005, mostly positive from 2006-2013 (p. 132).
- Icy Strait zooplankton were numerically dominated by calanoid copepods. In 2014, large calanoids were anomalously low while small calanoids were anomalously positive (p. 132).
- In the Alaskan Shelf region sampled by the continuous plankton recorder, copepod community size anomalies remained negative, while mesozooplankton biomass anomalies became positive in 2014. Large diatom abundance anomalies was average (p. 137).

- Jellyfish CPUE in the bottom trawl survey remained low in the western GOA. In contrast, catches in the central GOA during the last two surveys have been the highest since 1990 (p. 144).
- Jellyfish biomass during 2014 GOA IERP surveys was the largest relative to the previous four years. In contrast to jellyfish catches in the EBS, the GOA catches are more diverse, with *Aequorea* and *Chrysaora* as the top two geni (p. 142).
- The icthyoplankton abundance timeseries was extended to 2013, after no survey during 2012. The abundance of pollock larvae in 2013 was the largest since 1981. Rockfish and cod larvae also showed record high abundances during 2013 (p. 146).
- Although the estimated total mature herring biomass in southeastern Alaska has been above the long-term (1980-2014) median of 91,281 tons since 1997, a decrease in biomass has been observed since the peak in 2011. The most notable drop in biomass was observed in Hoonah Sound (p. 152).
- The total number of salmon harvested in 2014 was 44% of the record peak harvest in 2013. Marine survival of Prince William Sound hatchery pink salmon does not appear to have shifted after the 1988/89 or the 1998/99 climate regime shifts. Marine survival was 11.33% in 2013, an all-time high since 1979 (p. 157).
- A new indicator from the Auke Creek Weir in Southeast Alaska provides the longest-running continuous time series of coho salmon survival estimates available in the North Pacific. Trends provide an 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. The historical trend shows marine survival of wild coho salmon from Auke Creek varies from 11.7% to 47.8%, with an average survival of 24.1% from smolt years 1980-2013. Marine survival for 2013 was 22.7% (p. 165).
- Ecosystem indicators predict a low 2015 pink salmon harvest in southeast Alaska of about 54 M fish, somewhat above the historical average. However, as of October 2015, harvests have been only 34 M fish, with lower than expected returns particularly in the southern portion (p. 161).
- A new Southeast Alaska Coastal Monitoring project Chinook salmon index is the abundance estimate of ocean age-1 fish sampled in Icy Strait, lagged two years later to their ocean year of recruitment as ocean age-3 fish, the age when most reach legal size. Based on this Chinook index, June 1-ocean abundance has been below average in 9 of the past ten years. Most recently, Chinook salmon fishery recruitment appears weak in 2014 and 2016, but strong in 2013, and particularly strong in 2015 (p. 167).
- Ecosystem indicators predict above average recruitment to age-2 sablefish in 2016 (p. 191).
- Length-weight residuals for most groundfish species were positive in the first two years of the survey (1985-1987). The residuals have been mixed for all species since then, but generally smaller and varying from year to year. Most species were generally in better condition in the Kodiak area, especially southern rock sole. Fish condition was generally worse in the southeastern area than other areas of the GOA (p. 187).
- The depth distribution of rockfish in the Gulf of Alaska has remained constant for each species over time. In the past, a shift in the distribution of rockfish from the eastern and SE areas of the Gulf of Alaska was noted; however, in the 2015 bottom trawl survey data this trend was not significant. Variability in rockfish distribution with temperature has been higher for most species across the time series than for the other variables (p. 191).
- Arrowtooth flounder, flathead sole, and other flatfish continue to dominate the biomass in the ADF&G trawl survey. A decrease in overall biomass is apparent from 2007 to 2014 from years of record high estimates seen from 2002 to 2005 (p. 197).
- In 2014, overall gadid biomass in the ADF&G trawl survey slightly decreased in offshore area of Barnabus Gully and in the inshore areas of Kiliuda and Ugak Bays. Below average anomaly values for arrowtooth flounder and flathead sole were recorded for both inshore and offshore areas, while was

above average. Skates and cod were above average for offshore areas, but below average inshore (p. 197).

- The bottom trawl survey catches the most echinoderms, eelpouts, and poachers in the central GOA. An exceptionally high catch of poachers occurred in 2015 in the western GOA. Few echinoderms are caught in the western GOA, while few poachers are caught in the eastern GOA (p. 203).
- Total trawl survey CPUE in the western GOA varied over time with lowest abundances in 1999 and 2001, but no significant trend over the 20-year time period from 1993 to 2013. The eastern GoA shows a significantly increasing trend over time (p. 211).
- "Mushy" halibut were reported during the 2015 fishing season (p. 221)
- *Ichthyophonus*, a non-specific fungus-like protozoan fish parasite, has caused epizootic events among economically important fish stocks including herring and salmon. Recent research found that of the fish sampled in lower Cook Inlet, 23% had *Ichthyophonus* in 2012, and 29% had *Ichthyophonus* in 2013. However, findings did not support the hypothesis that reduced halibut size-at-age may be caused by *Ichthyophonus* (p. 221).
- 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. Other regions of locally higher richness and diversity include the banks and troughs off the Kenai Peninsula and nearshore areas of Kodiak Island and in Cook Inlet. (p. 214).

Fishing and Fisheries Trends

Alaska-wide

- With the Arctic FMP closure included, almost 65% of the U.S. EEZ of Alaska is closed to bottom trawling (p. 233).
- At present, no BSAI or GOA groundfish stock or stock complex is subjected to overfishing, and no BSAI or GOA groundfish stock or stock complex is considered to be overfished or to be approaching an overfished condition. The only crab stock considered to be overfished is the Pribilof Islands blue king crab stock, which is in year 1 of a new rebuilding plan. None of the non-FSSI stocks are subject to overfishing, known to be overfished, or known to be approaching an overfished condition (Table 15) (p. 259).

Bering Sea

- Since 1993, discard rates of managed groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock and non-pollock fisheries in the Bering Sea/Aleutian Islands (BSAI). Discard rates in the BSAI fixed gear sector fell from around 20% in 1993 to 12% in 1996, and since then have generally fluctuated between 10% and 14% (p. 223).
- Trends in total non-target catch in the groundfish fisheries have varied in the EBS. The catch of Scyphozoan jellyfish peaked in 2014. HAPC biota catch decreased from 2003 to 2007 and has been generally steady since. Sea stars dominate the catch of assorted invertebrates (p. 226).
- There seems to be a generally decreasing trend in seabird bycatch since the new estimation procedures began in 2007, indicating no immediate management concern other than continuing our goal of decreased seabird bycatch. Estimated bycatch was lowest in 2014, although two endangered short-tailed albatross fisheries-related mortalities were observed (p. 229).

Aleutian Islands

- Discard rates have declined over the past nine years. Discards and discard rates are much lower now than they were in 1996 (p. 223).
- Since 1993, discard rates of managed groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock and non-pollock fisheries in the Bering Sea/Aleutian Islands (BSAI). Discard rates in the BSAI fixed gear sector fell from around 20% in 1993 to 12% in 1996, and since then have generally fluctuated between 10% and 14% (p. 223).
- Trends in total non-target catch in the groundfish fisheries have varied in the AI. The catch of Scyphozoan jellyfish has been variable and shows no apparent trend over time. HAPC biota and assorted invertebrate catches reached new peaks in 2013, but dropped in 2014 (p. 226).
- EStimated seabird bycatch continues to be low in the Aleutian Islands (p. 229).

Gulf of Alaska

- Discarded tons of groundfish have remained relatively stable in the past few years with the exception of fixed gear, in which discard rates jumped from 4% in 2012 to to 14% in 2013 and remained high at 10% in 2014. Improved observer coverage on vessels less than 60' long and on vessels targeting IFQ halibut may account for the increase (p. 223).
- Sea anemones comprise the majority of non-target catch in groundfish fisheries in the GOA. The catch of Scyphozoan jellies in the GOA has been variable from 2003-2014. From 2007 to 2013, the catch of Scyphozoan jellies has alternated between years of low (odd years) to relatively higher catches (even years). The 2014 catch breaks from this pattern and remains at a low catch level, roughly equivalent to 2013 (p. 226).
- There seems to be a generally decreasing trend in seabird bycatch since the new estimation procedures began in 2007, indicating no immediate management concern other than continuing our goal of decreased seabird bycatch (p. 229).

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* indicates contribution updated in 2015
† indicates new contribution

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

December 2014 SSC Comments

The SSC acknowledges the tremendous amount of effort that compiling this document takes for the editor and the contributors, and thanks the editor for her presentation to the SSC. Changes to the format and the increase in the quantity and quality of the content have been steadily improving this document. The SSC commends the attempts to align this document with the ongoing Integrated Ecosystem Assessments and with species-specific stock assessments these efforts will only improve the utility of the document. The authors and editor have been very responsive to SSC comments, and this year is no exception. Many of our comments from 2013 were directly addressed or are now active areas of effort.

Thank you.

The SSC appreciated the updated regional ecosystem assessments for all four regions, and specifically, the progress that has been made to develop a GOA assessment with an initial list of appropriate ecosystem indicators. The SSC looks forward to the inclusion of a GOA report card and ecosystem assessment in the near future.

We are pleased to present the first GOA report card and new assessment this year. While the process of selecting the report card indicators differed from that used for the EBS and AI, the structure and content of the report card and assessment is similar. Instead of holding in-person workshops for the teams of experts to participate in indicator selection, we used an online survey to broaden the input to 43 experts. We plan to refine our list with collaboration from the GOA IERP project to incorporate the findings in the project synthesis. We are in the process of writing a manuscript comparing methods we have used to select indicators for all three report cards.

The continued efforts to expand the Arctic assessment and the responsiveness to our comments regarding this regions assessment from last year are extremely valuable. We would reiterate our request for the development of an Arctic report card in the future.

We will continue to plan to develop an Arctic report card in the future. During this next year, we have prioritized reconvening the EBS team to revisit the EBS report card indicators and update as needed to reflect the increase in knowledge of the ecosystem since the report card was first developed in 2010.

Also, the SSC appreciated the general effort towards using the information within the entire chapter to begin to predict future conditions, and specifically, highlighting the preliminary forecast of conditions in the EBS for 2015. These predictive capabilities will only improve as the time series on which they are based grow.

We have included predictions and forecasts again in the EBS assessment this year. We've also incorporated predictions within the new GOA assessment.

Effort should be made to relate these indices to process-oriented models, or to develop process-oriented models that will provide a mechanistic understanding of the ecological basis of the index, which would provide additional confidence in the predictions. The SSC further suggests looking at NOAAs climate forecast system for the GOA (Saha et al. 2012 and Saha et al. 2014).

The SSC had a short list of additional sections for consideration. First, the SSC suggested including relevant terrestrial indicators which may strongly influence marine systems. Two such indicators include estimated freshwater contributions resulting from glacial melt and permafrost thaw.

We were unable to include terrestrial indicators this year, although we do include the freshwater discharge time series from the GAK1 station in the GOA report card.

Second, the SSC suggested developing a Disease Ecology (or similarly named section) section under Ecosystem Indicators would allow for the inclusion and tracking of available information about diseases and parasites, such as the mushy halibut syndrome or Ichthyophonus.

We added a new section on Disease Ecology this year, which includes information on mushy halibut and Ichthyophonus.

Third, the SSC suggested developing a Tradeoffs (or similarly named) section under Ecosystem-Based Management (Fishing-related) Indicators which includes conceptual models depicting the expected interactions/ effects of management actions on relevant ecosystem indicators.

This is good idea that we hope to incorporate in the near future.

In addition to updates to a large number of ecosystem indicators, there are new contributions to the list of indicators, for example, the Chinook abundance index for SE Alaska and the preliminary euphausiid index in the GOA. The SSC notes the multiple new indicators in the Groundfish section, primarily the addition of the groundfish condition contributions for the GOA and the AI. Here, Weight-at-age for groundfish stocks where age information is available may be an alternative to length-weight residuals for groundfish condition that could tease apart year-class impacts.

The author of the groundfish condition indicator agrees that this would be a good refinement, but at present would require extensive effort to summarize stock assessment values.

A potential new ecosystem indicator estimates centers of distribution of specific fish species over time in the EBS, GOA and AI is available on theOceanAdapt website (http://oceanadapt.rutgers.edu/). Finally, the SSC appreciated the ongoing effort to improve the implications sections for each of the ecosystem indicators and would like to see these efforts continued, as the quality of the implications sections remains variable.

This is an ongoing effort.

The SSC particularly noted the strong positive SST anomalies that impacted the North Pacific in late 2013 and persisted into 2014, which influenced physical conditions in all of the regions and is exemplified in the "warm blob" in the GOA discussed in the hot topics section. The SSC commends the contributors and editor for attempting to incorporate this information into explanations of why other indicators may be changing, for example, into the discussions regarding the generally successful year for seabird reproduction and some of the groundfish biomass indicators.

We included more discussion on this in the GOA assessment as well as a new review of all 2015 ABL survey activity, which includes observations of ecosystem response to current conditions.

Importantly, the PDO transitioned to positive in 2014. Regarding the regime shift indicator, newly separated into EBS and GOA components, the SSC noted the timing when the leading principal component of the 16 biological time series went negative was also a period when pollock biomass was quite high and still rising. It would be interesting to know if pollock was driving this, or simply responding.

This is an interesting question that we are currently unable to answer definitively. However, as the dominant biomass, the pollock trend is likely influencing the overall trend in this indicator, particularly during the shift noted above. As a side note, we were unable to provide an update to the regime shift indicator this year, but we plan to continue updating this indicator as it provides interesting view of patterns that may not be noted when with other analytical perspectives.

In the Western Aleutian Islands the negative weight length residuals of ground fish suggest some sort of bottom-up limitation. It would be of interest to pull together oceanographic data that might shed light on whether there may be bottom-up limitation of fish growth there.

This is an interesting topic that we plan to address next year, when we have NOAA survey data. Unfortunately for the data-poor Aleutian Islands, we have few new data to report in non-survey years.

Specific to the EBS, a serious omission is the lack of recent data from the two time series on Bering Sea copepods. The zooplankton time series are the extremely important for relating variations in pollock recruitment to climate variability. Both the sampling in spring and the BASIS sampling in late summer/fall are needed.

We have added quite a bit of zooplankton data this year. We have the new rapid zooplankton assessments for the EBS and GOA provided by EcoFOCI that gives us a leading indicator of summer zooplankton communities. We also present the current GOA euphausiid index from the acoustic survey. Unfortunately there was not acoustic survey in the EBS this year. We also present a new contribution on euphausiid indicators from groundfish food habits.

In the AI, care is needed in interpreting forage fish abundance trends from the tufted puffin chick meals. The decline in use of a particular prey may indicate a decline in the abundance or availability of that prey, or it may signal that an alternative prey has become more available. That said, it could be useful to explore the feasibility of the use of squid by puffins as an indicator of squid abundance. Additionally, a negative winter NPI is most likely to affect the auklet breeding by depriving them of food in winter so that they are in too poor condition to breed successfully. The SSC also agrees that reproductive anomalies may be a better indicator for planktivorous fish species than chick diets, as breeding success integrates environmental conditions over a long period of time- at least from when the birds return to the colonies in spring until the chicks fledge in late summer or fall. In the GOA, *the OCSEAP time series was focused on upwelling and the foraging of shearwaters along the rims of the troughs or canyons, and this may help to explain why euphausiids are changing in this area.*

We agree that puffins are imperfect samplers of forage fish, just as are the bottom trawls and groundfish. We are currently investigating how different sampling methods (birds, fish, and nets) provide information on forage fish trends. Exploring trends in squid abundance as indicated by puffins is an interesting research topic that we may pursue in the future. Interestingly, the negative NPI this past winter coincided with the poor least auklet breeding success, supporting the hypothesized links between the conditions index by the NPI and auklets.

Again, the SSC noted the new salmon indicators included in the GOA assessment, and it is very encouraging to see these developing indices and the attempts to relate them to the physical environment. Sydeman and colleagues have developed some indicators using birds in the California Current System Progress in Oceanography, 101, 1-146 (August 2012), and the EBS (Deep-Sea Research II 55 (2008) 1877 1882) that could be useful in this regard.

In addition to the indicators, we include a Hot Topic on chum salmon in the EBS and its connections with age-0 pollock.

Trends in non-target species suggest another case of odd/even year differences; specifically, more jellyfish were caught in even years. It might be useful to pull together all of the examples of odd/even year differences in abundance, reproduction etc. and see if there are any connections of interest.

This is an active area of our related research.

As a final point, the SSC echoes the concerns brought up by the PT regarding the ecosystem indicator that describes the trawl disturbance area. As currently estimated, there is potential for underestimating reductions in trawl effort and the SSC supports the PT recommendation that alternatives to this index be investigated that might be more useful.

We are currently working with Lewis and Olson to use a VMS-based database to produce much more precise estimates of trawled area in the EBS, AI and GOA. We hope to include these new indicators in the next edition of this report.

Introduction

The goal of the Ecosystem Considerations report is to provide stronger links between ecosystem research and fishery management and to spur new understanding of the connections between ecosystem components by bringing together the results of many diverse research efforts into one document. There are four main sections:

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

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

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

The purpose of the third section, the Ecosystem Assessment, is to synthesize historical climate and fishing effects on the eastern Bering Sea/Aleutian Islands and Gulf of Alaska ecosystems using information from the Ecosystem Status and Management Indicators section and stock assessment reports. Notable trends, “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. In future drafts, the Ecosystem Assessment section will also provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function.

The purpose of the fourth section, Ecosystem Status and Management Indicators, is to provide detailed information and updates on the status and trends of ecosystem components as well as to provide either early signals of direct human effects on ecosystem components that might warrant management intervention or to provide evidence of the efficacy of previous management actions. Ecosystem-based management indicators should also track performance in meeting the stated ecosystem-based management goals of the NPFMC, which are:

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

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

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

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

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

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

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

It was requested that contributors to the ecosystem considerations report provide actual time series data or make it available electronically. Many of the time series data for contributions are available on the web, with permission from the authors. We are in the process of improving online access to indicators and plan to debut a new webpage in the near future.

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

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

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

Ecosystem Assessment

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Introduction

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

This assessment originally provided a short list of key indicators to track in the EBS, AI, and GOA, using a stepwise framework, the DPSIR (Drivers, Pressure, Status, Indicators, Response) approach (Elliott, 2002). In applying this framework we initially determined four objectives based, in part, on stated ecosystem-based management goals of the NPFMC: maintain predator-prey relationships, maintain diversity, maintain habitat, and incorporate/monitor effects of climate change. Drivers and pressures pertaining to those objectives were identified and a list of candidate indicators were selected that address each objective based on qualities such as, availability, sensitivity, reliability, ease of interpretation, and pertinence for addressing the objectives (Table 1). Use of this DPSIR approach allows the Ecosystem Assessment to be in line with NOAA's vision of Integrated Ecosystem Assessments (IEA)(Figure 7).

We initiated a regional approach to ecosystem assessments in 2010 and presented a new ecosystem

Figure 7: The IEA (integrated ecosystem assessment) process.

assessment for the eastern Bering Sea. In 2011 we followed the same approach and presented a new assessment for the Aleutian Islands based upon a similar format to that of the eastern Bering Sea. In 2012, we provided a preliminary ecosystem assessment on the Arctic. Our intent was to provide an overview of general Arctic ecosystem information that may form the basis for more comprehensive future Arctic ecosystem assessments. This year, we present a new Gulf of Alaska report card and assessment, similar to those for the eastern Bering Sea and Aleutian Islands.

While all sections follow the DPSIR approach in general, the eastern Bering Sea and Aleutian Islands assessments are based on additional refinements contributed by Ecosystem Synthesis Teams. For these assessments, the teams focused on a subset of broad, community-level indicators to determine the current state and likely future trends of ecosystem productivity in the EBS and ecosystem variability in the Aleutian Islands. The teams also selected indicators that reflect trends in non-fishery apex predators and maintaining a sustainable species mix in the harvest as well as changes to catch diversity and variability. Future assessments will address additional ecosystem objectives identified above. Indicators for the new Gulf of Alaska report card and assessment were also selected by a team of experts, via an online survey instead of an in-person workshop. We plan to convene teams of experts to produce a report card and full assessment for the Arctic in the near future.

The entire ecosystem assessment is now organized into five sections. In the first “Hot topics” section we present succinct overviews of potential concerns for fishery management, including endangered species issues, for each of the ecosystems. In the next sections, we present the region-specific ecosystem assessments. This year, we have included full assessments and report cards for the eastern Bering Sea and the Gulf of Alaska. We updated the Aleutian Islands report card where possible and include a minimal assessment due to this being a non-survey year for NOAA. For the Arctic, we include last year's assessment as we have few updates.

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

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

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

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

Hot Topics

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

Hot Topics: Arctic

Evaluating and ranking threats to the long-term persistence of polar bears

Polar bears (*Ursus maritimus*) were listed as globally threatened under the Endangered Species Act in 2008. This listing was primarily due to observed reductions in their sea ice habitat and the expectation that sea ice coverage will continue to decline in the future (USFWS, 2008). The diminishing sea ice coverage also increases polar bear exposure to other stressors related to increasing anthropogenic activity in the Arctic, such as petroleum extraction and shipping. A new report from the United States Geological Survey (USGS) indentified stressors affecting the long-term persistence of polar bears worldwide and evaluated the relative influence of these stressors

(Atwood et al., 2015). Their study used a Bayesian network model which integrated environmental, ecological, and anthropogenic stressors.

Results indicate that the overall condition of sea ice and the availability of marine mammal prey had the most influence on the polar bear population outcomes. Stressors related to anthropogenic activity in the Arctic were much less influential to the population outcomes. The overall condition of sea ice and secondarily, the availability of marine mammal prey, were directly influenced by climate change. Polar bear population outcomes decreased by the end of the century under both stabilized and unabated greenhouse gas emissions. They concluded that minimizing the projected loss of sea ice habitat will be needed for the long-term persistence of polar bears, and will likely require stabilizing or reducing greenhouse gas emissions. Reducing the negative effects of anthropogenic activity on polar bears had a much smaller effect on polar bear population outcomes, but mitigating these human activities is more practical for resource managers to enact. *Contributed by Andy Whitehouse*

Hot Topics: Eastern Bering Sea

Chum salmon distribution, diet, and bycatch

Chum salmon diets and foraging behavior provide an important ecological dimension to understanding changes in chum salmon bycatch over time. The number of chum salmon captured incidentally as bycatch in eastern Bering Sea groundfish fisheries has varied significantly since the inception of the North Pacific Observer Program in 1991, ranging from approximately 700,000 in 2005 to 13,000 in 2010. A period of high bycatch of chum salmon in the pollock fishery occurred from 2004 to 2006. Since 2002, ecosystem studies on marine life and the physics and biology of the southeastern Bering Sea were conducted by AFSC during late summer and fall. During a period of warm years (2004-2006), the survey participants observed higher surface densities of age-0 pollock and a high proportion (90%) of age-0 pollock in the diets of immature chum salmon. Chum salmon bycatch numbers were positively correlated with surface trawl catches of age-0 pollock on the eastern Bering Sea shelf ($r = 0.83$, $p < 0.01$) and more strongly correlated surface trawl catches of age-0 pollock in regions where bycatch occurred ($r = 0.91$, $p < 0.001$). The close association between chum salmon feeding on age-0 pollock, surface trawl catch of age-0 pollock, and chum salmon bycatch highlights the importance of chum salmon foraging behavior (particularly on age-0 pollock) to chum salmon bycatch in eastern Bering Sea groundfish fisheries. *Contributed by Jim Murphy*

Increased sightings of dead birds at sea

The USFWS has conducted offshore seabird surveys on research vessels every year from 2006-2015, averaging approximately 20,000 km surveyed per year. Prior to 2014, during these surveys the USFWS observers recorded one or two dead birds a year. In 2014 there was a sharp increase in observations of dead seabirds (most appeared to be murres), with 51 recorded, including 28 during a three-day period in August; extrapolated numbers of dead birds for this offshore "die off" was conservatively estimated at approximately 32,500 birds, and was associated with a large coccolithophore bloom in the southern Bering Sea that year. In 2015, the USFWS seabird surveys recorded 19 dead birds in pelagic waters, with 8 in the coccolithophore bloom in the south Bering

Sea. In 2015, dead birds were encountered at sea from the northern GOA to the Chukchi Sea, from July through September. Throughout the spring, summer, and fall of 2015, there were also reports of dead and sickly seabirds (primarily murres) washing up on beaches throughout the northern GOA, and fewer reports in the Bering Sea. Other species affected were crested auklets, northern fulmars, shearwaters, puffins, murrelets, and gulls. At least 78 seabird carcasses were sent to the National Wildlife Health Center in Virginia for necropsy and tested for toxins. To date, nearly all birds were emaciated and none had indications of disease or toxins, suggesting the birds starved to death due to lack of food or because their ability to forage was affected. However, it is unknown if the starvation was proceeded by illness or toxic exposure that affected the bird's ability to forage. *Contributed by Kathy Kuletz and Elizabeth Labunski*

Hot Topics: Gulf of Alaska

Too warm for larval walleye pollock survival in 2015?

The 2015 Eco-FOCI GoA larval survey was conducted from May 14 to June 5. A total of 276 stations were sampled using the 20/60 cm bongo array with 0.153/0.505 mm mesh to collect larvae and zooplankton. Tows were conducted to 10 meters off bottom or 100 meters maximum. A Sea-Bird FastCat was mounted above the bongo array to acquire gear depth, temperature, and salinity profiles. Argos satellite-tracked drifters were released at each of the following locations: the base of Shelikof Strait, Gore Point, Amatuli trough, and the east side of Kodiak Island, to study drift and transport of walleye pollock larvae. All drifters were drogued at 40 meters (depth of larval pollock residence) to assess current strength and direction.

Larval walleye pollock rough counts for 2015 were consistently lower throughout the grid compared to the counts in 2013 (Figure 1, note drastic reduction in RCountL scale range for 2015). The temperature field at 40 meters in 2015 was also 3-5°C warmer than in 2013. From the drifter tracks, we found persistent eddies (Figure 2) at the base of Shelikof Strait and along the east side of Kodiak Island (a recent update shows that the Shelikof drifter has spun out of the eddy and is heading towards the Alaska Peninsula). The drifter released off of Gore Point did not pass through Kennedy Strait and down Shelikof Strait, as would be expected, but is instead heading down the east side of Kodiak Island. The Amatuli trough drifter has been flushed out into the Gulf of Alaska.

We found above-average abundances of larval walleye pollock in 2013, but the 2013 year-class was reported to have resulted in slightly below average numbers of age-1 recruits in Table 1.18 of the 2014 Gulf of Alaska pollock stock assessment. Based on the low rough counts of larval walleye pollock and higher temperatures found in 2015, will the 2015 year-class result in even lower age-1 returns and potentially be deemed a recruitment failure? *Contributed by Ann Dougherty*

Very few age-0 pollock in late summer, 2015

The purpose of Eco-FOCI late-summer research in the western Gulf of Alaska (GOA) is to extend a time series of age-0 walleye pollock abundance estimates, and to monitor the neritic environment with special focus on primary (walleye pollock, Pacific cod, rockfishes, sablefish, and arrowtooth flounder) and secondary (capelin and eulachon) fishery species. The goal during 2015 was to sample

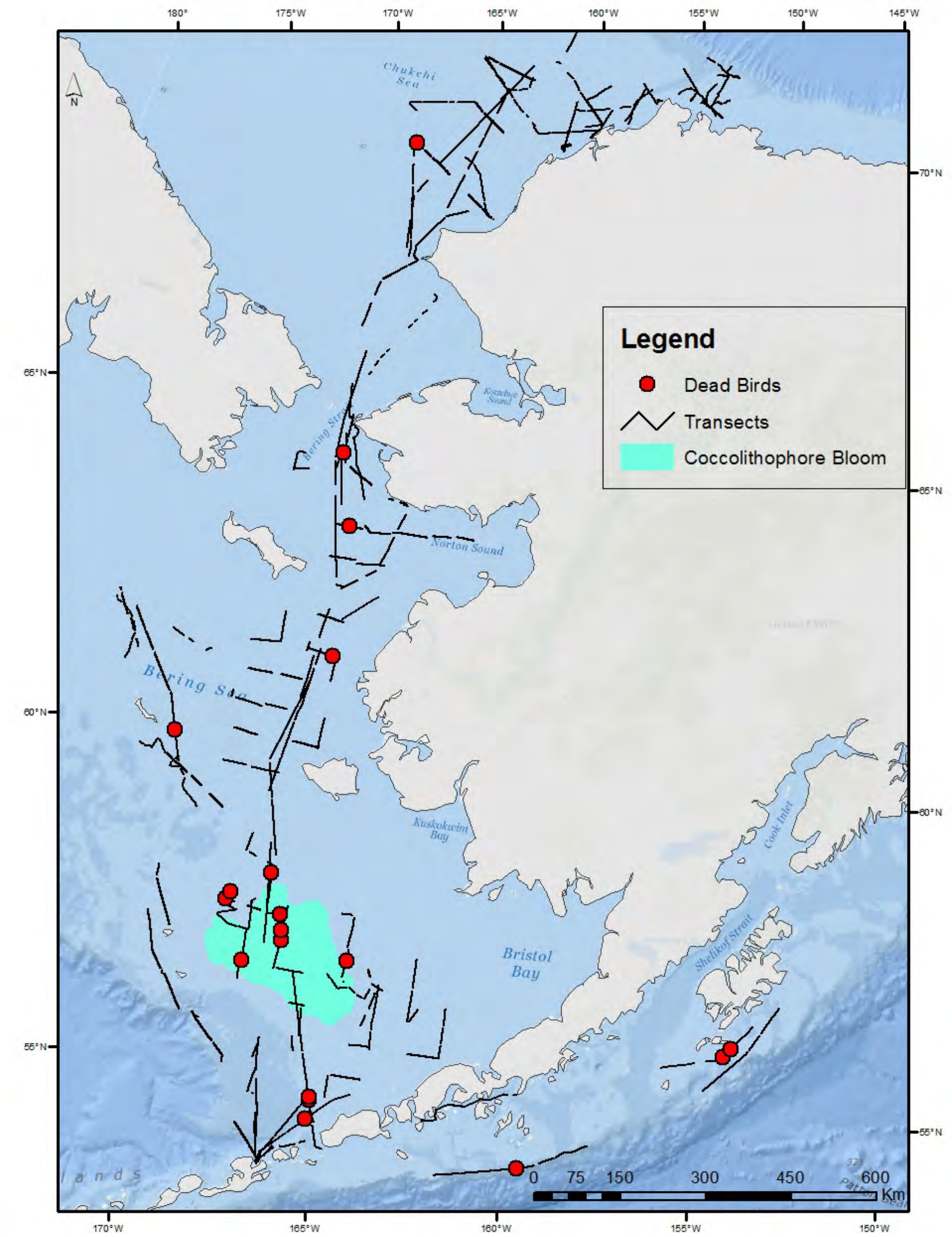

Figure 8: Dead birds observed during surveys from July through September 2015. A coccolithophore bloom is delineated in light blue.

at sites that were occupied during late-summer 2013; however, weather and ship time constraints prevented a complete repetition.

There were fewer age-0 walleye pollock in the Eco-FOCI index area in 2015 than in any other year in the time series (Figure 11). On average, there were 70 individuals per square kilometer of sea surface area (0.00007 fish / m^2). This corresponds with the low number of pollock larvae observed earlier during spring (see Dougherty topic above). Three of the 26 index sites were not occupied

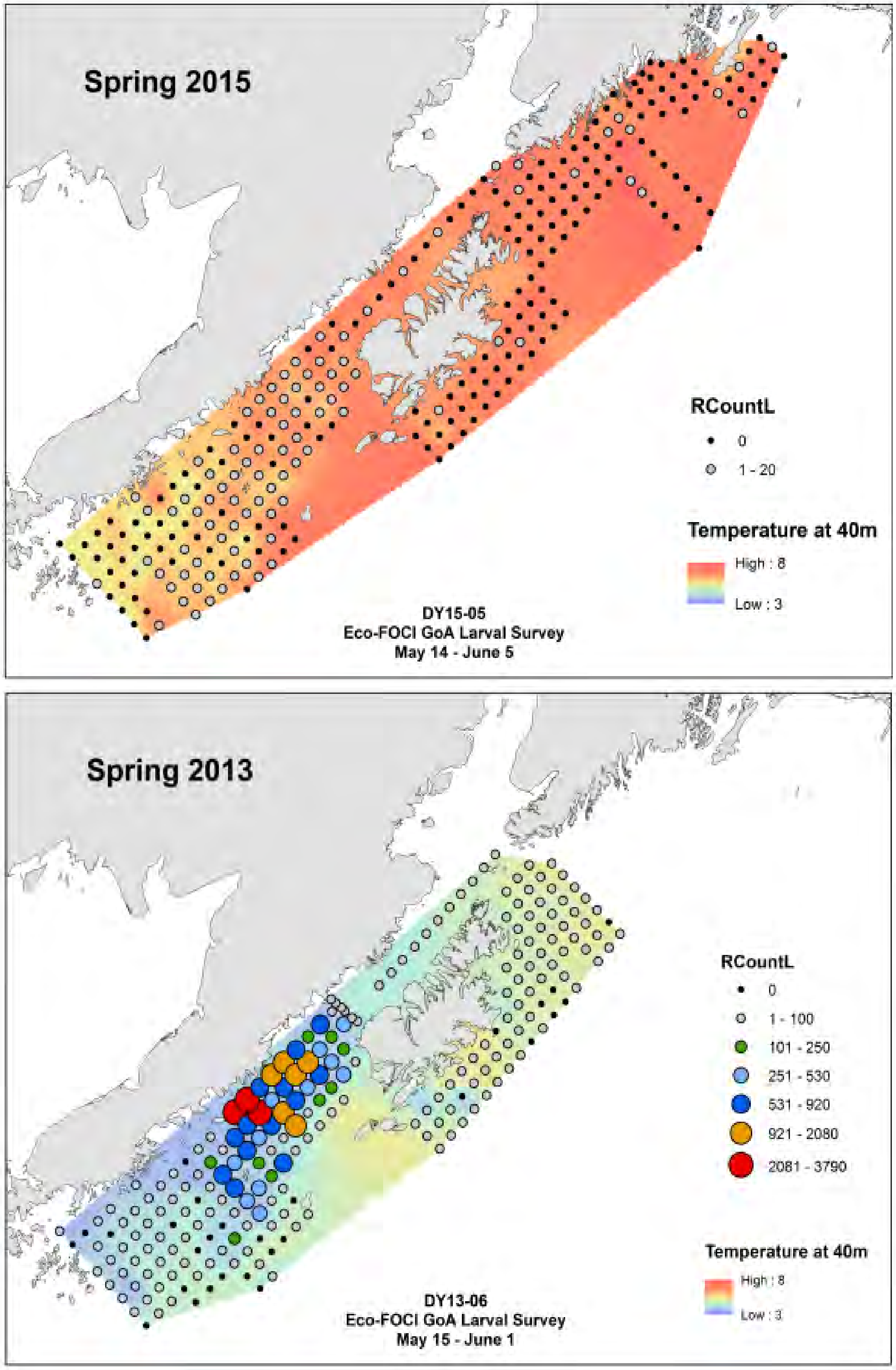

Figure 9: Temperatures and larval walleye pollock abundances as determined at sea in 2015 (top) and 2013 (bottom). 2015 was much warmer with many fewer larval pollock observed.

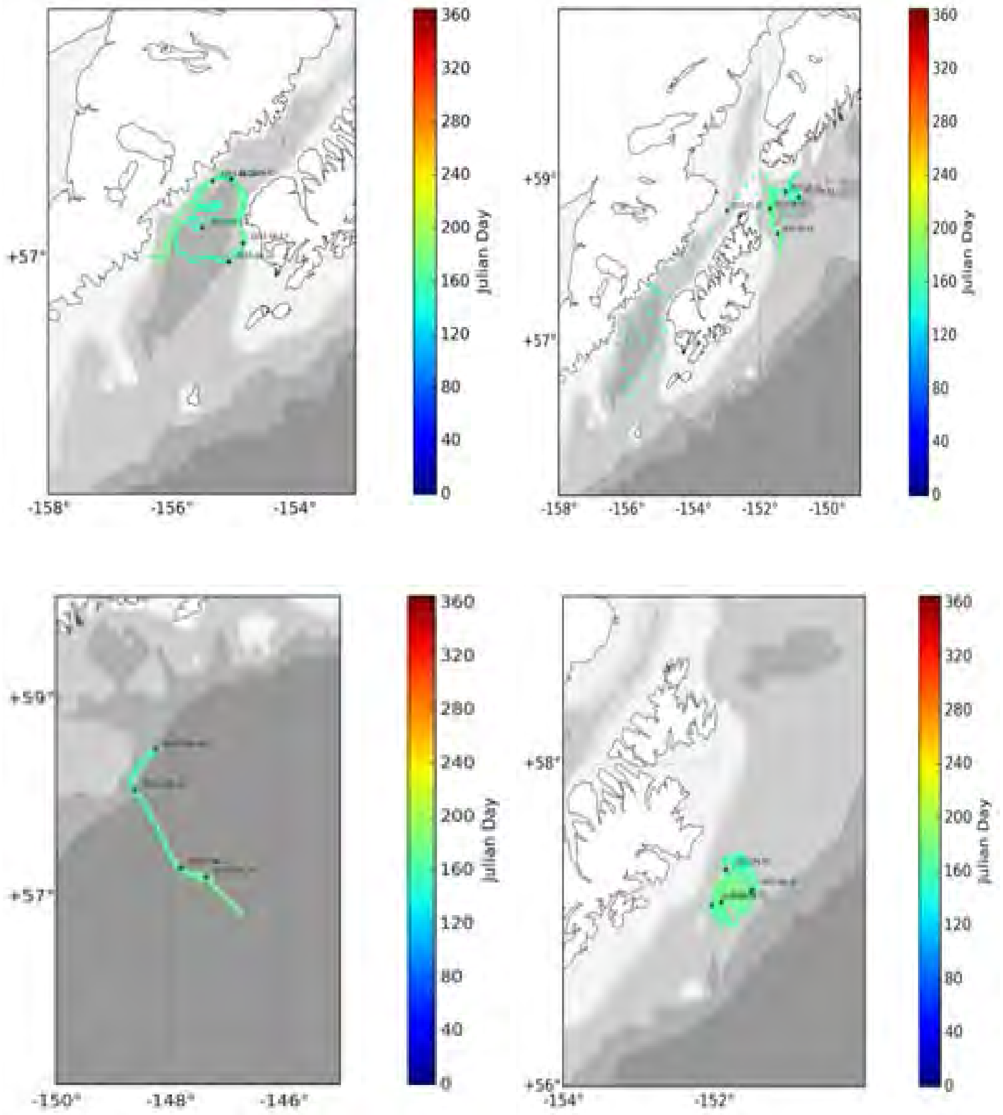

Figure 10: Trajectories of satellite-tracked drifters deployed during the EcoFOCI Late Larval Survey in 2015. Trajectories indicate anomalous circulation patterns over the GOA shelf in 2015.

due to bad weather; nevertheless, the 2015 year class appears to be very small.

Geographically, age-0 walleye pollock were more abundant in the Eco-FOCI index area than off east Kodiak Island (Fig. 1). This is consistent with previous years; however, the extended coverage revealed relatively high abundance estimates in Shelikof Strait (Figure 12). In addition to the low abundance of age-0 pollock, very few age-1 individuals were collected (ca. 14-20 cm SL) as evident in the size composition (Figure 12 inset). Another noteworthy finding was that large numbers of age-0 juvenile rockfishes (ca. 9-50 mm total length) were encountered in Shelikof Strait as part of a larger concentration around the eastern end of the Kodiak Archipelago (Figure 12). Age-0 rockfishes were also abundant west of the Shumagin Islands. This was the first year age-0 rockfishes were enumerated as part of the Recruitment Processes Alliance with the Ecosystems Monitoring

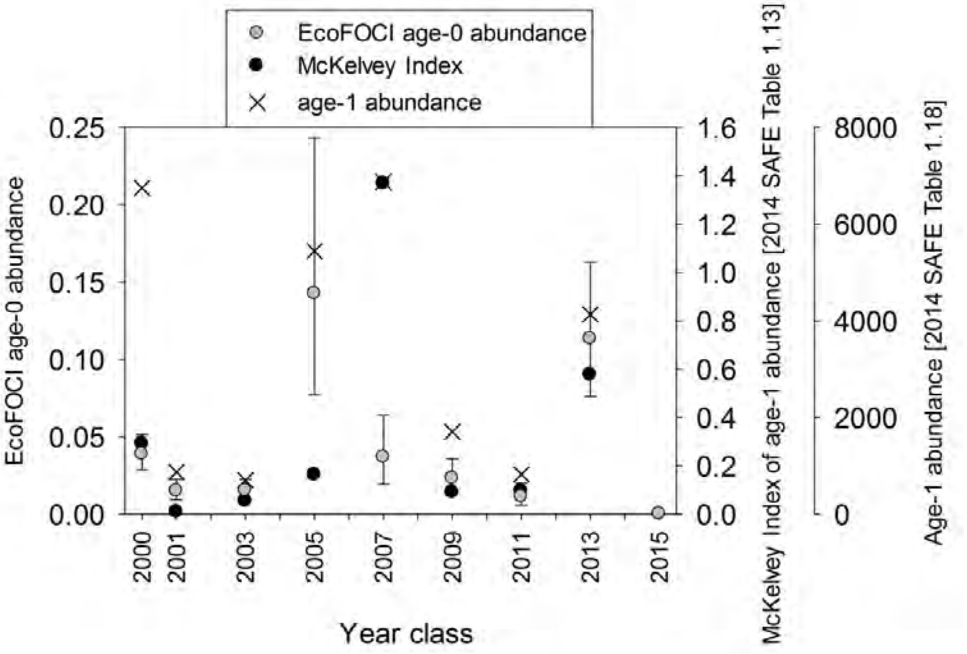

Figure 11: Abundance of year-classes of pollock measured as age-0's during late summer (Eco-FOCI, mean +1 SE), winter age-1 (McKelvey Index), and estimated as age-1 in the GOA pollock stock assessment (Dorn et al., 2014)

and Assessment Program at the Auke Bay Laboratory so it is not possible to compare late-summer abundance with previous years, but larval rockfishes were also unusually abundant during the spring ichthyoplankton survey (A. Dougherty pers. commun.).

Unusual Mortality Event for Marine Mammals

Since May 2015, elevated numbers of large whale mortalities have occurred in the Western Gulf of Alaska, encompassing the areas around Kodiak Island, Afognak Island, Chirikof Island, the Semidi Islands, and the southern shoreline of the Alaska Peninsula (Figures 13 and 14). This event has been declared an Unusual Mortality Event (UME). Most whale carcasses have been floating and were not retrievable. Also, the majority of carcasses were in moderate to severe decomposition with only one whale sampled to date. *As reported at* `http://www.nmfs.noaa.gov/pr/health/mmume/large_whales_2015.html`

One suspected cause is a harmful algal bloom, according to Bree Witteveen, UAF (Alaska Dispatch News, June 18, 2015).

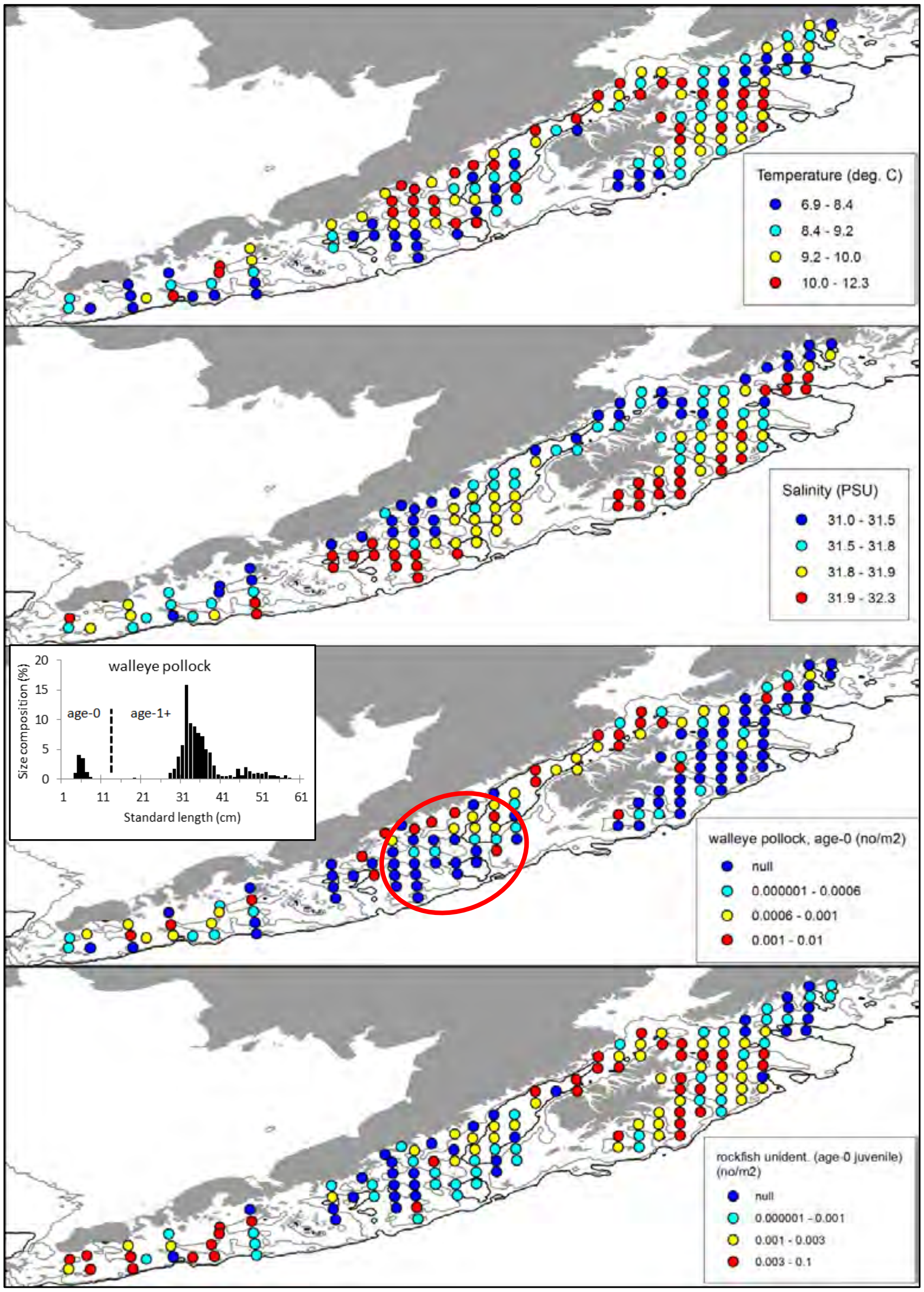

Figure 12: Geographic distributions of water temperature and salinity, measured at 40-m depth, and abundance estimates of two groups of age-0 juvenile fishes: walleye pollock and rockfishes during August-September 2015. For walleye pollock, the age-0 portion of the pollock population is identified on the inset size composition and the index area is within the red circle.

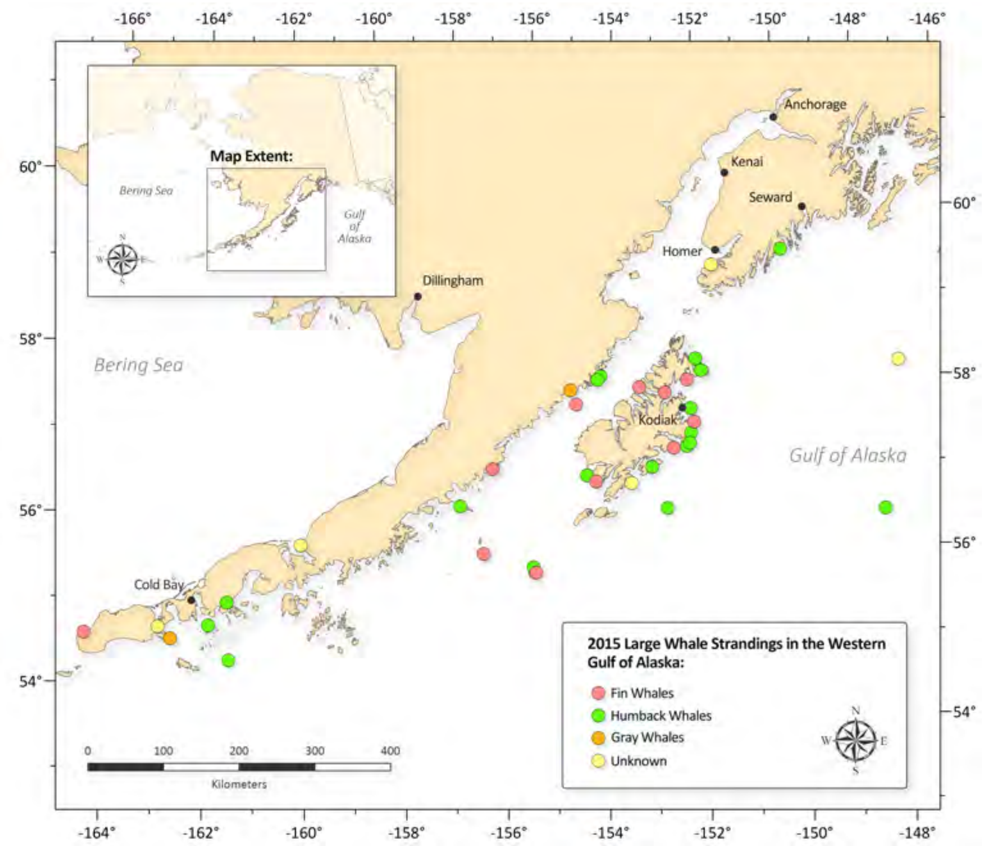

Figure 13: 2015 large whale stranding locations in the Western Gulf of Alaska through October 2, 2015 (`http://www.nmfs.noaa.gov/pr/health/mmume/large_whales_2015.html`)

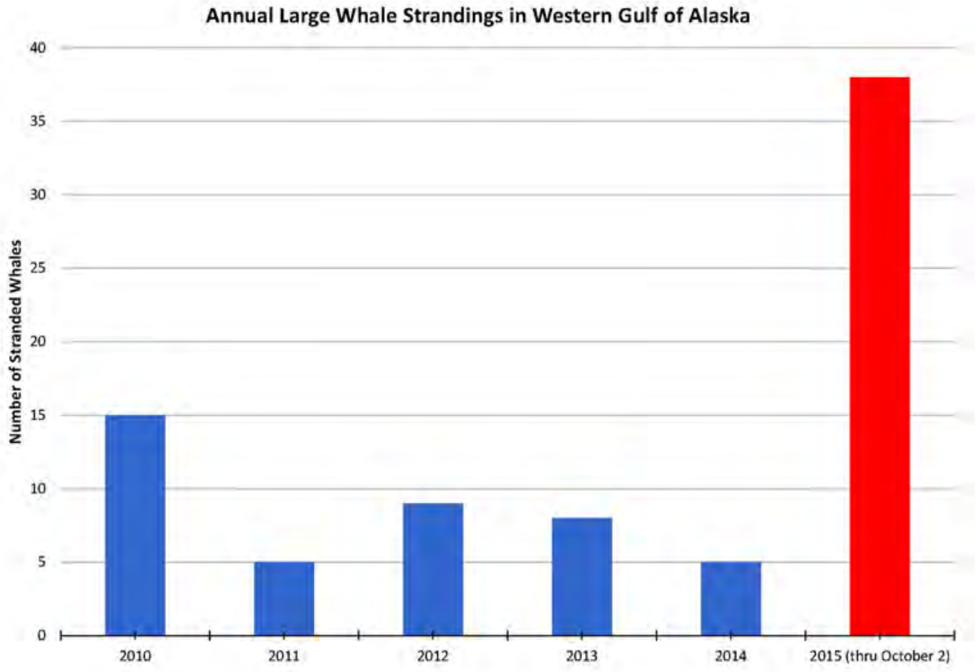

Figure 14: 2015 large whale stranding numbers in the Western Gulf of Alaska through October 2, 2015 (`http://www.nmfs.noaa.gov/pr/health/mmume/large_whales_2015.html`)

Preliminary Assessment of the Alaska Arctic

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This preliminary assessment of the Arctic was not updated this year. We include it here as a reference for the study area and indicators that have been suggested for the development of a future full Arctic Assessment and Report Card.

Defining the Alaska Arctic assessment area

In 2012 preliminary assessment of the Alaska Arctic, we proposed the inclusion of the northern Bering Sea (>approx. 60°N) within the Alaska Arctic assessment area. The Alaska Arctic assessment area would then include the entire Arctic management area (NPFMC, 2009) and the northern Bering Sea (Figure 15). This suggestion was made in recognition of the growing body of scientific literature that indicates the northern Bering Sea is biologically and physically distinct from the southeastern Bering Sea (Grebmeier et al., 2006; Mueter and Litzow, 2008; Sigler et al., 2011; Stabeno et al., 2012; Stevenson and Lauth, 2012). The northern Bering Sea is not presently part of the assessed area in the eastern Bering Sea. Thus including the northern Bering Sea within the proposed Arctic area would create a continuum of assessed large marine ecosystems (LMEs) throughout Alaska. In the time since our preliminary assessment was published, the Arctic Council, an international forum of Arctic governments and indigenous communities (`http://www.arctic-council.org`), has published a revision to their boundaries for LMEs of the Arctic Area (PAME, 2013). In their revision they moved the southern boundary of the Chukchi LME further south into the northern Bering Sea. Previously their boundary was at the Bering Strait (∼66°N) but is now located south of St. Lawrence Island at 61.5°N. Similarly, the rationale for this revision was in recognition of the combined biological and physical properties linking the northern Bering Sea to the Chukchi Sea. As this Arctic section of the Ecosystem Considerations report progresses we will likely specify 61.5°N as the southern boundary of the Alaska Arctic assessed area, coincident with the LME boundary revisions made by the Arctic Council.

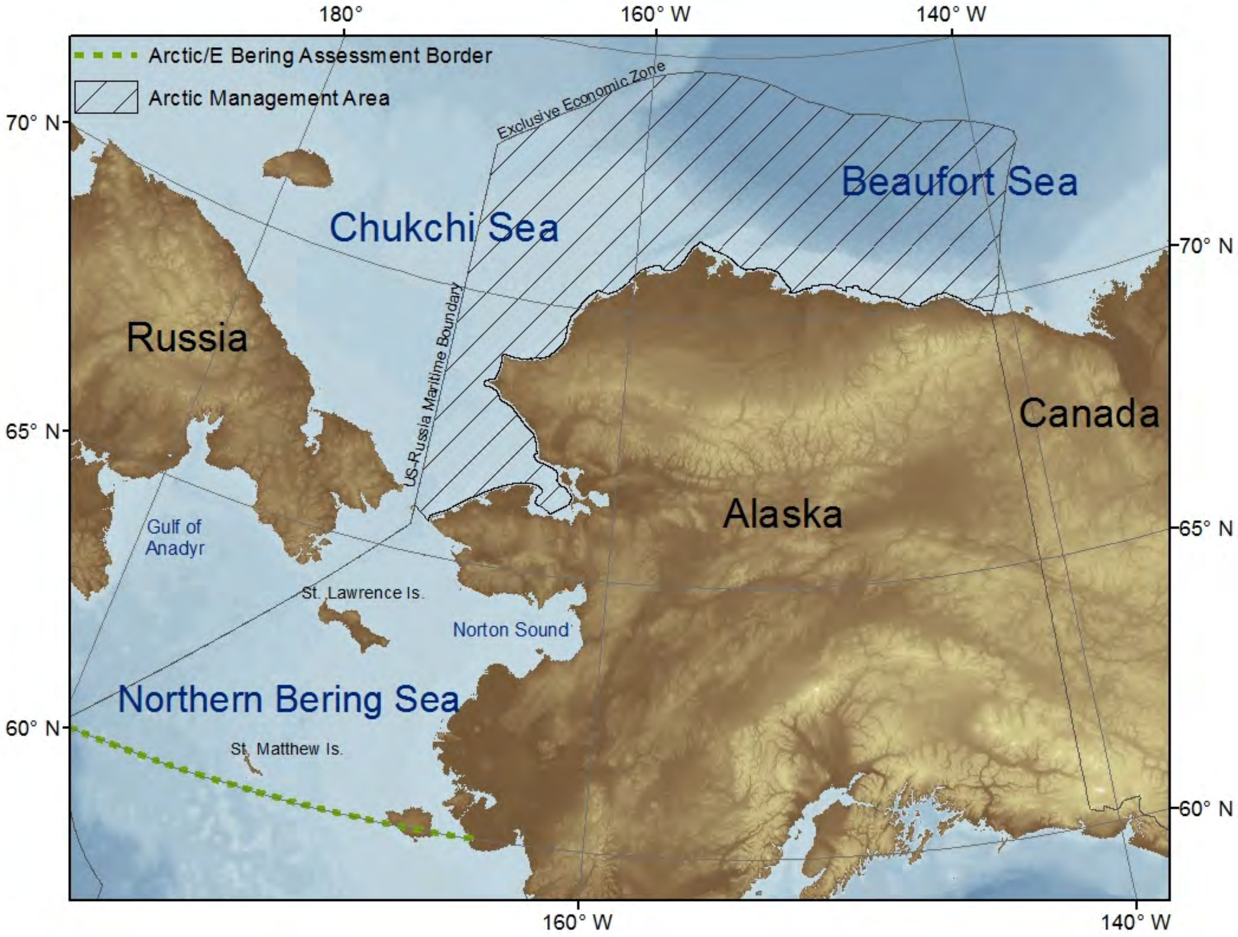

Figure 15: The proposed Arctic assessment area in Alaska, encompassing the northern Bering Sea, Chukchi Sea, and Beaufort Sea, within US territorial waters. The existing Arctic management area is filled with hatched lines.

General ecosystem information

Most of the Alaska Arctic is covered by sea ice for some portion of the year and the seasonal presence and dynamics of sea ice has a strong influence on ecosystem structure and function. During years of low ice coverage, the most southerly portions of the northern Bering Sea may only be covered by sea-ice for a few weeks or not at all. The Chukchi and Beaufort seas are covered by sea ice for about 6 to 8 months of the year. During years of heavy summer ice coverage, portions of the northern Chukchi and Beaufort seas may retain their ice coverage throughout the year. However, Arctic sea ice cover has declined over recent decades, with the seven lowest annual sea ice minima over the satellite record (1979-present) occurring in the last 7 years, 2007-2013 (Comiso, 2012; Stroeve et al., 2012)(`http://nsidc.org`). A recent reconstruction of Arctic sea ice cover over the last 1,450 years has indicated that the observed declines in sea ice starting in the 1990's are the lowest over this time period, and fall outside the range of variability in previous observations (Kinnard et al., 2011). Regionally, some of the most pronounced declines of September ice extent in recent decades have been observed in the Chukchi and Beaufort seas (Meier et al., 2007).

The persistence of sea ice during the summer season has implications for the primary productivity regimes in these northern systems. Primary production during winter is limited by ice coverage and shortened day length, including periods of arctic night in the Chukchi and Beaufort seas. Phytoplankton growth begins in late winter with the return of daylight and an ice algae bloom that continues until the onset of ice melt (Cota, 1985; Cota and Smith, 1991)). At a time when food may be limited, the ice algae bloom provides early season forage for ice-associated invertebrates, which in turn are preyed upon by Arctic cod *Boreogadus saida*) (Bradstreet and Cross, 1982; Legendre et al., 1992; Gradinger and Bluhm, 2004). In seasonally ice covered areas, ice algae may contribute less than 5% to total annual primary production (water column and sea ice), while at the northern margins of the Chukchi and Beaufort seas, which may experience year-round ice coverage, ice algae can account for more than 50% of the annual primary production budget (Gosselin et al., 1997). Additionally, recent work in the northern Chukchi Sea has indicated that under-ice phytoplankton blooms, which had previously been unaccounted for, may contribute substantially to total primary production (Arrigo et al., 2012). Current estimates of primary production over Arctic continental shelves that do not take these under-ice blooms into account may be several times too low (Arrigo et al., 2012). The breaking-up and melting of sea ice in spring strengthens water column stratification, and when combined with increasing day-length, induces an ice edge phytoplankton bloom that follows the retreating ice edge northward (McRoy and Goering, 1974; Niebauer et al., 1981; Sakshaug, 2004).

Seasonal ice coverage cools the entire water column over the shallow shelves of the northern Bering and Chukchi seas to temperatures below 0°C. These cold temperatures limit the northern distribution of sub-Arctic populations of groundfish, such as walleye pollock and Pacific cod (Osuga and Feeney, 1978; Wyllie-Echeverria and Wooster, 1998; Mueter and Litzow, 2008; Stevenson and Lauth, 2012), and may constrain their growth (Pauly, 1980). During summer much of the zooplankton community occupying the northern Bering and Chukchi seas are of Pacific origin, and are advected into these Arctic waters through Bering Strait (Springer et al., 1989; Hopcroft et al., 2010; Matsuno et al., 2011). Here, the cold water temperatures may limit zooplankton growth and their grazing efficiency of phytoplankton (Coyle and Pinchuk, 2002; Matsuno et al., 2011). Cold-adapted Arctic zooplankton species are more prevalent in the northern portions of the Chukchi Sea, near the continental slope and canyons (Lane et al., 2008). In years of low ice coverage, an overall northward distribution shift in southern extent of Arctic species and the northern extent of Pacific species has been observed (Matsuno et al., 2011). Additionally, an increase in total zooplankton abundance and biomass has also been observed in years of low ice coverage, and this has been in part attributed to an increased influx of larger zooplankton species of Pacific origin and temperature effects on their growth (Matsuno et al., 2011).

The annual dynamics of sea ice also affects the distribution of marine mammals. Pacific walrus and ice seals utilize sea ice in the Bering Sea during winter to haulout, breed, and whelp. Ringed seals are present throughout the Alaska Arctic during winter and maintain breathing holes in the ice to keep access to the water (Lowry et al., 1980; Kelly, 1988). Ringed seals also construct resting lairs over breathing holes and beneath the snow cover, which provide protection from the elements and predators, and are used to raise pups (Burns, 1970; Smith et al., 1991; Kelly et al., 2010). Pinnipeds may also use sea ice as a form of transportation during ice retreat and as a platform to rest between foraging excursions. Polar bears utilize sea ice as platform to hunt from throughout the year. Pregnant female polar bears may also excavate maternity dens on sea ice in the fall, where they will give birth to cubs in winter (Lentfer and Hensel, 1980; Amstrup and Gardner, 1994; Fischbach et al., 2007). Belugas and bowhead whales spend the winter along the ice edge in the northern Bering Sea, and in the spring they follow regularly recurring leads and fractures in the ice that roughly follow the Alaska coast during migration toward their summering grounds in the Beaufort Sea (Frost et al., 1983; Ljungblad et al., 1986; Moore and Reeves, 1993; Quakenbush et al., 2010). Belugas also forage near the ice edge and in more dense ice coverage among leads and polynyas in both the Beaufort and Chukchi seas (Richard et al., 2001; Suydam, 2009). Seabirds may also concentrate near the ice-edge (Divoky, 1976; Bradstreet and Cross, 1982; Hunt, 1991), preying on ice-associated invertebrates and Arctic cod (Bradstreet and Cross, 1982).

Marine mammals have been important subsistence resources in Alaska for thousands of years and the continued subsistence harvests of marine mammals are important to the maintenance of cultural and community identities (Hovelsrud et al., 2008). The presence and dynamics of sea ice is an integral part of many subsistence harvests, including the hunting of bowhead whales (George et al., 2004), belugas (Huntington et al., 1999), Pacific walrus (Fay, 1982), and ice seals (Kenyon, 1962). Traditional knowledge of sea ice behavior, the effect of environmental conditions on sea ice stability, and how sea ice conditions relate to the seasonal presence and migratory habits of marine mammals has accumulated over time. The sharing of this knowledge helps maintain the successful and safe harvest of marine mammals (Huntington et al., 1999; George et al., 2004; Noongwook et al., 2007).

The net flow of water through the northern Bering and Chukchi seas is northward (Coachman et al., 1975; Walsh et al., 1989; Woodgate et al., 2005). High levels of primary production in the northern Bering and southern Chukchi seas is maintained throughout the open water season by nutrient rich water advected from the Bering Sea continental slope and the Gulf of Anadyr (Springer and McRoy, 1993; Springer et al., 1996). During the open water season, primary production in the northern Chukchi Sea is focused in the vicinity of the ice edge (Wang et al., 2005) and Barrow Canyon where occasional flow reversals allow for upwelling of Arctic basin waters, which promote phytoplankton blooms (Aagaard and Roach, 1990; Hill and Cota, 2005; Woodgate et al., 2005). Primary production in the Beaufort Sea may be enhanced during summer when sea ice retreats beyond the shelf break allowing for phytoplankton blooms driven by upwelling along the shelf break (Pickart et al., 2009).

The northern Bering and Chukchi seas are benthic-dominated systems. Several ecological studies carried out over the last approximately 50 years have documented the abundant community of benthic invertebrates (Sparks and Pereyra, 1966; Feder and Jewett, 1978; Stoker, 1981; Grebmeier et al., 1988; Feder et al., 1994, 2005, 2007; Bluhm et al., 2009). Here, the combination of high primary production, shallow continental shelves (< 60 m), and cold water limiting the growth and grazing of zooplankton results in high delivery of organic matter to the benthos, where it supports an abundant benthic community (Grebmeier et al., 1988; Grebmeier and McRoy, 1989; Dunton et al., 2005; Lovvorn et al., 2005). The prominent benthos supports a community of benthic-foraging specialists, including gray whale (Highsmith and Coyle, 1992), Pacific walrus (Fay, 1982), bearded seals (Lowry et al., 1980), and diving ducks (eiders) (Lovvorn et al., 2003).

Species of commercial interest

Snow crabs are the basis of an economically important fishery in the eastern Bering Sea (NPFMC, 2011) and are a species of potential commercial importance in the Alaska Arctic (NPFMC, 2009). Snow crab are a dominant benthic species in the Chukchi and Beaufort seas. However, they are seldom found to grow to a commercially viable size, which is >78 mm carapace width (CW) (Frost et al., 1983; Paul et al., 1997; Fair and Nelson, 1999; Bluhm et al., 2009). More recently, a trawl survey of the western Beaufort Sea in August 2008 (Rand and Logerwell, 2011) documented the first records of snow crab in the Beaufort Sea at sizes equal to, or greater than the minimum legal size in the eastern Bering Sea, finding males as large as 119 mm CW. Studies of snow crab reproduction biology have observed some flexibility in the size at maturation, indicating snow crabs in these colder Arctic waters may mature at a smaller size (Somerton, 1981; Paul et al., 1997; Orensanz et al., 2007). Snow crabs are also found throughout the northern Bering Sea.

Commercially important species of king crab have been sparsely encountered in the Chukchi Sea (Barber et al., 1994; Fair and Nelson, 1999; Feder et al., 2005) and were not encountered during the 2008 survey of the western Beaufort Sea (Rand and Logerwell, 2011). In the northern Bering Sea blue king crab are found near St. Matthew Island and north of St. Lawrence Island, and red king crab in Norton Sound (Lauth, 2011). The northern Bering Sea (as defined here) includes the northern half of the Alaska Dept. of Fish & Game management area for St. Matthew Island blue king crab. Following a ten year closure to rebuild the St. Matthew Island stock of blue king crab, the commercial fishery was reopened in 2009/10 (NPFMC, 2011). Red king crab presently support both, commercial and subsistence fisheries in Norton Sound (NPFMC, 2011).

The fish resources of the Alaska Arctic have not been as thoroughly sampled as in other large marine ecosystems in Alaska (e.g., eastern Bering Sea, Gulf of Alaska, Aleutian Islands), but a limited number of standardized demersal trawl surveys have been conducted in the region since the mid 1970's. The northern Bering and southeastern Chukchi seas were surveyed in 1976 (Wolotira et al. 1977), the northeastern Chukchi Sea in 1990 (Barber et al., 1994, 1997), the western Beaufort Sea in 2008 (Rand and Logerwell, 2011), the northern Bering Sea again in 2010 (Lauth, 2011),and the eastern Chukchi Seat in 2012 (Arctic EIS, https://web.sfos.uaf.edu/wordpress/arcticeis/). The catch data from these trawl surveys indicate that fish sizes are generally small and demersal fish biomass is low. Though fish have not been particularly abundant in survey catches, when present they have been dominated by cods, flatfishes, sculpins, and eelpouts (Wolotira et al., 1977; Barber et al., 1997; Lauth, 2011; Rand and Logerwell, 2011). In the Chukchi and Beaufort seas, Arctic cod has been consistently identified as the most abundant fish species (Alverson and Wilimovsky, 1966; Quast, 1974; Wolotira et al., 1977; Frost et al., 1983; Barber et al., 1997; Rand and Logerwell, 2011). They occur in benthic and pelagic habitats in ice-free waters and are also found in association with sea-ice during ice covered periods (Bradstreet et al., 1986; Gradinger and Bluhm, 2004; Parker-

Stetter et al., 2011). Arctic cod primarily prey on pelagic and ice-associated invertebrates and also form an important prey base for pelagic predators, including belugas, seabirds, and ice seals (Bradstreet and Cross, 1982; Frost and Lowry, 1984; Welch et al., 1992). Commercially important species of the eastern Bering Sea, such as walleye pollock and Pacific cod, have been infrequently encountered in the Chukchi and Beaufort seas (Frost et al., 1983; Barber et al., 1997; Norcross et al., 2010; Rand and Logerwell, 2011).

Gaps and needs for future Arctic assessments

The intent of adding the Alaska Arctic to the regions assessed in the Ecosystem Considerations report is to provide information placed within a broad ecosystem context to fisheries managers that would be useful when making decisions on the authorization and management of new fisheries in the Alaska Arctic. We intend for future Arctic assessments to include indicators that directly address ecosystem-level processes and attributes that can inform fishery management advice. There is a continued need to convene Arctic experts to identify a list of indicators and corresponding time series data that best capture ecosystem components and trends that would be of value to fishery managers. Several biomass indices are presently used as indicators in assessments of the EBS, GOA, and AI. Time series data to support similar indices in the Alaska Arctic are lacking, but recent ongoing studies are accumulating data that may be of use as indicators.

Several data sets that may be of future use are being collected by the Distributed Biological Observatory (DBO,`http://www.arctic.noaa.gov/dbo/index.html`). The DBO is a coordinated effort by international members of the Pacific Arctic Group (PAG, `http://pag.arcticportal.org`)) that has begun to collect scientific observations at selected locations (transects) over a latitudinal gradient from the northern Bering Sea to the western Beaufort Sea, in an effort to track ecosystem change over time (Figure 16)). As data accumulate, it is hoped that the sampling design of the DBO across a range of latitude will permit it to detect emergent patterns and trends. The data to be collected include oceanographic measurements (temperature, chlorophyll, etc.) and biological measurements, such as species composition, biomass, and the size and condition of selected key species (Grebmeier et al., 2010). Many of these metrics may be suitable for use as indicators in future Arctic assessments.

Potential indicators

In the 2013 preliminary Arctic assessment we suggested a short list of potential indicators as a starting point for indicator discussion and development. in 2014 we presented an expanded list that includes the indicators suggested in the 2013 document, some of which are presently available (both climate indicators), and some additional biological indicators that may be of value, but are not presently available. The compiled list of potential indicators includes:

Climate

- *Arctic Oscillation index* (`www.cpc.ncep.noaa.gov`). This index tracks large scale climate patterns in the Arctic and offers a limited capacity to predict the extent of Arctic sea ice

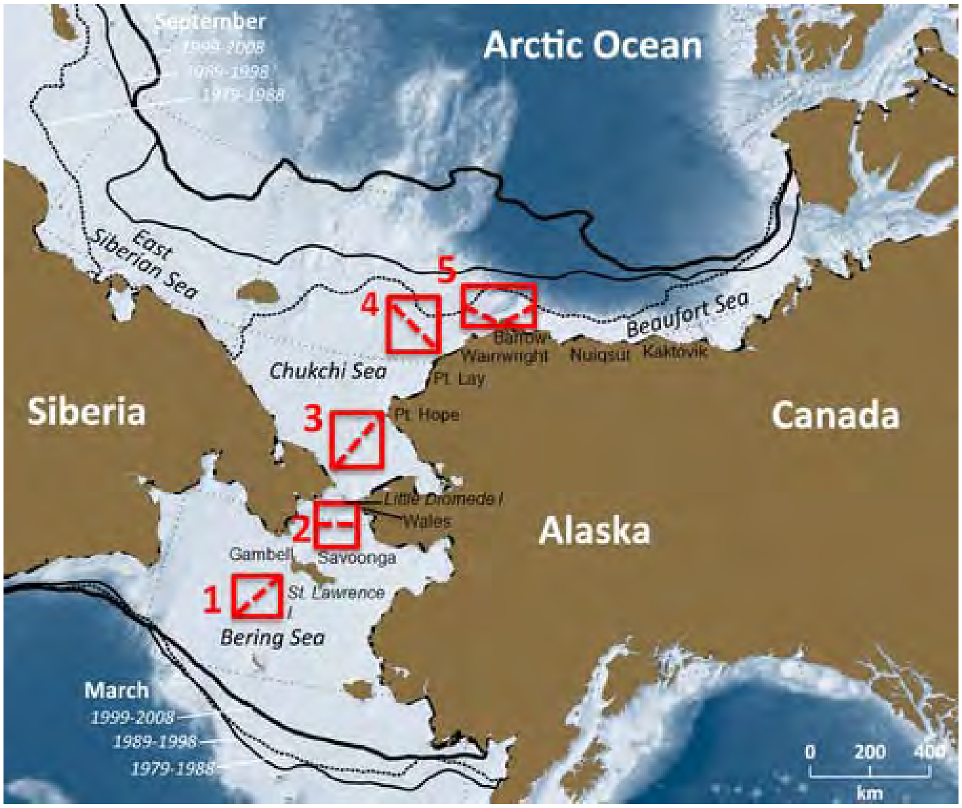

Figure 16: The Distributed Biological Observatory (DBO) in the Alaska Arctic. The red boxes are regional areas selected for observation and the dashed lines are the sampling transect lines. Figure from `http://www.arctic.noaa.gov/dbo/index.html`.

(Rigor et al., 2002). We already track this index (p. 95).

- *September sea ice index* (`http://nsidc.org/data/seaice_index/`) This index monitors the status and trends of September sea ice coverage for the entire Arctic over the satellite record (1979-present). The end of the sea ice melt season and the annual minimum in total Arctic sea ice extent occurs during September. We already track this index (p. 99).

Plankton

- *A primary production time series.* Developing a primary production time series (remote sensing or in situ) would improve our ability to recognize changes in the primary production regime of the Alaska Arctic. Climate change and alterations to sea ice phenology are expected to effect the timing (Ji et al., 2013) and magnitude (Brown and Arrigo, 2012) of phytoplankton blooms. Such changes may have consequences for herbivorous zooplankton whose life history events are linked to the cycle of Arctic primary production events (Conover and Huntley, 1991; Conover and Siferd, 1993; Ji et al., 2012; Daase et al., 2013)
- *Zooplankton species composition and biomass.* Zooplankton species of Arctic and subarctic (Pacific) origin are present in the Chukchi Sea (Lane et al., 2008; Hopcroft et al., 2010;

Matsuno et al., 2011). Species of Pacific origin are advected by the net northrward flow of water from the Bering Sea into the Chukchi Sea and influence the species composition and biomass of zooplankton in the Chukchi Sea (Hopcroft et al., 2010; Matsuno et al., 2011).

Fish

- *Fish biomass (or index of abundance).* Previous efforts to quantitatively sample fish resources of the Alaska Arctic have been separated in both space and time and often confounded by the use of different sampling methodologies, preventing the establishment of a baseline. Instead, the data provide a series of benchmarks presently unsuitable for the establishment of temporal biomass trends. Establishment of such a baseline would require quantitative sampling of fish biomass at regular interavals (e.g, every 1 to 3 years), such as from trawl surveys. Development of such a time series would permit the tracking of biomass and community composition over time and allow for the identifications of significant changes.Previous efforts to quantitatively sample fish resources of the Alaska Arctic have been separated in both space and time and often confounded by the use of different sampling methodologies, preventing the establishment of a baseline. Instead, the data provide a series of benchmarks presently unsuitable for the establishment of temporal biomass trends. Establishment of such a baseline would require quantitative sampling of fish biomass at regular interavals (e.g, every 1 to 3 years), such as from trawl surveys. Development of such a time series would permit the tracking of biomass and community composition over time and allow for the identifications of significant changes, such as what might be expected with climate change (Hollowed et al. 2013). Recent demersal trawl survey work has helped to describe current conditions in the Chukchi Sea (Goddard et al. 2013) but continued work will be necessary for development of biomass indicators. A summary of recent efforts to sample fish resources in Arctic Alaska is available at the marine fish section of NOAA's Arctic Report Card (`http://www.arctic.noaa.gov/reportcard/marine_fish.html`). Additionally, Logerwell et al. (in review) has synthesized data from recent fish surveys (2007-2012) in the Alaska Arctic from multiple habitat types across the Beaufort and Chukchi Seas to explore patterns in community composition, habitat use, and life history.

Seabirds

- *Black guillemot (Cepphus grylle) reproductive success.* Trends in the reproductive success of black guillemots on Cooper Island, AK may provide an indication of overall favorable or declining conditions for piscivorous sea ice associated seabirds.
- *Black guillemot food habits.* Changes in diet of black guillemots on Cooper Island, AK may affect growth, survival, and reproductive success, and may be a reflection of changing climatic conditions (e.g., loss of sea ice) and the availability of preferred prey.

Marine mammals

- *Marine mammal body condition.* Changes in body condition (e.g., body mass at age and season) may reflect changes in climate and/or changes in prey distribution and availability.

- *Marine mammal abundance/biomass.* Determining for which species time series data exists or initiating regular censuses for other species to track the overall health and persistence of marine mammal populations in the Alaska Arctic.

Humans

- *An index of subsistence hunting of marine mammals* intended to provide a gross measurement of human interaction with the marine environment. This index could be based on the number/mass of harvested animals and/or effort (CPUE), may be species specific or aggregate, or could be a measure of subsistence participation in aggregate or by community (number of people participating/permits). The success of any particular subsistence hunt may be subject to a multitude of factors including (but not limited to) effort, hunter experience, environmental factors, and prey abundance. An index of subsistence hunting would ideally be sufficiently broad in scope to minimize the effects of such confounding factors, but focused enough to provide an informative measure of direct human interaction with living marine resources.

Eastern Bering Sea Ecosystem Assessment

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Summary

Recap of the 2014 ecosystem state

Some of the ecosystem indicators that we follow are updated to the current year's state, while others can be updated only to the end of the previous calendar year or before due to the nature of the data collection, processing, or modelling. Thus some of the "new updates" in each Ecosystem Considerations report reflect information from the previous year. Below is an updated summary of last year (i.e., 2014) that includes 2014 information that we have received in 2015. Our goal is to provide a complete picture of 2013 based on the status of most of the indicators we follow. The next section provides a summary of the 2015 ecosystem state based on indicators that are updated in the current year.

The year 2014 broke the sequence of seven years with cold winter-spring temperatures (2007-2013), following the seven warm temperature years (2000-2006)(Overland et al., p.99). January-May 2014 near surface air temperature anomalies in the southeastern Bering Sea were +2°C, in contrast to 2013 at -2.5°C and 2012 at -3°C; sea ice maximum extent was reduced. Warm temperatures related to weaker winds than normal and mild temperatures over the northern North Pacific. Summer 2014 continued warm conditions due to high sea level pressures and weak winds. Ocean temperatures reflected the shift to warmer conditions throughout the year. The cold pool extent for summer 2014 retreated in contrast to recent cold years. Warmer ocean heat storage persisted into fall 2014.

Biota associated with bottom habitat, such as sea whips, anemones, and sponges, all showed light declines in survey catch rates compared with the year before, although these trends may be influenced by gear selectivity.

The 2014 springtime drift patterns based on OSCURS model time series runs did not appear to be consistent with years of good recruitment for winter-spawning flatfish such as northern rock sole, arrowtooth flounder and flathead sole. This was the third spring with drift pattern that are not consistent with good recruitment for these flatfish.

In the pelagic zone, preliminary euphausiid abundance as determined by acoustics continued a decline seen since a peak in abundance was observed in 2009. This suggests that foraging conditions for euphausiid predators were relatively more limited this year. However, concurrent estimates of copepod abundance are not currently available, thus it is unknown whether planktivorous predators experienced limited prey resources overall. Jellyfish catch rates during summer remained elevated, but continuing a decline seen since a peak in 2011. In contrast, record abundances of jellyfish were caught in during fall surface trawls and as bycatch in commercial pollock fisheries. Together, these surveys indicate that jellyfish, primarily one species *Chrysaora melanaster*, has remained abundant in the EBS since about 2009 relative to low values seen in the early to mid-2000s.

Length-weight residuals, an indicator of fish condition, for planktivous age-1 pollock were strongly positive, similar to those during the warm years of 2002-2005, and indicative of good foraging conditions. Colder later summers during the age-0 phase followed by warmer spring temperatures during the age-1 phase, as occurred in 2013-2014, are assumed favorable for the survival of pollock from age-0 to age-1, further supporting that the 2013 pollock year class experienced favorable conditions in 2014. However a new multiple regression model incorporating biophysical indices from 2013 and 2014 indicated that the average ocean productivity (based on chum salmon growth), warm spring sea temperatures (less favorable), and above average predator abundances (as measured by pink salmon) would result in below average age-1 pollock recruitment in 2014.

Length-weight residuals for all analyzed groundfish species including age 2+ pollock were positive, with the exception of Pacific cod. Residuals for age-1 and older pollock are not well-correlated in most years. Residuals were negative for both age-classes in 1999 and 2012, both particularly cold years; similarly, residuals were positive in the warm years of 2003 and this year. However, the link with warm and cold years is not always simple as residuals were positive for both pollock age-classes in 2010, which was a cold year. However, this year appears to favor both age-1 and older pollock, indicating favorable foraging conditions.

Survey biomass of motile epifauna has been above its long-term mean since 2010, although the recent increasing trend has stabilized. However, the trend of the last 30 years shows a decrease in crustaceans (especially commercial crabs) and a long-term increase in echinoderms, including brittle stars, sea stars, and sea urchins. The extent to which this reflects changes in survey methodology rather than actual trends is not known. Survey biomass of benthic foragers has remained stable since 1982, with interannual variability driven by short-term fluctuations in yellowfin and rock sole abundance. Survey biomass of pelagic foragers has increased steadily since 2009 and is currently above its 30-year mean. While this is primarily driven by the increase in walleye pollock from its historical low in the survey in 2009, it is also a result of increases in capelin from 2009-2014, perhaps due to cold conditions prevalent in recent years. Fish apex predator survey biomass is currently near its 30-year mean, although the increasing trend seen in recent years has leveled off. The increase since 2009 back towards the mean is driven primarily by the increase in Pacific cod from low levels in the early 2000s. Arrowtooth flounder, while still above its long-term mean, has declined nearly 50% in the survey from early 2000s highs, although this may be due to a distributional shift relative to the summer survey in response to colder water over the last few years, rather than a population decline.

