Ecosystem Considerations
2012

Edited by:
Stephani Zador
Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center,
National Marine Fisheries Service, NOAA
7600 Sand Point Way NE
Seattle, WA 98115

With contributions from:

Alex Andrews, Kerim Aydin, Rachel Baker, Sonia Batten, Nick Bond, Greg Buck, Kristin Cieciel, Ken Coyle, Miriam Doyle, Sherri Dressel, Lisa Eisner, Ed Farley, Emily Fergusson, Shannon Fitzgerald, Wyatt Fournier, Sarah Gaichas, Jeanette Gann, Jessica Gharrett, Angie Greig, Kyle Hebert, Ron Heintz, Terry Hiatt, Gerald Hoff, James Ingraham, Carol Ladd, Ned Laman, Robert Lauth, Jean Lee, Mike Litzow, Ellen Martinson, Kate Mier, Jamal Moss, Franz Mueter, Marcia Muto, Jeffrey Napp, John Olson, Joe Orsi, Ivonne Ortiz, James Overland, Patrick Ressler, Chris Rooper, Sigrid Salo, Stacy Shotwell, Elizabeth Siddon, Paul Spencer, Phyllis Stabeno, Wes Strasburger, William Stockhausen, Molly Sturdevant, Todd TenBrink, Dan Urban, Jason Waite, Muyin Wang, Alex Wertheimer, Andy Whitehouse, Carrie Worton, Atsushi Yamaguchi, and Stephani Zador

Reviewed by:
The Plan Teams for the Groundfish Fisheries of the
Bering Sea, Aleutian Islands, and Gulf of Alaska

November 16, 2012
North Pacific Fishery Management Council
605 W. 4th Avenue, Suite 306
Anchorage, AK 99301

Eastern Bering Sea 2012 Report Card

- The North Pacific atmosphere-ocean system reflected a combination of a **response to La Niña and intrisic variability**. The combination of the **neutral to weak El Niño expected this winter** and a continuation of reduced ice cover in the central Arctic should yield **a lighter ice year for the Bering in 2013**.
- **Ocean temperatures remained cold and sea ice remained extensive**, similar to 2008 and 2010. Ice retreat this year (and 2009) was the latest recorded since 1985. Summer was calm and cool, but had the **most extensive cold pool area of the recent decade**.
- The summer ***Calanus* copepod time series showed an increase in abundance** in 2011 relative to 2010, but remained below the 2009 peak. 2011 was **the fourth year that concentrations remained well above average**, following patterns also seen in fall zooplankton abundance during cold years. This suggests that prey availability for planktivorous fish, seabirds, and mammals continued to be high during the summer of 2011.
- **Jellyfish remain abundant**, although peak abundances observed in fall 2010 and summer 2011 declined by fall 2011 and summer 2012.
- **While commercial crab stocks are relatively low**, overall **motile epifauna biomass remains stable or increasing** since the late 1980s. Higher levels since 2003 are driven by increases in brittle stars and echinoderms, although these series show high within-year variances in the survey.
- **Biomass of benthic foragers has remained stable** since 1982, with interannual variability driven by short-term fluctuations in yellowfin and rock sole abundance.
- **Biomass of pelagic foragers has increased to nearly average** from record survey lows in 2009. While pollock has increased from low levels, this is additionally driven by increases in capelin seen in 2010-2012.
- **Fish apex predator biomass has increased appreciably in the last few years**, driven primarily by the increase in Pacific cod from lows in 2007-2009 to higher levels in 2010-2012. Arrowtooth flounder biomass has decreased from all-time survey highs during 2004-2005, though it remains high relative to pre-1989 levels.
- **Thick-billed murre reproductive success on St. George Island was near average** in 2012, a substantial increase from the record low in 2011. This suggests that **foraging conditions were favorable for piscivorous seabirds**.
- **Northern fur seal pup production for St. Paul Island has declined over the long term**. The most recent pup production estimates for St. Paul and St. George Islands in 2010 were 8.8% and 1.0% less than the 2008 estimates.
- The maximum potential **area of seafloor habitat disturbed by trawl gear increased in 2011** to the highest level since 1998. The cause of this increase is currently unknown.

Hot topic In September the Department of Commerce declared commercial king salmon fisheries in the Yukon and Kuskokwim rivers failures after extrememly low returns over the summer. The two leading hypotheses for the reduced runs are climate change and fishing.

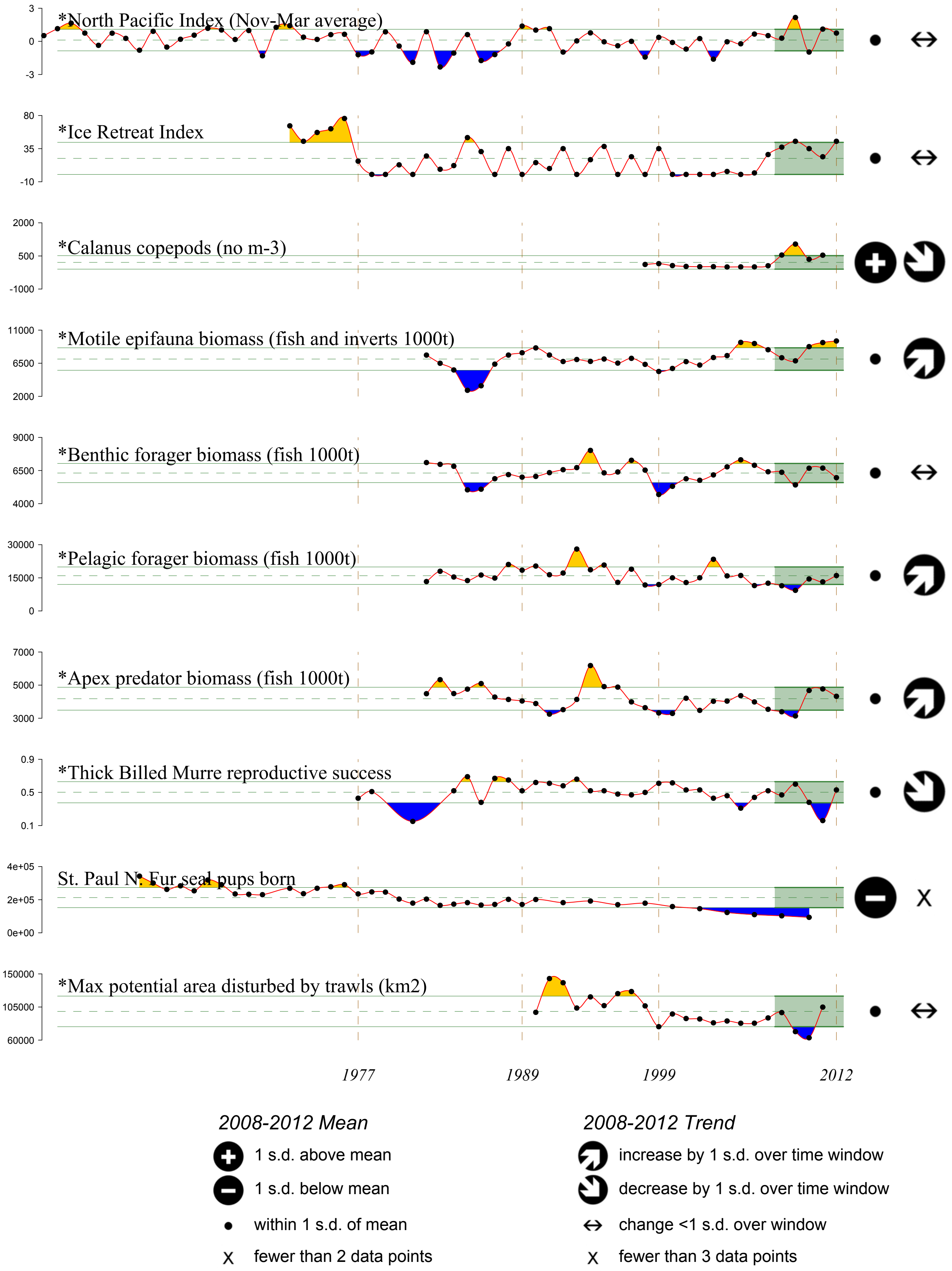


Figure 1: Eastern Bering Sea ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2012.

Aleutian Islands 2012 Report Card

Region-wide

- In 2011/2012, the winter North Pacific Index was nearly one positive standard deviation of the 1975-2012 mean implying a **weak Aleutian Low pressure system and less storminess** than average in the region. **Westerly wind anomalies prevailed** in this region for much of the past year, which may have **suppressed northward transport through Unimak Pass and perhaps also the Aleutian North Slope Current**.
- **Water column temperatures were the coldest recorded** during eight survey years since 1994.
- **Biomass of pelagic forager and apex fish predator foraging guilds has decreased across the region** since the last survey in 2010, although patterns vary among species. The overall decline **may indicate an underlying environmental shift, lower catchability due to cold water or reflect high variances commonly observed in estimated biomass among survey years**.
- There are several species showing longitudinal trends in the fish pelagic foragers foraging guild: the **biomass of walleye pollock increases towards the east**, whereas that of **northern rockfish and Pacific ocean perch increases towards the west**.
- **Fishing patterns have recently changed throughout the system**, largely in response to increased protection for Steller sea lions, although the final impacts to individual fishing sectors are currently unknown.
- The amount of **area with observed trawling has declined overall**, likely reflecting less fishing effort, particularly in the western ecoregion.
- 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.

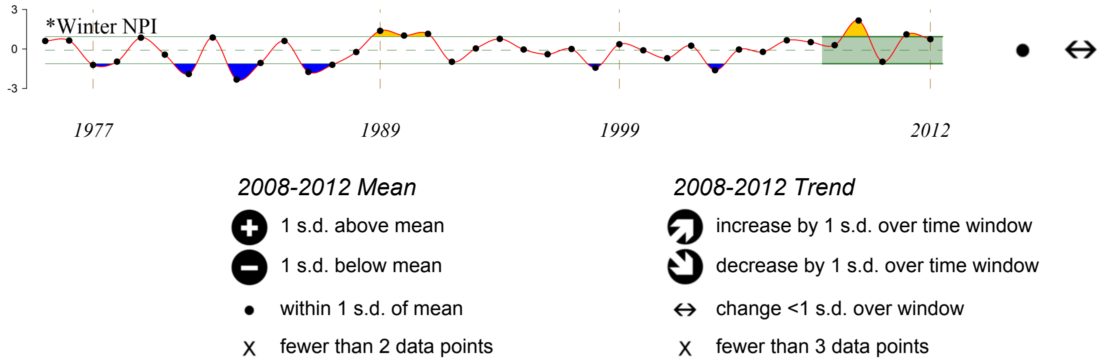


Figure 2: The winter North Pacific Index time series. * indicates time series updated in 2012.

Western Ecoregion

- Although **reproductive success of planktivorous auklets increased in 2012**, but has shown an overall declining trend in the past five years, **possibly indicating a return to average zooplankton foraging conditions** compared with the above average reproductive years of 2007-2009.
- **Forage fish trends have varied** in tufted puffin chick meals. In general, *Ammodytes* (sand lance) have been more common since 2000, whereas gadids have been less common. The numbers of hexagrammids varied among years, but show a decreasing trend in the past five years.
- The **pelagic fish foraging guild biomass has decreased** since the last survey in 2010. Pollock, Pacific Ocean perch, and Atka mackerel contributed to this trend; whereas northern rockfish increased.
- The **decrease in the fish apex predators foraging guild** apparent in the 2012 trawl survey is driven by Pacific cod, skates and large scuplins, reversing the increasing trend in this foraging guild observed in 2010.
- Steller **sea lions continue their decades-long decline** in this ecoregion although at a slower rate. Between 1991 and 2008, non-pup counts declined 81%, or at a rate of -10% per year.
- The **amount of area trawled declined dramatically** in 2011 due to recent measures aiming at increasing protection for Steller sea lions.

Hot topic A recent analysis of spatial concentration of blackspotted/rougheye rockfish harvest relative to abundance indicates that exploitation rates for the western Aleutian Islands have been at or above the natural mortality rate (M) in 2004, 2006, and from 2008-2010, ranging between 1.00 to 1.94 times the M value of 0.03. Thus, the fishery is obtaining higher catches than would be expected from the survey data. One potential explanation is that differences in the timing and spatial distribution of trawls between the fishery and surveys may affect the availability to and catchability of the fishing gear. It is also possible that the survey abundance in the western Aleutians is an underestimate of the true abundance.

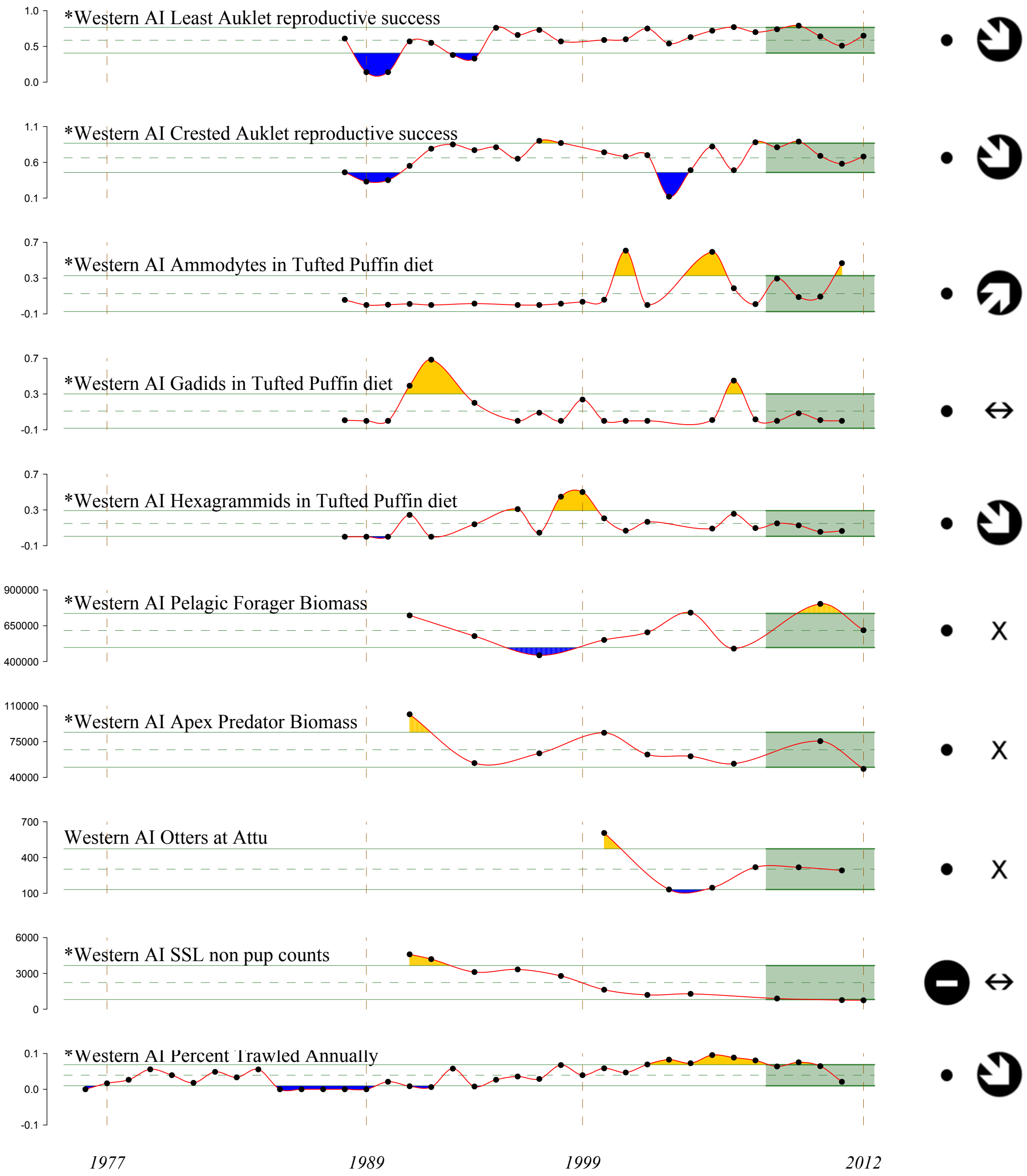


Figure 3: Western Aleutian Islands ecoregion indicators. * indicates time series updated in 2012. See Figure 2 for legend.

Central Ecoregion

- The **pelagic fish foraging guild biomass declined** overall since the last survey in 2010, reversing an increasing trend since 1994. Most of the decline can be attributed to Atka mackerel, although Pacific Ocean perch biomass has increased.
- The **slight decline in fish apex predator biomass** is largely driven by arrowtooth and Kamchatka flounders. Pacific cod biomass increased.
- **Counts of non-pup Steller sea lions in 2011 continued to decline**. The recent counts are more than one standard deviation below the long term mean.
- **School enrollment has shown no trend** in recent years, following a decline since peak enrollment in 2000.

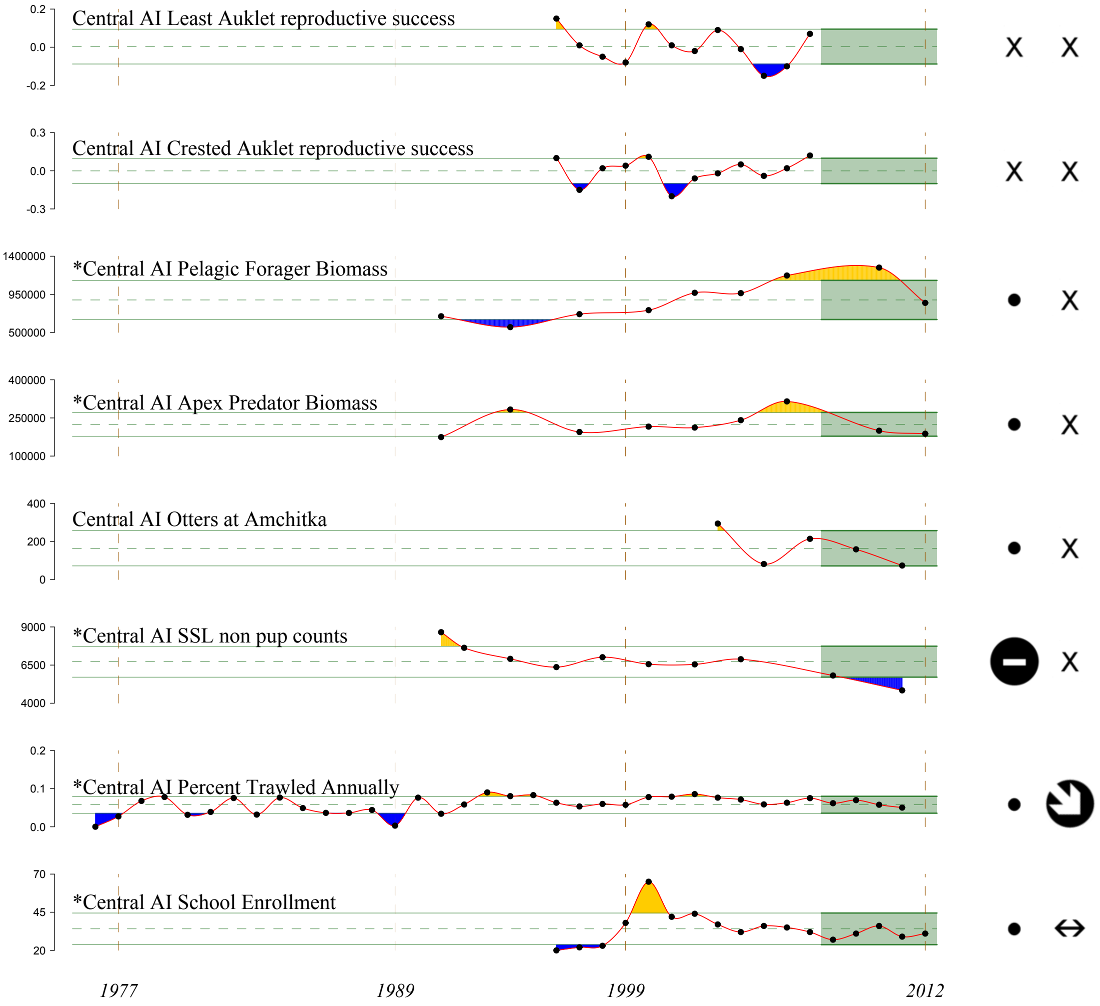


Figure 4: Central Aleutian Islands ecoregion indicators. * indicates time series updated in 2012. See Figure 2 for legend.