With the reduced cold pool seen in 2014, cold water-avoiding groundfish such as pollock and especially arrowtooth flounder likely expanded their range onto the shelf, increasing their predatory impact there. The cold pool potentially serves as a refuge for age-1 pollock, so it is possible that the reduction in the cold pool may have increased predation pressure on age-1 pollock by groundfish predators.

Seabirds breeding on the Pribilof Islands experienced overall early nesting and high reproductive success, indicating that foraging conditions were favorable for these piscivorous and planktivorous predators. However, there were many dead birds encountered at sea, many in association with a large coccolithophore bloom, which can indicate poor foraging conditions. Because environmental conditions have been shown to related to successful breeding at lagged scales, the breeding success in summer 2014 may have been influenced by favorable conditions experienced this summer and/or the past few seasons. Observations in 2014 of the lowest seabird bycatch in all federally-managed groundfish fisheries in a time series that began in 2007 may provide further support that foraging conditions were favorable for seabirds, based on the assumption that birds are less likely to forage on offal at fishing vessels in years with abundant prey. In contrast, the number of fur seals pups born at the Pribilofs was 2.1% less than during the last count in 2012, indicating continued unfavorable conditions for fur seals breeding there. The larger rookery on St. Paul Island this year had 5.2% fewer pups born this year than during the last count, but the smaller rookery at St. George Island has 17% more pups born.

In general, the shift from sequential cold years to a warm year appeared to coincide with a surge in productivity for groundfish and seabirds as indicated by general biomass trends, groundfish condition, and seabird reproductive success. Some, such as overall pollock and arrowtooth flounder biomass, are likely influenced by the reduction in the cold pool, which expanded their preferred thermal habitat. New early warning indicators provide further support, as community resilience appeared to be declining during the sequential cold years, with recovered resilience during 2014. Groundfish condition was positive most groundfish species and seabird reproductive success was high, indicating favorable conditions for these piscivorous and planktivorous predators. This was not the case for fur seals, which may be responding to a different suite of population pressures or a similar suite in a different way. This pattern of high productivity in years immediately following cold years may be similar to that in 2003, which saw peak survey estimates of pollock biomass and increasing groundfish condition. However, the subsequent warm years after 2003 saw a decreasing trend in groundfish productivity. This pattern may repeat with the continued warm conditions in 2015.

Current conditions: 2015

This year was characterized by warm conditions that were first seen in 2014, and continued through the winter, during which the PDO reached the highest winter value seen in the record extending back to 1900. The extent of sea ice during winter was reduced, as was as the size of the cold pool of bottom water during the summer. From October to March, mean air temperatures were 1-3^o warmer than normal. The warm weather can be attributed mostly to relatively warm and moist air aloft over the Bering Sea shelf due to an atmospheric circulation that suppressed the development of extremely cold air masses over Alaska, the usual source of the lower-atmospheric flow for the Bering Sea shelf. The 2015 springtime drift pattern was onshelf, which appears to be consistent with years of good flatfish recruitment. This follows three years (2012-2014) of wind patterns that were more offshelf, which is considered less favorable for recruitment. The climate models used for seasonal weather predictions are indicating strong El Niño conditions for the winter of 2015-16, which should serve to maintain a positive state for the PDO.

Small copepods comprised the majority of the zooplankton identified during the first spring rapid zooplankton assessment. Lipid-rich large zooplankton and euphausiids were observed in the north near the retreating ice edge, providing support of the Oscillating Control Hypothesis. However the prevalence of small copepods, as expected during warm years, indicates that the condition of the age-0 pollock may not be favorable for overwinter survival of this year class. Jellyfish continue to be abundant.

Survey biomass of motile epifauna has been above its long-term mean since 2010, with no trend in the past 5 years. However, the trend of the last 30 years shows a decrease in crustaceans (especially commercial crabs) and a long-term increase in echinoderms, including brittle stars, sea stars, and sea urchins. In fact, there has been a unimodal increase in brittle stars since 1989, and there was a large step increase for sea urchin in 2004-2005. Possible explanations for these trends include both bottom-up and top-down influences. The area of bottom habitat disturbed by trawls decreased notably in $\sim$ 1999. It's possible that less habitat disturbance has promoted brittle star abundance trends. An alternative hypothesis could be related to the long-term decrease in crabs, which along with flathead sole and eelpouts, eat the most brittle stars. Decreased crabs populations could indicate less depredation on brittle stars.

Survey biomass of benthic foragers decreased substantially in 2015, which contributed to the change in their previously stable recent trend to negative. Interannual variability in this foraging guild is driven by short-term fluctuations in yellowfin and rock sole abundance. Recent declines could possibly be related to the consecutive years of springtime drift patterns that have been linked with poor recruitment of flatfish.

Survey biomass of pelagic foragers has increased steadily since 2009 and remains above its 30-year mean. While this is primarily driven by the increase in walleye pollock from its historical low in the survey in 2009, it is also a result of increases in capelin during the sequence of cold years. Interestingly, capelin abundance has not dropped in the past two warm summers. Fish apex predator survey biomass is currently above its 30-year mean, although the increasing trend seen in recent years has leveled off. The increase since 2009 back towards the mean is driven primarily by the increase in Pacific cod from low levels in the early 2000s.

Seabirds breeding on the Pribilof Islands experienced overall late nesting and low reproductive success, indicating that foraging conditions were not favorable for these piscivorous and planktivorous predators. This hypothesis is supported by the observation of elevated numbers of dead birds observed floating at sea, with many found in the coccolithophore bloom in the south Bering Sea. Given that nearly all of the birds examined were emaciated and none had indications of disease or toxins, it is likely that the birds starved to death due to lack of food or because their ability to forage was affected. Counts of fur seal pups are conducted biannually so we don't have updated data for this year.

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

Forecasts and Predictions

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

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

The regional model is based on the Regional Ocean Modeling System (ROMS) implemented at 10km resolution (Hermann et al., 2013), and includes an embedded Nutrient Phytoplankton Zooplankton (NPZ) model with euphausiids (Gibson and Spitz, 2011). The regional models were developed with funding from NOAA/NPCREP and the NSF/NPRB funded Bering Sea Project, and calibrated through repeated hindcasts of the region covering the period 1972-2012.

A particular metric of interest is the summer cold pool, the proportion of the summer BTS survey area under a particular temperature. Figure 17 shows the cold pool with limits of 0°C, 1°C, and 2°C. Shown are BTS survey data, ROMS hindcast results 1982-2012, and ROMS 9-month ahead predictions. The most recent prediction, made in October 2015, is shown for summer 2016.

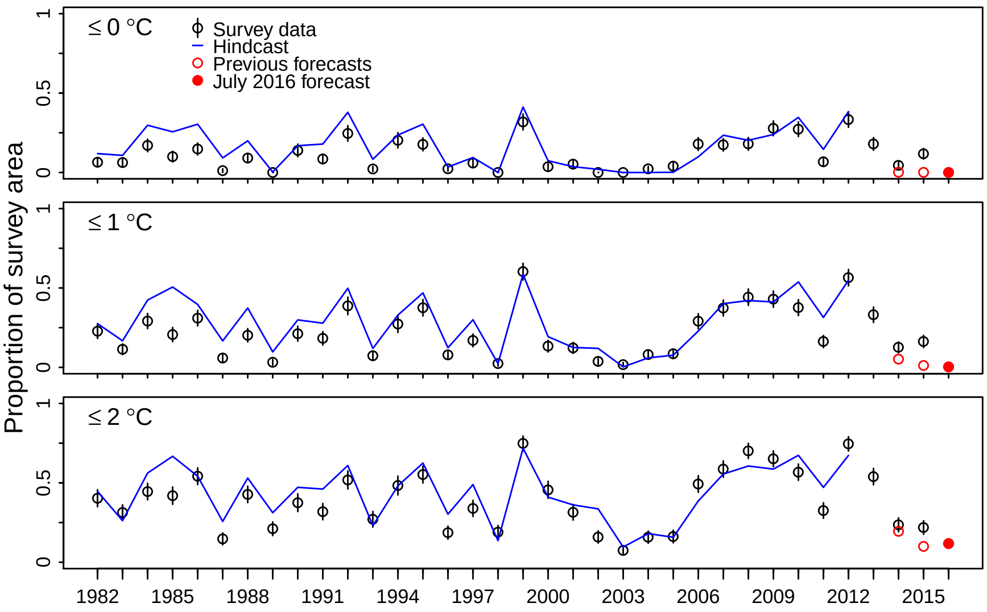

Figure 17: The eastern Bering Sea cold pool with limits of 0°C, 1°C, and 2°C. Shown are BTS survey data, ROMS hindcast results 1982-2012, and ROMS 9-month ahead predictions. The most recent prediction, made in October 2015, is shown for summer 2016.

The model successfully predicted a transition from cold to warm conditions between 2013-2014, and continued warm conditions through summer 2015. However, predictions for 2014-2015 ran slightly warmer than the data indicated; a pattern of warm bias in warm years is also evident in the hindcast. Biases may include mismatches between survey and model area and depth. The prediction for 2016 indicates continued warm conditions and a small cold pool, though likely subject to a similar bias. It is worth noting that the model has not yet been tested in a prediction of a warm-to-cold transition.

Recruitment predictions: This report now includes several indicators which make pollock recruitment predictions. In this section, we have summarized these predictions so that we can more easily track how they compare and how well they hold up over time.

Recruitment of pollock to age-1 in 2015 is predicted to be below average based on a model that includes age-4 chum salmon growth (indicating ocean productivity) and sea surface temperature. Similarly, recruitment to age-3 is predicted be relatively weak for the 2012 year class based on a combination of low energy density and small size during fall (p.171). The average energy content of young of the year pollock during fall from 2003 to 2011 has explained 68% of the recruitment to age-3. Following this relationship, Heintz et al. predict that the 2014 year class should have intermediate recruitment success to age-3 in 2017. In contrast, the Temperature Change index values in 2015 (p.174) indicate an expected below average abundances of age-3 pollock in 2017 based on warm temperatures in late summer 2014 and the following spring. Eisner and Yasumiishi (p.173) demonstrate a significant positive relationship between abundances of large zooplankton and recruitment of that year class of pollock to age-3. The most recent data included in this analysis is from 2010. However, assuming that this relationship holds, one could speculate that the finding of predominantly small zooplankton in the spring rapid zooplankton assessment (p.126) indicates that recruitment of age-3 pollock in 2018 could be poor.

Description of the Report Card indicators

For a description of the indicators in the report card, please see the 2014 report in the archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Gaps and needs for future EBS assessments

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

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

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

In the future we would like to develop the ability to measure chlorophyll in sediments as is done for the Northern Bering Sea by Grebmeier and Cooper. It will be important to decide where such measurements should be taken. New production at M2 is thought to be low and may not be good for epibenthic fish. The location formerly occupied by M3 would have been good, but it was abandoned because boats kept running over the mooring there.

Some index of stratification may be a proxy for new production. We have stratification data for M2, but no primary production data to go with it.

Spatial scales for assessment: The team reviewed EBS bottom trawl survey data at the guild level to determine whether there were striking changes in distribution patterns over time. No patterns of immediate concern were detected; however, the team felt that including a thorough spatial investigation of key indices would be a high priority in upcoming assessments. For example, spatial distributions of zooplankton, benthos, and forage fish would be critical for predicting the foraging success of central place foragers such as seabirds and pinnipeds. It may be desirable to examine the selected indices by domain (e.g., outer, middle, and inner shelf) rather than EBS-wide. Distributional indices could be developed for foraging guilds, indicator species, and fisheries (see below) similar to some already presented in the Ecosystem Considerations SAFE (e.g. Mueter et al. on p. 218). In addition, an index of cold-pool species or other habitat specific groups could be developed and tracked. Spatially explicit indicators could be used to investigate observed patterns such as the relative success of commercial crabs in Bristol Bay versus further out on the EBS shelf.

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

1. Bienniel pup production estimation at each rookery
2. Adult female summer foraging, physiology and energy transfer to pup with specific focus on differences by rookery and foraging habitat in the eastern Bering Sea
3. Adult female and pup over-winter satellite tracking to determine foraging and pelagic habitat differences by year and rookery
4. Pup and adult female tagging to determine fur seal survival and reproductive rates

These programs have been underway since the early 2000s, but particularly in the case of item 4 above, take many years (e.g., decades to determine reproductive rates of such a long-lived species) to produce results. NMML needs to continue this field work, and couple it with habitat and ecosystem models to help us understand the differences in fur seal population responses between Bogoslof and the Pribilof Islands, and differences in responses between air-breathing and fish apex predator responses over the last 20 years.

Differences in Steller sea lion population response between the Pribilofs and the eastern Aleutian Islands also requires further research, and may be related to spatial-temporal distribution and abundance of prey.

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

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

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

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

Future use of ecosystem/climate models in development: Several reviews of the utility of ecosystem models are available. Hollowed et al examined which quantitative modeling tools were needed to support an Ecosystem Approach to Management (EAM) in the EBS. This review revealed that a diverse suite of models were utilized to support an EAM in the EBS (Table 2). Single-species stock assessment and projection models are the most commonly used tools employed to inform managers. Comprehensive assessments (e.g. Management Strategy Evaluation) are emerging as a new and potentially valuable modeling approach for use in assessing trade-offs of different strategic alternatives. In the case of management in the Eastern Bering Sea, end-to-end models and coupled biophysical models have been used primarily to advance scientific understanding, but have not been applied in a management context. In future synthesis attempts, we will add a section that brings forward predictions from different models to initiate an evaluation of the predictive skill of different assessment tools.

Table 2: Suite of models used for implementation of an ecosystem approach to management in the Bering Sea (From Hollowed et al. (2011)).

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

Aleutian Islands Ecosystem Assessment

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[7]University of Alaska Fairbanks
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[9]Habitat Conservation Division, Alaska Regional Office, National Marine Fisheries Service, NOAA
[10]Alaska Biological Science Center, USGS
[11]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[12]Oceana
[13]North Pacific Research Board
[14]Alaska Maritime National Wildlife Refuge, USFWS

Editor's note: This year we have added the latest data points to the Aleutian Islands Report Card, but did not due any indepth analysis due to the lack of new survey information. In this section we include the description of the ecoregions and explanations of the indicators from past assessments.

The Aleutian Islands ecosystem assessment area

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

The three Aleutian Islands ecoregions are defined from west to east as follows (Figure 18). The Western Aleutian Islands ecoregion spans 170° to 177°E. These are the same boundaries as the North Pacific Fishery Council fishery management area 543. This ecoregion was considered to be distinct from the neighboring region to the east by primarily northward flow of the Alaska Stream through wide and deep passes (Ladd, pers. comm.), with fewer islands relative to the other ecoregions.

The Central Aleutian Islands ecoregion spans 177°E to 170°W. This area encompasses the North Pacific Fishery Council fishery management areas 542 and 541. There was consensus among the group that the eastern boundary of this ecoregion occurs at Samalga Pass, which is at 169.5°W, but for easier translation to fishery management area, it was agreed that 170°W was a close approximation. The geometry of the passes between islands differs to the east and west of Samalga Pass (at least until Amchitka Pass). In the Central ecoregion the passes are wide, deep and short. The Alaska Stream, a shelf-break current, is the predominant source of water (Figure 19). There is more vertical mixing as well as bidirectional flow in the passes. This delineation also aligns with studies suggesting there is a biological boundary at this point based on differences in chlorophyll, zooplankton, fish, seabirds, and marine mammals (Hunt and Stabeno, 2005).

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

Indicators

The suite of indicators that form the basis for the assessment was selected to provide a comprehensive view of the Aleutian Island ecosystem reflecting across trophic levels from the physical

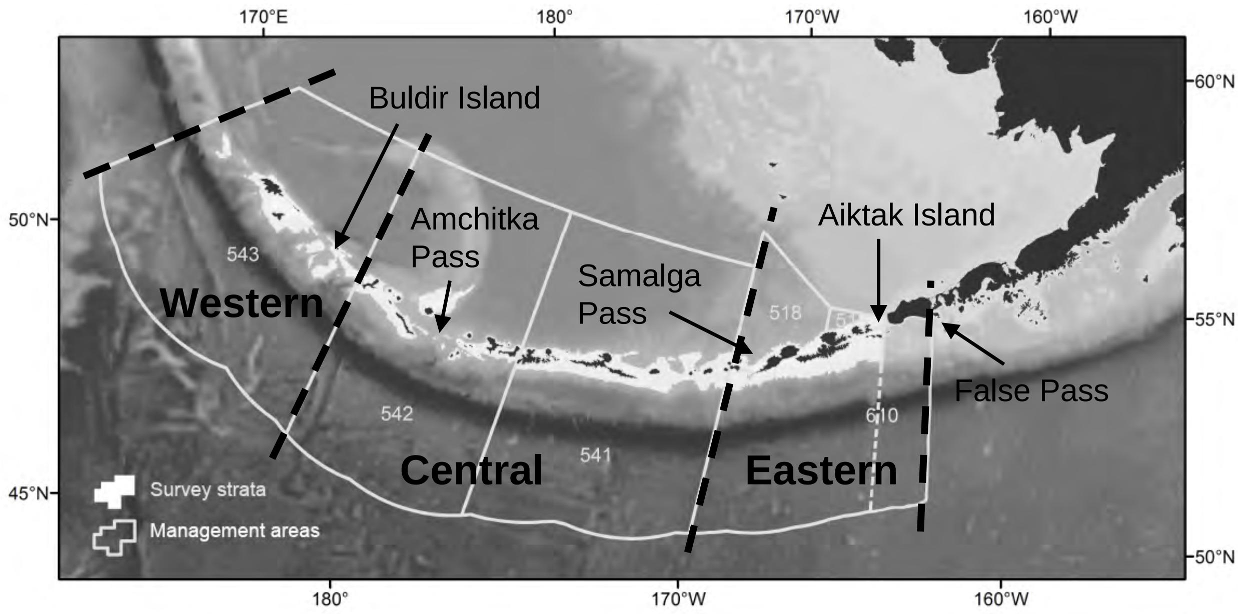

Figure 18: The three Aleutian Islands assessment ecoregions. Seabird monitoring islands are indicated by arrows.

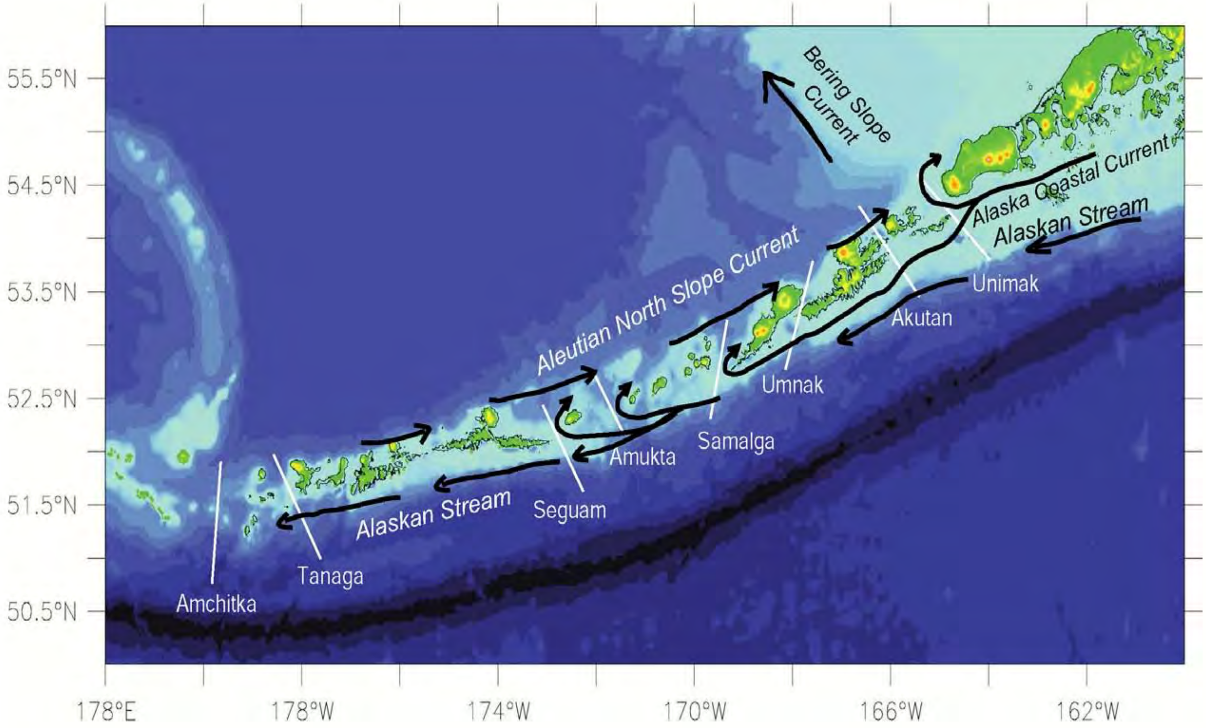

Figure 19: Ocean water circulation in the Aleutions. Currents are indicated with black lines. Passes are indicated with white lines. Image from Carol Ladd.

environment to top predators and humans, as well as both the nearshore and offshore. Ideally, they could be regularly updatable across all ecoregions, thereby characterizing a global attribute with local conditions. Although a single suite of indicators were chosen for the entire ecosystem, not all are available or applicable in each of the three ecoregions. The final selection reflected the limitations of available data sets for this region.

1. Winter North Pacific Index anomaly relative to the 1961-2000 mean
2. Reproductive anomalies of planktivorous least auklet and crested auklets as indicators of zooplankton productivity
3. Proportions of *Ammodytes*, gadids, and hexagrammids in tufted puffin chick diets
4. Apex predator and pelagic forager fish biomass indices
5. Sea otter counts
6. Steller sea lion non pup counts (juveniles and adults)
7. Percent of shelf <500m deep trawled
8. K-12 enrollment in Aleutian Islands schools

Winter North Pacific Index The North Pacific Index (Trenberth and Hurrell, 1994), the area weighted mean sea level pressure over the region 30° - 65°N, 160°E - 140°W, is a widely used measure of the intensity of the Aleutian Low. A negative winter (November - March) NPI anomaly implies a strong Aleutian Low and generally stormier conditions. It has been suggested that correlations between a strong Aleutian Low and decreased seabird productivity in the Aleutian Islands may be due to decreased prey (zooplankton) availability (Bond et al., 2011). The winter index is the average NPI from November through March (year of January), and the anomalies are normalized by the mean (8.65) and standard deviation (2.23) for 1961-2000.

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

Reproductive success is defined as the ratio of number of nest sites with a fledged chick to the number of nest sites with eggs. In the Western ecoregion, reproductive success of least and crested auklets were recorded annually at Buldir Island from 1988-2010 with the exception of 1989 and 1999. In the Central ecoregion, reproductive success was monitored annually at Kasatochi Island from

1996-2007. In 2008 a volcanic eruption covered the monitored colony in ash, disrupting breeding. It is unknown when auklets will nest there again and if so, whether observations will continue. Data were extracted from reports produced by the Alaska Maritime National Wildlife Refuge.

Proportions of hexagrammids, gadids, and *Ammodytes* in tufted puffin chick diets Tufted puffins (*Fratercula cirrhata*) are medium-sized seabirds that nest in varying densities throughout the Aleutians. The USFWS stations field biologists to monitor puffin chick diets annually at Buldir and Aiktak Islands (Figure 18) and less frequently at other Aleutian islands on which they occur. Puffins carry multiple prey items in their bills when they return to their colonies to feed their chicks. Forage fish and squid comprise most of puffin chick diets. In the absence of direct measures of forage fish abundance, time series of percent biomass of hexagrammids, gadids, and *Ammodytes* in puffin chick meals were selected as indicators of forage fish recruitment and system-wide productivity.

Apex predator and pelagic forager fish biomass indices We present two foraging guilds to indicate the status and trends for fish in the Aleutian Islands: apex predators and pelagic foragers. Each is described in detail below. This guild analysis was based on the time series available as part of the NOAA summer bottom trawl survey for the Aleutian Islands (Western and Central ecoregions) and the Aleutian Islands and Gulf of Alaska combined (Eastern ecoregion). These two guilds are based on the aggregation of Aleutian species by trophic role, habitat and physiological status. The species included in each guild are listed in Table 3.

Table 3: Species included in foraging guild-based fish biomass indices for the Aleutian Islands

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

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

Sea otter counts Sea otters (*Enhydra lutris*) counts were selected as a representative of the nearshore Aleutian environment. The >300 islands which make up the Aleutian chain provide extensive nearshore habitat. Sea otters are an integral component of the coastal ecosystems in which they occur. Sea otter predation limits the distribution and abundance of their benthic invertebrate prey, in particular herbivorous sea urchins. Otter-induced urchin declines increase the distribution and abundance of kelp in Alaska (Estes and Duggins, 1995) and in other areas of their range (Breen et al., 1982; Kvitek et al., 1998). This trophic cascade initiated by sea otters has indirect effects on other species and processes. Kelp forests are more productive than habitat without kelp (a.k.a. "sea urchin barrens"), fixing 3-4 times more organic carbon through photosynthesis (Duggins et al., 1989). This increased primary production results in increased growth and population size of consumers such as mussels and barnacles (Duggins et al., 1989). Rock greenling (*Hexagrammos lagocephalus*), a common fish of the kelp forests of the Aleutian Islands, are an order of magnitude more abundant in kelp forests than in sea urchin barrens (Reisewitz et al., 2006). Kelp forests likely function as nearshore habitat for other Aleutian Islands fish, such as the related Atka mackerel (*Hexamgrammos monopterygius*). Sea otter impacts on kelp forests also influence the behavior and foraging ecology of other coastal species such as Glaucous Winged Gulls (Irons et al., 1986) and Bald Eagles (Anthony et al., 2008).

Sea otter survey methods are detailed in Doroff et al. Doroff et al. (2003). Skiff-based surveys of sea otters were conducted several times during 2003, 2005, 2007, 2009 and 2011 at Amchitka Island, Kiska and Little Kiska Islands, Attu Island, Agattu Island, Rat Island and the Semichi Islands when viewing conditions were good to excellent (Beaufort sea state of 1-2, and .1 km of clear visibility at sea level). Full surveys were not conducted in 2011 at Kiska and Little Kiska Islands, in 2003 at Rat Island, and in 2005 and 2011 at the Semichi Islands. Two or more observers counted sea otters from a 5.2-m skiff as it was run parallel to shore along the outer margins of kelp (*Alaria fistulosa*) beds at 15-22 km/h. Sea otters were counted with the unaided eye, using binoculars to confirm sightings or to count animals in large groups. The shoreline of each island was divided into contiguous segments, each 3-10 km in length and separated by distinctive topographic features (e.g., prominent points of land). Counts were recorded separately for each section. To maximize the time series available for this assessment, only counts of otters at Attu are presented for the Western ecoregion and counts at Amchitka for the Central ecoregion.

Steller sea lion non pup counts Counts of adult and juvenile Steller sea lions (*Eumetopias jubatus*) are used in the Aleutian Island ecosystem assessment to represent the status of an apex piscivorous predator whose diet consists primarily of commercially-fished species. The Steller sea lion inhabits coastal regions of the North Pacific Ocean, breeding in summer on terrestrial rookeries located from California north throughout the Gulf of Alaska, the eastern Bering Sea, the Aleutian Islands, Kamchatka Peninsula, Sea of Okhotsk, and the Kuril Islands (NMFS, 2010). The Steller sea lion is the world's largest member of the Otariidae family of pinnipeds. On average, Steller sea lions consume 6-10% of their body weight per day, but during lactation, energy intake by adult females may increase by as much as 3-fold (Keyes, 1968; Winship et al., 2002; Williams, 2005). Steller sea lions are generalist predators and consume a wide variety of fish and cephalopods in habitats ranging from nearshore demersal to offshore epi-pelagic, with local diets reflecting the species composition of the local fish community (Pitcher and Fay, 1982; Riemer and Brown, 1997; Sinclair and Zeppelin, 2002; Waite and Burkanov, 2006; Trites et al., 2007; McKenzie and Wynne, 2008; Fritz and Stinchcomb, 2005). In the Aleutian Islands, the diet consists largely of Atka mackerel, followed by salmon, cephalopods, Pacific cod, sculpins and walleye pollock (Sinclair and

Zeppelin, 2002). Unlike phocid pinnipeds, otariids do not have large blubber (energy) stores, and as a consequence, require reliable access to predictable, local prey aggregations to thrive (Williams, 2005; Sigler et al., 2009).

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

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

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

Percent of shelf <500m trawled The annual and cumulative percentage of AFSC RACE 5 km x 5 km survey cells with observed commercial trawling, was developed from the North Pacific Observer Program foreign and domestic database in the Aleutian Islands region in waters with a bottom depth shallower than 500 meters. For the annual index, a cell is counted as trawled if there is a single trawl in the cell for that year. For the cumulative index, a cell is counted as trawled if there is a single observed trawl end position in the cell for the entire time series in each period: 1977-1989, 1990-1999, 2000-2010. Periods were chosen based on significant policy changes: 1990 marks the start of the domestic fisheries, while in 1999 and 2000 the US government issued emergency interim rules to further protect Steller sea lions. These rules expanded the number of seasonal and year-round pollock trawl exclusion zones around important rookeries and haulouts, implemented measures to disperse pollock fishing effort spatially and tempoarlly, and closed the Aleutian Islands to pollock trawling; additional restrictions were placed on the Atka mackerel fishery in the AI. New extensive protection measures for Steller sea lion were implemented in 2011 which significantly expand closures.

The time series begins in 1977 for both indices. These indices measure the annual and cumulative impacts of trawling on AI shelf habitat within each eco-region, allowing for an evaluation of changes in these indices. Increases in the cumulative index are thought to indicate an expansion of the trawl fisheries into previously untrawled areas. Caution should be taken in the interpretation of these indices because only observed effort is included and changes in the indices may be influenced by changes in observer coverage. For example, a large increase in the annual and cumulative indices can be seen in 1991, when the domestic fishery observer program was implemented. Further, the implication of these indices is that the impact of a single trawl is the same as multiple trawls in an area, this is a gross simplification. Future work should concentrate on assessing the appropriate weighting of trawl impacts on different habitat types and defining habitat types in the Aleutian Islands region.

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

Gulf of Alaska Ecosystem Assessment

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We present an initial Gulf of Alaska Report Card this year. The report card follows the format of those for the eastern Bering Sea and Aleutian Islands. This associated ecosystem assessment defines the report card indicators, describes how they were selected, and provides a synthesis of the current state of the Gulf of Alaska ecosystem based on the report card indicators as well as other indicators.

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

During 2014 and 2015, we used an online survey format to solicit opinions from ecosystem experts on the most appropriate indicators to include in the report card. The purpose of this format was to increase the group size and diversity in GOA expertise of the participants in the indicator selection process by soliciting information online. In the past, we had broadened the expertise of the team developed to select the Aleutian Islands indicators relative to the eastern Bering Sea team based on comments from the Scientific and Statistical Committee of the North Pacific Fisheries Management Council. We hope that by surveying a greater number of individuals than were involved with indicator selection for the eastern Bering Sea and Aleutian Islands, the survey results reflect broader expertise and an "equal voice" from all participants. We plan to review and refine these indicators in conjunction with the NPRB-sponsored GOA IERP synthesis team this coming winter. The survey was conducted under the requirements of the Paperwork Reduction Act.

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. There is one set of indicators for the entire Gulf, although further refinement may include separate components to represent smaller scales such as west vs east. The final list on indicators in this report card includes:

1. The winter Pacific Decadal Oscillation
2. Fresh water input
3. Mesozooplankton biomass
4. Copepod community size
5. Motile epifauna biomass
6. Capelin abundance
7. Apex predator biomass
8. Black-legged kittiwake reproductive success
9. Steller sea lion non-pup estimates
10. Human population

Winter Pacific Decadal Oscillation

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

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

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

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

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

Capelin relative abundance These data represent the percent prey composition (for each prey type, percentage of the total number of prey items) that was capelin in diets of tufted puffin chicks at East and West Amatuli islands, Alaska. Samples ("bill-loads") were collected from burrow screening or found at burrows during chick growth and productivity monitoring by Alaska Maritime National Wildlife Refuge staff, U.S. Fish and Wildlife Service.

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

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

Steller sea lion non-pup estimates The agTrend model was used to produce abundance estimates of Steller sea lions within the bounds of the Gulf of Alaska. This region includes the ranges of two distinct populations, the western and eastern, which have shown different population trends. The eastern population has been increasing at a greater rate than the Gulf of Alaska portion of the western population. We present the sum of these distinct populations for this edition, but may revise this in the future.

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

Current Environmental State

The current environmental state in the Gulf of Alaska is notable for the anomalously warm surface water present since early 2014. This began as the "Warm Blob" in the NE Pacific and has seen some evolution in its pattern since that time, related in part to sea level pressure and wind anomalies. The upper ocean has remained fresher than usual with a relatively strong pycnocline, also continuing conditions first seen in early 2014. The sub-arctic front in 2015 was farther north than usual, which is consistent with the poleward surface currents shown in the Ocean Surface Currents - Papa Trajectory Index section (see p. 115). The coastal wind anomalies were generally downwelling favorable during fall and winter 2015 but switched to more upwelling favorable during the spring and summer, resulting in more moderate SST anomalies along the coast as compared with the much warmer than normal water offshore by summer 2015. The PDO switched to a positive phase in 2014 and reached record positive values during winter 2015. An El Niño has developed along the equator and is predicted to be strongly positive during the upcoming 2015/2016 winter. These two changes in climate indices signal potential shifts in ecosystem state, some of which may be observed immediately (e.g., range shifts in upper trophic organisms) and some which may be expected to be observed at a lag (e.g., recruitment of upper trophic organisms).

Notable observations during 2015 summer surveys which may or may not be attributed to the anomalously warm conditions and/or shifts in climate include: increased Pacific pomfret abundance; these pomfret were eating age-0 rockfish and sablefish; coho salmon were eating the abundant young sablefish; the second highest Icy Strait temperature was recorded; juvenile pink and coho salmon showed early outmigration; the largest body size of juvenile pink and coho on record was observed; pteropods (*Limacina*) were abundant; large ocean sunfish (*Mola mola* 900 lbs and 400 lbs) were caught in June and July; and unusual catches of Pacific saury and market squid. In addition, there was an Unusual Mortality Event for marine mammals declared as elevated numbers of dead large whales were found on beaches or floating at sea throughout the western Gulf of Alaska (see p. 54). One suspected cause is a harmful algal bloom, although this is currently under investigation. Also, while seabirds showed mostly poor reproduction in the Gulf of Alaska, there was not complete failure. However, many birds showed signs similar to that of toxicosis (H. Renner, pers. comm.). Carcasses are being analyzed to determine cause of mortality.

The NOAA summer bottom trawl survey is conducting biennially over a large part of the Gulf of Alaska shelf. However, some catch patterns align closely with those of the annual bottom trawl survey conducted by ADF&G over a more restricted area, Barnabus Gully. For example, both arrowtooth flounder and Pacific halibut appear to have increased in abundance until approximately 2003, after which there has been a general declining pattern. Both species increased in the NOAA survey in 2015 relative to 2013; 2015 results were not available for the ADF&G survey in time for this report.

Despite some increase in catch rates, groundfish condition, as indicated by length-weight residuals from the NOAA bottom trawl survey, were negative overall for all sampled species in 2015. The only areas with positive residuals were for pollock and arrowtooth flounder in southeast Alaska and Pacific cod in the Yakutat region. Age-1 pollock also showed some positive residuals by area, but remained negative overall. The reoccurrence of "mushy" halibut syndrome in 2015 provides additional supportive evidence for poor conditions for groundfish in the Gulf of Alaska. The condition is considered a result of nutritional myopathy, and thus many be indicative of poor prey conditions for halibut.

Indications of the relatively low quality of foraging conditions for groundfish, including for young of the year, are suggested in the rapid zooplankton counts, conducted for the first time this year. Abundances of the small copepods were several orders of magnitude higher than either large copepods or euphausiids. Survey stations in areas of relatively cooler water had higher large zooplankton proportions and abundances. These spatial patterns are consistent with a lower trophic response to the thermal patterns in the Gulf. Summer acoustic surveys indicated that euphausiid abundance during 2015 was slightly lower than that during 2013. Possible factors that could influence trends in abundance include bottom up forcing by temperature or top down forcing by predation, but neither appear to explain these trends in the Gulf of Alaska (Simonsen et al., in press). Few age-0 pollock were observed during late summer surveys, corresponding with the low number of pollock larvae observed earlier during spring. Thus, the current assessment of the 2015 pollock year class appears to be very small.

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.cfm`

Physical Environment

North Pacific Climate Overview

Contributed by N. Bond (UW/JISAO))
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Last updated: September 2015

Summary: *The state of the North Pacific atmosphere-ocean system during 2014-2015 featured the continuance of 2013-2014 sea surface temperature (SST) anomalies with some evolution in the pattern. This development can be attributed to the seasonal mean sea level pressure (SLP) and wind anomalies such as the cyclonic wind anomalies in the central Gulf of Alaska in fall 2014 and winter 2015, with a reversal to anticyclonic flow in the following spring and summer of 2015. The Bering Sea experienced the second consecutive winter of reduced sea ice, in what may turn out to be the early stage of an extended warm spell. The Pacific Decadal Oscillation (PDO) was positive during the past year, especially during the winter months. The climate models used for seasonal weather predictions are indicating strong El Niño conditions for the winter of 2015-16, and its usual impacts on the mid-latitude atmospheric circulation, which should serve to maintain a positive state for the PDO.*

Regional Highlights:

Arctic. The timing of the onset of ice in the Chukchi and coastal portion of the Beaufort Sea during fall 2014 was comparable to that of most recent years. Air temperatures in these regions were systematically higher than normal from fall 2014 through spring 2015. It remained relatively warm in the Chukchi Sea through the summer of 2015, but temperatures were near normal in the

Beaufort Sea where the ice was slow to retreat with a band of ice just off the coast east of Barrow that persisted through late summer. This can be attributed to westerly wind anomalies along the northern coast of Alaska and hence southward Ekman transports, and a lack of warm water from the Mackenzie River plume, which instead advected eastward towards the Canadian Archipelago. This contrasts with the norm for the last decade or so, which has included anomalous winds from the east. For the Arctic as a whole, the area of sea ice cover at the end of the 2015 melt season is liable to resemble that of 2011, which represented the 3^{rd} lowest value in the observational record.

Bering Sea. The Bering Sea shelf experienced weather during the past cold season of 2014-15 in an overall sense that was quite similar to 2013-14. For the period of October 2014 through March 2015, mean air temperatures were 1-2° C warmer than normal on the southern portion of the shelf and about 3° C warmer than normal in the north. The warm weather can be attributed mostly to relatively warm and moist air aloft over the Bering Sea shelf due to an atmospheric circulation that suppressed the development of extremely cold air masses over Alaska, the usual source of the lower-atmospheric flow for the Bering Sea shelf. The relative warmth of the water in the south prevented ice from reaching as far as south as usual even though there were periods of sustained northerly winds late in the cold season, such as during the middle part of April 2015. The consequence was a cold pool that did not extend much south of 59° N. The weather during summer of 2015 tended to be warm, with a typical amount of storminess.

Alaska Peninsula and Aleutian Islands. Some of the abnormally warm water that developed in the NE Pacific during early 2014 appears to have made it to the Aleutians and through the eastern Aleutian passes into the Bering Sea, presumably during the winter when the local winds were favorable for northward transports. During the period from fall 2014 to summer 2015, upper ocean temperature anomalies in the western Aleutians cooled from above normal to near normal. These anomalies remained general above normal along the arc of the eastern Aleutian Islands and Alaska Peninsula.

Gulf of Alaska. The upper ocean in this region remained fresher than usual with a relatively strong pycnocline, in the continuation of conditions first seen in early 2014. The sub-arctic front was farther north than usual, which is consistent with the poleward surface currents shown in the Ocean Surface Currents - Papa Trajectory Index section (see p. 116). The coastal wind anomalies were generally downwelling favorable during fall and winter but switched to more upwelling favorable during the spring and summer, resulting in more moderate SST anomalies along the coast as compared with the much warmer than normal water offshore by summer 2015.

West Coast of Lower 48. This region continues to be impacted by warm (in some cases record) upper ocean temperatures. The winter featured suppressed precipitation in California and warm air temperatures along the entire coast. The lack of winter snowpack and relatively warm and dry weather in spring and summer led to rivers and streams running extremely low and warm, with detrimental effects on many returning adult salmon runs. The spring and summer included relatively robust upwelling in the northern portion of this domain and hence a thin strip of water of moderate temperatures in the immediate vicinity of the coast. Nevertheless, the proportion of northern, lipid-rich copepods was relatively low in sampling carried out on the Newport, OR line and therefore it is expected that conditions will favor species adapted to warmer water and associated prey. The wind anomalies were mostly downwelling favorable south of roughly Cape Mendocino during spring and summer, which served to maintain the warm waters. The effects of the highly unusual atmospheric and oceanic conditions on the marine ecosystem are receiving considerable attention from the research community. Additional information on the state of the

California Current system is available at `http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm`.

Sea Surface Temperature and Sea Level Pressure Anomalies

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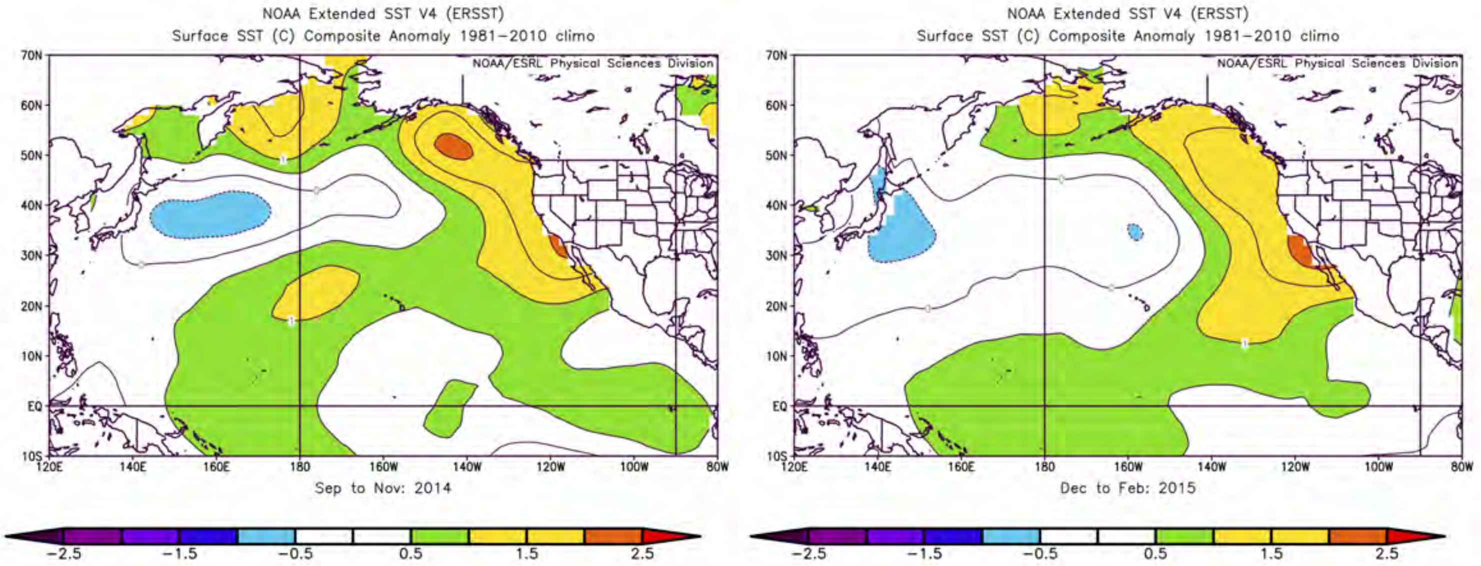
Last updated: August 2015

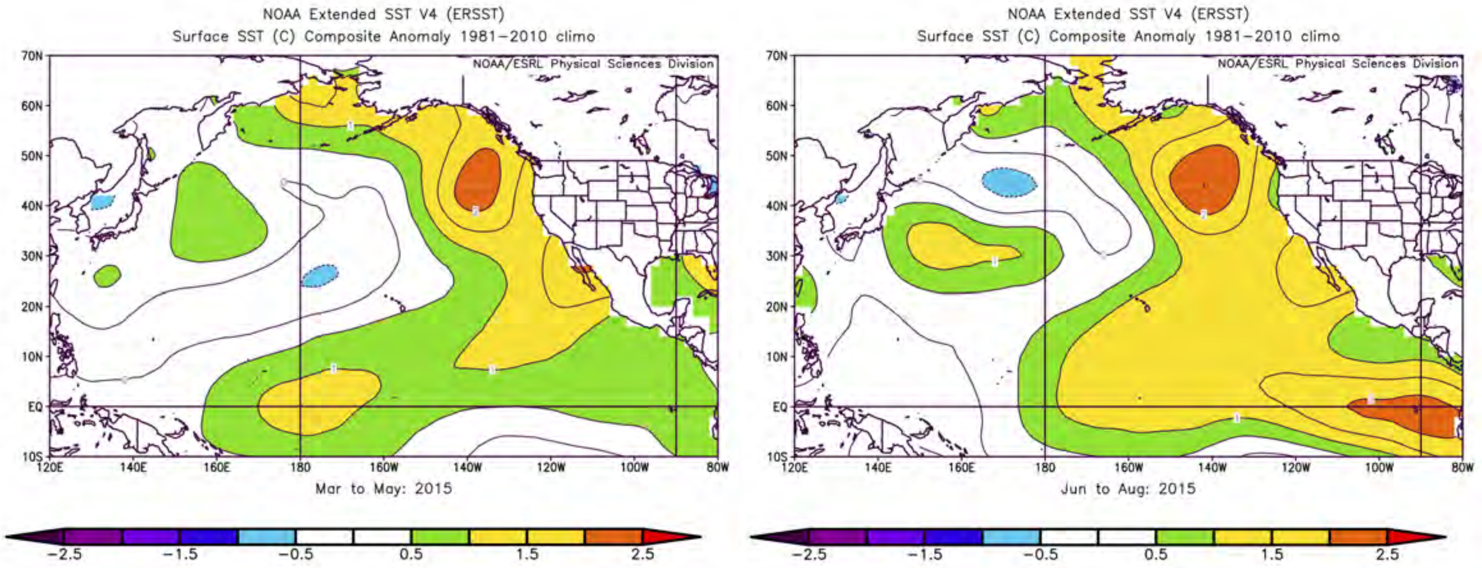
Description of indices: The state of the North Pacific climate from autumn 2014 through summer 2015 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981-2010. The SST data are from NOAA's Extended Reconstructed SST 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 anomalies that occurred during the past year in the North Pacific beginning in autumn of 2014 reflect, to a large extent, the maintenance of conditions that developed during the previous year. In particular, two leading large-scale climate indices for the North Pacific, the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO) were strongly positive and moderately negative (respectively), following a transition in sign the year before. 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 2014 (Figure 20a) included positive anomalies exceeding 1^o C along the west coast of North America from Baja California to the Gulf of Alaska, and in the western Bering Sea. The pattern of anomalous SLP during autumn 2014 featured strongly negative anomalies in the NE Pacific with a peak amplitude greater than 5 mb near 40^o N, 140^oW (Figure 21a). This SLP pattern implies anomalous downwelling in the coastal waters extending from Northern California through the Gulf of Alaska (GOA), and anomalous winds from the east across the Bering Sea. This period included a notable event that is the most intense storm on record for the North Pacific as gauged by minimum barometric pressure. This storm originated in early Novermber as supertyphoon Nuri in the western North Pacific, underwent a transition to an extratropical cyclone, and reached its maximum strength as an extratropical cyclone with a central pressure of 924 mb in the Bering Sea. Extremely high, significant wave heights and hurricane-force winds accompanied this storm.

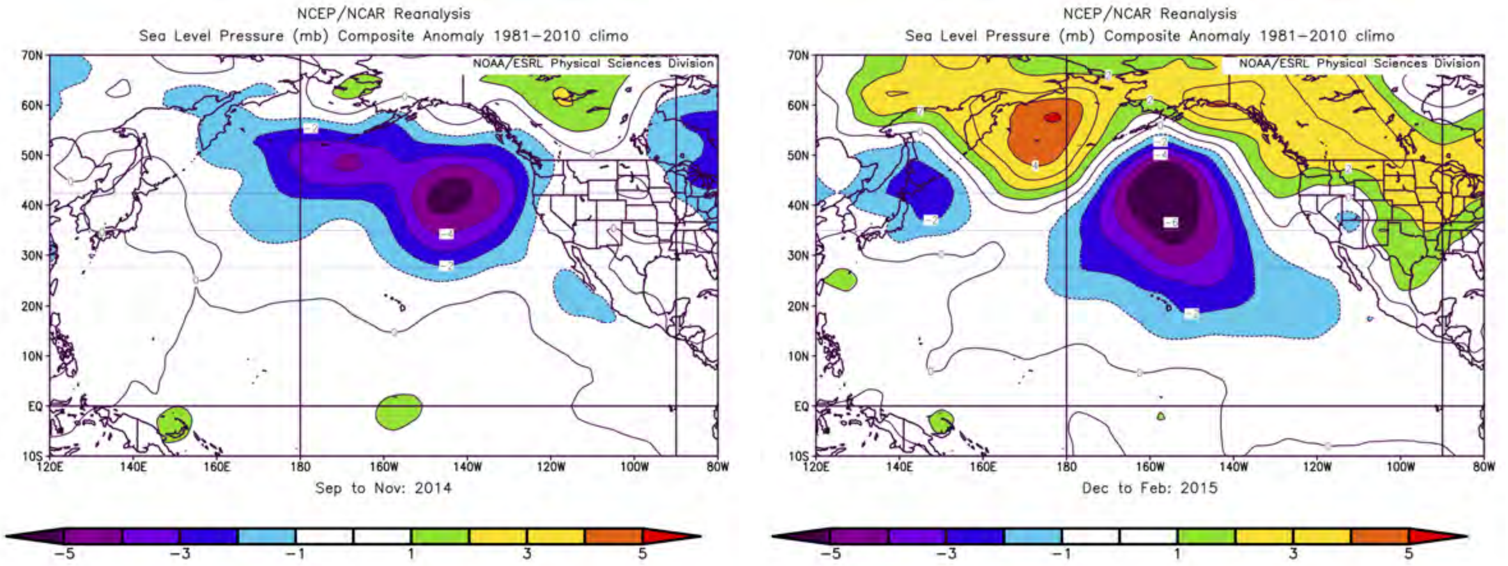


(a) Autumn (b) Winter

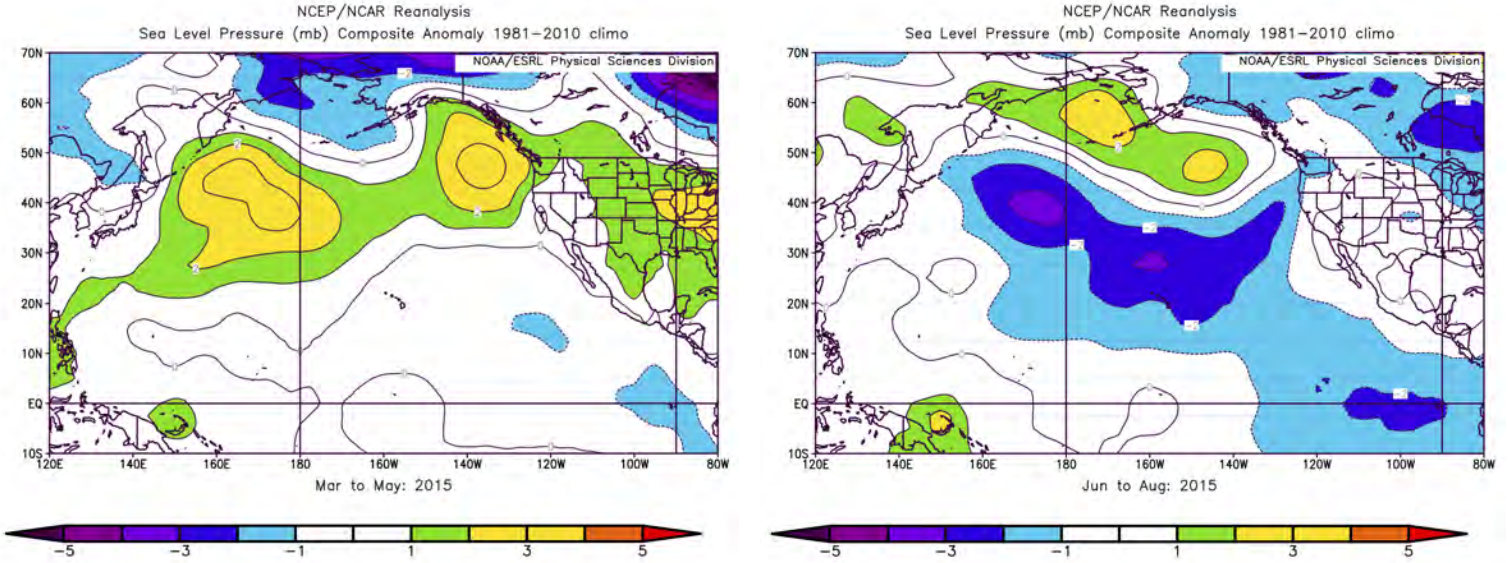


(c) Spring (d) Summer

Figure 20: SST anomolies for autumn (September-November 2014), winter (December 2014 -February 2015), spring (March - May 2015), and summer (June - August 2015).



(a) Autumn (b) Winter



(c) Spring (d) Summer

Figure 21: SLP anomolies for autumn (September-November 2014), winter (December 2014 -February 2015), spring (March - May 2015), and summer (June - August 2015).

The pattern of North Pacific SST during winter (Dec-Feb) of 2014-15 relative to the seasonal mean (Figure 20b) essentially reflects persistence from the preceding autumn. The SLP also remained much lower than normal between Alaska and the Hawaiian Islands (Figure 21b). At more northern latitudes, a band of higher than normal SLP extended to east Siberia, across Alaska and through western Canada, with a maximum positive anomaly over the western Bering Sea. This SLP distribution implies reduced storminess for the Bering Sea and for the west coast of North America from California to the Alaska Peninsula. There were regions of moderately enhanced wind speeds in the offshore portion of the eastern and northern Gulf of Alaska. The overall pressure pattern, and accompanying basin-scale atmospheric circulation, resulted in warmer than normal winter temperatures in western North America, with particularly prominent warm anomalies extending from the eastern tip of Siberia to the Alaska mainland. The lack of cold air over the Alaska interior meant fewer and weaker cold-air outbreaks over the Bering Sea shelf than usual.

The distribution of anomalous SST in the North Pacific during spring (Mar-May) of 2015 (Figure 20c) resembled that of the season before, with an increase in the magnitude of the positive anomalies off the coast of the Pacific Northwest. The SST anomalies in the tropical Pacific also increased from the dateline to the coast of South America. The SLP anomaly pattern (Figure 21c) for spring 2015 was substantially different than that for the previous winter. The most prominent features were a band of positive anomalies between roughly 30^o and 50^oN extending from the east coast of Asia to the west coast of North America, and anomalously low pressure to the north from the eastern tip of Siberia to the far northern portion of western Canada. This is typically a cold weather pattern for the southeast Bering Sea shelf. Nevertheless, the air temperatures at St. Paul Island were still above normal for this season as a whole, presumably in part because of the effects of warm ocean temperatures and reduced ice cover.

The SST in summer (Jun-Aug) 2015 (Figure 20d) was cooler than normal in a small region extending from the southern Sea of Okhotsk to the south of the Aleutian Islands, and then curving south to northwest of the Hawaiian Islands. The eastern portion of the North Pacific basin was quite warm, with prominent positive anomalies off the coast of the Pacific Northwest and in the eastern tropical Pacific. The latter feature is an indication of the El Niño that developed from spring into summer of 2015. The distribution of anomalous SLP (Figure 21d) during summer 2015 included higher than normal SLP over the Gulf of Alaska; as shown in Figure 20d there was surface warming under the central part of this SLP anomaly and a moderation of temperatures in the coastal zones of the western Gulf of Alaska and the Pacific Northwest due to anomalous upwelling favorable winds. Lower than normal SLP from the southern Sea of Okhotsk to north of the Hawaiian Islands implies enhanced storminess, which apparently served to slightly suppress the usual rate of summer warning in that portion of the North Pacific.

Climate Indices

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Last updated: August 2015

Description of indices: Climate indices provide a complementary perspective on the North

Pacific atmosphere-ocean climate system to the SST and SLP anomaly maps presented above. The focus here is on five commonly used indices: the NINO3.4 index to characterize the state of the El Niño/Southern Oscillation (ENSO) phenomenon, Pacific Decadal Oscillation (PDO) index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO) and Arctic Oscillation (AO). The time series of these indices from 2005 through early summer 2016 are plotted in Figure 22.

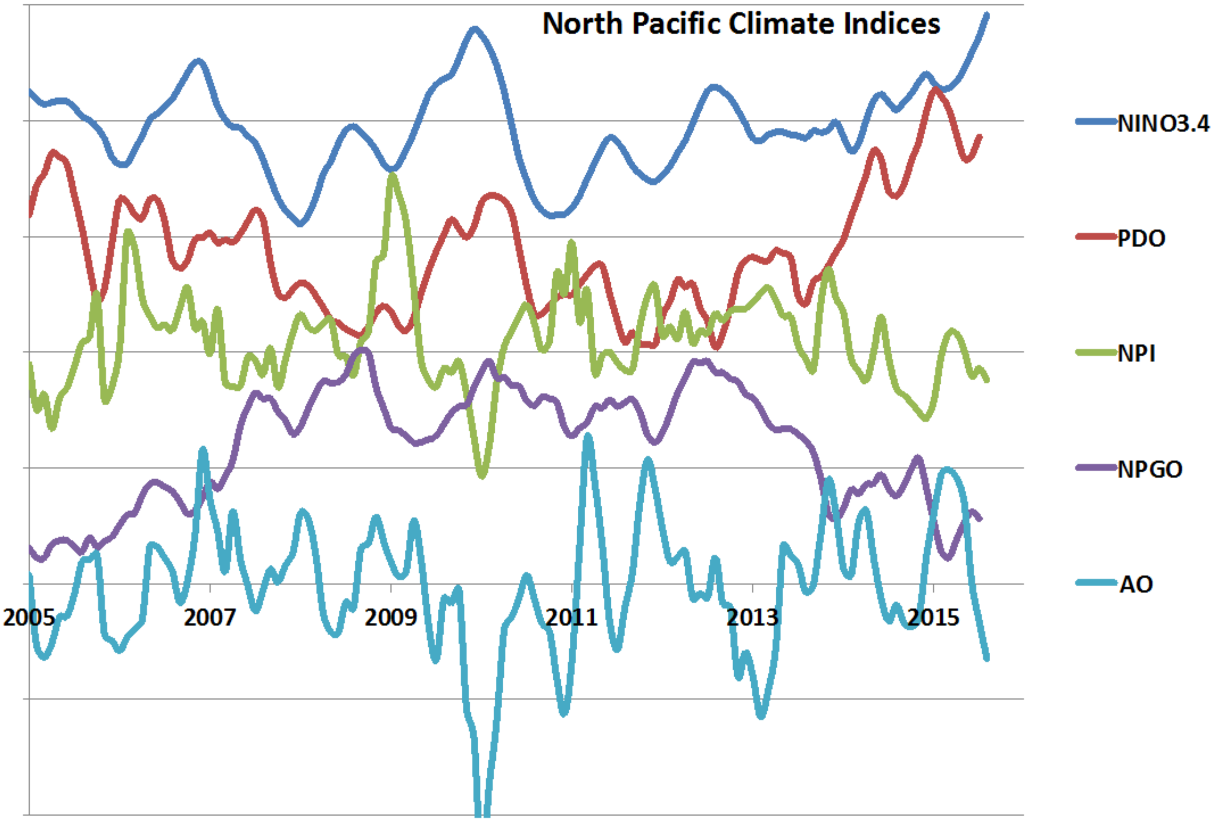

Figure 22: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Earth Systems Laboratory at `http://www.esrl.noaa.gov/psd/data/climateindices`.

Status and trends: The North Pacific atmosphere-ocean climate system has undergone substantial change over the past two years. The ENSO has transitioned from a near-neutral (slightly positive) state late in 2014 to strongly positive (∼+2)at the time of this report (note that the indices shown in Figure 22 are updated through July or August and have been smoothed with three-month running means). The PDO sharply increased late in 2014, and then moderated during spring 2015. The PDO value of 2.5 during December 2014 was the largest during a winter month in the record extending back to 1900. Changes in the PDO typically lag those in ENSO by a few months due to the North Pacific oceanic response to atmospheric teleconnection patterns emanating from the tropical Pacific, but over the past two years the changes in the PDO have mostly led and surpassed ENSO. The NPI was negative during the fall and early winter (implying a strong and often displaced Aleutian Low, as indicated in Figures 20b and 21b). This development occurred relatively independent of ENSO, at least as gauged by the NINO3.4 index. The generally negative values of the NPI are consistent with the positive trend in the PDO.

The North Pacific Gyre Oscillation (NPGO) represents the second leading mode of variability for the North Pacific, and has been shown to relate to chemical and biological properties in the northeastern Pacific, in particular the Gulf of Alaska. The NPGO has undergone a general decrease from a strongly positive state in 2012 to negative in 2015. A negative sense of this index implies a reduced west wind drift and projects on weaker than normal flows in both the Alaska Current portion of the Subarctic Gyre and the California Current. There is tentative evidence that the NPGO, and in particular its atmospheric counterpart the North Pacific Oscillation (NPO), can impact ENSO through its association with the strength of tradewinds in the eastern subtropical Pacific. The climate community is taking great interest in the recent conditions in the North Pacific and it is possible that the strength of the fluctuations, i.e., the signals, are great enough to gain better understanding of the interactions between extratropical and tropical modes of variability in the Pacific. 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, at a latitude of roughly 45° N. It has a weakly positive correlation with sea ice extent in the Bering Sea. The AO was negative late in 2014, strongly positive during the early part of 2015, and then negative during the summer of 2015. It does not appear that the variations in the AO were closely related to conditions in the vicinity of Alaska during the last few years.

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

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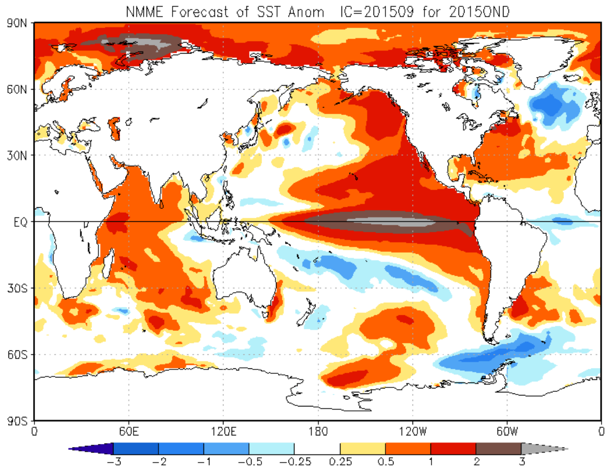
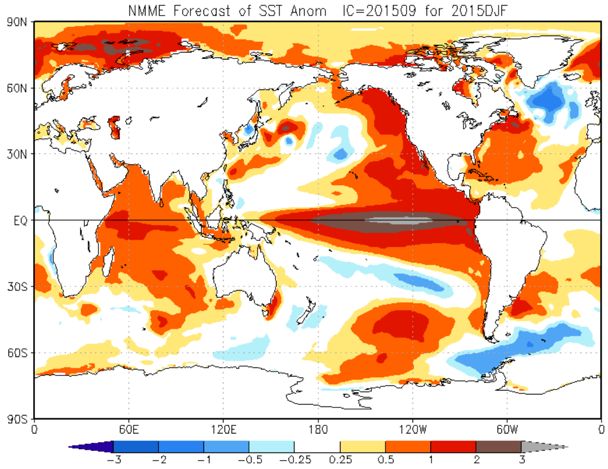
Last updated: August 2015

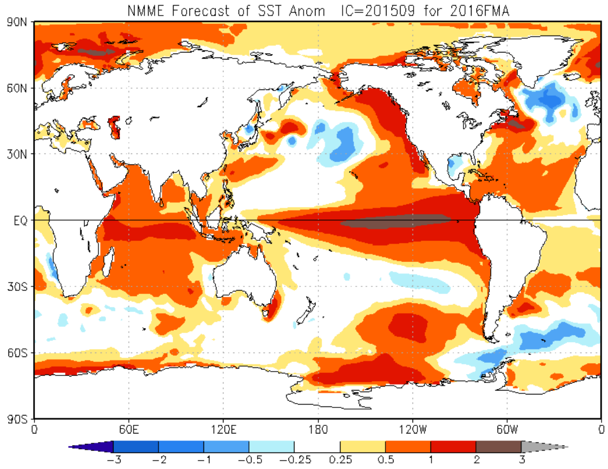
Description of indicator: Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figure 23. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: `http://www.cpc.ncep.noaa.gov/products/NMME/`.



(a) Months OND



(b) Months DJF



(c) Months FMA

Figure 23: Predicted SST anomalies from the NMME model for OND (1 month lead), DJF (3 month lead), and FMA (5 month lead) for the 2015-2016 season.

Status and trends: These NMME forecasts of 3-month average SST anomalies indicate a continuation of warm conditions in the eastern North Pacific through the end of the year (Oct-Dec 2015) with a smaller region of slightly cooler water than normal in the central North Pacific (Figure 23a). This overall pattern is maintained, with some strengthening of the central North Pacific cold anomaly, through the 3-month periods of December 2015 - February 2016 (Figure 23b) and February - April 2016 (Figure 23c). These SST patterns project onto a positive sense for the PDO, which represents a continuation of the present phase that began in 2014. All three 3-month periods feature strong to very strong El Nino conditions in the tropical Pacific.

Implications At the time of this writing (late summer 2015) 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 El Niño with unusually high confidence. These same models also agree that there will be a marked weakening of the El Nino in early 2016, as is usually the case, since El Niños rarely last longer than a calendar year. It bears noting that this El Niño is already in the moderate-strong category and apt to strengthen over the next 2 months. It is therefore likely to have teleconnections to the high-latitude North Pacific that have occurred with past El Niños, notably a deeper than normal Aleutian low during winter. Among the other consequences of the projected weather during the upcoming fall and winter is a continuation of considerably warmer than normal SSTs in the Gulf of Alaska and the eastern Bering Sea shelf into spring 2016.

Arctic

Arctic Sea Ice Cover

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Last updated: October 2015

Description of indicator: The National Snow and Ice Data Center provides monthly (or more frequently) updates on Arctic sea ice conditions. The following is taken from the website (`http://nsidc.org/arcticseaicenews/`.

Status and trends: The seasonal daily minimum ice extent of 4.41 million square kilometers was set on September 11th (Figure 24). This was the fourth lowest in the satellite record (Figure 25).

Eastern Bering Sea

Eastern Bering Sea Climate - FOCI

Contributed by J. Overland, P. Stabeno, C. Ladd, S. Salo, M. Wang, and N. Bond (NOAA/PMEL)
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Last updated: September 2015

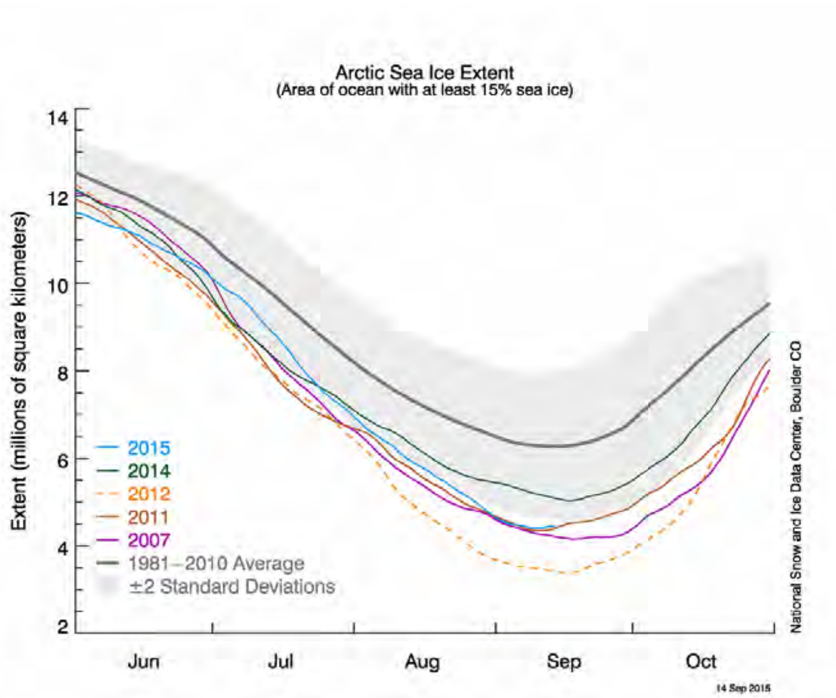

Figure 24: The graph above shows Arctic sea ice extent as of September 14, 2015, along with daily ice extent data for last year and the three lowest ice extent years (2012, 2007, and 2011). 2015 is shown in blue, 2014 in green, 2012 in orange, 2011 in brown, and 2007 in purple. The 1981 to 2010 average is in dark gray. The gray area around the average line shows the two standard deviation range of the data. Credit: National Snow and Ice Data Center

Summary. The warm year of 2015 followed the warm year of 2014 in breaking the unusual sequence of seven years with cold winter-spring temperatures (2007-2013), following the seven warm temperature years (2000-2006). Record warm near surface air temperature anomalies were observed during 2015 over continental Alaska (seconded warmest) and extending into the SE Bering Sea from November through June of +3°C compared with +2°C in 2014 and in contrast to 2013 at -2.5°C and 2012 at -3°C; sea ice maximum extents were reduced. Extreme warm conditions related to the return of the positive Pacific Decadal Oscillation (PDO) in fall 2014, which was not seen since 2003. Warm sea temperatures, associated air temperatures, and higher geopotential heights along SE Alaska provided persistent southerly winds over the Gulf of Alaska throughout winter and spring that brought the relatively mild conditions. The cold pool extent for summer 2014 and 2015 retreated in contrast to recent cold years.

Air temperatures. Positive near surface air temperature anomalies for winter- spring in southwest Alaska and the southeastern Bering Sea were extreme with monthly averaged values at $+3^{O}$C over extensive regions (Figure 26). Alaska conditions were part of the return of the Pacific Decadal Oscillation (PDO). The return of the strong positive PDO, not seen since 2003, has positive SSTs along the coastal Gulf of Alaska (see Bond, p.90), with associated low level warm air temperature anomalies (Figure fig.FWSlowairt). Winds follow the contours of higher geopotential heights, associated with the warm temperature regions and the coastal mountains (Figure 28), giving southerly winds that advect warm temperatures into Alaska. Summer was characterized by a return to long term climatological air temperatures (not shown).

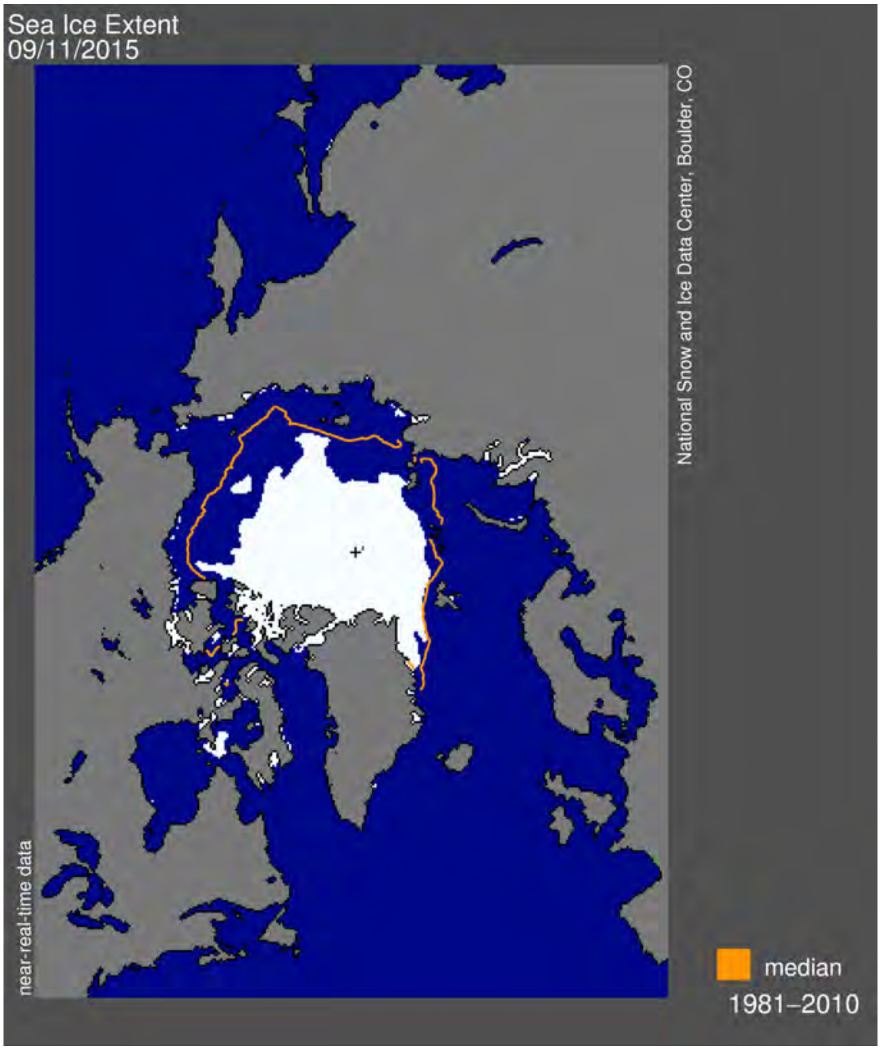

Figure 25: Arctic sea ice extent for September 11, 2015, was 4.41 million square kilometers (1.70 million square miles). The orange line shows the 1981 to 2010 average extent for the day. The black cross indicates the geographic North Pole. Credit: National Snow and Ice Data Center

Sea ice. Seasonal sea ice is a defining characteristic of the Bering Sea shelf. The presence of sea ice influences the timing of the spring bloom and bottom temperatures throughout the year. Sea ice extent in 2008, 2010, 2012 and 2013 (Figure 29) were close to record maximum extents not seen since the early 1970s, and contrast to the warm years of 2000-2005 (except 2002). Spring 2014 and 2015 had a return to less sea ice cover.

Ocean temperatures. The cold pool (Figure 30), defined by bottom temperatures <2°C, influences not only near-bottom biological habitat, but also the overall thermal stratification and ultimately the mixing of nutrient-rich water from depth into the euphotic zone during summer. The cold pool extent for summer 2014 and 2015 retreated in area compared to the prominent sequence of recent cold years.

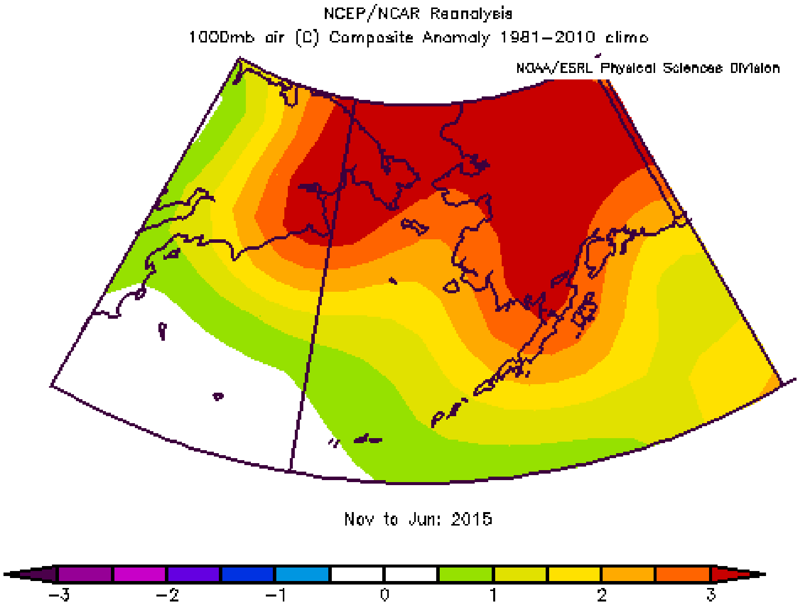

Figure 26: Near surface air temperature anomaly over the greater Bering Sea region for Winter-Spring 2015.

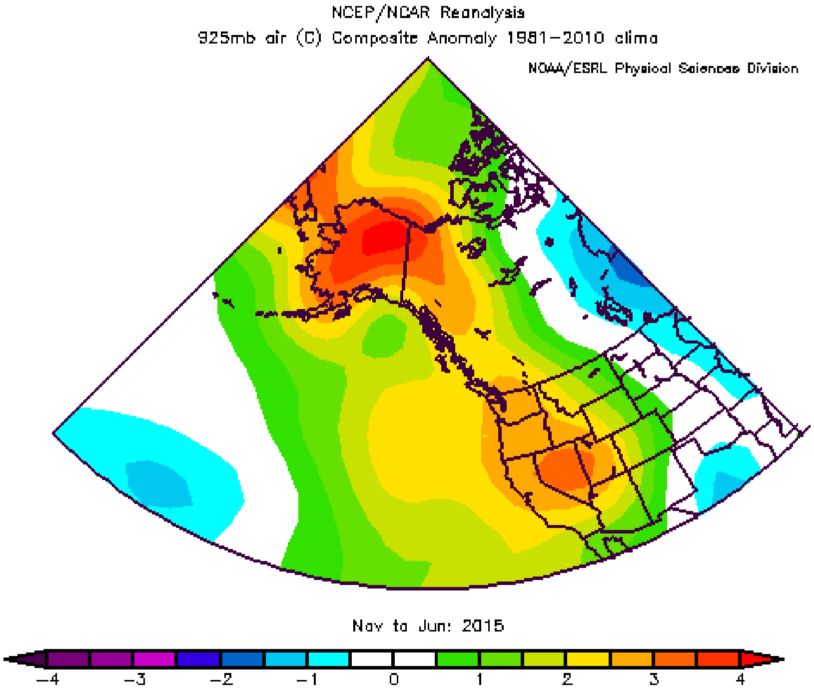

Figure 27: Low level air temperature anomaly over western North America associated with the return of the PDO for Fall-Winter-Spring 2015.

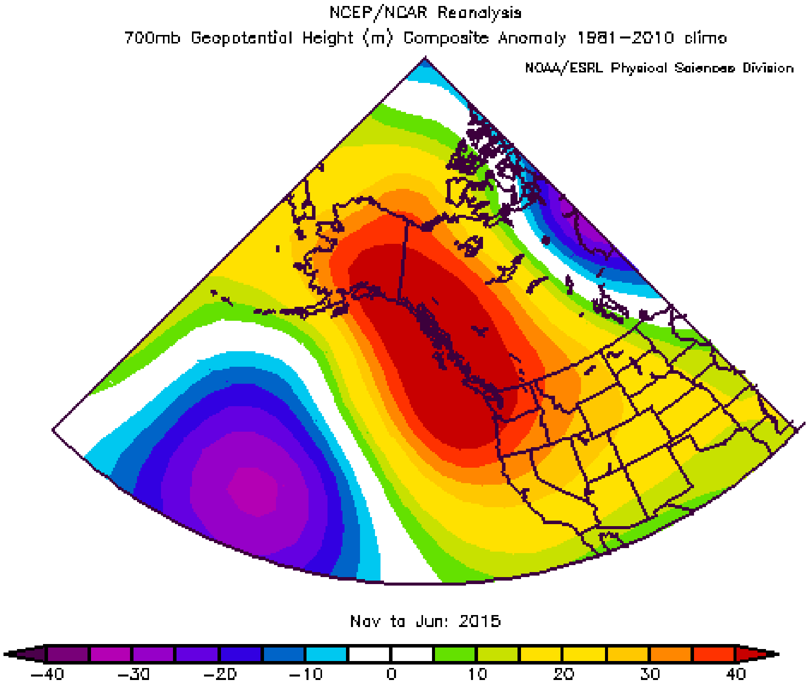

Figure 28: Geopotential height anomaly over western North America for Fall-Winter-Spring 2015. Winds follow the contours of constant heights thus showing strong wind from the south reaching Alaska and the SE Bering Sea over this extended period.

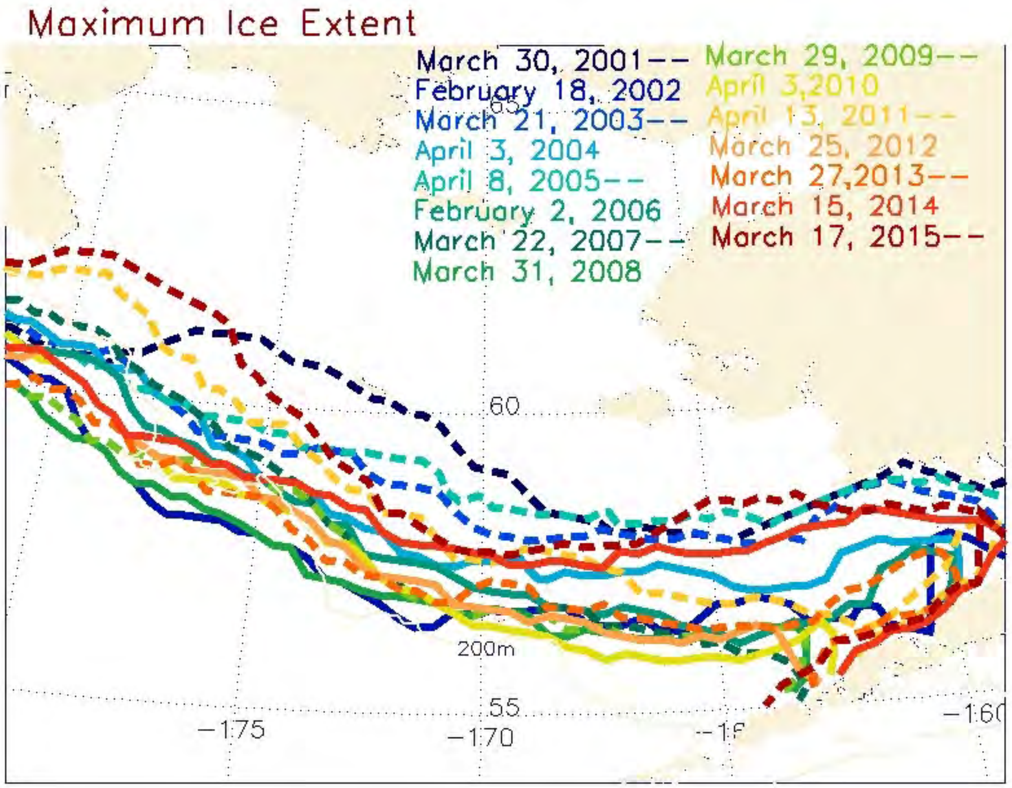

Figure 29: Recent springtime ice extents in the Bering Sea.