Eastern Ecoregion

- **Forage fish trends have varied** in tufted puffin chick meals. In general, ***Ammodytes* (sand lance) and gadids have shown opposite trends**. *Ammodytes* were more common from 1998 to 2008, and have shown a declining trend in the last five years. Gadids were more common through the 1990s and have been increasing recently. Hexagrammids are uncommon in this region. These **patterns suggest puffins are responding to changes in forage fish availability**.
- The **fish pelagic forager biomass declined** to the lowest value since 2002. Pollock and Atka mackerel contributed to this trend.
- **Fish apex predator biomass declined to the lowest in the time series**. All species groups declined since the last survey in 2010.
- In contrast to the other ecoregions, **non-pup counts of Steller sea lions remained high** in 2011. Counts were largely stable through the 1990s, but increased at a rate of 3% per year between 2000 and 2008.
- **School enrollment has fluctuated** in this ecoregion, but has shown no overall trend in the past five years.

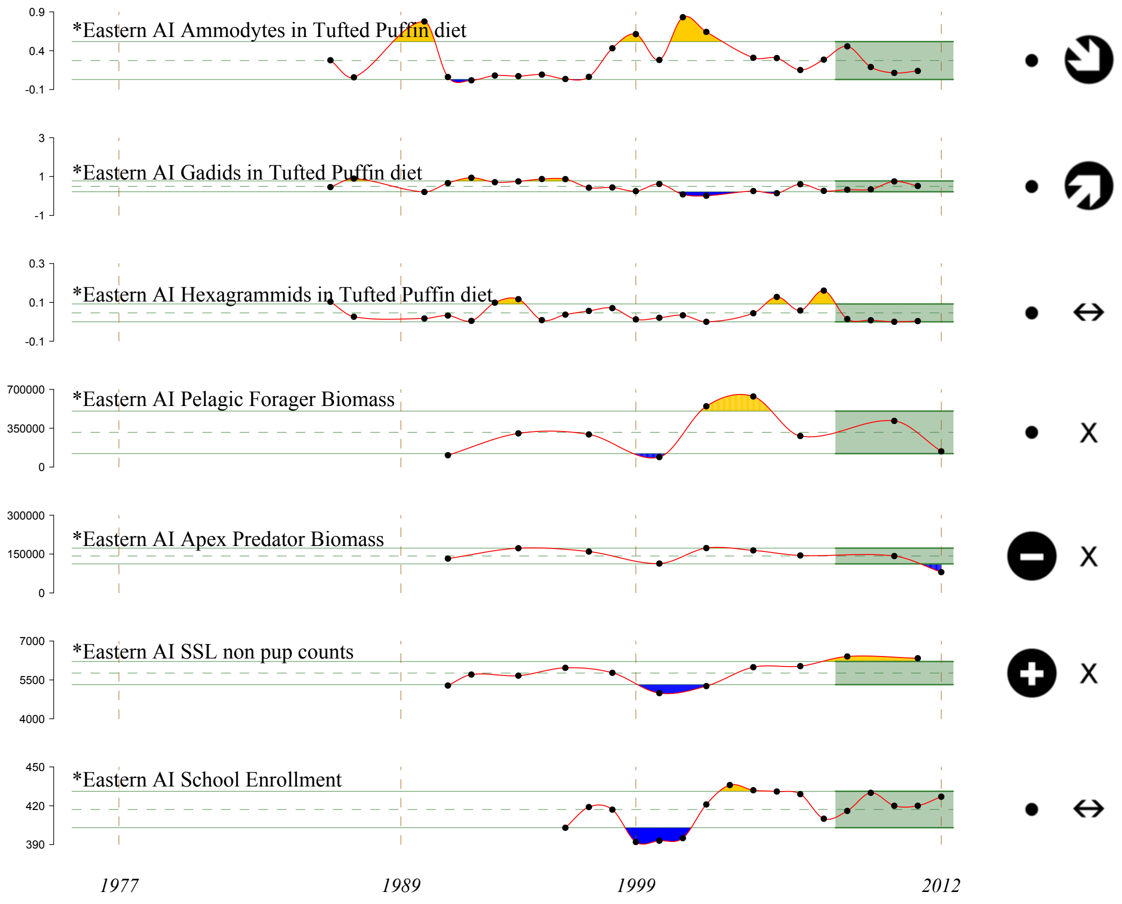


Figure 5: Eastern Aleutian Islands ecoregion indicators. * indicates time series updated in 2012. See Figure 2 for legend.

Executive Summary of Recent Trends

Physical and Environmental Trends

- The state of the North Pacific atmosphere-ocean system during 2011-2012 reflected the combination of a response to La Niña and intrinsic variability. The Aleutian low was weaker than usual in the winter of 2011-12, and the sea level pressure was higher than normal in the eastern portion of the basin for the year as a whole (p. 71)
- Cooler than normal upper ocean temperatures prevailed in the eastern portion of the North Pacific and warmer than normal temperatures occurred in the west-central and then central portion of the basin. This pattern reflects a continuation of a negative sense to the Pacific Decadal Oscillation (PDO) (p. 71)
- The ENSO indices for the tropical Pacific indicate a warming trend for the first half of 2012; the models used to forecast ENSO are indicating outcomes for the winter of 2012-13 ranging from near neutral to a weak-moderate El Niño (p. 71).
- It is likely that there will be a warming of Alaskan waters over the next 2-3 seasons, relative to the mostly cooler than normal temperatures that have prevailed over the last 5 years (p. 78).

Arctic

- The tendency for reduced sea ice cover in the Arctic during the summer has continued into 2012. The distribution of the arctic sea ice in early August 2012 differs somewhat from recent years. Specifically, high ice concentrations have persisted in the Chukchi and in the western portion of the Beaufort Sea (p. 71).
- If the ice pack retreats to well north of Alaska, as it has in recent summers, there should again be a delay the development of ice in marginal seas such as the Bering Sea during the following cold season (p. 71).

Bering Sea

- After the unusual sequence six years of warm winter-spring temperatures (2000-2005), four years of cold temperatures (2007-2010) and a cool summer in 2011, winter-spring 2012 returned to continue the cold sequence with a vengeance (p. 80)
- The Bering Sea shelf experienced another relatively heavy ice year, especially in terms of maximum ice extent (p. 71).
- Sea ice extents in 2012, 2008 and 2010 are close to record extents, not seen since the early 1970s, and contrast to the warm years of 2000-2005 (except 2002). Steady northeast winds throughout winter and spring 2012 contributed to the major extent which lasted into May (p. 80).

- The average surface temperature, 4.8°C, was slightly lower than 2011 (5.0°C) and still much lower than the long-term mean of 6.3°C. The average bottom temperature in 2012 was 1.0°C which was much colder than 2011 (2.4C) and lower than the grand mean from 1982 to 2012 of 2.3°C (p. 86).
- Mean water column salinities in the south Bering Sea middle domain were higher in warm years (2002-2005) than in cold years (2006-2011) with greatest differences observed near mooring M4 (p. 87
- Unlike a year ago, the summer of 2012 has been relatively calm (p. 71, 80).
- The cold pool for summer 2012 had the most extensive area of the recent decade (p. 80).
- The combination of El Niño expected this winter and a continuation of reduced ice cover in the central Arctic (more on this below) should yield a lighter ice year for the Bering in 2013 (p. 71).

Alaska Peninsula and Aleutian Islands

- Westerly wind anomalies have prevailed in this region for much of the past year. Anomalies in this sense tend to suppress the northward transport through Unimak Pass and perhaps also the Aleutian North Slope Current. A possible implication is a reduced supply of nutrients onto the southern Bering Sea shelf, but the importance of this mechanism is poorly known (p. 71).
- Eddy energy south of Amutka Pass was low from the spring of 2010 through early 2012, but recent data shows the existence of an eddy in the region beginning in late April 2012 (p. 89).
- 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, 2006/2007, 2009/2010 and summer 2012. These fluxes were likely smaller during the period from spring 2010 until early spring 2012 (p. 89).
- Water temperatures have varied considerably during the eight survey years reported with 2012 producing some of the coldest temperatures of the series. The pattern of cooler temperatures observed in 2012 was similar to that observed in 2000 which had previously been considered the coldest year in the series (p. 91).

Gulf of Alaska

- The poleward branch of the Alaska Current in the southeastern portion of the Gulf increased markedly from summer into fall of 2011, and after declining over the course of the winter, again increased from spring into summer 2012. These changes from season to season are consistent with the winds (p. 71).
- The mixed layer depths in the Gulf were shallower than usual during the winter of 2011-2012 but by early summer 2012 were near their seasonal norms (p. 71).
- Eddy Kinetic Energy (EKE) levels were approximately average off Kodiak and high in the northern Gulf of Alaska in 2011 (p. 94).
- Phytoplankton biomass was probably more tightly confined to the shelf during 2009 due to the absence of eddies, while in 2007, 2010 and 2011, phytoplankton biomass likely extended farther off the shelf (p. 94).
- Cross-shelf transport of heat, salinity and nutrients were probably weaker in 2009 than in 2007, 2010, and 2012 (or other years with large persistent eddies) (p. 94).
- The 2011/2012 PAPA trajectory followed the general northeastwardly path of most drifters, but was notable because its ending latitude was the northernmost of all trajectories since 1994 (p. 96).

Ecosystem Trends

Alaska-wide

- Total estimated seabird bycatch in all Alaskan groundfish fisheries in 2011 was 9,298 birds (p. 171).
- The estimated numbers of seabirds bycaught in the longline fishery are 30% above the 2007-2010 average of 7,249. The increased numbers in 2011 are due to a doubling of the gull (*Larus* spp) numbers (1,084 to 2,206) and a 3-fold increase in Northern fulmar (*Fulmaris glacialis*) bycatch, from 1,782 to 5,848 (p. 171).
- Although rare, regime shifts are extremely disruptive to Alaskan fisheries. the most recent reanalysis of the Hare and Mantua datasets found no evidence of recent abrupt community-level biological change in Alaska, although the abrupt 2007-08 change in basin-scale data suggests some possibility of ongoing changes across the northeast Pacific, possibly in response to a large change in the PDO-NPGO phase space between 2006 and 2008 (p. 179)

Arctic

- The most recent population abundance estimate in 2004 of 12,631 (CV=0.2442) whales in the Western Arctic stock (excluding calves) was calculated from aerial photographic surveys of bowhead whales in 2003, 2004, and 2005. The rate of increase indicates a steady recovery of the stock (p. 175).