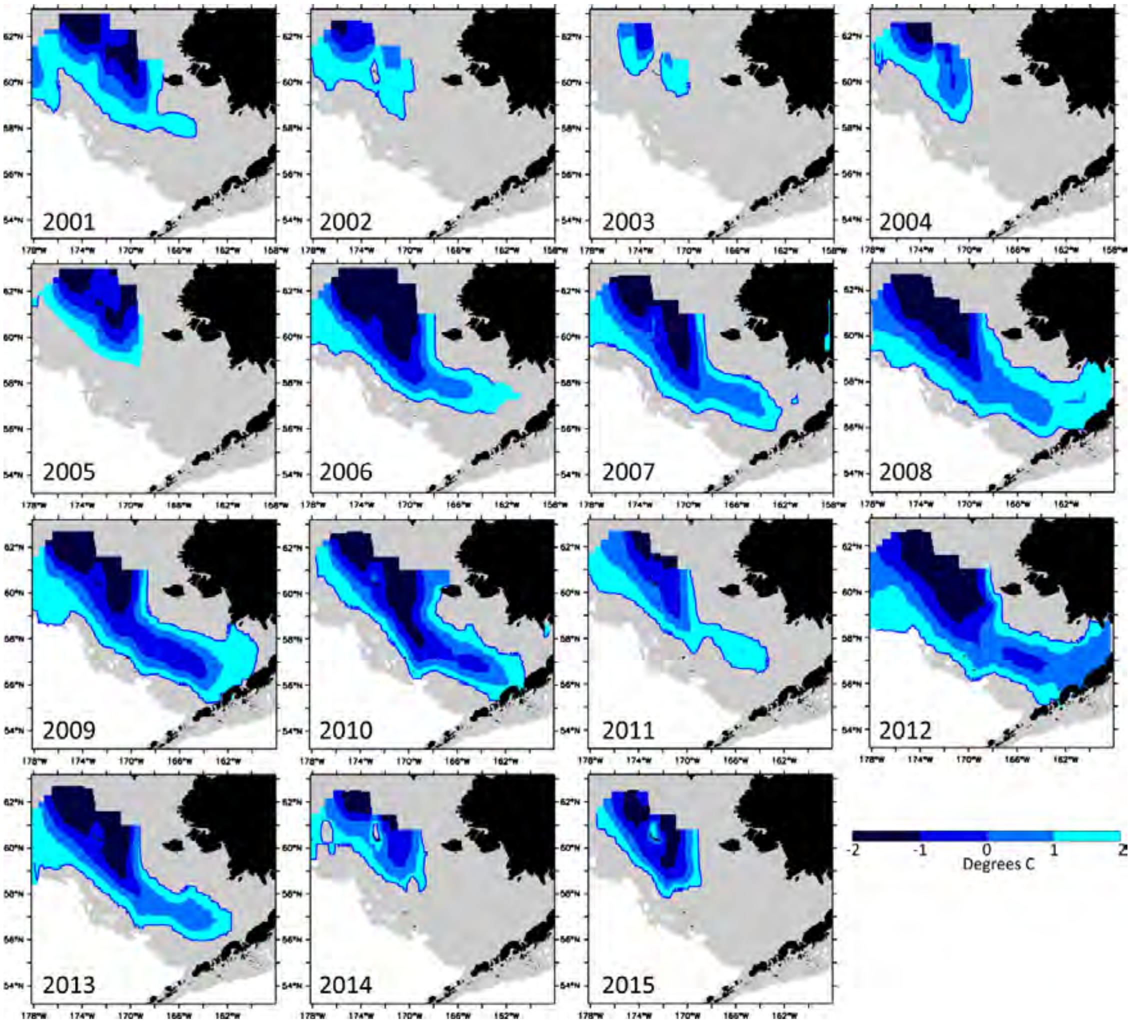

Figure 30: Cold Pool extent in southeast Bering Sea from 2001 to 2015. After an extensive sequence of cold years, the years 2014 and 2015 resemble earlier warm years.

Summer Bottom and Surface Temperatures - Eastern Bering Sea

Contributed by Robert Lauth and Gerald Hoff, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2015

Description of indicator: Survey operations for the annual AFSC bottom trawl survey in 2015 started on 2 June and finished on 29 July.

Status and trends: Warmer average surface and bottom temperatures for the eastern Bering Sea shelf continued in 2015 (Figure 31). The 2015 average surface temperature was 7.2°C, which was above the time-series mean (6.4°C) and one degree lower than the average surface temperature in 2014 (8.2°C). The average bottom temperature in 2015 was 3.4°C, which was also above the long-term mean (2.4°C) and the eigth highest in the 34-year time-series. The "cold pool", defined as an area with temperatures <2°C, was slightly larger than 2014 and confined mostly to the northwestern middle shelf (Figure 31).

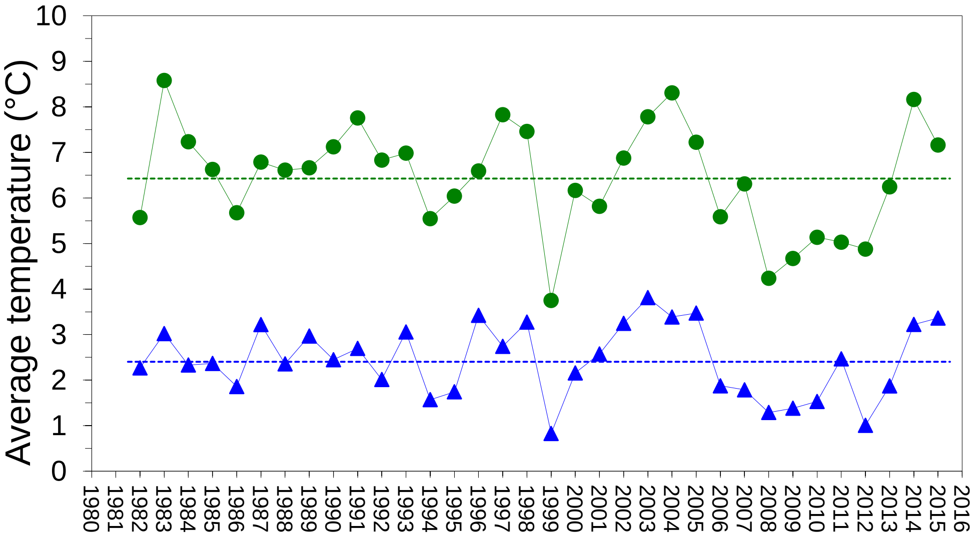

Figure 31: Average summer surface (green triangles) and bottom (blue dots) temperatures (°C) of the eastern Bering Sea shelf collected during the standard bottom trawl surveys from 1982-2015. Survey water temperatures for each year were weighted by the proportion of their assigned stratum area. Dotted line represents the time-series mean for 1982-2015.

Factors influencing observed trends: Warm and cold years are the result of interannual variability in the extent, timing, and retreat of sea ice on the EBS shelf. During warm years, sea ice generally does not extend as far down the shelf and retreats sooner.

Implications: The relatively large interannual fluctuations in bottom temperature on the EBS shelf can influence the spatial and temporal distribution of groundfishes and the structure and ecology of the marine community (Kotwicki et al., 2005; Mueter and Litzow, 2008; Spencer, 2008). The timing of phytoplankton and subsequent zooplankton blooms are also affected by the extent of sea ice and timing of its retreat which in turn can affect survival and recruitment in larval and juvenile fishes as well as the energy flow in the system (Hunt et al., 2002; Coyle et al., 2011).

Variations in Temperature and Salinity During Late Summer/ Early Fall 2002-2014 in the Eastern Bering Sea

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Last updated: September 2015

Description of indicator: Oceanographic and fisheries data were collected over the eastern Bering Sea (EBS) shelf during fall 2002-2014 for a multiyear fisheries oceanography research program, Bering-Arctic-SubArctic Integrated Survey (BASIS). Stations were located between 54°N and 70°N, at ∼60 km resolution, although spatial coverage varied by region and year. Bristol Bay stations were sampled from mid-August to early September, while stations in the central and northern EBS were generally sampled from mid-September to early October. Physical oceanographic data were obtained from vertical conductivity-temperature-depth (CTD) profiles. Mean temperature and salinity above and below the mixed layer depth (MLD) were estimated for each station following methods in (Danielson et al., 2011). Normalized anomalies (mean yearly value minus average value over 2002-2014 normalized by standard deviation) of temperature and salinity were separately computed for each Bering Sea Project region (Ortiz et al., 2012) for 2002-2014 (Figures 32, 33, 34, 35, 36). Normalized anomalies of MLD were similarly estimated for middle and outer domain regions (Figure 37). Only station locations sampled 5+ years were included in the analyses (Figure 32).

Status and trends: Temperatures above and below the MLD (Tabove, Tbelow) were roughly warmer than average in 2002-2005, average in 2006, cooler than average in 2007-2012 and warm again in 2014 in regions south of 63°N, (Figures 33, 34). In regions north of 63°N warmer than average temperatures were primarily observed 2003-2004 and in 2007. Note that data for 2014 north of 60°N were not available for these analyses. Salinities above and below the MLD (Sabove, Sbelow) for the majority of Bering Sea middle domain regions (3, 5, 6, 9, 10) were generally higher in warm years (2002-2005 and 2014) than in cold years (2006-2012), with differences particularly evident in the south middle regions 3 and 6 (Figures 35, 36). In the inner domain, near the Alaska Peninsula (region 1), outer domain (region 4) and regions north of 63°N, Sabove and Sbelow varied interannually, with no apparent trends between warm and cold periods (Figure 34). The average MLD for 2002-2014 varied approximately 10 m in the south middle domain (region 3 and 6) and 6-7 m in north middle domain (regions 9, 10), and 13 m in the south outer domain (region 4), although variations did not appear to necessarily co-vary with warm cold year periods (Figure 37). For example, in region 3, the MLD varied from 14 m to 23.5 m with shallowest values in 2004, 2007 and 2014 and deepest in 2003, 2008, 2009 and 2011.

Factors influencing observed trends: Sea ice during winter and spring extended further to the south as the climate cooled. The cold pool is related to sea ice and thus extends further to the south in years with higher sea ice coverage in the southern Bering Sea. The cold pool (located below the MLD) is always present in the north Bering Sea since ice covers this region each year. The lower bottom salinities near the coast (e.g. inner domain regions and Norton Sound) indicate major freshwater input from the Yukon and Kuskoquim rivers (Figure 32,35, 36). Variations in salinity

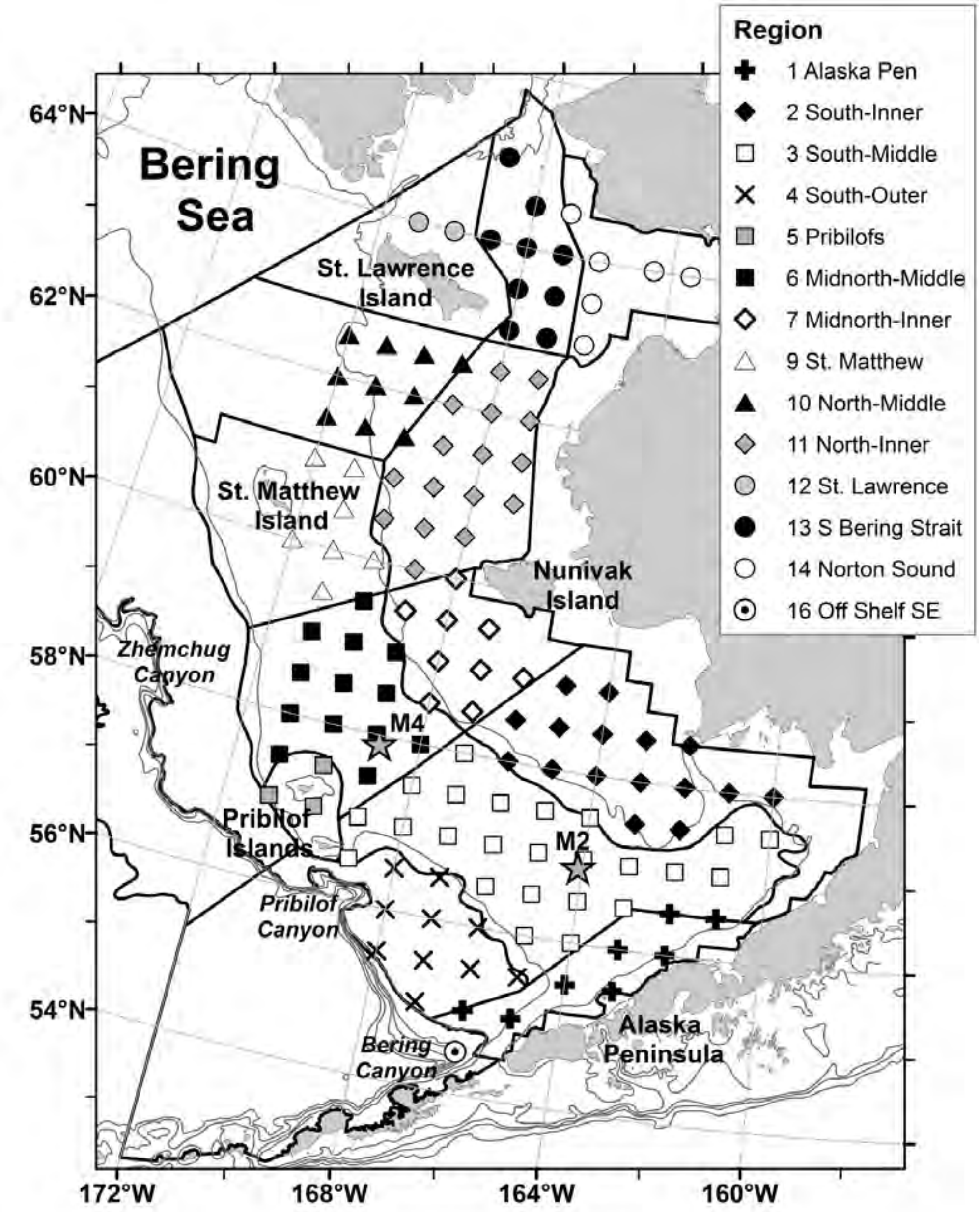
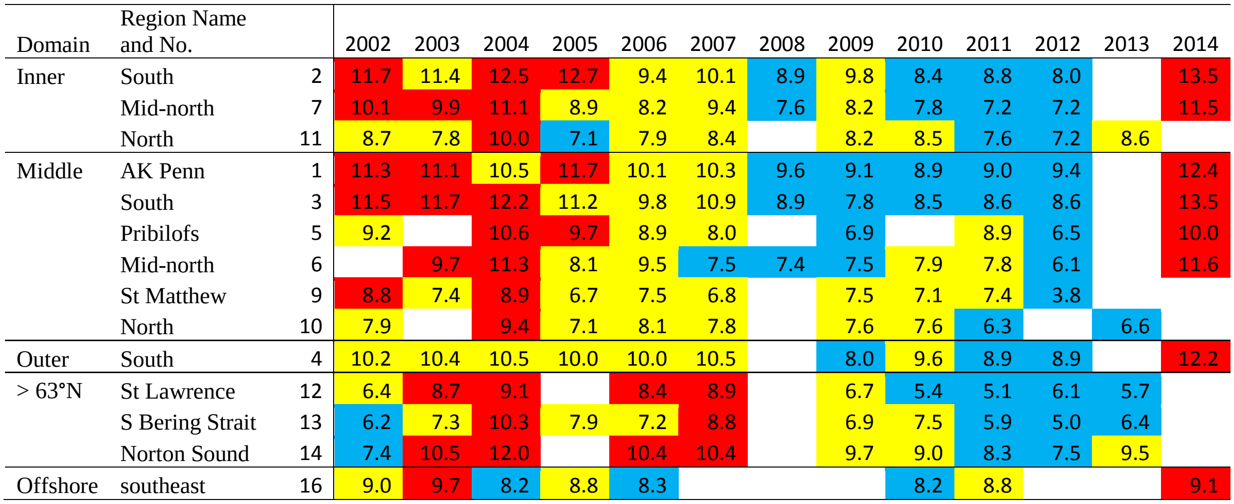


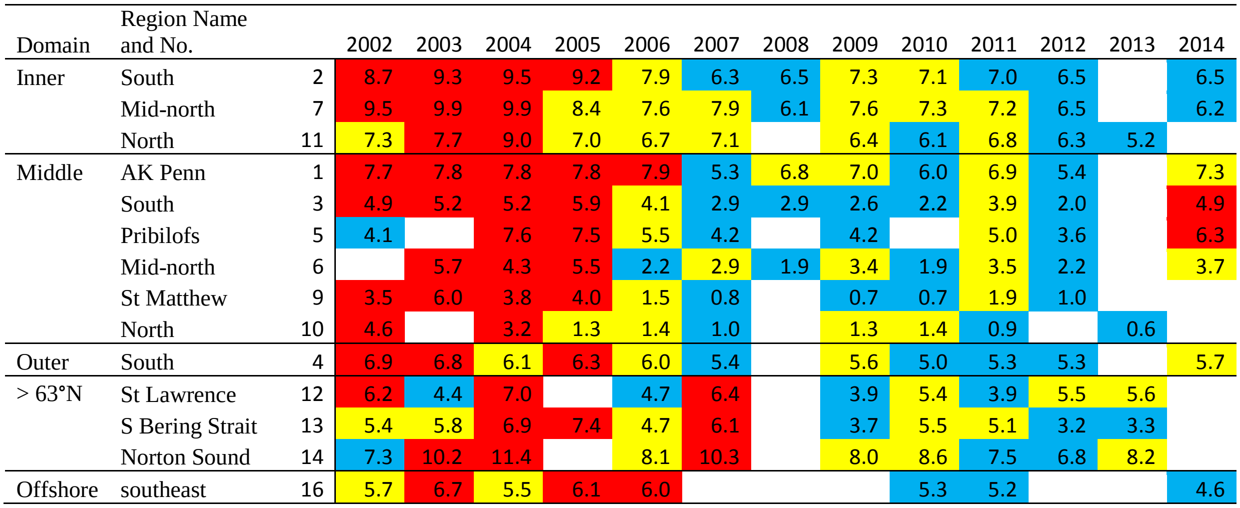
Figure 32: Stations within each Bering Sea Project region (Ortiz et al., 2012) sampled a minimum of 5 years between 2002 and 2014. We sampled three inner shelf regions (regions 2, 7, 11), six middle shelf regions (regions 1, 3, 5, 6, 9, 10), one outer shelf region (region 4) and three regions north and east of St. Lawrence Island (regions 12, 13 and 14).

in the middle and outer shelf may be partially related to wind direction, with southeasterly winds producing enhanced on-shelf flows in warm years (Danielson et al., 2012). Therefore, the lower salinity in cold years near M4 may be due to ice melt and possibly reduced onshore flow of higher salinity waters. Tabove and Sabove are influenced by temporal mixing events relating to episodic wind mixing/storm events while Tbelow and Sbelow may better reflect longer term climatic shifts. For example, in 2005 (a warm year), Tbelow was warmer than average in the middle domain regions



Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Inner	South	2	11.7	11.4	12.5	12.7	9.4	10.1	8.9	9.8	8.4	8.8	8.0		13.5
	Mid-north	7	10.1	9.9	11.1	8.9	8.2	9.4	7.6	8.2	7.8	7.2	7.2		11.5
	North	11	8.7	7.8	10.0	7.1	7.9	8.4		8.2	8.5	7.6	7.2	8.6	
Middle	AK Penn	1	11.3	11.1	10.5	11.7	10.1	10.3	9.6	9.1	8.9	9.0	9.4		12.4
	South	3	11.5	11.7	12.2	11.2	9.8	10.9	8.9	7.8	8.5	8.6	8.6		13.5
	Pribilofs	5	9.2		10.6	9.7	8.9	8.0		6.9		8.9	6.5		10.0
	Mid-north	6		9.7	11.3	8.1	9.5	7.5	7.4	7.5	7.9	7.8	6.1		11.6
	St Matthew	9	8.8	7.4	8.9	6.7	7.5	6.8		7.5	7.1	7.4	3.8		
	North	10	7.9		9.4	7.1	8.1	7.8		7.6	7.6	6.3		6.6	
Outer	South	4	10.2	10.4	10.5	10.0	10.0	10.5		8.0	9.6	8.9	8.9		12.2
> 63°N	St Lawrence	12	6.4	8.7	9.1		8.4	8.9		6.7	5.4	5.1	6.1	5.7	
	S Bering Strait	13	6.2	7.3	10.3	7.9	7.2	8.8		6.9	7.5	5.9	5.0	6.4	
	Norton Sound	14	7.4	10.5	12.0		10.4	10.4		9.7	9.0	8.3	7.5	9.5	
Offshore	southeast	16	9.0	9.7	8.2	8.8	8.3				8.2	8.8			9.1

Figure 33: Mean temperature above the MLD color coded by normalized anomaly.

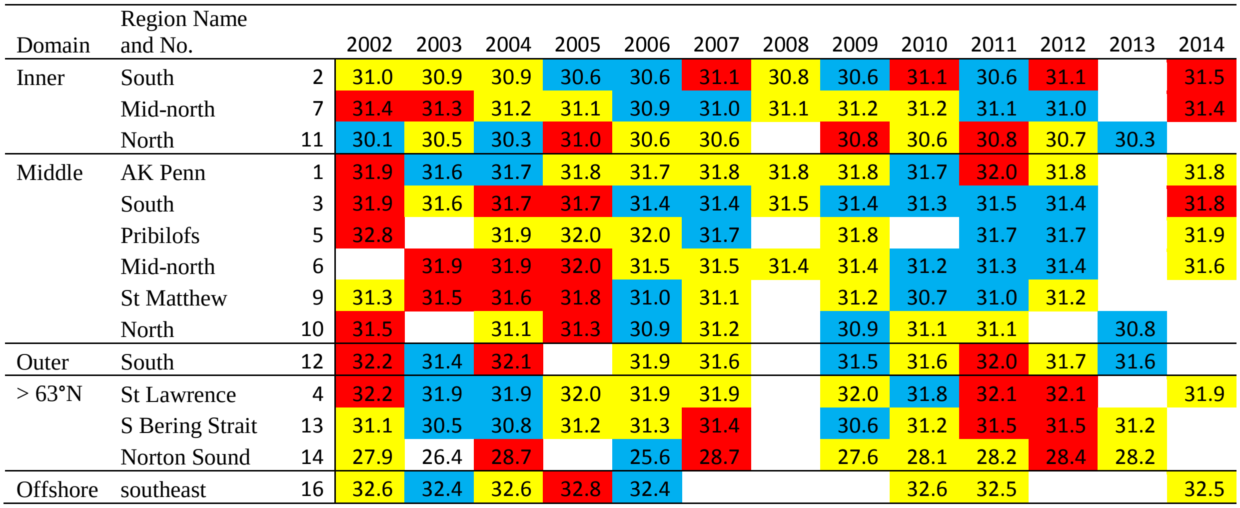


Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Inner	South	2	8.7	9.3	9.5	9.2	7.9	6.3	6.5	7.3	7.1	7.0	6.5		6.5
	Mid-north	7	9.5	9.9	9.9	8.4	7.6	7.9	6.1	7.6	7.3	7.2	6.5		6.2
	North	11	7.3	7.7	9.0	7.0	6.7	7.1		6.4	6.1	6.8	6.3	5.2	
Middle	AK Penn	1	7.7	7.8	7.8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

Figure 34: Mean temperature below the MLD color-coded by normalized anomaly.

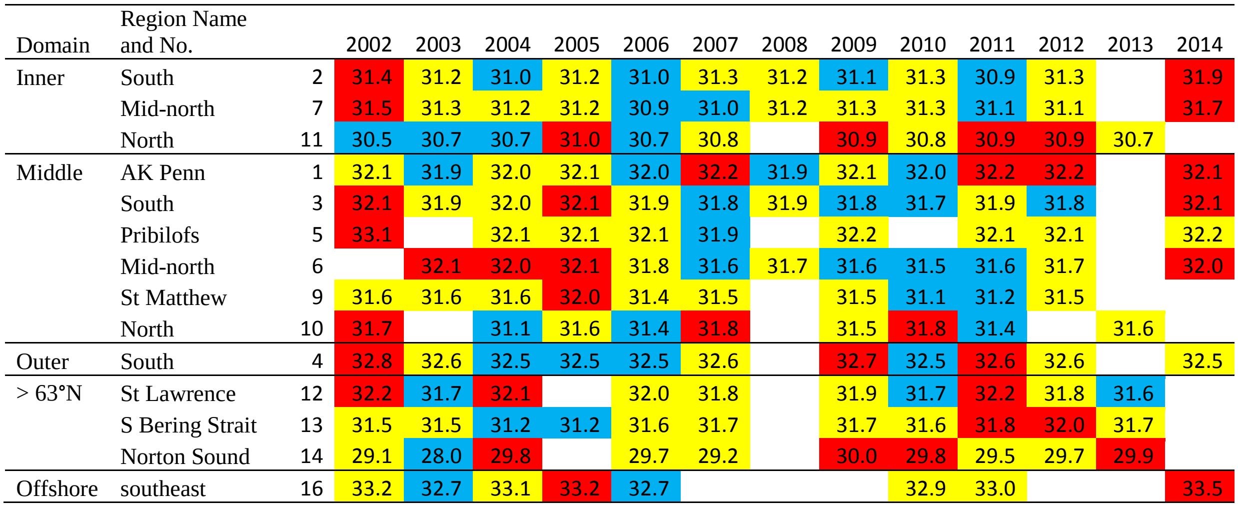
3, 6, and 9 reflecting the lack of sea ice during spring (Figure 34). In contrast, Tabove was average in these regions (Figure 33), due to high wind mixing in August prior to and during the survey (Eisner et al., 2015).

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



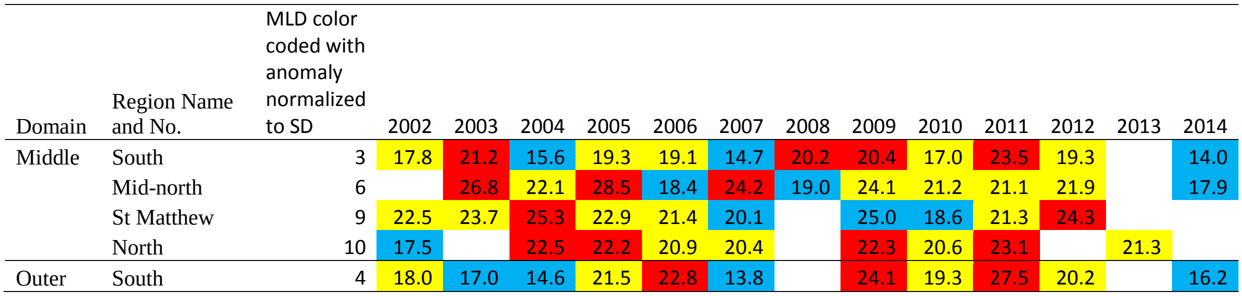
Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Inner	South	2	31.0	30.9	30.9	30.6	30.6	31.1	30.8	30.6	31.1	30.6	31.1		31.5
	Mid-north	7	31.4	31.3	31.2	31.1	30.9	31.0	31.1	31.2	31.2	31.1	31.0		31.4
	North	11	30.1	30.5	30.3	31.0	30.6	30.6		30.8	30.6	30.8	30.7	30.3	
Middle	AK Penn	1	31.9	31.6	31.7	31.8	31.7	31.8	31.8	31.8	31.7	32.0	31.8		31.8
	South	3	31.9	31.6	31.7	31.7	31.4	31.4	31.5	31.4	31.3	31.5	31.4		31.8
	Pribilofs	5	32.8		31.9	32.0	32.0	31.7		31.8		31.7	31.7		31.9
	Mid-north	6		31.9	31.9	32.0	31.5	31.5	31.4	31.4	31.2	31.3	31.4		31.6
	St Matthew	9	31.3	31.5	31.6	31.8	31.0	31.1		31.2	30.7	31.0	31.2		
	North	10	31.5		31.1	31.3	30.9	31.2		30.9	31.1	31.1		30.8	
Outer	South	12	32.2	31.4	32.1		31.9	31.6		31.5	31.6	32.0	31.7	31.6	
> 63°N	St Lawrence	4	32.2	31.9	31.9	32.0	31.9	31.9		32.0	31.8	32.1	32.1		31.9
	S Bering Strait	13	31.1	30.5	30.8	31.2	31.3	31.4		30.6	31.2	31.5	31.5	31.2	
	Norton Sound	14	27.9	26.4	28.7		25.6	28.7		27.6	28.1	28.2	28.4	28.2	
Offshore	southeast	16	32.6	32.4	32.6	32.8	32.4				32.6	32.5			32.5

Figure 35: Salinity above the MLD color-coded by normalized anomaly.



Domain	Region Name and No.		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Inner	South	2	31.4	31.2	31.0	31.2	31.0	31.3	31.2	31.1	31.3	30.9	31.3		31.9
	Mid-north	7	31.5	31.3	31.2	31.2	30.9	31.0	31.2	31.3	31.3	31.1	31.1		31.7
	North	11	30.5	30.7	30.7	31.0	30.7	30.8		30.9	30.8	30.9	30.9	30.7	
Middle	AK Penn	1	32.1	31.9	32.0	32.1	32.0	32.2	31.9	32.1	32.0	32.2	32.2		32.1
	South	3	32.1	31.9	32.0	32.1	31.9	31.8	31.9	31.8	31.7	31.9	31.8		32.1
	Pribilofs	5	33.1		32.1	32.1	32.1	31.9		32.2		32.1	32.1		32.2
	Mid-north	6		32.1	32.0	32.1	31.8	31.6	31.7	31.6	31.5	31.6	31.7		32.0
	St Matthew	9	31.6	31.6	31.6	32.0	31.4	31.5		31.5	31.1	31.2	31.5		
	North	10	31.7		31.1	31.6	31.4	31.8		31.5	31.8	31.4		31.6	
Outer	South	4	32.8	32.6	32.5	32.5	32.5	32.6		32.7	32.5	32.6	32.6		32.5
> 63°N	St Lawrence	12	32.2	31.7	32.1		32.0	31.8		31.9	31.7	32.2	31.8	31.6	
	S Bering Strait	13	31.5	31.5	31.2	31.2	31.6	31.7		31.7	31.6	31.8	32.0	31.7	
	Norton Sound	14	29.1	28.0	29.8		29.7	29.2		30.0	29.8	29.5	29.7	29.9	
Offshore	southeast	16	33.2	32.7	33.1	33.2	32.7				32.9	33.0			33.5

Figure 36: Salinity below the MLD color-coded by normalized anomaly.



Domain	Region Name and No.	MLD color coded with anomaly normalized to SD	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Middle	South	3	17.8	21.2	15.6	19.3	19.1	14.7	20.2	20.4	17.0	23.5	19.3		14.0
	Mid-north	6		26.8	22.1	28.5	18.4	24.2	19.0	24.1	21.2	21.1	21.9		17.9
	St Matthew	9	22.5	23.7	25.3	22.9	21.4	20.1		25.0	18.6	21.3	24.3		
	North	10	17.5		22.5	22.2	20.9	20.4		22.3	20.6	23.1		21.3	
Outer	South	4	18.0	17.0	14.6	21.5	22.8	13.8		24.1	19.3	27.5	20.2		16.2

Figure 37: MLD color-coded by normalized anomaly.

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

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Last updated: September 2015

Description of indicator: Wilderbuer et al. (2002, 2013) summarized a study examining the recruitment of winter-spawning flatfish in relation to decadal atmospheric forcing, linking favorable recruitment to the direction of wind forcing during spring. OSCURS model time series runs indicated in-shore advection to favorable nursery grounds in Bristol Bay during the 1980s. The pattern changed to off-shore in the 1990-97 time series coincided with below-average recruitment for northern rock sole, arrowtooth flounder and flathead sole, relative to the 1980s. Favorable springtime winds were present again in the early 2000s which also corresponded with improved recruitment. The time series is updated through 2015 and shown for 2007 through 2015 in (Figure 38).

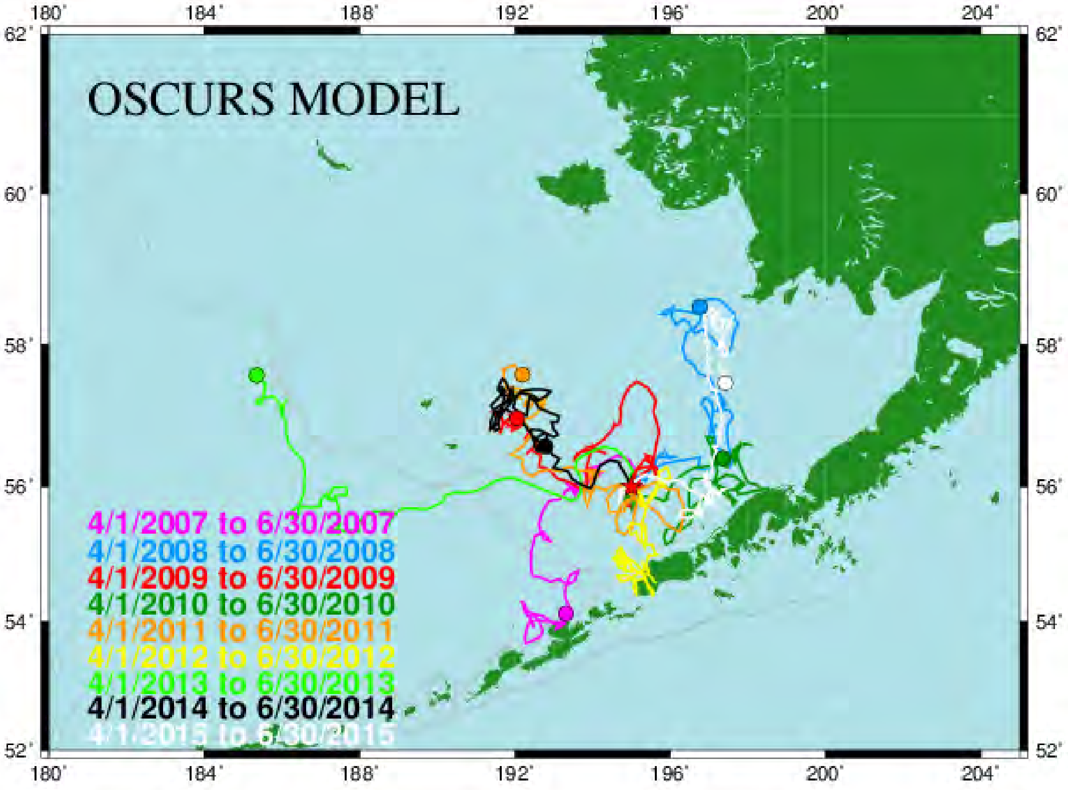

Figure 38: OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56°N, 164°W from April 1-June 30 for 2007-2015.

Status and trends: The 2015 springtime drift patterns appear to be consistent with years of good recruitment for winter-spawning flatfish. Two out of the past nine OSCURS runs for 2007-2014 were consistent with those which produced above-average recruitment in the original analysis (2008, 2010). The north-northeast drift pattern suggests that larvae may have been advected to favorable, near-shore areas of Bristol Bay by the time of their metamorphosis to a benthic form of juvenile flatfish. Preliminary estimates of rock sole recruitment in recent years are consistent with this larval drift hypothesis. For arrowtooth flounder and flathead sole, the correspondence between the springtime drift pattern from OSCURS and estimates of year class strength have weakened since the 1990s. Arrowtooth flounder produced year classes of average strength during some off-shore drift years, suggesting that this species may have different timing for spawning, larval occurrence and settlement preferences than northern rock role. In the case of flathead sole, the 2001 and 2003 year-classes appear stronger than the weak recruitment that has persisted since the 1990s.

Implications: The 2015 springtime drift pattern appears to be consistent with years of good recruitment for northern rock sole, arrowtooth flounder and flathead sole, following three years (2012-2014) of wind patterns that may not promote average to above-average recruitment. 2011 featured a mixture of wind direction as there were strong northerly winds for part of the spring but also southerly winds that would suggest increased larval dispersal to Unimak Island and the Alaska Peninsula. In 2012 and 2014 the pattern was more across-shelf in a northerly direction, opposite of 2011.

Aleutian Islands

Eddies in the Aleutian Islands - FOCI

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Description of indicator: Eddies in the Alaskan Stream south of the Aleutian Islands have been shown to influence flow into the Bering Sea through the Aleutian Passes (Okkonen, 1996). By influencing flow through the passes, eddies could impact flow in the Aleutian North Slope Current and Bering Slope Current as well as influencing the transports of heat, salt and nutrients (Mordy et al., 2005; Stabeno et al., 2005) into the Bering Sea.

Since 1992, the Topex/Poseidon/Jason/ERS satellite altimetry system has been monitoring sea surface height. Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (Ducet et al., 2000). Eddy kinetic energy (EKE) calculated from gridded altimetry data is particularly high in the Alaskan Stream from Unimak Pass to Amukta Pass (Figure 39) indicating the occurrence of frequent, strong eddies in the region. The average EKE in the region 171°W-169°W, 51.5°-52.5°N (Figure 40) provides an index of eddy energy likely to influence the flow through Amukta Pass. Numerical models have suggested that eddies passing near Amukta Pass may result in increased flow from the Pacific to the Bering Sea (Maslowski et al., 2008). The altimeter products were produced by the CLS Space Oceanography Division (AVISO, 2015).

Status and trends: Particularly strong eddies were observed south of Amukta Pass in 1997, 1999, 2004, 2006/2007, 2009/2010, and summer 2012. Eddy energy in the region has been low from the fall 2012 through June 2015.

Factors causing trends: The causes of variability in EKE are currently unclear and a subject of ongoing research.

Implications: These trends indicate that higher than average volume, heat, salt, and nutrient fluxes to the Bering Sea through Amukta Pass may have occurred in 1997/1998, 1999, 2004,

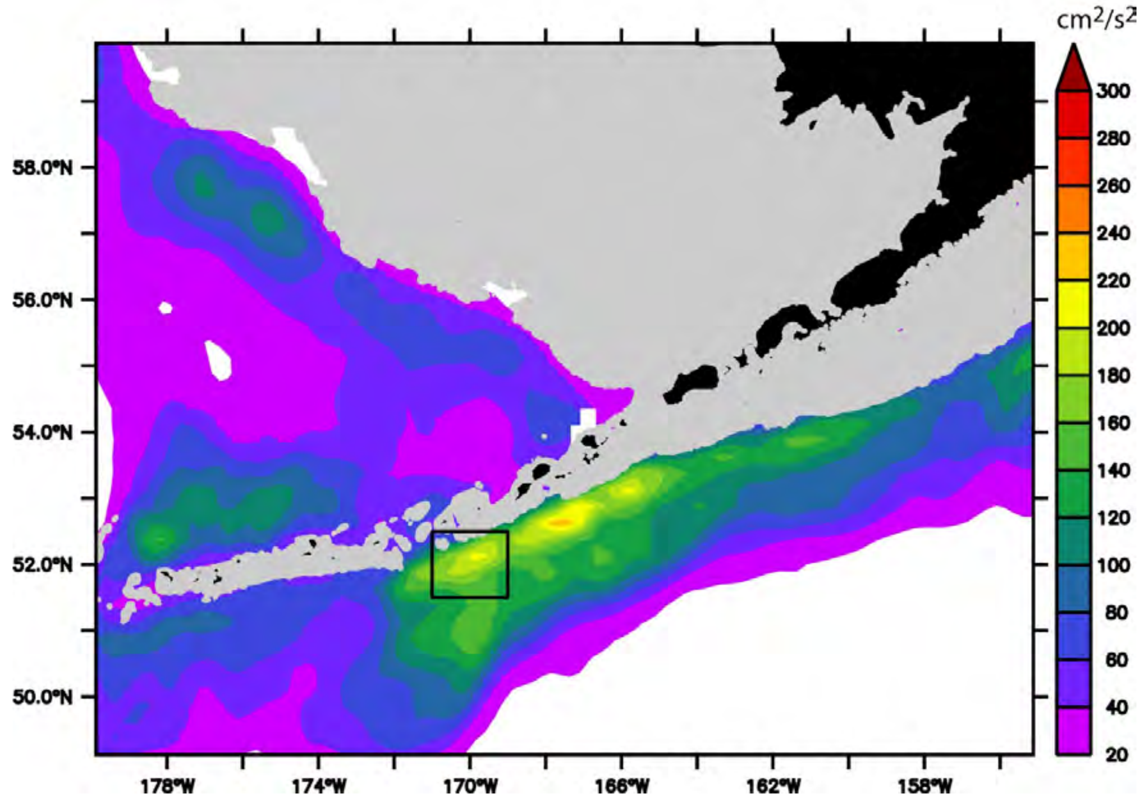

Figure 39: Eddy Kinetic Energy averaged over October 1993 - October 2014 calculated from satellite altimetry. Square denotes region over which EKE was averaged for Figure 40.

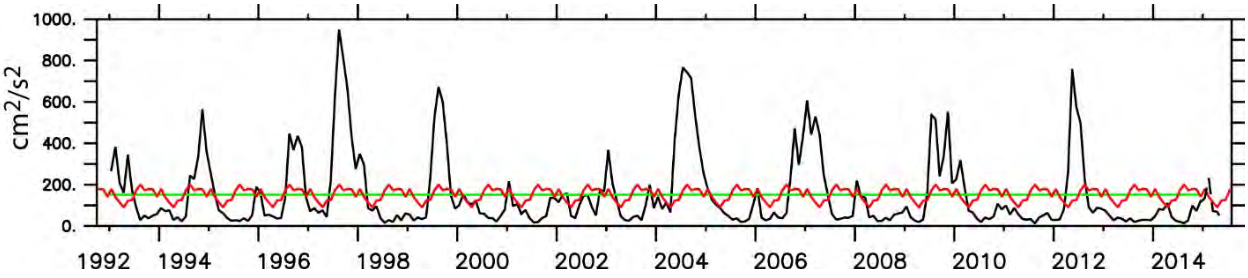

Figure 40: Eddy kinetic energy (cm^2 s^{-2}) averaged over region shown in Figure 39. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product). Red: seasonal cycle. Green (straight line): mean over entire time series.

2006/2007, 2009/2010, and summer 2012. These fluxes were likely smaller during the period from fall 2012 until early 2015.

Gulf of Alaska

Eddies in the Gulf of Alaska - FOCI

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Last updated: August 2015

Description of indicator: Eddies in the northern Gulf of Alaska have been shown to influence distributions of nutrients (Ladd et al., 2009, 2005; Ladd, 2007), phytoplankton (Brickley and Thomas, 2004) and ichthyoplankton (Atwood et al., 2010), and the foraging patterns of fur seals (Ream et al., 2005). Eddies propagating along the slope in the northern and western Gulf of Alaska are generally formed in the eastern Gulf in autumn or early winter (Okkonen et al., 2001). 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 41; 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 41). 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 41). By averaging EKE over regions c and d (see boxes in Figure 41), we obtain an index of energy associated with eddies in these regions (Figure 42). The altimeter products were produced by the CLS Space Oceanography Division (AVISO, 2015).

Status and trends: The seasonal cycle of EKE averaged over the two regions (c and d) are out of phase with each other. Region (c) exhibits high EKE in the spring (March-May) and lower EKE in the autumn (September-November) while region (d) exhibits high EKE in the autumn and low EKE in the spring. EKE was particularly high in region (c) in 2002-2004 when three large persistent eddies passed through the region. In region (d), high EKE was observed in 1993, 1995, 2000, 2002, 2004, 2006, 2007, 2010, 2012 and 2013. Near-real-time data suggests that EKE was also high in spring 2015 in region (d) while in region (c), EKE values in spring 2015 were near the climatological mean. 2015 EKE is calculated from near-real-time altimetry data which has lower quality than the delayed time data and may be revised.

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

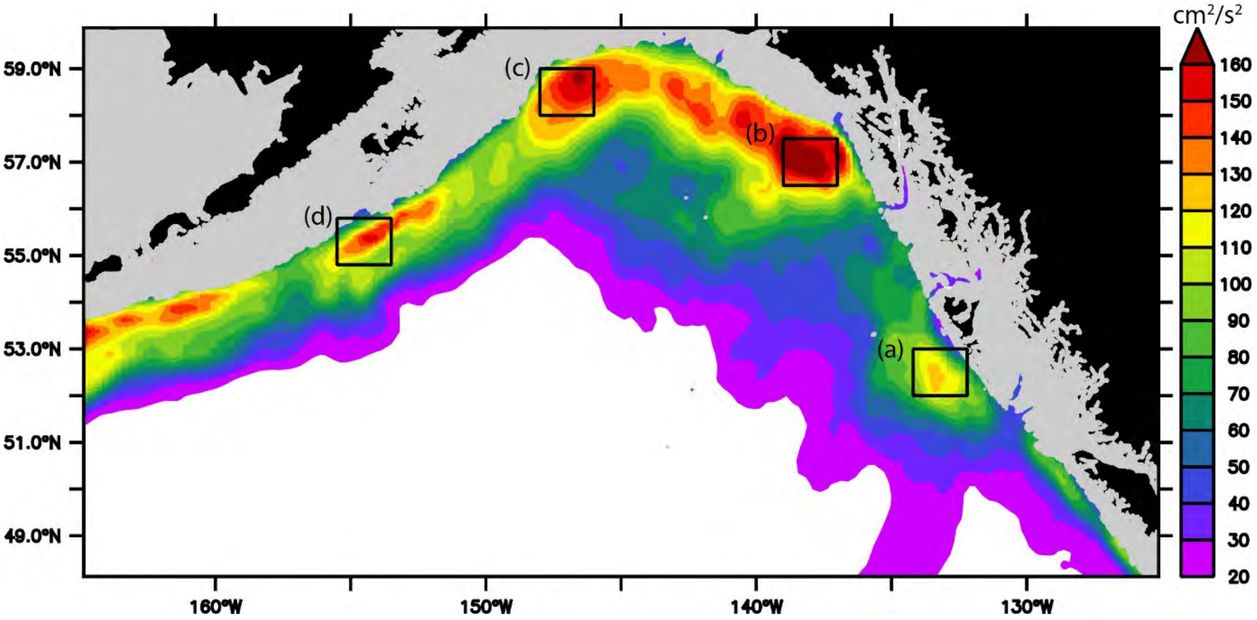

Figure 41: Eddy Kinetic Energy averaged over October 1993-October 2014 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 42.

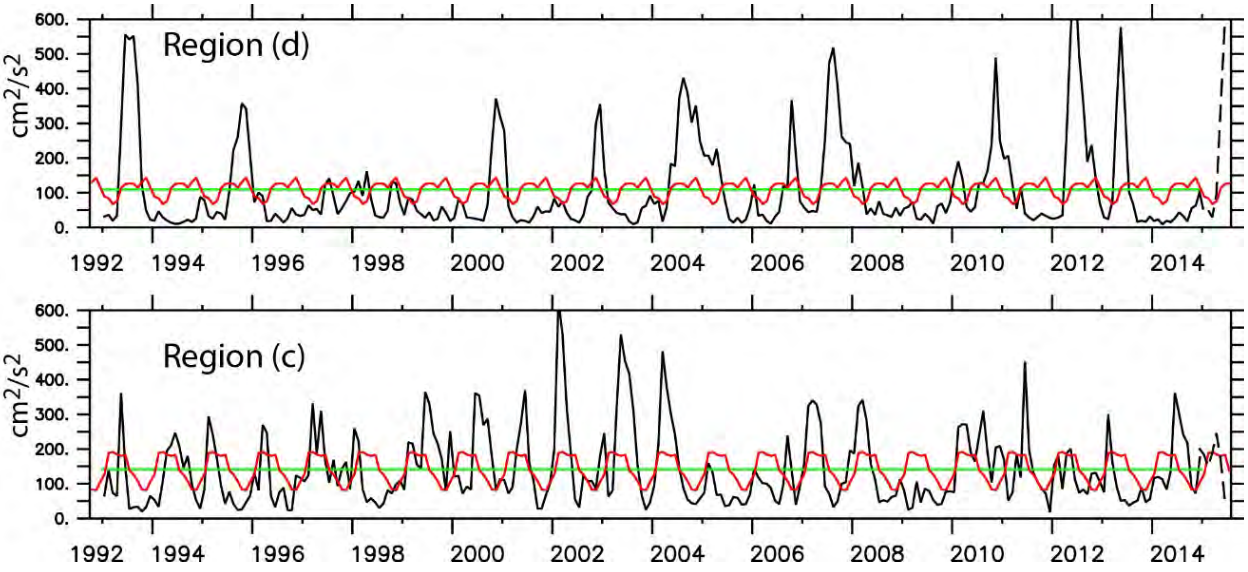

Figure 42: Eddy kinetic energy (cm^2 s^{-2}) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 41. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product), Red: seasonal cycle. Green (straight line): mean over entire time series.

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

Ocean Surface Currents - Papa Trajectory Index

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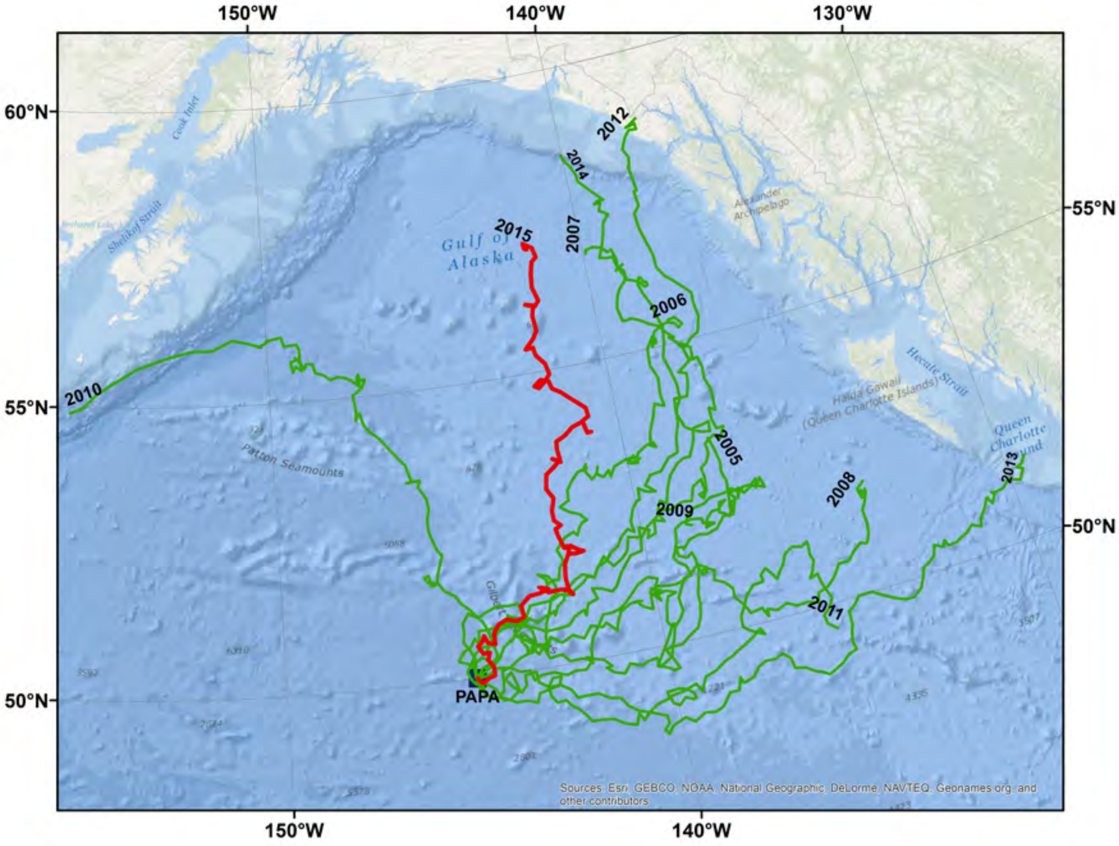
Last updated: September 2015

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 43). 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 2014 (trajectory endpoints years 1902-2015).

Status and trends: In general, the trajectories fan out northeastwardly toward the North American continent (Figure 43). The 2009/2010 trajectory was an exception and resulted in the westernmost trajectory endpoint for the entire set of model runs (1902-2015). This trajectory was, however, consistent with the atmospheric conditions that existed during the winter of 2009-2010 (N. Bond, U.W., pers. comm.). Under the influence of contemporaneous El Niño conditions, the Aleutian Low in the winter of 2009-2010 was anomalously deep and displaced to the southeast of its usual position in winter (Bond and Guy, 2010), resulting in anomalously high easterly (blowing west) wind anomalies north of Ocean Station PAPA. The 2011/2012 trajectory followed the general northeastwardly path of most drifters, but was notable because its ending latitude was the northernmost of all trajectories since 1994. The 2012/2013 trajectory was notable as ending up the furthest east among trajectories in recent years. However, the ending latitude was only somewhat southerly of the average ending latitude for all trajectories (Figure 44) and certainly not atypical. This is consistent with the northeast Pacific wind forcing, which featured very strong westerly anomalies. The 2013/14 trajectory was quite similar to the 2011/12 trajectory, although it did not reach as far north as the latter. As with the 2013/14 trajectory, the 2014/15 trajectory also followed a northerly route, although it was further to the west than the 2013/14 trajectory. These coincided with the development (2013/14) and continuation (2014/15) of a "blob" of warm surface waters along the eastern Pacific coast and the return of the Pacfic Decadal Oscillation (PDO) to a warm, positive phase associated with winds from the south near the coast. The increased southerly winds contributed to well above-average sea surface temperatures in the Gulf of Alaska in 2014/15.



Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, NAVTEQ, Geonames.org, and other contributors

Figure 43: Simulated surface drifter trajectories for winters 2004-2015 (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).

The PTI time series (Figure 44, 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. However, such swings are not uncommon over the entire time series. The change between 2013/14 and 2014/15 was a relatively rare event when the index changed very little.

Using a 5-year running mean boxcar filter to smooth the raw PTI reveals multidecadal-scale oscillations in the north/south component of the drift trajectories (Figure 44), red line and squares), with amplitudes over 7° latitude. Over the past century, the filtered PTI has undergone four complete oscillations with distinct crossings of the mean, although the durations of the oscillations are not identical: 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.

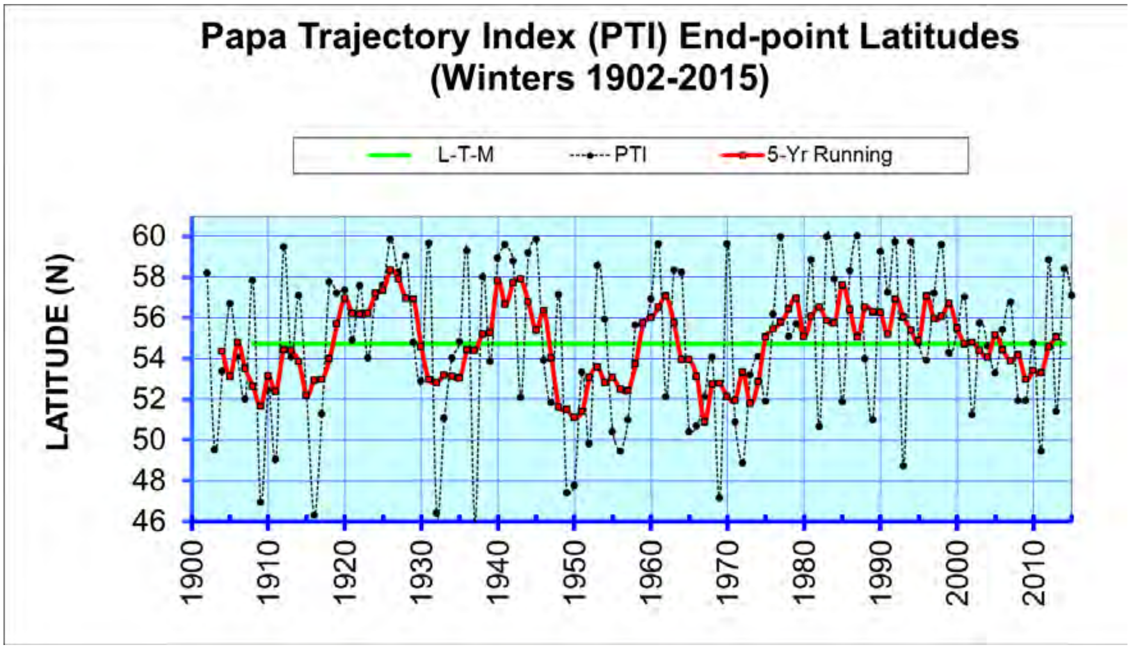


Figure 44: Annual, long-term mean (green line) and 5-year running mean (red line and squares) of the PAPA Trajectory Index time-series (dotted black line and points) for 1902-2015.

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 may have ended rather quickly, however, as it now appears the filtered PTI is about to cross the mean in the opposite direction. If this occurs, the recent period of predominantly southern flow will have 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 Alaska's heat budget. In addition, the PDO recently (July, 2014) shifted into a positive and warm phase, associated with warm SST anaomlies near the coast in the eastern Pacific and low sea level pressures over the North Pacific, the latter of which contributes to southerly winds and northerly flows. Individual trajectories also reflect interannual variability in regional (northeast Pacific) wind patterns.

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

Although the PTI was smaller than the mean in both 2010/11 and 2012/13, it was substantially larger than the mean in both 2011/12, 2013/14, and 2014/15. It is possible that the short period of negative PTI (southward trajectory anomalies) that began in earnest in the late 2000s has ended. On the other hand, the last few years may be more a temporary exception. Either way, the trajectory for 2012/13 indicated the potential for southeast Alaska to have experienced an influx of open ocean type organisms at the lower trophic levels in 2013, as well as a southward shift in the "boundary" between sub-arctic and sub-tropical species. The trajectories for 2013/14 and 2014/2015 indicate a northward shift in the "boundary" between sub-arctic and sub-tropical species, as well as a relative absence of open ocean type organisms at the lower trophic levels in southeast Alaska.

Gulf of Alaska Survey Bottom Temperature Analysis

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Description of indicator: Ocean circulation in the Gulf of Alaska (GOA) is dominated by two current systems, the Alaska Current and the Alaska Coastal Current (Stabeno et al., 2004). The Alaska Current is driven by the West Wind Drift of the subarctic gyre in the North Pacific basin and flows to the north-northwest from the survey boundary at Dixon Entrance. It is characterized by numerous eddies and meanders until forced to the southwest around Prince William Sound, forming the origins of the Alaska Coastal Current. The majority of this water flows through Shelikof Strait, with the remainder passing to the south of Kodiak Island, forming the origins of the Alaska Stream which continues to flow to the west along the Aleutian Islands (Stabeno et al., 1995). In addition, tidal forces dominate circulation in some local areas, particularly around Cook Inlet and many of the bays along the Alaska Peninsula.

Since 1993, water column temperatures have been routinely recorded on GOA surveys with 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 to 2001. The analyses presented here utilize all of the available bathythermic data collected on our GOA surveys since 1993. The downcasts from each trawl haul were isolated and used to inform the models.

The changing spatial and temporal coverage of the GOA survey along with the steady increase of water temperatures over the surveys 3-month duration complicate inter-annual temperature comparisons. Start dates for the surveys included in the analysis range from the middle of May to the first week in June, while end dates range 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 varied between survey years. In addition, water temperatures rise in the GOA as the summer advances and the bottom trawl survey progress from the western GOA to southeast Alaska, particularly in the upper 200 m of the water column.

To account for these issues and to make inter-annual comparisons more meaningful, an attempt was made to remove the effect of collection date on water temperature by standardizing all GOA bottom trawl surveys to a median date. This was achieved with generalized additive modeling (GAM) to estimate the effects of collection date on temperature at depth across survey areas and years which accounted for 81% of the total deviance in the temperature data. The resulting model was used to predict the temperature at depth from the estimated median day of July 10 for all GOA groundfish survey trawl hauls. Residuals from this GAM were added to the predicted median day temperature-at-depth to produce the final temperature anomaly estimates for each station and depth during each survey year. To facilitate visualization, these temperature estimates were averaged over systematic depth bins in -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 200 m, and 100 m bins between 500 and 1000 m) to capture the rapid changes in water temperatures often seen in these depths. To further stretch the color ramp and enhance the visual separation in the mid-range of the temperature anomalies (between about 4 and 7C), predicted temperature anomalies $> 7.5^{O}$C and $< 3.5^{O}$C were fixed at 7.5 and 3.5^{O}C (e.g., a 12.5^{O}C temperature anomaly was recoded as 7.5^{O}C for the graphic representation).

Status and trends: The 2015 pattern of water temperatures was similar to the pattern seen during the 2005 bottom trawl survey (Figure 45). The water column appears stratified and thermocline depths (ca. 6°C) are deeper than those observed in the last 4 GOA surveys (2007 2013). Overall GOA water temperatures in 2015 appear to be markedly warmer in the upper 200 m than during recent survey years. The 2015 temperature anomaly profiles are most similar to those from 2005 which was categorized as a weak ENSO year and is the next warmest survey year in our survey series.

Factors influencing observed trends: These data represent a snapshot of water temperatures collected during bottom trawl surveys in the Gulf of Alaska. Since each temperature bin represents data that were collected over a relatively short period as the vessels moved through the area, it is difficult to draw general conclusions as these temperatures are often greatly affected by short term events such as storm events, tidal currents, and changes in freshwater discharge. More persistent phenomena like mesoscale eddies, seasonal changes in solar heat flux, ENSO events, and changes in the Alaska Coastal Current play an important role in determining water column temperatures. The strength and persistence of eddies is 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). More recent phenomena like the “Ridiculously Resilient Ridge” of atmospheric high pressure that helped to establish the warm water “Blob” in the Northeast Pacific (Bond et al., 2015) are currently influencing water temperatures in our survey area.

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 in relation to the warm core eddies that are a prominent feature of the central GOA (Atwood et al., 2010). Adult fish distribution can change in response to water temperatures as well (Kotwicki and Lauth, 2013). The effects of interannual differences in water column temperatures on fish populations in the GOA require more study to be better understood.

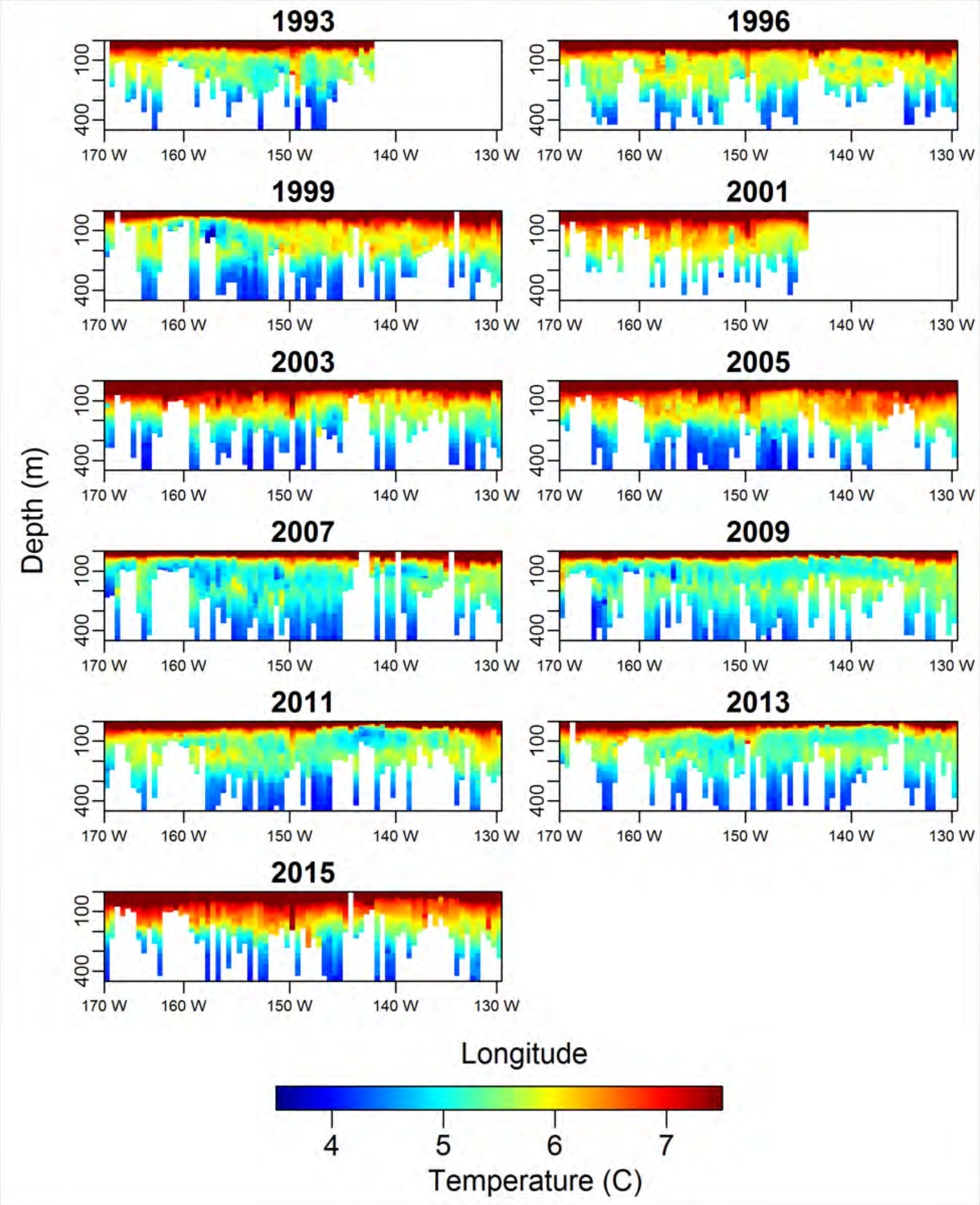

Figure 45: Temperature (°C) anomaly profiles predicted from a generalized additive model (i.e., date standardized temperatures + GAM residuals) at systematic depth increments and -degree longitude intervals for years 1993-2015; values ≤ 3.5°C and ≥ 7.5°C were fixed at 3.5 and 7.5°C to visually enhance midrange temperature differences.

Habitat

Structural Epifauna (HAPC Biota) - Eastern Bering Sea

Contributed by Robert Lauth, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2015

Description of indicator: Groups considered to be structural epifauna include: seapens/whips, corals, anemones, and sponges. Corals are rarely encountered on the Bering Sea shelf so they were not included here. Relative CPUE was calculated and plotted for each species group by year for 1982-2015. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: It is difficult to detect trends of structural epifauna groups in the Bering Sea shelf from the RACE bottom trawl survey results because there is taxonomic uncertainty within the groups and because the quality and specificity of field identifications have varied over the course of the time series (Stevenson and Hoff, 2009). Moreover, relatively large variability in the relative CPUE values makes trend analysis difficult (Figure 46). However, catch rates generally show increasing trends in anemones and sponges in recent years. Catch rates of seawhips have been variable.

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

Implications: Changes in structural epifauna CPUE may indicate changes in habitat, but at present no research has demonstrated definitive links.

Structural Epifauna (HAPC Biota)- Gulf of Alaska

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Last updated: October 2015

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.

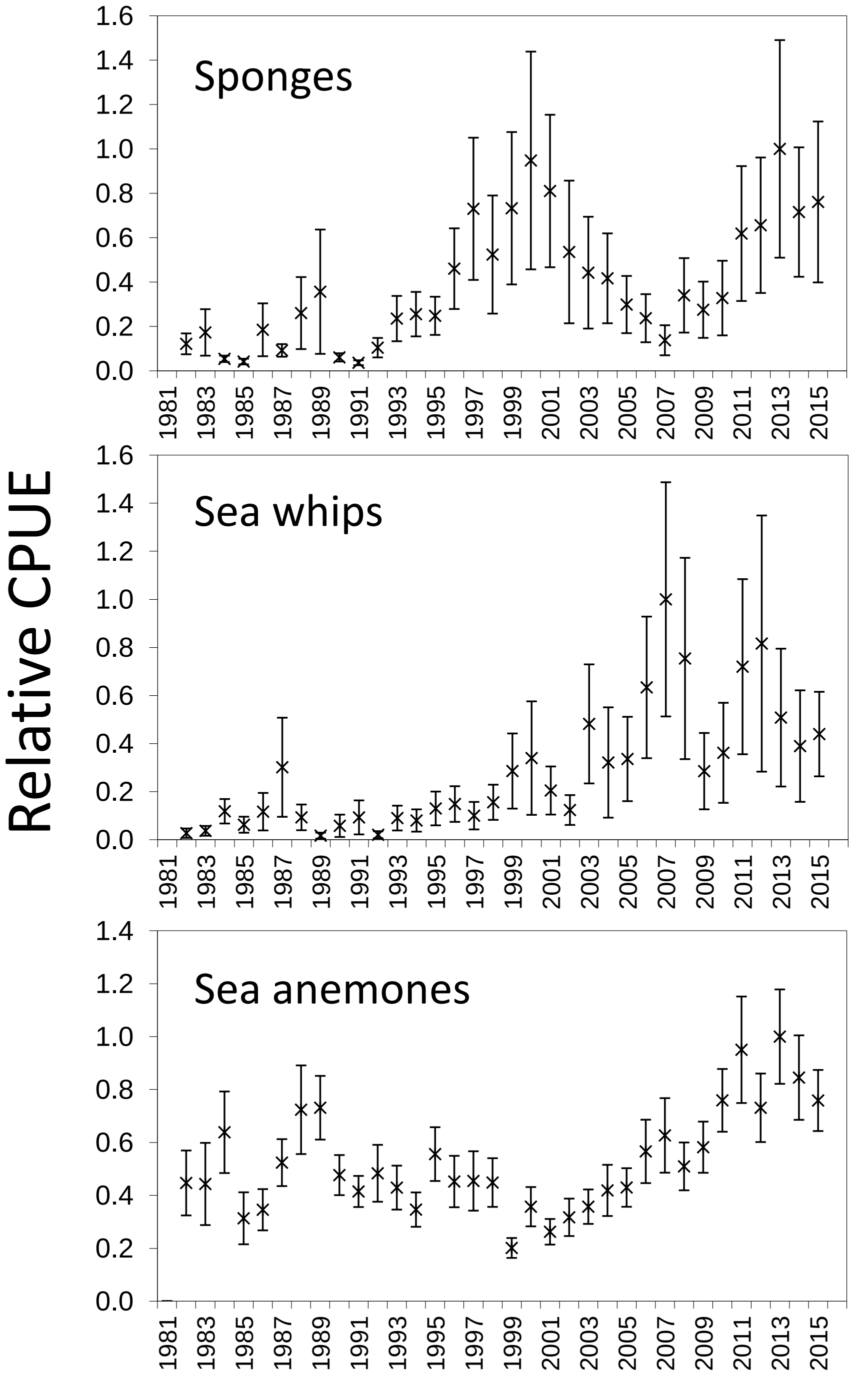

Figure 46: Relative CPUE trends of structural epifauna from the AFSC bottom trawl survey of the eastern Bering Sea shelf during the May to August time period from 1982-2015. Data points are shown with standard error bars.

Status and trends: A few general patterns are clearly discernible (Figure 47).Sponges are caught in about 50% of bottom trawl survey hauls in all areas of the GOA. However, the CPUE is generally highest in the western GOA and decreases to the east. Sponge CPUE has generally declined in the western GOA during the time series, while CPUE has remained fairly constant in the two 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 western and central GOA. Gorgonian corals show an opposite pattern, as they are in highest abundance in the eastern 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 a large CPUE in 2005 in the central GOA, but they occur uncommonly in bottom trawl tows (< 10% occurrence). Stony coral CPUEs have been highest in the western GOA and highly variable. Soft coral CPUE has been uniformly low with the exception of a large catch in the western GOA in the 1984 survey.

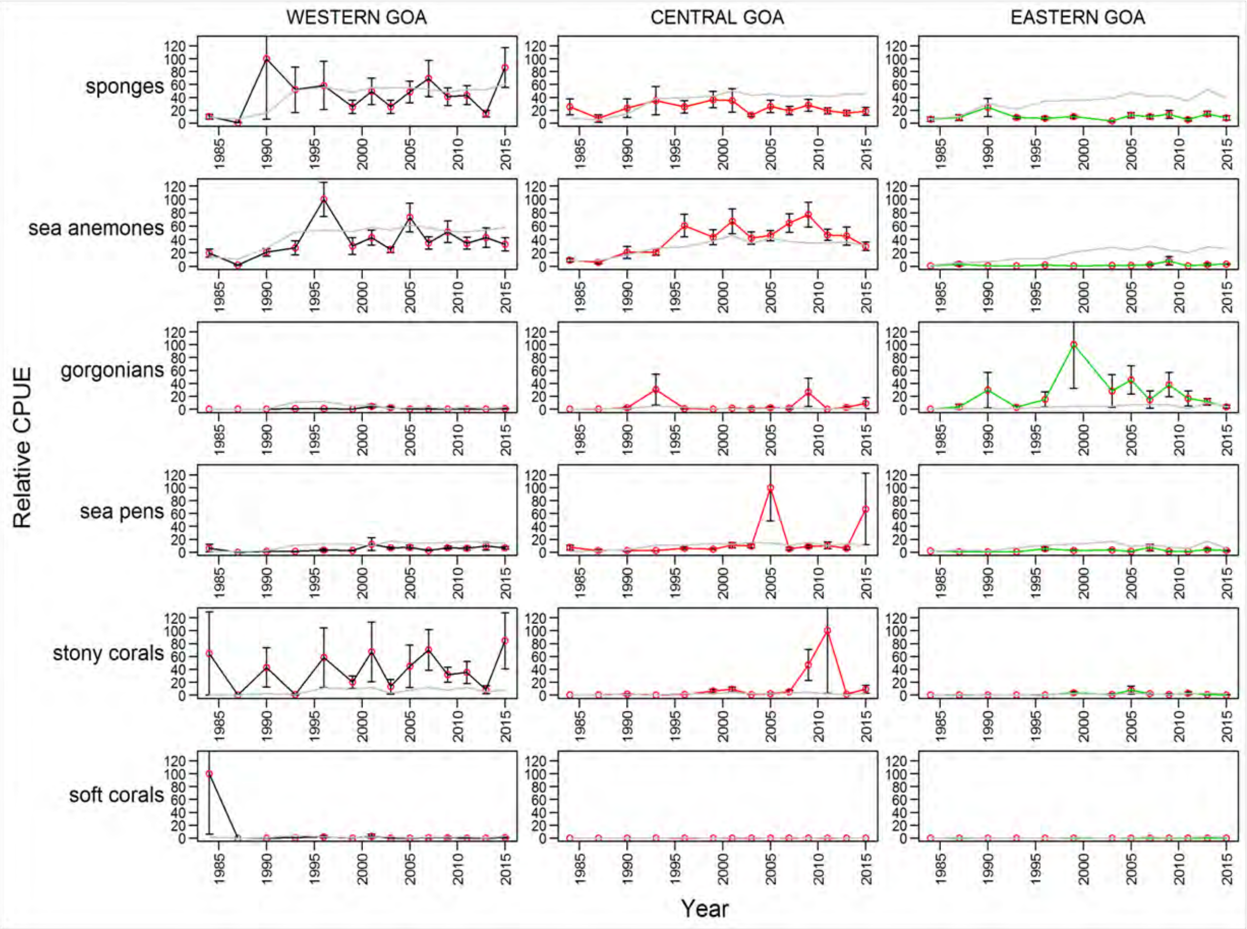

Figure 47: Mean CPUE of HAPC species groups by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2015. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

Factors influencing observed trends: The Gulf of Alaska survey does not sample any of these fauna well. The survey gear does not perform well in many of the areas where these groups are likely to be more abundant and survey effort is quite limited in these areas. In tows where they are encountered, the standard survey gear is ill-suited for efficient capture of these groups. Another complicating factor in interpreting these results is that the gears used by the Japanese vessels in the surveys prior to 1994 were quite different from the survey gear used aboard American vessels in subsequent surveys and likely resulted in different catch rates for many of these groups. In recent years, more emphasis has been placed on the collection of more detailed and accurate data on structural epifauna, and it is likely that this increased emphasis influenced the results presented here.

Implications: Changes in structural epifauna CPUE may indicate changes in habitat, but at present no research has demonstrated definitive links.

Primary Production

There are no updates to primary production indicators in this year's report. See the appendix for a list of indicators not updated, and see the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Zooplankton

Spring Eastern Bering Sea Zooplankton Rapid Assessment

Contributed by Coleen Harpold, EcoFOCI Program, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: August 2015

Description of indicator: In 2015 EcoFOCI implemented a method for an at sea zooplankton community rapid assessment to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20 / 60 cm oblique bongo tows to 10m off bottom), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories chosen are ecologically important and are highly influenced by cold and warm years. The categories are small copepods, large copepods, and euphausiids. Small copepods are less than or equal to 2mm total length and include species such as *Pseudocalanus* spp. Large copepods are those greater than 2mm total length and include *Calanus marshallae* and *Neocalanus* spp. The euphausiid category comprises all life stages. Small copepods were usually counted from the 153μm mesh 20 centimeter bongo net. Large copepods and euphausiids were counted from the 333μm 60 centimeter bongo net. Other rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method. Detailed information on these taxa are provided after in-lab processing protocols have been followed (1+ years post survey).

Status and trends: The plankton community at six stations along the 70 m isobath on the southern Bering Sea shelf was assessed in May 2015 (Figure 48). Small copepods made up the majority of the plankton at four out of the six stations. Large copepods were present at all six stations but were in the minority of the zooplankton community relative to small copepods at most stations. Euphausiid larvae / juveniles were only present at three out of the six stations. The zooplankton community appeared to be different near the ice edge to include more lipid-rich prey (large copepods and larval / juvenile euphausiids) and there were no small copepods. This change was accompanied by an algal bloom as verified by onboard phytoplankton analysis (L. Eisner, pers. comm.). There are no interannual trends to report this year, as it is the first year of the zooplankton rapid assessment.

Factors influencing observed trends: Sea surface temperatures were warmer than average (as shown elsewhere in this report) and the ice retreated early and was blown back down into the study area (P. Stabeno, pers. comm.). These data are an early indication that a secondary phytoplankton bloom and associated large copepods may occur at the ice edge after an initial sea ice retreat, even

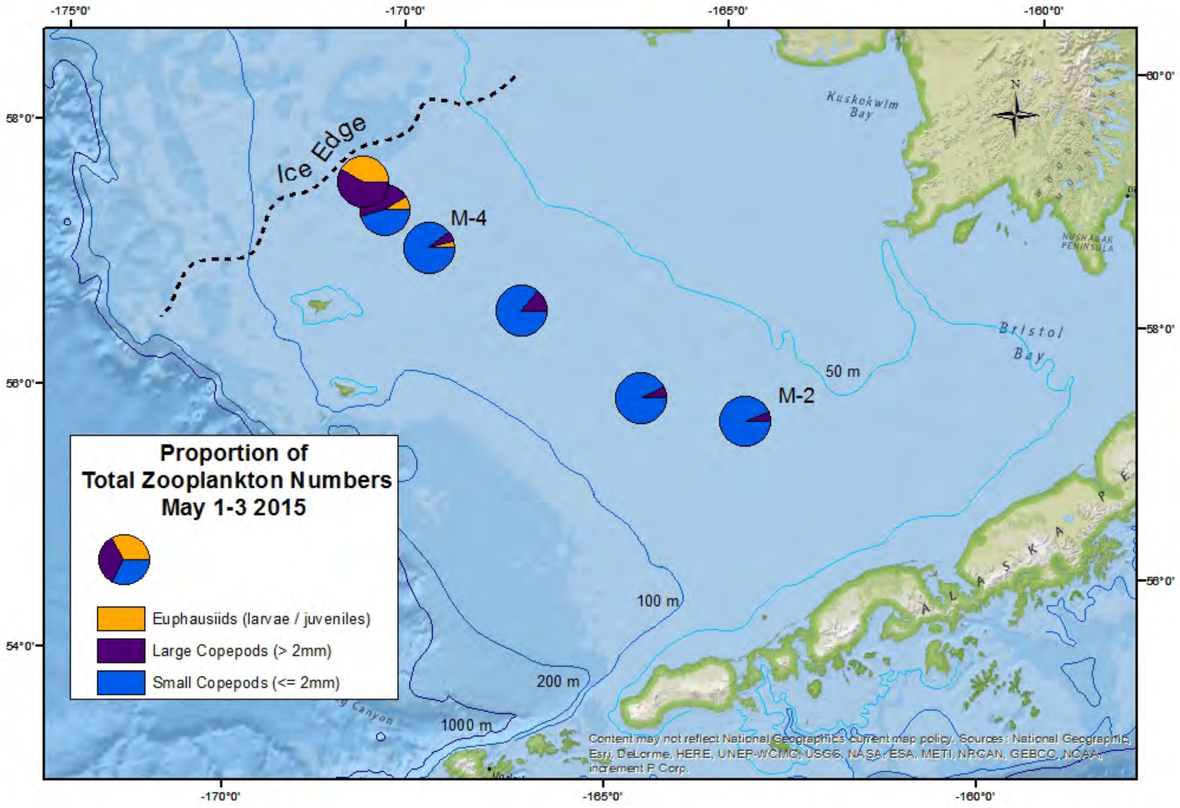

Figure 48: Proportion of total zooplankton numbers during rapid assessment, May 1-3, 2015.

in a warm year. The large proportion of small copepods at most stations is consistent with previous observations of warm year phenomena.

Implications: Previous research suggests that the ratio of small to large copepods may be particularly important to juvenile walleye pollock survival through first winter and varies from cold to warm years (Hunt et al., 2011). These data seem to support the Oscillating Control Hypothesis and suggest that lipid rich prey (large copepods and euphausiid larvae / juveniles) are associated with the ice edge. Therefore the setup of lipid rich prey conditions needed for a strong year class of pollock are likely related to sea surface temperature and the timing of ice edge retreat. The position of the ice edge when it retreats in relation to the walleye pollock larval population may be an important factor in pollock survival through the first winter.