Bering Sea

- The maximum potential area of seafloor disturbed by trawling remained relatively stable in the 2000s, decreased in 2009-2010 and increased in 2011 (p. 99).
- EBS trawl survey structural epifauna catch rates generally show increasing trends in recent years: sea anemones declined from 2011, while sponges and seawhips were higher (p. 102).
- Highest phytoplankton biomass was observed in the Outer shelf near the Pribilof Islands, and in the south Inner shelf. Lowest biomass was observed in the north Bering and SE Middle shelf (in a region of high stability). Larger phytoplankton were seen on the Inner shelf and near the Pribilofs. Smaller phytoplankton were seen on the SE Middle shelf (an area of lower total chla), and in the Outer shelf (an area of higher total chla) (p. 106).
- In the south Bering Sea, phytoplankton biomass and mean size of assemblages were higher in warm (03-05) than in cold (06-09) years on the Middle shelf. This trend was not observed in the north Bering Sea (p. 106).
- Temporal trends in surface carbon uptake rates over the SEBS (inner and middle domains combined) remain relatively invariable from 2006-2011 with an exception during 2007, where median ^{13}C uptake rates decreased by a factor greater than 5 ($P = 0.008$). Significant decreases in phytoplankton carbon uptake and chlorophyll biomass during late summer/early fall will negatively impact energy flow to higher trophic levels (p. 110).
- Both the large copepod, *Calanus marshallae* and euphausiid summer time series show a large increase since 2001-2005 ("warm years"), with the copepod increase lagging that for euphausiids. Both series showed a smaller decline in 2010 but remained well above 2001-2005 levels. The *Calanus* spp. series showed a slight increase in 2011, but remained below the 2009 peak (p. 113).
- Continuous plankton recorder observations indicated that mesozooplankton biomass appeared to be low in southern Bering Sea regions in 2011 (p. 123).

- Mean monthly copepod community size from 2011 was similar to the long term mean for the southern Bering Sea and Alaskan shelf, suggesting that the low biomass was not the result of an absence of a particular group of copepods (p. 123).
- In warm years, the large copepod, *Calanus marshallae*, was in lower abundance during fall surveys than in cold years (p. 114).
- North-south variations in large zooplankton were also observed, with more Cnidaria present in the northern Bering and more polychaeta (in warm years) and pteropods in the southern Bering Sea (p. 114).
- Jellyfish relative CPUE during summer 2012 was was down slightly from 2011, but remained relatively high when compared to the last 10 years of summer surveys (p. 116).
- In fall of 2011, total jellyfish biomass decreased by almost half compared to the previous fall. However, for the first time since sampling started in 2004, the biomass was recorded higher in the north than in the south (p. 127).
- Young of year pollock energy density increased from values near 3.6 kJ/g in 2003-2005 to values near 5.0 kJ/g in 2008-2011. In 2011 the average energy content remained high (12.0 kJ/fish) suggesting that the number of age-1 recruits per spawner should continue to be above the overall median level in 2012 (p. 117).
- The CPUE of capelin during fall surveys of surface waters increased after 2008, whereas the CPUE of age-0 walleye pollock declined (p. 129).
- In 2012, aerial surveys of Togiak District herring recorded 167,738 tons, which is 116% of the most recent 10-year average and 114% of the 20-year average (p. 137).
- The 2011 Bristol Bay sockeye run of 30.3 million fish was close to the long-term average of 30.6 million, but 21% below the forecasted run size (p. 142).
- The 2012 springtime drift patterns based on OSCURS model time series runs do not appear to be consistent with years of good recruitment for winter-spawning flatfish such as northern rock sole, arrowtooth flounder and flathead sole (p. 153).
- In 2010, the Temperature Change index value was below the long term average, therefore we expect below average numbers of pollock to survive to age-3 in 2012. In the future, the Temperature Change values in 2011 and 2012 indicate above average abundances of age-3 pollock in 2013 and below average abundances of age-3 pollock in 2014 (p. 154).
- Eelpouts, poachers, and sea stars show broadly similar time trends in trawl survey CPUE, but no outstanding changes for 2012 (p. 161).
- The temporal trend in the first principal component (PC1) of a multivariate seabird index based on Pribilof Islands seabird reproduction increased from 2011, indicating earlier hatch dates and higher reproductive success for common murres and St. Paul thick-billed murres. The temporal trend of the second principal component (PC2) continued the nearly annual trend reversal with the 2012 value showing an increase from the previous year and indicating an increase in kittiwake reproductive success (p. 169).
- Total trawl survey CPUE in the EBS shows an apparent long-term increase from 1982-2005, followed by a decrease from 2005 to 2009 and an increase in 2010. 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. 181).
- Species richness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2012. The average number of species per haul increased by one to two species from 1995 to 2004 and has remained relatively high since then. The Shannon Index increased from 1985 through 1998, decreased sharply in 1999, and has been highly variable since then. Diversity was low in 2002/03, increased substantially in 2004, decreased through 2010, but was high in the last two years (p. 184).

- 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. In 2009, the average center of gravity temporarily shifted back to deeper waters but has been relatively shallow with little change in latitude since 2010 (p. 187).

Aleutian Islands

- AI trawl survey structural epifauna showed variable distributions: Sponges are caught in most tows in the AI west of the southern Bering Sea. Stony corals are commonly captured outside of the southern Bering Sea and their abundance appears highest in the central and eastern AI. Sea anemones are common in survey catches but abundance trends are not clear. Sea pens are most likely to be encountered in the southern Bering Sea and eastern AI (p. 102).
- Jellyfish were generally more abundant in 2004 and 2006 than in other years and continued to be at low levels in 2012 (p. 167).
- Eelpout CPUEs have generally been highest in the central and eastern AI and have remained high since 1991 except for 2012 in the central AI. Poachers occur in a relatively large number of tows across the AI survey area, but mean CPUE trends are unclear (p. 167).

Gulf of Alaska

- Icy Strait zooplankton density anomalies were strongly negative from 1997-2005, strongly positive in 2006-2009, then reversed in both 2010 and 2011. Total density showed little correspondence with annual temperature trends, with both positive and negative anomalies in both warm and cold years (p. 118).
- Zooplankton was numerically dominated by calanoid copepods, including small and large species (p. 118).
- Mesozooplankton biomass was apparently low in the Alaskan shelf region (northern GOA) in 2011, while the oceanic Northeast Pacific showed a late and extended biomass peak. Larger species were present in the northeast Pacific later into summer than average, consistent with cool La Niña conditions delaying their development (p. 123).
- Coherent patterns and synchronicity in ichthyoplankton trends were observed among groups of species from 1981 to 2009 (p. 148).
- Presently, four of the five crab fisheries analyzed show no increases in the spatial variability of the catch, and thus are not showing patterns that might be consistent with declining resilience and an increased chance of sudden collapse (p. 158).
- Forage species catch rates remain at low levels, one to two orders of magnitude lower than peak values observed in the 1970s and early 1980s. Eulachon, which in recent years has had the highest catch rates of the time series, decreased in 2011 to a rate below the long-term average (p. 133).
- An impending shift in the marine community was not indicated by the STARS analysis including the 2011 small mesh survey data (p. 133).
- Spatial patterns were apparent in the 2011 GOAIERP survey. The highest CPUE of juvenile salmon was in the central GOA and the mouth of Cross Sound. Catches of age-0 marine fish were relatively low, with most rockfish located off the shelf in the southeast and arrowtooth flounder on the shelf and in the central regions (p. 135).

- Although the long-term trends in most Southeast Alaska herring spawning areas are increasing, an apparent decrease in biomass was observed between 2010 and 2011 for some areas, including Tenakee Inlet and Hobart Bay. Nevertheless, the 2010 and 2011 estimates of spawning biomass, combined for the entire region, were the two highest in the 32-year time series (p. 139).
- 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 in 2010 (2008 brood year) is at an all-time high since 1977 (p. 142).
- In addition to pink salmon CPUE, peak migration month, NPI, and %pink in catch are significantly correlated with harvest and suggest a low to intermediate pink harvest in 2012 (p. 146).
- The depth distribution of rockfish in the Gulf of Alaska has remained constant for each species over time with the exception of shortraker rockfish. Changes in rockfish distribution with temperature have occurred over the time series, most notably since 2007 where there has been a constriction of the range of mean-weighted temperatures for rockfish (p. 156).
- 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 2011 from years of record high catches seen from 2002 to 2005 (p. 161).
- Total trawl survey CPUE in the western GOA varied over time with lowest abundances in 1999 and 2001. The eastern GoA shows a significantly increasing trend from 55 kg/ha in 1990 to 70 kg/ha in 2011 (p. 181).

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. 195).
- At present, no BSAI or GOA groundfish stock or stock complex is overfished and no BSAI or GOA groundfish stock or stock complex is being subjected to overfishing. The Pribilof Island blue king crab stock is only stock considered overfished. This stock is on a continuing rebuilding plan (year 9 of 10-year plan). The status of the Bering Sea snow crab rebuilding program has changed from rebuilding to rebuilt (p. 198).
- Since the 1990s, the Alaskan management trend has been towards increasingly specific management, from more finely divided allocations (by season, area, gear, sectors), to capacity removal, to "rights-based" catch share management such as Community Development Quota (CDQ) allocations, cooperatives and individual quotas (p. 206).
- The pattern of changes in the total number of vessels harvesting groundfish and the number of vessels using hook and line gear have been very similar since 1994. Numbers have generally decreased since 1994 and were low in the past 5 years (2007-2011). The total number of vessels was 1,518 in 1994 and 987 in 2011. Hook and line/jig vessels accounted for about 1,225 and 676 of these vessels in 1994 and 2011, respectively. The number of vessels using trawl gear decreased from 257 in 1994 to 177 in 2011. During the same period, the number of vessels using pot gear peaked in 2000 at 343, and decreased to 184 in 2011 (p. 210).

Bering Sea

- Discarded tons of groundfish continued a long term decreasing trend in 2011, while the discard rate dropped to 3% (p. 190).

- Non-specified catch comprised the majority of non-target catch during 1997-2011. The catch of non-specified species has decreased overall since the late 1990s. HAPC biota catch has generally decreased since 2004. The catch of forage species increased in 2011, primarily due to capelin and eulachon (p. 190).

Aleutian Islands

- Discard rates have declined over the past eight years. Discards and discard rates are much lower now than they were in 1996 (p. 190).
- Non-specified catch comprised the majority of non-target catch during 1997-2011. The non-specified catch dropped in 2010-2011, primarily due to a reduction in the catch of giant grenadiers. HAPC catch has been variable over time in the AI and is driven primarily by sponges caught in the trawl fisheries for Atka mackerel, rockfish and cod. Forage fish catches in the AI are minimal (p. 190).

Gulf of Alaska

- Discard rates in the Gulf of Alaska have varied over time but were lower than average in 2010 and 2011 (p. 190).
- Non-specified catch comprised the majority of non-target catch during 1997-2011. The catch of non-specified species in the GOA has been generally consistent aside from a peak in 1998 and lows in 2009 and 2010. The catch of forage species increased in 2010-2011, primarily due to eulachon and other osmerids (p. 190).

Contents

***EBS Report Card** 1

***AI Report Card** 3

***Executive Summary** 8

Physical and Environmental Trends . . . 8
Ecosystem Trends . . . 9
Fishing and Fisheries Trends . . . 13

***Responses to SSC comments** 30

Introduction 34

Ecosystem Assessment 37

Introduction . . . 37
*Hot Topics . . . 39
    Arctic Sea Ice Record Minimum . . . 39
    Ice Seal and Walrus Unusual Mortality Event Update . . . 41
    Commerical King Salmon Fisheries Failures . . . 42
    Area-Specific Exploitation Rates of BSAI Blackspotted/Rougheye Rockfish . . . 42
    Gulf of Alaska Anomalous Conditions in 2011 . . . 43
    Reoccurrence of “Mushy” Halibut Syndrome . . . 44
†Arctic . . . 44
    Rationale . . . 44
    General ecosystem information . . . 45

Species of commercial interest 48

Gaps and needs 49

Potential indicators 49

*Eastern Bering Sea 52

Summary 52

Evaluation of 2011 predictions 54

Gaps and needs for future EBS assessments 55

*Aleutian Islands 59

Summary 59

Indicator Development 65

Evaluation of predictions and updates to recommendations 66

Area-Specific Exploitation Rates of BSAI Blackspotted/Rougheye Rockfish 66

Gulf of Alaska 68

Conclusions 68

Ecosystem Status and Management Indicators **71**

Ecosystem Status Indicators 71

Physical Environment 71

*North Pacific Climate Overview 71

*Sea Surface Temperature and Sea Level Pressure Anomalies 72

*Climate Indices 76

*Seasonal Projections from the National Centers for Environmental Prediction (NCEP) 78

Eastern Bering Sea 80

*Eastern Bering Sea Climate - FOCI 80

*Summer Bottom and Surface Temperatures - Eastern Bering Sea 86

*Variations in Temperature and Salinity During Late Summer/Fall 2002-2011 in the Eastern Bering Sea - BASIS 87

Aleutian Islands 88

*Eddies in the Aleutian Islands - FOCI 89

*Water Temperature Data Collections - Aleutian Islands Trawl Surveys 90

Gulf of Alaska 94

*Eddies in the Gulf of Alaska - FOCI . . . 94

*Ocean Surface Currents - PAPA Trajectory Index . . . 96

Gulf of Alaska Survey Bottom Temperature Analysis . . . 99

Habitat . . . 99

*Area Disturbed by Trawl Fishing Gear in the Eastern Bering Sea . . . 99

*Structural Epifauna - Bering Sea . . . 102

*Structural Epifauna - Aleutian Islands . . . 102

Structural Epifauna - Gulf of Alaska . . . 106

Nutrients and Productivity . . . 106

*Phytoplankton Biomass and Size Structure During Late Summer to Early Fall in the Eastern Bering Sea . . . 106

†Trends in Surface Carbon Uptake by Phytoplankton During Late Summer to Early Fall in the Eastern Bering Sea . . . 110

Gulf of Alaska Chlorophyll a Concentration off the Alexander Archipelago . . . 112

Zooplankton . . . 113

*Bering Sea Zooplankton . . . 113

*Late Summer/Fall Abundances of Large Zooplankton in the Eastern Bering Sea . . . 114

*Jellyfish - Eastern Bering Sea . . . 116

*Trends in Jellyfish Bycatch from the Bering Aleutian Salmon International Survey (BASIS) . . . 116

*Long-term Zooplankton Trends in Icy Strait, Southeast Alaska . . . 118

*Continuous Plankton Recorder Data from the Northeast Pacific . . . 123

Forage Fish . . . 127

*Fall Condition of YOY Predicts Recruitment of Age-1 Walleye Pollock . . . 127

†Forage Fish CPUE - BASIS . . . 129

*Gulf of Alaska Small Mesh Trawl Survey Trends . . . 133

†Regional Distribution of Juvenile Salmon and Age-0 Marine Fish in the Gulf of Alaska 135

Herring . . . 136

*Togiak Herring Population Trends . . . 137

Prince William Sound Pacific Herring . . . 138

*Southeastern Alaska Herring . . . 139

Salmon . . . 142

*Historical and Current Alaska Salmon Trends 142

*Forecasting Pink Salmon Harvest in Southeast Alaska 145

Groundfish 147

†Gulf of Alaska Ichthyoplankton Abundance Indices 1981-2009 148

Trends in Groundfish Biomass and Recruits per Spawning Biomass 152

Bering Sea Groundfish Condition 152

*Update on Eastern Bering Sea Winter Spawning Flatfish Recruitment and Wind Forcing152

*Pre- and Post-Winter Temperature Change Index and the Recruitment of Bering Sea Pollock 154

*Distribution of Rockfish Species in Gulf of Alaska and Aleutian Islands Trawl Surveys 155

Benthic Communities and Non-target Fish Species 157

†Spatial Variability of Catches in Bering Sea and Gulf of Alaska Crab Fisheries 158

Bering Sea/Aleutian Islands King and Tanner Crab Stocks 160

*Miscellaneous Species - Eastern Bering Sea 161

*ADF&G Gulf of Alaska Trawl Survey 161

Miscellaneous Species - Gulf of Alaska 165

Lingcod Catches in the Gulf of Alaska 167

*Miscellaneous Species - Aleutian Islands 167

Seabirds 169

*Multivariate Seabird Indices for the Eastern Bering Sea 169

*Seabird Bycatch Estimates for Alaskan Groundfish Fisheries, 1993-2011 171

Marine Mammals 174

Steller Sea Lion (*Eumetopias jubatus*) 174

Northern Fur Seal (*Callorhinus ursinus*) 175

Harbor Seals (*Phoca vitulina*) 175

Arctic Ice Seals: Bearded Seal, Ribbon Seal, Ringed Seal, Spotted Seal 175

*Bowhead Whale (*Balaena mysticetus*) 175

Ecosystem or Community Indicators 179

*Indicators of Basin-scale and Alaska-wide Community Regime Shifts 179

*Total Catch-Per-Unit-Effort of All Fish and Invertebrate Taxa in Bottom Trawl Surveys180

Biodiversity (Evenness) of the Groundfish and Invertebrate Community for the Eastern Bering Sea Slope 184

*Average Local Species Richness and Diversity of the Groundfish Community 184

Combined Standardized Indices of Recruitment and Survival Rate 186

*Spatial Distribution of Groundfish Stocks in the Eastern Bering Sea 187

Ecosystem-Based Management Indicators 189

Ecosystem Goal: Maintain Diversity 189

*Time Trends in Groundfish Discards 190

*Time Trends in Non-Target Species Catch 190

Ecosystem Goal: Maintain and Restore Fish Habitats 194

*Areas Closed to Bottom Trawling in the EBS/ AI and GOA 195

Hook and Line (Longline) Fishing Effort in the Gulf of Alaska, Bering Sea and Aleutian Islands 197

Groundfish Bottom Trawl Fishing Effort in the Gulf of Alaska, Bering Sea and Aleutian Islands 197

Groundfish Pelagic Trawl Fishing Effort in the Gulf of Alaska, Bering Sea and Aleutian Islands 198

Pot Fishing Effort in the Gulf of Alaska, Bering Sea, and Aleutian Islands 198

Ecosystem Goal: Sustainability (for consumptive and non-consumptive uses) 198

*Fish Stock Sustainability Index and Status of Groundfish, Crab, Salmon and Scallop Stocks 198

Total Annual Surplus Production and Overall Exploitation Rate of Groundfish 204

Community Size Spectrum of the Bottom Trawl-Caught Fish Community of the Eastern Bering Sea 206

Ecosystem Goal: Humans are part of ecosystems 206

*Fishing Overcapacity Programs 206

*Groundfish Fleet Composition 210

Distribution and Abundance Trends in the Human Population of the Bering Sea/Aleutian Islands 211

Distribution and Abundance Trends in the Human Population of the Gulf of Alaska . 212

References **213**

* indicates contribution updated in 2012
† indicates new contribution

List of Tables

1 Objectives, drivers, pressures and effects, significance thresholds and indicators for fishery and climate induced effects on ecosystem attributes 38

2 Suite of models used for implementation of an ecosystem approach to management in the Bering Sea (From Hollowed et al. (2011)). 58

3 Anomalies (calculated for 2003-2009, 2010, or 2011) for the south Bering Sea Middle shelf for mean water column T, stability over top 70 m, mean chla and ratio of large (>10 μm) to total chla over top 50 m (Aug-Sept) from BASIS data, and wind speed cubed (u^{*3}) near mooring M4 (Aug) from NCEP data. Positive indicates above average and negative below average values.110

4 Zooplankton longterm mean total density (numbers^{-3}) and percent composition for taxa important in fish diets by month in Icy Strait, Southeast Alaska. 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) from 1997-2011. Values are references for the 0-lines shown in Figure 53 anomalies. 120

5 Catch per unit effort (number per km^2) of capelin, age 0 Pacific cod, age 0 walleye pollock, Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon International Survey along the **northeastern** Bering Sea shelf. * preliminary data. 131

6 Catch per unit effort (number per km^2) of capelin, age 0 Pacific cod, age 0 walleye pollock, Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon International Survey along the **southeastern** Bering Sea shelf. * preliminary data. 131

7 The two best SECM pink salmon forecast models for the 2012 SEAK harvest. 149

8 Pearson's correlation coefficient relating the temperature change index (t+x) to subsequent estimated year class strength of pollock (Age-x+1). Bold values are statistically significant ($p < 0.05$). 156