Spring Gulf of Alaska Zooplankton Rapid Assessment

Contributed by Nissa Ferm, EcoFOCI Program, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA Contact: nissa.ferm@noaa.gov

Last updated: August 2015

Description of indicator: In 2015 EcoFOCI implemented a method for an at sea zooplankton community rapid assessment to provide leading indicator information on zooplankton composition in Alaska's Large Marine Ecosystems. The rapid assessment, which is a rough count of zooplankton (from paired 20 / 60 cm oblique bongo tows to 10m off bottom), provides preliminary estimates of zooplankton abundance and community structure. The method employed uses coarse categories and standard zooplankton sorting methods (Harris et al., 2005). The categories chosen are ecologically important and are highly influenced by cold and warm years. The categories are small copepods, large copepods, and euphausiids. Small copepods are less than or equal to 2mm total length and include species such as *Pseudocalanus* spp. Large copepods are those greater than 2mm total length and include *Calanus marshallae* and *Neocalanus* spp. The euphausiid category comprises all life stages. Small copepods were usually counted from the 153μm mesh 20 centimeter bongo net. Large copepods and euphausiids were counted from the 333μm 60 centimeter bongo net. Other rarer zooplankton taxa were present but were not sampled effectively with the on-board sampling method. Detailed information on these taxa are provided after in-lab processing protocols have been followed (1+ years post survey).

Status and trends: In May and June of 2015 the zooplankton rapid assessment was conducted at 140 stations to provide leading indicator information on zooplankton composition in the Gulf of Alaska (Figure 49). Abundances of the small copepods were several orders of magnitude higher than either large copepods or euphausiids. Large copepod abundances east of the Shumagin islands were more abundant and some near proportional to small copepod abundances. Euphausiids were only recorded at 51 of the stations with an average abundance of 12 per cubic meter. Euphausiids during the spring consist mainly of furcillia stages and small juveniles (5-10mm). The highest abundances were found on the southeastern side of Kodiak Island. The map provided shows abundances and proportionality of these three indicator groups. As this is the first year there are no trends to report.

Factors influencing observed trends: Temperature at 40 meters depth was warmer than usual, ranging from 5-6^{o}C. The warmer than average temperatures favor small copepod species. Southwest of Kodiak temperatures were slightly cooler than that northeast of Kodiak. See Dougherty contribution p. 50 for a temperature map. Stations in the cooler area had higher large zooplankton proportions and abundances, thus providing higher quality prey fields. Observations are consistent with Warm Blob observations for the Gulf of Alaska and indicate lower trophic response to thermal shifts.

Implications: Low abundances of lipid rich large copepods, particularly *Calanus marshallae* and *Neocalanus spp.*, can directly impact the survivability of young of the year commercially important fish species such as walleye pollock and Pacific cod. Small copepod species do not store lipids like their larger counterparts making them a poor prey resource which negatively affects the condition of fish before their first winter.

Gulf of Alaska Euphausiids ("krill")

Contributed by Patrick Ressler and Kirsten Simonsen, Midwater Assessment and Conservation Engineering Program (MACE), Resource Assessment and Conservation Engineering Division, Alaska

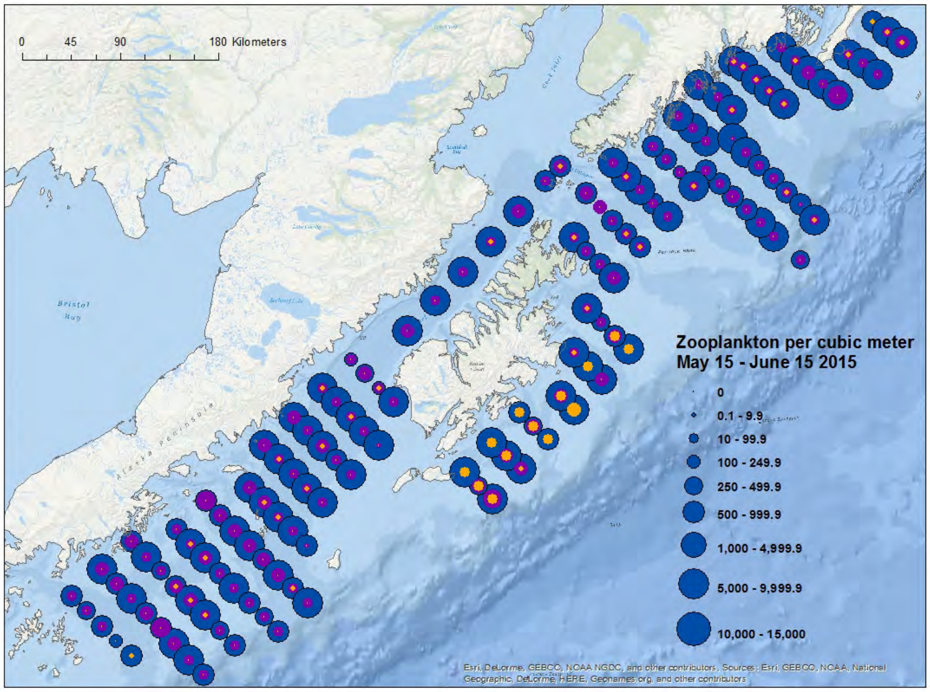

Figure 49: Proportion of total zooplankton numbers during rapid assessment, May 15 - June 15, 2015. Orange circles are euphausiids, purple are large copepods, and dark blue are small copepods.

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Last updated: October 2015

Description of indicator: The Gulf of Alaska survey of the abundance and distribution of euphausiids ("krill", principally *Thysanoessa* spp.) has been developled based on methods developed by Ressler et al. (2012) in the Bering Sea. The survey incorporates both acoustic and Methot trawl data from the summer Gulf of Alaska acoustic-trawl surveys for pollock conducted in 2003, 2005, 2011, 2013, and 2015 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, the index report here is limited to areas that were consistently sampled in all years (Figure 50). *These data are preliminary and will change.*

Status and trends: Results indicate that highest abundance of euphausiids was observed in 2011, with lowest euphausiid abundance in 2003 (Figure 51). There was a small decline in 2015 relative to 2013. Species composition data from summer 2015 Methot trawls are not yet available.

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

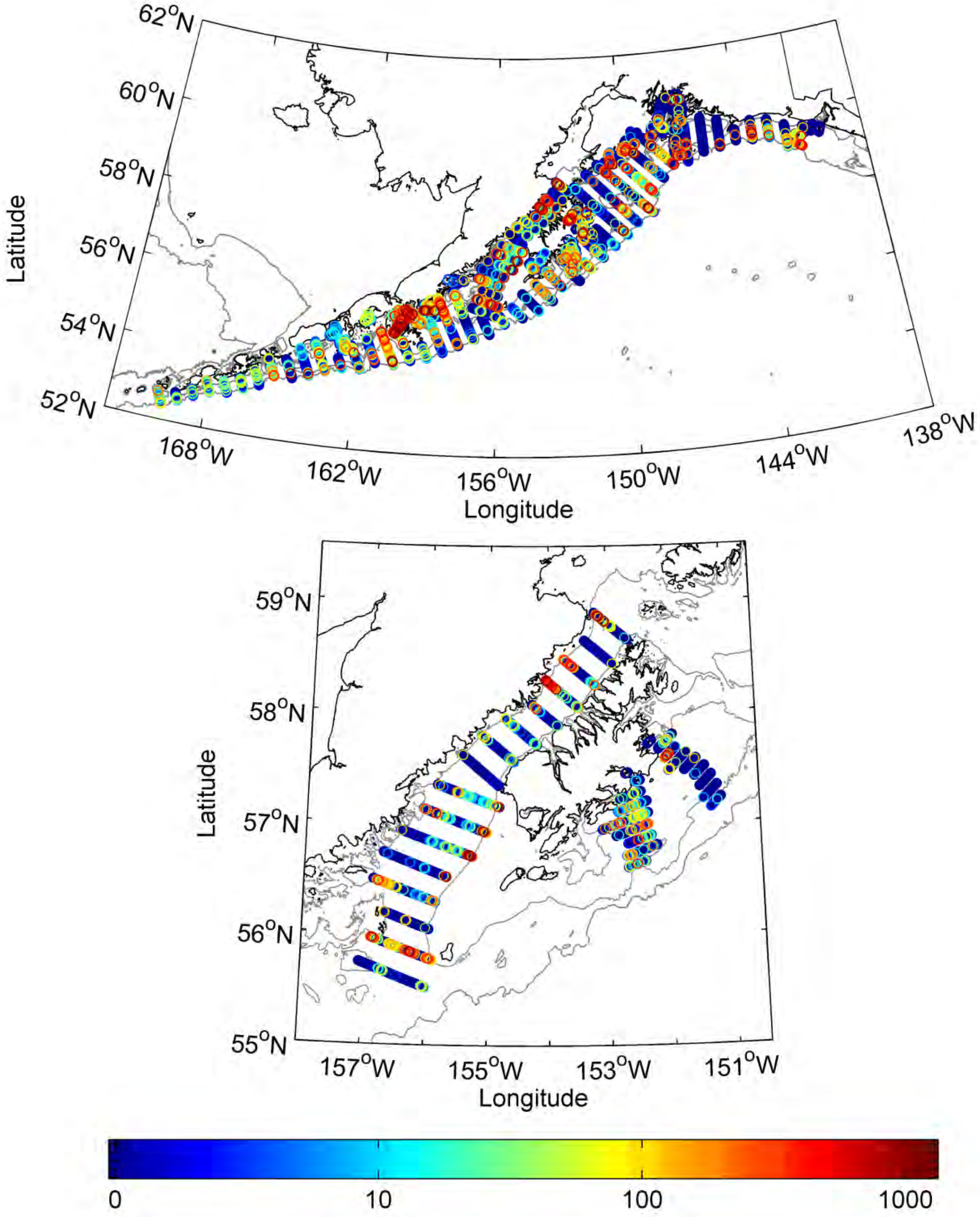

Figure 50: Spatial distribution of acoustic backscatter density (s_A at 120 kHz, m^2 nmi^{-2}) attributed to euphausiids in consistently sampled areas in the entire GOA survey area (top panel) and the consistently sampled areas around Kodiak Island (bottom panel; Shelikof Strait, Barnabas Trough, and Chiniak Trough) during the 2015 Gulf of Alaska summer acoustic-trawl survey.

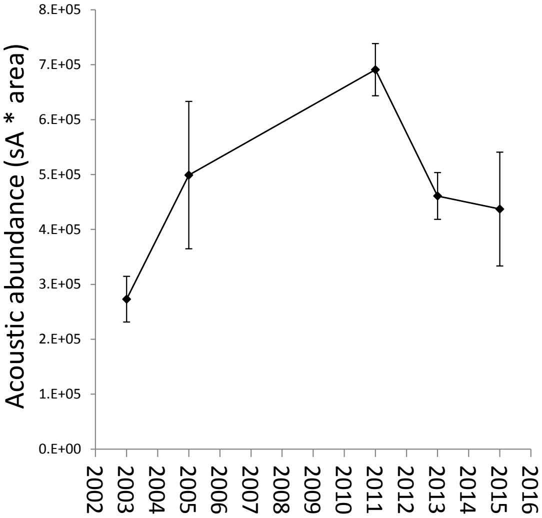

Figure 51: Acoustic backscatter estimate of euphausiid abundance from NOAA-AFSC Gulf of Alaska summer acoustic-trawl survey. Error bars are approximate 95% confidence intervals computed from geostatistical estimates of relative estimation error (Petitgas, 1993).

and food supply, and top-down control through predation (Hunt et al. accepted). 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. in review). Euphausiid abundance is not strongly correlated with the abundance of pollock (a major predator) in models of either system.

Implications: Euphausiids are a key prey species for fish species of both ecological and economic importance in the Gulf of Alaska, including walleye pollock (*Gadus chalcogrammus*), Pacific Ocean perch (*Sebastes alutus*), arrowtooth flounder (*Atheresthes stomias*), capelin (*Mallotus villosus*), eulachon (*Thaleichthys pacificus*), and as well as many species of seabirds and marine mammals. These data suggest a moderate level of euphausiid prey availability in 2015.

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

Contributed by Emily Fergusson and Joe Orsi, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: August 2015

Description of indicator: The Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories, AFSC, has collected zooplankton and temperature data during fisheries oceanography surveys annually since 1997 (Orsi et al. 2014; `http://www.afsc.noaa.gov/abl/msi/msi_secm.htm`). The SECM project primarily samples 8 stations in the vicinity of Icy Strait in the northern region of southeastern Alaska (SEAK), including monthly sampling with CTDs and plankton nets in May to August. Surface trawling for juvenile Pacific salmon (*Oncorhynchus* spp.), the most abundant forage species in local epipelagic waters in day time, and associated nekton is conducted in June to August. The primary goals of this research are to investigate how climate change may affect SEAK ecosystems, to increase understanding of the early marine ecology of salmon and their trophic linkages, and to develop an annual forecast of the adult pink salmon (*O. gorbuscha*) from stock assessments of juveniles in the prior year (Fergusson et al., 2013; Orsi et al., 2014). Biophysical parameters representing temperature, zooplankton prey, and fish abundance and condition are used to characterize seasonal and interannual ecosystem conditions for inside waters of northern Southeast Alaska.

This report presents 2014 monthly temperature and zooplankton data in relation to long-term trends in Icy Strait. The Icy Strait Temperature Index (ISTI, °C) is computed from CTD data at 1-m increments over the 20-m upper water column ($\geq$160 observations per month each year).Zooplankton total density (number per m^3) and percent composition were computed from 333-μm bongo net samples collected at 4 stations ($\leq$200 m depth) (Orsi et al., 2004; Park et al., 2004). Temperature and zooplankton anomalies were computed as deviations from the long-term monthly mean values. These indices may help to explain climate-related variation in prey fields for diverse fish communities (Sturdevant et al., 2012; Fergusson et al., 2013).

Status and trends: Overall, monthly mean temperatures ranged from approximately 6.2 °C to 11.4 °C, while ISTIs ranged from 8.3 C to 10.3 C. ISTI anomalies did not exceed ±1.5 °C (Figure 52). Compared to the time series, 2014 temperatures were anomalously warm in May and June then switched to being anomalously cool in July and August. The ISTI shows the annual temperature trend identifying warm and cool years, with 10 years warmer and 8 years colder than average (9.3 ^{O}C), 2014 ISTI was just above average. In the most anomalous years, all 4 months were warm (2003 and 2005) or cold (2002, 2006, 2008, 2012; Figure 52, top), whereas moderately warm or cold years had unique months of temperature reversal. For example, the warm years of 2004 and 2010 were actually colder than average in June and July, respectively.

Overall, long-term mean zooplankton density peaked in May and June at ~1,750 organisms per m^3, and declined ~50% by August (Table 1). Compared to the time series, 2014, total density was anomalously low for all months. Density anomalies were mostly negative from 1997-2005, positive in 2006-2009, negative in 2010-2011, and positive in 2012-2013 (Figures 53 and 54). Total density showed little correspondence with annual temperature trends, with both positive and negative monthly anomalies in both warm and cold years.

Overall, zooplankton was numerically dominated by calanoid copepods, including small species (≤2.5 mm length; ≤74% composition; primarily *Pseudocalanus* spp.) and large species (>2.5 mm; ≤34% composition; primarily *Metridia* spp.) (Table 4). Five other taxa important in fish diets (Sturdevant et al. 2012; Fergusson et al. 2013) contributed small percentages (decapod larvae, ≤1%; euphausiids, ≤7%; gastropods, ≤4%; larvaceans, ≤6%; and amphipods, ≤3%). For 2014, large calanoids and larvaceans were anomalously low while small calanoids and amphipods, in July, were anomalously high. Small and large calanoids typically had inverse monthly composition anomalies that indicated different seasonality and temperature response (Figures 53 and 54). However, these anomalies varied from year to year, suggesting different innate timing cues. In some years, high percentages of euphausiid larvae (2000, 2002, 2010), larvaceans (2003, 2010, 2013), or gastropods (2005, 2012) contributed to monthly composition anomalies (Figures 53 and 54). Such shifts could lead to mismatched timing of prey fields for planktivorous fish.

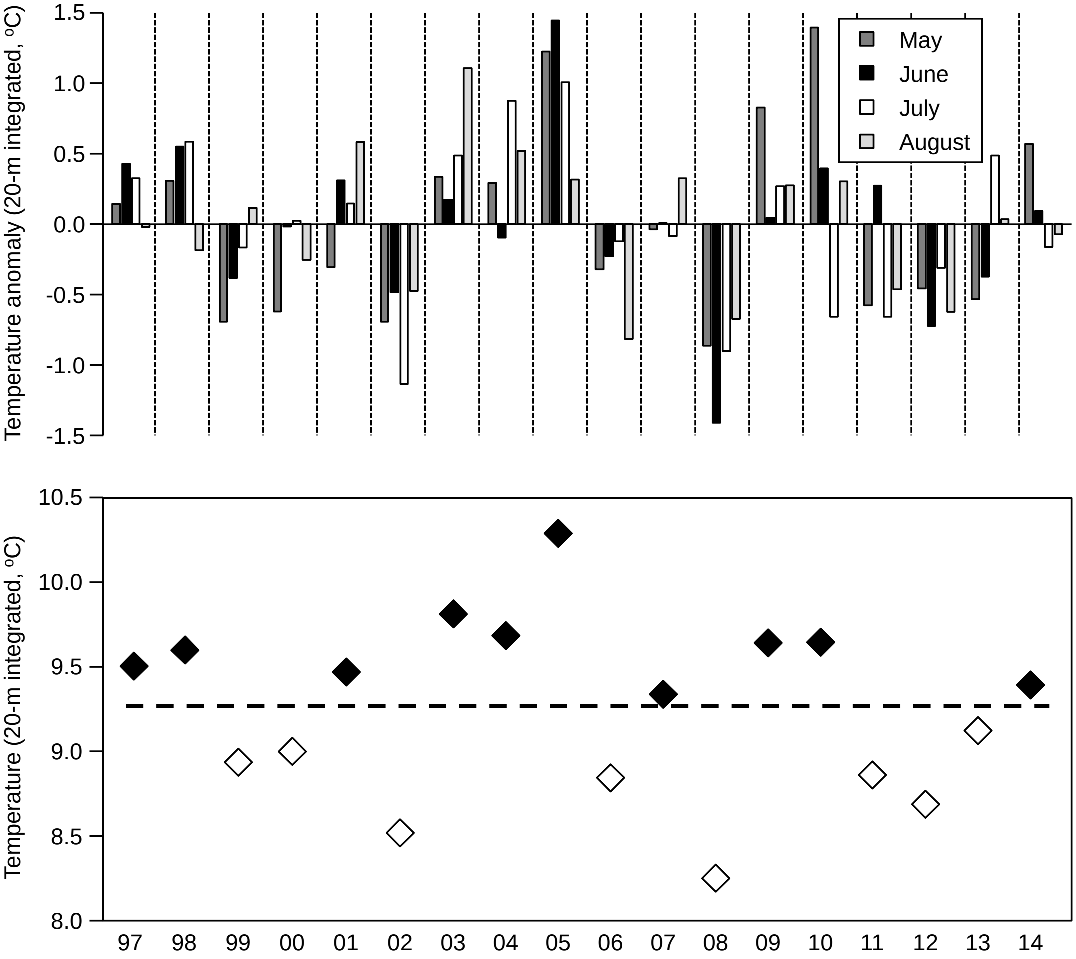

Figure 52: Marine climate relationships for the northern region of Southeast Alaska from the SECM 18-year time series, 1997-2014. Upper panel: mean monthly temperature anomalies (°C, 20-m integrated water column) in Icy Strait; lower panel: mean annual Icy Strait Temperature Index (ISTI°C, 20-m integrated water column and 18 year mean ISTI (dashed line), showing warm (black markers) and cold (white markers) years. Long-term mean temperatures are indicated in the top panel key by month.

Factors influencing observed trends: Our research in SEAK over the past 18 years described

Table 4: Zooplankton long-term mean total density (numbers^{-3}) and taxonomic percent composition in Icy Strait, Southeast Alaska, 1997-2014. Data represent 4 stations sampled annually across the strait ($\leq$ 200 m depth) with a 0.6 m diameter 333-μm mesh Bongo net (double-oblique trajectory). Values are references for the 0-lines shown in Figures 53 and 54 interannual anomalies.

	Total organisms	Large calanoids	Small calanoids	Decapod larvae	Euphausiid larvae	Amphipods	Other	
May	1782(149)	34(2)	48(3)	5(1)	1(0)	6(2)	<1(0)	6(1)
June	1754(182)	23(2)	<1(0))	7(2)	2(1)	5(1)	<1(0)	5(1)
July	1308(123)	15(1)	74(2)	<1(0)	1(0)	1(0)	3(1)	3(0)
August	985(131)	14(2)	74(4)	<1(0)	4(4)	2(0)	2(0)	3(0)

annual trends in temperature, prey fields, and other biophysical factors (Orsi et al., 2013). We documented a significant link between ISTI and a basin-scale climate index, with limited diet-climate relationships (Sturdevant et al., 2012, 2013; Fergusson et al., 2013). Although subarctic zooplankton typically follow seasonal cycles of abundance, responses to climate change may be species-specific based on life history, seasonal timing cues, physiology, and environmental parameters other than temperature (Mackas et al., 2012), and these responses could depend on the monthly timing, magnitude, and duration of temperature anomalies in warm or cold years. Therefore, the simple ISTI may not explain shifts in abundance and composition of these prey fields, particularly at broad taxonomic scales. Further analysis of specific target prey at a species specific level is planned to refine this index so it more accurately reflects critical trophic interactions with respect to climate change. Additionally, adding a prey quality measure, such as % lipid, is planned to further refine this index

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). Although links between climate and plankton have been documented in Alaskan waters, mechanisms are poorly understood. In the Bering Sea, the magnitude and timing of production of the large copepod, *Calanus marshallae*, varied among years, reflecting interannual ocean-atmosphere conditions (Baier and Napp, 2003), and in SEAK, large copepods with long life spans were thought to be more sensitive to climate fluctuation than small copepods (Park et al., 2004). Temperature and other climate metrics may affect fish production and recruitment directly or indirectly, through prey resources (Beamish et al., 2004, 2012; Coyle et al., 2011). In dynamic ecosystems such as SEAK (Weingartner et al., 2009), the effects of climate variation on prey fields are likely to be complex, varied, and difficult to distinguish from natural variation, particularly if annual temperature changes are moderate. However, further analysis of the potentially more direct links between monthly temperature and zooplankton secondary production may lead to improved understanding of marine mechanisms that influence fish recruitment during periods of climate change (Downton and Miller, 1998; Francis et al., 1998).

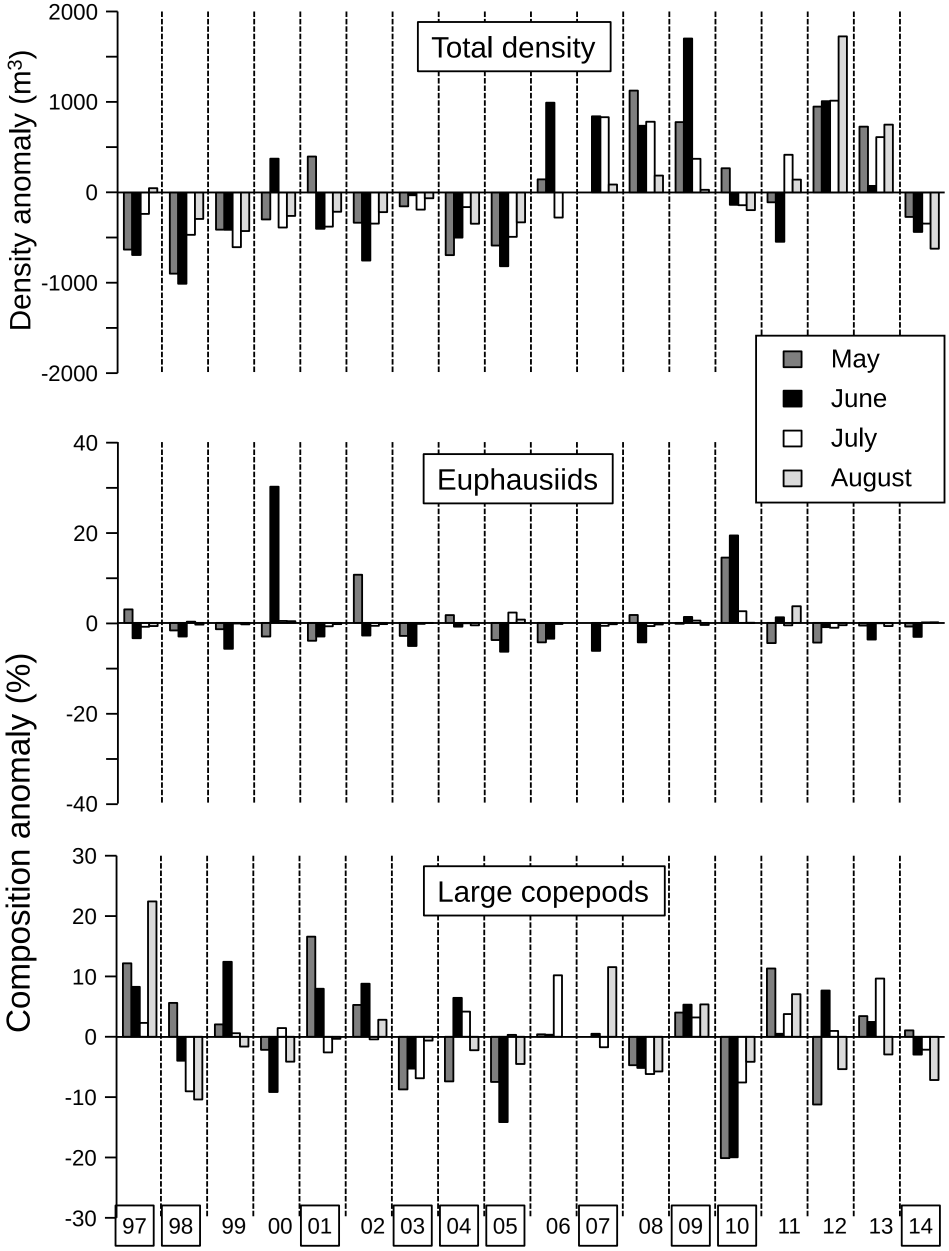

Figure 53: Total zooplankton, euphausiid and large copepod density and composition anomalies for the SECM 18-yr time series from Icy Strait, Southeast Alaska, 1997-2014. Long-term monthly means are indicated by the 0-line (values given in Table 4). Data (shaded bars) are deviations for total density (number/m^3; top left panel), and taxonomic percent composition. No samples were available for August 2006 or May 2007. Warm years are indicated in boxes on the x-axis; see Figure 52.

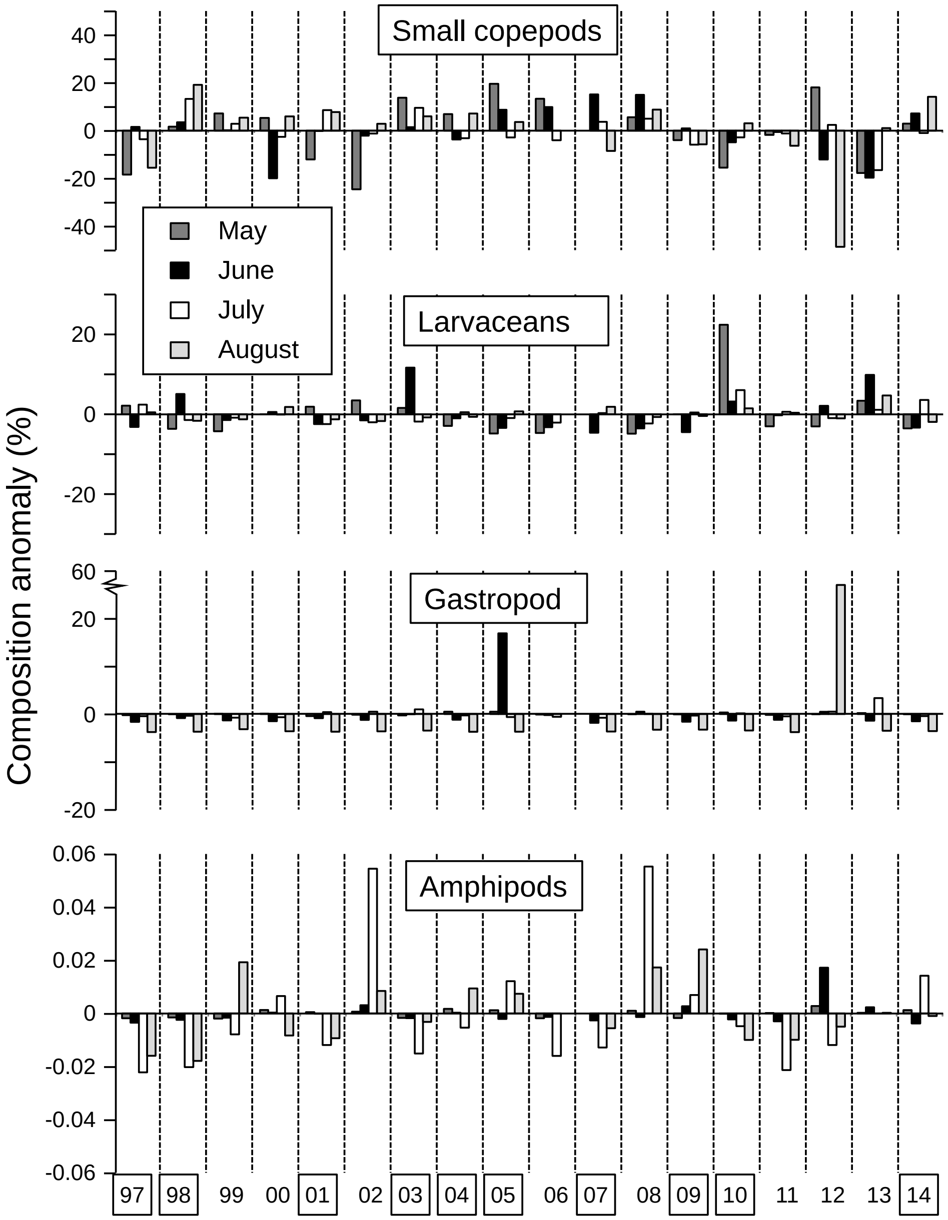

Figure 54: Small copepod, larvacean, gastropod, and amphipod density and composition anomalies for the SECM 18-yr time series from Icy Strait, Southeast Alaska, 1997-2014. Long-term monthly means are indicated by the 0-line (values given in Table 4). Data (shaded bars) are deviations for total density (number/m^3; top left panel), and taxonomic percent composition. No samples were available for August 2006 or May 2007. Warm years are indicated in boxes on the x-axis; see Figure 52.

Continuous Plankton Recorder Data from the Northeast Pacific

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Last updated: August 2015

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 which follows a great circle route across the Pacific terminating in Japan. Several indicators are now routinely derived from the CPR data and updated annually. In this report we update three indices for three regions (Figure 55); 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 abundance data) and mean Copepod Community Size (Richardson et al., 2006) as an indicator of community composition. Anomaly time series of each index have been calculated as follows: A monthly mean value (geometric mean) 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.

The indices are calculated for three regions; the oceanic North-East Pacific, the Alaskan shelf SE of Cook Inlet and the deep waters of the southern Bering Sea (Figure 55). The oceanic NE Pacific region has the best temporal sampling resolution as both transects intersect here. This region has been sampled up to 9 times per year with some months sampled twice. The southern Bering Sea is sampled only 3 times per year by the east-west transect while the Alaskan shelf region is sampled 5-6 times per year by the north-south transect.

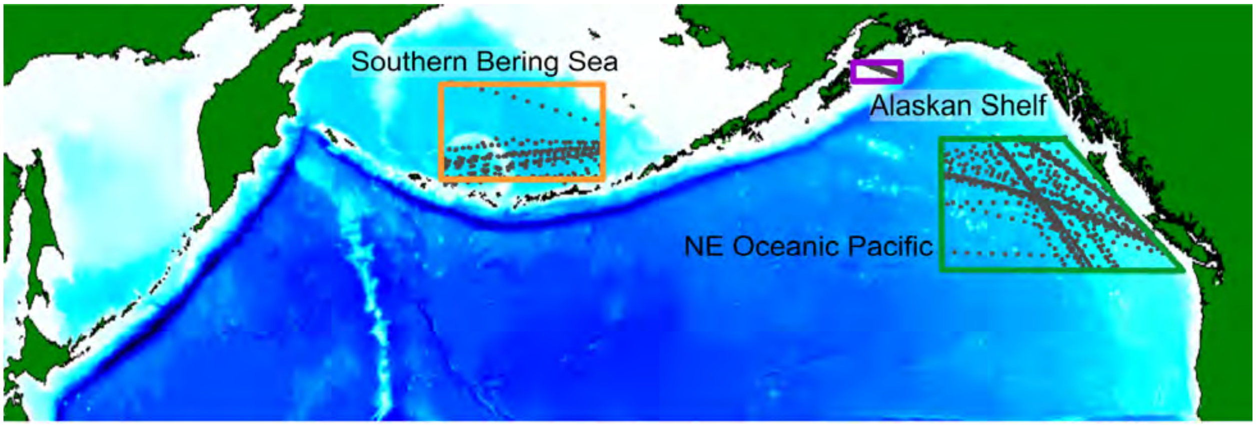

Figure 55: Boundaries of the three regions described in this report. Dots indicate actual sample positions (note that for the Alaskan Shelf region the multiple (>50) transects overlay each other almost entirely).

Status and trends: Ocean conditions in 2014 were warm across much of the north Pacific, with strongly positive values of the Pacific Decadal Oscillation (PDO) through the year, and an anomalous pool of warm water persisting in the NE Pacific that is receiving much attention. The lower trophic level responses to this warmth, as seen by the CPR, are a mixture of what we would expect from a warm, PDO positive year and some unusual index values (Figure 56).

Diatoms were low on the Alaskan shelf and the oceanic region. Until 2013 there were significant positive relationships between annual anomalies of diatoms and the PDO in these two regions, but this broke down in 2014 in both cases. Diatoms in the southern Bering Sea were relatively high in 2014 but because of the relatively infrequent sampling we cannot be certain whether this was due to the timing of the sampling relative to the seasonal cycle.

The Copepod Community Size index saw neutral anomaly values for the southern Bering Sea and oceanic regions, but a strongly negative value for the Alaskan shelf region. This latter result is what would be expected in PDO positive conditions, when warm waters favor smaller, more southern-origin species.

The mesozooplankton biomass anomalies were positive in the oceanic region, and on the Alaskan shelf but negative in the southern Bering Sea. For the Alaskan shelf region, the late spring values were mainly responsible for the positive anomaly, being exceptionally high in May and June but near average in other months. For the oceanic region, the positive anomaly was caused by a somewhat early, and unusually extended, productive season.

Factors influencing observed trends: The lower than expected diatom numbers in the oceanic region are consistent with findings by Whitney (2015) for the transition zone slightly to the south, which speculates that the warm anomaly offshore reduced nutrient export causing a reduction in phytoplankton growth and biomass. For the Alaska shelf the diatom data suggest that in 2014 there was likely something fundamentally different in the nutrient regime, or water column structure, that influenced the productivity of the larger species that make up the CPR diatom data, but this is as yet unknown.

The negative anomaly for the Copepod Community Size Index on the Alaskan shelf was caused by a higher contribution of smaller species. A separate analysis of warm water copepod species, which tend to have a smaller body size, showed that 2014 was second only to 2005 in terms of their abundance, in-line with the positive PDO values for both years. We would have expected the oceanic region to show a similar high abundance of warm water species and a correspondingly low Copepod Community Size index based on the PDO index for 2014 but in fact warm water species were only slightly elevated in abundance relative to 2013. Clearly, larger-bodied species were still relatively abundant despite the warm conditions.

Implications: Each of these variables is important to the way that ocean climate variability is passed though the phytoplankton to zooplankton and up to higher trophic levels. Changes in community composition (e.g. abundance of large diatoms, prey size as indexed by mean copepod community size) may reflect changes in the nutritional quality of the organism to their predators. Changes in abundance or biomass, together with size, influence availability of prey to predators.

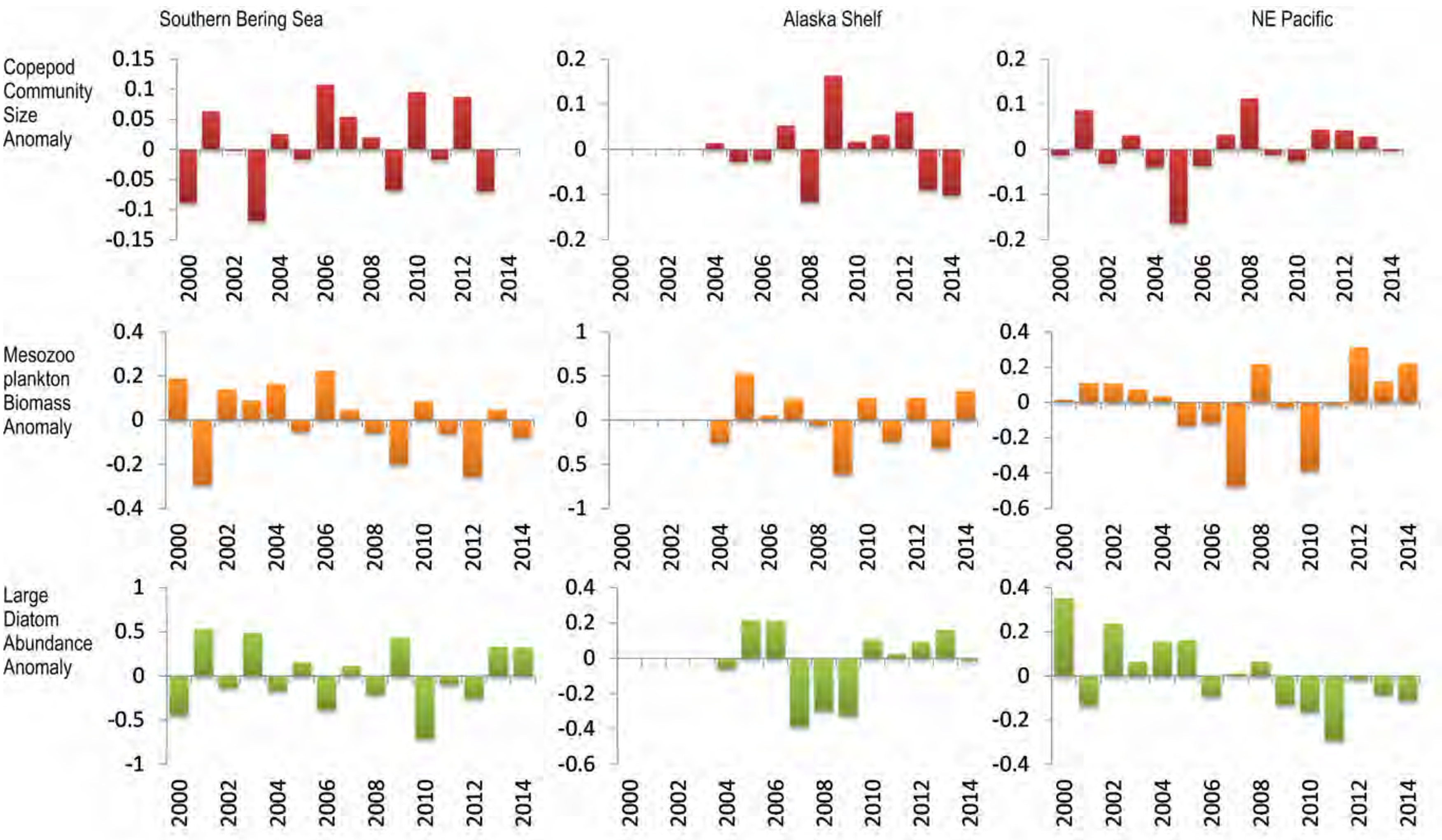

Figure 56: Annual anomalies of three indices of lower trophic levels (see text for description and derivation) for each region shown in (Figure 55). Note that sampling of this Alaskan Shelf region did not begin until 2004.

Jellyfish

Jellyfish - Eastern Bering Sea

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Description of indicator: The time series of jellyfish (principally *Chrysaora melanaster*) was updated for 2015 (Figure 57). Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

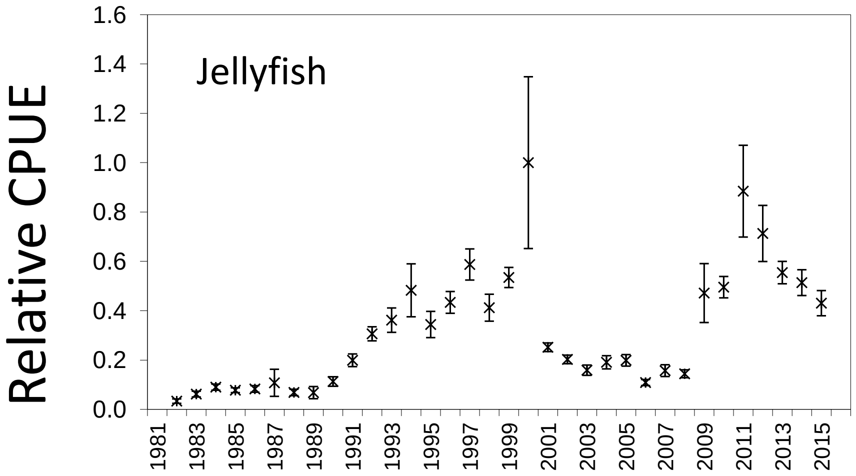

Figure 57: AFSC eastern Bering Sea bottom trawl survey relative CPUE for jellyfish during the May to August time period from 1982-2015.

Status and trends: Jellyfish relative CPUE in 2015 was down slightly from 2014, but remained relatively high when compared to the last 10 years. The increasing trend in jellyfish biomass throughout the 1990's was first reported by Brodeur et al. (1999). The peak in the year 2000 was followed by a precipitous decline and stabilization until an increase in 2009-2014.

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

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

Trends in Jellyfish Bycatch from the Bering Aleutian Salmon International Survey (BASIS)

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Last updated: August 2015

Description of indicator: Jellyfish sampling was incorporated aboard the BASIS (Bering Aleutian Salmon International Surveys) vessels beginning in 2004 and continued through 2014. Starting in 2015 in the Southeast Bering a gear and survey change will occur resulting in this index ending. However, it will continue in the North Bering Sea until 2018. All jellyfish medusae caught in the surface trawl (top 18-20 m of the water column) are sorted by species and subsampled for bell diameter and wet weight. Six species are commonly caught with the surface trawl: *Aequorea* sp., *Chrysaora melanaster*, *Cyanea capillata*, *Aurelia labiata*, *Phacellocephora camtschatica*, and *Staurophora mertensi*. Biomass is calculated for each species and compared across species, and oceanographic domains on the Bering Sea shelf.

Status and trends: The biomass in 2014 for the north remained consistent with a slight increase to previous years, and the dominant species in terms of biomass and abundance was *C. melanaster* (Figure 58). The south was our highest year on record for the 11 years of this survey. Despite anecodatal reports of large die offs early in the season, record catches were recorded. The coverage for the 2013 survey did not include anything below 60 °N. Unlike in 2012, half the total catch did not come from a single station but was spread out over the entire sampling grid. Yearly distributions throughout the sample grid for all species have been patchy. Despite uneven distributions throughout oceanographic domains, highest concentrations of all species were found to occur in the Middle Domain. Of the six species sampled, *C. melanaster* had the highest CPUE (catch per unit effort) for all years.

Starting in 2007, notable declines in jellyfish species compostion were observed for all taxa except *C. melanaster* and continued through 2012 (Figure 59). The dominant species continues to be *C. melanaster*, nearly quadrupling its biomass in 2012 compared to 2004. During 2007-2012, biomass of all other species have remained low in comparison to 2004-2006, suggesting that the trend for the region had shifted from multiple species to a single species dominant.There could possibly be a shift back to multiple taxa present in the future as seen by changes in the presence of other taxa in 2014.

Factors causing observed trends: The cause for these shifts in biomass and distribution do not seem to rely solely on physical ocean factors (temperature and salinity). These shifts could also be a result of environmental forcing earlier in the growing season or during an earlier life history stage (polyp), which may influence large medusae biomasses and abundances (Purcell et al., 2009).

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

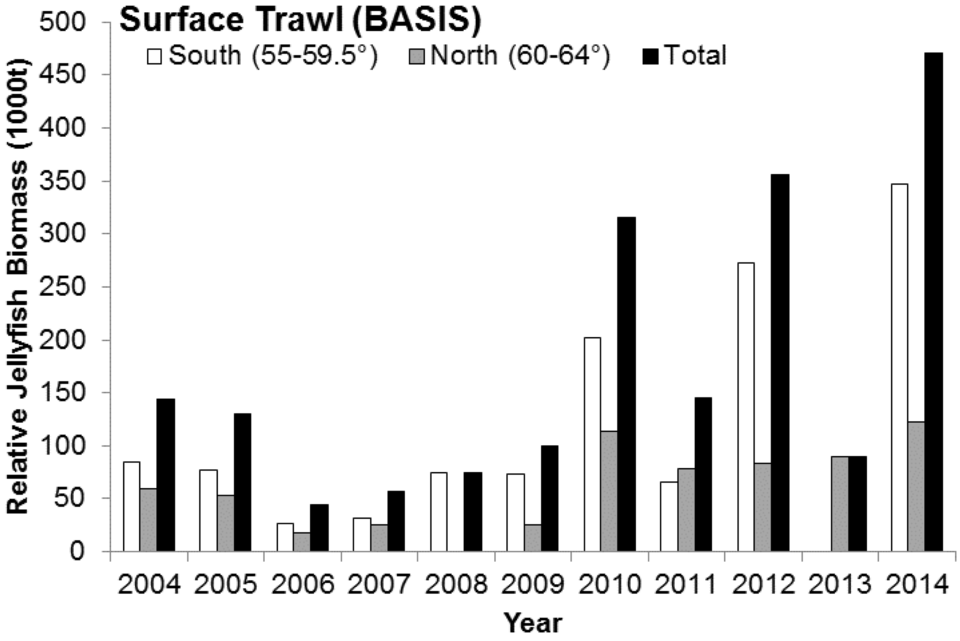

Figure 58: Total annual jellyfish biomass (1000 t) split by region. Includes combined species caught in surface trawls in the Eastern Bering Sea during August-October. Biomass was calculated using average effort per survey area in km^2 by year.

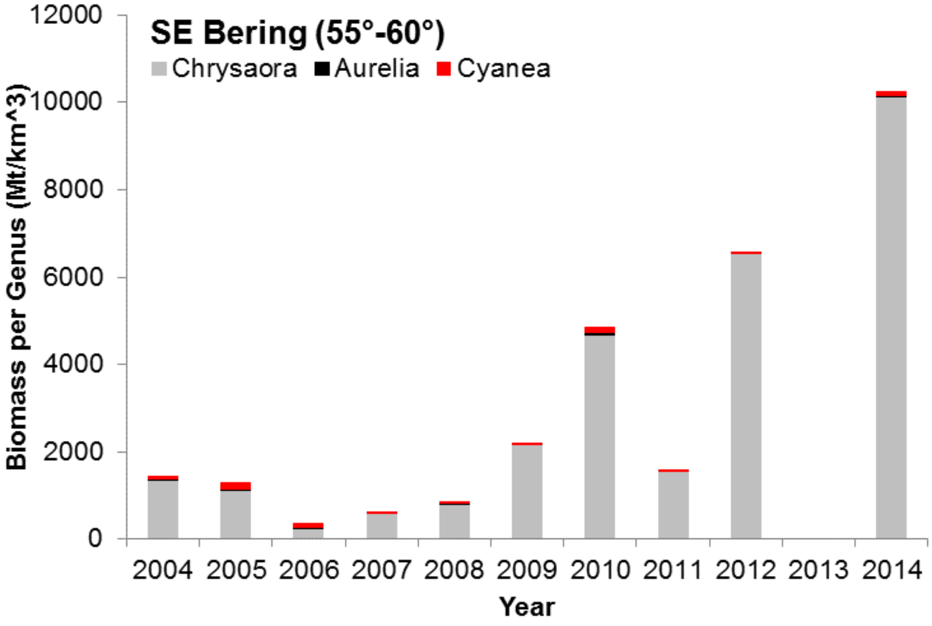

Figure 59: BASIS surface trawl jellyfish biomass (1000t) by genus for 2004-2014 in the southeastern Bering Sea during August -October. Biomass was calculated using average effort per survey area in km^3 by year. Survey spatial coverage was reduced to 60°N and below for all years.

Jellyfish - Gulf of Alaska bottom trawl survey

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Last updated: October 2015

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. 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. 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 central and eastern GOA than in other areas (Figure 60). The frequency of occurrence in trawl catches is generally high across all areas, but has been variable. Jellyfish catches in the western GOA have been uniformly low. Jellyfish catch in the central GOA during the last two surveys have been the highest since 1990. Jellyfish catches in the eastern GOA have also been increasing over the last two surveys.

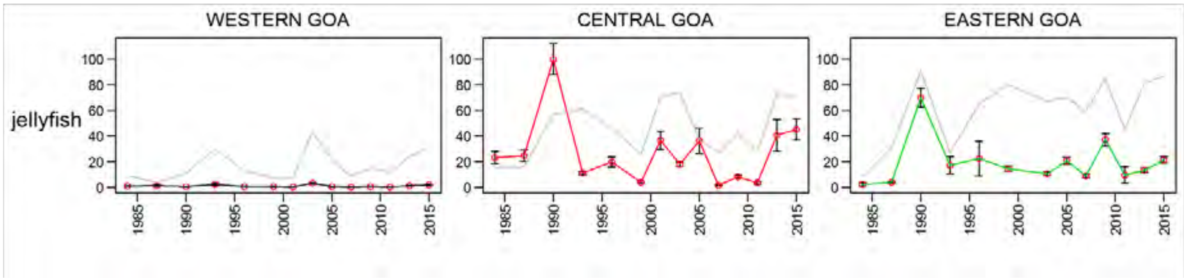

Figure 60: Relative mean CPUE of jellyfish species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2015. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

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 provide limited information about abundance or abundance trends for jellyfish due to problems in catchability. Therefore, the indices presented are likely of limited value to fisheries management.

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

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Last updated: September 2015

Description of indicator: Jellyfish sampling was incorporated during the Gulf of Alaska Project starting in 2011 and continuing through 2015. All jellyfish medusae caught in the surface trawl (top 18-20 m of the water column) are sorted by species and subsampled for bell diameter and wet weight. Eight species are commonly caught with the surface trawl (Can-trawl net with a 1.2 cm mesh liner in the cod-end) in the eastern Gulf of Alaska (GOA): *Aequorea* sp., *Chrysaora* spp., *Cyanea capillata*, *Aurelia labiata*, *Phacellocephora camtschatica*, *Hormiphora* sp., *Staurophora mertensi* and *Salpa* spp. Biomass is calculated for each species and compared across genus.

Status and trends: The biomass in 2014 was the largest for the four years of collected jellyfish catch data (Figure 61). This significant increase was consistent with the southeastern Bering Sea in 2014 which documented the largest catches on record for the Bering Aleutian Salmon International Surveys (BASIS) surveys (see 141). *Aequorea* and *Chrysaora* are the top two genera in terms of catch and abundance observed in the eastern GOA (Figure 62). One striking difference with the GOA survey data is the diversity in species seen verses the Bering BASIS surveys which have been single species dominant by *Chrysaora melanaster* for almost a decade.

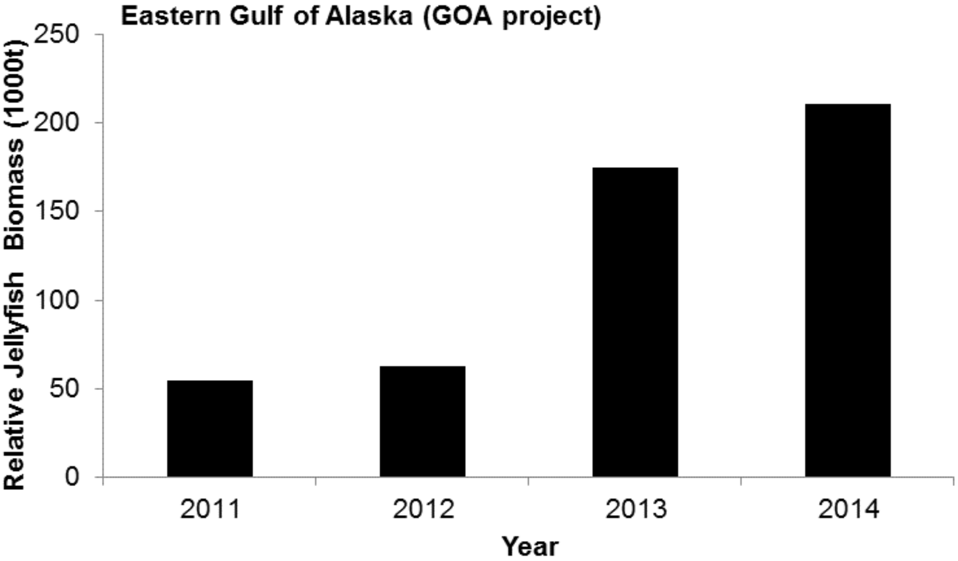

Figure 61: Total annual jellyfish biomass (1000 t) for eastern Gulf of Alaska region. Includes combined species caught in surface trawls in the Gulf of Alaska during June-August. Biomass was calculated using average effort per survey area by year.

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

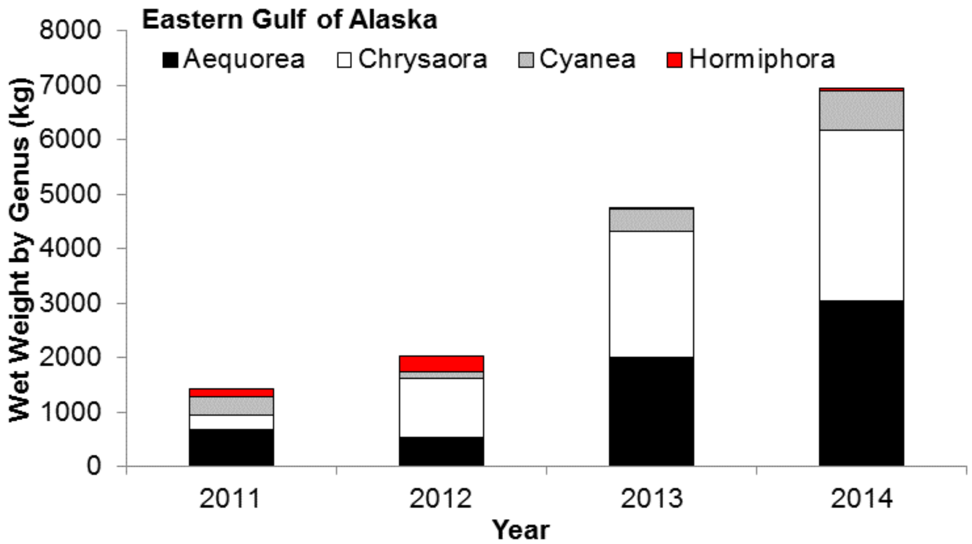

Figure 62: The Gulf of Alaska Project total surface trawl catch of jellyfish (wet weight) by genus for 2011-2014 during July-August. Chosen genera was based on the top four most encountered species during the survey.

jellyfish in general in the GOA.

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

Ichthyplankton

Gulf of Alaska Ichthyoplankton Abundance Indices 1981-2013

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Last updated: August 2015

Description of indicator: The Alaska Fisheries Science Center's (AFSC) EcoDAAT Database includes data from collections in the Gulf of Alaska (GOA) from 1972 to the present and with annual sampling from 1981-2011 and biennial sampling thereafter. Since 1985 these collections have been part of AFSC's recruitment processes research under the Ecosystems and Fisheries Oceanography Coordinated Investigations Program (EcoFOCI). The primary sampling gear used for these collections is a 60-cm bongo sampler fitted with 333 or 505-m mesh nets and oblique tows are carried out mostly from 100 m depth to the surface or from 10 m off bottom in shallower water (Matarese et al., 2003, Ichthyoplankton Information System `http://access.afsc.noaa.gov/ichthyo/index.cfm`). Historical distribution of sampling effort extends from the coastal area to the east of Prince William Sound southwestwards along the Alaska Peninsula to Umnak Island, covering coastal, shelf and adjacent deep water but has been most intense in the vicinity of Shelikof Strait and Sea Valley during mid-May through early June (Figure 63). From this area and time, a subset of four decades of data has been developed into a time-series of ichthyoplankton species abundance (after Doyle et al., 2009)) and it is now updated through 2013 (Table 5). Although there is a potential confounding factor from variation in timing of surveys over the time-series, the shift in the median survey date is less than a week except for 2011 when it was +8.5 days and all sampling was carried out in early June.

Status and trends: Historical trends in late spring abundance are presented for the most abundant larval taxa in the GOA, representing commercially and ecologically important species (Figure 64). The time-series extends from 1981 through 2013 with no data for 1984 and 1986. No sampling was carried out in 2012, but an extensive survey took place in 2013. Mean abundance values are normalized over the time-series. Trends in abundance of these species throughout the time series have been previously explored and investigated in relation to time-series of atmospheric and oceanographic variables on both the ocean basin and local scales (Doyle et al., 2009; Doyle and Mier, 2012). Abundance of walleye pollock larvae displayed a moderately positive anomaly for 2010, a slightly negative response in 2011 and then a very high positive anomaly in 2013. The abundance of larvae in 2013 was the second largest of the time series after 1981 (Mean catch per $10m^2 = 2601.442$ in 1981 vs. mean catch per $10m^2 = 1626.114$ in 2013). For rockfish larvae, a moderate positive anomaly in 2010 was followed by a very high positive anomaly in 2011 and an even higher one in 2013. Pacific cod also showed a high positive anomaly in 2013. For flatfishes in 2013, moderately positive anomalies occurred in starry flounder, northern and southern rock sole and Pacific halibut while moderately negative anomalies occurred in flathead sole and arrowtooth flounder.

Table 5: Survey schedule and number of stations sampled within the chosen study area (Figure 63) from which the late-spring time-series of larval abundance indices were calculated. Median survey shift = number of days difference (+/-) between a particular year's median sampling survey date and the time-series median survey date (Julian Day 148).

Year	Cruise	Dates	Median survey shift	No. Stations
1981	3SH81	May 23-28	-4	34
	4MF81	May 21-24		59
1982	2DA82	May 23-28	-1	32
1983	1CH83	May 21-28	-2.5	52
1985	2PO85	May 23 - June 1	0	55
1987	3MF87	May 19-23	-6	40
1988	4MF88	May 21 - June 6	2	149
1989	4MF89	May 29 - June 5	4.5	95
1990	4MF90	May 30 - June 5	4	102
1991	4MF91	May 19-24	-6.5	70
1992	4MF92	May 18-26	-4.5	105
1993	5MF93	May 27 - June 1	0.5	74
1994	6MF94	May 24 - June 1	0	98
1995	8MF95	May 22-28	-3	77
1996	8MF96	May 25-31	1	96
1997	8MF97	May 24-30	-1	94
1998	5MF98	May 22-28	-2	95
1999	2WE99	May 25 - June 1	1	67
	5MF99	May 26-31		25
2000	6MF00	May 28 - June 2	3.5	81
2001	3MF01	May 27-31	1	78
2002	4MF02	May 27-30	0	59
2003	5MF03	May 28 - June 1	1.5	72
2004	5MF04	May 23 - June 3	1.5	84
2005	6MF05	May 22 - June 3	0	85
2006	4MF06	May 22 - June 1	-1	81
2007	5MF07	May 20-28	-4	79
2008	4DY08	May 24-30	-1	82
2009	4DY09	May 28 - June 6	4.5	83
2010	3DY10	May 23-28	-1	83
2011	2DY11	June 2-7	8.5	51
2013	DY 13-06	May 17 - June 1	-3.5	109
Total	Total	Range		Total
30	32	May 17 - June 7		2246

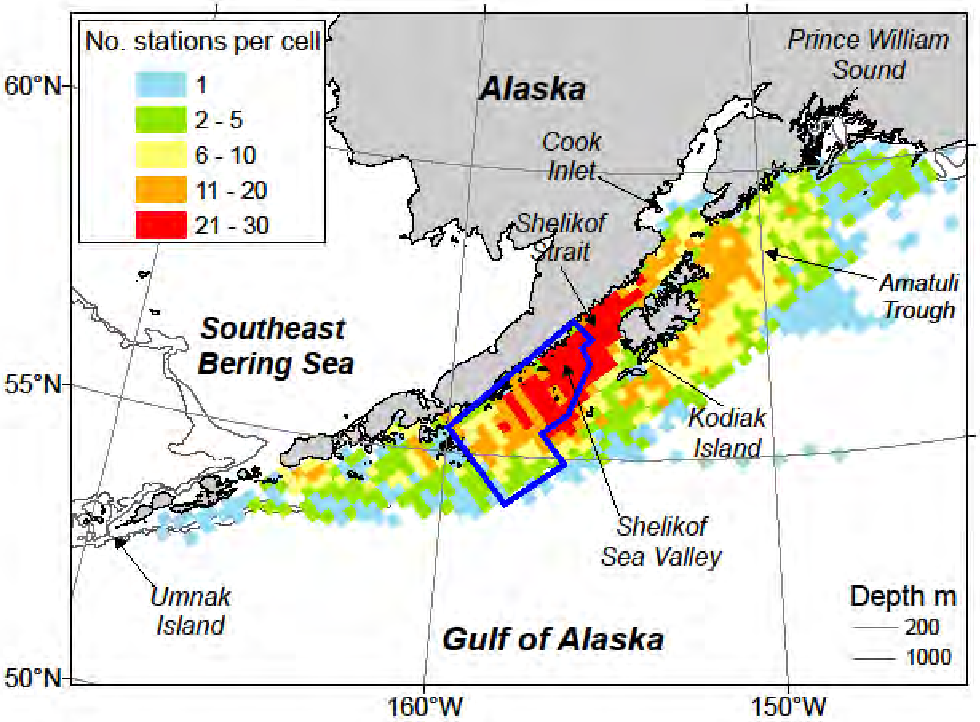

Figure 63: Distribution of ichthyoplankton sampling in the Gulf of Alaska by NOAA's Alaska Fisheries Science Center using a 60 cm frame bongo net. Sampling effort is illustrated by the total number of stations sampled in 20 km^2 grid cells over these years. A late spring time-series of mean abundance of ichthyoplankton species has been developed for the years 1981-2011, from collections in the polygonal area outlined in blue where sampling has been most consistent during mid-May through early June.

Factors influencing observed trends: Similarities in response to environmental forcing were apparent among species that display similarities in patterns of early life history exposure to the environment (Doyle et al., 2009). For instance, the deepwater spawners, northern lampfish, arrowtooth flounder, and Pacific halibut, were most abundant in the study area during the 1990s, in association with enhanced wind-driven onshore and alongshore transport. Years of high abundance for the late winter to early spring shelf spawners Pacific cod, walleye pollock, and northern rock sole were associated with cooler winters and enhanced alongshore winds during spring. High larval abundance for spring-summer spawning rockfish species and southern rock sole seemed to be favored by warmer spring temperatures later in the time-series.

The 2013 time series data suggest that environmental conditions in the Gulf of Alaska favored high abundances of certain species of fish larvae in May 2013 (7 out of 12 show positive anomalies, the remaining 5 are neutral to slightly negative - see Figure 64). Increases in observed abundances across some species in that year may be due to: 1) circulation features that favored retention of larvae over the shelf, indeed, satellite-tracked drifter trajectories indicate the presence of eddies in the region in spring (Figure 65), 2) improved growth and survival mediated by moderate temperature (see Dougherty, this document, for survey temperatures in 2013 and 2015), and 3) robust feeding conditions (NPRB/GOAIERP zooplankton data analyses in progress, Hopcroft personal communication). More information on factors influencing larval abundance and distribution will be made available through the GOA IERP Synthesis program (2015-2018).

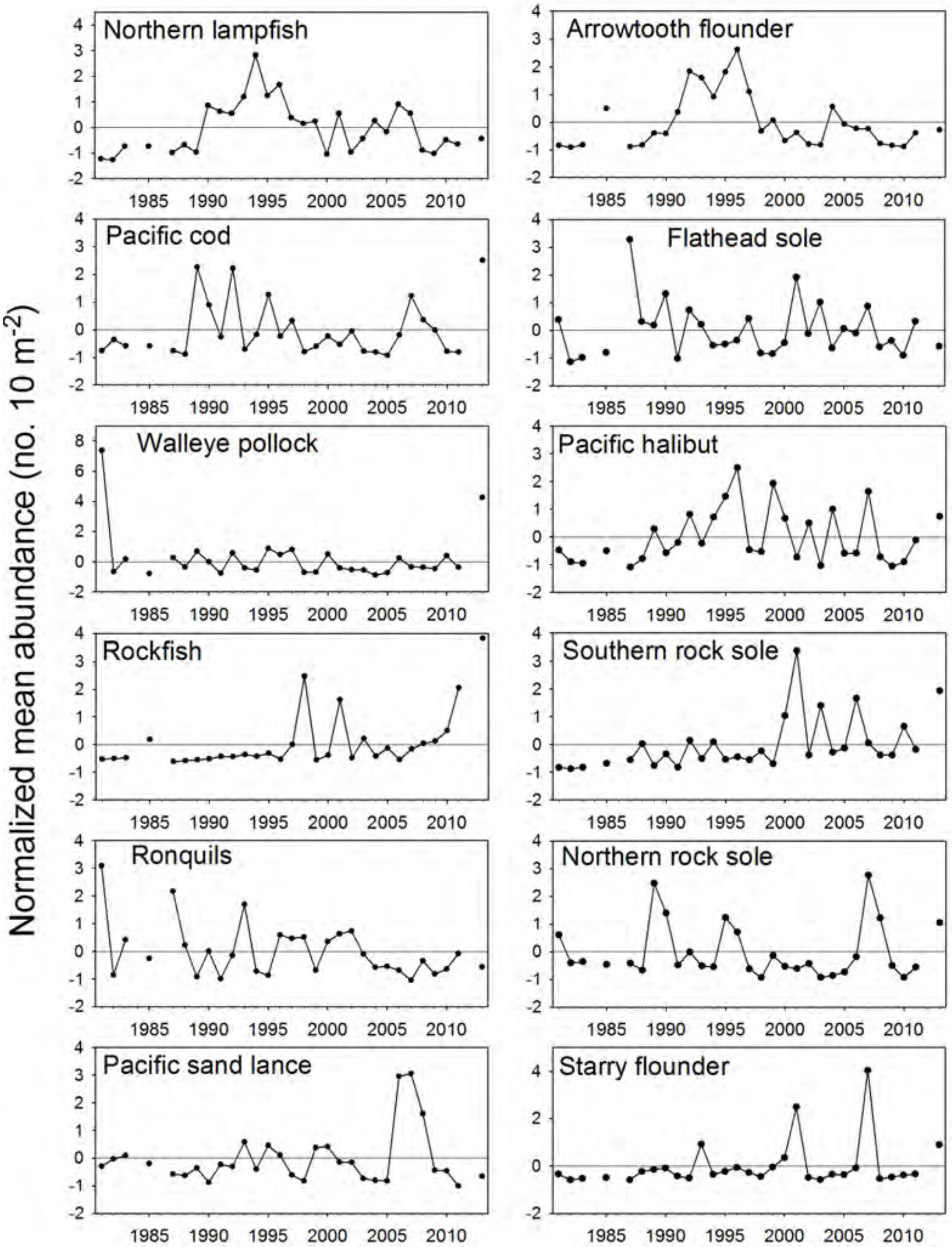

Figure 64: Interannual variation in late spring larval fish abundance for the most abundant species in the Gulf of Alaska. For each year, the larval abundance index is expressed as the log10 of mean abundance (no. 10 m^{-2}+1) standardized by the time-series mean and standard deviation. No data are available for 1984, 1986, and 2012.

Implications: The 2013 time series data suggest that environmental conditions in the Gulf of Alaska favored high abundances of larvae for gadids, rockfish, and several species of flatfish in May 2013. However, examination of the stock assessment of age-1 individuals derived from the 2013 year class indicates average or even poor recruitment to age-1 of selected midwater species (pollock, cod) (`http://www.afsc.noaa.gov/refm/stocks/assessments.htm`). This suggests density-dependent

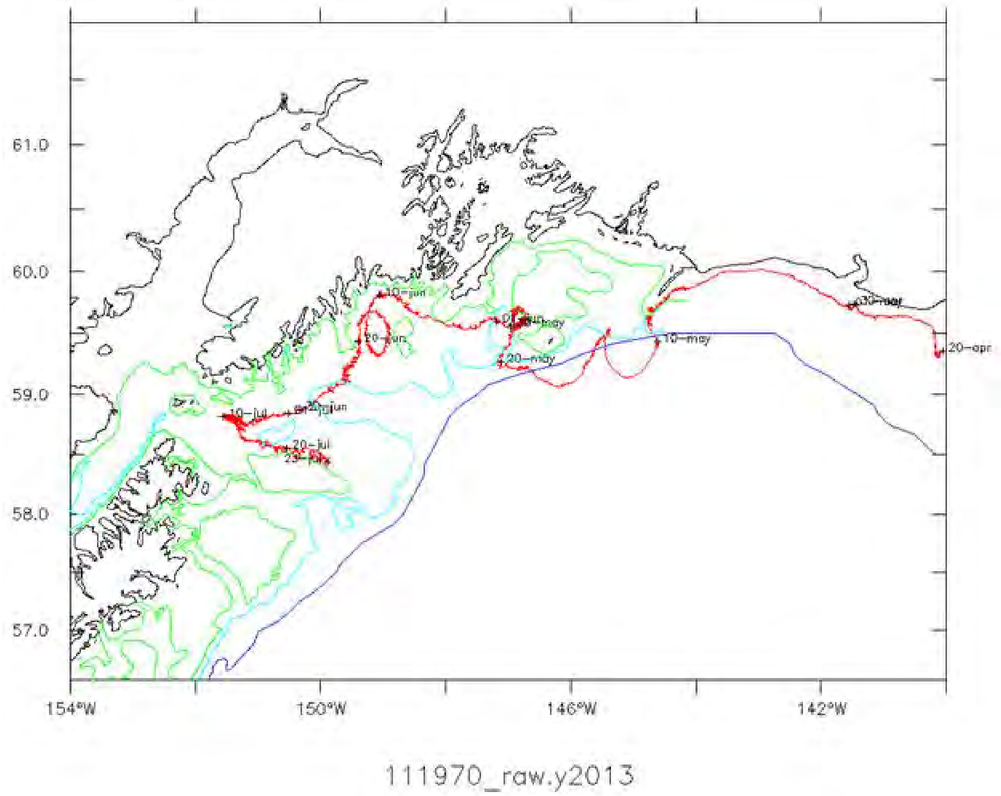

Figure 65: Satellite-tracked drifter drouged at 40m depth. Trajectory indicates on-shelf retention in the central GOA in 2013.

regulation of the post-larval or juvenile population, an observation that is consistent with current understanding of recruitment modulation in these taxa. Continued examination of larval gadids is recommended however, as extremely low larval abundances may be harbingers of poor recruitment (see Dougherty, this issue) even though high larval abundances do not necessarily imply a robust year class. Similar examination of selected flatfish species (Northern rock sole, Southern rocksole, flathead sole)) demonstrate species-specific recruitment trends to age-1 consistent with observations made during the larval survey (Figure 64). Data from the Bering Sea suggest wind-driven advection of larval flatfish stages is linked to year-class strength (Wilderbuer et al., 2013). As such, we will increase effort to examine the relationships between flatfish larval densities, climate variables, and recruitment to determine mechanisms underlying variability in cohort strength in the Gulf of Alaska and determine whether viable year-class indices may be developed.

Forage Fish

There are no updates to forage fish indicators in this year's report. See the appendix for a list of indicators not updated, and see the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Herring

Togiak Herring Population Trends

Contributed by Greg Buck, Alaska Department of Fish and Game
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Last updated: September 2015

Description of indicator: The biomass of Pacific herring occurring in the Togiak District of Bristol Bay has been tracked through aerial surveys since the late 1970s using methods described by Lebida and Whitmore (1985). An age-structured analysis (ASA) model is used to forecast biomass (Funk et al., 1992; Zheng et al., 1993). This model uses age composition information collected from the fishery. While we don't believe that herring are fully recruited into the fishery until around age-8, the model takes this into account and provides an estimate of all age classes back through age-4 (Figure 66). While we believe that this estimate of age-4 abundance is a reasonably valid picture of recruitment trends in this population, we also believe that the model has a tendency to over hindcast recruitment in the early 1980s due to factors that include limited data from that period.

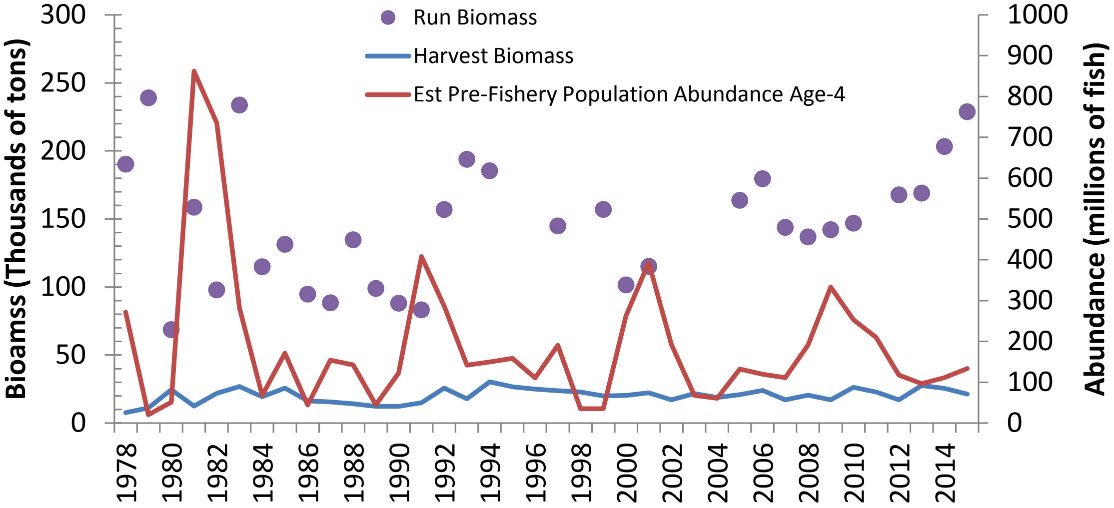

Figure 66: Observed total run and harvest biomass (hundreds of tons) with estimated abundance of age 4+ herring (millions of fish), for Pacific herring in Togiak District of Bristol Bay, Alaska 1978 - 2015.

Status and trends: The largest biomass observed in Togiak District of Bristol Bay occurred in 1979 when 239,022 tons was estimated while the smallest occurred in 1980 with 68,686 tons (Figure 66). In 2015 we observed 228,807 tons which approximates the most recent 10-year average and 103% of the most recent 20-year average (Buck, In prep).

An active sac roe fishery is conducted on this population, primarily with gillnet and purse seine gear. A small spawn on kelp quota is allowed but has not been utilized since 2003. The sac roe fishery harvested 28,782 tons in 2015 which is 127% of the 10-year average and 131% of the 20-year average (Buck, In prep).

Factors causing observed trends: Pacific herring recruitment is both highly variable and cyclic with large recruitment events occurring roughly every 8 to 10 years in this population. Fish from the most recent large recruitment event began to show up in the commercial harvest around 2009 at age-4. Williams and Quinn (2000) demonstrate that Pacific herring populations in the North Pacific are closely linked to environmental conditions particularly water temperature. We believe that closer examination of environmental conditions such as sea surface temperature, air temperature, and Bering Sea ice cover specific to the Bristol Bay area may increase our understanding of the recruitment process at play in this population.

Implications: Herring are an important forage fish for piscivorous fish, seabirds, and marine mammals as well as the basis for a roe fishery. The cyclic nature of recruitment into this population has implications for predators and prey of Pacific herring as well as the fishery. The Alaska Department of Fish and Game consider this population healthy and sustainable at current harvest levels.

Southeastern Alaska Herring

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Last updated: October 2015

Description of indicator: Pacific herring (*Clupea pallasi*) populations in southeastern Alaska are monitored by the Alaska Department of Fish and Game. Populations are tracked using spawn indices. Stock assessments that combine spawn indices with age and size information have been conducted each fall by the Alaska Department of Fish and Game for nine spawning areas in southeastern Alaska for most years since 1980. The magnitude and regularity of spawning in these areas has warranted annual stock assessment surveys and potential commercial harvests at these locations during most of the last 30 years. Although spawning occurs at other locales throughout southeastern Alaska, little or no stock assessment activity occurs at these locations other than occassional aerial surveys to document the miles of spawn along shoreline. Spawning at the nine primary sites for which regular assessments are conducted probably accounts for the majority of the spawning biomass in southeastern Alaska in any given year.

Status and trends: Herring spawning biomass estimates in southeastern Alaska often change markedly from year to year, rarely exhibiting consistent, monotonic trends (Figures 67, 68). Over the period 1980 through 2014, some stocks have undergone increasing trends (Sitka Sound, Craig, Seymour Canal, Hoonah Sound), while others have declined (Kah Shakes/Cat Island, Lynn Canal not shown in figures), and yet others have exhibited no obvious trend (West Behm Canal, Hobart Bay/Port Houghton, Tenakee Inlet, Ernest Sound). Although the estimated total mature herring biomass in southeastern Alaska has been at or above the long-term (1980-2014) median of 91,281 tons since 1997 (2014 total is 95,089 tons), a decrease in biomass has been observed since the peak around 2011 (Figure 69). The most dramtic drop in biomass has been observed in Hoonah Sound where the mature biomass dropped from 14,664 tons to 412 tons in just two years. It is apparent that the herring population in southeastern Alaska has come down from a period of high productivity during about 2005-2011, with mature biomass in most areas showing a downward trajectory through 2014 (Figure 1a). The herring biomass in Sitka Sound continues to be by far the highest in the region. Since 1980, herring biomass near Sitka has contributed between 37% and 73% (median of 58%) of the total estimated annual mature biomass among the nine surveyed spawning locations. Excluding the Sitka biomass from the combined estimate, the southeastern Alaska herring biomass in 2014 dropped below the median (41,010 tons over 1980-2014) for the first time since 2003 (Figure 69).

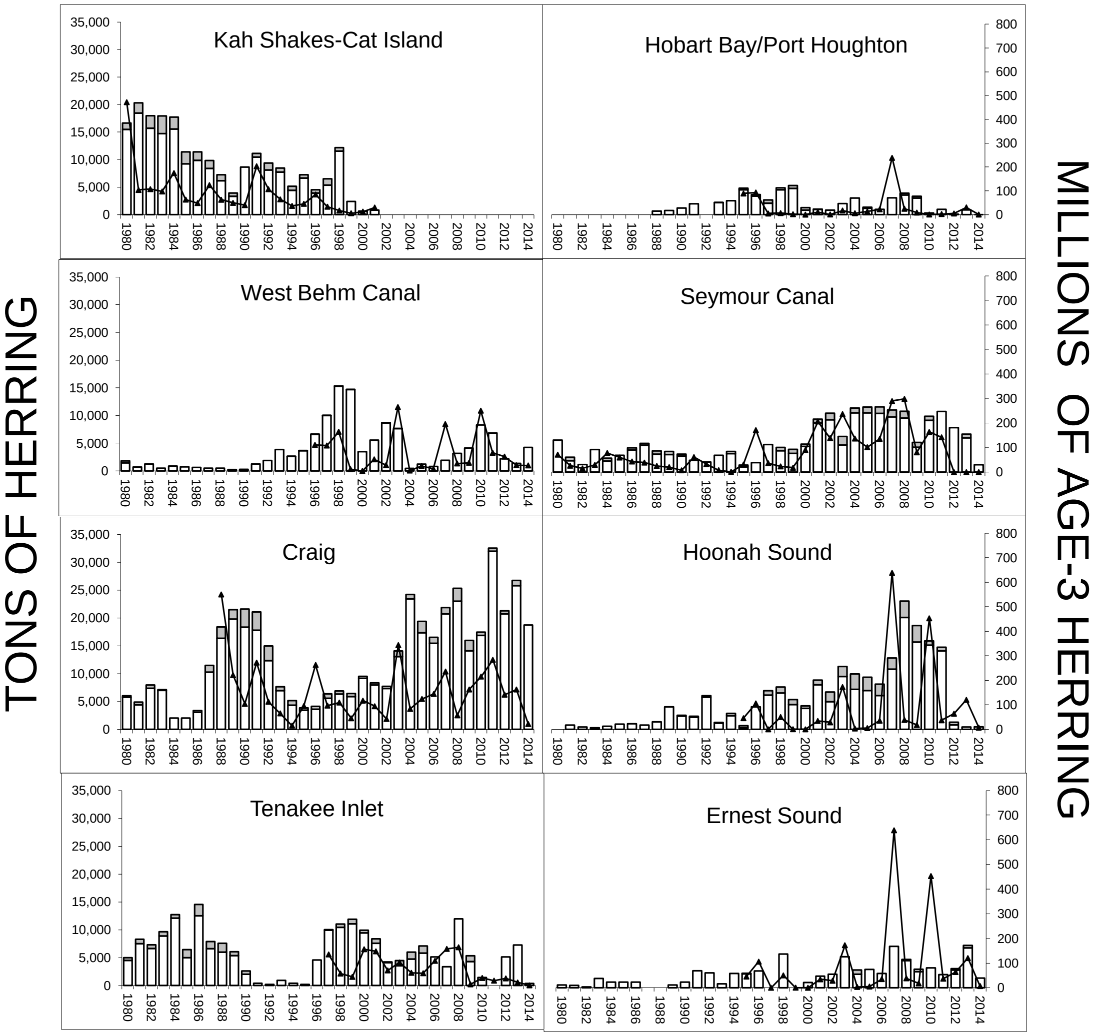

Figure 67: Estimated post-fishery mature herring biomass (white bars in tons), catch (gray bars in tons) and age-3 abundance (black line) at eight major spawning locations in southeastern Alaska, 1980-2014. Estimates of age-3 abundance for Tenakee Inlet were unavailable by time of publication.

In southeastern Alaska, the first potential age of recruitment to the mature population of herring is three years old. Estimated abundance of total age-3 herring (used to gauge recruitment) has varied greatly among and within stocks over time (Figures 67, 68). The number of age-3 herring has been estimated for Seymour Canal and Sitka for most years since 1980, for Craig in every year since 1988, for Tenakee Inlet every years since 1997, and for West Behm Canal, Ernest Sound, Hobart Bay-Port Houghton, and Hoonah Sound for most years since 1995. An oscillating recruitment pattern with

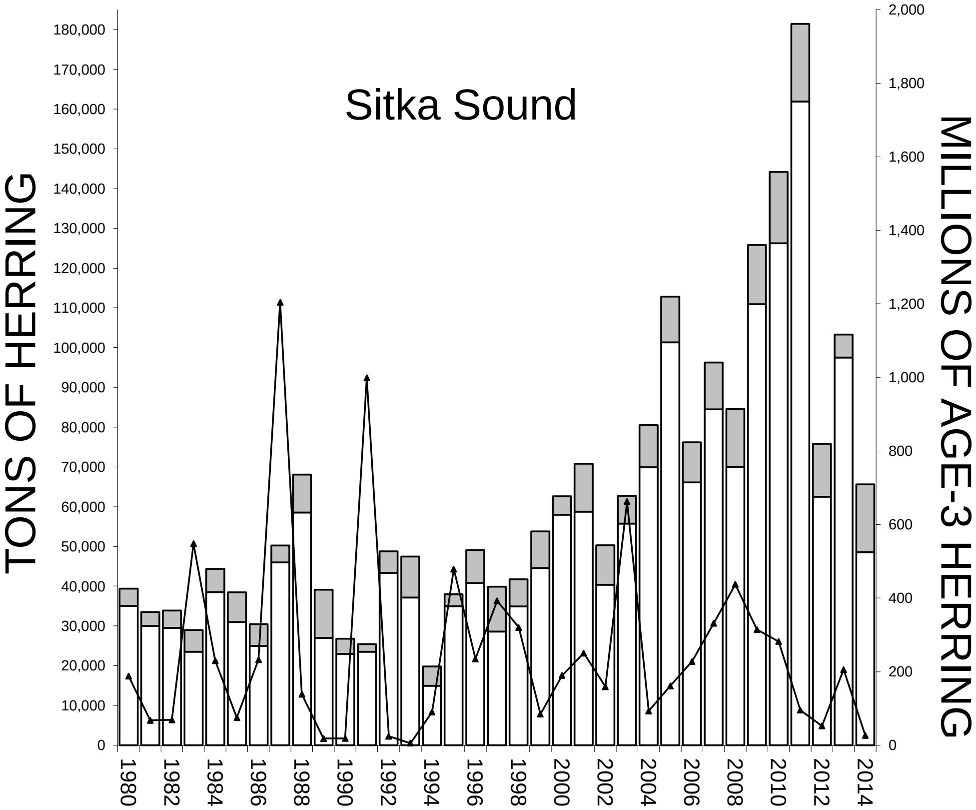

Figure 68: Estimated post-fishery mature herring biomass (white bars in tons), catch (gray bars in tons) and age-3 abundance (black line) at Sitka Sound spawning location in southeastern Alaska, 1980-2014.

strong recruit classes every three to five years was observed for Sitka Sound and Craig stocks prior to 1997. For Sitka Sound, the stock with the greatest annual recruit abundance, oscillating years of extremely high and low recruit abundance in the 1980s and early 1990s changed to more consistent, intermediate recruit abundances in the mid-1990s through 2014 (Figure 68). Estimates of age-3 herring abundance in 2014 were very low for all spawning areas (Figures 67, 68).

Factors influencing observed trends: The generally increasing long-term trends of biomass observed for many herring stocks in southeastern Alaska, particularly over the last decade, are thought to be at least partially a result of higher survival rates among adult age classes. Age-structure analysis (ASA) modeling of several herring stocks in the region suggests that changes in survival during the late 1990s are partially responsible for the observed increasing and high herring abundance levels. For example, for the Sitka stock, during the period 1980-1998, survival has been estimated to be 58%, while for the period 1999-2014 survival is estimated at 76%. These shifts in survival coincide with time periods of change in ocean conditions, as indexed by the Pacific Decadal Oscillation (PDO) (predominately positive phase in the former and predominantly negative phase during the latter time periods). There has been some speculation and debate about the extent to which commercial harvests may have contributed to marked declines in estimated abundance and/or localized changes in herring spawning sites in some areas of southeastern Alaska, notably Revillagigedo Channel (Kah Shakes/Cat Island) and Lynn Canal. In the Revillagigedo Channel area, significant spawning and a fishery occur at Annette Island, a site outside the management jurisdiction of the State and from which limited data are gathered by the department. Although

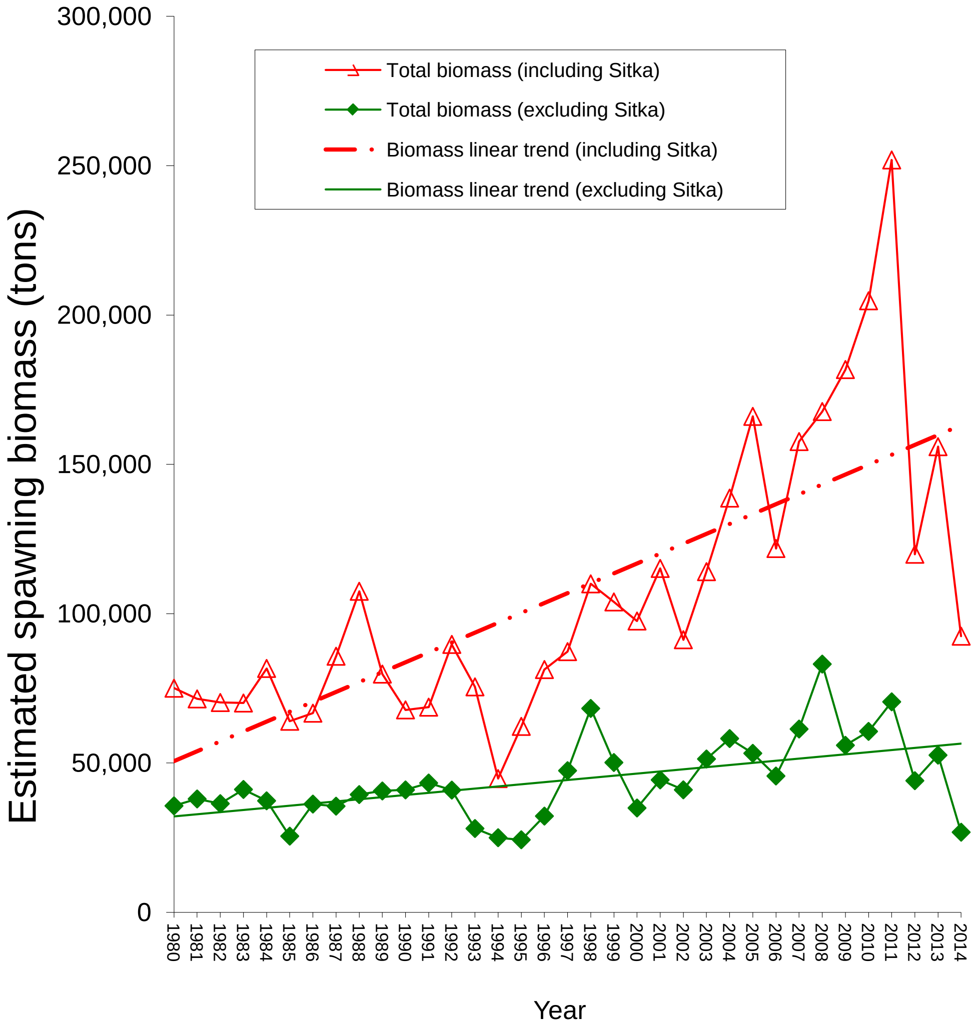

Figure 69: Estimated combined annual mature herring biomass (including and excluding Sitka) at major southeastern Alaska spawning areas, 1980-2014.

spawning activity at the Kah Shakes and Cat Island sites in Revillagigedo Channel has declined in recent years, this decline may be at least partially attributable to a shift of herring spawning grounds within the Annette Island Reserve, bordering Revillagigedo Channel. Long-term surveys of spawning biomass have not been conducted in the Lynn Canal spawning area long-term surveys of spawning biomass have not been conducted. Reasons for the biomass decline in the area are unknown but possibilities include commercial harvest, increased predation by marine mammals and fish, and shoreline development on or near spawning grounds. **Implications:** The harvest rate policy in southeastern Alaska allows for harvest rates ranging from 10 to 20% of the forecasted spawning biomass when the forecast is above a minimum threshold biomass. The rate of harvest depends upon the ratio of forecast to threshold (the more the forecast exceeds the threshold, the higher the harvest rate). Consequently, catch limits have varied in direct proportion to forecasted biomass (Figures 1a,1b). The lower abundance of mature herring observed at some spawning areas will likely reduce commercial harvest opportunity in the region due to lower guideline harvest levels. However, the short life-span of herring and the natural volatility of stock levels, particularly of smaller-sized stocks, make it difficult to speculate on long-term fishery implications. The relationship between PDO phase and herring survival suggests that survival may decline if the PDO shifts to a positive (i.e., warm) phase, however this is an area that requires further research.

Salmon

Historical and Current Alaska Salmon Trends

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Last updated: August 2015

Description of indicator: This contribution provides historic and current catch information for salmon of the Bering Sea and Gulf of Alaska and takes a closer look at two stocks that could be informative from an ecosystem perspective: Bristol Bay sockeye salmon and Prince William Sound hatchery pink salmon. This contribution summarizes available information that is included in current Alaska Department of Fish and Game (ADF&G) agency reports (Munro and Tide, 2014).

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

Status and trends: Catches from directed fisheries on the five salmon species have fluctuated over the last 35-40 years (Figure 70) but in total have been generally strong. According to ADF&G, total salmon commercial harvests from 2014 totaled 157.9 million fish, which was about 25 million more than the preseason forecast of 132.6 million. The 2014 total salmon harvest is little more than half the 2013 total harvest of 282.9 million which was bolstered by the catch of 226.3 million pink salmon. In 2015 ADF&G is forecasting a substantial increase in the total commercial salmon catch to 220.9 million fish, due to an expected increase in the number of pink salmon. Projections for 2016 are not yet available.

Bering Sea Chinook salmon abundance in the Arctic-Yukon-Kuskokwim region has been declining since 2007 and 2014 Chinook salmon harvests were below average. For the seventh consecutive year, no commercial periods targeting Chinook salmon were allowed on the mainstem of the Yukon River. In the Kuskokwim Area, Chinook salmon abundance was poor and only 8 of 13 escapement goals were met. In Bristol Bay, Chinook salmon were primarily caught during directed sockeye periods. The total 2014 Chinook salmon harvest in Bristol Bay was about 15,000 which is approximately 75% below the average for the last 20 years.

The 2014 harvest of 287,000 coho salmon in Bristol Bay was the largest coho harvest in the last 20 years. Coho salmon harvests were also above average in the Arctic-Yukon-Kuskokwim region. Chum salmon catches in Bristol Bay were below the recent 20 year average harvest, while harvests were above average in the Arctic-Yukon-Kuskokwim region.

The 2014 Bristol Bay sockeye salmon run of 41.1 million fish was 55% above the preseason forecast of

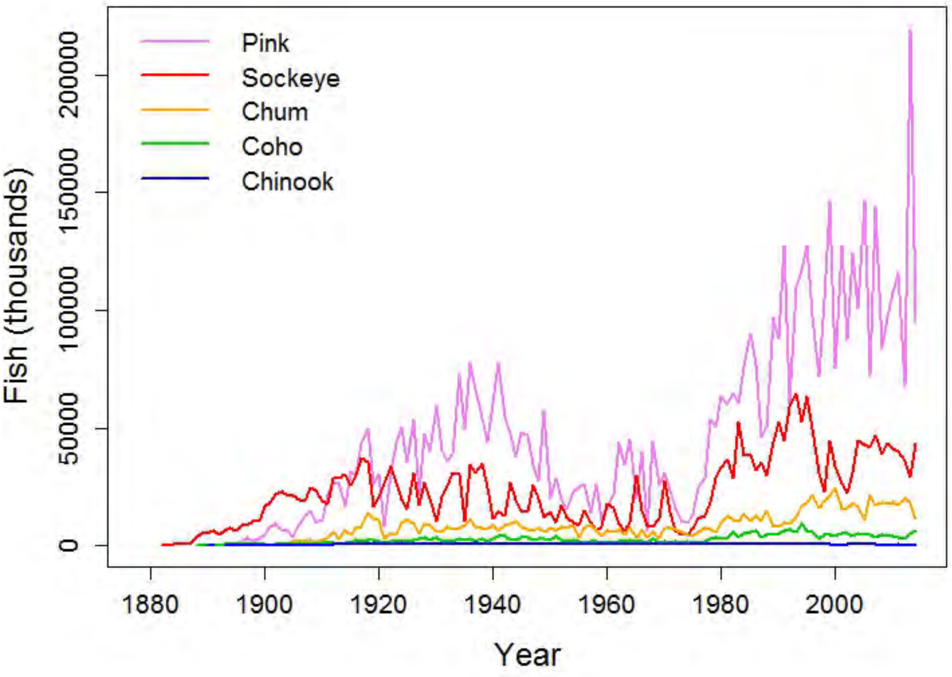

Figure 70: Alaska historical commercial salmon catches, 2014 values are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.)

26.6 million, and was 19% above the recent 20-year average (1994-2013) of 34.7 million. Historically, total runs to Bristol Bay have been highly variable, but in recent years, 2004-2011, sockeye salmon runs have been well above the long term mean (Figure 70). Run size decreased each year from 2009 to 2013, when the run size dipped below the long-term historical average run size of 32.4 million fish before rebounding in 2014. The forecast for 2015 Bristol Bay sockeye is for another above average run size similar to 2014 at 54 million. Preliminary information suggests that the 2015 forecast may have been low (Figure 71). Recruitment for most Bristol Bay sockeye salmon stocks was moderate to strong in the 1980s and into the mid-1990s. The number of returning adult sockeye salmon produced from each spawner increased dramatically for most Bristol Bay stocks, beginning with the 1973 brood year (>1979 return year) (Fair, 2003). Poor returns in 1996-98, however, suggested a return to a level of productivity similar to the pre-1978 period (Fair, 2003). Fish from the 1996-98 return years reared in the ocean when temperatures were above average, whereas cooler than average ocean temperatures characterized the pre-1978 period.

Gulf of Alaska In the Southeast/Yakutat region, 2014 salmon harvests totaled 49.8 million, which was 89% of the recent 10-year average harvest and 122% of the long-term average harvest. Pink salmon comprised 75% of the total number of salmon harvested in 2014. Since 2006 pink salmon returns have followed a cycle of strong odd years and weak even years and that pattern continued in 2014. The 2013 pink salmon harvest in the Southeast region reached a record high of 94.8 million. The total 2014 salmon harvest was 44% of the 2013 harvest. The salmon harvested in 2013 was the largest going back to 1962.

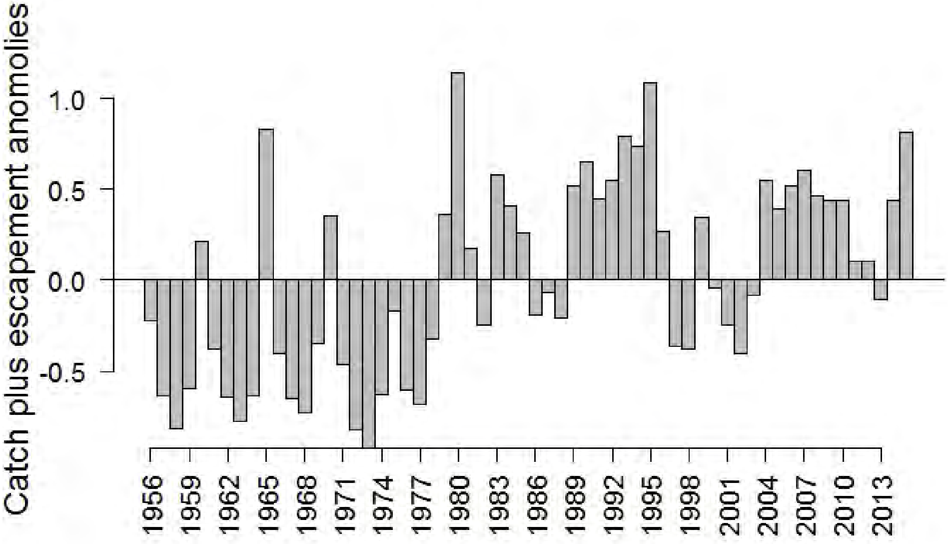

Figure 71: Historical catch plus escapement anomalies of Bristol Bay sockeye salmon, 1956-2015. Data provided by Charles Brazil (ADF&G). Note: the value for 2015 is preliminary and subject to revision.

In the Southeast/Yakutat region, the harvest of 428,000 Chinook salmon was the third highest over the previous 53 years, and was above the long-term average harvest and the recent 10-year average harvest. The coho salmon harvest of 3.8 million was also above both the long-term average harvest and the recent 10-year average. In contrast, the commercial harvest of 6.7 million chum salmon in the Southeast/Yakutat region was below the recent 10-year average harvest of 10.5 million.

In the Prince William Sound Area of the Central region, the 2014 total salmon harvest was 49.7 million fish, of which 44.3 million were pink salmon. This was the third largest even-year pink salmon harvest for the Prince William Sound Area. The catch of other salmon species in the Prince William Sound Area included 3.3 million sockeye, 1.5 million chum, 610,000 coho, and 11,000 Chinook. Historically, pink salmon catches increased in the late 1970s to the mid-1990s and have generally remained high in all regions in the last decade. Marine survival of Prince William Sound hatchery pink salmon does not appear to have shifted after the 1988/89 or the 1998/99 climate regime shifts (Figure 72). Marine survival dropped from 11.17% in 2010 (2008 brood year) to 4.34% in 2011 and 3.80% in 2012, but rose to 11.33% in 2013, an all-time high since 1979 (Wiese et al., 2015).

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

Bristol Bay sockeye salmon display a variety of life history types. For example, their spawning habitat is highly variable and demonstrates the adaptive and diverse nature of sockeye salmon in this area (Hilborn et al., 2003). Therefore, productivity within these various habitats may be affected differently depending upon varying conditions, such as climate (Mantua et al., 1997), so

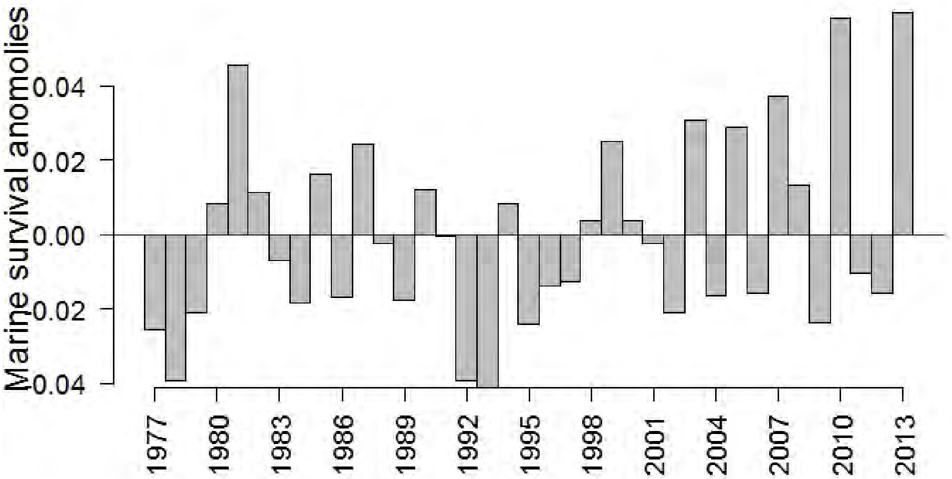

Figure 72: Marine survival of Prince William Sound hatchery pink salmon by year of return (brood year +2 years) from 1977 to 2013. Data reproduced from Sheridan et al. (2014).

more diverse sets of populations provide greater overall stability (Schindler et al., 2010). The abundance of Bristol Bay sockeye salmon may also vary over centennial time scales, with brief periods of high abundance separated by extended periods of low abundance (Schindler et al., 2006).

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

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

Implications: Salmon have important influences on Alaska marine ecosystems through interactions with marine food webs as predators on lower trophic levels and as prey for other species such as Steller sea lions. In years of great abundance, salmon may exploit prey resources more efficiently than their competitors. Springer and van Vliet (2014) recently demonstrated negative relationships between seabird reproductive activity and years of high pink salmon abundance. In addition, the dominant temporal pattern in kittiwakes reproductive success at the Pribilofs is negatively correlated with pink salmon abundance (this doc, p. 206, and Zador et al. (2013)). Directed salmon fisheries are economically important for the state of Alaska. The trend in total salmon catch in recent decades has been for generally strong harvests, despite annual fluctuations.

Forecasting Pink Salmon Harvest in Southeast Alaska

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Last updated: August 2015

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

To develop the pre-season pink salmon forecast, ecosystem metrics were obtained from stations sampled in the vicinity of Icy Strait (58°N, 135°W) by SECM research in coastal SEAK (Orsi et al., 2015). This locality is the principal northern exit route for seaward migrating juvenile salmon through SEAK to the GOA. Based on salmon origin information from coded-wire tags and thermally induced otolith marks, fish exiting this migration corridor are comprised of stocks originating predominately from SEAK. Temporally, oceanographic sampling occurred in May, June, July, and August, while surface trawling (0-20 m depth) for epipelagic fish species is conducted in the latter three months as fish move offshore.

The ecosystem indicators used for pre-season pink salmon forecast models consist of juvenile pink salmon abundance during trawl surveys and other associated biophysical metrics. The primary forecast model used is a step-wise regression of juvenile pink salmon abundance (trawl CPUE) in summer (June or July) compared to harvest the ensuing year (Wertheimer et al. 2014). Additional explanatory ecosystem variables in this regression model are used some years to better explain residual error in the relationship. A secondary complementary model uses a summed ranked approach of a broad suite of six ecosystem metrics, all significantly ($p<0.05$) correlated with harvest over the prior 17 year SECM time series: CPUE measures (two), peak migration month, pink salmon relative catch composition, predation impact index, and the summer North Pacific Index.

Status and trends: Based on ecosystem metrics, the pink salmon harvest to SEAK in 2015 is forecasted to be around 54 M fish, somewhat above the historical average. This above average forecast is actually moderate when considering the recent increases in abundance of the odd year pink salmon harvests in 2009, 2011, and 2013 which was 38.0, 58.9, and 94.7 M fish, respectively (Figure 73). Of all the large basin scale physical ecosystem metrics considered to influence SEAK pink salmon production, only the North Pacific Index (NPI, summer) was significantly correlated with harvest over the recent 19-yr time series, the remaining five significant ecosystem metrics were biological (juvenile pink salmon abundance, distribution, timing, and depredation, Figure 74).

Given the ecosystem conditions and SECM metrics sampled in 2014, the two best SECM forecast models for the 2015 SEAK pink salmon harvest are shown below in Table 6. Each forecast model value has an 80% bootstrap confidence interval shown in parentheses. The 2-parameter model is the best fit predictor for the relationship of the 19-year time series of SECM data parameters

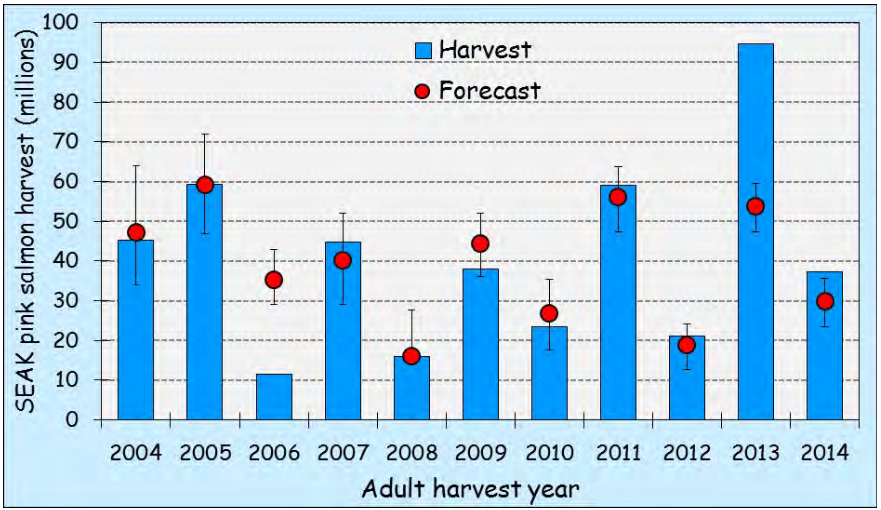


Figure 73: Previous SECM pink salmon pre-season forecast model predictions (with 80% confidence intervals) and actual SEAK harvests over the past 11 years. Harvest data from the SEAK pink salmon fishery still incomplete for 2015, and 2015 SECM surveys still ongoing for the 2016 forecast.

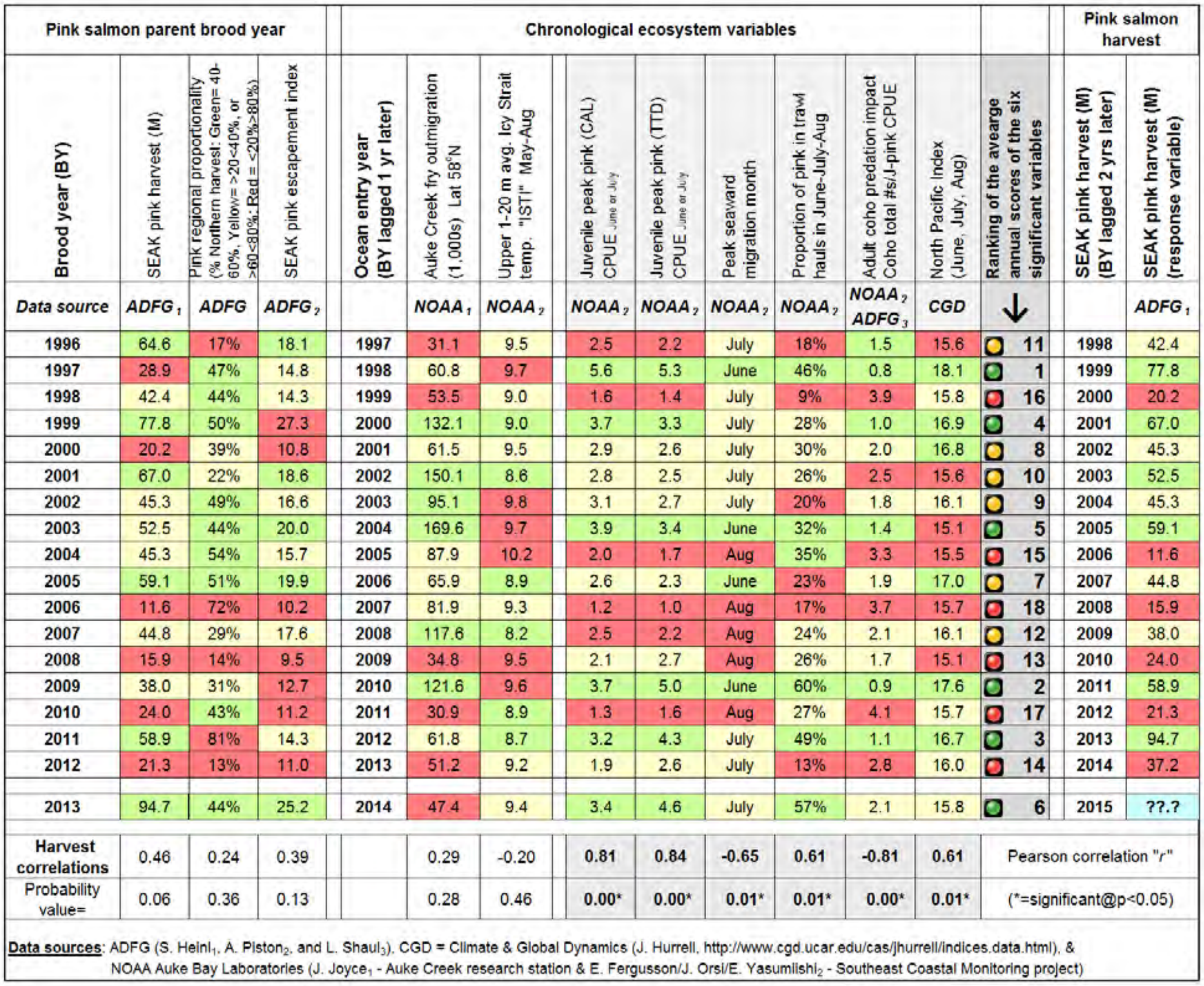
Table 6: The two best SECM pink salmon forecast models for the 2013 SEAK harvest.

2013 SECM pink salmon forecast models	Adj. R^2	AICc	P	Prediction for 2015
(1-parameter) Peak CPUE_{cal}	63%	143.0	<0.001	55.5 M
(2-parameter) Peak $\mathbf{CPUE_{cal}+ISTI_{20m\ temp}}$	74%	137.8	<0.001	**54.5 M (48-58)**

with subsequent SEAK pink salmon harvests from 1998 to 2014, based on the R2 and AICc. An alternative forecast is depicted in Figure 75.

A chronological set of ecosystem metrics associated with SEAK adult pink harvest over the 18-year SECM time series are shown in Figure 74. Note that in addition to the CPUE metrics, four other variables are significantly correlated with harvest (Peak migration month, %pink in June-July trawl hauls, the North Pacific Index, and Adult coho predation impact). Additionally, this matrix shows that anomalously low (red: 2000, 2006, 2008, 2012) or high (green: 1999, 2001, 2005, 2011, 2013) return years always flag 3-5 ecosystem indicators of the respective color signal in each row. For the 2015 forecast, however, there were no "red" ecosystem indicator flags and three "yellow" and "green" ecosystem indicator flags.

Factors influencing observed trends: Pink salmon year-class success has varied widely in SEAK, with annual harvests ranging from 3 to 95 M fish since 1960 (ADFG 2015). Pink salmon are an ecologically and economically important resource in SEAK, and in 2013 reached a record harvest of 95 M fish valued at over $125 M. These returns also show decadal abundance trends and alternating odd-even year brood line dominance patterns. This variability may result from dynamic ocean conditions or ecological interactions that affect juvenile salmon or overwintering adults above the transition domain in the North Pacific. Additionally, pink salmon production in SEAK is predominately derived from >97% wild stocks of varied run timings that originate from >2,000 anadromous streams throughout the region (Piston and Heinl, 2013). Pink salmon in SEAK are a key stock group proposed for monitoring in the North Pacific (Orsi et al., 2014).



Pink salmon parent brood year				Chronological ecosystem variables										Pink salmon harvest	
Brood year (BY)	SEAK pink harvest (M)	Pink regional proportionality (% Northern harvest: Green= 40-60%, Yellow= >20<40%, or >60<80%; Red = <20%>80%)	SEAK pink escapement index	Ocean entry year (BY lagged 1 yr later)	Auke Creek fry outmigration (1,000s) Lat 58°N	Upper 1-20 m avg. Icy Strait temp. "ISTI" May-Aug	Juvenile peak pink (CAL) CPUE June or July	Juvenile peak pink (TTD) CPUE June or July	Peak seaward migration month	Proportion of pink in trawl hauls in June-July-Aug	Adult coho predation impact Coho total #s/J-pink CPUE	North Pacific Index (June, July, Aug)	Ranking of the avearge annual scores of the six significant variables	SEAK pink harvest (M) (BY lagged 2 yrs later)	SEAK pink harvest (M) (response variable)
Data source	*ADFG*[1]	*ADFG*	*ADFG*[2]		*NOAA*[1]	*NOAA*[2]	*NOAA*[2]	*NOAA*[2]	*NOAA*[2]	*NOAA*[2]	*NOAA*[2] *ADFG*[3]	*CGD*	↓		*ADFG*[1]
1996	64.6	17%	18.1	1997	31.1	9.5	2.5	2.2	July	18%	1.5	15.6	🟡 11	1998	42.4
1997	28.9	47%	14.8	1998	60.8	9.7	5.6	5.3	June	46%	0.8	18.1	🟢 1	1999	77.8
1998	42.4	44%	14.3	1999	53.5	9.0	1.6	1.4	July	9%	3.9	15.8	🔴 16	2000	20.2
1999	77.8	50%	27.3	2000	132.1	9.0	3.7	3.3	July	28%	1.0	16.9	🟢 4	2001	67.0
2000	20.2	39%	10.8	2001	61.5	9.5	2.9	2.6	July	30%	2.0	16.8	🟡 8	2002	45.3
2001	67.0	22%	18.6	2002	150.1	8.6	2.8	2.5	July	26%	2.5	15.6	🟡 10	2003	52.5
2002	45.3	49%	16.6	2003	95.1	9.8	3.1	2.7	July	20%	1.8	16.1	🟡 9	2004	45.3
2003	52.5	44%	20.0	2004	169.6	9.7	3.9	3.4	June	32%	1.4	15.1	🟢 5	2005	59.1
2004	45.3	54%	15.7	2005	87.9	10.2	2.0	1.7	Aug	35%	3.3	15.5	🔴 15	2006	11.6
2005	59.1	51%	19.9	2006	65.9	8.9	2.6	2.3	June	23%	1.9	17.0	🟡 7	2007	44.8
2006	11.6	72%	10.2	2007	81.9	9.3	1.2	1.0	Aug	17%	3.7	15.7	🔴 18	2008	15.9
2007	44.8	29%	17.6	2008	117.6	8.2	2.5	2.2	Aug	24%	2.1	16.1	🟡 12	2009	38.0
2008	15.9	14%	9.5	2009	34.8	9.5	2.1	2.7	Aug	26%	1.7	15.1	🔴 13	2010	24.0
2009	38.0	31%	12.7	2010	121.6	9.6	3.7	5.0	June	60%	0.9	17.6	🟢 2	2011	58.9
2010	24.0	43%	11.2	2011	30.9	8.9	1.3	1.6	Aug	27%	4.1	15.7	🔴 17	2012	21.3
2011	58.9	81%	14.3	2012	61.8	8.7	3.2	4.3	July	49%	1.1	16.7	🟢 3	2013	94.7
2012	21.3	13%	11.0	2013	51.2	9.2	1.9	2.6	July	13%	2.8	16.0	🔴 14	2014	37.2
2013	94.7	44%	25.2	2014	47.4	9.4	3.4	4.6	July	57%	2.1	15.8	🟢 6	2015	??.?
Harvest correlations	0.46	0.24	0.39		0.29	-0.20	0.81	0.84	-0.65	0.61	-0.81	0.61	Pearson correlation "*r*"		
Probability value=	0.06	0.36	0.13		0.28	0.46	0.00*	0.00*	0.01*	0.01*	0.00*	0.01*	(*=significant@p<0.05)		

Data sources: ADFG (S. Heinl[1], A. Piston[2], and L. Shaul[3]). CGD = Climate & Global Dynamics (J. Hurrell, http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html), & NOAA Auke Bay Laboratories (J. Joyce[1] - Auke Creek research station & E. Fergusson/J. Orsi/E. Yasumiishi[2] - Southeast Coastal Monitoring project)

Figure 74: Matrix of ecosystem metrics considered for pink salmon forecasting. The ranges of values within each metric column are color-coded below, with the highest values in green, intermediate values in yellow, and the lowest values in red. The response variable of pink salmon harvest in Southeast Alaska (SEAK) is the right hand column and the grey column with stoplight colors shows the annual rank score by year.

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

Implications: These ecosystem indicators in concert suggest an above average pink salmon harvest in 2015. By virtue of their high numerical abundance and annual biomass, pink salmon are a keystone species in the epipelagic waters of the GOA ecosystem. The short one-ocean winter lifespan of this species and wide ocean distribution makes pink salmon an ideal ecological indicator of changing ocean conditions from climatic shifts. Consequently, understanding factors affecting year class strength of pink salmon annual cycles may help identify important trophic dynamics in the

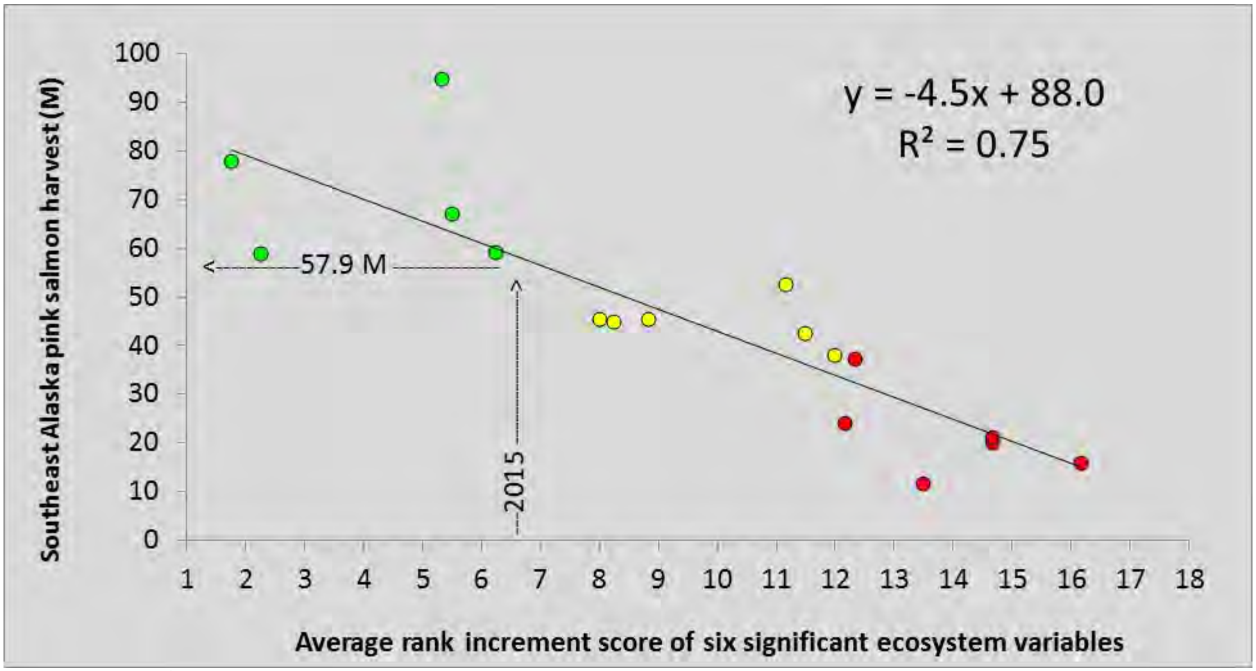


Figure 75: A complementary approach to forecasting pink salmon returns using a hind cast regression of the average ranks of the six significant ecosystem metrics and SEAK pink salmon harvest the ensuing year.

GOA ecosystem that impact multiple species. Terrestrially, pink salmon also serve as an important conduit of marine derived nutrients to the temperate rainforests of coastal Alaska. Economically, pink salmon have been called the "bread and butter" fish of SEAK, and are represented by primarily wild stocks (>95%) from over 2,500 SEAK stream systems. This production base can contribute to an annual commercial SAEK harvest of upwards of 95 M fish, worth over $125 M ex-vessel value. Ecologically, this large 2013 harvest in SEAK represented a significant component in the GOA ecosystem, comprising 21% of the 643,779 metric tons of fish commercially harvested off Alaska in the GOA and adjacent coastal waters, and pink salmon from all regions representing 46% of the harvest.

Marine Survival of Coho Salmon from Auke Creek, Southeast Alaska

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Last updated: August 2015

Description of indicator: The time series of marine survival estimates for wild coho salmon from the Auke Creek Weir in Southeast Alaska is the most precise and longest-running continuous series available in the North Pacific. Auke Bay Laboratory began monitoring wild coho salmon survival in 1980. All coho salmon smolts leaving the Auke Lake watershed have been counted, subsampled for age and length, and injected with coded wire tags (CWT). Research studies over the last 35 years have captured and sampled virtually all migrating wild juvenile and adult coho salmon. These migrating fish included those with both 1 and 2 freshwater annuli and 0 or 1 ocean annuli. Marine survival is estimated as the number of adults (harvest plus escapement) per smolt. The index is presented by smolt (outmigration) year. The precision of the survival estimate was high due to 100% marking and sampling fractions that minimized the variance in the survival estimate and made the series an excellent choice for model input relating to nearshore and gulf-wide productivity. It is the only continuous marine survival and scale data set in the North Pacific that recovers all returning age classes of wild, CWT coho salmon as ocean age 0 and 1.

Status and trends: The historical trend shows marine survival of wild coho salmon from Auke Creek varies from 11.7% to 47.8%, with an average survival of 24.1% from smolt years 1980-2013 (Figure 1; top panel). Marine survival for 2013 was 22.7% and overall survival averaged 19.6% over the last 5 years and 20.4% over the last 10 years. The survival index for ocean age-1 coho varies from 9.4% to 36.6% from smolt years 1980-2013 (Figure 76; middle panel) and for ocean age-0 coho varies from 2.0% to 11.2% from smolt years 1980-2014 (Figure 76; bottom panel).

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

Implications: The marine survival index of coho salmon at Auke Creek is related to ocean productivity indices and to important rearing habitats shared by groundfish species. The trends in coho salmon marine indices from Auke Creek provide a unique opportunity to examine annual variation in habitat rearing areas and conditions because ocean age-0 coho adults occupy only nearshore and strait habitats prior to returning to the creek. Ocean age-0 coho leave freshwater in May through June and return in August through October, the same time sablefish are moving from offshore to

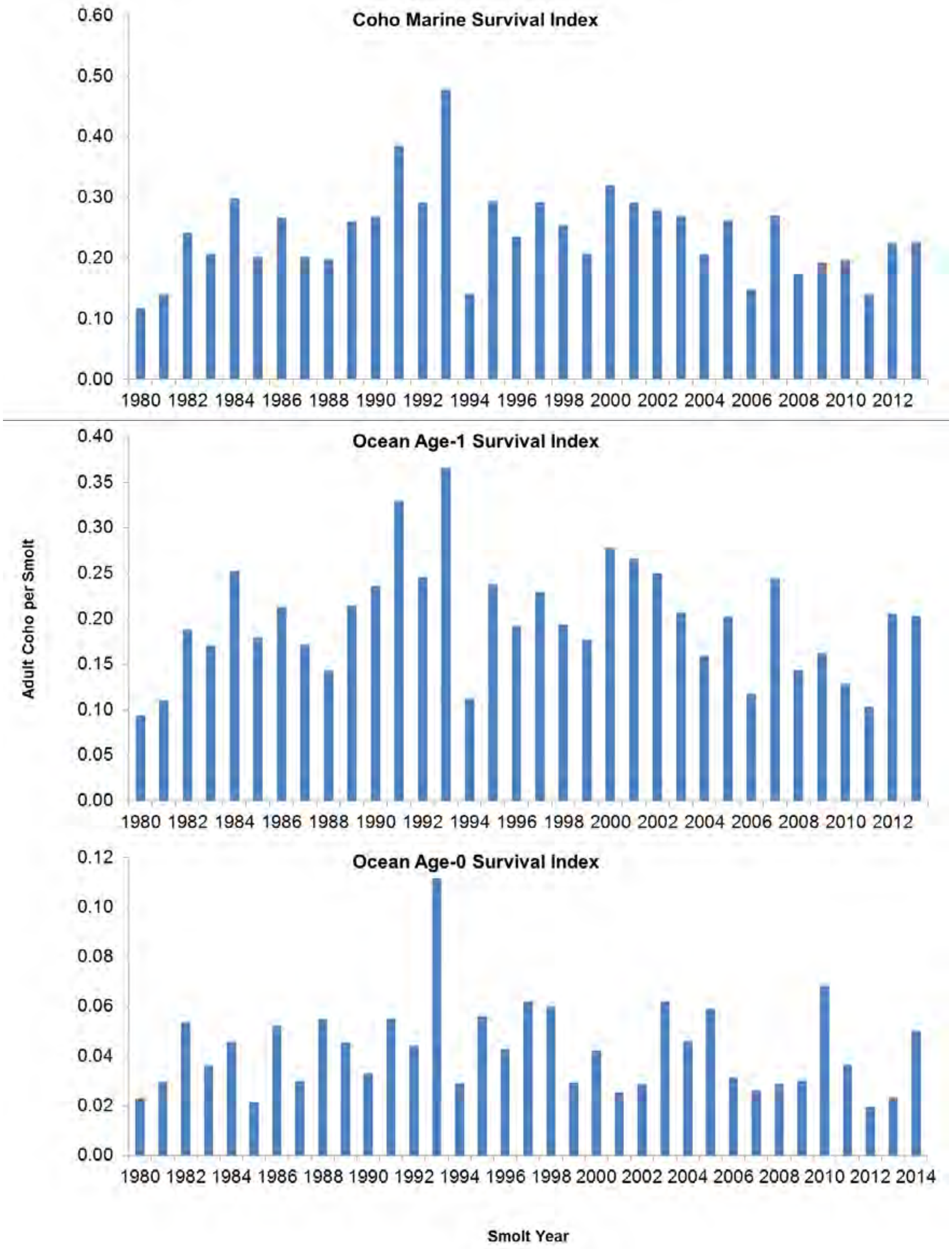

Figure 76: Auke Creek coho salmon marine survival indices showing total marine survival (ocean age-0 and age-1 harvest plus escapement; top panel), percentage of ocean age-1 coho per smolt (harvest plus escapement; middle panel), and percentage of ocean age-0 coho per smolt (escapement only; bottom panel) by smolt year.

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.

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

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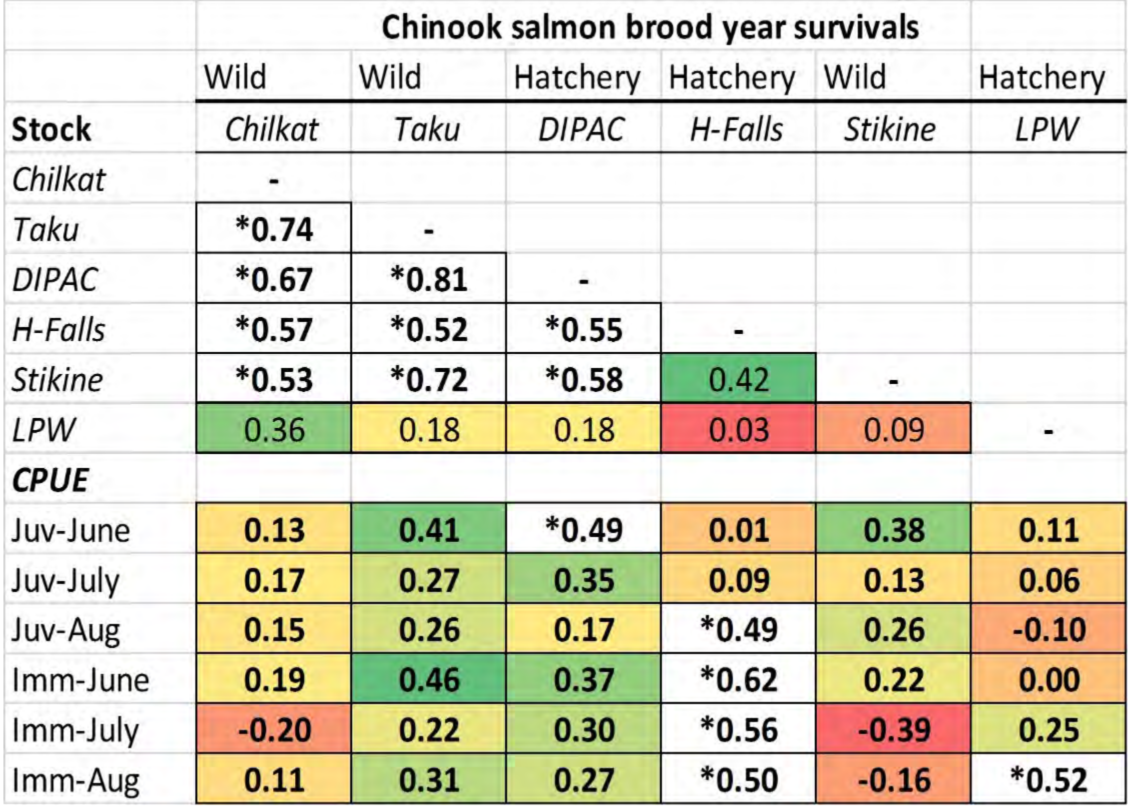
Description of indicator: The Southeast Alaska Coastal Monitoring (SECM) project has a time series of ecosystem metrics in coastal Southeast Alaska (SEAK) and in the Gulf of Alaska (GOA) from annual surface trawl and oceanographic sampling over the past 19 years. The SECM monthly time series of Chinook salmon (*Oncorhynchus tshawytscha*) catch data of juvenile and immature fish data have been shown to be correlated to brood year survival and has been used to develop a SEAK Chinook salmon abundance index beginning in 2013 (Orsi et al., 2013; Zador, 2014).

The SECM data for the Chinook salmon index was obtained from stations sampled in the vicinity of Icy Strait (58°N, 135°W)(Orsi et al., 2015). This locality is the principal northern exit route for seaward migrating juvenile salmon through SEAK to the GOA. Based on salmon origin information from coded-wire tags, SEAK juvenile Chinook salmon are found in this migration corridor in fall and also the ensuing spring as over wintering immature 1-ocean fish. This suggests SEAK Chinook salmon smolts have a localized early marine residency pattern and often linger in Icy Strait as older immature fish, rather than heading directly seaward. SECM survey catches are mostly comprised of immature ocean age-1 fish in early summer and some juvenile (ocean age-0) fish in fall. Abundance information on ocean age-1 fish in June has been significantly correlated to brood year survival of selected stocks of wild and hatchery Chinook salmon in SEAK (Orsi et al., 2013). To understand linkages of critical early marine periods to survival, annual ocean catch data of juvenile and immature Chinook salmon pre-recruits were examined from research surface trawling in Icy Strait, Southeast Alaska from 1997 to 2014. In total, 1,108 Chinook salmon were sampled in 1,037 trawl hauls from May to September. Origins of 50 fish recovered with coded-wire tags (CWTs) indicated most to be SEAK origin (48), and either immature (ocean-age 1) or juvenile (ocean-age 0).

Status and trends: Based on coded-wire tags Chinook salmon recoveries, juvenile fish occurred June-September, whereas immature fish occurred May-August. Chinook stock analysis indicates that sampled fish represent both wild and hatchery stocks from the northern region of SEAK. Nearly all these fish are immature and are represented by primarily ocean age-1 fish, mostly in June. There is a significant correlation between ocean age-1 abundance of Chinook salmon caught in SECM surveys in June and Chinook salmon brood year survivals as well as among wild and hatchery stocks (Figure 77). This information suggests Chinook salmon marine survival is set after their first ocean winter and regional concordance exists among the brood year survivals of neighboring SEAK stocks. Thus, a SECM Chinook salmon index of the abundance of ocean age-1 fish sampled in Icy Strait could be lagged two years to the future to anticipate recruitment of legal-sized fish as ocean age-3 fish. Based on this SECM Chinook index, June 1-ocean Chinook abundance has been below average in 9 of the past 13 years (Figure 78). Most recently, Chinook salmon fishery recruitment appears weak in 2014 and 2016, but strong in 2013, and particularly strong in 2015.



	Chinook salmon brood year survivals					
	Wild	Wild	Hatchery	Hatchery	Wild	Hatchery
Stock	*Chilkat*	*Taku*	*DIPAC*	*H-Falls*	*Stikine*	*LPW*
Chilkat	-					
Taku	***0.74**	-				
DIPAC	***0.67**	***0.81**	-			
H-Falls	***0.57**	***0.52**	***0.55**	-		
Stikine	***0.53**	***0.72**	***0.58**	0.42	-	
LPW	0.36	0.18	0.18	0.03	0.09	-
CPUE						
Juv-June	**0.13**	**0.41**	***0.49**	**0.01**	**0.38**	**0.11**
Juv-July	**0.17**	**0.27**	**0.35**	**0.09**	**0.13**	**0.06**
Juv-Aug	**0.15**	**0.26**	**0.17**	***0.49**	**0.26**	**-0.10**
Imm-June	**0.19**	**0.46**	**0.37**	***0.62**	**0.22**	**0.00**
Imm-July	**-0.20**	**0.22**	**0.30**	***0.56**	**-0.39**	**0.25**
Imm-Aug	**0.11**	**0.31**	**0.27**	***0.50**	**-0.16**	***0.52**

Figure 77: Correlation matrix of Chinook salmon hatchery and wild survivals and CPUE data of Chinook salmon from surface trawl sampling from the Southeast Alaska Coastal Monitoring project in the marine waters of Icy Strait, Alaska, June-August, 1997-2014. Number of years in each paired comparison ranged from 11-14 years, and trawl sampling did not occur in June of 2009. Asterisks denote significant differences (uncorrected for multiple comparisons) at P-value <0.05.

Factors influencing observed trends: Alaska stocks Chinook salmon spend a large portion of their life history in marine waters within the U.S. Exclusive Economic Zone (EEZ) and also beyond the 200-mile EEZ of the coastal States north of 33°N in international waters (NPAFC 2014). However, year class strength is often set earlier, further inshore of the EEZ, during their seaward migration phase as juveniles or during the ensuing overwintering phase of immatures.

As in most of Alaska, Chinook salmon returns to SEAK have been in decline for almost a decade. This trend is also apparent in the SECM Chinook salmon abundance index (Figure 78). Based on this index of age 1-ocean fish, there appears to be two strong Chinook salmon year classes emerging: one as age 3-ocean fish in 2103 and another two years later in 2015. Contrary to many of the assumptions of negative impacts of pink salmon on other species, in the case of these two strong year classes of Chinook, they coincide with the same ocean entry years of the high juvenile pink

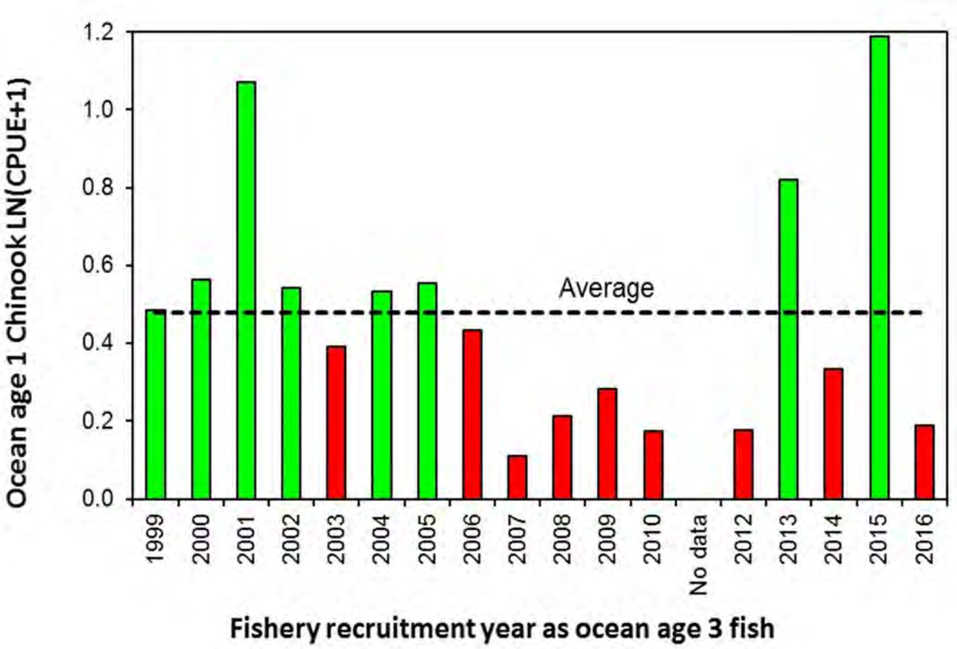


Figure 78: The Southeast Alaska Coastal Montioring project Chinook salmon index estimate of ocean age-1 fish sampled in Icy Strait in June, lagged two years later to potential recruitment of ocean age-3 fish, 1999-2016. No trawling was conducted in June of 2009, so the index was not available for 2011

salmon abundances in 2010 and 2012. This suggests that both juvenile Chinook and pink salmon mutually benefited from favorable ocean conditions in 2010 and 2012, or the smaller, more abundant juvenile pink salmon proved to be a predator buffer to the larger Chinook salmon juveniles.

Implications: Chinook salmon returns throughout Alaska have been in decline for about the past decade (ADFG 2013, Pacific Salmon Commission 2014). Consequently, understanding Chinook salmon abundance trends is important, as high catches of immature Chinook have the potential to trigger management actions in Alaskas groundfish fisheries and production may be influenced by climate. Understanding migration and abundance of Chinook salmon stocks during critical early marine periods is also important because declining returns in some regions of Alaska have effectuated commercial fishery disaster declarations since 2012.

This study indicates SEAK Chinook salmon stocks have initial localized marine distributions as juveniles, are present as immature fish the ensuing spring and summer, and research catch rates of pre-recruits holds promise as a leading ecosystem indicator stock assessment tool for managers. The CPUE of ocean-age 1 Chinook salmon has promise as a leading indicator of upcoming fishery recruitment strength two years later and may be a useful leading ecosystem indicator stock assessment tool for managers. Ocean survivals of wild and hatchery SEAK stocks of Chinook salmon in some cases were positively correlated (significantly for one stock) to catches of juvenile or immature fish aligned by ocean entry year.

Research catches of juvenile and immature Chinook salmon of pre-recruit size during SECM surveys has helped define their Essential Fish Habitat in the U.S. EEZ of Alaska (Echave et al., 2012), identify distributions of threatened and endangered Chinook salmon stocks along the SEAK coastline and in the Gulf of Alaska (Trudel et al., 2009; Fisher et al., 2014), and to determine their ecological role in large marine ecosystems (Orsi et al., 2007).

Groundfish

Fall Condition of YOY Predicts Recruitment of Age-1 Walleye Pollock

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Description of indicator: Average Energy Content (AEC) is the product of the average individual mass and average energy density (i.e., kJ/fish) of young-of-the-year (YOY) Walleye Pollock (*Gadus chalcogrammus*; hereafter pollock) collected during the late-summer BASIS surveys in the eastern Bering Sea (EBS). Average individual mass is estimated at sea from the total mass divided by the total number of YOY pollock caught in each haul. The average energy density of YOY pollock is estimated in the laboratory from fish collected in each haul and weighted by catch. The product of the two averages represents the average energy content for an individual YOY pollock in a given year. We related AEC to the number of age-3 recruits per spawner (R/S) using the index of adult female spawning biomass as an index of the number of spawners.

The analytical process of measuring energy density follows strict protocols. YOY pollock are retained from each haul in which sufficient pollock are caught, frozen, and shipped to NOAA/Auke Bay Laboratories for analysis. Catch records are examined and multiple (3-5) fish from each haul that are representative of the average length of YOY pollock are analyzed in order to estimate the average energy density per haul. Fish are dried, homogenized, and combusted in a Parr Instrument 6725 Semimicro Calorimeter (Siddon et al., 2013*b*, for detailed methods see).

Status and trends: Energy density (kJ/g), mass (g), and standard length (mm) of YOY pollock have been measured annually since 2003. Over that period energy density has varied with the thermal regime in the EBS. Between 2003 and 2005 the southeastern Bering Sea experienced warm conditions characterized by an early ice retreat. Thermal conditions in 2006 were intermediate, indicating a transition, and ice retreated much later in the years following 2006 (i.e., cool conditions). The transition between the warm and cool conditions is evident when examining energy density over the time series (Figure 79). Energy density increases from 3.63 kJ/g in 2003 to 5.26 kJ/g in 2010. In contrast, the size (mass or length) of the fish has been less influenced by thermal regime. The average mass of the fish was similar between warm (2.15 g) and cool (2.18 g) years, while the length was greater in warm years (72.6 mm) than cool years (67.6 mm).

Relating the AEC of YOY pollock to year class strength from the age-structured stock assessment indicates the energetic condition of pollock prior to their first winter predicts their survival to age-3. The AEC of YOY pollock in 2003-2014 accounts for 68% of the variation in the number of age-3 recruits per spawner (Figure 80). In 2012, the AEC of YOY pollock was the lowest in the time series (6.57 kJ/fish) and the fish had the smallest mass and length in the BASIS survey time series. The AEC estimate is outside of the calibration, therefore no predication of recruits per spawner can be made. In 2014, the AEC of YOY pollock was intermediate (9.75 kJ/fish) and the fish were intermediate mass and length compared to the BASIS time series, therefore the model predicts an

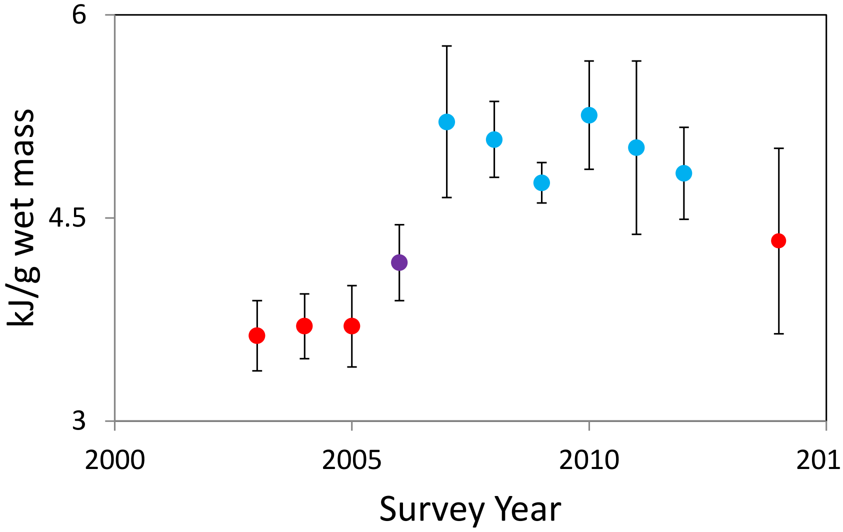

Figure 79: Average energy density (kJ/g) of young-of-the-year walleye pollock (*Gadus chalcogrammus*) collected during the late-summer BASIS survey in the eastern Bering Sea 2003-2014.

intermediate level of recruits per spawner. The AEC of YOY pollock has been dropping since the recent cold years (i.e., 2010) consistent with a warmer thermal regime in the EBS.

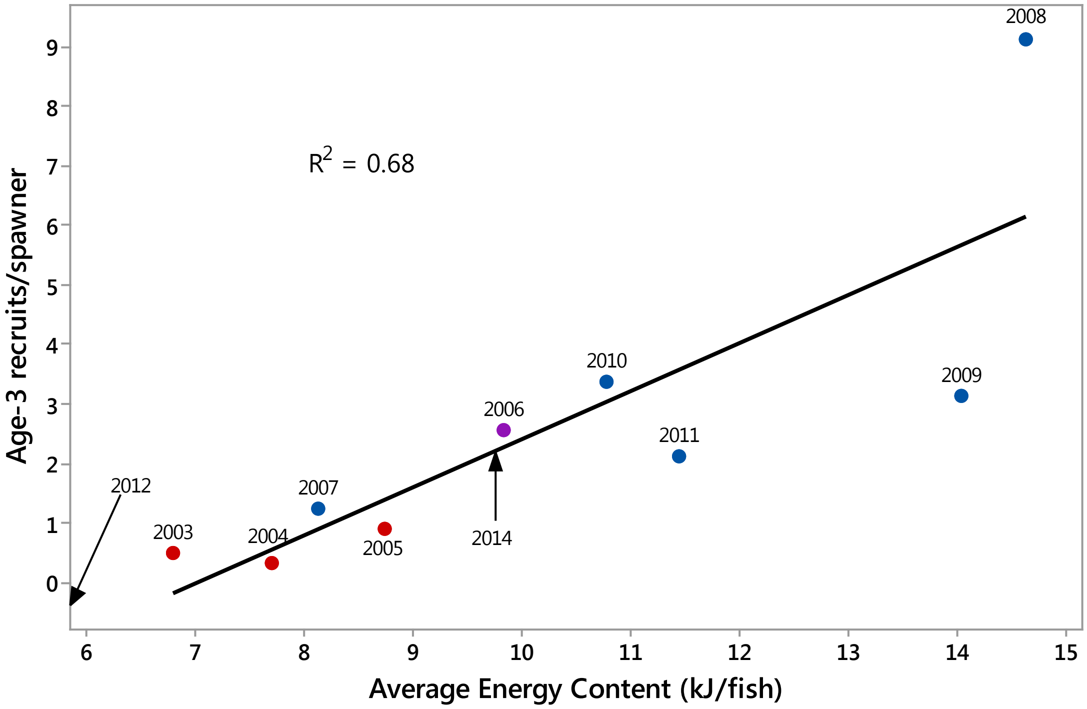

Figure 80: Relationship between average energy content (AEC) of individual young-of-the-year walleye pollock (*Gadus chalcogrammus*) and the number of age-3 recruits per spawner from the 2014 stock assessment (Ianelli et al., 2014).

Factors influencing observed trends: Pollock are susceptible to size dependent mortality during their first winter (Heintz and Vollenweider, 2010). This effect can be particularly important in determining recruitment. For example, size dependent mortality during winter among salmon can be proportionally as high as mortality during the first 40 days at sea (Farley et al., 2007). Thus the critical size hypothesis posits a positive effect of size on winter survival. While size may be a good predictor within a year, BASIS data indicate a weak relationship between size and recruitment among years. Similarly, high energy density does not necessarily predict high survival among years because energy density is mass normalized and does not convey information about size. AEC of individual YOY pollock integrates information about size and energy density into a single index.

YOY pollock have a relatively narrow window within which they can provision themselves prior to winter. Larval pollock allocate the majority of their ingested energy into developmental processes leaving little energy for somatic growth or sequestration of energy stores. They can only invest energy in growth and storage after they have successfully transitioned into fully developed juveniles (Siddon et al., 2013*a*). Their success at exploiting this window likely depends on water temperatures, prey quality, and foraging costs (Siddon et al., 2013*b*). Cold years appear to be associated with greater densities of euphausiids, as well as medium and large copepods in the middle domain (Hunt et al., 2011). These species are higher in lipid, affording YOY pollock a higher energy diet than that consumed in warm years. In addition, the lower temperatures optimize their ability to store lipid (Kooka et al., 2007). While cold conditions in the EBS are associated with improved nutritional status of YOY pollock prior to winter, 2012 demonstrates conditions can be too cold to support good survival. In May of 2012 ice cover still reached as far south as the Alaska Peninsula, suggesting summer temperatures were very low when larvae were developing. Consequently, YOY pollock sampled in 2012 on the BASIS survey were the smallest in the 10-year time series.

Implications: The current data indicate that recruitment to age-3 should be relatively weak for the 2012 year class while the 2014 year class should have intermediate recruitment success to age-3.

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

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Description of indicator: Interannual variations in large zooplankton abundance (sum of all large zooplankton taxa, excluding euphausiids) were compared to age-3 walleye pollock abundance (millions of fish) per biomass (thousands of tons) of spawner for year classes 2003-2010 on the southeastern Bering Sea shelf. Zooplankton samples were collected with oblique bongo tows over the water column (60 cm, 505 μm mesh nets) on BASIS fishery oceanography surveys during mid-August to late September, for three warm years (2003-2005) followed by one average (2006) and four cold years (2007-2010) (Eisner et al., 2014). Pollock abundance and biomass was available from the stock assessment report for the 2006-2013 year classes (Ianelli et al., 2014).

Status and trends: For the 2003-2010 year classes of pollock, a positive significant (P = 0.011) linear relationship was found between mean abundances of large zooplankton at year t (when pollock were age-0), and age-3 pollock abundance at year t+3 (Figure 81a). A strong relationship (P = 0.004) was also observed for large zooplankton and age- 3 pollock abundance (t+3)/ spawner biomass (t) (Figure 81b). These results suggest that increases in the availability of large zooplankton prey during the first year at sea were favorable for age-0 pollock survival and recruitment into the fishery at age- 3.

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

Implications: If the relationship between large zooplankton and age 3 pollock remains robust as more years are added to the analysis, this index could be used to predict the survival of pollock three years in advance of recruiting to age 3, the year pollock enter the fishery, from zooplankton data collected 3 years prior. This relationship also provides further support for the revised oscillating control hypothesis that suggests as the climate warms, reductions in the extent and duration of sea ice could be detrimental to large crustacean zooplankton and subsequently to the pollock fishery in the southeastern Bering Sea (Hunt et al., 2011).

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

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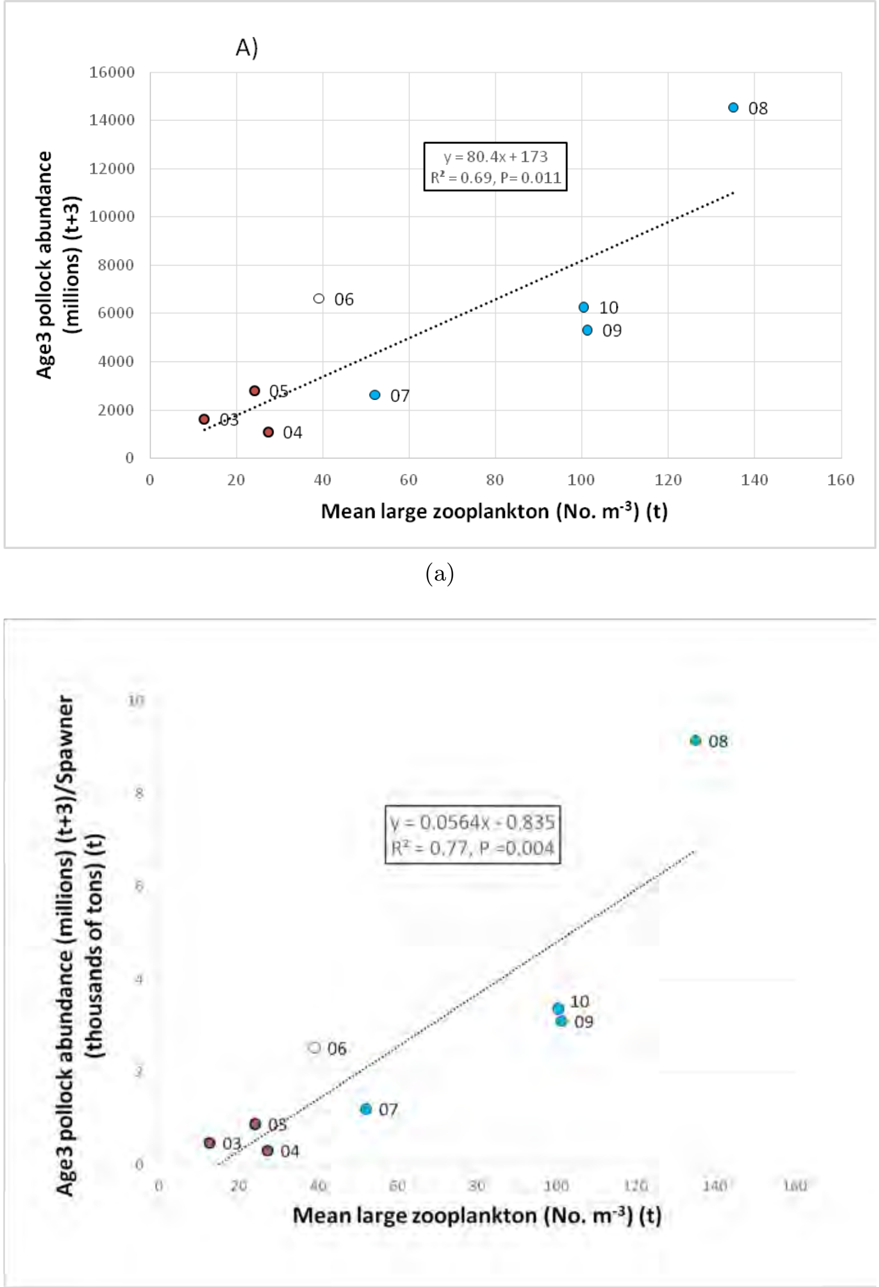
Description of indicator: The Temperature Change (TC) index is a composite index for the pre- and post-winter thermal conditions experienced by pollock (*Gadus chalcogramma*) from age-0 to age-1 in the eastern Bering Sea (Martinson et al., 2012). The TC index (year t) is calculated as the difference in the average monthly sea surface temperature in June (t) and August (t-1) (Figure 82) in an area of the southern region of the eastern Bering Sea (56.2°N to 58.1°N latitude by 166.9°W to 161.2°W longitude). Time series of average monthly sea surface temperatures were obtained from the NOAA Earth System Research Laboratory Physical Sciences Division website. Sea surface temperatures were based on NCEP/NCAR gridded reanalysis data (Kalnay et al., 1996, data obtained from `http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl`). Less negative values represent a cool late summer during the age-0 phase followed by a warm



(a)

(b)

Figure 81: Linear relationships between a) mean large zooplankton abundance (t) and a) age-3 pollock abundance (t+3) and between b) mean large zooplankton abundance (t) and age-3 pollock abundance (t+3)/Spawner biomass (t). Orange symbols are warm (low ice) years, blue are cold (high ice) years and white is an average year. Year classes (when pollock were age-0) and zooplankton were collected are shown next to symbols.

spring during the age-1 phase for pollock.

Status and trends: The 2015 TC index value is -5.96, lower than the 2013 TC index value of -3.84. Both the late summer and following spring sea temperatures were warmer than average. The TC index was positively correlated with subsequent recruitment of pollock to age-1 through age-6 for based on abundance estimates from Table 1.25 in Ianelli et al. 2014 (Table 7). Over the longer period (1964-2014), the TC index was more statistically significant for the age-1, age-2, and age-3 pollock, than for the older pollock (Table 7). For years 2002-2014, this relationship was less statistically significant.

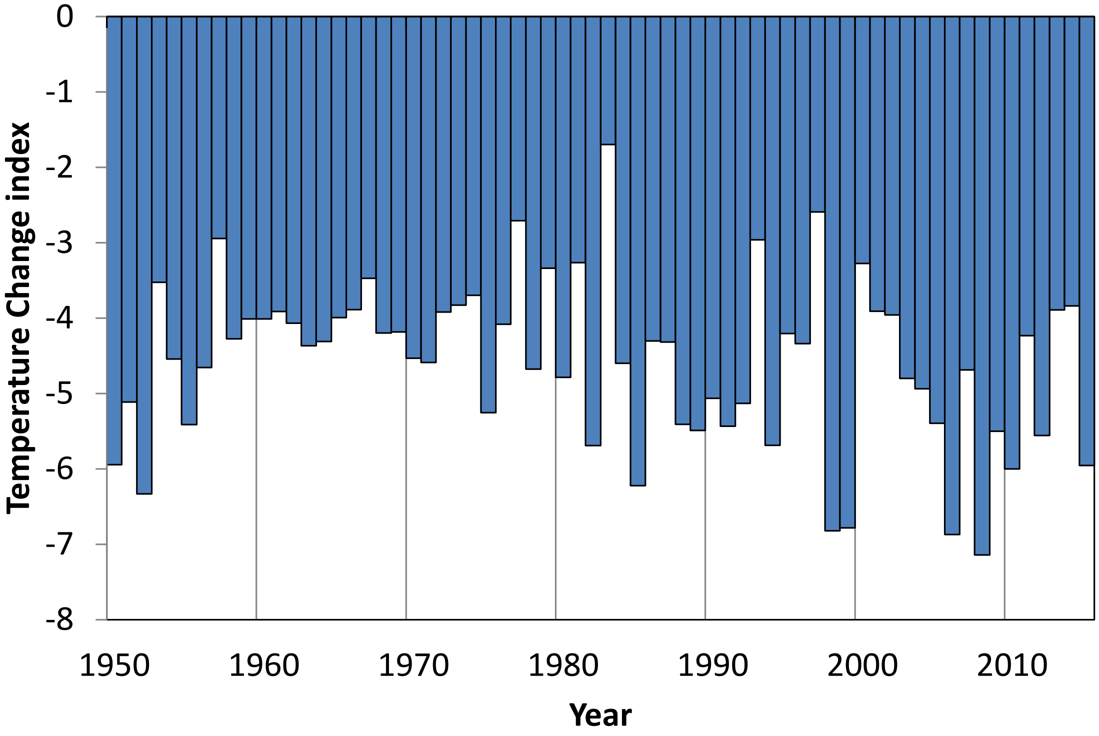


Figure 82: The Temperature Change index value from 1950-2015.

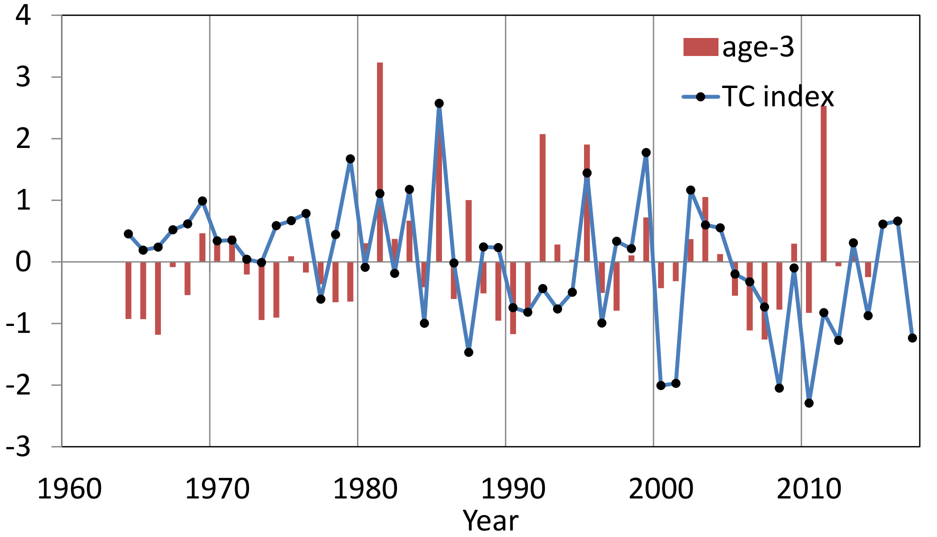


Figure 83: Normalized times series values of the Temperature Change index (t-2) and the estimated abundance of age-3 walleye pollock in the eastern Bering Sea (t)) from Table 1.25 in Ianelli et al. 2014.

Table 7: Pearson's correlation coefficient relating the Temperature Change index to subsequent estimated year class strength of pollock (Age-x+1). Bold values are statistically significant ($p < 0.05$).

	Correlations				
	t Age-1	t+1 Age-2	t+2 Age-3	t+3 Age-4	t+4 Age-5
1964-2014	**0.38**	**0.38**	**0.36**	**0.31**	0.28
1995-2014	0.29	0.29	0.21	0.21	0.17

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

Implications: In 2013, the TC index value of -3.89 was above the long-term average of -4.60, therefore we expect slightly above average numbers of pollock to survive to age-3 in 2015 (Figure 82). In the future, the TC values of -5.96 in 2015 indicate an expected below average abundances of age-3 pollock in 2017.

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

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Description of indicator: Chum salmon growth and sea temperature were used to predict the recruitment of pollock to age-1 in 2014 and 2015 (Yasumiishi et al., 2015). Chum salmon are incidentally captured in the commercial fisheries for walleye pollock (*Gadus chalcogrammus*) in the Bering Sea (Stram and Ianelli). We used the intra-annual growth in body weight of these immature and maturing age-4 chum salmon from the pollock fishery as a proxy for ocean productivity experienced by age-0 pollock on the eastern Bering Sea shelf. Adult pink salmon are predators and competitors of age-0 pollock (Coyle et al., 2011). We modeled age-1 pollock recruitment estimates from 2001 to 2010 as a function of chum salmon growth and sea temperature, and used the model parameters and biophysical indices from 2013 and 2014 to predict age-1 pollock abundances in 2014 and 2015. Estimates of age-1 pollock abundance were from (Ianelli et al., 2014).

Status and trends: Pollock recruitment was highly variable within the 10-year time series, 2001-2010 (Figure 84). In a multiple regression model, age-1 pollock recruitment was negatively related to spring sea temperatures during their age-1 stage and positively related to chum salmon growth during the pollock age-0 stage ($R^2 = 0.73$; p -value $= 0.008$).

Model residuals (Figure 85) had an alternating year pattern. A slight alternating year pattern was observed in the time series, with higher recruitment to age-1 in odd-numbered years. The higher than expected (positive residuals) recruitment to age-1 in odd-years (age-0 in even-numbered years) may be associated with fewere adult pink salmon (a predator and competitor) in even-years as age-0s or as a predator buffer in odd-years during the early spring age-1 stage of pollock.

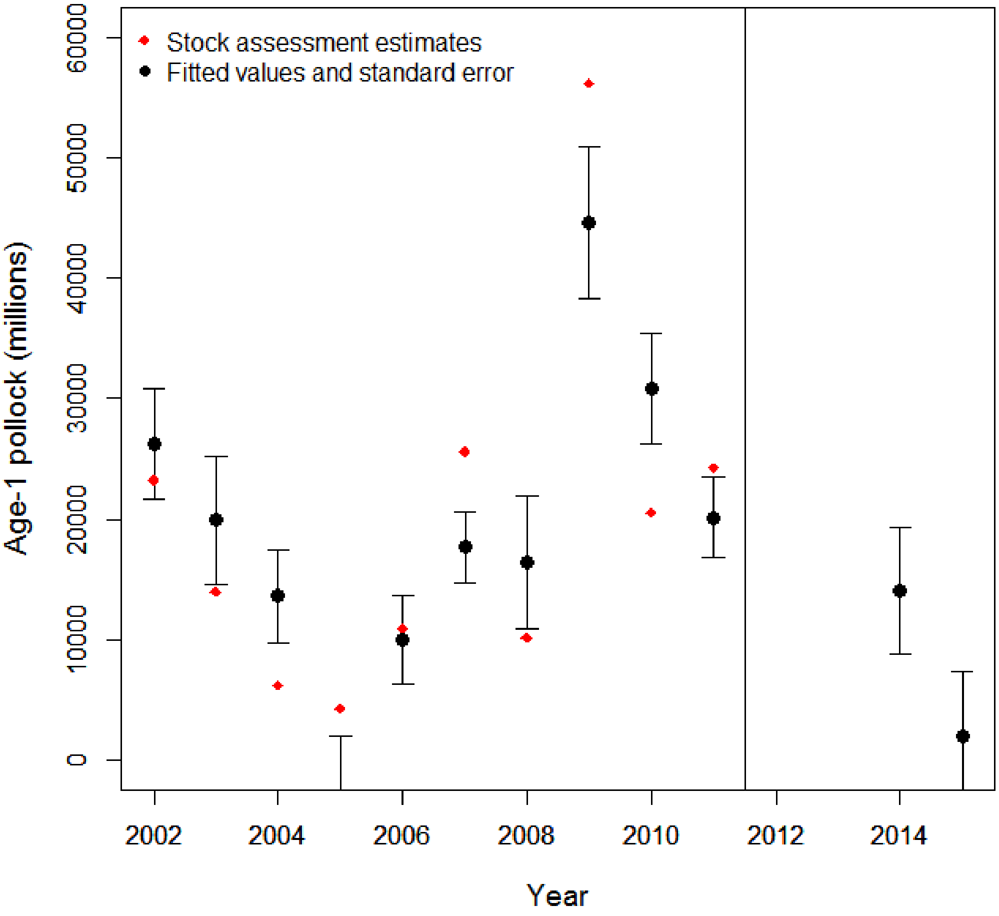

Figure 84: Age-1 pollock modeled as a function of the intra-annual growth in body weight of chum salmon during the age-0 stage (t-1) and spring sea temperature during the age-1 stage (t).