9 Total **estimated** seabird bycatch in Alaskan groundfish fisheries, all gear types and Fishery Management Plan areas combined, 2007 through 2011. Note that these numbers represent extrapolations from observed bycatch, not direct observations. See text for estimation methods.174

10 (from Allen and Angliss (2012)). Summary of population abundance estimates for the Western Arctic stock of bowhead whales. The historical estimates were made by back-projecting using a simple recruitment model. All other estimates were developed by corrected ice-based census counts. Historical estimates are from Woodby and Botkin (1993); 1978-2001 estimates are from George et al. (2004) and Zeh and Punt (2004). 177

11 Recent subsistence harvest estimates (Suydam et al. 2011, IWC 2011, Allen and Angliss 2012). 178

12 Summary of status for FSSI and non-FSSI stocks managed under federal fishery management plans off Alaska, 2011. 199

13 FSSI stocks under NPFMC jurisdiction updated June 2012, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm`. . . . 202

13 FSSI stocks under NPFMC jurisdiction updated June 2012, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm`. . . . 203

14 Non-FSSI stocks, Ecosystem Component Species, and Stocks managed under an International Agreement updated June 2012, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm`. See website for definition of stocks and stock complexes. 205

List of Figures

1 Eastern Bering Sea ecosystem assessment indicators; see text for descriptions. * indicates time series updated in 2012. 2

2 The winter North Pacific Index time series. * indicates time series updated in 2012. 3

3 Western Aleutian Islands ecoregion indicators. * indicates time series updated in 2012. See Figure 2 for legend. 5

4 Central Aleutian Islands ecoregion indicators. * indicates time series updated in 2012. See Figure 2 for legend. 6

5 Eastern Aleutian Islands ecoregion indicators. * indicates time series updated in 2012. See Figure 2 for legend. 7

6 Arctic sea ice extent as of October 15, 2012, along with daily ice extent data for the previous five years. 2012 is shown in blue, 2011 in orange, 2010 in pink, 2009 in navy, 2008 in purple, and 2007 in green. The gray area around the average line shows the two standard deviation range of the data. Figure from National Snow and Ice Data Center (`http://nsidc.org/arcticseaicenews/`). 40

7 The proposed Alaskan Arctic assessment area, encompassing the northern Bering Sea, Chukchi Sea, and Beaufort Sea, within US territorial waters. The existing Arctic management area is filled with hatched lines. 46

8 The standardized seasonal mean (Jan, Feb., Mar.) Arctic oscillation index (blue line) from 1950 through 2011. The black line represents the standardized five year running mean of the index. Image source: NOAA/National Weather Service/Climate Prediction Center, `http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml`. 50

9 The average September sea ice extent over the years 1979 to 2011, with the linear trend line. Image source: National Snow and Ice Data Center, `http://nsidc.org/arcticseaicenews/category/analysis/`. 51

10 The three Aleutian Islands assessment ecoregions. Seabird monitoring islands are indicated by arrows. 60

11 Ocean water circulation in the Aleutions. Currents are indicated with black lines. Passes are indicated with white lines. Image from Carol Ladd. 61

12 Estimated biomasses of fish apex predators and pelagic foraging guilds aggregated by Aleutian Islands ecoregions. 63

13 SST anomolies for autumn, winter, spring, and summer. 74

14 SLP anomolies for autumn, winter, spring, and summer. 75

15 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`. 77

16 Seasonal forecast of SST anomalies from the NCEP coupled forecast system model for August 2012 through April 2013. 79

17 Mean monthly surface air temperatures anomalies in St. Paul, Pribilof Islands, a) unsmoothed, January 1995 through April 2012, and b) smoothed by 13-month running averages, January 1916 through April 2012. The base period for calculating anomalies is 1961-2000. 81

18 Surface air temperature anomaly over the greater Bering Sea region for Winter-Spring 2012. All individual months resemble the composite. 82

19 Sea level pressure (SLP) for January through June 2012. Note the center of the Aleutian low is centered in the Gulf of Alaska, east of its climatological location. 82

20 Surface air temperature anomaly over the greater Bering Sea region for July-August 2012. . 83

21 Recent springtime ice extents in the Bering Sea. Ice extent in 2006 through 2010 exceed the minimums of the early 2000s (except for 2002). 83

22 Depth averaged temperatures and temperature anomalies measured at Mooring 2, 1995-2012 in the southeast Bering Sea (C). Ellipses show the amount of sea ice in the vicinity of M2 during March and April. 84

23 Cold Pool locations in southeast Bering Sea from 2001 to 2012. The year 2012 has the maximum southeastward extent of the cold pool of the decade. 85

24 Average summer surface (open circles) and bottom temperatures (solid circles) (°C) of the eastern Bering Sea shelf collected during the standard bottom trawl surveys from 1982-2011. Survey water temperatures for each year were weighted by the proportion of their assigned stratum area. 86

25 Water column temperature normalized anomalies (-1 to 1) by BSIERP region, BASIS data, mid Aug-Sept, 2022-2011. Red = anomalies 0.4 to 1 (highest temp.), yellow = -0.3 to 0.3, blue = -1 to -0.4. 87

26 Water column salinity normalized anomalies (-1 to 1) by BSIERP region, BASIS data, mid Aug-Sept, 2022-2011. Red = anomalies 0.4 to 1 (highest salinity), yellow = -0.3 to 0.3, blue = -1 to -0.4. 88

27 Map of Bering Sea Integrated Ecosystem Research Program (BSIERP) regions 1-16 (Ortiz et al. In review). 89

28 Contours of bottom temperature for mid-Aug to Sept, 2003-2010. Black dots are station locations. 90

29 Contours of bottom salinity for mid-Aug to Sept, 2003-2009. Black dots are station locations. Circle shows location of mooring M4. 91

30 Eddy Kinetic Energy averaged over October 1993 - October 2011 calculated from satellite altimetry. Square denotes region over which EKE was averaged for Figure 31. 92

31 Eddy kinetic energy ($cm^2 s^{-2}$) averaged over region shown in Figure 30. 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. 92

32 Date adjusted temperature profiles by ½ degree longitude intervals for years 1994-2012. . . . 94

33 Eddy Kinetic Energy averaged over October 1993-October 2011 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 34. . . . 95

34 Eddy kinetic energy ($cm^2 s^{-2}$) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 33. 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. 96

35 Simulated surface drifter trajectories for winters 2002-2012. End points of 90-day trajectories for simulated surface drifters released on Dec. 1 at Ocean Weather Station PAPA are labelled with the year of the release (50°N, 145°W). 97

36 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 1902-2012. 98

37 (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 101

38 Total maximum potential area disturbed (assuming no spatial overlap of trawls), and the percent area disturbed. The green 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 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. 101

39 Relative CPUE trends of structural epifauna from the RACE bottom trawl survey of the eastern Bering Sea shelf, 1982-2012. Data points are shown with standard error bars. 103

40 Mean CPUE of HAPC species groups by area from RACE bottom trawl surveys in the Aleutian Islands from 1980 through 2012. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches. The Western, Central, and Eastern Aleutians correspond to management areas 543, 542, and 541, respectively. The Southern Bering Sea corresponds to management areas 519 and 518. 105

41 Spatial variations for integrated chla (mg m-2), mean chla (mg m-3), ratio of large assemblages to total (>10 μm /total chla) averaged over top 50 m, and stability (J m-3) averaged over top 70 m for 2003-2009 combined. 108

42 Ratio of large assemblages to total (>10 μm /total chla) in Middle Domain in the north (60 - 63°N) and south (54.5 - 59.5°N) Bering Sea for 2003-2010. 109

43 Interannual variations in mean August wind speed cubed (u^{*3}) at mooring M4 and mean chla over the top 50 m (Aug-Sept) for the south Bering Sea Middle shelf for 2003-2011. 109

44 Surface carbon uptake normalized to chlorophyll a concentrations over the southeast Bering Shelf (SEBS) showing a significant drop (in red) in 2007 uptake rates compared with other years. Single outlier removed from 2007 dataset. 111

45 Surface chorophyll a concentrations at production stations over the southeast Bering Shelf (SEBS) showing a significant drop (in red) in 2007. Single outlier removed from 2007 dataset. 112

46 Silicate concentrations at production stations over the southeast Bering Shelf (SEBS) showing a significant drop (in red) during 2007. Single outlier removed from 2007 dataset. 112

47 Estimated density of *Calanus* copepods and euphausiids (No. m^{-3}) in the eastern Bering Sea 1980-2011. 114

48 Mean abundance of large zooplankton collected with oblique bongo tows (505 μm mesh) on the Bering Sea shelf (<100 m) during BASIS surveys in the northern (top panel) and southern (bottom panel) Bering Sea. 115

49 AFSC eastern Bering Sea bottom trawl survey relative CPUE for jellyfish during the May to August time period from 1982-2012. 117

50 Total jellyfish biomass (1000 t) by year. 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. 118

51 BASIS surface trawl Biomass (1000t) by genus for 2004-2011 in the Eastern Bering Sea during August -October. Biomass was calculated using average effort per survey area in km^2 by year. 119

52 Marine climate relationships for the northern region of Southeast Alaska from the SECM 15-year time series, 1997-2011. Upper panel: mean monthly temperatures (°C, 20-m integrated water column) in Icy Strait; lower panel: correlation of mean annual temperature (°C, 20-m integrated water column) with the Multivariate ENSO Index (MEI), showing warm-versus-cold years. Longterm mean temperatures are indicated in the key. 121

53 Zooplankton density and composition anomalies for the SECM 15-yr time series from Icy Strait, Southeast Alaska, 1997-2011. Longterm 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 percent numerical composition of taxa important in fish diets. No samples were collected in August 2006, and the May 2007 night time values were omitted (denoted by x). 122

54 Mean (black lines), minimum and maximum (grey lines) monthly mesozooplankton biomass for the NE Pacific CPR sampling of the regions shown above right (2000 to 2010 except Alaskan Shelf regions where time series extends from 2004 to 2010), together with monthly data for 2011 overlaid as points. 124

55 Mean (black lines), minimum and maximum (grey lines) copepod community size for the NE Pacific CPR sampling of the regions shown above right (2000 to 2010 except Alaskan Shelf regions where time series extends from 2004 to 2010), together with monthly data for 2011 overlaid as points. 125

56 Day of the year when peak biomass of *Neocalanus plumchrus* occurred (based on stage composition, when 50% population was at copepodite stage 5), upper panel. Lower panel shows the length of the season calculated as the number of days between the 25th and 75th percentile of cumulative biomass. 126

57 Annual changes in the average energy density of age-0 pollock sampled by surface trawl during BASIS surveys. 128

58 Relationship between average energy content (AEC) of individual age-0 pollock and the number of age-1 recruits per spawner as shown in the 2011 stock assessment (Ianelli et al. 2011). 129

59 BASIS survey grid on the eastern Bering Sea shelf. 130

60 Catch per unit effort (number per km^2) of capelin, age-0 Pacific cod, age-0 walleye pollock , Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon Internatinoal Survey along the northeastern Bering Sea shelf. 2012 data are preliminary. 132

61 Catch per unit effort (number per km^2) of capelin, age-0 Pacific cod, age-0 walleye pollock , Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon Internatinoal Survey along the southeastern Bering Sea shelf. 2012 data are preliminary. 132

62 Anomalies from the long-term mean of forage species CPUE (kg km^{-1}) in the Gulf of Alaska, 1972-2011. 134

63 Time series of spatial variance in the cod:prey ratio (coefficient of variation in CPUE log + 10 ratio) in Pavlof Bay (line and squares) as adapted from Litzow et al. (2008). Heavy line indicates distinct states in the times series as defined by sequential t tests for analysis of regime shifts (STARS, $p = 0.03$, l = 5, H = 2). 135

64 Distribution of juvenile salmon in the Gulf of Alaska during summer months in 2011. 136

65 Distribution of age-0 marine fish in the Gulf of Alaska during summer months in 2011. 137

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 - 2012. 138

67 Estimated post-fishery mature herring biomass (white bars in tons), catch (gray bars in tons) and age-3 recruitment to mature population (black line) at nine major spawning locations in southeastern Alaska, 1980-2011. Estimates of recruitment for Tenakee Inlet were unavailable by time of publication. 140

68 Estimated combined annual mature herring biomass (including and excluding Sitka) at major southeastern Alaska spawning areas, 1980-2011. 141

69 Alaskan historical commercial salmon catches and ex-vessel values. 2011 values are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.) 143

70 Historical catch plus escapement anomalies of Bristol Bay sockeye salmon, 1956-2011. Data provided by Charles Brazil (ADF&G). Note: the value for 2012 is preliminary and subject to revision. 144

71 Marine survival of Prince William Sound hatchery pink salmon by year of return (brood year +2 years). Data reproduced from Botz et al. (2012). 145

72 Previous Southeast Alaska (SEAK) pink salmon forecast model predictions (with 80% confidence intervals) and harvests. 147

73 Matrix of ecosystem metrics considered for pink salmon forecasting. 148

74 Distribution of ichthyoplankton sampling in the Gulf of Alaska by NOAAs Alaska Fisheries Science Center from 1972 through 2009 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 1981-2009, from collections in the polygonal area outlined in blue where sampling has been most consistent during mid-May through early June (Doyle et al., 2009). 150

75 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. . . 151

76 OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56°N, 164°W from April 1-June 30 for 2004-2012. 153

77 The Temperature Change index value from 1950-2012. 155

78 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). 155

79 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. 157

80 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. 158

81 Trends in variability (SDL, standard deviation of log-transformed catch data) for historical crustacean catch data from the Bering Sea and Gulf of Alaska during the 1960s-2000s. Collapsing fisheries (n = 12) showed positive average slopes (i.e., increasing variability) prior to collapse, while non-collapsing fisheries (n = 2) did not show increasing variability. Differences in trend were statistically significant between the two groups (one-tailed P = 0.02). Error bars = 95% CI, figure redrawn from Litzow et al. (in prep.). 159

82 Current trends in spatial variability of catches for five crab fisheries in the Bering Sea and Gulf of Alaska. Fishing seasons are plotted to the calendar year including December for Bristol Bay red king crab, and to the year including January for all others. Black lines are best-fit linear trends, and P values are for one-tailed tests for increasing trends in SDL (standard deviation of log-transformed catch data). 160

83 AFSC eastern Bering Sea bottom trawl survey relative CPUE for miscellaneous species during the May to August time period from 1982-2012. 162

84 Adjoining survey areas on the east side of Kodiak Island used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results. 163

85 A comparison of standardized anomaly values for selected species caught from 1988-2011 in Kiliuda and Ugak Bays and Barnabas Gully during the ADF&G trawl surveys. 164

86 Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2010, with corresponding El Niño years represented. 165

87 Total catch per km towed (mt/km) during the ADF&G trawl survey from adjacent areas off the east side of Kodiak Island, 1987 to 2011. 166

88 Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Aleutian Islands from 1980 through 2012. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches. The Western, Central, and Eastern Aleutians correspond to management areas 543, 542, and 541, respectively. The Southern Bering Sea corresponds to management areas 519 and 518. 168

89 Biplot of the PC1 and PC2 values for each dataset in blue. 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. Years in the 1996-2011 time series are depicted numerically in black. 170

90 Loadings (absolute correlations) measuring the strength of association between individual time series and the first (PC1, top) and second (PC2, bottom) principal components. 171

91 The value of PC1 (top) and PC2 (bottom) over time. Higher values of PC1 indicate earlier seabird hatch dates and higher cormorant and murre reproductive success (except for St. George thick-billed murres). Higher values of PC2 indicate higher kittiwake reproductive success, and new with the inclusion of 2012 data, St. Paul thick-billed murre reproductive success and St. Paul black-legged kittiwake hatch dates. 172

92 Total estimated seabird bycatch by year in the Alaskan demersal longline fishery derived by employing three methods: the Fish and Wildlife Service (Stehn et al., 2001), the National Marine Mammal Laboratory (Fitzgerald et al., 2008), and this preliminary report, using the Alaska Regional Office Catch Accounting System (Cahalan et al., 2010). 173

93 (George et al., 2004). Population abundance estimates for the Western Arctic stock of bowhead whales, 1977-2001, as computed from ice-based counts, acoustic locations, and aerial transect data collected during bowhead whale spring migrations past Barrow, Alaska. Error bars show +/- 1 standard error. 177

94 Winter (NDJFM) PDO-NPGO phase space, 1965-2012. Colors highlight recent years (2008-12) and two historical periods of strong PDO influence in the ecosystem (1965-77 and 1978-88). Plotted values are 3-year running means, except for 2012, which is a 2-year mean. 180

95 Total change in the PC1-PC2 phase space for 64 biology time series, Baja California to the Bering Sea, 1965-66 to 2007-08. Each column plots a year-to-year change in the phase space, calculated as the length of the hypotenuse joining PC1 and PC2 vectors. Error bars = 95% CI associated with estimating missing values. The 2007-08 change was 311% of the mean change for other years ($t_{41} = 22.69$, $p < 0.0001$). 181

96 Time series of first two PC scores for 35 Alaskan biology time series, 1965-2008. Error bars = 95% CI associated with uncertainty through estimation of missing time series values; columns with no error bars indicate years with no missing values. Individual populations listed to the right of panels are time series showing strongest loading (≥ 0.2) on each PC score. 182

97 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 ($t = 3.258$, $p = 0.014$). 183

98 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 ($t = 1.221$, $p = 0.232$). 184

99 Model-based annual averages of species richness (average number of species per haul, dots), and species diversity (Shannon index) in the Eastern Bering Sea, 1982-2012, 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 area swept, depth, date of sampling, and geographic location. 185

100 Average spatial patterns in local species richness (left, number of taxa per haul) and Shannon diversity in the Eastern Bering Sea. The 50 m, 100 m, and 200 m depth contours are shown as black lines. Note highest richness along 100 m contour, highest diversity on middle shelf. . 186

101 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 weighted least-squares regression on annual average temperature with first-order auto-correlated residuals over time (Northward displacement: $R^2 = 0.24$, $t = 3.75$, $p < 0.001$; depth displacement: $R^2 = 0.25$, $t = -3.60$, $p = 0.001$). Solid lines denote linear regressions of residual variability over time (top: $R^2 = 0.57$, $t = 4.34$, $p < 0.001$; bottom: $R^2 = 0.61$, $t = -6.68$, $p < 0.001$). 188

102 Average North-South and East-West displacement across 39 taxa on the eastern Bering Sea shelf relative to species-specific centers of distribution. 189

103 Total biomass and percent of total catch biomass of managed groundfish discarded in the EBS, GOA, and AI areas, 1994-2011. (Includes only catch counted against federal TACS) . . 192

104 Total catch of non-target species (tons) in the EBS, AI, and GOA groundfish fisheries. 193

105 Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures. 196

106 The trend in total Alaskan FSSI score from 2006 through 2012. All scores are the 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/statusoffisheries/SOSmain.htm`. The maximum possible FSSI score is 140 in all years. Scores for 2007 were not available at the time of document preparation. 200

107 Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1994-2010. 211

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

December 2012 SSC Comments

The SSC commends the Ecosystem editors and contributors for continued improvement and for their responsiveness to SSC comments. The Eastern Bering Sea (EBS) and Aleutian Islands (AI) (new) Report Cards and the Hot Topics sections highlight interesting changes and are informative. It might be preferable to move the Hot Topics section to the report card, as it is short and provides information of immediate concern. The SSC looks forward to the preparation of a Gulf of Alaska (GOA) Report Card.

Thank you. Due to staff loss, we have postponed the development of a GOA Report Card and Assessment until winter, 2013. Since we currently have hot topics for all four ecosystems, but report cards for only two, we kept the hot topics in the assessment this year. We plan to move them to the report cards in the future. This year, we included short summaries of the hot topics pertinent to each report card.

These report card and hot topics sections would be even more useful if there was a short set of paragraphs that synthesized the views of the authors and Plan Teams as to the management implications of any findings.

We will attempt to do this after the Plan Teams have met and before the report is sent to the SSC. The Plan Teams have also included synthesized views in the Introduction of the SAFE (under Ecosystem Considerations) for the last several years.

The Ecosystem Trends section was succinct and useful. The listing of critical information gaps and research needs for each region will be helpful for the assembly of the Research Priorities report later in the year. New indices include EBS phytoplankton biomass and size structure, GOA Chlorophyll a, Icy Strait zooplankton trends, forecasts for SE Alaska pink salmon harvests, EBS slope groundfish and invertebrate community biodiversity, a multivariate seabird index for the EBS, and an index of Alaska-wide community regime shifts. The new seabird index shows some interesting results that may be useful in future ecosystem evaluations.