Factors influencing observed trends: The model parameters (2001-2010) and biophysical indices (2013and 2014) were used to predict the recruitment of Bering Sea pollock in 2014. The 2013 biophysical indices (chum salmon growth = 0.969 kg, spring sea temperature = 3.95°C) produced a forecast of 14 million (3,837 standard error, c.v. = 0.22) age-1 pollock in 2014. The 2014 biophysical indices (chum salmon growth = 0.80 kg, spring sea temperature = 4.00°C) produced a forecast of 5 million age-1 pollock in 2015. The 2014 biophysical indices indicated below ocean productivity (chum salmon growth) and warm spring sea temperatures (less favorable). These factors are

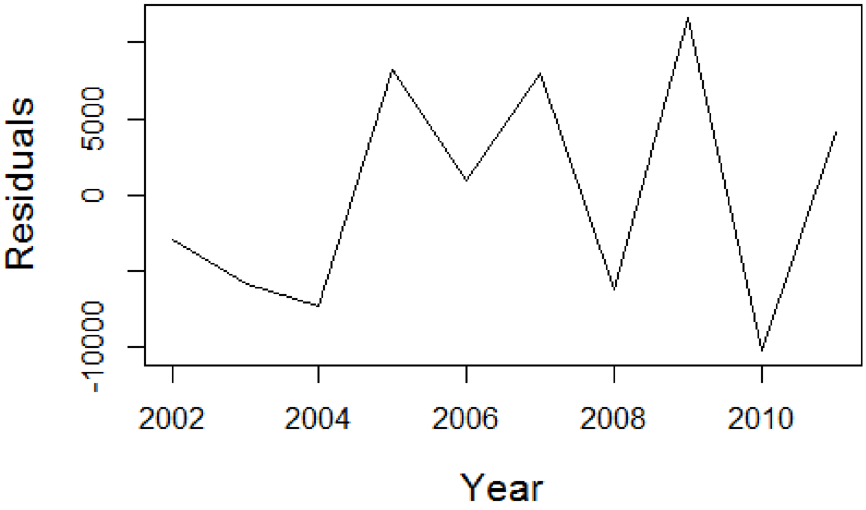

Figure 85: Residuals of the regression model relating age-1 pollock abundance (t) to spring sea surface temperature (t) and chum salmon growth (t-1).

expected to result in below average age-1 pollock recruitment in 2015.

Implications: The model predicts a below average recruitment of pollock to age-1 in 2015.

Multispecies Model Estimates of Time-varying Natural Mortality

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

Status and trends: We estimate that age-1 natural mortality (i.e., M1+M2) for pollock, cod and arrowtooth flounder was highest between 1980-2000 (e.g., peak natural mortality for pollock was in 1987 at 2.32) and has been marginally lower in the last 20 years (Figure 86). Recent natural mortality rates have been relatively stable since 2000 at around 1.85, 0.66, and 0.60 for pollock, cod and arrowtooth flounder, respectively.

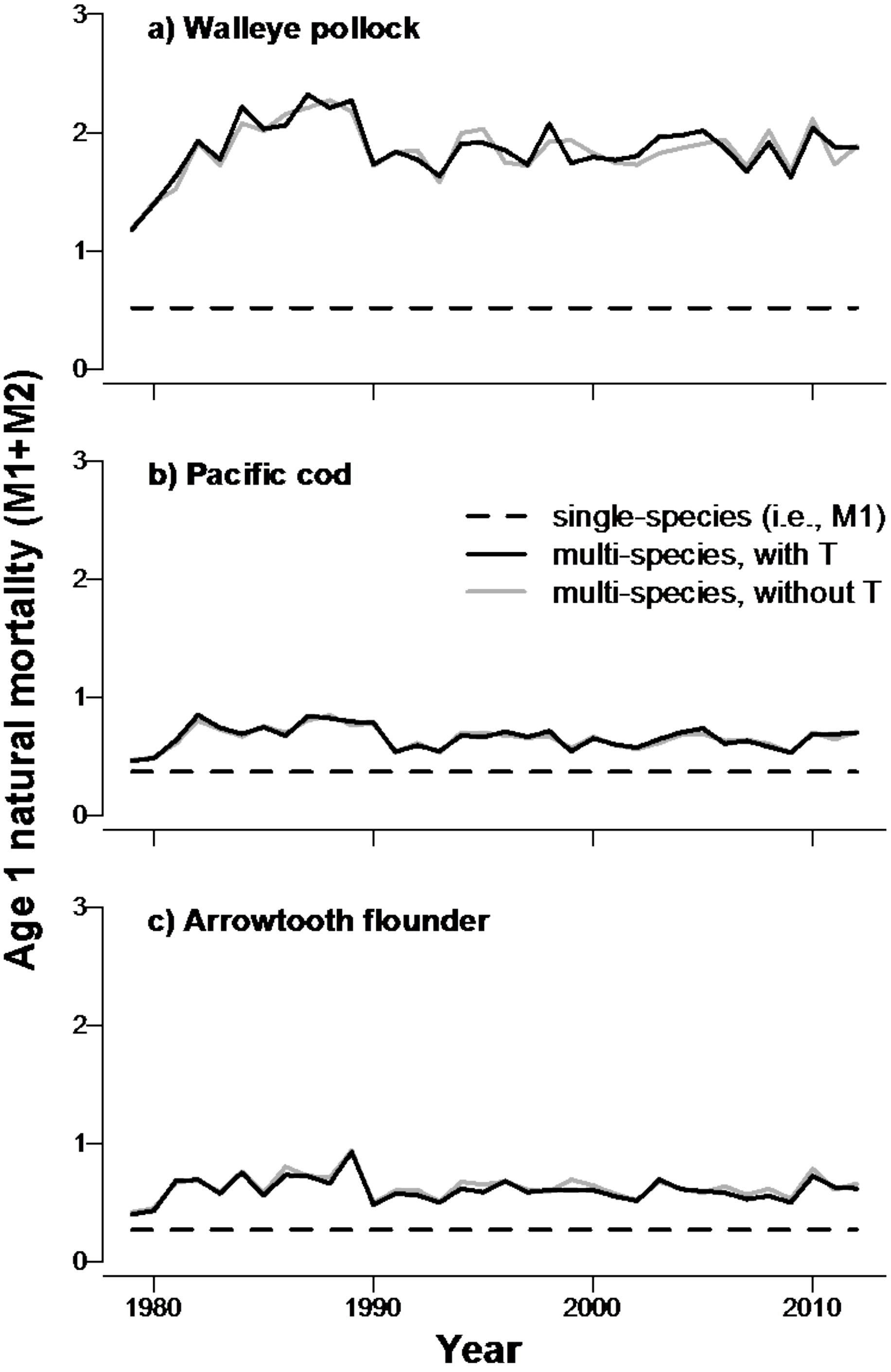

Figure 86: Annual variation in total mortality (M1 + M2) for age-1 pollock (a), Pacific cod (b), and arrowtooth flounder (c) from the single-species models (dashed line), multi-species models with temperature (black line), and multi-species models where temperature was held at a constant mean observed value of 2.51 ^{O}C (gray line). From Holsman et al. (in press).

Factors influencing observed trends: Temporal patterns in natural mortality reflect annually varying changes in predation mortality that primarily impact age-1 fish (but also impact ages-2 and -3 fish in the model). Until recently (i.e., 2006), approximately half of pollock predation mortality was due to cannibalism by older conspecifics. However, predation by arrowtooth flounder has exceeded cannibalism as the largest source of predation mortality of age-1 pollock since 2007 (Figure 87).

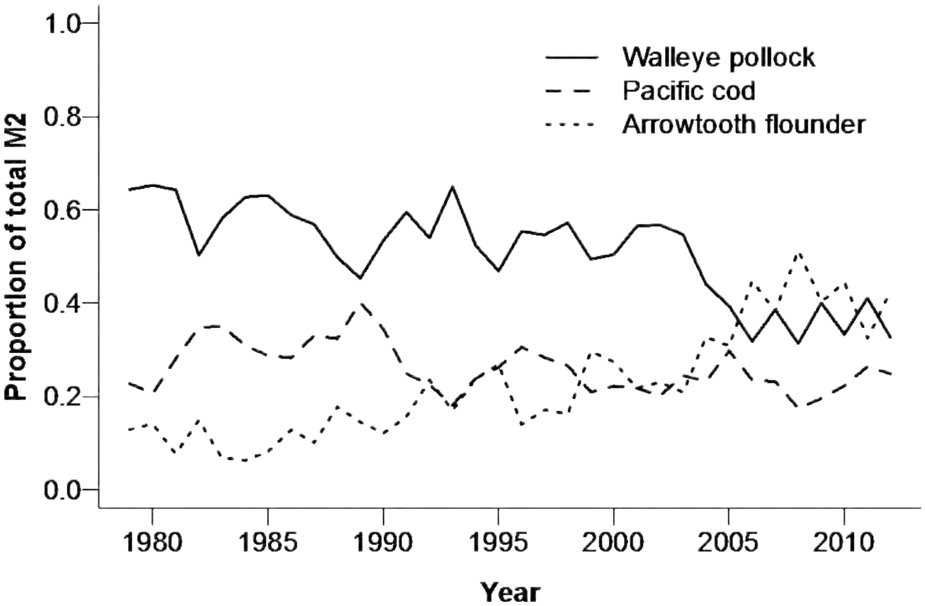

Figure 87: Proportion of total predation mortality for age-1 pollock by pollock (solid), Pacific cod (dashed), and arrowtooth flounder (dotted) predators across years. From Holsman et al. (in press).

Between 1980 and 1993, the relatively high natural mortality rates reflected patterns in combined predator demand for prey that peaked in the mid 1980s (collectively 8.95 million t per year as compared to recent predator demand of 7.6 billion t per year; Holsman et al. 2015). Although the slight peak in predation mortality of pollock in 2006 corresponds to a large cohort of cannibalistic 5-7 year old pollock and 2 year old cod, the primary driver of predation mortality since 2006 appears to be the result of increased consumption of pollock by arrowtooth flounder. This pattern may reflect larger spatial overlap among prey of arrowtooth flounder and pollock driven by thermal conditions that favor arrowtooth flounder, higher metabolic (and energetic) demand under warm conditions, and increases in arrowtooth flounder biomass in the Bering Sea (Holsman and Aydin, 2015; Spencer et al., In press; Hunsicker et al., 2013; Zador et al., 2011).

Implications: We find evidence for a recent shift in the dominant predator of Bering Sea pollock, with increasing importance of arrowtooth flounder predation on pollock since 2006. This suggests that increasing trends in arrowtooth flounder biomass could negatively impact pollock populations in the Bering Sea, particularly during warm years when thermal conditions increase arrowtooth flounder predation pressure on juvenile pollock.

Eastern Bering Sea 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 eastern Bering Sea shelf bottom trawl survey data was utilized to acquire lengths and weights of individual fish for walleye pollock, Pacific cod, arrowtooth flounder, yellowfin sole, flathead sole, northern rock sole, and Alaska plaice. Only summer standard survey strata and stations were included in analyses (no corner stations were included)(Figure 88). Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 82 and 90 were excluded from analyses because they are not standard survey strata. Length-weight relationships for each of the seven species were estimated with a linear regression of log-transformed values over all years where data was available (during 1982-2015). Predicted log-transformed weights were calculated and subtracted from measured log-transformed weights to calculate residuals for each fish. Length-weight residuals were averaged for the entire EBS and for the 6 strata sampled in the standard summer survey. Temporal and spatial patterns in residuals were examined.

Status and trends: Length-weight residuals varied over time for all species with a few notable patterns (Figure 89). Residuals for all species where there was data were negative in 1999, a cold year in the Bering Sea. Residuals became positive or more positive in 2002 for five of the seven species examined. Flatfish residuals were generally positive from 2002 to 2004 or 2005 depending on species. Age 1 walleye pollock and Pacific cod residuals were positive from 2001 to 2004 or 2005. In 2008, all species except flathead sole and walleye pollock had negative residuals. There has been a distinct negative trend in Pacific cod since a peak value in 2003. Age 1 walleye pollock and older walleye pollock were not well correlated in most years. Length-weight residuals for all species were lower in 2015 than in 2014 indicating smaller weight at length.

Spatial trends in residuals were also apparent for some species (Figure 90). Generally, fish were in better condition on the outer shelf (strata 50 and 60). For all species except yellowfin sole (which did not occur in outer shelf strata), residuals were almost always positive on the northern outer shelf (stratum 60). For yellowfin sole, residuals were positive in the outermost shelf strata in which they occurred (stratum 40) except in 1999. In addition to having positive residuals on the outer shelf, gadids tended to have negative residuals on the inner shelf (Figure 90). Pollock residuals were generally positive in strata 50 and 60 and negative in strata 10, 20, and 40. Cod residuals were generally positive in stratum 60 and negative in strata 10 and 20. Spatial patterns in flatfish

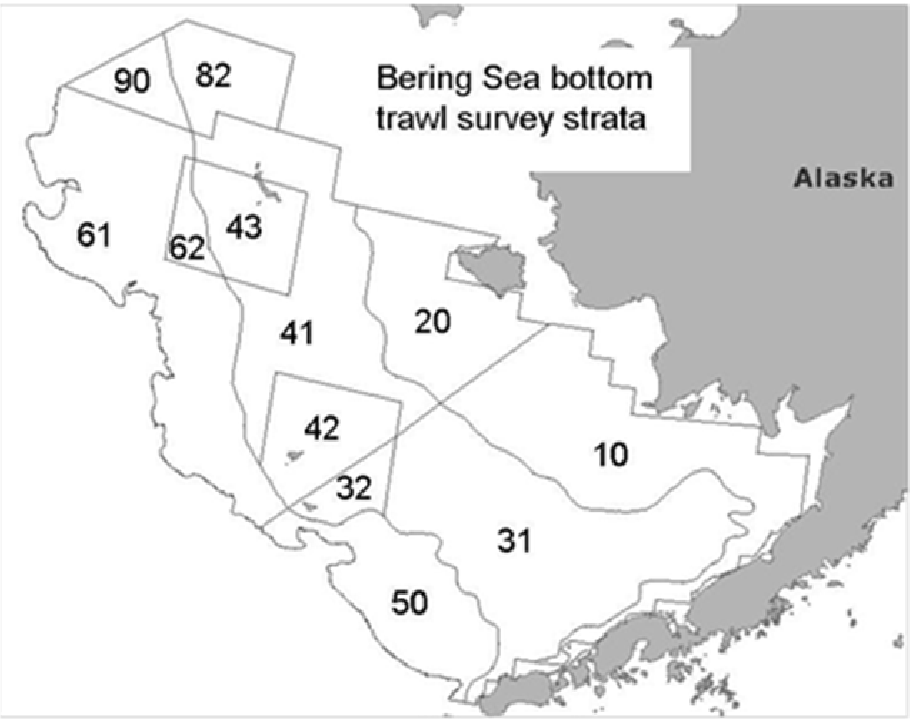

Figure 88: NMFS summer bottom trawl survey strata. Survey strata 31 and 32 were combined as stratum 30; strata 61 and 62 were combined as stratum 60; strata 41, 42, and 43 were combined as stratum 40. Strata 82 and 90 were excluded from analyses because they are not standard survey strata.

residuals were also apparent but varied among species. Alaska plaice residuals were almost always negative in stratum 40. Flathead sole residuals were often positive in strata 40 (Figure 90).

Factors influencing observed trends: One potential factor causing the observed temporal variability in length-weight residuals is temperature. The year 1999 was a particularly cold year in the Bering Sea and also a year of negative length-weight residuals for all groundfish examined (where data existed). Despite the abundant large crustacean zooplankton and relatively high microzooplankton productivity present in 1999 (Hunt et al., 2008), the spatial distribution of some groundfish species is affected by temperatures and a cold year may, therefore, have affected the spatial overlap of fish and their prey. Cold temperatures may have also affected fish energy requirements and prey productivity. Conversely, the warmer than normal 2015 temperatures across the Bering Sea shelf may have resulted in negative trends for length-weight residuals.

Other factors that could affect length-weight residuals include survey sampling timing and fish migration. The date of the first length-weight data collected annually varied from late May to early June (except 1998, where the first data available was collected in late July). Also, the bottom trawl survey is conducted throughout the summer months, and as the summer progresses, we would expect fish condition to improve. Since the survey begins on the inner shelf and progresses to the outer shelf, the higher fish condition observed on the outer shelf may be due to the fact that they are sampled later in the summer and/or differences in spatial distribution of more lipid-rich zooplankton. We also expect that some fish will undergo seasonal and, for some species, ontogenetic

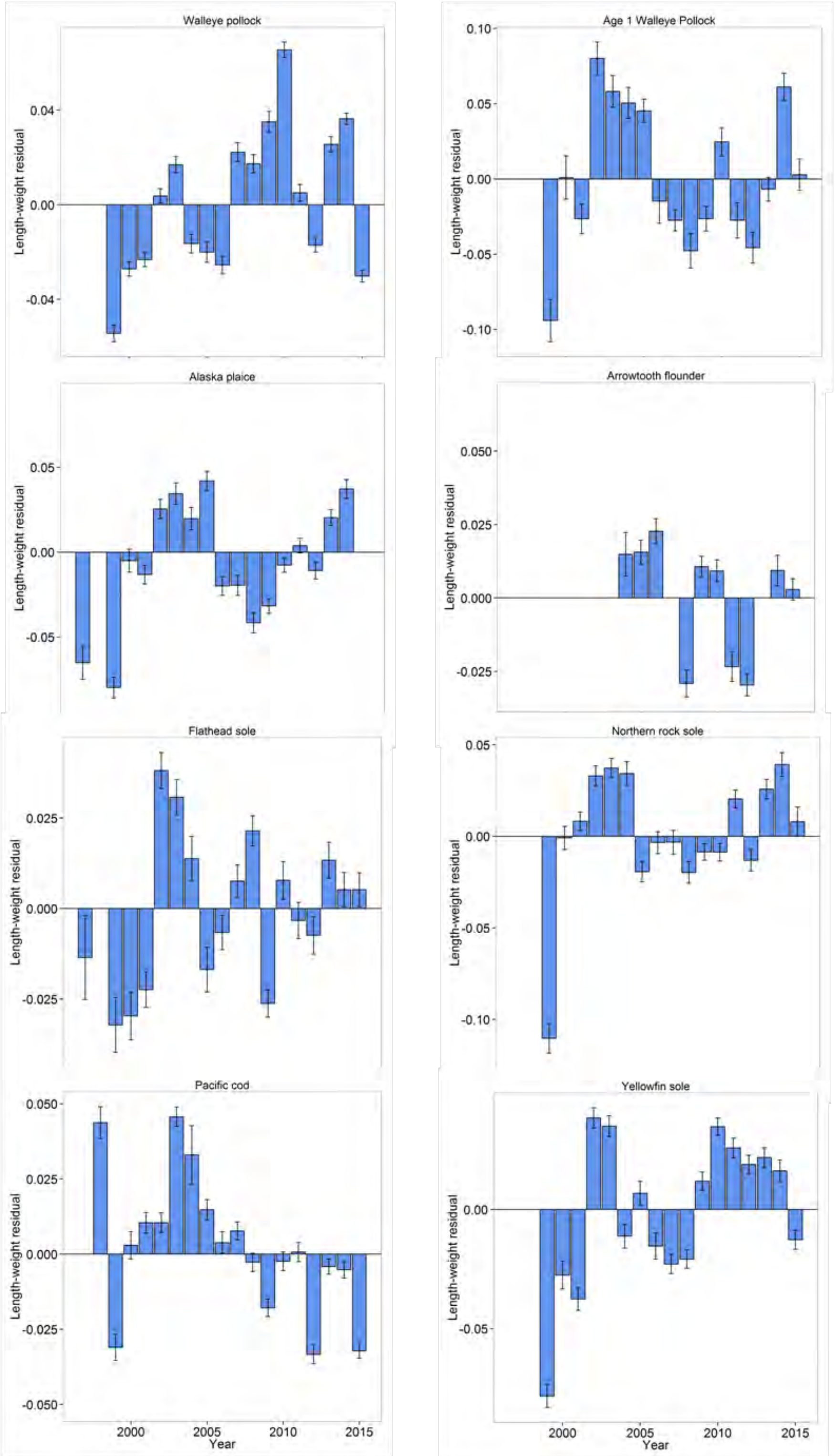

Figure 89: Length-weight residuals for seven Eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997-2014.

migrations through the survey months. For example, seasonal migrations of pollock occur from overwintering areas along the outer shelf to shallow waters (90-140 m) for spawning (Witherell, 2000). Pacific cod concentrate on the shelf edge and upper slope (100-250 m) in the winter, and move to shallower waters (generally <100 m) in the summer (Witherell, 2000). Arrowtooth flounder are distributed throughout the continental shelf until age 4, then, at older ages, disperse to occupy both the shelf and the slope (Witherell, 2000). Flathead sole overwinter along the outer shelf, and move to shallower waters (20-180 m) in the spring (Witherell, 2000). Yellowfin sole concentrate on the outer shelf in the winter, and move to very shallow waters (<30 m) to spawn and feed in the summer (Witherell, 2000). How these migrations affect the length-weight residuals is unknown at this time.

Implications: A fish's condition may have implications for its survival. For example, in Prince William Sound, the condition of herring prior to the winter may in part determine their survival (Paul and Paul 1999). The condition of Bering Sea groundfish, may therefore partially contribute to their survival and recruitment. In the future, as years are added to the time series, the relationship between length-weight residuals and subsequent survival can be examined further. It is likely, however, that the relationship is more complex than a simple correlation. Also important to consider is the fact that condition of all sizes of fish were examined and used to predict survival. Perhaps, it would be better to examine the condition of juvenile fish, not yet recruited to the fishery, or the condition of adult fish and correlations with survival.

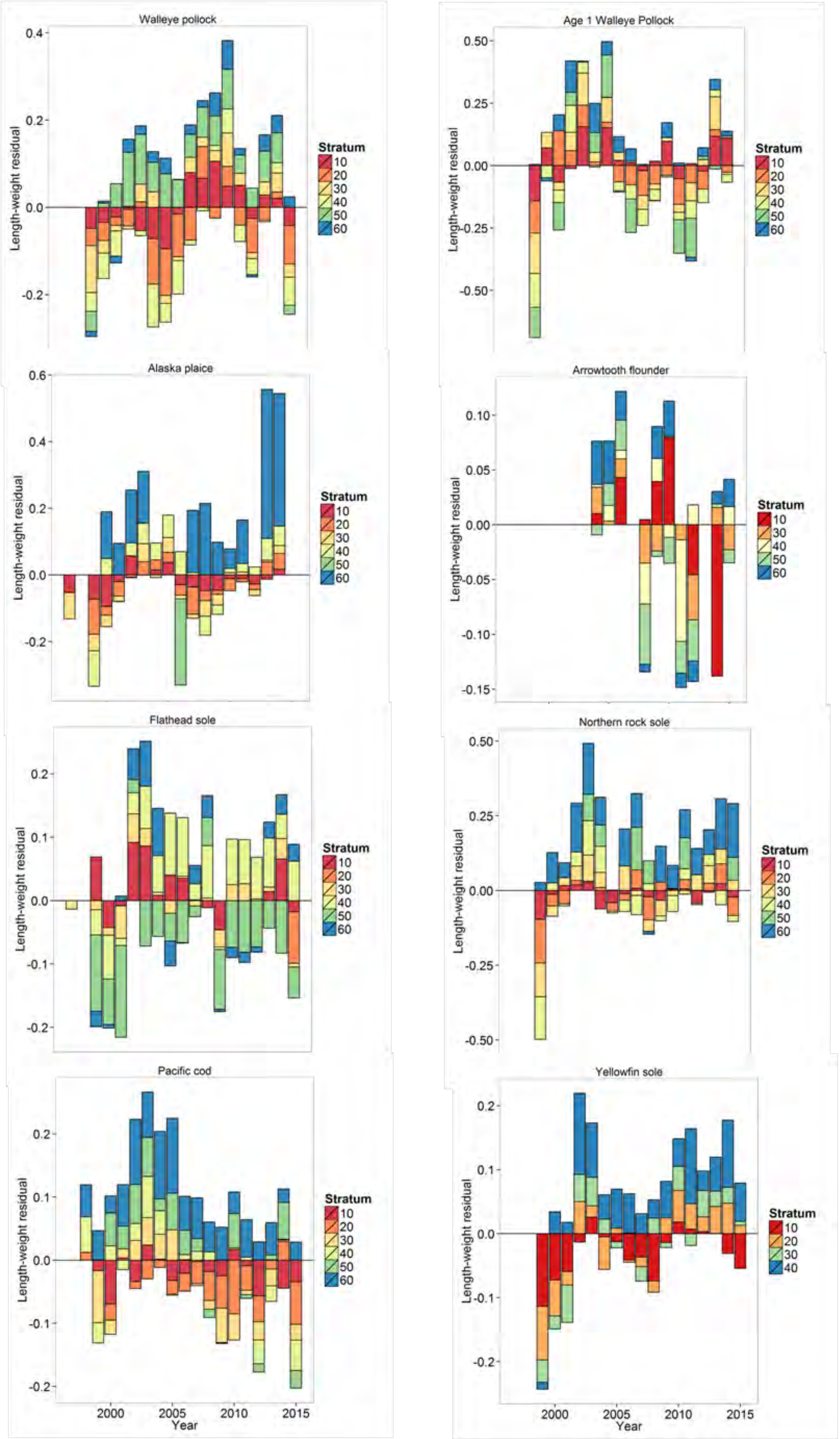

Figure 90: Length-weight residuals for seven Eastern Bering Sea groundfish sampled in the NMFS standard summer bottom trawl survey, 1997-2015, by survey strata (10 - 60).

Gulf of Alaska Groundfish Condition

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Description of indicator: Length-weight residuals are an indicator of somatic growth (Brodeur et al., 2004) and, therefore, a measure of fish condition. Fish condition is an indicator of how heavy a fish is per unit body length, and may be an indicator of ecosystem productivity. Positive length-weight residuals indicate fish are in better condition (i.e., heavier per unit length); whereas, negative residuals indicate fish are in poorer condition (i.e., lighter per unit length). Fish condition may affect fish growth and subsequent survival (Paul et al., 1997; Boldt and Haldorson, 2004). The AFSC Gulf of Alaska bottom trawl survey data was 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 was available (during 1984-2014). 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 91). Residuals for most species where there was data were positive in the first two years of the survey (1985-1987). The residuals have been mixed for all species since then, generally smaller and varying from year to year. The exception might be for Pollock, where there has been a noticeable uptick of fish condition in 3 of the last 5 surveys.

Spatial trends in residuals were also apparent for some species (Figure 92). 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. For Pacific Ocean perch, the Kodiak and Shumagin areas generally had positive length-weight residuals. Arrowtooth flounder was 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

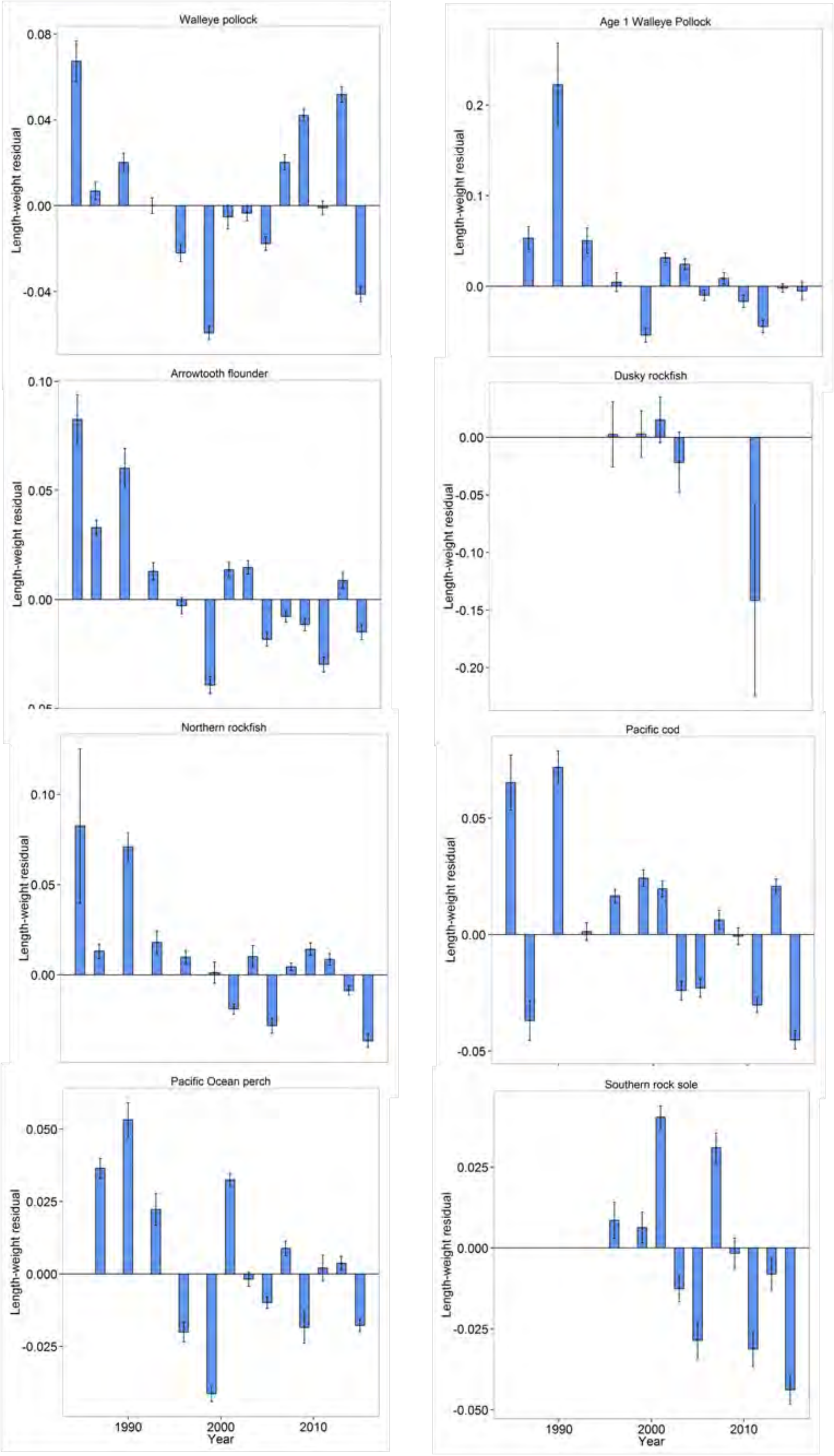

Figure 91: Length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985-2013.

to east. Therefore, it is impossible to separate the in-season time trend from the spatial trend in

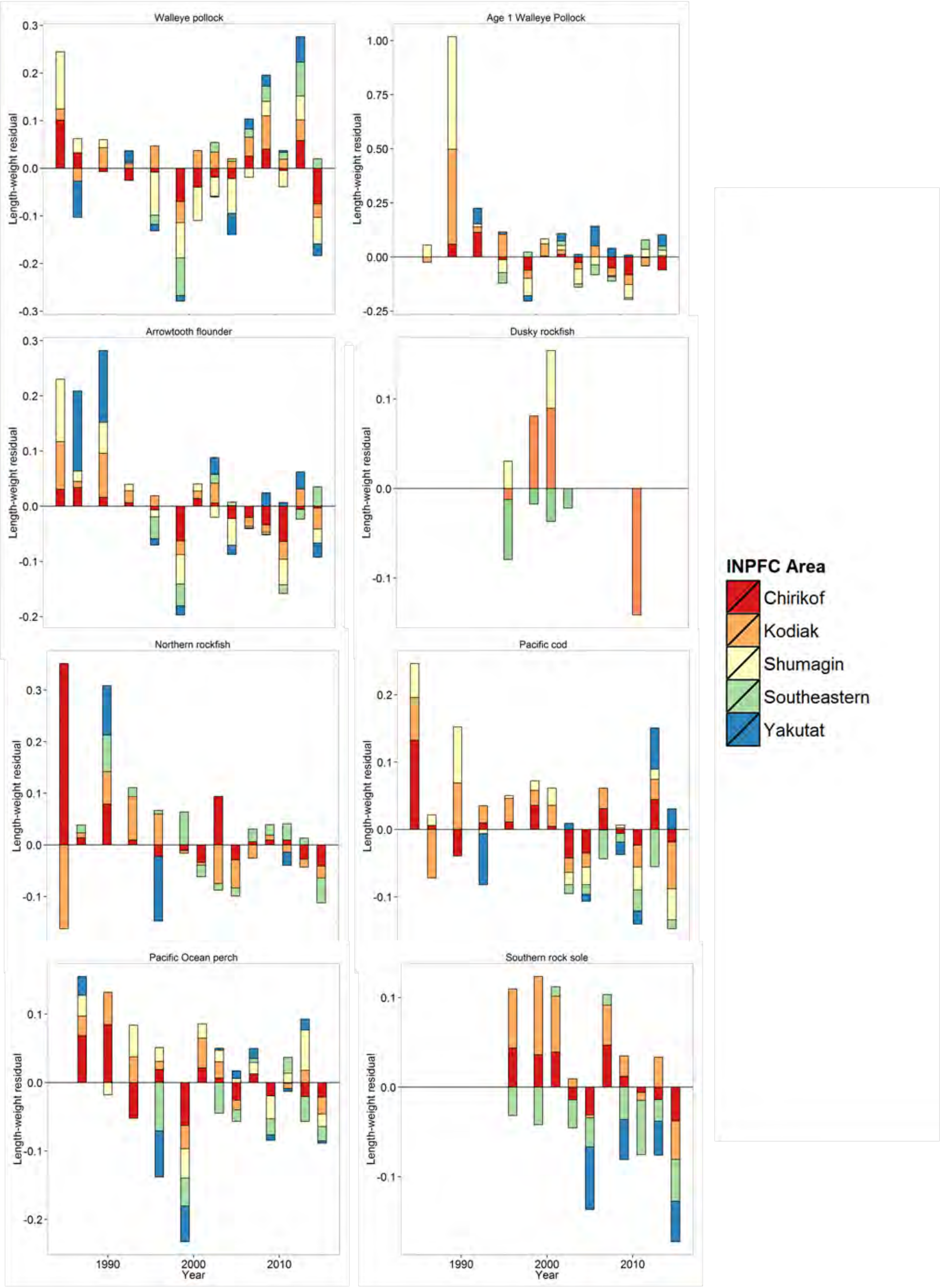

Figure 92: Length-weight residuals for Gulf of Alaska groundfish sampled in the NMFS standard summer bottom trawl survey, 1985-2013, by INPFC area.

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 therefore partially contribute to their survival and recruitment. In the future, as years are added to the time series, the relationship between length-weight residuals and subsequent survival can be examined further. It is likely, however, that the relationship is more complex than a simple correlation. Also important to consider is the fact that condition of all sizes of fish were examined and used to predict survival. Perhaps, it would be better to examine the condition of juvenile fish, not yet recruited to the fishery, or the condition of adult fish and correlations with survival.

Southeast Coastal Monitoring Survey Indices and the Recruitment of Alaska Sablefish to Age-2

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Last updated: August 2015

Description of indicator: Biophysical indices from surveys and fisheries were used to predict the recruitment of sablefish to age-2 from 2011 to 2016 (Yasumiishi et al., 2015). The southeast coastal monitoring project has an annual survey of oceanography and fish in inside and outside waters of northern southeast Alaska (Orsi et al. 2012). Oceanographic sampling included, but was not limited to, sea temperature and chlorophyll *a*. These data are available from documents published through the North Pacific Anadromous Fish Commission website from 1999 to 2012 (`www.npafc.org`) and from Emily Fergusson. 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: Estimated recruitment to sablefish to age-2 was described as a function of late August sea temperature, late August chlorophyll *a*, and a juvenile pink salmon productivity index (based on adult salmon returns to southeast Alaska during the age-1 stage) during the age-0 stage for sablefish (Figure 93; Table 8). A multiple regression model indicated that chlorophyll *a* during the age-0 phase was most strongly correlated with sablefish recruitment ($R^2 = 0.88$; p-value = 0.00006) with a three-fold increases in chlorophyll *a* in 2000 and recruitment (age-2) in 2002. Sea temperature and pink salmon productivity explained an additional 10% of the variation in sablefish recruitment ($R^2 = 0.98$; p-value < 0.00001).

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: The model parameters (2001-2010) and biophyscial indices (2009-2014) were used to predict the recruitment of Gulf of Alaska sablefish (2011-2016). **Above average recruitment of sablefish to age-2 is expected in 2016**.

Distribution of Rockfish Species in Gulf of Alaska and Aleutian Islands Trawl Surveys

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Table 8: Sablefish estimates from Hanselman et al. (2013), predictor variables used in the model (2001-2012), model estimates and standard errors (2001-2012), and forecast estimates (2011-2016); SE = standard error; SST = sea surface temperature.

	Assessment	Model				
	Estimates	Fitted and forecasts		Predictor variables		
Year	Sablefish (t)	Estimates	SE	Chla(t-2)	SST(t-2)	Adult pink salmon (t-1)
2001	11.60	8.93	0.77	2.15	13.4	31,009,547
2002	42.39	42.07	1.50	6.08	12	85,654,226
2003	7.69	9.11	0.64	1.63	12.8	61,929,924
2004	14.43	14.48	0.98	2.64	10.7	72,431,623
2005	6.67	6.56	0.74	1.22	13.1	60,965,661
2006	10.73	10.38	1.27	1.05	14.5	79,033,917
2007	8.42	9.80	0.96	2.68	12.5	21,848,850
2008	9.54	9.66	0.99	2.15	10.8	62,435,599
2009	9.37	10.60	1.01	2.33	14.2	25,406,377
2010	20.75	19.37	0.70	3.59	11.7	50,695,114
2011		10.40	0.72	2.52	12.3	35,196,281
2012		3.10	1.07	0.55	12.7	73,123,947
2013		12.02	1.03	3.06	11.2	32,320,595
2014		17.60	1.75	1.58	12.7	119,898,191
2015		11.67	0.83	1.92	14.2	50,944,432
2016		22.59	0.66	3.73	12.4	58,000,000

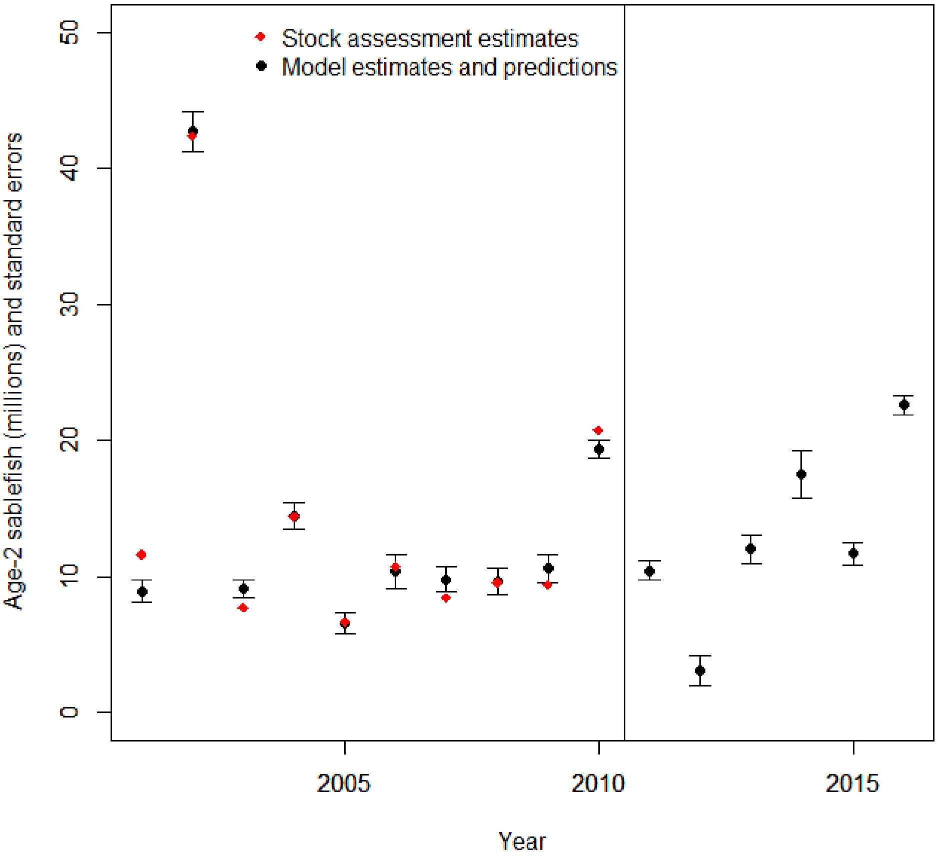

Figure 93: Age-2 sablefish modeled as a function of chlorophyll ^{a} during the age-0 stage (t-2), sea temperature during the age-0 stage (t-2), and juvenile pink salmon productivity during the age-0 stage and overwintering survival to age-1 (based on adult pink salmon in year t-1).

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 and Aleutian Islands. 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: There are two statistically significant depth-related trends over the time series that have continued over the last couple of surveys, as the distribution of both adult rougheye rockfish and shortraker rockfish have been shallower in the most recent surveys of the Aleutian Islands (Figure 94). Northern rockfish have also shown a significant trend over the last few surveys in their mean-weighted distribution towards the western Aleutians. There were no significant trends in mean-weighted temperature distributions for any species and all species were found within about 1°C over the entire time series, although since 2000 the mean-weighted temperature distributions have decreased for most species (∼0.1 - 0.5°C). There was high variability in the mean-weighted variables in the 1991 Aleutian Islands survey, but since then the time series is remarkably stable.

The depth distribution of rockfish in the Gulf of Alaska has remained constant for each species over time (Figure 95). Variability in rockfish distribution with temperature has been higher for most species across the time series than for the other variables. In past contributions, a shift in the distribution of rockfish from the eastern and SE areas of the Gulf of Alaska was noted; however, in the 2015 bottom trawl survey data this trend (although present for all species except dusky rockfish) was not significant.

Factors causing observed trends: The observed changes in depth and spatial distributions for adult rougheye rockfish, shortraker rockfish, northern rockfish, and shortspine thornyhead in the GOA and AI are probably related to changes in overall abundance. Although it is interesting to note that in the cases of adult rougheye rockfish and shortraker rockfish their depth range has become shallower while the temperatures occupied by the species have not changed significantly in recent surveys.

It is unclear why the shift in rockfish distribution from the eastern GOA and SE Alaska was not found in the 2015 survey data. It may be related to increased abundance of major rockfish species in the central and western GOA.

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 94: Plots of mean weighted (by catch per unit effort) distributions of six rockfish species-groups along three environmental variables in the Aleutian Islands. 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.

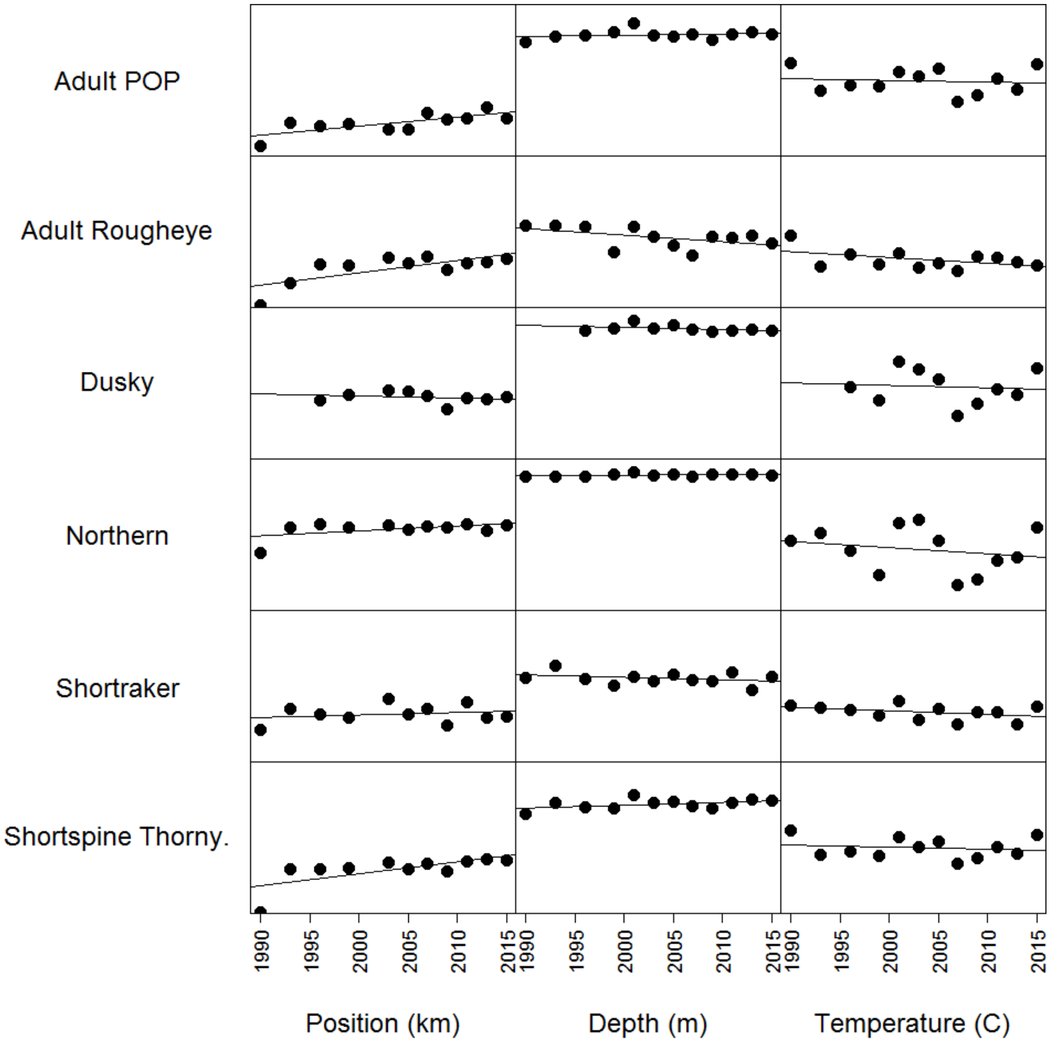

Figure 95: Plots of mean weighted (by catch per unit effort) distributions of six rockfish species-groups along three environmental variables in the Gulf of Alaska. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance 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 - Eastern Bering Sea

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Last updated: October 2015

Description of indicator: “Miscellaneous” species fall into three groups: eelpouts (Zoarcidae), poachers (Agonidae) and sea stars (Asteroidea). The three dominant species comprising the eelpout group are marbled eelpout (*Lycodes raridens*), wattled eelpout (*L. palearis*) and shortfin eelpout (*L. brevipes*). The biomass of poachers is dominated by a single species, the sturgeon poacher (*Podothecus acipenserinus*) and to a lesser extend the sawback poacher (*Sarritor frenatus*). The composition of sea stars in shelf trawl catches are dominated by the purple-orange sea star (*Asterias amurensis*), which is found primarily in the inner/middle shelf regions, and the common mud star (*Ctenodiscus crispatus*), which is primarily an inhabitant of the outer shelf. Relative CPUE was calculated and plotted for each species or species group by year for 1982-2015. Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: The trend in relative CPUE for eelpout and sea star groups was very similar to 2014. The poacher group CPUE increased by 28% with a large increase in relative standard error (Figure 96).

Factors causing observed trends: Determining whether this trend represents a real response to environmental change or is simply an artifact of standardized survey sampling methodology will require more specific research on survey trawl gear selectivity and on the life history characteristics of these epibenthic species.

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

ADF&G Gulf of Alaska Trawl Survey

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Last updated: August 2015

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, 2013). The survey uses a large mesh bottom trawl net. The smallest mesh size in the codend has a 3.2 cm stretch mesh

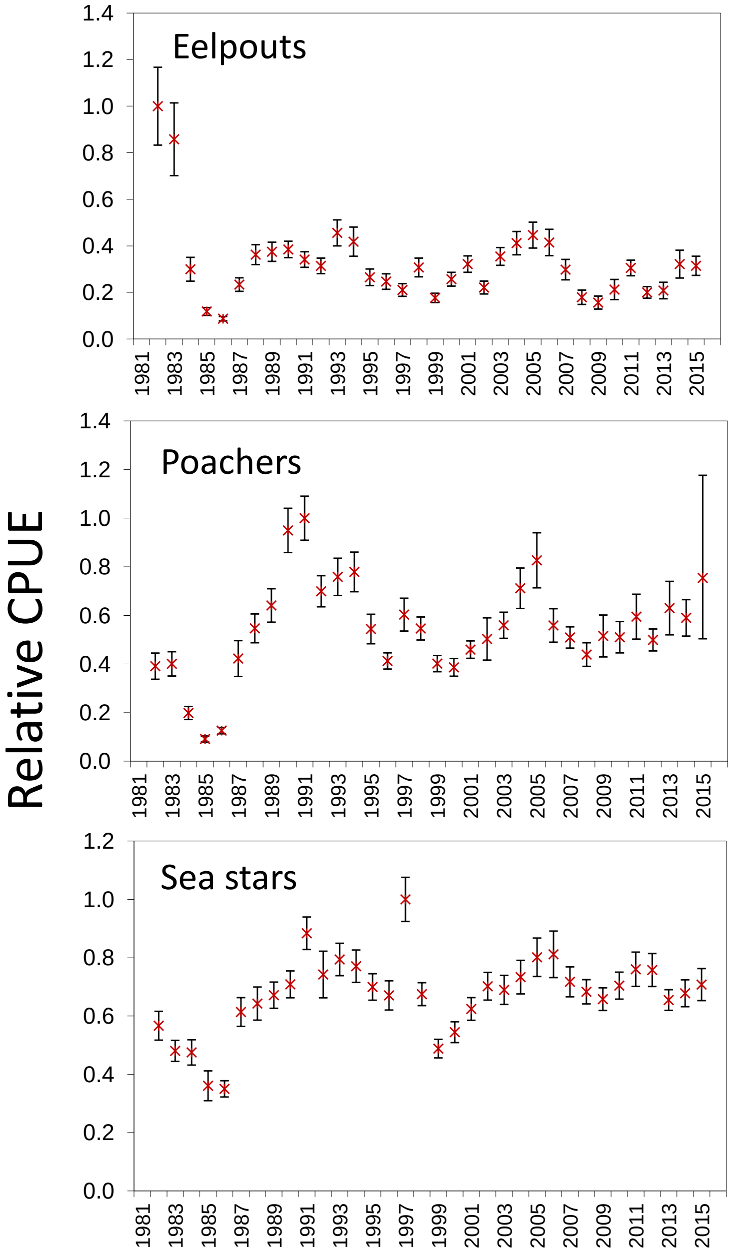

Figure 96: AFSC eastern Bering Sea bottom trawl survey relative CPUE for miscellaneous species during the May to August time period from 1982-2015.

liner, and thus does not sample juvenile fish (e.g., pollock sizes captured in 2014 ranged from 14-79 cm). While the survey covers a large portion of the central and western Gulf of Alaska, results from Kiliuda and Ugak Bays (inshore) and the immediately contiguous Barnabas Gully (offshore) (Figure 97) are broadly representative of the survey results across the region. These areas have been surveyed annually since 1984, but the most consistent time series begins in 1988. In 2014, a total of 371 stations were sampled from June 12 through September 12. Standardized anomalies, a measure of departure from the mean, for the survey catches (kg/km towed) from Kiliuda and Ugak Bays, and Barnabas Gully were calculated and plotted by year for selected species (arrowtooth flounder *Atheresthes stomias*, flathead sole *Hippoglosoides elassodon*, Tanner crab *Chionoecetes bairdi*, Pacific cod *Gadus macrocephalus*, skates, and Pacific halibut *Hippoglossus stenolepis*) using the method described by Link et al. (2002) (Figure 98). Bottom temperatures for each haul have been recorded since 1990 (Figure 99).

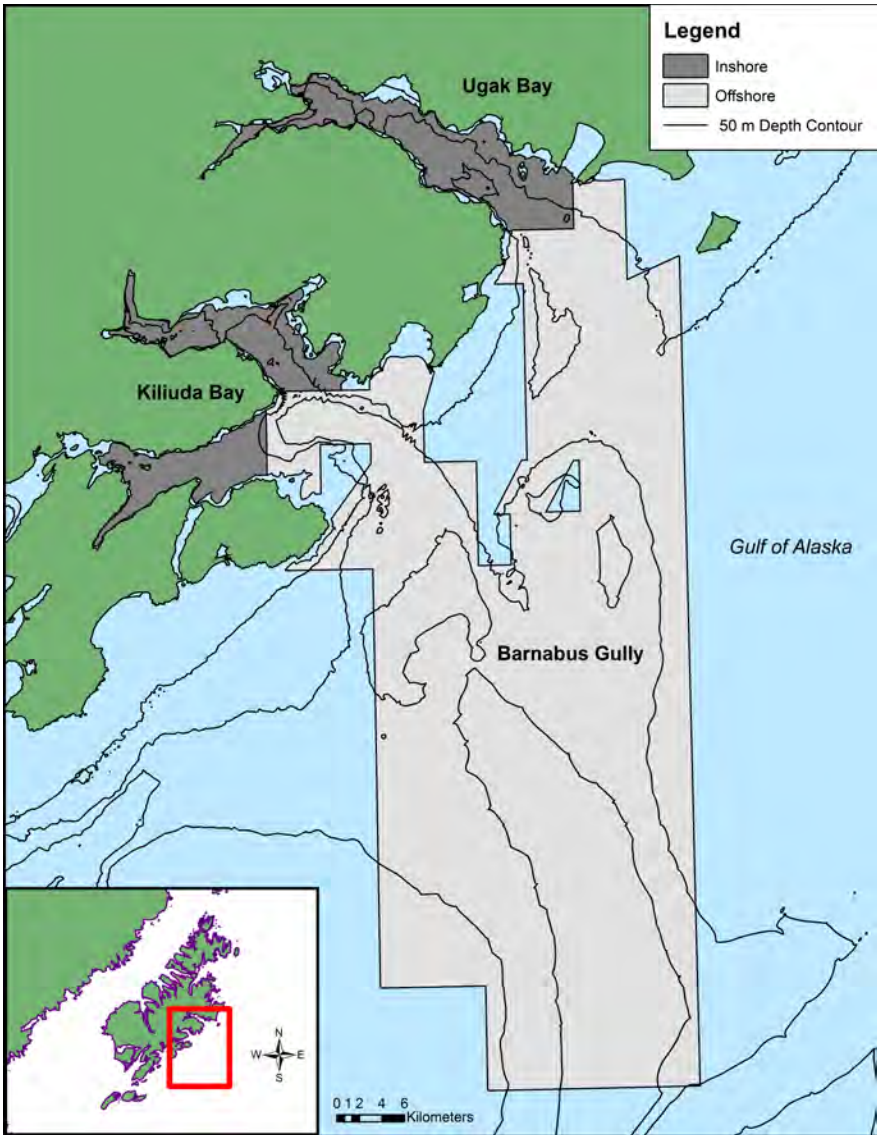

Figure 97: Kiliuda Bay, Ugak Bay, and Barnabus Gully survey areas used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

Status and trends: Arrowtooth flounder, flathead sole, and other flatfish continue to dominate the catches in the ADF&G trawl survey. A decrease in overall biomass is apparent from 2007 to 2014 from years of record high catches seen from 2002 to 2005 (Figure 100).

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

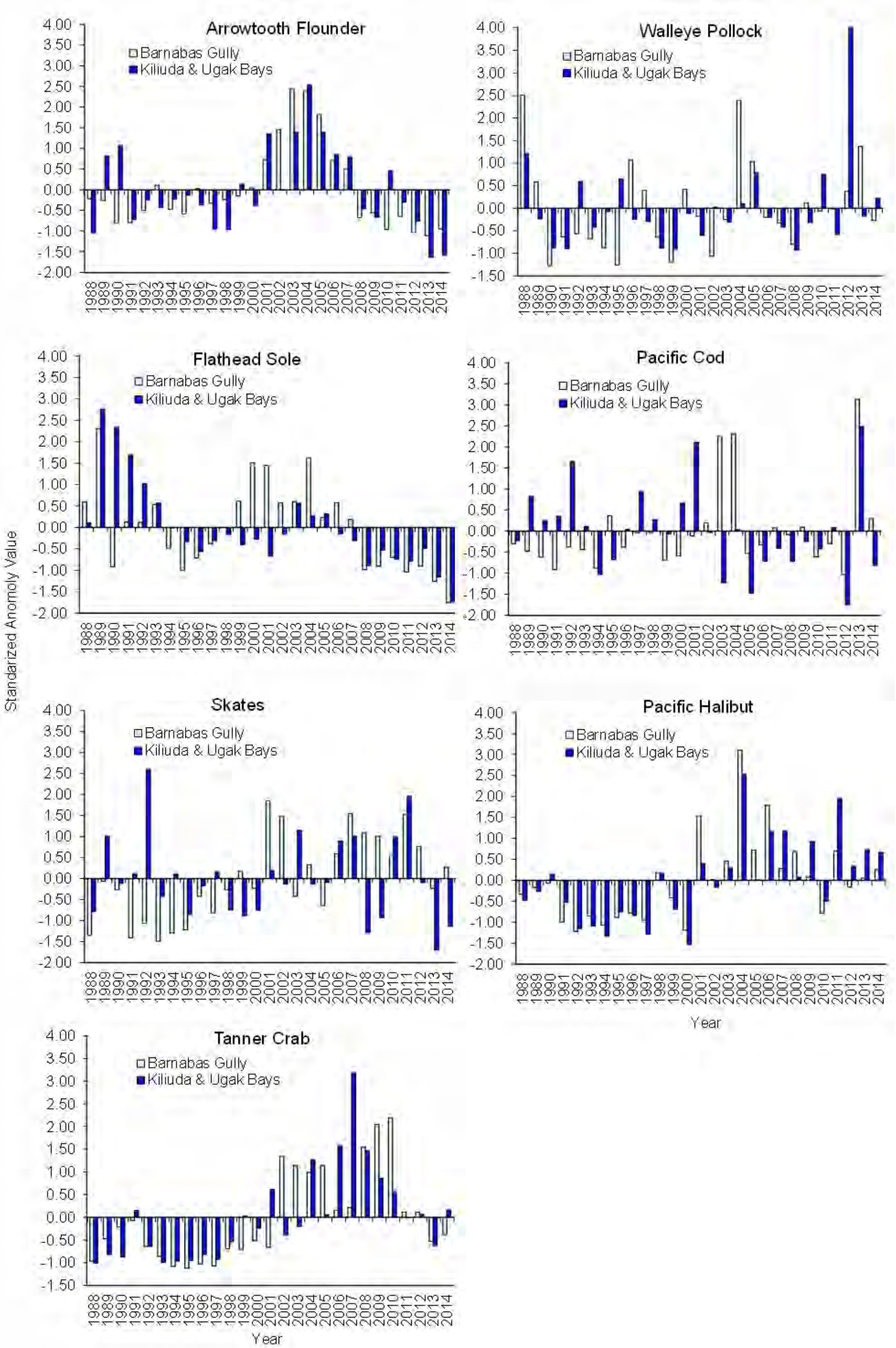

Figure 98: A comparison of standardized anomaly values for selected species caught from 1988-2014 in Barnabas Gully and Kiliuda and Ugak Bays during the ADF&G trawl survey.

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 2014 with Pacific

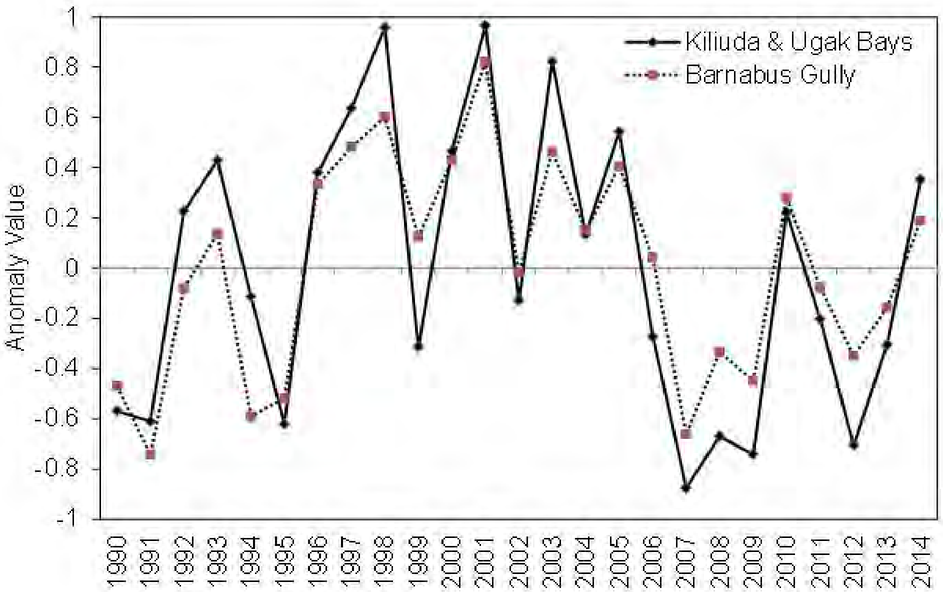

Figure 99: Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2014, with corresponding El Niño years represented.

cod making up 18% of catch and walleye pollock 82%.

In 2014, overall gadid catches have slightly decreased in offshore area of Barnabus Gully and in the inshore areas of Kiliuda and Ugak Bays (Figure 100). Below average anomaly values for arrowtooth flounder and flathead sole were recorded for both inshore and offshore areas, while Pacific halibut were well above average (Figure 98). Skates and Pacific cod anomaly values were below average for the inshore areas, while Tanner crab and walleye pollock were below average for the offshore areas.

Temperature anomalies for both inshore, Kiliuda and Ugak Bays and offshore stations, Barnabas Gully, from 1990 to 2014, show similar oscillations with periods of above average temperatures corresponding to the strong El Niño years (1997-1998; Figure 99; `http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html`). Cooler temperatures were apparent from 2011 to 2013, with temperatures markedly increasing in 2014.

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 100) 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 2006, corresponds to years of greatest production and corresponding catches. Lower than average temperatures have been recorded from 2007 to 2009 along with decreasing overall abundances. This may 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 and need to be studied further. Monitoring these trends is an important process used in establishing harvest levels for state water fisheries.

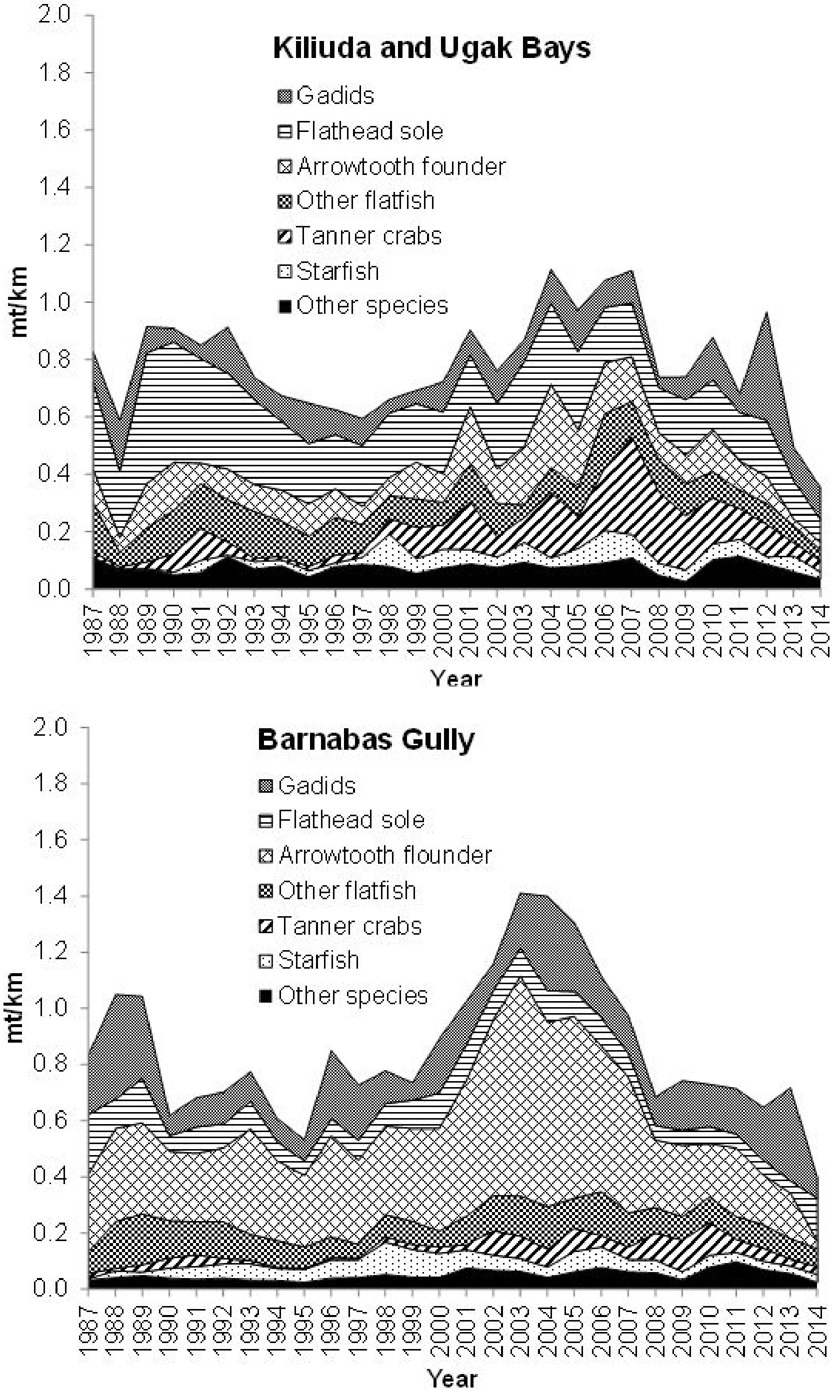

Figure 100: Total catch per km towed (mt/km) of selected species from Barnabus Gully and Kiliuda and Ugak Bay survey areas off the east side of Kodiak Island, 1987 to 2014.

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

Miscellaneous Species - Gulf of Alaska

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Last updated: October 2015

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 central GOA and they are consistently captured in 50% of bottom trawl hauls in all areas (Figure 101). Eelpout CPUE has been variable, with peak abundances occurring in 1993, 2001 and 2009 in the western GOA, 2003 and 2011 in the central GOA and peak catches since 1999 in the eastern GOA. Poacher CPUE has been in decline since the peak in 1993. Poachers have been uniformly in low abundance in the eastern GOA and have been variable, but somewhat higher in the central GOA. All species have shown increases over the last few surveys in the central GOA.

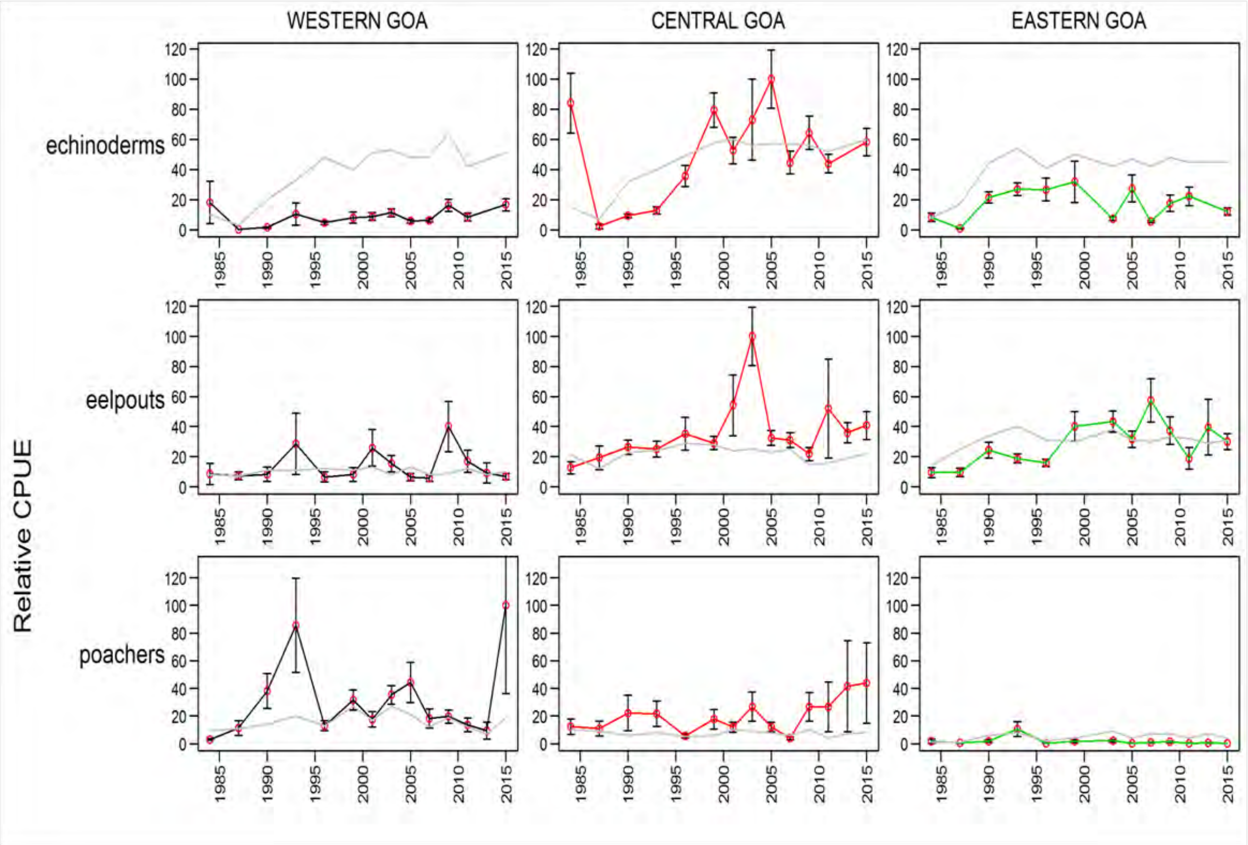

Figure 101: Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Gulf of Alaska from 1984 through 2015. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches.

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: GOA survey results provide limited information about abundance or abundance trends for these species due to problems in catchability. Therefore, the indices presented are likely of limited value to fisheries management.

Seabirds

Multivariate Seabird Indicators for the Eastern Bering Sea

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Last updated: Oct 2015

Description of indicator: The index is derived from the first two principal components of a principal components analysis (PCA) that combines reproductive effort data (mean hatch date and reproductive success) from common murre *Uria aalge*, thick-billed murre *U. lomvia*, black-legged kittiwake *Rissa tridactyla*, red-legged kittiwake *R. brevirostris*, and red-faced cormorants *Phalacrocorax urile* breeding on the Pribilof Islands. Data are collected by the USFWS Alaska Maritime National Wildlife Refuge. The most recent PCA includes 17 individual data sets spanning 1996 to 2015.

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

Status and trends: The PCA on the 20 yr annual time series (1996-2015) explained 66.4% of the variance in the data in the first two components. All seabird phenology and red-faced cormorant and common murre reproductive success time series were associated (loadings ≥ 0.2) with PC1, which explained 43.6% of the total variance (Figure 102). All kittiwake and St. Paul thick-billed murre reproductive success time series were strongly associated (loadings ≥ 0.3) with PC2, which explained 22.7% of the total variance. Also, St. George thick-billed murre reproductive success, which grouped with kittiwake reproductive success in PC2 in previous years, was not associated with either PC.

The temporal trend in PC1 had been increasing since 2011, but dropped sharply in 2015. This indicates that that there were later hatch dates for all species and lower reproductive success for cormorants and common murres (Figure 103). The dominant temporal trend among kittiwake reproductive success data is an alternating biennial pattern. PC2 continued the nearly annual trend reversal with the 2015 value showing a decrease from the previous year and indicating a decrease in kittiwake reproductive success.

Factors influencing observed trends: Time series analysis of PC1 and PC2, calculated from 1996-2011 data, against selected environmental variables showed significant, but in most cases, lagged relationships between ocean conditions and seabird reproductive effort (Zador et al., 2013). Warmer bottom and surface temperatures, greater wind mixing and higher stratification correlated with delayed and lower productivity for most seabirds up to 2 years later. Later ice retreat was correlated with lower kittiwake productivity 2 years later, but higher local abundances of age-1 walleye pollock were linked to higher kittiwake productivity the following year. The biennial pattern

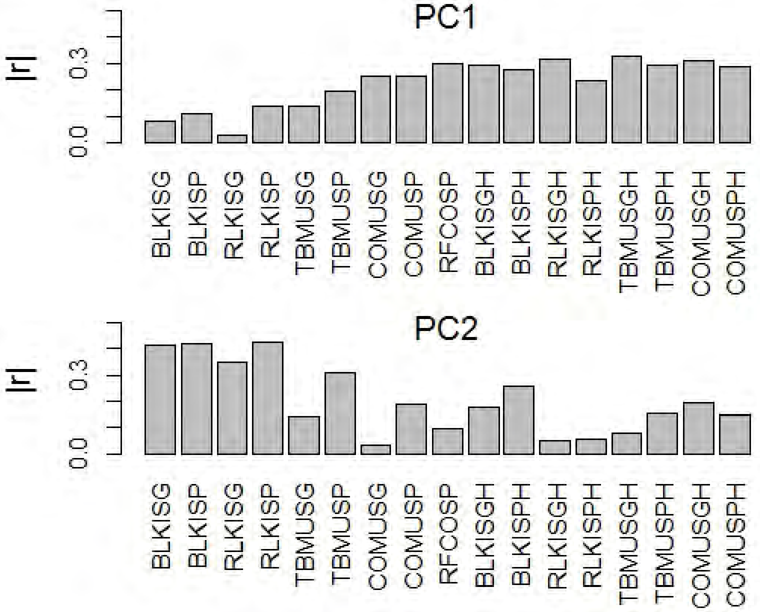

Figure 102: Loadings (absolute correlations) measuring the strength of association between individual time series and the first (PC1, top) and second (PC2, bottom) principal components. The datasets are labeled in order with a 4-letter bird species code following American Ornithological Union convention (e.g., BLKI: black-legged kittiwake), a 2-letter island code (SP: St. Paul; SG: St. George), and H if it is a hatch date time series.

in PC2 negatively correlates with pink salmon abundance using the reconstructed Kamchatka pink salmon run size through 2012 from (Springer and van Vliet, 2014))(t = 3.5, p = 0.003).

Implications: These results indicate that 2015 was a poor reproductive year for Pribilof seabirds. The eastern Bering Sea and the North Pacific, where many Pribilof seabirds overwinter, experienced the second warm year after several sequential cold years. These oceanographic changes have influenced biological components of the ecosystem, which appears to have negative influences on seabird reproductive activity. Also, years of high pink salmon abundance, the odd-numbered years after 1997, correlate with poor kittiwake productivity. This correspondence may be a result of competition between abundant zooplanktivorous pink salmon and kittiwakes or related responses to environmental conditions. The winter distribution of kittiwakes overlaps with the pink salmon in the North Pacific, thus broad-scale environmental exposure may be similar.

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

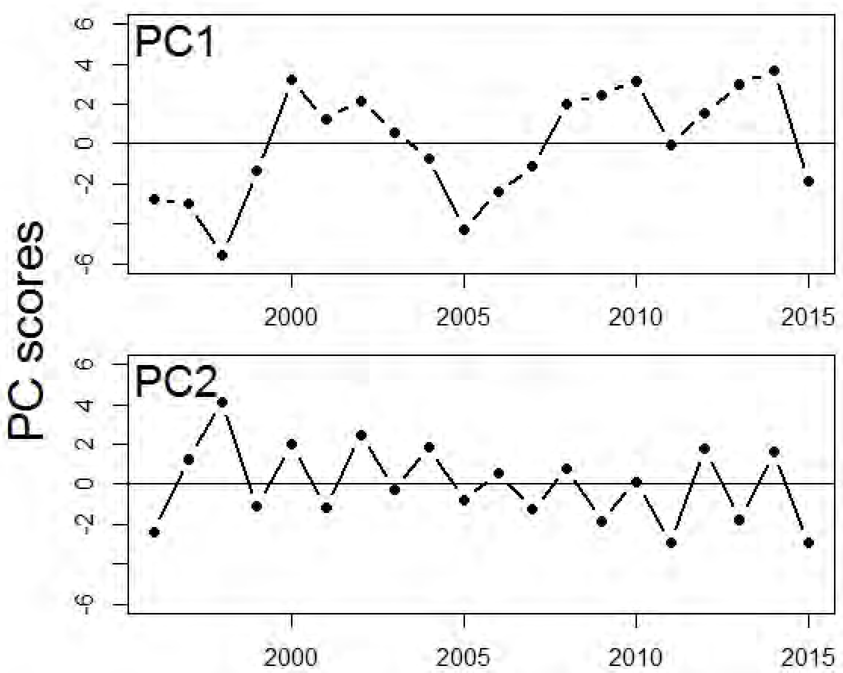

Figure 103: The value of PC1 (top) and PC2 (bottom) over time. Higher values of PC1 indicate earlier seabird hatch dates and higher cormorant and common murre reproductive success. Higher values of PC2 indicate higher kittiwake reproductive success, and to a lesser degree, St. Paul thick-billed murre reproductive success

Marine Mammals

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

There are no updates to marine mammal indicators in this year's report. See the appendix for a list of indicators not updated, and see the contribution archive for previous indicator submissions at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Ecosystem or Community Indicators

Early Warning Indicators

Contributed by Mike Litzow[1] and Bob Lauth[2]
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Last updated: November 2014

Description of indicator: Early warning indicators (EWI), such as rising variance and autocorrelation in key system parameters, are expected to detect an increased risk of a tipping point to an alternate state in a population or community. Increases in these statistics are proposed as indicators of "critical slowing down" as a system loses resilience and becomes more prone to an abrupt shift (Scheffer et al., 2009). Empirical studies applying EWI to real ecosystems are becoming more common (Scheffer et al., 2012), and there is some indication that inflated EWI have preceded historic fisheries collapses and community shifts in Alaska (Litzow et al., 2008, 2013).

We tested three EWI (spatial variability in CPUE, spatial correlation in CPUE, temporal autocorrelation in CPUE) for 23 well-sampled taxa in the Bering Sea trawl survey time series (1982-2014). During 2006-13, Bering Sea temperatures fell to cold levels not seen since the 1976/77 regime shift, and our hypothesis was that decreased resilience in the post-1976/77 community during this cold anomaly would be reflected in increasing values of the three EWI.

Status and trends: Even after adjusting α to account for multiple hypothesis testing, the null hypothesis (EWI not inflated in 2006-13 relative to 1982-2005) was rejected in 22 of the 69 indicator-taxon combinations (community-wide randomization test, $p < 0.00001$). Four taxa (Tanner crab, rock sole, Alaska plaice, shortfin eelpout) showed significant increases in two indicators, and two taxa (walleye pollock and yellowfin sole) showed significant increases in all three indicators (Figure 104).

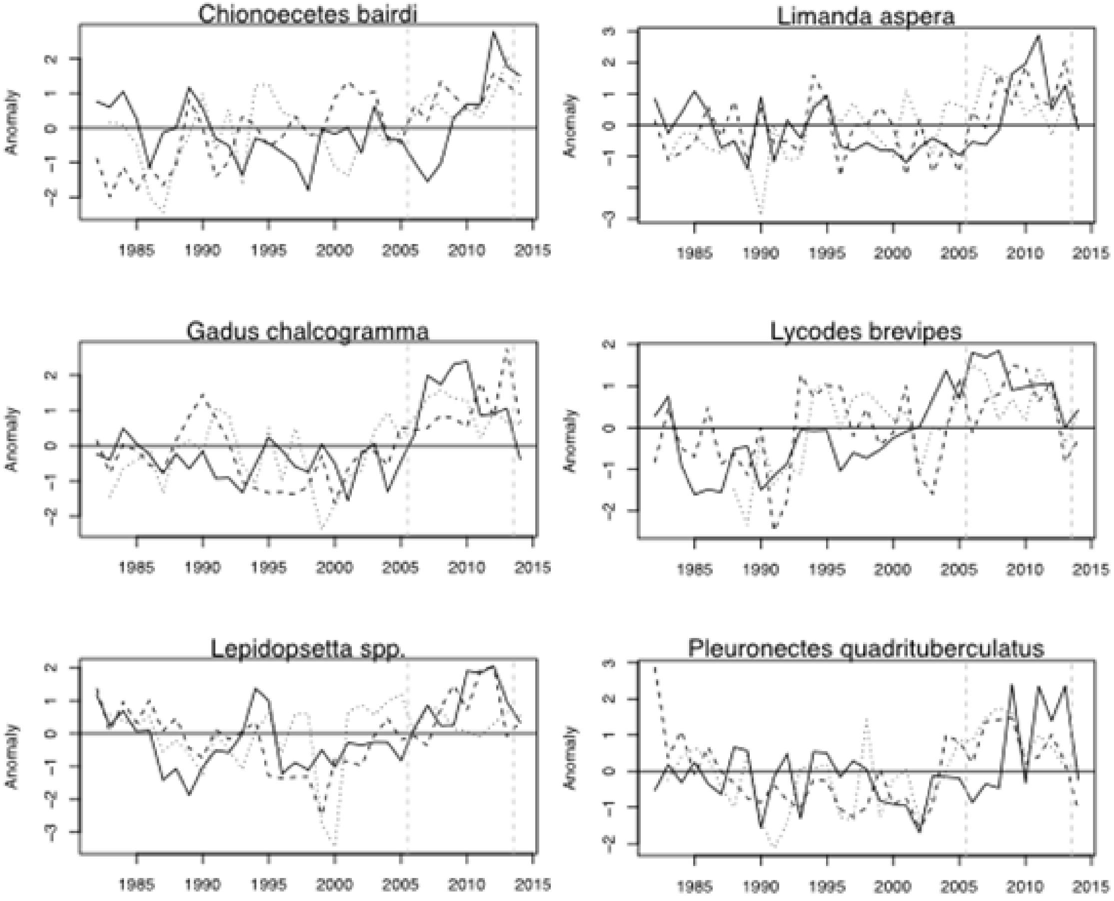

Figure 104: Early warning indicator (EWI) time series for Bering Sea taxa showing significant increases in 2 indicators. Solid lines = spatial variability in CPUE (SD of log-transformed data), dashed lines = spatial correlation in CPUE (Moran's I), dotted lines = temporal autocorrelation in CPUE (AR1). Vertical dashed lines delineate cold period (lines at 2005.5 and 2013.5) .

In 2014, when bottom temperatures reverted to "warm" conditions, (3.2°C, 1.5°C above the 2006-2013 mean), 11 of the 22 inflated EWIs showed significant declines from their 2006-13 values (randomization test, p = 0.004).

Factors influencing observed trends: The inflated EWI that we observed are consistent with degraded resilience in the Bering Sea demersal community during the 2006-13 cold anomlay. There is some possibility that increases in CPUE variability and autocorrelation are merely an artifact of cold-dependent distributional changes in sampled taxa. However, further analysis not presented here suggests that temperature-dependent changes in distribution are unlikely to explain the inflated EWI we observed.

Implications: These results are consistent with declining community resilience during the cold period, and recovered resilience with warming in 2014. The application of EWI in fisheries management is at a very early state, and these results suggest the potential value in monitoring the variance and autocorrelation of key parameters, rather than mean values.

Total Catch-Per-Unit-Effort of All Fish and Invertebrate Taxa in Bottom Trawl Surveys

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[2]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2014

Description of indicator: The index provides a measure of the overall biomass of demersal and benthic fish and invertebrate species. We obtained catch-per-unit-effort (CPUE in kg ha) of fish and major invertebrate taxa for each successful haul completed during standardized bottom trawl surveys on the eastern Bering Sea shelf (EBS, 1982-2014) and on the Gulf of Alaska shelf (GoA, 1993-2013). 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 across the survey region, we modeled log-transformed total CPUE (N = 12,210, 5728, and 1,422 hauls in the EBS, western GoA, and eastern GoA, respectively) as smooth functions of depth, Julian Day and location (latitude / longitude in the EBS, alongshore distance, sampling stratum, and depth in the GoA) using Generalized Additive Models following (Mueter et al., 2002). Hauls were weighted based on the area represented by each station. The CPUE index does not account for gear or vessel differences, which are strongly confounded with interannual differences and may affect results prior to 1982 in the Bering Sea. Data prior to 1990 was not included for the Gulf of Alaska, to avoid confounding due to gear and vessel issues.

Status and trends: Total log(CPUE) in the EBS shows an apparent long-term increase from 1982-2005, followed by a decrease from 2005 to 2009, increased CPUE in 2010-2013, and a substantial increase in 2014 to the highest observed value in the time series (Figure 105). Estimated means prior to 1988 may be biased due to unknown gear effects and because annual differences are confounded with changes in mean sampling date, which varied from as early as June 15 in 1999 to as late as July 16 in 1985. On average, sampling occurred about a week earlier in the 2000s compared to the 1980s. Recent changes in CPUE in the EBS have been most pronounced on the middle-shelf, which is occupied by the cold pool during cold years. Higher CPUEs on the middle shelf during the 2001-2005 warm period appeared to be related to the increasing colonization of this area by subarctic demersal species (Mueter and Litzow, 2008). Total log(CPUE) in the western GoA varied over time with lowest abundances observed in 1999 and 2001, but no significant trend over the 20-year time period from 1993 to 2013 (Figure 106). The eastern GoA shows a significantly increasing trend in CPUE over time (Simple linear regression, t=2.914, p = 0.0225).

Factors influencing observed trends: Commercially harvested species account for over 70% of survey catches. Fishing is expected to be a major factor determining trends in survey CPUE, but environmental variability is likely to account for a substantial proportion of the observed variability in CPUE through variations in recruitment, growth, and distribution. The increase in survey CPUE in the EBS in the early 2000s primarily resulted from increased abundances of walleye pollock and

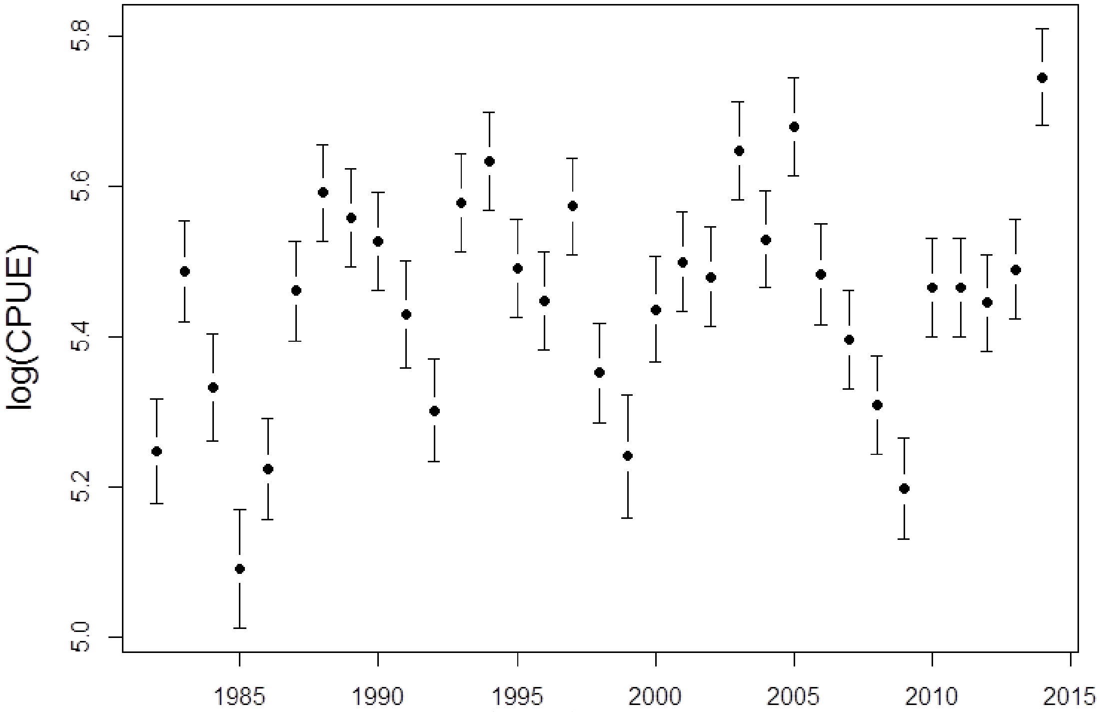

Figure 105: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2012 in the Bering Sea with approximate pointwise 95% confidence intervals and linear time trend. Estimates were adjusted for differences in depth, day of sampling, net width and sampling location among years. Gear differences prior to 1988 were not accounted for. A linear time trend based on generalized least squares regression assuming 1st order auto-correlated residuals was not significant ($t = 1.221$, $p = 0.232$).

a number of flatfish species (arrowtooth flounder, yellowfin sole, rock sole, and Alaska plaice) due to strong recruitments in the 1990s. Decreases in 2006-2009 are largely a result of decreases in walleye pollock abundance. Increases in pollock and Pacific cod biomass in 2010 resulted in the observed increase in log(CPUE). In addition, models including bottom temperature suggest that, in the EBS, CPUE is greatly reduced at low temperatures ($< 1^{\circ}$C) as evident in reduced CPUEs in 1999 and 2006-2009, when the cold pool covered a substantial portion of the shelf. Overall, there is a moderate positive relationship between average bottom temperatures and CPUE in the same year ($r = 0.51$, $p = 0.010$), but not in the following years. The reduction in CPUE during cold periods is likely due to a combination of actual changes in abundance, temperature-dependent changes in catchability of certain species (e.g. flatfish, crab), and changes in distribution as a result of the extensive cold pool displacing species into shallower (e.g. red king crab) or deeper (e.g. arrowtooth flounder) waters.

Increases in CPUE in the GoA between 1999/2001 and 2003 were largely due to a substantial increase in the abundance of arrowtooth flounder, which accounted for 43% of the total survey biomass in 2003 in the western GOA. The significant increase in total CPUE in the eastern GoA was associated with increases in arrowtooth flounder (particularly 1990-93), several rockfish species, Pacific hake, and spriny dogfish. The increase in total CPUE in the Bering Sea in 2014 was largely due to an increase in walleye pollock catches in the bottom trawl survey.

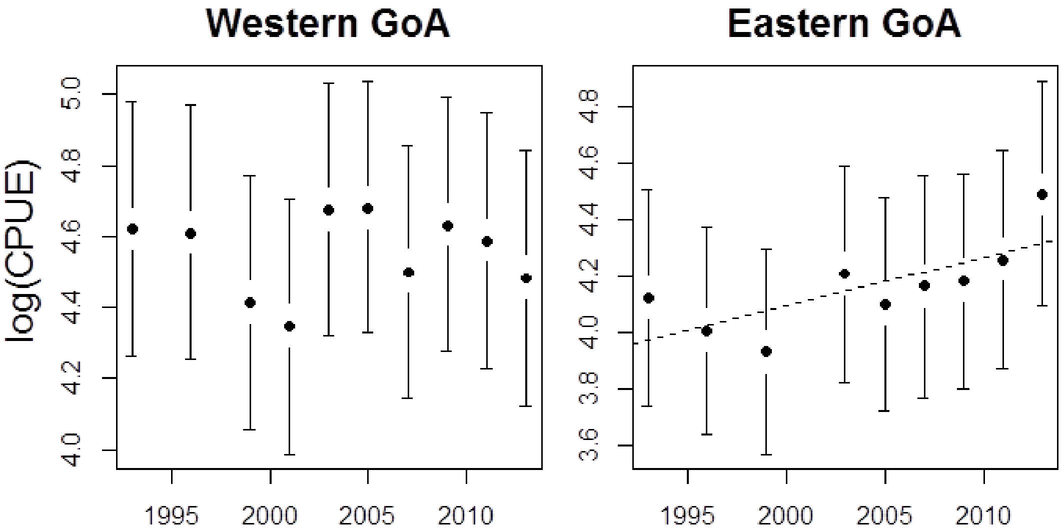

Figure 106: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from in the western Gulf of Alaska (west of 147°W) by survey year with approximate 95% confidence intervals. Estimates were adjusted for differences in depth and sampling locations (alongshore distance) among years. Linear trend in eastern GOA based on generalized least squares regression assuming 1st order auto-correlated residuals (t = 3.258, p = 0.014).

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

Average Local Species Richness and Diversity of the Groundfish Community

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Last updated: October 2014

Description of indicator: This section provides indices of local species richness and diversity based on standard bottom trawl surveys in the eastern Bering Sea (EBS), western Gulf of Alaska (wGOA), and eastern Gulf of Alaska (eGOA). We computed the average number of fish and major invertebrate taxa per haul (richness) and the average Shannon index of diversity (Magurran, 1988) by haul based on CPUE (by weight) of each taxon. Indices for the EBS were based on 45 fish and invertebrate taxa that were consistently identified throughout all surveys since 1982 (Table 1 in Mueter and Litzow (2008), excluding Arctic cod because of unreliable identification in early years). Indices 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), depth, and date of sampling. In addition to trends in the indices over time, we mapped average spatial patterns for each index across the survey region.

Status and trends: Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2014 (Figure 107). The average number of species per haul increased by one to two species from 1995 to 2004, remained relatively high through 2011 and both richness and diversity have decreased since then. Richness tends to be highest along the 100 m isobaths, while diversity tends to be highest on the middle shelf (Figure 108). Local richness and diversity are lowest inshore and in the northern part of the survey region.

Richness and diversity are generally higher in the eastern Gulf of Alaska than in the western Gulf with, on average, 2-3 additional species per haul in the east (Figure 109). Richness has been relatively stable in the western Gulf with relatively low richness in recent years. Local species richness in the eastern Gulf increased substantially in 2013, while diversity has been declining slightly since 2007 (Figure 109). Both richness and diversity tend to be highest along the shelf break and slope (Figure 110), with richness peaking at or just below the shelf break (200-300m), and diversity peaking deeper on the slope. Other regions of locally higher richness and diversity include the banks and troughs off the Kenai Peninsula and nearshore areas of Kodiak Island and in Cook Inlet.

Factors influencing observed trends: The average number of species per haul depends on the spatial distribution of individual species (or taxa). If species are, on average, more widely distributed in the sampling area the number of species per haul increases. Spatial shifts in distribution from year to year can cause high variability in local species richness in certain areas, for example along the 100m contour in the Eastern Bering Sea. These shifts appear to be the primary drivers of changes in species richness. Local species diversity is a function of how many species are caught in a haul and how evenly CPUE is distributed among the species. Both time trends (Figures 107

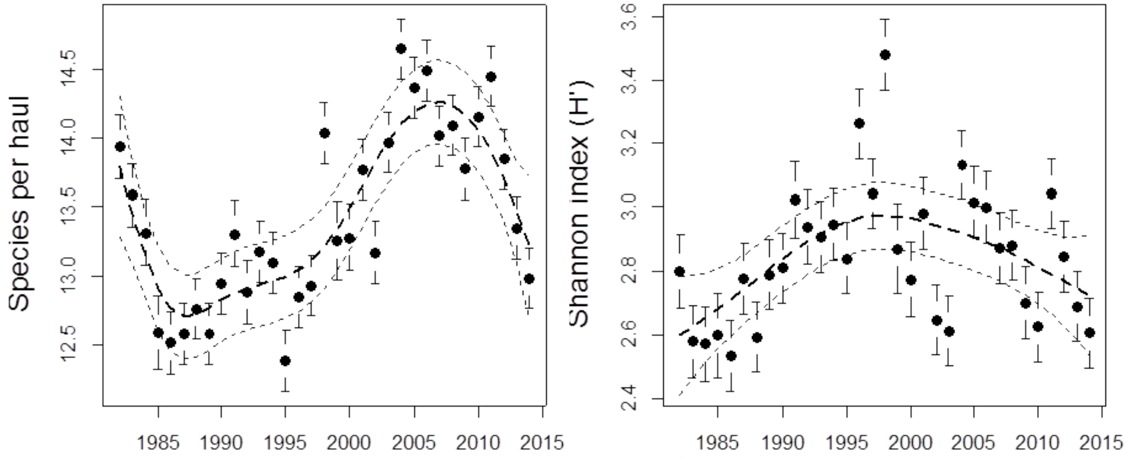

Figure 107: Model-based annual averages of species richness (average number of species per haul, dots), and species diversity (Shannon index) in the Eastern Bering Sea, 1982-2014, based on 45 fish and invertebrate taxa collected by standard bottom trawl surveys with pointwise 95% confidence intervals (bars) and loess smoother with 95% confidence band (dashed/dotted lines). Model means were adjusted for differences in depth, date of sampling, and geographic location.

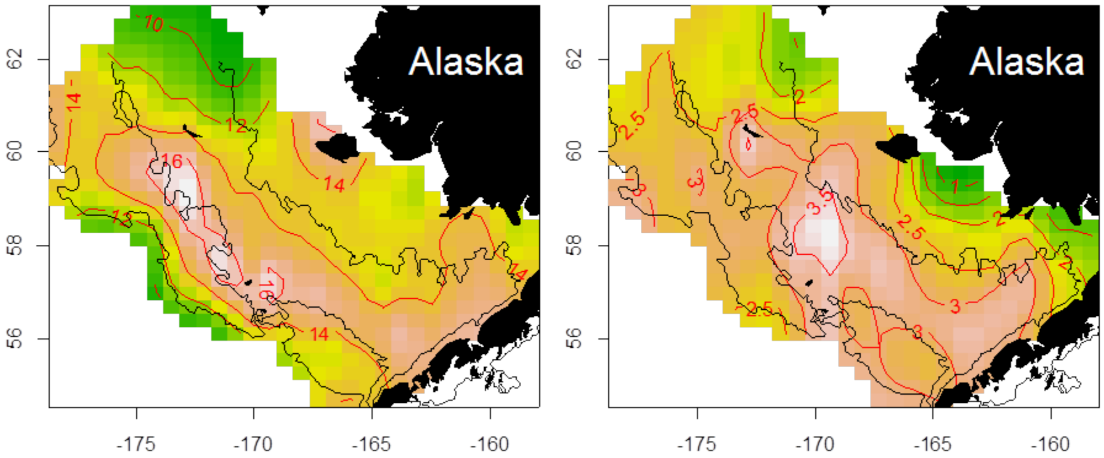

Figure 108: Average spatial patterns in local species richness (left, number of taxa per haul) and Shannon diversity in the Eastern Bering Sea. The 50m, 100m, and 200 m depth contours are shown as black lines. Color scales is from highest (white) to lowest (green). Note highest richness along 100 m contour, highest diversity on middle shelf.

and 109 and spatial patterns in species diversity (Figures 108 and 110) differed markedly from those in species richness. For example, low species diversity in 2003 in the EBS occurred in spite of high average richness, primarily because of the high dominance of walleye pollock, which increased from an average of 18% of the catch per haul in 1995-98 to 30% in 2003, but decreased again to an average of 21% in 2004. The increase in species richness in the EBS, which was particularly pronounced on the middle shelf, has been attributed to subarctic species spreading into the former cold pool area as the extent of the cold pool decreased from 1982 to 2005 (Mueter and Litzow, 2008).

However, species diversity has been relatively low in recent years, compared to the 1990s, which

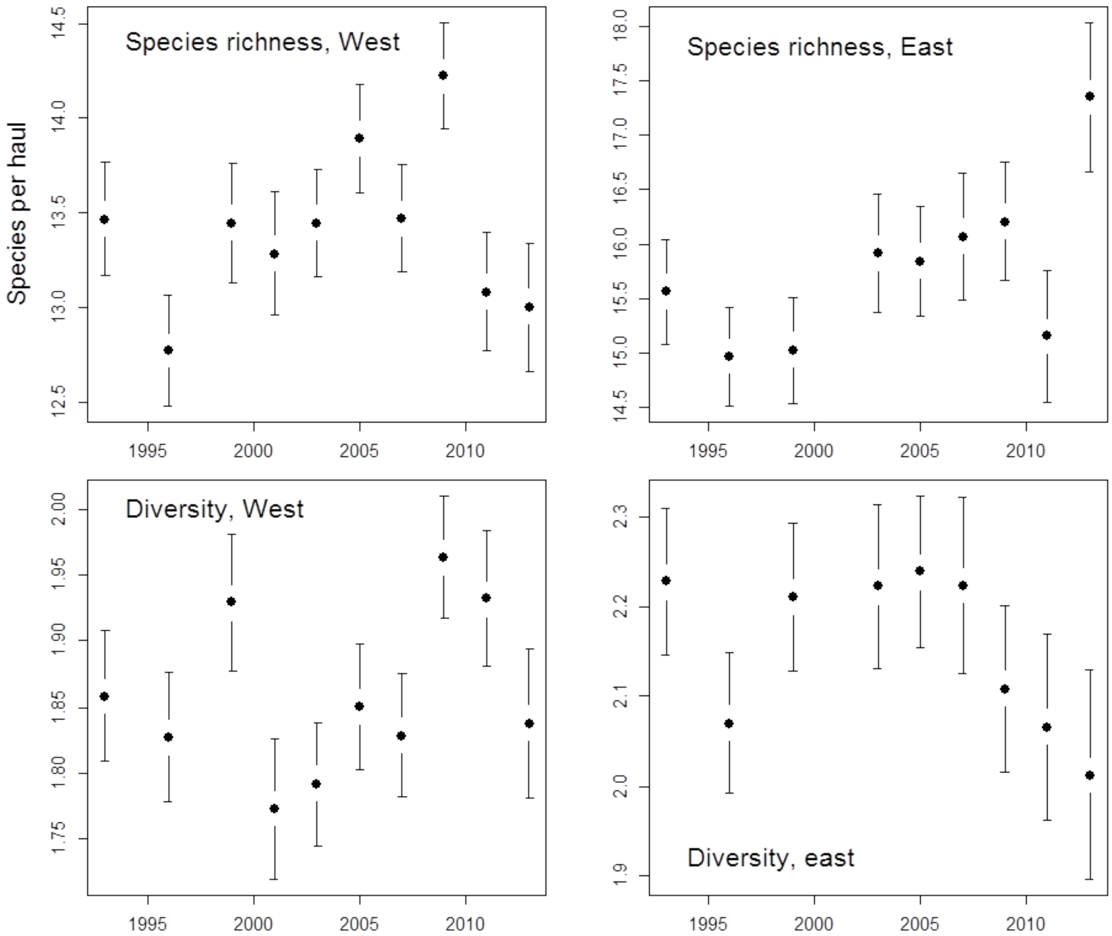

Figure 109: : Model-based annual averages of species richness (average number of species per haul, top panels) and species diversity (Shannon index, bottom panels), 1993-2013, for the Western (left) and Eastern (right) Gulf of Alaska based on 76 fish and invertebrate taxa collected by standard bottom trawl surveys with 95% pointwise confidence intervals. Model means were adjusted for differences in depth, date of sampling, and geographic location.

suggests that species remain patchily distributed such that a given haul may be dominated by one or a few species. Spatially, species richness tends to be highest along the 100 m contour in the EBS, whereas species diversity is highest on the middle shelf because the middle shelf region is less dominated by a few abundant species. In the GOA, highest species richness tends to occur around the Shumagins and Kodiak Island, off the Kenai Peninsula, and along the slope in SE Alaska. Spatial patterns in diversity were similar in the western GOA but a region of high diversity on the inner shelf between Prince William Sound (146°W) and Yakutat (140°W) was not evident in species richness. This is a region of relatively low biomass and the observed high diversity may be due to a more even abundance across species.

Implications: The effect of fishing on species richness and diversity are poorly understood at present and this index likely reflects changes in spatial distribution and species composition that can only be interpreted in the context of environmental variability in the system. In the EBS, local species richness may be particularly sensitive to long-term trends in bottom temperature as the cold pool extent changes (Mueter and Litzow, 2008) and may provide a useful index for monitoring

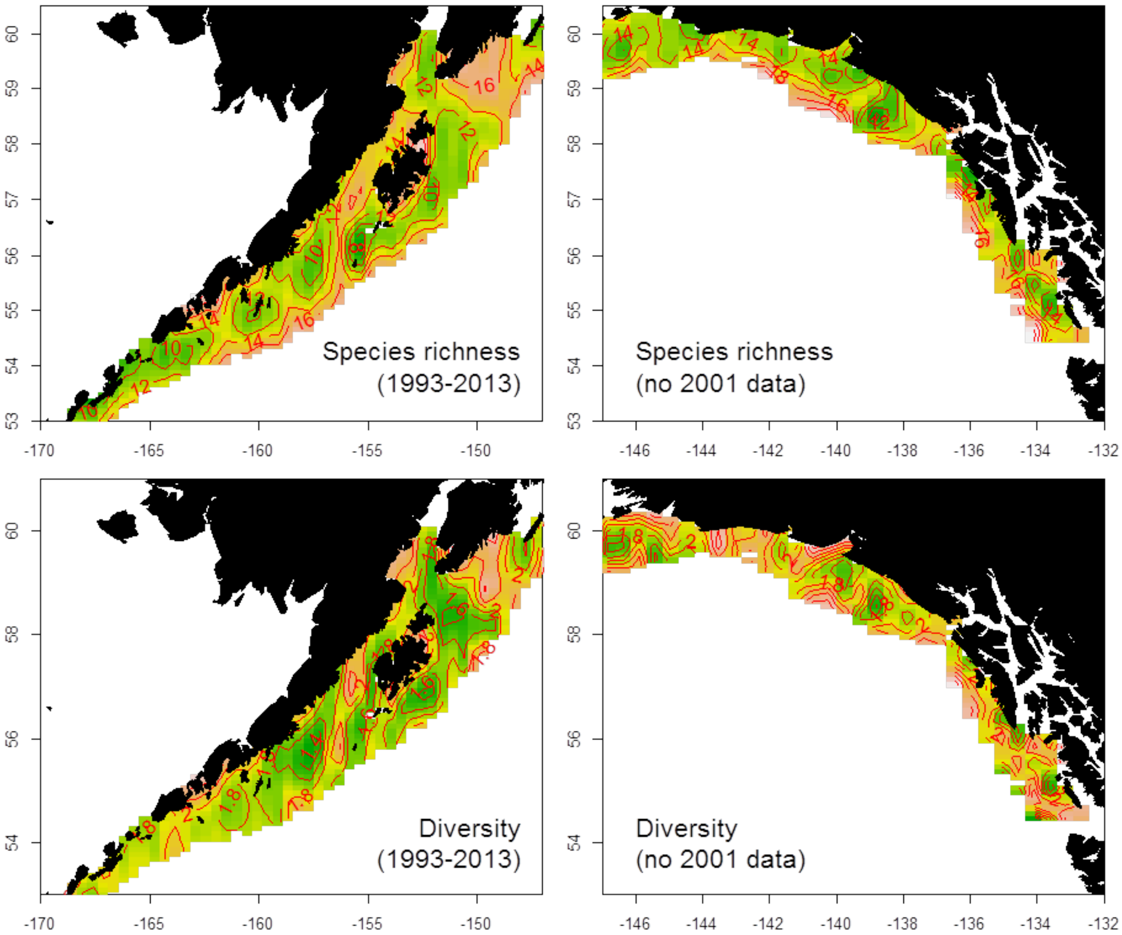

Figure 110: Average spatial patterns in local species richness (species per haul, top panels) and Shannon diversity (bottom panels) for the Western (left) and Eastern (right) Gulf of Alaska.

responses of the groundfish community to projected climate warming with local richness increasing during the recent warm period and decreasing during the subsequent cold period from 2007 to 2014. The increase in local species richness in the eastern GOA in 2013 appears to have resulted from increased catches of a number of fish and invertebrate species, including walleye pollock, several *Sebastes* species, skates, grenadiers, sea stars and others.

Spatial Distribution of Groundfish Stocks in the Eastern Bering Sea

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Last updated: October 2014

Description of indicator: We provide indices of changes in the spatial distribution of groundfish on the eastern Bering Sea shelf. The first index provides a simple measure of the average North-South displacement of major fish and invertebrate taxa from their respective centers of gravity (e.g., Woillez et al., 2009) based on AFSC-RACE bottom trawl surveys for the 1982-2014 period. Annual centers of gravity for each taxon were computed as the CPUE-weighted mean latitude across 285 standard survey stations that were sampled each year and an additional 58 stations sampled in 32 of the 33 survey years. Each station (N=343) was also weighted by the approximate area that it represents. Initially, we selected 46 taxa as in Table 1 of Mueter and Litzow (2008). Taxa that were not caught at any of the selected stations in one or more years were not included, resulting in a total of 39 taxa for analysis. In addition to quantifying N-S shifts in distribution, we computed CPUE and area-weighted averages of depth to quantify changes in depth distribution. Because much of the variability in distribution may be directly related to temperature variability, we removed linear relationships between changes in distribution and temperature by regressing distributional shifts on annual mean bottom temperatures. Residuals from these regressions are provided as an index of temperature-adjusted shifts in distribution.

Status and trends: Both the latitudinal and depth distribution of the demersal community on the eastern Bering Sea shelf show strong directional trends over the last three decades, indicating significant distributional shifts to the North and into shallower waters (Figure 111). This distribution was largely maintained through the recent cold years. Strong shifts in distribution over the 33 year time series remain evident even after adjusting for linear temperature effects (Figure 111). Average spatial displacements across all species by year suggest that most interannual shifts in distribution occur along a NW-SE axis (i.e. along the main shelf/slope axis), but that a pronounced shift to the Northeast and onto the shelf occurred between the 1990s and 2000s (Figure 112). On average, there was a gradual shift to the north from 2001 to 2005, which reversed as temperatures cooled after 2006, continuing through recent years. From 2009 through 2014, the average center of gravity has shifted between deeper and shallower waters (SW-NE axis) and is currently (2014) further NE (Figure 112) and shallower (Figure 111) than in most years.

Factors influencing observed trends: Many populations shift their distribution in response to temperature variability. Such shifts may be the most obvious response of animal populations to global warming (Parmesan and Yohe, 2003). However, distributional shifts of demersal populations in the Bering Sea are not a simple linear response to temperature variability (Mueter and Litzow, 2008). The reasons for residual shifts in distribution that are not related to temperature changes remain unclear but could be related to density-dependent responses (Spencer, 2008) in combination with internal community dynamics (Mueter and Litzow, 2008). Unlike groundfish in the North

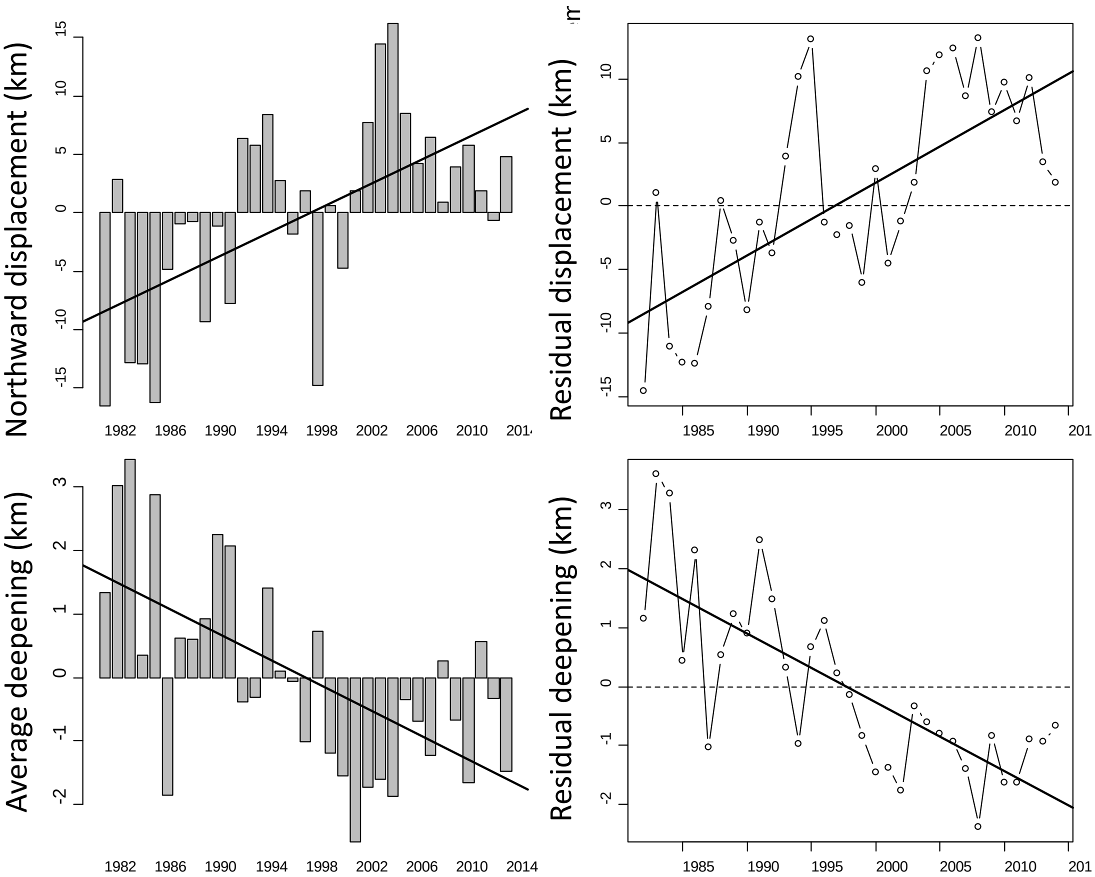

Figure 111: Left: Distributional shifts in latitude (average northward displacement in km from species-specific mean latitudes) and shifts in depth distribution (average vertical displacement in m from species-specific mean depth, positive indices indicate deeper distribution). Right: Residual displacement from species-specific mean latitude (top) and species-specific mean depth (bottom) after adjusting the indices on the left for linear effects of mean annual bottom temperature on distribution. Residuals were obtained by linear regression of the displacement indices on annual average temperature (Northward displacement: $R^2 = 0.23$, $t = 4.08$, $p < 0.001$; depth displacement: $R^2 = 0.25$, $t = -3.60$, $p = 0.001$). Solid lines denote linear regressions over time (Northward displacement: $R^2 = 0.36$, $t = 2.89$, $p < 0.007$; Residual northward displacement: $R^2 = 0.47$, $t = 3.21$, $p = 0.003$; depth displacement: $R^2 = 0.42$, $t = -3.69$, $p < 0.001$; residual depth displacement: $R^2 = 0.57$, $t = -6.48$, $p < 0.001$).

Sea, which shifted to deeper waters in response to warming (Dulvy et al., 2008), the Bering Sea groundfish community shifted to shallower waters during the recent warm period (Figure 111). Surprisingly, the summer distribution has remained relatively shallow despite very cold temperatures on the shelf.

Implications: Changes in distribution have important implications for the entire demersal community, for other populations dependent on these communities, and for the fishing industry. The demersal community is affected because distributional shifts change the relative spatial overlap of different species, thereby affecting trophic interactions among species and, ultimately, the relative abundances of different species. Upper trophic level predators, for example fur seals and seabirds on the Pribilof Islands and at other fixed locations, are affected because the distribution and hence

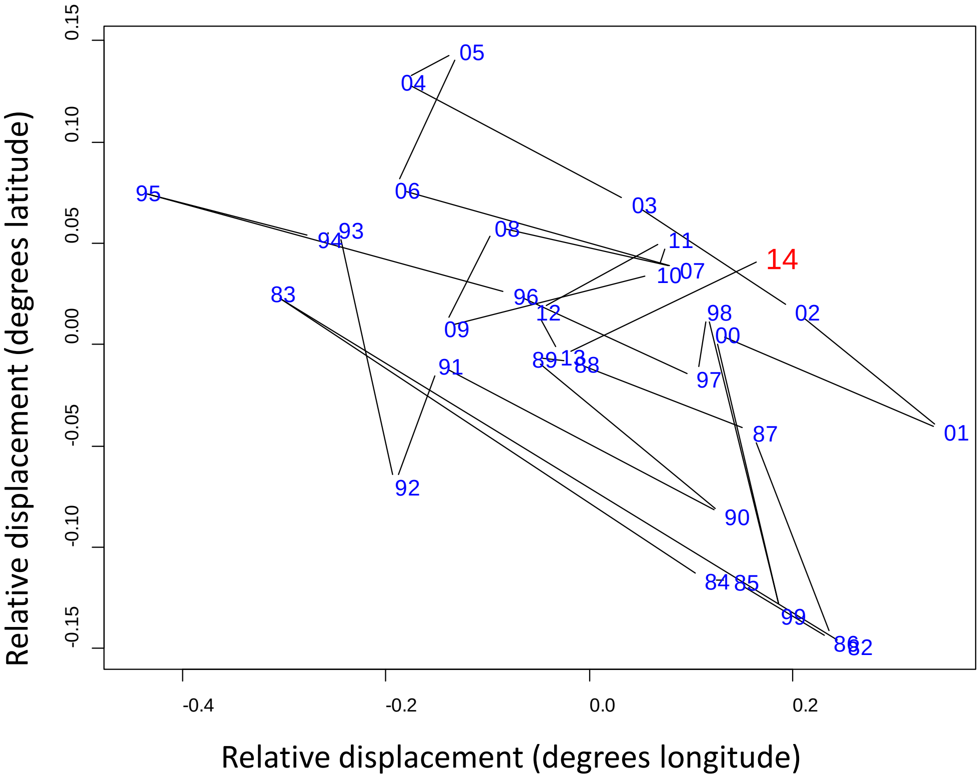

Figure 112: Average North-South and East-West displacement across 39 taxa on the eastern Bering Sea shelf relative to species-specific centers of distribution.

availability of their prey changes. Finally, fisheries are directly affected by changes in the distribution of commercial species, which alters the economics of harvesting because fishing success within established fishing grounds may decline and travel distances to new fishing grounds may increase. A better understanding of the observed trends and their causes is needed to evaluate the extent to which fishing may have contributed to these trends and to help management and fishers adapt to apparent directional changes in distribution that are likely to be further exacerbated by anticipated warming trends associated with increasing CO_2 concentrations.

Disease Ecology Indicators

"Mushy" Halibut Syndrome Occurrence

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Last updated: October 2015

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

Status and trends: ADF&G received numerous reports of "mushy" halibut during the 2015 sport fishing season (`http://www.adfg.alaska.gov/sf/fishingreports/index.cfm?adfg=r2.archive&area_key=8&updateid=3882&year=2015`).

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

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

Ichthyophonus Parasite

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Last updated: September, 2015

Description of indicator: *Ichthyophonus*, a non-specific fungus-like protozoan fish parasite, has caused epizootic events among economically important fish stocks including herring and salmon. The parasite has been documented in over 100 fish species, and infection can result in reduced growth, stamina, and overall fish health. In some cases, individuals show external symptoms including black papules, muscle ulcers, and roughening of the skin. Researchers at the FAST Lab investigated the prevalence and load of Ichthyophonus in Pacific halibut (Hippoglossus stenolepis) in 2012 and 2013. The lab developed a Pepsin digestion assay to assess the degree of the infection. This assay allows for the rapid collection of tissues for Ichthyophonus testing as they can be sampled without aseptic methods and can be frozen.

Status and trends: Recent research found that of the fish sampled in lower Cook Inlet, 23% (71/315) had *Ichthyophonus* in 2012, and 29% (73/248) had *Ichthyophonus* in 2013 (Grenier, unpub. data). The parasite infected heart tissues, was never found in liver, spleen, or kidney tissues, and was more prevalent in older fish. Parasite load varied widely among infected fish from 6 to 1,245 *Ichthyophonus schizonts* per gram of heart tissue.

Factors influencing observed trends: Interestingly, our findings did not support the hypothesis that reduced halibut size-at-age may be caused by *Ichthyophonus*.

Implications: This project lays important methodological groundwork for the expansion of groundfish fitness research to the Bering Sea Aleutian Islands and Gulf of AK. This research is being expanded in order to refine our Pepsin digestion assay, continue assessing Pacific halibut and include Pacific cod and pollock, and sample fish from the ports of Valdez, Whittier, and Seward in addition to Homer, AK. We will employ a length-based sampling design to allow the comparison of *Ichthyophonus* loads in heavier (fitter) versus lighter fish of a given size. As with our earlier research, we will work cooperatively with the ADFG port sampling program and the charter halibut fleets.

Ecosystem-Based Management Indicators

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

Maintaining Diversity: Discards and Non-Target Catch

Time Trends in Groundfish Discards

Contributed by Jean Lee, Resource Ecology and Fisheries Management Division, AFSC, NMFS, NOAA, and Alaska Fisheries Information Network, Pacific States Marine Fisheries Commission
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Last updated: November 2015

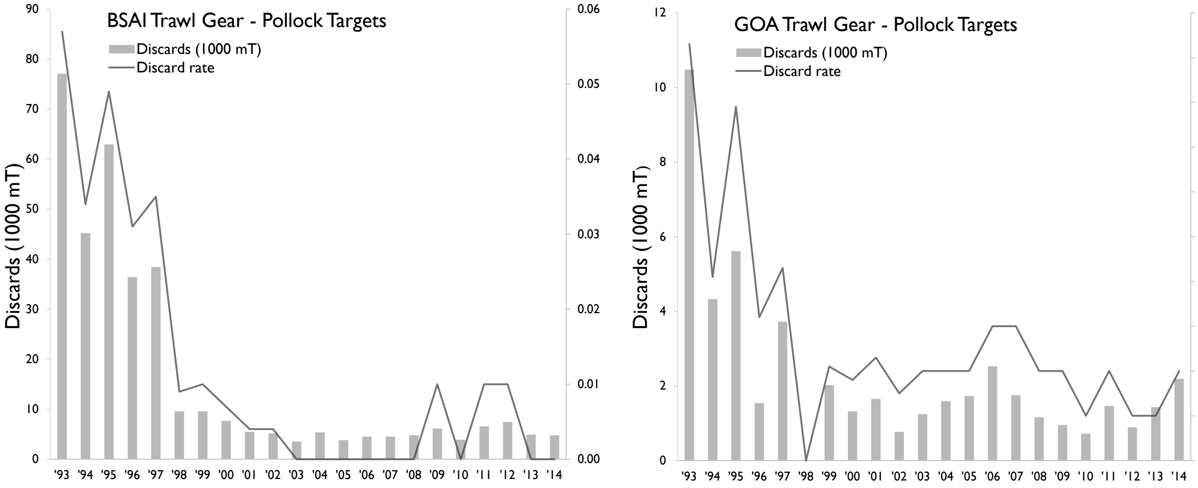
Description of indicator: Estimates of groundfish discards for 1994-2002 are sourced from NMFS Alaska Regions blend data, while estimates for 2003 and later come from the Alaska Regions Catch Accounting System. These sources, which are based on observer data in combination with industry landing and production reports, provide the best available estimates of groundfish discards. Discard rates as shown here are calculated as the weight of groundfish discards divided by the total (i.e., retained and discarded) catch weight for the relevant area-gear-target sector.

Figures for 2013 and later may not be directly comparable to figures from prior years, particularly in the GOA fixed gear sector where the halibut fishery is primarily prosecuted. Beginning in 2013, the Catch Accounting System includes more comprehensive estimates of groundfish discarded in the fixed gear halibut fishery. Discard rates prior to 2013 are calculated as the weight of FMP groundfish discards divided by the weight of groundfish catch, excluding discards and catch of groundfish on halibut targets. Beginning in 2013, discard rates represent the weight of FMP groundfish discards divided by the weight of groundfish and halibut catch, and are calculated inclusive of catch on halibut targets. Discard volumes in all years include discards on halibut targets.

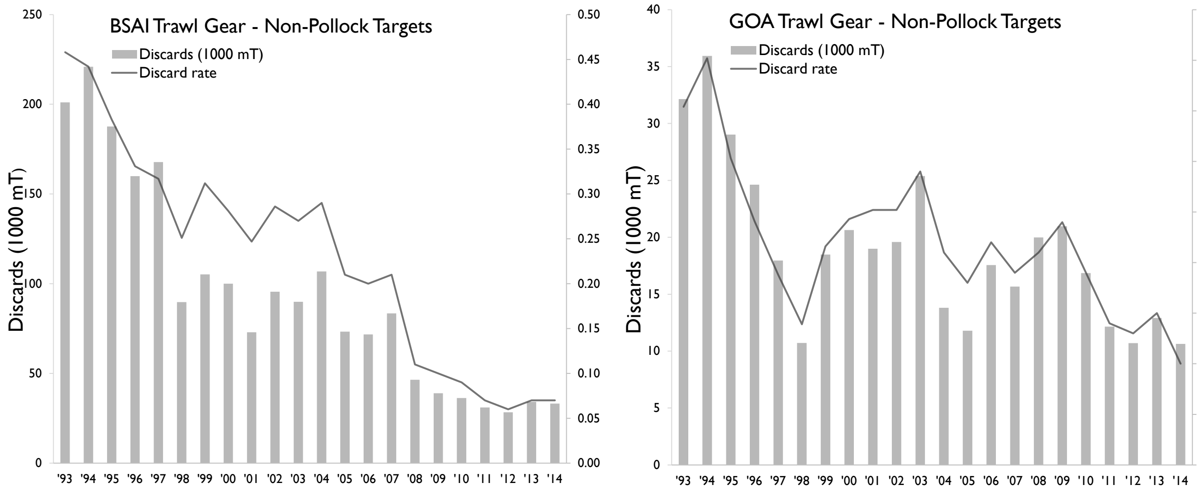
Status and trends: Since 1993, discard rates of managed groundfish species in federally-managed Alaskan groundfish fisheries have generally declined in the trawl pollock fisheries in both the Bering Sea/Aleutian Islands (BSAI) and the Gulf of Alaska (GOA), as well as in the BSAI non-pollock trawl sector (Figure 113). In the GOA non-pollock trawl sector, discard rates dropped from 40% in 1994 to less than 15% in 1998, trended upwards from 1998 to 2003, and have generally declined over the last ten years. Discard rates in the BSAI fixed gear sector fell from around 20% in 1993 to 12% in 1996, and since then have generally fluctuated between 10% and 14%. Rates in the GOA fixed gear sector over the most recent 20 years for which data are available have varied between a high of 15% in 1993 to a low of 1% in 1998.

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

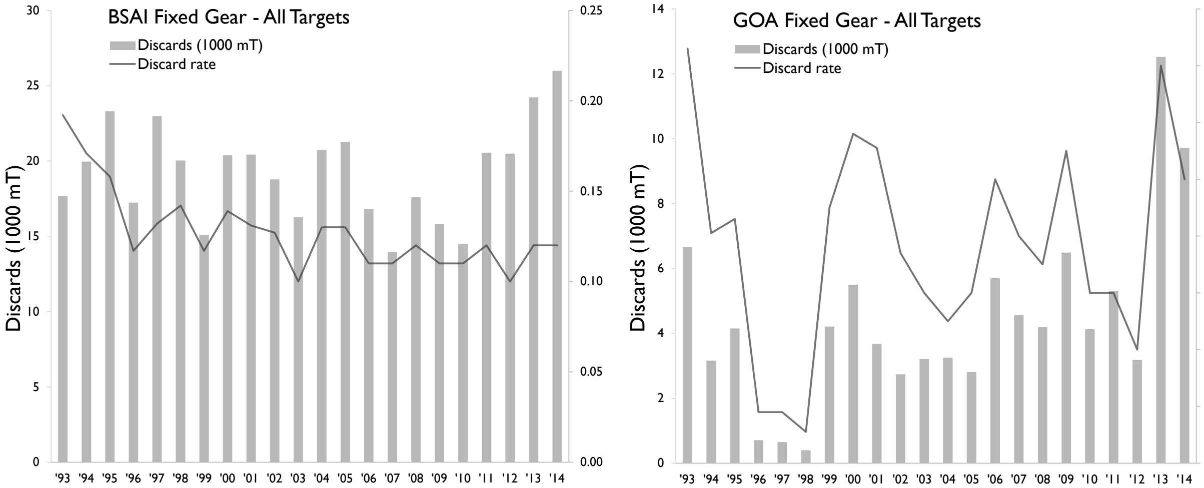
Implications: Discards add to the total human impact on the biomass without providing a benefit to the Nation.



(a) EBS (b) GOA



(c) EBS (d) GOA



(e) EBS (f) GOA

Figure 113: Total biomass and percent of total catch biomass of managed groundfish discarded in the BSAI and GOA fixed gear, pollock trawl, and non-pollock trawl sectors, 1993-2014 (Includes only catch counted against federal TACS).

Time Trends in Non-Target Species Catch

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[2]Ecosystem Assessment Program, Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, Woods Hole MA,
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Last updated: August 2015

Description of indicator: We monitor the catch of non-target species in groundfish fisheries in the Eastern Bering Sea (EBS), Gulf of Alaska (GOA) and Aleutian Islands (AI) ecosystems. In previous years we included the catch of "other" species, "non-specified" species, and forage fish in this contribution. However, stock assessments have now been developed or are under development for all groups in the "other species" category (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid), some of the species in the "non-specified" group (giant grenadier, other grenadiers), and forage fish (e.g., capelin, eulachon, Pacific sandlance, 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`). Starting with the 2013 Ecosystem Considerations Report, the three categories of non-target species we continue to track here are:

1. Scyphozoan jellyfish
2. species associated with Habitat Areas of Particular Concern-HAPC species (seapens/whips, sponges, anemones, corals, tunicates)
3. Assorted invertebrates (bivalves, brittle stars, hermit crabs, miscellaneous crabs, sea stars, marine worms, snails, sea urchins, sand dollars, sea cucumbers, and other miscellaneous invertebrates).

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

Status and trends: The catch of all three non-target species groups has been highest in the EBS (Figure 114). Scyphozoan jellyfish catches in the GOA are two orders of magnitude lower than the EBS and three orders of magnitude lower in the AI. Catches of HAPC biota are intermediate in the AI and lowest in the GOA. The catches of assorted invertebrates in the EBS are about twice the catch in the GOA. The catch of assorted invertebrates is lowest in the AI.

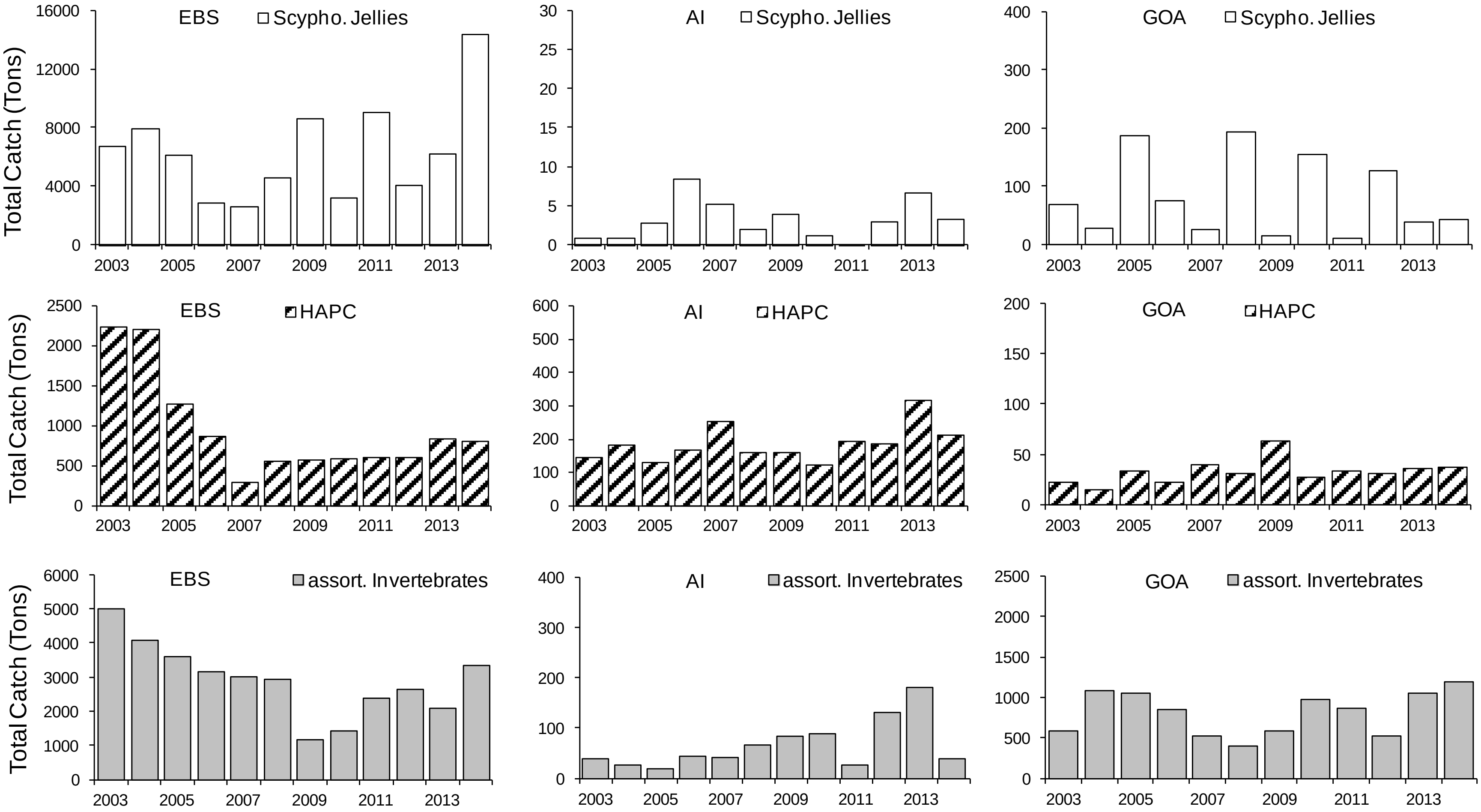

Figure 114: Total catch of non-target species (tons) in the EBS, AI, and GOA groundfish fisheries (2003-2013). **Please note the different y-axis scales** between regions and species groups.

In the EBS, the catch of Scyphozoan jellyfish has fluctuated over the last twelve years and peaked in 2014. The catch of jellyfish in 2014 is more than double the catch in 2013 and 59% higher than the previous high catch in 2011. Previous highs in jellyfish catch in 2009 and 2011 were followed by sharp drops the following year to catches less than half the size. Jellyfish are primarily caught in the pollock fishery. HAPC biota catch decreased from 2003 to 2007 and has been generally steady since. Benthic urochordata, caught mainly by the flatfish fishery, comprised the majority of HAPC biota catches in the EBS from 2003 through 2008, From 2009-2014, benthic urochordata accounted for most of the HAPC catch except for 2011 and 2014 when it was surpassed by sponges and sea anemones. Sea stars dominate the catch of assorted invertebrates in all years (2003-2014) and are primarily caught in flatfish fisheries.

In the AI, the catch of Scyphozoan jellies has been variable and shows no apparent trend over time. The catch in 2014 was half the catch in 2013. HAPC catch has been variable over time in the AI and peaked in 2013. The HAPC catch in 2014 is about a third less than the catch in 2013. The HAPC catch is driven primarily by sponges caught in fisheries for Atka mackerel, rockfish and cod. Assorted invertebrate catches have generally trended upward from 2005 to a peak in 2013, with the exception of 2011 where the catch dropped back to nearly the 2005 level. The catch of assorted invertebrates dropped considerably in 2014 and was only 20% of the 2013 catch. Over that same span the assorted invertebrate catch has been dominated by sea stars and unidentified invertebrates. Assorted invertebrates are primarily caught in fisheries for Atka mackerel, cod, and rockfish.

The catch of Scyphozoan jellies in the GOA has been variable from 2003-2014. From 2007 to 2013, the catch of Scyphozoan jellies has alternated between years of low (odd years) to relatively higher catches (even years). The 2014 catch breaks from this pattern and remains at a low catch level, roughly equivalent to 2013. Scyphozoan jellies are primarily caught in the pollock fishery. The catch of HAPC biota in the GOA has been variable, but generally low in comparison to the EBS and AI. Sea anemones comprise the majority of the HAPC biota catch in the GOA, and they are caught primarily in the flatfish and cod fisheries. The catch of assorted invertebrates has been variable and shown little trend. Sea stars are caught primarily in the cod and flatfish fisheries and have dominated the assorted invertebrate catch, accounting for more than 90% of the total in each year. The catch of assorted invertebrates in 2014 increased 14% from 2013, and was the highest over the time period 2003-2014.

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

Implications: The catch of HAPC species and assorted invertebrates in all three ecosystems is very low compared with the catch of target species. HAPC species may have become less available to the EBS fisheries (or the fisheries avoided them more effectively) since 2005. The interannual variation and lack of a clear trend in the catch of scyphozoan jellyfish in all three ecosystems may reflect interannual variation in jellyfish biomass or changes in the overlap with fisheries. Abundant jellyfish may have a negative impact on fishes as they compete with planktivorous fishes for prey resources (PurcellSturdevant2001), and additionally, jellyfish may prey upon the early life history stages (eggs and larvae) of fishes (Purcell and Arai, 2001; Robinson et al., 2014).

Seabird Bycatch Estimates for Alaskan Groundfish Fisheries, 2007-2014

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Last updated: September 2015

Description of indicator: This report provides estimates of the numbers of seabirds caught as bycatch in commercial groundfish fisheries in Alaska operating in federal waters of the U.S. Exclusive Economic Zone for the years 2007 through 2013. Estimates of seabird bycatch from earlier years using different methods are not included here. Fishing gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic trawl. These numbers do not apply to gillnet, seine, or troll fisheries. Data collection on the Pacific halibut longline fishery began in 2013 with the restructured observer program, although some small amounts of halibut fishery information were collected in years previous when an operator had both halibut and sablefish individual fishing quota. Estimates are based on two sources of information, (1) data provided by NMFS-certified Fishery Observers deployed to vessels and floating or shoreside processing plants (AFSC, 2011), and (2) industry reports of catch and production. The NMFS Alaska Regional Office Catch Accounting System (CAS) produces the estimates (Cahalan et al., 2010). The main purpose of the CAS is to provide near real-time delivery of accurate groundfish and prohibited species catch and bycatch information for inseason management decisions. It is also used for the provision of estimates of non-target species (such as invertebrates) and seabird bycatch in the groundfish fisheries. At each data run, the CAS produces estimates based on current data sets, which may have changed over time. Changes in the data are due to errors that were discovered during observer debriefing, data quality checks, and analysis. Examples of the possible changes in the underlying data are: changes in species identification; deletion of data sets where data collection protocols were not properly followed; or changes in the landing or at-sea production reports where data entry errors were found. **Status and trends:** This year we present the estimates of seabird bycatch by large marine ecosystem (LME) (Figure 115, Table tab.bycatchEBS). The 2014 estimated numbers for the combined groundfish fisheries in the EBS are the lowest since the beginning of the time series in 2007. Most of this decline was due to lower than average numbers of fulmars and shearwaters caught. In contrast higher than average auklets were caught, although these still comprise a small proportion of the catch. Two short-tailed albatross were observed to be bycaught. One was observed directly, and one determined to be a short-tailed albatross at a later date by experts viewing photo documentation.

In the Aleutian Islands, fulmars and gulls were estimated to be bycaught in lower than average numbers in 2014, while black-footed and unidentified albatross were estimated to be higher (Figure 115, Table tab.bycatchAI). Total numbers have remained between 133 and 202 from 2011 - 2014.

Estimated numbers of seabirds bycaught in the Gulf of Alaska has declined overall since 2007, minus a peak in 2011 and a low value in 2012 (Figure 115, Table 11). 2014 stands out as having more black-footed albatross and few fulmars caught compared to previous years.

Table 9: **Estimated** seabird bycatch in Eastern Bering Sea groundfish fisheries and all gear types, 2007 through 2014. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species/Species Group	2007	2008	2009	2010	2011	2012	2013	2014
Unidentified Albatross	0	0	0	0	0	0	0	11
Short-tailed Albatross	0	0	0	15	5	0	0	9
Black-footed Albatross	18	7	5	9	2	0	1	10
Laysan Albatross	5	7	14	16	29	48	20	17
Northern Fulmar	2821	1185	571	569	160	512	196	117
Shearwaters	3157	2132	7215	1923	5405	2992	2883	701
Storm Petrels	1	0	0	0	0	0	0	0
Gull	718	1348	911	703	1650	835	416	572
Kittiwake	10	0	16	0	6	5	3	9
Murre	6	6	13	102	14	6	3	47
Puffin	0	0	0	9	0	0	0	0
Auklets	0	3	0	0	0	7	4	105
Other Alcid	0	0	105	0	0	0	0	0
Other	0	0	136	0	0	0	0	0
Unidentified	461	267	501	253	378	308	278	76
Grand Total	7196	4955	9487	3600	7649	4713	3803	1675

Table 10: **Estimated** seabird bycatch in Aleutian Islands groundfish fisheries and all gear types, 2007 through 2014. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species/Species Group	2007	2008	2009	2010	2011	2012	2013	2014
Unidentified Albatross	0	0	0	0	0	0	0	21
Black-footed Albatross	0	0	0	0	5	0	12	19
Laysan Albatross	13	51	35	133	13	76	107	44
Northern Fulmar	77	308	306	369	50	15	44	51
Shearwaters	734	39	49	88	42	60	0	64
Storm Petrels	0	44	0	0	0	0	0	0
Gull	38	19	36	186	23	12	24	0
Auklets	0	0	0	0	0	0	0	2
Unidentified	5	1	7	18	0	3	10	0
Grand Total	868	461	434	794	133	166	197	202

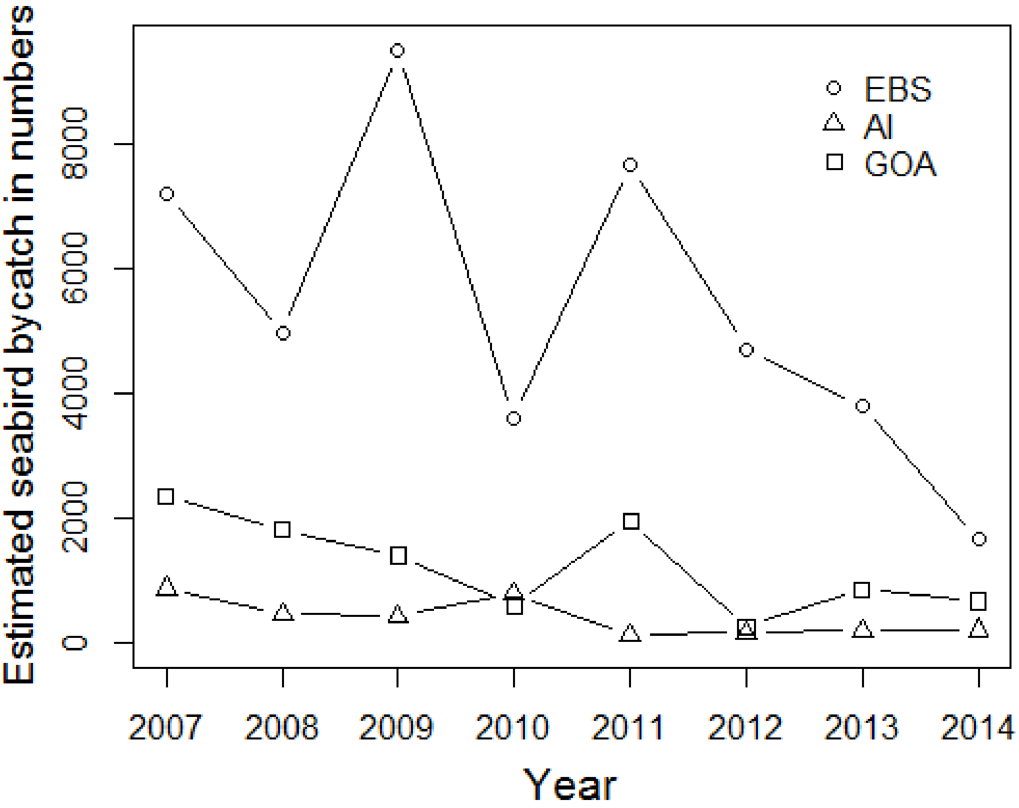

Figure 115: Total estimated seabird bycatch in eastern Bering Sea (EBS), Aleutian Islands (AI), and Gulf of Alaska (GOA) groundfish fisheries, all gear types combined, 2007 to 2014.

Factors influencing observed trends: A marked decline in overall numbers of birds caught after 2002 reflected the increased use of seabird mitigation devices. A large portion of the freezer longline fleet adopted these measures in 2002, followed by regulation requiring them for the rest of the fleet beginning in February 2004. There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. Work has continued on developing new and refining existing mitigation gear (Dietrich and Melvin, 2008). The longline fleet has traditionally been responsible for about 91% of the overall seabird bycatch in Alaska, as determined from the data sources noted above. However, standard observer sampling methods on trawl vessels do not account for additional mortalities from net entanglements, cable strikes, and other sources. Thus, the trawl estimates are biased low (Fitzgerald et al., in prep). For example, the 2010 estimate of trawl-related seabird mortality is 823, while the additional observed mortalities (not included in this estimate and not expanded to the fleet) were 112. Observers now record the additional mortalities they see on trawl vessels and the AFSC Seabird Program is seeking funds to support an analyst to work on how these additional numbers can be folded into an overall estimate. The challenge to further reduce seabird bycatch is great given the rare nature of the event. For example, Dietrich and Fitzgerald (2010) found in an analysis of 35,270 longline sets

Table 11: **Estimated** seabird bycatch in Gulf of Alaska groundfish fisheries and all gear types, 2007 through 2014. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.

Species/Species Group	2007	2008	2009	2010	2011	2012	2013	2014
Unidentified Albatross	17	0	0	0	10	0	19	0
Black-footed Albatross	182	295	51	62	215	141	232	376
Laysan Albatross	0	168	101	85	164	17	75	32
Northern Fulmar	1466	893	678	175	873	19	337	43
Shearwaters	31	0	0	0	61	0	65	0
Gull	593	184	387	279	614	50	119	164
Auklets	0	0	0	0	0	0	0	5
Other	0	0	0	0	0	0	0	49
Unidentified	49	274	188	0	9	33	7	0
Grand Total	2339	1814	1406	601	1946	260	854	670

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 **??**). **Implications:** There seems to be a generally decreasing trend in seabird bycatch since the new estimation procedures began in 2007, indicating no immediate management concern other than continuing our goal of decreased seabird bycatch. It is difficult to determine how seabird bycatch numbers and trends are linked to changes in ecosystem components because seabird mitigation gear is used in the longline fleet. There does appear to be a link between poor ocean conditions and the peak bycatch years, on a species-group basis. Fishermen have noted in some years that the birds appear “starved” and attack baited longline gear more aggressively. In 2008 general seabird bycatch in Alaska was at relatively low levels (driven by lower fulmar and gull bycatch) but albatross numbers were the highest at any time between 2002 and 2013. This could indicate poor ocean conditions in the North Pacific as albatross traveled from the Hawaiian Islands to Alaska. Broad changes in overall seabird bycatch, up to 5,000 birds per year, occurred between 2007 and 2013. This probably indicates changes in food availability rather than drastic changes in how well the fleet employs mitigation gear. A focused investigation of this aspect of seabird bycatch is needed and could inform management of poor ocean conditions if seabird bycatch rates (reported in real time) were substantially higher than normal.

Maintaining and Restoring Fish Habitats

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

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Last updated: August 2015

Description of indicator: Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut) (Figure 116, Table 12) Some of the trawl closures are in effect year-round while others are seasonal. In general, year-round trawl closures have been implemented to protect vulnerable benthic habitat. Seasonal closures are used to reduce bycatch by closing areas where and when bycatch rates had historically been high.

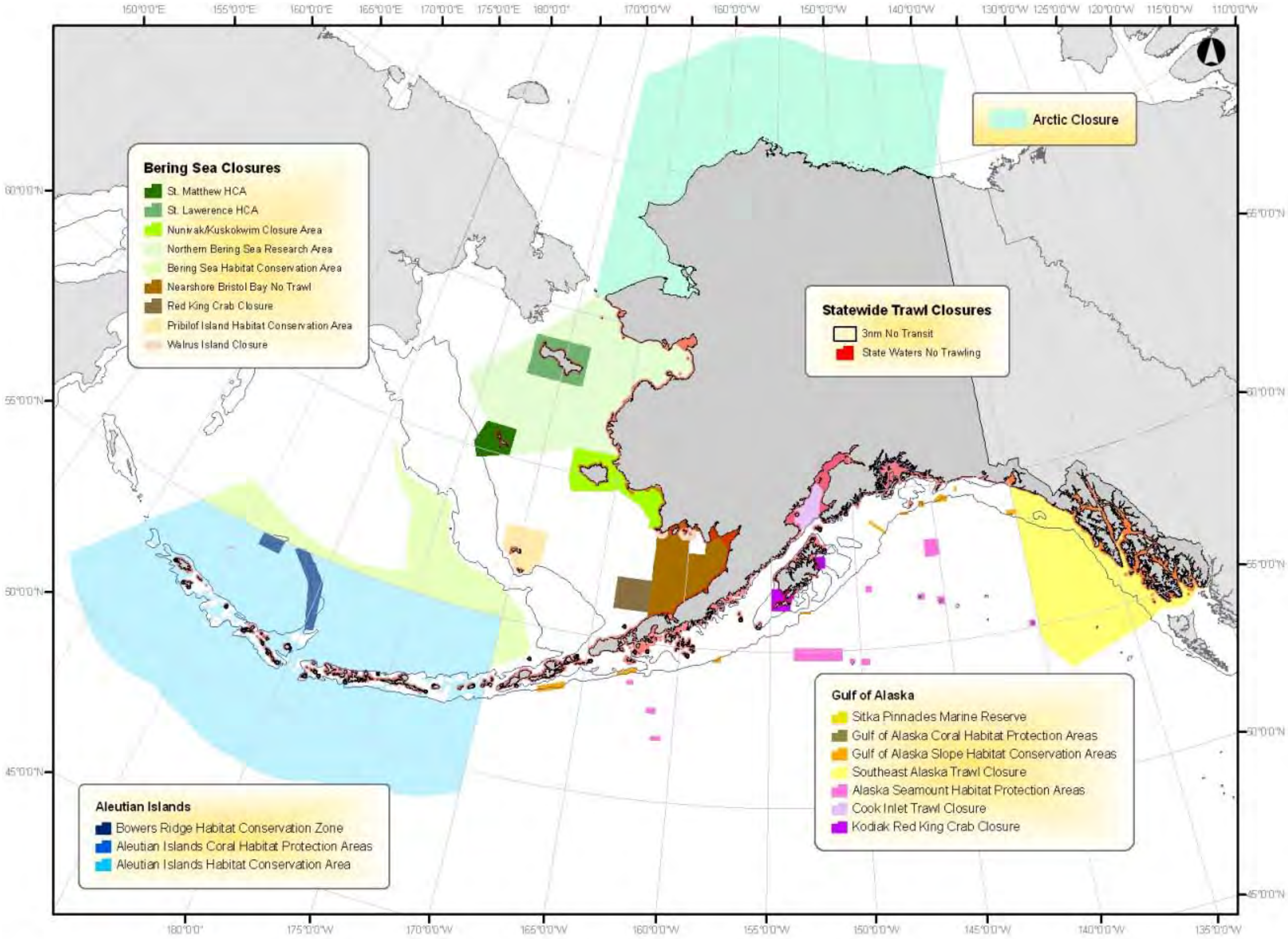

Figure 116: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

Table 12: Groundfish trawl closure areas, 1995-2009. License Limitation Program (LLP); Habitat Conservation Area (HCA); Habitat conservation zone (HCZ).

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

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

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

In 2013, the Council adopted 5 Areas of Skate Egg Concentrations has Habitat Areas of Particular Concern. No management measures or closures are associated with these HAPCs.

Closures to fishing related to Steller Sea Lions are very complex and establishing how much area is closed to fishing is related to prey for sea lions rather than blanket gear type closures. Protection measures increased in 2010, closing significant portions of the western Aleutian Islands to fishing for SSL prey species for all gear types. These closures were subsequently modified and relaxed in 2014. It is beyond the scope of this section to detail all closures related to Steller Sea Lions. For more information, please see `http://alaskafisheries.noaa.gov/sustainablefisheries/sslpm/`.

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

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

Steller Sea Lion closure maps are available here:

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

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

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

Area Disturbed by Trawl Fishing Gear in the Eastern Bering Sea

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Last updated: July 2015

Description of indicator: Fishing gear can affect habitat used by a fish species for the processes of spawning, breeding, feeding, or growth to maturity. An estimate of the area of seafloor disturbed by trawl gear may provide an index of habitat disturbance. The area disturbed in the Eastern Bering Sea floor was calculated from observer trawl data each year from 1990-2014. The duration of every trawl haul was multiplied by a fishing effort adjustment as outlined in Appendix B of the January 2005 EFH EIS (`http://www.fakr.noaa.gov/habitat/seis/efheis.htm`). Table B.2-4 in the EIS document lists the adjustment factor for each gear type and vessel class. The adjustment converted trawl haul duration to area disturbed based on the type of trawl gear used (pelagic or bottom) and the vessel length. The adjustment also expanded smaller vessel fishing effort, which has 30% observer coverage, to simulate 100% coverage. Records missing trawl haul duration data and short wire hauls (hauls pulled in but not immediately brought on board) were assigned the average trawl haul duration over all years of 228 minutes (no more than 5% of hauls in any given year needed this adjustment).

An upper limit of the total area potentially disturbed by trawl hauls was estimated by assuming that no trawl hauls overlapped spatially. To find the percent disturbed, it was necessary to find the total area of the Eastern Bering Sea being considered (Figure 117a). NMFS reporting areas for the Bering Sea were used as a baseline; however, Norton Sound was excluded because it is beyond the range of many commercially fished groundfish species. The Bering Sea Habitat Conservation boundary was used to exclude areas beyond the shelf break. The resulting total area considered was 742,647 km^2. The percent of area disturbed was estimated in two ways: 1) with no spatial overlap of trawl hauls in a given year, providing an estimate of the maximum potential percent of area disturbed and 2) with spatial overlap of trawl hauls within 400 km^2 cells to limit the disturbance of trawls recorded in a cell to 400 km^2, providing an estimate of potential percent of area disturbed. The average distance of a haul based on recorded start and end locations is 14 km with a standard deviation of 10 km. The cell size was chosen to reflect this spatial resolution of the hauls. Though this cell size allows some overlap of hauls, it still may over estimate the percent area disturbed in a year. The map below shows in what areas trawling disturbances accumulated over various time intervals (Figure 117b).

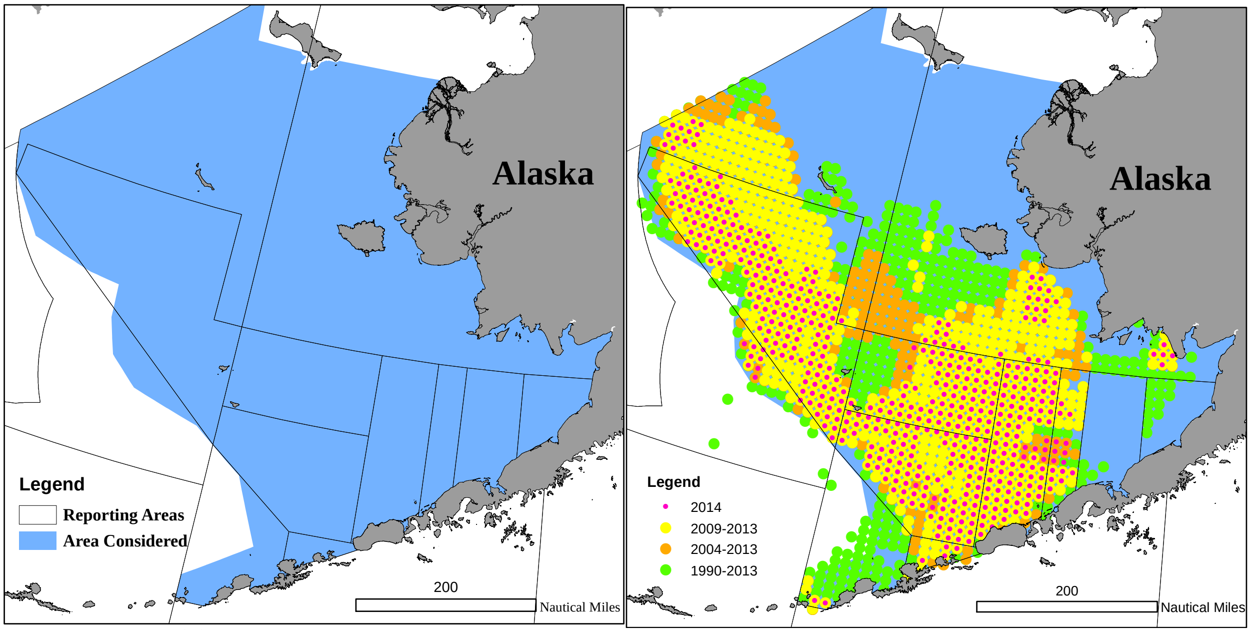

Figure 117: (a) Map of Eastern Bering Sea area considered when estimating percent area potentially disturbed by trawl fishing gear. (b) Map of 400 square kilometer cells with some trawling in cumulative time periods. Cells with fewer than 3 vessels are not shown

Status and Trends: The maximum total area of seafloor in the Eastern Bering Sea potentially disturbed by trawls varied around 120,000 km^2 in the 1990s and decreased in the late 1990s to approximately 90,000 km^2. The area disturbed remained relatively stable in the 2000s with a slight increase in the 2007-2008. The percent of total area disturbed varied between 10% and 15% in the 1990s and between 9% and 11% in the 2000s, however due to trawls overlapping the same area the more realistic area disturbed was less than 10% from the mid 1990s on. Reduction in hours fished in the 2000s indicates greater fishing efficiency.

Factors Causing Trends: Trends in seafloor area disturbed can be affected by numerous variables, such as individual fishery movements, fish abundance and distribution, management actions (e.g., closed areas), changes in the structure of the fisheries due to rationalization, increased fishing skills (e.g., increased ability to find fish), and changes in vessel horsepower and fishing gear.

During 1993-1999, fishing effort was more concentrated in the southern area compared to 1990-1992 and 2000-2008, where effort was spread out spatially, particularly towards the northwest. This may, in part, explain the larger difference between the upper and lower estimates of percent area disturbed (with no overlap and with overlap within 400 km^2 cells, respectively) during 1993-1998 relative to other years (Figure 118).

As of 1999 only pelagic trawls can be used in the Bering Sea pollock fisheries. To check to see if this affected the trends the graph was recalculated making no distinction between gears. The result showed no change to the trend. Short-wiring was only identified in the database from 1995 onward, however short-wiring accounts for only 2% of the total hauls and does not explain the early 1990 trends.

Implications: Habitat damage varies with the physical and biological characteristics of the areas fished, recovery rates of HAPC biota in the areas fished, and management changes that result in spatial changes in fishing effort. Effort is underway to create an indicator that estimates fishing gear bottom contact more precisely, which will serve to represent potential area disturbed more accurately.

Observed Fishing Effort in the Eastern Bering Sea, Aleutian Islands, and Gulf of Alaska

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Last updated: August 2015

Description of indicator: Observed fishing effort is used as an indicator of total fishing effort. It should be noted, however, that all fishing effort is not observed. Prior to January 2014, catcher vessels under 60' were not observed, vessels between 60'-125' required 30% observer coverage, and vessels over 125' required 100% observer coverage. In January 2014, a restructured observer system was implemented whereby all sectors of the groundfish fishery, including vessels less than 60' and the commercial halibut sector would be observed. NMFS now has the flexibility to decide when and where to deploy observers based on a scientifically defensible deployment plan. The development of the restructured observer program is still in progress, and more information is available at `http://alaskafisheries.noaa.gov/sustainablefisheries/observers/`.

Longline fishing effort is measured by the number of observed longline sets. Although the number of hooks on a set may vary, when aggregated over time and regions (AI, BS, GOA) the number of sets is representative of the number of hooks fished. This fishery is prosecuted with anchored lines, onto which baited hooks are attached. Gear components which may interact with benthic habitat include the anchors, groundline, gangions, and hooks. The fishery is prosecuted with both catcher and catcher-processor vessels. Pelagic trawl fishing effort is measured by the number of

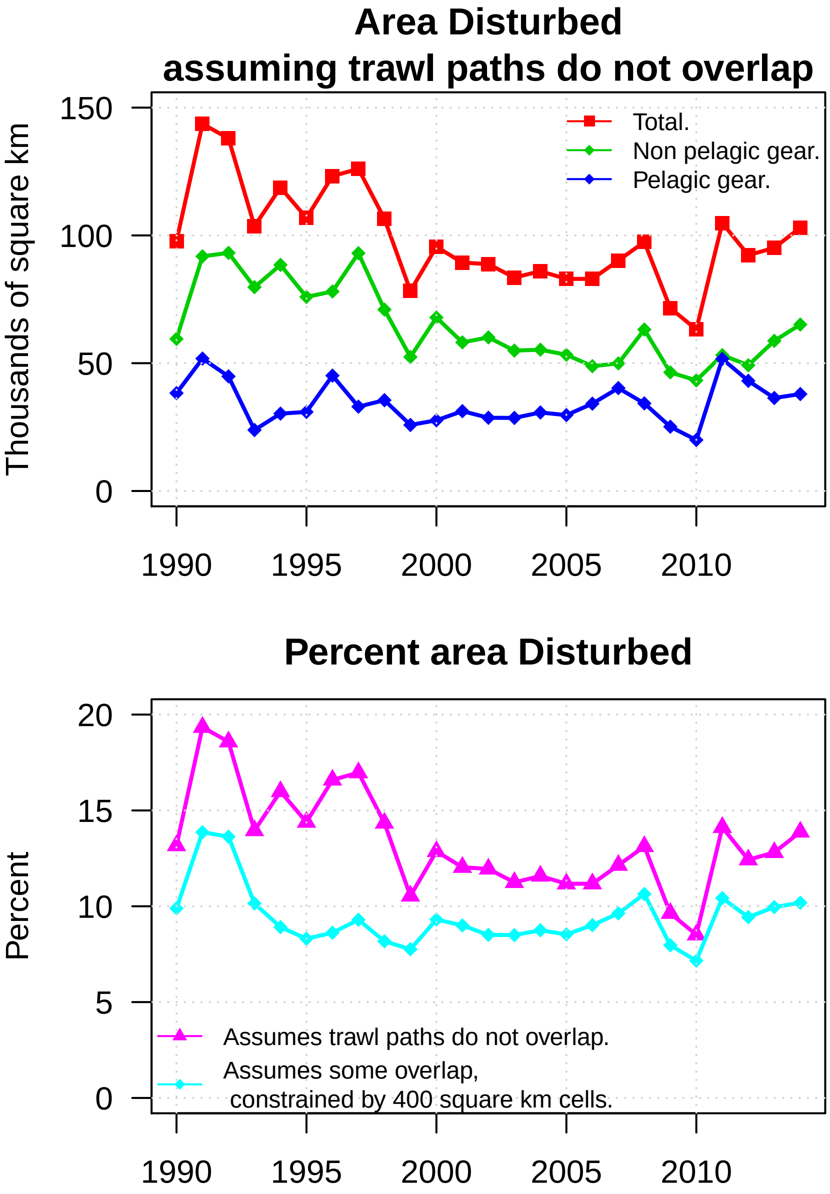

Figure 118: Total maximum potential area disturbed (assuming no spatial overlap of trawls), and the percent area disturbed. The pink line, representing percent area disturbed, sums the area disturbed assuming no spatial overlap of trawl hauls in a year, thus providing an upper limit to the estimate of area disturbed. The light blue line represents the percent area disturbed with spatial overlap of trawl hauls within 400 km^2 cells, thereby, limiting the disturbance of trawls recorded in a cell to 400 km^2.

observed tows. This fishery is prosecuted with towed pelagic trawls. Gear components which may interact with benthic habitat include the trawl sweeps and chain footrope. The fishery is prosecuted with both catcher and catcher-processor vessels. Non-pelagic trawl fishing effort is measured by the number of observed tows. This fishery is prosecuted with towed non-pelagic trawls. Gear components which may interact with benthic habitat include the trawl doors, sweeps, and footropes. The fishery is prosecuted with both catcher and catcher-processor vessels. In both pelagic and non-pelagic trawling, the number of hours in a tow may vary, but when aggregated over time and regions (AI, BS, GOA) the number of tows is representative of hours towed. Pot fishing effort is measured by the number of observed pot lifts, and is mainly a cod fishery prosecuted with set pots, which are generally converted from crab pots by adding triggers. Gear components which may interact with benthic habitat include the pot. The fishery is prosecuted with catcher vessels.

Non-confidential observed fishery data (1993-2014) can be found at `http://www.afsc.noaa.gov/FMA/spatial_data.htm` and includes both target species and bycatch information. Data are updated several times a year. AFSC trawl survey data (1982-2014) for the Aleutian Islands, Bering Sea, and Gulf of Alaska can be found at `http://www.afsc.noaa.gov/RACE/groundfish/survey_data/data.htm`. Survey data includes all species caught and identified. The observed fishery effort data in this section is summarized on a 100km^2 grid over a ten year period by region (AI, BS, GOA), and filtered for confidentiality.

Status and trends in the Bering Sea: Historic effort in the longline, pelagic trawl, non-pelagic trawl, and pot fisheries in the eastern Bering Sea is shown in Figure 119.

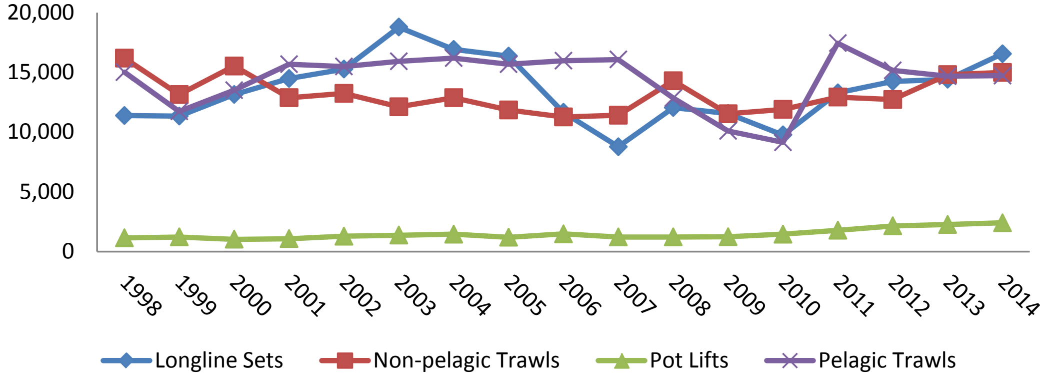

Figure 119: Bering Sea observed fishing effort, 1998-2014.

Longline. For the period 2005-2014, there were a total of 133,338 observed longline sets in the Bering Sea fisheries (Figure 120). During 2014, the amount of observed longline effort was 16,541 sets, which is higher than both 2013 and the 10-year average for the fishery. Areas of higher fishing effort are generally to the north of Unimak Island, the shelf edge represented by the boundary of report area 521, and to the south and west of St. George and St. Paul Islands. This fishery occurs mainly for Pacific cod, Greenland turbot, and sablefish. In 2014, fishing effort was anomalously high throughout much of the Bering Sea, with negative anomalies in Area 509 and to the north of Zhemchug Canyon (Figure 121).

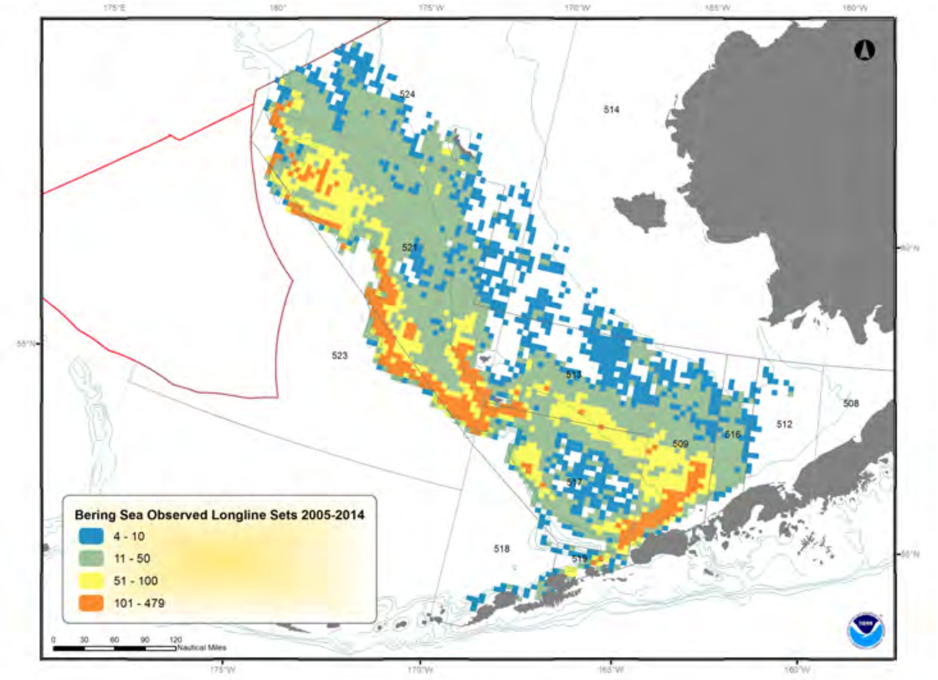

Figure 120: Observed longline effort (sets) in the Bering Sea, 2005-2014.

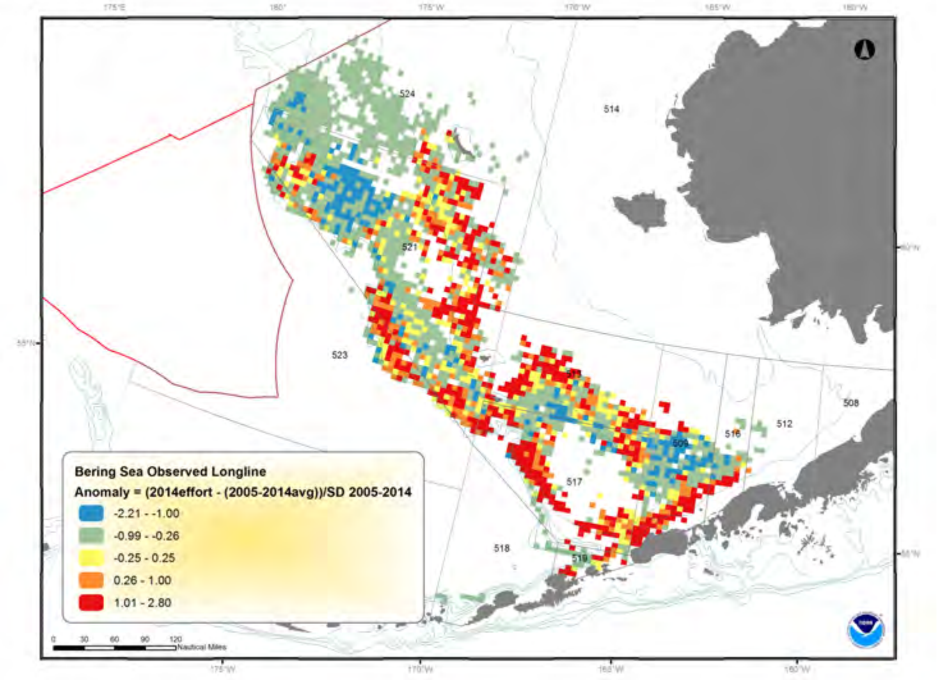

Figure 121: Observed longline fishing effort in 2014 relative to the 2005-2014 average in the Bering Sea. Anomalies calculated as (observed effort for 2014 - average observed effort from 2005-2014)/stdev(effort from 2005-2014).

Pelagic trawl. For the period 2005-2014 there were 141,773 observed pelagic trawl tows in the Bering Sea (Figure 122). There were 14,718 observed tows in 2014, which is just slightly higher than the 10-year average and a consistent with 2013. Areas of high fishing effort are generally north of Unimak Island and between the 100 and 200m contours in management areas 509, 513, 517, 519, and 521. The predominant species harvested within the eastern Bering Sea is walleye pollock. Pollock occur on the sea bottom, the midwater and up to the surface. Most catch of pollock is taken at 50-300m. In 2014, fishing effort was higher than normal throughout much of the southern Bering Sea, with lower than average areas in the mid- to upper Bering Sea, with the exception of several areas near Zhemchug Canyon (Figure 123).

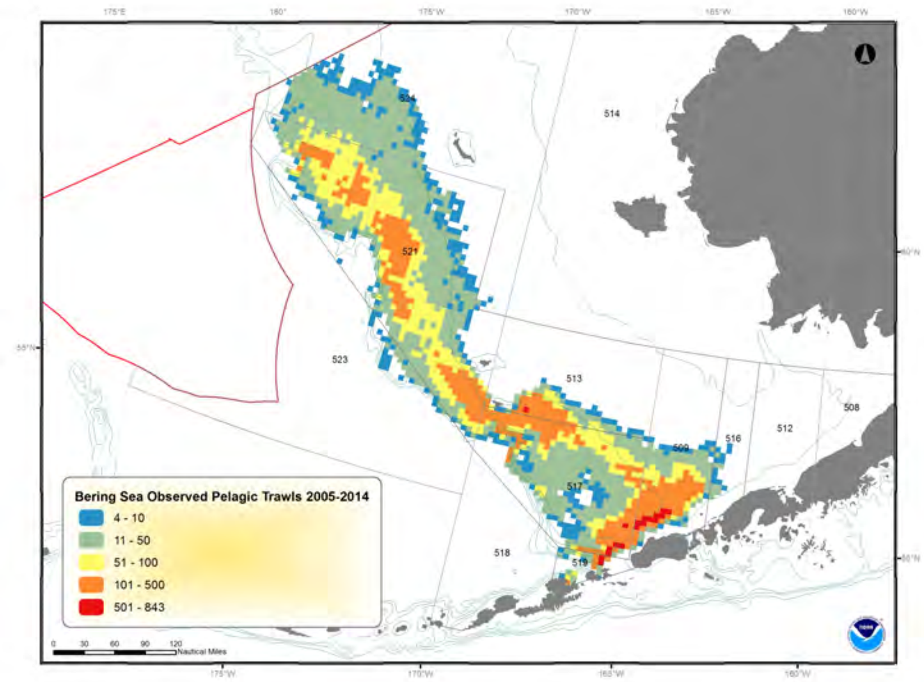

Figure 122: Spatial location and density of observed pelagic trawling in the Bering Sea, 2005-2014.

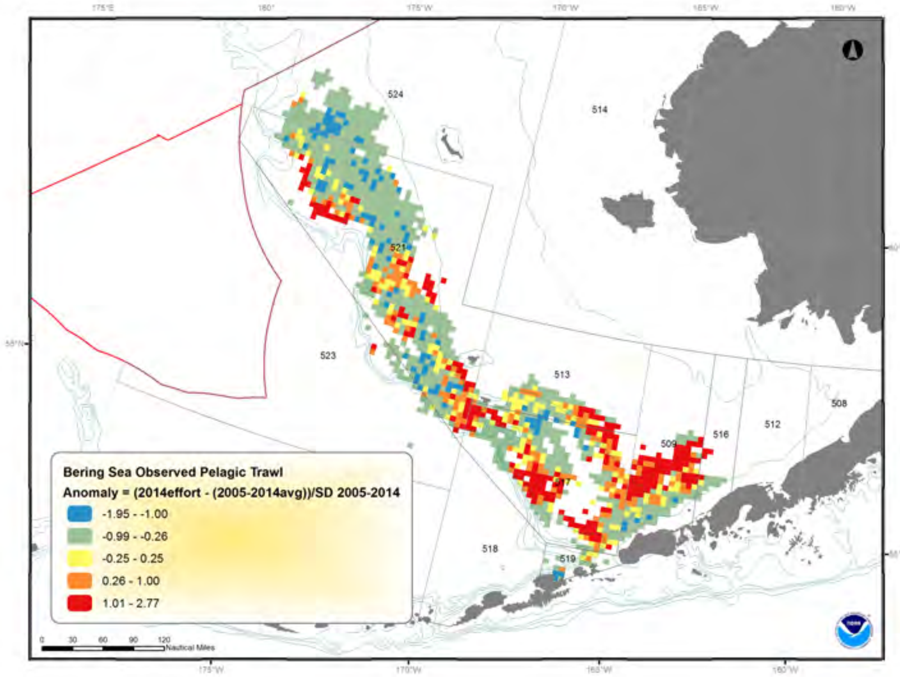

Figure 123: Observed pelagic trawl fishing effort in 2014 relative to the 2005-2014 average in the Bering Sea. Anomalies calculated as (estimated effort for 2014 - average effort from 2005-2014)/stdev(effort from 2005-2014).

Non-pelagic trawl. For the period 2005-2014, there were a total of 127,657 observed bottom trawl tows in the Bering Sea fisheries(Figure 124). During 2014, observed bottom trawl effort consisted of 14,982 tows, which was similar to 2013 and higher than the 10-year average. Areas of high fishing effort are north of Unimak Pass/Island as well the southeast portion of Area 513, western portions of Area 509, and to the west of St. Paul Island in Area 521. Additional small areas of concentration exist near Cape Constantine and off of Kuskokwim Bay. The primary catch in these areas was Pacific cod and yellowfin sole. In 2014, fishing effort was higher than average in the the central Bering Sea, the northwest corner of Unimak Island, and along the shelf break of Area 517. Effort was lower to the north and east of Unimak Island For the period 2003-2012, there were a total of 122,948 observed bottom trawl tows in the Bering Sea fisheries. During 2012, observed bottom trawl effort consisted of 12,720 tows, which was slightly above average compared to the past 10 years. Spatial patterns of fishing effort are summarized on a 10 km2 grid . Areas of high fishing effort are north of Unimak Pass/Island as well the southeast portion of Area 51, western portions of Area 509, and to the west of St. Paul Island in Area 521. Additional small areas of concentration exist near Cape Constantine and off of Kuskokwim Bay. The primary catch in these areas was Pacific cod and yellowfin sole. In 2012, fishing effort was higher than average north of Unimak Island and the Alaska Peninsula in the southern portion of area 509, as well as to the north of Area 513 (Figure 125).

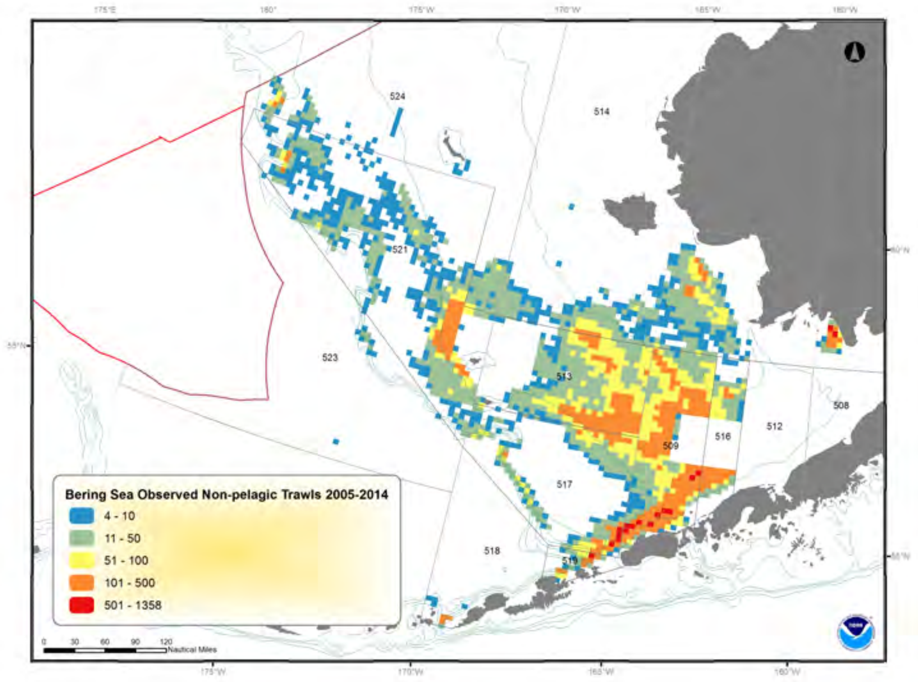

Figure 124: Spatial location and density of observed bottom trawling in the Bering Sea, 2005-2014.

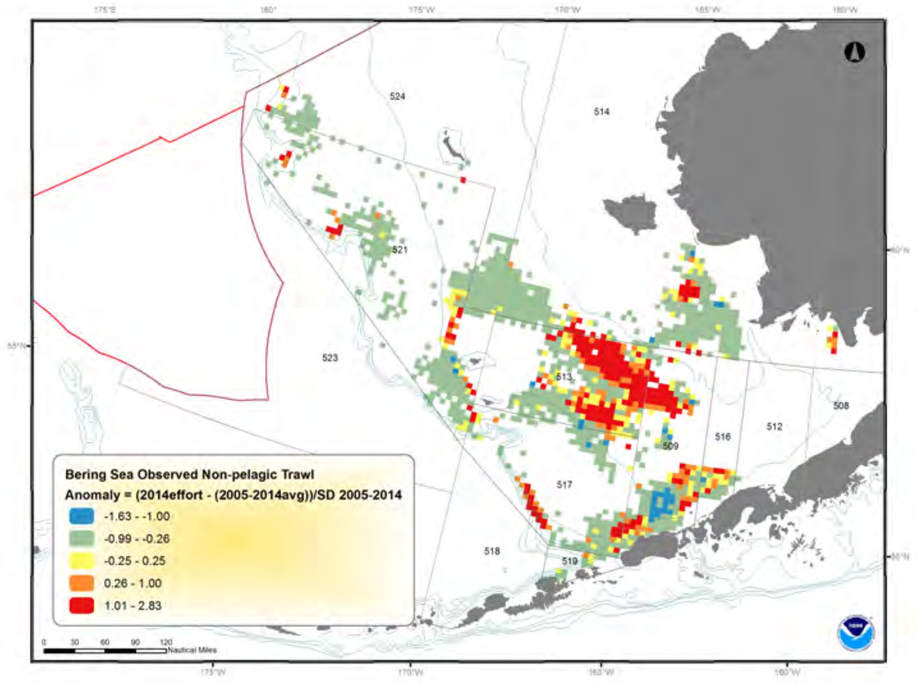

Figure 125: Observed bottom trawl fishing effort in 2014 relative to the 2005-2014 average in the Bering Sea. Anomalies calculated as (estimated effort for 2014 - average effort from 2005-2014)/stdev(effort from 2005-2014).

Pot. For the period 2005-2014, there were a total of 16,492 observed pot lifts in the Bering Sea fisheries (Figure 126). During 2014, the amount of observed pot effort was 2,409 lifts, which was higher than the 10-year average but similar to effort in 2013. Areas of high fishing effort are west and north of Unimak Island and near Unalaska Island. This fishery occurs mainly for Pacific cod which form dense aggregations for spawning in the winter months. Increased effort anomalies occurred mainly to the east of Umnak Island, while areas near Akutan and Unalaska exhibited lower effort than average (Figure 127).

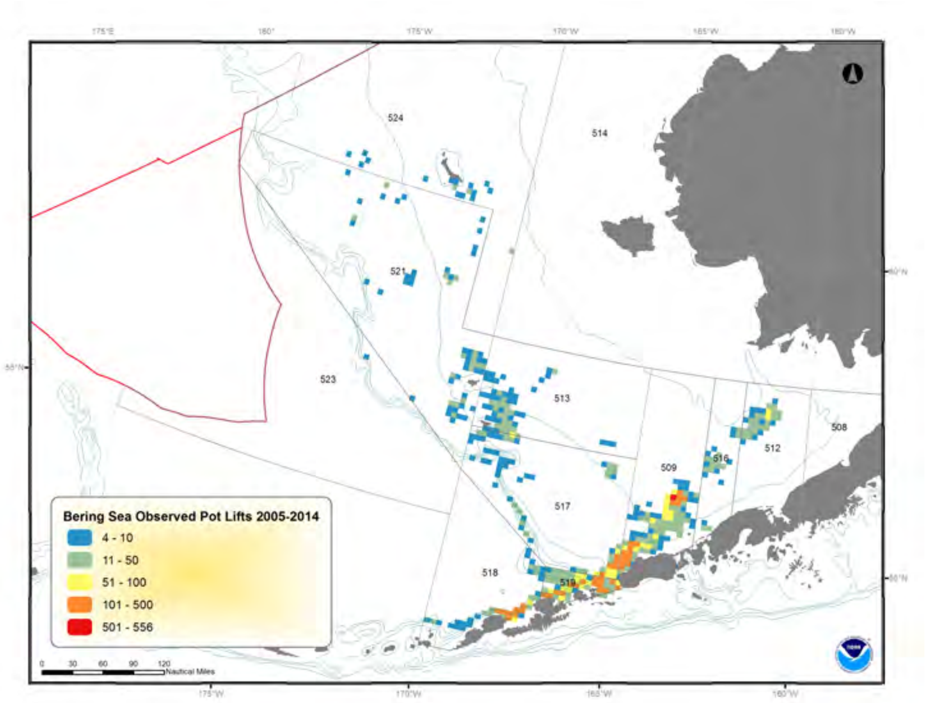

Figure 126: Spatial location and density of pot effort (observed number of pot lifts) in the Bering Sea, 2005-2014.

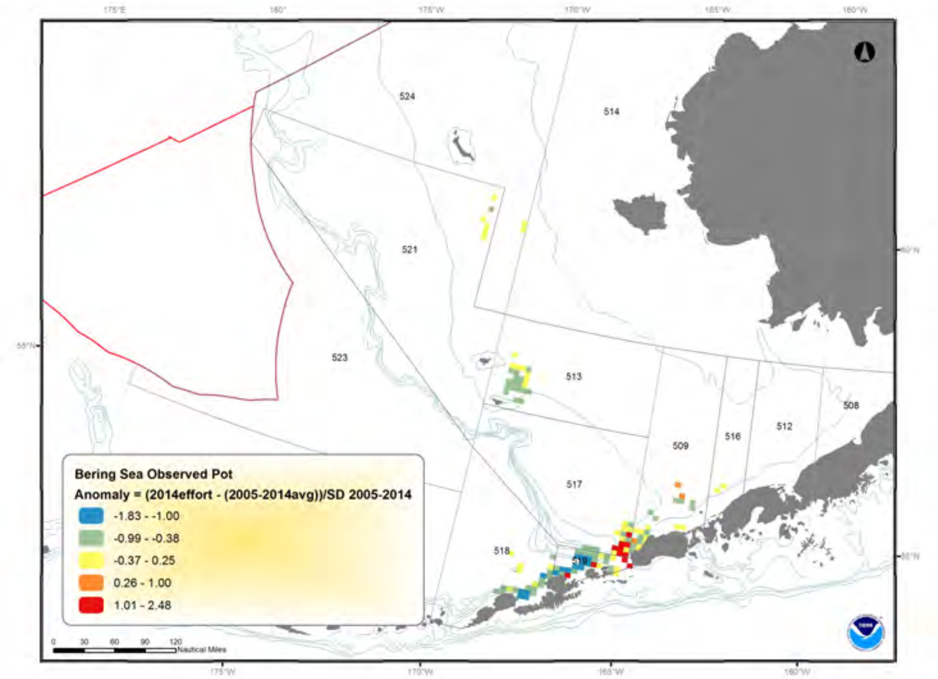

Figure 127: Observed pot fishing effort in 2014 relative to the 2005-2014 average in the Bering Sea. Anomalies calculated as (estimated effort for 2014 - average effort from 2005-2014)/stdev(effort from 2005-2014).

Status and trends in the Aleutian Islands: Effort in the longline, pelagic trawl, non-pelagic trawl, and pot fisheries in the Aleutian Islands is shown in Figure 128.

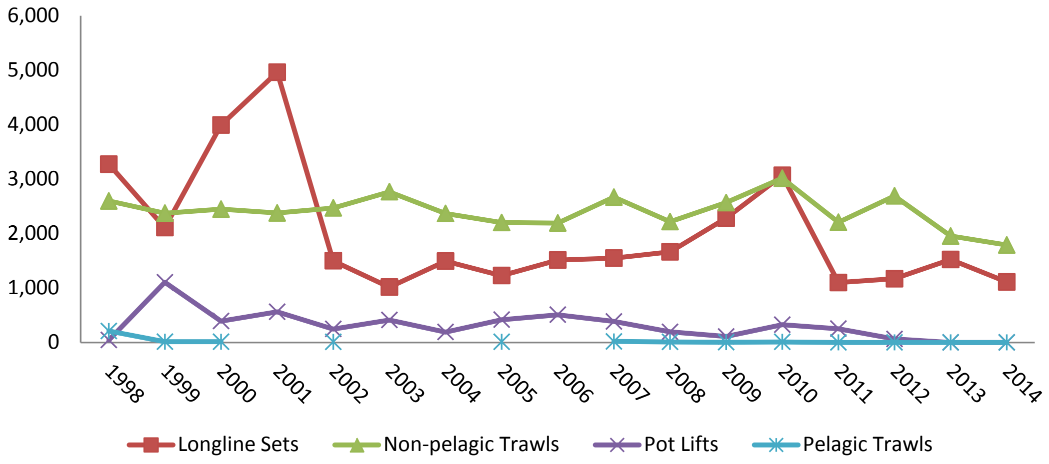

Figure 128: Aleutian Islands observed fishing effort 2005-2014.

Longline. For the period 2005-2014 there were 16,199 observed longline sets in the Aleutian Islands (Figure 129). During 2014, the amount of observed longline effort was 1,110 sets, which is below the 10-year average and also a decrease from 2013. The spatial pattern of high fishing effort are dispersed widely along the shelf edge. This fishery occurs mainly on Pacific cod, Greenland turbot, and sablefish. The catcher vessel longline fishery for cod occurs over softer bottom, with fish found in shallow (150-250 ft) waters during summer months, but deeper (300-800 ft) in the winter. The sablefish/Greenland turbot fishery occurs over silt, mud, and gravel bottom at depths of 150 to 600 fm. In 2014, fishing effort anomaly showed no specific patterns, with areas of increase and decrease throughout the Aleutian Islands (Figure 130).

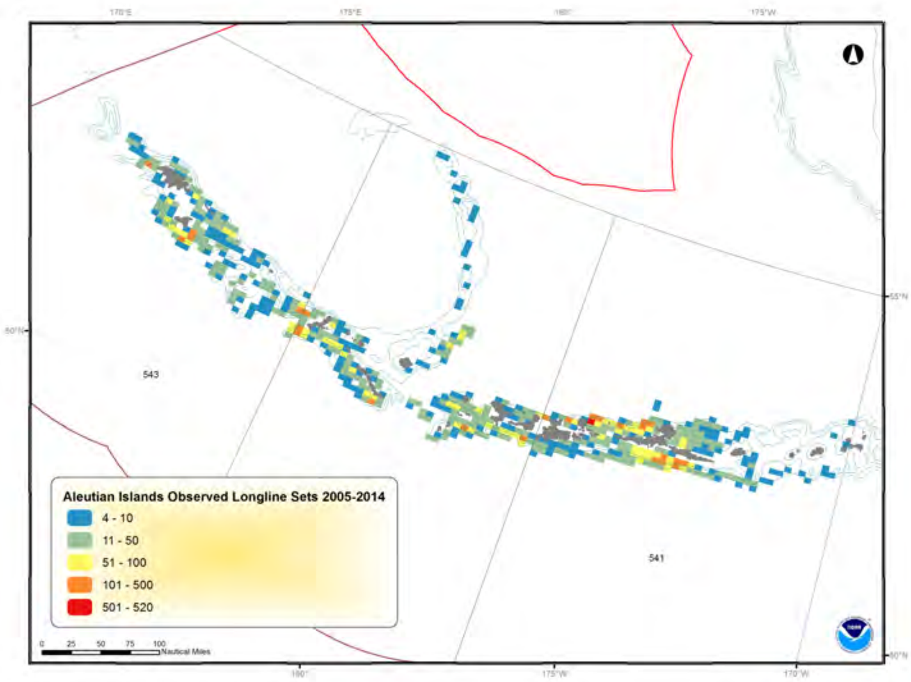

Figure 129: Observed longline effort (sets) in the Aleutian Islands, 2005-2014.

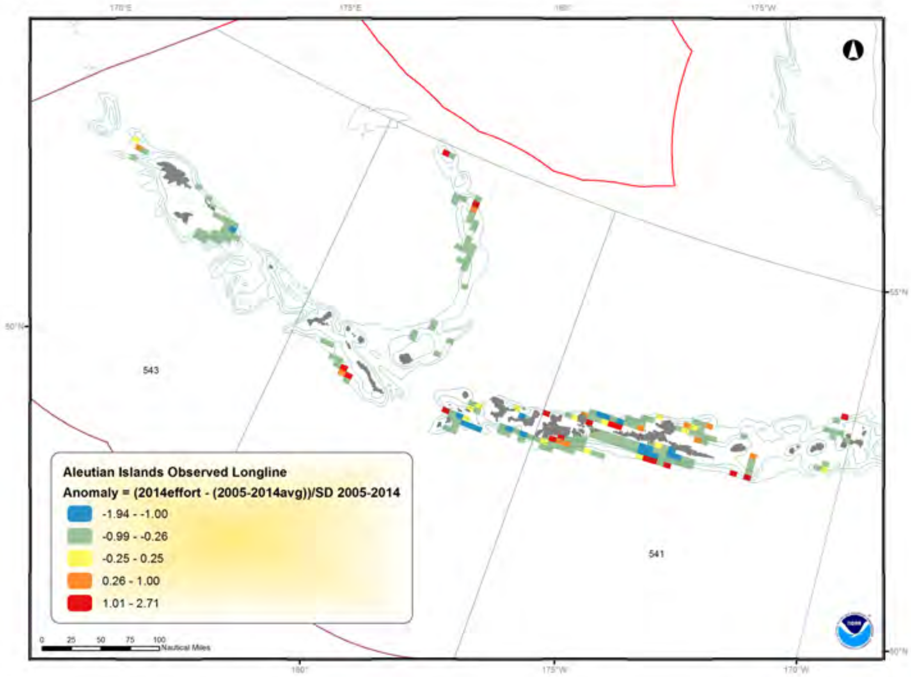

Figure 130: Observed longline fishing effort in 2014 relative to the 2005-2014 average in the Aleutian Islands. Anomalies calculated as (observed effort for 2014 - average observed effort from 2005-2014)/stdev(effort from 2005-2014).

Pelagic trawl. For the period 2005-2014 there were a total of 53 observed pelagic trawl tows in the Aleutian Islands. In 2001, 2003, 2004, 2006, 2012 - 2014 there were no observed pelagic trawl tows. Patterns of high fishing effort, mainly before 1999, were historically dispersed along the shelf edge. As there have been no tows were recorded in the Aleutian Islands in 2014, maps of effort and anomaly are not included.

Non-pelagic trawl. For the period 2005-2014 there were 23,499 observed bottom trawl tows in the Aleutian Islands (Figure 131). During 2014, the amount of observed bottom trawl effort was 1,789 tows, which is almost 24 percent below average for the 10-year period. It represents a decrease over 2013. Patterns of high and low fishing effort are dispersed throughout the Aleutian Islands. The primary catches in these areas are Pacific cod, Pacific ocean perch, and Atka mackerel. In 2014, areas of anomalous fishing effort were minimal but scattered throughout the region, with higher than average observed effort east of Agattu Island and on Petrel Bank (Figure 132). Some areas that were closed in 2012 due to SSL management measures have been reopened to varying degrees. In 2006, the Aleutian Islands Habitat Conservation Area (AIHCA) closed approximately 279,114 nm^2 to bottom trawl fishing in the three AI management areas.

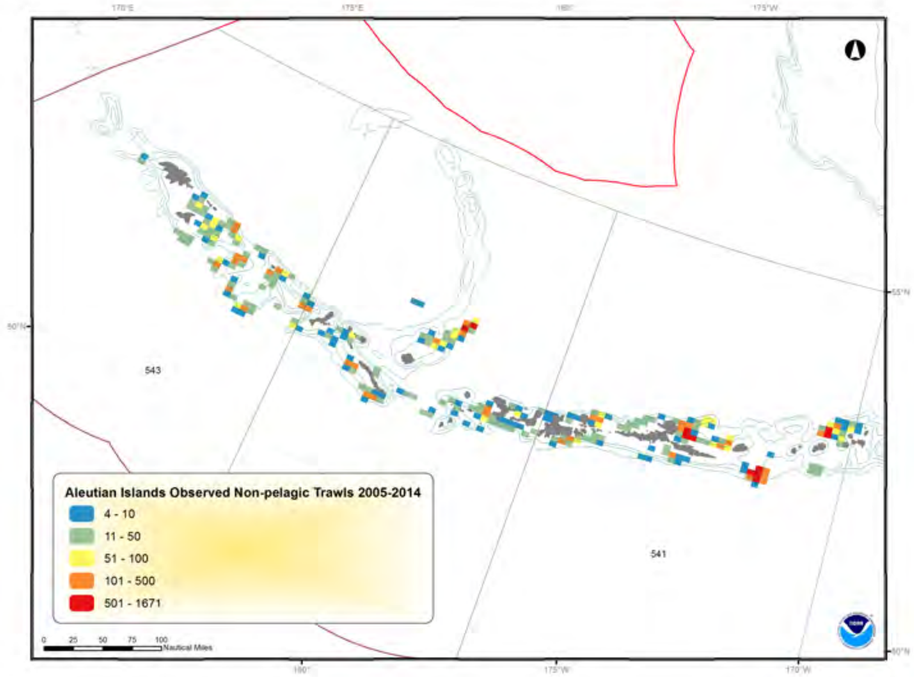

Figure 131: Spatial location and density of observed bottom trawl effort in the Aleutian Islands, 2005-2014.

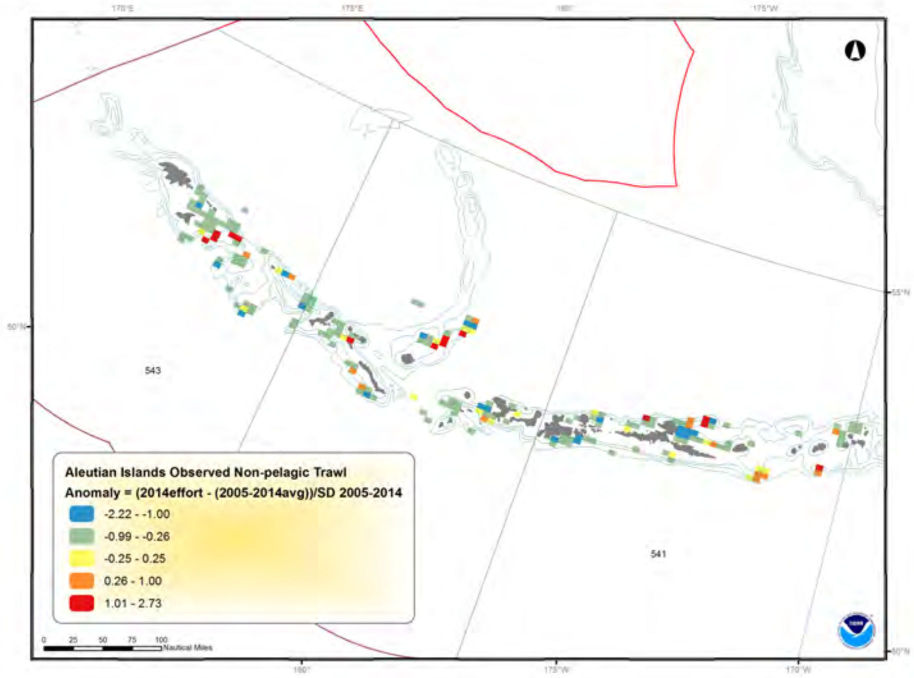

Figure 132: Observed bottom trawl fishing effort in 2014 relative to the 2005-2014 average in the Aleutian Islands. Anomalies calculated as (estimated effort for 2014 - average effort from 2005-2014)/stdev(effort from 2005-2014).

Pot. For the period 2005-2014 there were 2,253 observed pot lifts in the Aleutian Islands (Figure 133). During 2014, there was no observed pot effort. Fishing effort was dispersed along the shelf edge with high effort near Amlia and Seguam Islands. With no observed lifts in either 2013 or 2014, a map of fishing anomaly is not included.

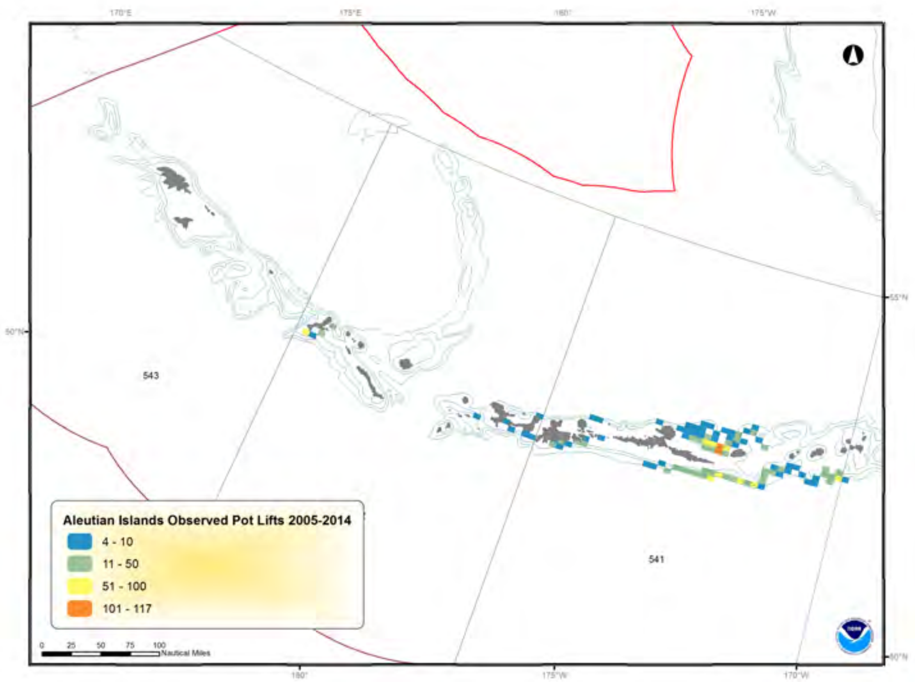

Figure 133: Spatial location and density of pot effort (observed number of pot lifts) in the Aleutian Islands, 2005-2014.

Status and trends: Effort in the longline, pelagic trawl, non-pelagic trawl, and pot fisheries in the Gulf of Alaska is shown in Figure 134.

Longline. For the period 2005-2014 there were 31,651 observed hook and line sets in the Gulf of Alaska. During 2014, the amount of observed longline effort was 5,233 sets, which is twice the 10-year average and almost 1,000 higher than in 2013. Patterns of high fishing effort were dispersed along the shelf in all management areas (Figure 135). The predominant hook and line fisheries in the Gulf of Alaska are composed of sablefish and Pacific cod. In southeast Alaska, there is a demersal rockfish fishery; dominant species include yelloweye rockfish (90%), with lesser catches of quillback rockfish. The demersal shelf rockfish fishery occurs over bedrock and rocky bottoms at depths of 75 m to ¿200 m. The sablefish longline fishery occurs over mud bottoms at depths of 400 to ¿1000 m. This fishery is often a mixed halibut/sablefish fishery, with shortraker, rougheye, and thornyhead rockfish also taken. Sablefish has been an IFQ fishery since 1995, which has reduced the number of vessels, crowding, gear conflicts and gear loss, and increased efficiency. The cod longline fishery generally occurs in the western and central Gulf of Alaska, opening on January 1st and lasting until early March. Halibut prohibited species catch sometimes curtails the fishery. The cod fishery occurs over gravel, cobble, mud, sand, and rocky bottom, in depths of 25 fathoms to 140 fathoms. In 2014, fishing effort anomalies were high throughout the region (Figure 136).

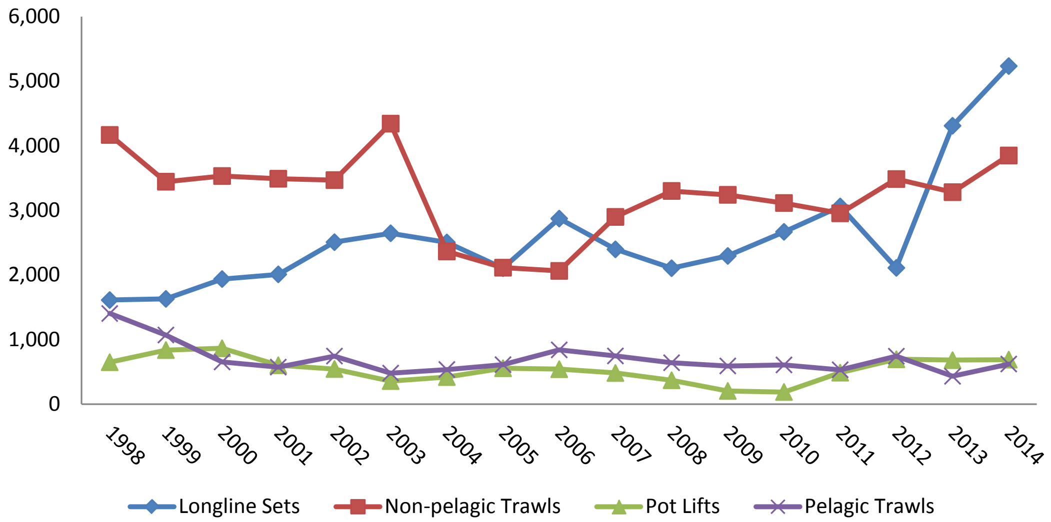

Figure 134: Gulf of Alaska observed fishing effort, 2005-2014.

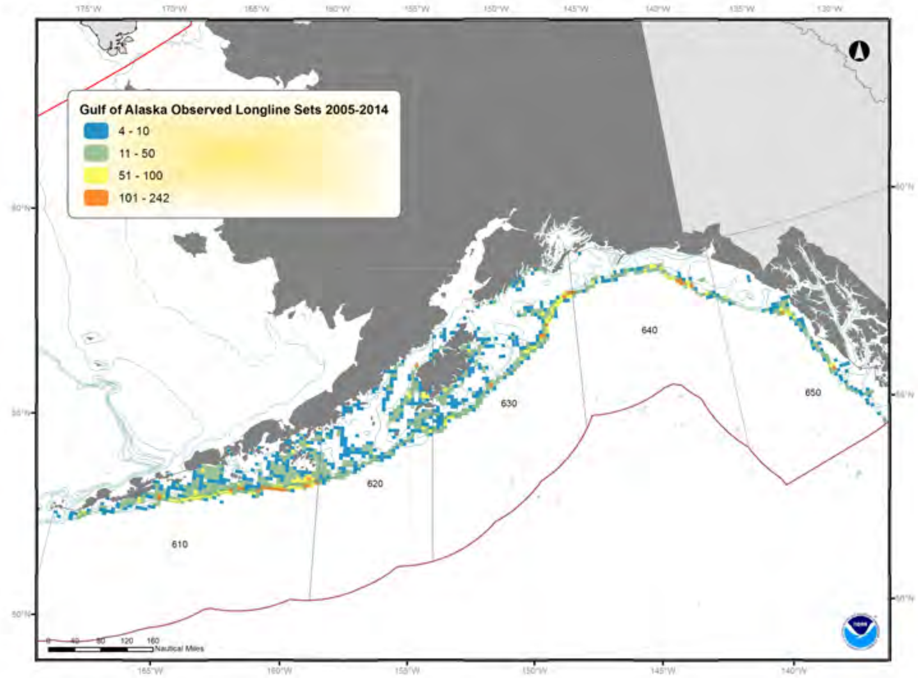

Figure 135: Observed longline effort (sets) in the Gulf of Alaska, 2005-2014.

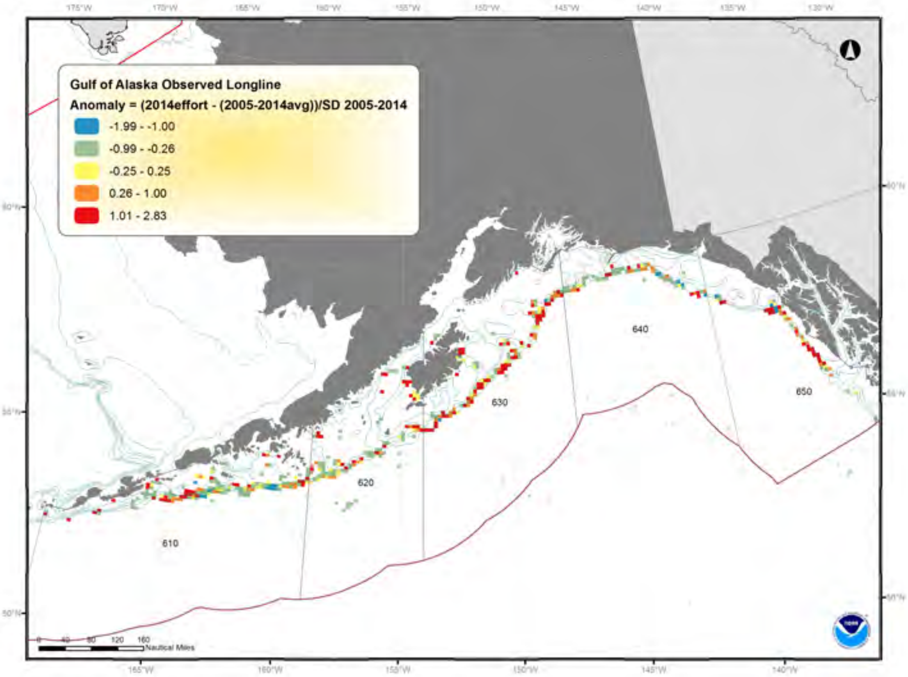

Figure 136: Observed longline fishing effort in 2014 relative to the 2005-2014 average in the Gulf of Alaska. Anomalies calculated as (observed effort for 2014 - average observed effort from 2005-2014)/stdev(effort from 2005-2014).

Pelagic trawl. The primary target of the GOA pelagic trawl fishery is pollock (Figure 137). The fleet is comprised of trawl catcher vessels that deliver their catch onshore for processing. For the period 2005-2014 there were 6,898 observed pelagic trawl tows in the Gulf of Alaska. The spatial pattern of this effort centers around Kodiak, specifically Chiniak Gully, Marmot Bay and Shelikof Strait, with limited fishing on the shelf break to the east and west. During 2014, the amount of trawl effort was 621 tows, which was above average for the 10-year period. The catch anomaly for 2014 was variable, with the highest anomaly centered in Shelikof Strait and the Shumagain Islands (Figure 138).

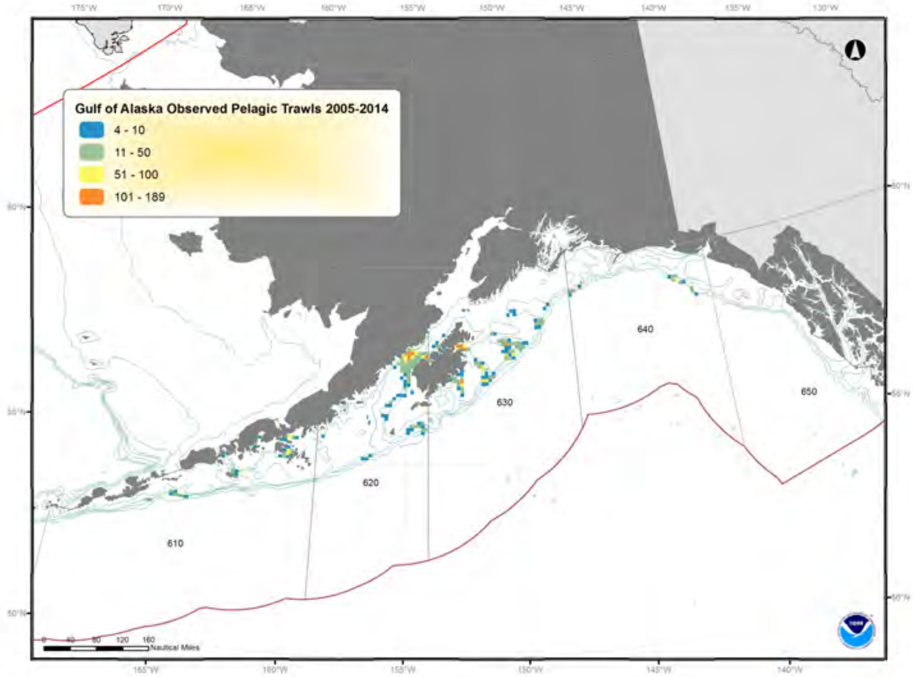

Figure 137: Spatial location and density of observed pelagic trawl effort in the Gulf of Alaska, 2005-2014.

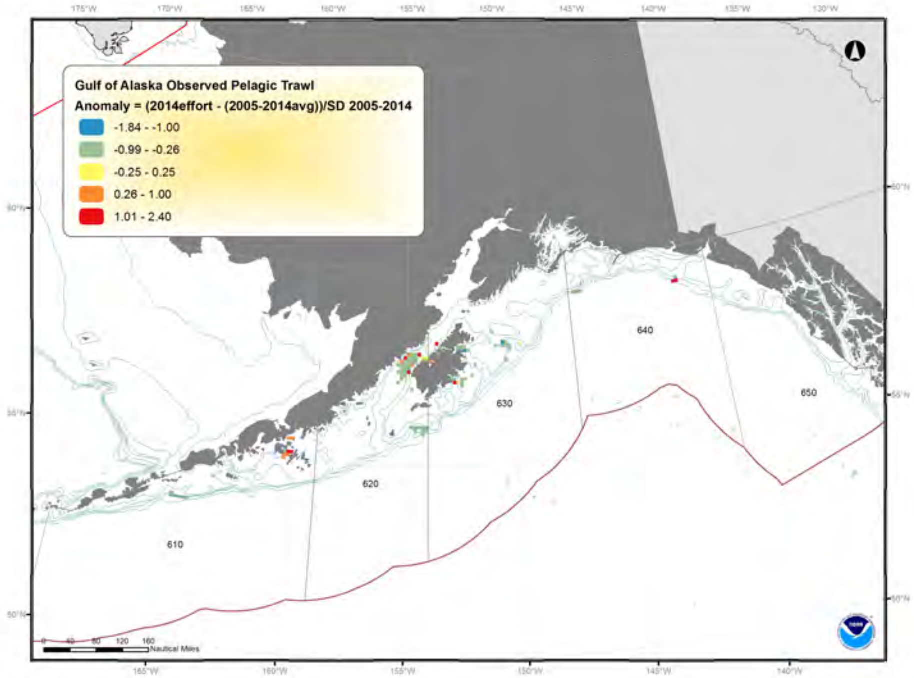

Figure 138: Observed pelagic trawl fishing effort in 2014 relative to the 2005-2014 average in the Gulf of Alaska. Anomalies calculated as (observed effort for 2014 - average observed effort from 2005-2014)/stdev(effort from 2005-2014).

Non-pelagic trawl. . For the period 2005-2014 there were 32.657 observed bottom trawl tows in the Gulf of Alaska. The spatial pattern of this effort is dispersed throughout the central and western Gulf. Patterns of high fishing effort were dispersed along the shelf edge with high pockets of effort near Chirkoff, Cape Barnabus, Cape Chiniak and Marmot Flats (Figure 139).Primary catches in these areas were Pacific cod, flatfish and rockfish. During 2014, the amount of trawl effort was 3,849 tows, which was an increase over 2013 and also above the average for the 10-year period. For 2014, fishing effort anomaly were focused to the west of Kodiak and Shumagain Islands (Figure 140). A larger portion of the trawl fleet in Kodiak is comprised of smaller catcher vessels previously had 30% observer coverage, and at least a portion of the increase in observed effort is can be attributed to changes in observer coverage.

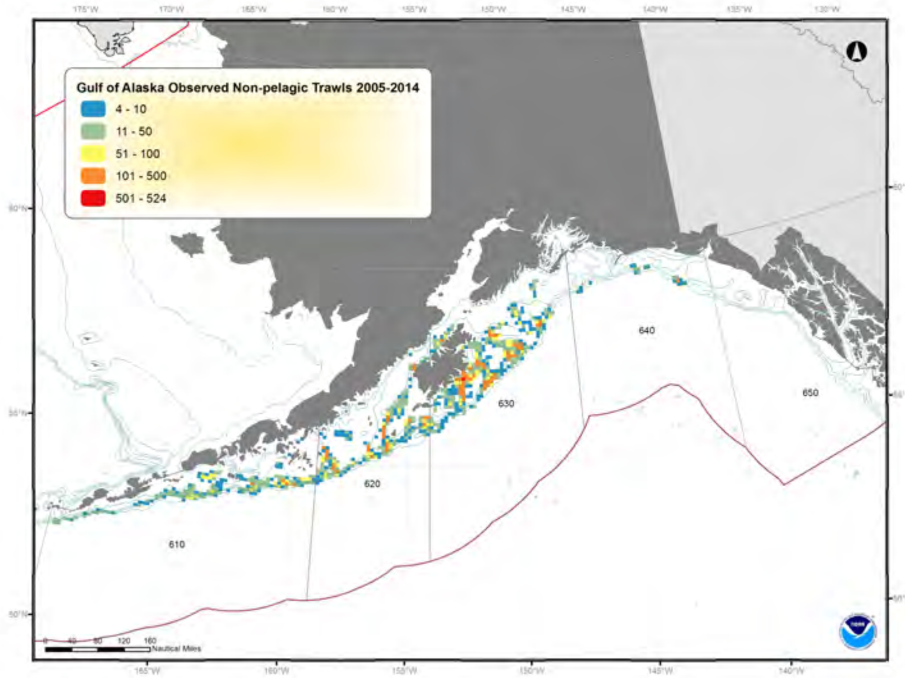

Figure 139: Spatial location and density of observed bottom trawl effort in the Gulf of Alaska, 2005-2014.

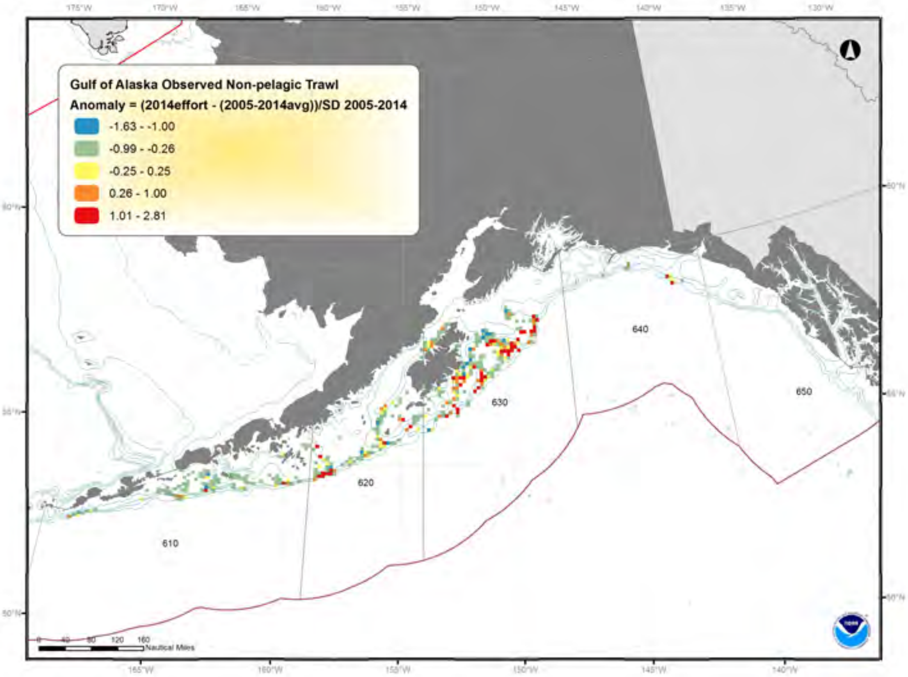

Figure 140: : Observed bottom trawl fishing effort in 2014 relative to the 2005-2014 average in the Gulf of Alaska. Anomalies calculated as (observed effort for 2014 - average observed effort from 2005-2014)/stdev(effort from 2005-2014).

Pot. For the period 2005-2014 there were 5,311observed pot lifts in the Gulf of Alaska. During 2014, the amount of observed pot effort was 689 lifts, which represents an increase from 2013 and is above the 10-year average of 483. Patterns of higher fishing effort were dispersed along the shelf to the east of Kodiak Island (Figure 141). Fishing effort in 2014 showed minor anomalies throught the region (Figure 142). Approximately 100 boats participate in this fishery. There is also a state-managed fishery in state waters. Vessels used in the inshore fishery are all catcher vessels of small (less than 60-foot LOA) and medium size (60- to 125-foot LOA). The offshore fishery includes some catcher-processors ranging from 90 to over 125 feet. The A season fishery begins on January 1st and concludes in early March. The B season fishery opens September 1 and can be expected to last 6 weeks or less. There is also a state-managed fishery in state waters.

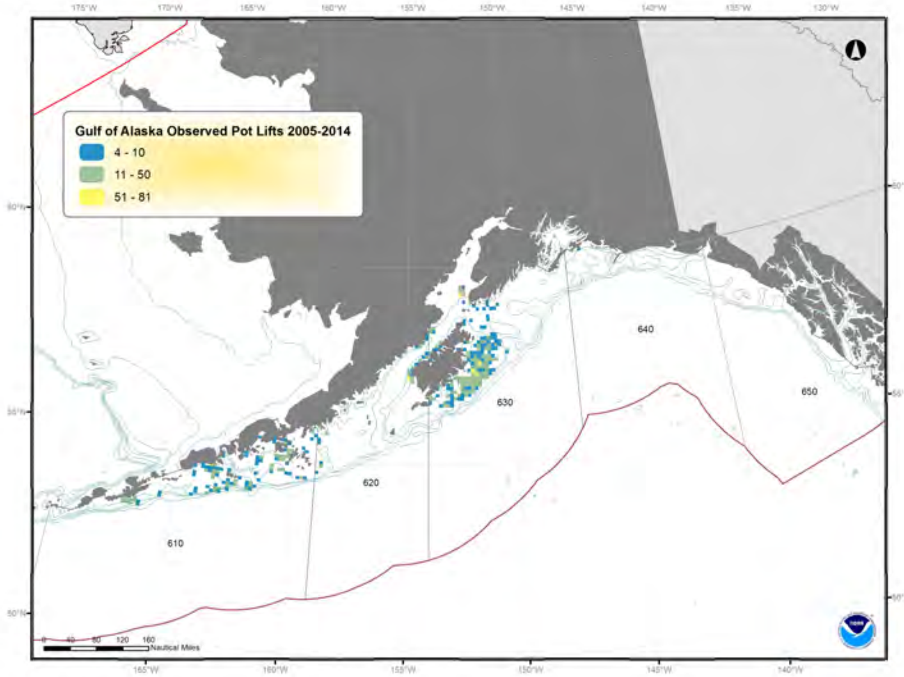

Figure 141: Spatial location and density of pot effort (observed number of pot lifts) in the Gulf of Alaska, 2005-2014.

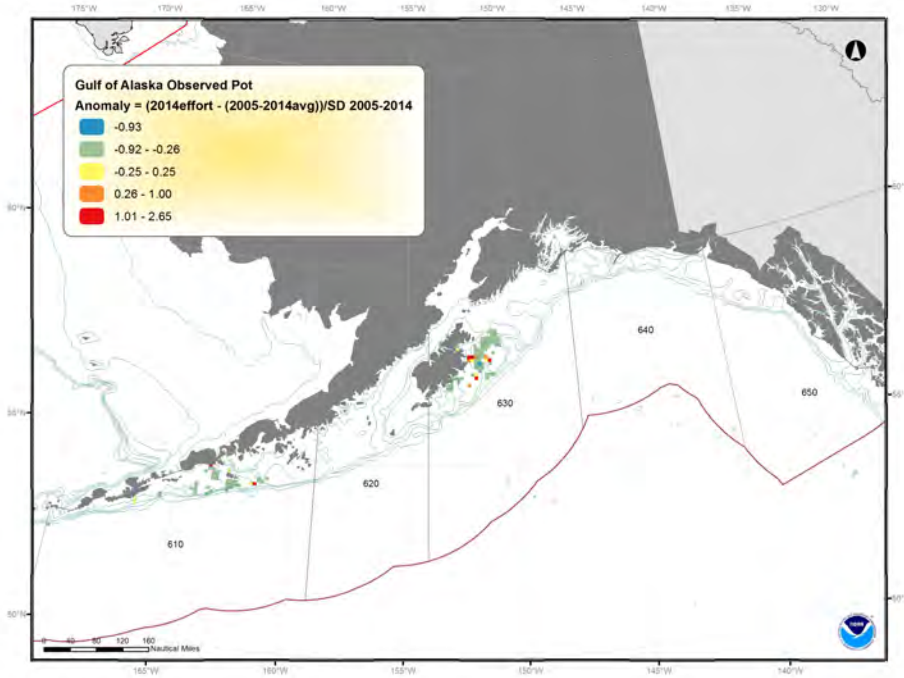

Figure 142: Observed pot fishing effort in 2014 relative to the 2005-2014 average in the Gulf of Alaska. Anomalies calculated as (observed effort for 2014 - average observed effort from 2005-2014)/stdev(effort from 2005-2014).

Factors causing observed trends: Fishing behavior is impacted by environmental, economic, and regulatory drivers. Specifically, spatial changes in fishing effort in the GOA and BSAI are driven primarily by the location of the target species and Federal regulations that limit the ability of certain vessel, gear, or operational types from directed fishing (e.g., closed areas). Moreover, changes in markets, environmental conditions, and the presence of non-target species (e.g. prohibited species) can also affect the fishing behavior of vessel operators during the fishing season. Information regarding area closures can be found in `http://www.npfmc.org/habitat-protections/` and other management actions at `http://alaskafisheries.noaa.gov/sustainablefisheries/amds/`.

Recent changes to the North Pacific Observer Program (Observer Program) have increased the amount of data accrued from longline vessel operating in the GOA. In 2013, NMFS made important changes to how observers are deployed, and the vessels and processors that must have some or all of their operations observed. In the GOA longline fishery, this resulted in an increase in observer effort on CVs less than 60 ft and does not indicate an increase in actual fishing trips. For example, in 2013 and 2014 changes in observer coverage have led to apparent increases in the GOA longline fishery effort, where the 10-year average had been approximately 2,542 observed tows. Between 2012 and 2014, observed effort increased from 2,109 events to 5,233 observations. This increase is largely due to to the increased observations of vessels less than 60' across all gear types. In 2012, less than 100 vessels in this class were observed, and in 2014 over 5,000 vessels were observed. Information on the restructured observer program can be found at `http://alaskafisheries.noaa.gov/sustainablefisheries/observers/`.

Reopening of areas closed in 2012 have affected the non-pelagic trawl fishing effort in the central and western Aleutian Islands. In recent years fishing in the Aleutian Islands has been restricted by the Stellar Sea Lion Closures. The western distinct population segment of Steller sea lions occurs in the Aleutian Islands subarea and is listed as endangered underPthe Endangered Species Act (ESA). Critical habitat has been designated for this area, including waters within 20 nautical miles (nm) of haulouts and rookeries. More information on SSL-related closures can be found at `https://alaskafisheries.noaa.gov/sustainablefisheries/sslpm/`.

The magnitude of the Bering Sea trawl fisheries is generally more than four times as large (in terms of effort) as the Aleutian Islands and Gulf of Alaska fisheries combined. The Bering Sea pollock fishery is the largest volume U.S. Fishery, and most pollock is harvested with pelagic trawl nets. Effort in the Bering Sea remained at a relatively stable through 2007, at which point it declined until rebounding in 2011. Pelagic trawl effort is near the long-term average in 2013 and 2014. Some of the consistency of effort can be attributed to changes in the structure of the groundfish fisheries due to rationalization. As of 1999, only pelagic trawls can be used in the Bering Sea pollock fisheries. Fluctuations in bottom trawl effort track well with overall landings of primary bottom trawl target species, such as flatfish and to a lesser extent cod and pollock. Some of the reduction in bottom trawl effort in the Bering Sea after 1997 can be attributed to changes in the structure of the groundfish fisheries due to rationalization (Ammendment 80). `http://alaskafisheries.noaa.gov/sustainablefisheries/amds/80/`.

Implications: Fishing effort is an indicator of potential damage to or removal of both living and nonliving bottom substrates, damage to small epifauna and infauna, and reduction in benthic biodiversity by mobile (pelagic and non-pelagic trawl) or fixed (longline, pot) gear. The effects of changes in fishing effort on habitat are largely unknown, although this is an active field of research and is currently being addressed in the Essential Fish Habitat 5-year Review (`http://www.npfmc.org/wp-content/PDFdocuments/membership/EcosystemCommittee/EcoPage/2014_EFH_research_program.`

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

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 2015

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

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

There are 199 FSSI stocks in the U.S., with a maximum possible score of 1,000. Beginning in 2015, the maximum possible FSSI score is 1,000 even if the number of stocks reported in the FSSI changes. Over time, the number of stocks included in the FSSI has changed as stocks have been added and removed from Fishery Management Plans (FMPs). Scaling FSSI to a 1,000 point scale permits tracking FSSI progress over time even as the number of stocks included changes. The FSSI previously contained 230 stocks. Details on FSSI scoring methodology can be found on the NOAA Fisheries, Status of Fisheries webpage (`http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/fssi.html`).

In the Alaska Region, there are 36 FSSI stocks and an overall FSSI of 144 would be achieved if every stock scored the maximum value, 4 (Tables 13 and 14). Prior to 2015 there were 35 FSSI stocks and maximum possible score of 140. To keep FSSI scores for Alaska comparable across years we will now be reporting the total Alaska FSSI as a percentage of the maximum possible score (i.e., 100%). Additionally, there are 30 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement (Table 13 and 15).

Status and trends: As of June 30, 2015, 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

Table 13: Summary of status for FSSI and non-FSSI stocks managed under federal fishery management plans off Alaska, updated through June 2015.

Jurisdiction	Stock Group	Number of Stocks	Overfishing				Overfished				Approaching Overfished Condition
			Yes	No	Unk	Undef	Yes	No	Unk	Undef	
NPFMC	FSSI	36	0	36	0	0	1	32	3	0	0
NPFMC	NonFSSI	30	0	29	1	0	0	5	25	0	0
	Total	66	0	65	1	0	1	36	29	0	0

to be overfished or to be approaching an overfished condition (Tables 13). The only crab stock considered to be overfished is the Pribilof Islands blue king crab stock, which is in year 1 of a new rebuilding plan. None of the non-FSSI stocks are subject to overfishing, known to be overfished, or known to be approaching an overfished condition.

The current overall Alaska FSSI is 133.5 out of a possible 144, or 92.7%, based on updates through June 2015 (Table 14). The overall Bering Sea/Aleutian Islands score is 86.5 out of a maximum possible score of 92. The BSAI groundfish score is 59 (including BSAI/GOA sablefish, see Endnote-g in Box A) of a maximum possible 60 and BSAI king and tanner crabs score is 27.5 out of a possible 32. The Gulf of Alaska groundfish score is 47 of a maximum possible 52 (excluding BSAI/GOA sablefish). Overall, the Alaska total FSSI score increased from 88.6% in 2014 to 92.7% 2015 (Figure 143)).

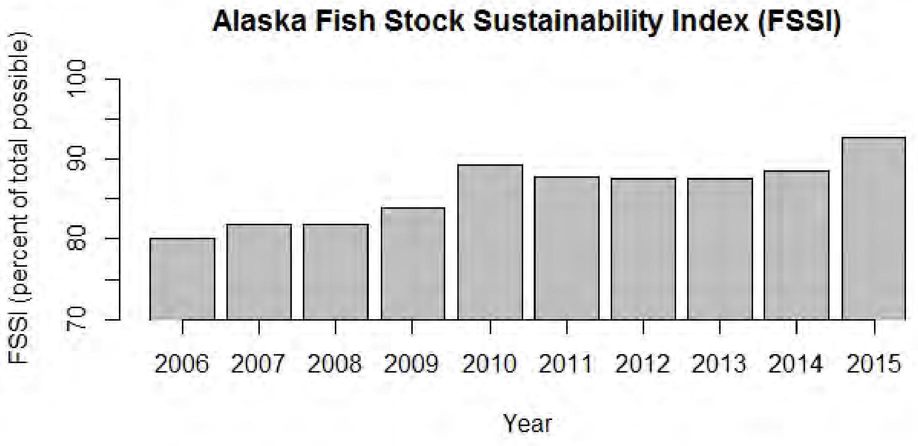

Figure 143: The trend in Alaska FSSI, as a percentage of the maximum possible FSSI from 2006 through 2015. The maximum possible FSSI is 140 for 2006 to 2014, and 144 in 2015. All scores are reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries`.

Factors influencing observed trends: Two stocks were added to the FSSI and one stock was removed from the FSSI and added to the non-FSSI. The BSAI skate and the GOA shallow water flatfish complexes were added to the FSSI and the Western Aleutian Islands red king crab was moved from FSSI to non-FSSI. Both the BSAI skate complex and the GOA shallow water flatfish complex scored the maximum of 4 points, while the W. Aleutian red king crab only scored 1.5 points last year. This resulted in a net FSSI gain of 6.5 points. Additional points were gained for the Pribilof Islands red king crab stock and the BSAI Blackspotted and Rougheye Rockfish stock, which both gained a point from last year for having biomass at or above 80% B_{MSY}. These changes resulted in the net FSSI increase from 124 to 133.5, or from 88.6% to 92.7%.

Crab groups in the BSAI region with FSSI scores less than 4 are golden king crab-Aleutian Islands (FSSI=1.5) and blue king crab-Pribilof Islands (FSSI=2). Neither of these king crab stocks are subject to overfishing. The Pribilof Islands blue king crab stock is considered overfished and is in year 1 of new rebuilding plan. Biomass for this stock is less than 80% of B_{MSY}. It is unknown if the golden king crab-Aleutian Islands stock is overfished and B_{MSY} is not estimated.

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

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

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

Table 14: FSSI stocks under NPFMC jurisdiction updated June 2015, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/`. See Box A for endnotes and definition of stocks and stock complexes.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/Bmsy	FSSI Score
Blue king crab - Pribilof Islands[a]	No	Yes	N/A	Year 1 of plan	Continue Rebuilding	0.06	2
Blue king crab - Saint Matthews Island[b]	No	No	No	N/A	N/A	1	4
Golden king crab - Aleutian Islands	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Red king crab - Bristol Bay	No	No	No	N/A	N/A	1.03	4
Red king crab - Norton Sound	No	No	No	N/A	N/A	1.06	4
Red king crab - Pribilof Islands[c]	No	No	No	N/A	N/A	0.91	4
Snow crab - Bering Sea	No	No	No	N/A	N/A	0.89	4
Southern Tanner crab - Bering Sea	No	No	No	N/A	N/A	2.61	4
BSAI Alaska plaice	No	No	No	N/A	N/A	1.79	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.51	4
BSAI Arrowtooth Flounder	No	No	No	N/A	N/A	2.61	4
BSAI Blackspotted and Rougheye Rockfish[d]	No	No	No	N/A	N/A	1.44	4
BSAI Flathead Sole Complex[e]	No	No	No	N/A	N/A	2.24	4
BSAI Rock Sole Complex[f]	No	No	No	N/A	N/A	2.06	4
BSAI Skate Complex[g]	No	No	No	N/A	N/A	2.06	4
BSAI Greenland halibut	No	No	No	N/A	N/A	0.58	3
BSAI Northern rockfish	No	No	No	N/A	N/A	1.94	4
BS Pacific cod	No	No	No	N/A	N/A	1.27	4
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.66	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	0.94	4
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.51	4
BSAI Yellowfin sole	No	No	No	N/A	N/A	1.63	4
BSAI GOA Sablefish[h]	No	No	No	N/A	N/A	1.03	4

Table 14: FSSI stocks under NPFMC jurisdiction updated June 2015, 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/Bmsy	FSSI Score
GOA Arrowtooth flounder	No	No	No	N/A	N/A	2.98	4
GOA Flathead sole	No	No	No	N/A	N/A	2.7	4
GOA Blackspotted and Rougheye Rockfish complex[i]	No	No	No	N/A	N/A	1.59	4
GOA Deepwater Flatfish Complex[j]	No	No	No	N/A	N/A	2.68	4
GOA Shallow Water Flatfish Complex[k]	No	No	No	N/A	N/A	2.63	4
GOA Demersal Shelf Rockfish Complex[l]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
GOA Dusky Rockfish	No	No	No	N/A	N/A	1.6	4
GOA Thornyhead Rockfish Complex[m]	No	Unknown	Unknown	N/A	N/A	not estimated	1.5
Northern rockfish - Western / Central GOA	No	No	No	N/A	N/A	1.63	4
GOA Pacific cod	No	No	No	N/A	N/A	1.5	4
GOA Pacific Ocean perch	No	No	No	N/A	N/A	1.41	4
GOA Rex sole	No	No	No	N/A	N/A	2.74	4
Walleye pollock - Western / Central GOA	No	No	No	N/A	N/A	1.09	4

Box A. Endnotes and stock complex definitions for FSSI stocks listed in Table 14, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/`.

(a) A new rebuilding plan for this stock was implemented January 1, 2015 but does not specify a target rebuilding date because it is not known when the stock is expected to rebuild. There is no directed fishing for the blue king crab-Pribilof Islands and the majority of blue king crab habitat is closed to bottom trawling, and beginning in 2015 there is a prohibition on directed cod pot fishing in the Pribilof Islands Habitat Conservation Zone (PIHCZ).

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

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

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

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

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

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

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

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

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

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

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

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

Table 15: Non-FSSI stocks, Ecosystem Component Species, and Stocks managed under an International Agreement updated June 2015, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/`. See website for endnotes and definition of stocks and stock complexes.

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

Humans as Part of Ecosystems

Groundfish Fleet Composition

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Last updated: November 2015

Description of indicator: Fishing vessels participating in federally-managed groundfish fisheries off Alaska principally use trawl, hook and line, and pot gear. Vessel counts were compiled from NMFS Alaska Region's blend and Catch-Accounting System estimates and from fish ticket and observer data through 2014. These figures count vessels only for trips where groundfish is targeted.

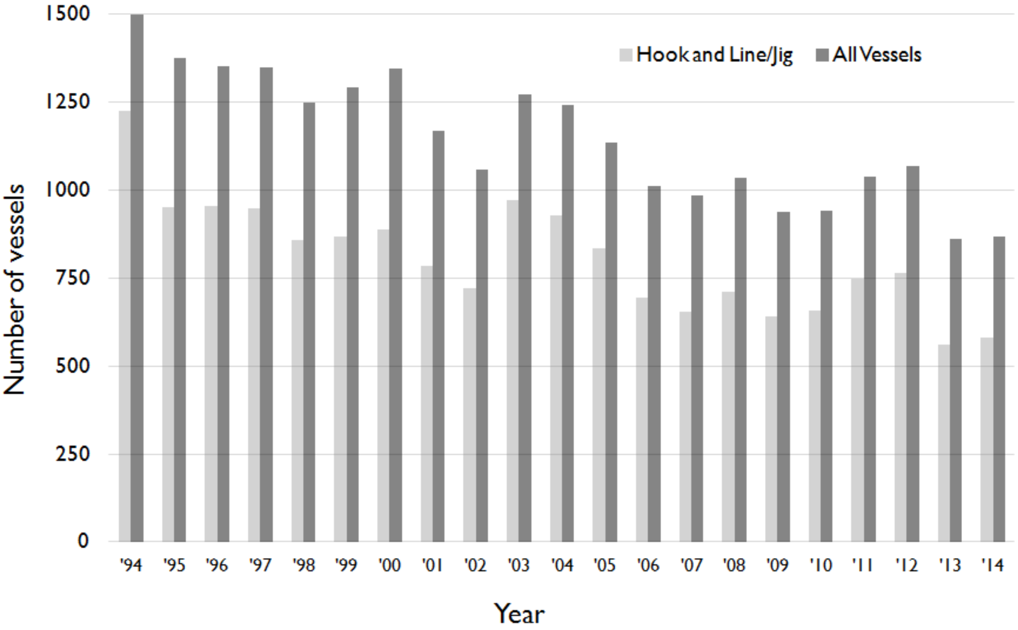
Status and trends: The total number of vessels participating in federally-managed fisheries off Alaska has generally decreased since 1994, though participation has remained relatively stable in recent years. Vessels using hook and line or jig gear have accounted for most of the participating vessels from 1994 to 2014. 581 such vessels participated in 2014, down from a high of 1,225 two decades prior. The number of active trawl-gear vessels has decreased steadily from over 250 annually in the period from 1994 to 1999 to around 180 in each of the last 5 years. During this period, counts of pot-gear vessels peaked at 343 in 2000, decreasing in 2014 to 152.

Vessel counts before and after 2003 may not be directly comparable due to changes in data sources. The Catch Accounting System (CAS), implemented in 2003 for in-season estimates of groundfish catch, registers the Federal Fisheries Permit number of catcher vessels delivering to motherships and shoreside processors, thus giving a more complete accounting of participating vessels than the previous "blend" system. The increase in 2003 in non-trawl vessel counts, in particular, is likely attributable this change.

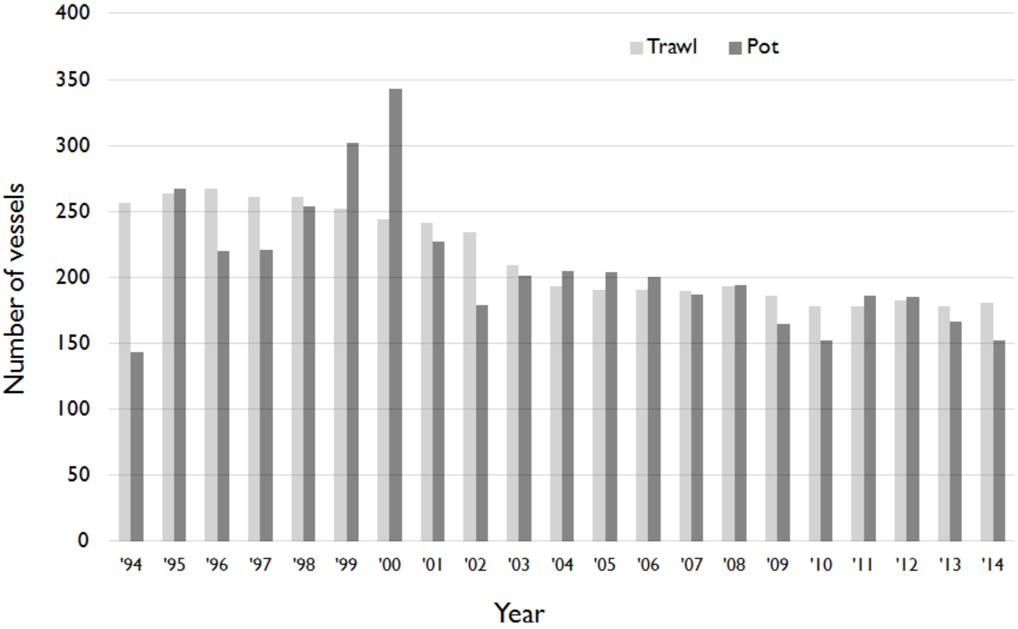
Factors influencing observed trends: Management measures designed to address overcapacity and end the "race for fish" account largely for the general decline in vessel participation over the last two decades. In the BSAI trawl pollock fishery, the American Fisheries Act (AFA) provides for a vessel buyback program permanently removing 9 vessels from all North Pacific fisheries; fixed allocations between sectors, with exclusive harvest privileges for certain vessels; and coordination of harvest within cooperatives. In 2000, the first year all sectors of the fishery were managed under AFA, the number of active vessels in the fishery fell from 140 to 113; participation in the last 5 years has since stabilized at around 100 vessels. The fixed gear sablefish fishery likewise experienced significant consolidation of its fleet upon transitioning from an open access to individual fishing quota (IFQ) structure in 1995, with the 331 active vessels in the 2013 fishery representing a 70% decline from participation levels during the final three years of open access management.

Participation by jig vessels increased slightly in 2011 and 2012 (331 and 359 vessels, respectively) over pre-2011 levels, which ranged from 173 to 248 during the preceding 5-year period. This trend follows implementation of Amendment 86 to the GOA groundfish FMP, which expands entry-level fishing opportunities by exempting certain jig vessels from License Limitation Program (LLP) licensing requirements when fishing in the Western and Central Gulf.

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



(a) Hook and Line, All vessels



(b) Trawl,Pot

Figure 144: Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1994-2014.

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Appendix

The indicators listed here were not updated in this year's report. For the most recent submissions, see the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Ecosystem Status Indicators

Physical Environment

Spatial Patterns in Near-Bottom Oceanographic Variables on the EBS Slope

Contributed by Gerald Hoff and Chris Rooper, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2013

Regional Water Mass Characteristics in the Northern Bering Sea

Contributed by Jeanette Gann and Lisa Eisner, Auke Bay Laboratory, National Marine Fisheries Service, NOAA
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Last updated: July 2013

Water Temperature Data Collections - Aleutian Islands Trawl Surveys

Contributed by Ned Laman, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: ned.laman@noaa.gov
Last updated: October 2014
Trawl surveys are conducted in alternate years in the Aleutian Islands.

Spatial Patterns in Near-Bottom Oceanographic Variables in the Gulf of Alaska

Contributed by Chris Rooper and Gerald Hoff, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: October 2013

Habitat

Structural Epifauna (HAPC Biota)- Aleutian Islands

Contributed by Chris Rooper, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Primary Production

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

Contributed by Lisa Eisner, Kristin Cieciel, Jeanette Gann
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Surface Silicate as a Potential Indicator of Nutrient Availability During Summer/ Early Fall in the Eastern Bering Sea; Implications for Age-0 Walleye Pollock Condition

Contributed by Jeannette Gann, Lisa Eisner, and Kristin Cieciel
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Gulf of Alaska Chlorophyll ^{a} Concentration off the Alexander Archipelago

Contributed by Jamal Moss and Stacy K. Shotwell Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Zooplankton

Bering Sea Zooplankton

Contributed by Patrick Ressler, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Late Summer/Fall Abundances of Large Zooplankton in the Eastern Bering Sea

Contributed by Alex Andrews[1], Lisa Eisner[1], and K. O. Coyle[2]
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Forage Fish

Forage Fish CPUE - Bering Aleutian Salmon International Survey - BASIS

Contributed by Ed Farley and Wes Strasburger, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Gulf of Alaska Smallmesh Trawl Survey Trends

Contributed by Dan Urban, Kodiak Laboratory, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Last updated: August 2014

Temporal Variability in Pacific Sand Lance Revealed by Puffins in the Gulf of Alaska

Contributed by William J. Sydeman[1], John F. Piatt[2], Sarah Ann Thompson[1], Marisol Garcia-Reyes[1], Scott Hatch[3], Heather Renner[4], and Stephani Zador[5]
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Regional Distribution of Juvenile Salmon and Age-0 Marine Fish in the Gulf of Alaska

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Herring

Prince William Sound Pacific Herring

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Groundfish

Trends in Groundfish Biomass and Recruits per Spawning Biomass

Contributed by Jennifer Boldt[1], Todd TenBrink[2], Steven Hare[3], and the Alaska Fisheries Science Center Stock Assessment Staff
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Aleutian Islands Groundfish Condition

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Benthic Communities and Non-target Fish Species

Spatial Variability of Catches in Bering Sea and Gulf of Alaska Crab Fisheries

Contributed by Mike Litzow[1,2], Franz Mueter[3], and Dan Urban[4]
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Bering Sea/Aleutian Islands King and Tanner Crab Stocks

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Miscellaneous Species - Aleutian Islands

Contributed by Chris Rooper, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Marine Mammals

Steller Sea Lions

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Northern Fur Seals

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Harbor Seals

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Arctic Ice Seals: Bearded Seal, Ribbon Seal, Ringed Seal, Spotted Seal

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Bowhead Whales

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Ecosystem or Community Indicators

Regime Shift Indicators for the Gulf of Alaska and Eastern Bering Sea

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Biodiversity (Evenness) of the Groundfish and Invertebrate Community for the Eastern Bering Sea Slope

Contributed by Gerald R. Hoff, Kodiak Laboratory, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
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Combined Standardized Indices of Recruitment and Survival Rate

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Ecosystem-Based Management (Fishing-related) Indicators

Sustainability

Total Annual Surplus Production and Overall Exploitation Rate of Groundfish

Contributed by Franz Mueter, University of Alaska Fairbanks, 17101 Point Lena Road, Juneau, AK 99801
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Community Size Spectrum of the Bottom Trawl-Caught Fish Community of the Eastern Bering Sea

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Humans as Part of Ecosystems

Distribution and Abundance Trends in the Human Population of the Bering Sea/Aleutian Islands

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Distribution and Abundance Trends in the Human Population of the Gulf of Alaska

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