Thank you.

The executive summaries were useful, but ordering the indicators and key points from physical through consumers in a way that aligns them with the trophic structure would improve readability. In addition, some consistency in order of the indicators across regions would be appreciated.

We have rearranged the presentation order of some of the indicators in the Ecosystem Status and Management Indicators section as well as the Executive Summary to better reflect trophic structure. For example, the entries on jellyfish have been grouped with zooplankton and the ADF&G small mesh survey results have been moved to the forage fish section. We have also rearranged the presentation order of the indicators in the report cards and executive summary so that indices are presented with climate and lower trophics first and apex predators and humans last. Also, where applicable, we have arranged the order of the ecosystem presentions within each section of the document to the Arctic first, eastern Bering Sea second, Aleutian Islands third, and Gulf of Alaska fourth.

The SSC also appreciates the attempt (page 58) to test predictions made in the December 2010 Ecosystem Considerations chapter. In the future, it would be useful to denote all predictions in the chapter in bold, and then systematically test which ones were accurate the following year. Those predictions that prove reliable could then be moved into the individual species' assessments.

Thank you. We plan to systematically test all predictions made in the assessments annually. We had hoped to explore formatting options for grouping and/or highlighting predictions made throughout the report, but were unable to this year. We hope to do this in next year's report.

The sections on community trends in school enrollments and population size were informative. The SSC suggests adding information on trends in employment or wage-paying jobs and average wages. Because of their importance, sections on school enrollments should be separate paragraphs at the end of each ecoregion discussion. It is also possible that these socio-economic indices should be in the Economic SAFE.

The Aleutian Islands Ecosystem Assesment Teams discussed several other indicators, such as deck and other fishing licenses, to represent human trends in the AI ecosystem, but decided that school enrollment was the best indicator of the sustainibility of human communities. Alternate socio-economic indicators were considered more appropriate for the Economic SAFE. We will coordinate our review of these indicators with the Economics group to avoid redundancy.

The SSC had some concern over the baseline dataset used when reporting anomalies, especially physical anomalies. Currently, the baseline period differs by parameter, and the time frame used to define the baseline is not always clear and often not legible in the figures. This makes it difficult to compare responses across variables directly. Please show the baseline over which the anomalies are determined and attempt to standardize to the extent practicable.

We attempted to clarify the baselines in the text. The report card figures calculates long-terms means based on the entire series depicted; the 5-year means are shown in green. The only case where an anomaly is calculated from a longer dataset is the NPI anomaly, which we listed in the text.

Leading indicators should provide predictive value and they should integrate upwards to predicted impacts on commercially important species and species of conservation concern. The SSC encourages a rigorous evaluation of which indicators provide good insight into ecosystem status. An example of an indicator with too little data to be a useful leading indicator at present is the analysis of AI *tufted puffin chick diets. Those indicators that cannot be updated in a timely fashion, preferably up to the summer before the SAFE document preparation may be more appropriately raised in the section on key data gaps.*

We received the puffin chick diet data in time to include it into the Aleutian Island ecosystem assessment this year. We anticipate that annual updates will be reliable and timely in the future. This will allow us to use these time series as an alternate form of forage fish indicators. Although we did not receive updated information for all indicators, we anticipate that we will be able to receive regular updates in the future. We will move indicators that do not prove to be regularly updatable to the data gap sections.

The authors recognize the need for improved data on forage species, and the SSC reiterates its concern that lack of data on forage fish, particularly myctophids, sand lance, and squid, continues to limit the evaluation of potential changes to these important prey groups for apex fish, seabird and marine mammal predators. Equally important is the lack of data on prey species during fall, specifically euphausiid abundance and distribution. The SSC encourages efforts to incorporate forage fish sampling and acoustic surveys for euphausiids during the fall BASIS surveys.

We have addressed forage fish data needs in a few ways. One is to include expanded seabird diet datasets (as described above). The other is to use the extensive food habits database to investigate forage fish temporal patterns in the diets large predatory fish such as halibut. The editor is coordinating with the forage fish assessment assessment author to develop new time series of forage fish, some of which will be included in the forage fish stock assessment rather than this report. Fall forage fish sampling from the BASIS survey has been included in this report as a new contribution. The acoustic survey data from this survey are not yet available for inclusion.

There seems to be disagreement between the ecosystem SAFE and the forage fish chapter about the underlying reliability and utility of CPUE and stock assessment for the various forage species. Clarification of CPUE data origin (trawl, acoustic, seabird) and the limitations of these sources should be included, and some effort made to coordinate data with the authors in charge of the forage fish chapter.

The editor has coordinated with the lead forage fish assessment assessment author to develop new time series of forage fish as well as to reduce possible redundancy and/or conflicts between the Ecosystem Considerations report and the forage fish stock assessment. To this end, the forage fish indices from the NOAA summer surveys in the EBS, GOA, and AI have been removed from this report and incorporated into the forage fish stock assessments.

Relative to marine mammals, this document seems overly focused on northern fur seals and Steller sea lions, with no mention made of recent changes in the conservation status of walrus (recently listed as a candidate species under ESA), spotted seals (the Southern Distinct Population Segment recently listed as threatened) or the pending resolution of conservation status of other ice seal species, not to mention small, piscivorous cetaceans. Many of these species rely heavily on large zooplankton, forage fish species, euphausiids, and juvenile cod/groundfishes, and their population distributions and foraging behaviors are influenced by many of the physical variables mentioned in the Ecosystem Considerations chapter. There is a need to encapsulate fully the ecosystem considerations relative to these stocks. Inclusion of ice seals and walrus in the Bering Sea Ecosystem Chapter is particularly important, as these are food resources for many coastal communities, and changes in their status may influence human behavior.

We incorporated a discussion of the effects of Arctic sea ice loss on marine mammals in the Arctic ecosystem assessment this year. We also included updated Steller sea lion data in the Aleutian Island ecosystem assessment. Pribilof Island fur seal pup counts will not be available until December, after finalization of this report. Given the biennial pup count schedule and December release of data, fur seal pup counts will always be 1-2 years behind in the eastern Bering Sea ecosystem assessment and report card. The updated Bowhead Whale contribution includes recent harvest data. We hope to restructure the entire marine mammal section in the Ecosystem Status and Indicators section of this report to include relevant and up to date summaries of all marine mammals species in next year's report.

A number of specific questions, minor edits and comments have been provided to the editor.

General Comments:

It would be very helpful if all place names mentioned in the text were also displayed on a map.

We were unable to complete this for this report, but will work on developing a single map of place names to include near the beginning of the 2013 report.

All figure legends, especially internal legends, need to be checked for readability at the size found in a printed document. Likewise, when possible, figures should be intelligible in a black and white printed version.

We have attempted to address this as much as possible this year, both by increasing fonts where we could and requesting larger fonts from contibuting authors.

It would help the SSC if tables and figures in the PowerPoint presentations include document page numbers to facilitate finding the originals.

We will follow this suggestion in all future powerpoint presentations.

When feasible, the SSC would like to have the editor of the Ecosystem Considerations Chapter provide the presentation to the SSC so that questions can be answered in depth and so that the editor can have a better understanding of the comments of the SSC.

We agree.

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 many diverse research efforts into one document. There are three main sections:

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

The purpose of the first section, the Executive Summary, is to provide a consise summary of the status of marine ecosystems in Alaska for stock assessment scientists, fishery managers, and the public. 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 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 third 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 appendix to the annual SAFE report. Each new Ecosystem Considerations appendix provides updates and new information to supplement the original appendix. The original 1995 appendix 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 appendix provided additional information on biological features of the North Pacific, and highlighted the effects of bycatch and discards on the ecosystem. The 1997 appendix 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 Nino, 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 appendix 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.

The 2000-2009 Ecosystem Considerations appendices included some new contributions in this regard and will continue be built upon. Evaluation of the meaning of the observed changes needs to be in the context of how the 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 appendix 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 could 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 appendix 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 appendix provide actual time series data or make it available electronically. Most of the time series data for contributions are now available on the web, with permission from the authors.

The Ecosystem Considerations appendix and data for many of the time series presented in the appendix are now 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 Appendix version prior to 2000, please contact the Council office (907) 271-2809.

Ecosystem Assessment

Stephani Zador and Kerim Aydin

Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: stephani.zador@noaa.gov
Last updated: October 2012

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 new this year, 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 SAFE 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 indices of current ecosystem conditions reflecting these ecosystem properties. In order to perform this synthesis, a blend of data analysis and modeling will need to be employed to place measures of 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 and candidate indicators were chosen 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 NOAAs vision of Integrated Ecosystem Assessments.

We initiated a regional approach to ecosystem assessments in 2010 and presented a new ecosystem assessment for the eastern Bering Sea. In 2011 we followed the same approach and presented a new assessment for the Aleutian Islands based upon a similar format to that of the eastern Bering

Sea. This year, we have included a new section on the Arctic. Our intent is to provide an overview of general Arctic ecosystem information that may form the basis for more comprehensive future Arctic ecosystem assessments.

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 thought to best guide managers on ensuring the needs of non-fishery apex predators and maintaining a sustainable species mix in the harvest, given the current state and likely future ecosystem trends. Future assessments will address additional ecosystem objectives identified above. We expect to apply a team synthesis approach to the GOA ecosystem in 2013 and to the Arctic at a later time.

The entire ecosystem assessment is now organized into six 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 four ecosystems. In the next four sections, we present the region-specific ecosystem assessments. The final section summarizes conclusions based upon all regions.

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

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

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

Hot Topics

Hot Topics: Arctic

Arctic Sea Ice Record Minimum

The National Snow and Ice Data Center reported that the Arctic sea ice cover likely melted to its minimum extent for the year on September 16 (NSIDC; `http://nsidc.org/news/press/2012_seaiceminimum.html`). Sea ice extent fell to 3.41 million square kilometers (1.32 million square miles), the lowest summer minimum extent in the satellite record. As the ice cover has changed from predominantly multi-year ice to seasonal ice cover, increasingly larger areas have been prone to summer melt. Summer melt was the primary factor influencing the record extent this year, as compared to unusual wind patterns which, in combination with thinner ice, influenced melt patterns in 2007, the year with the second lowest ice extent. The minimum extent this year is nearly 50% lower than the 1979-2000 average extent (Figure 6).

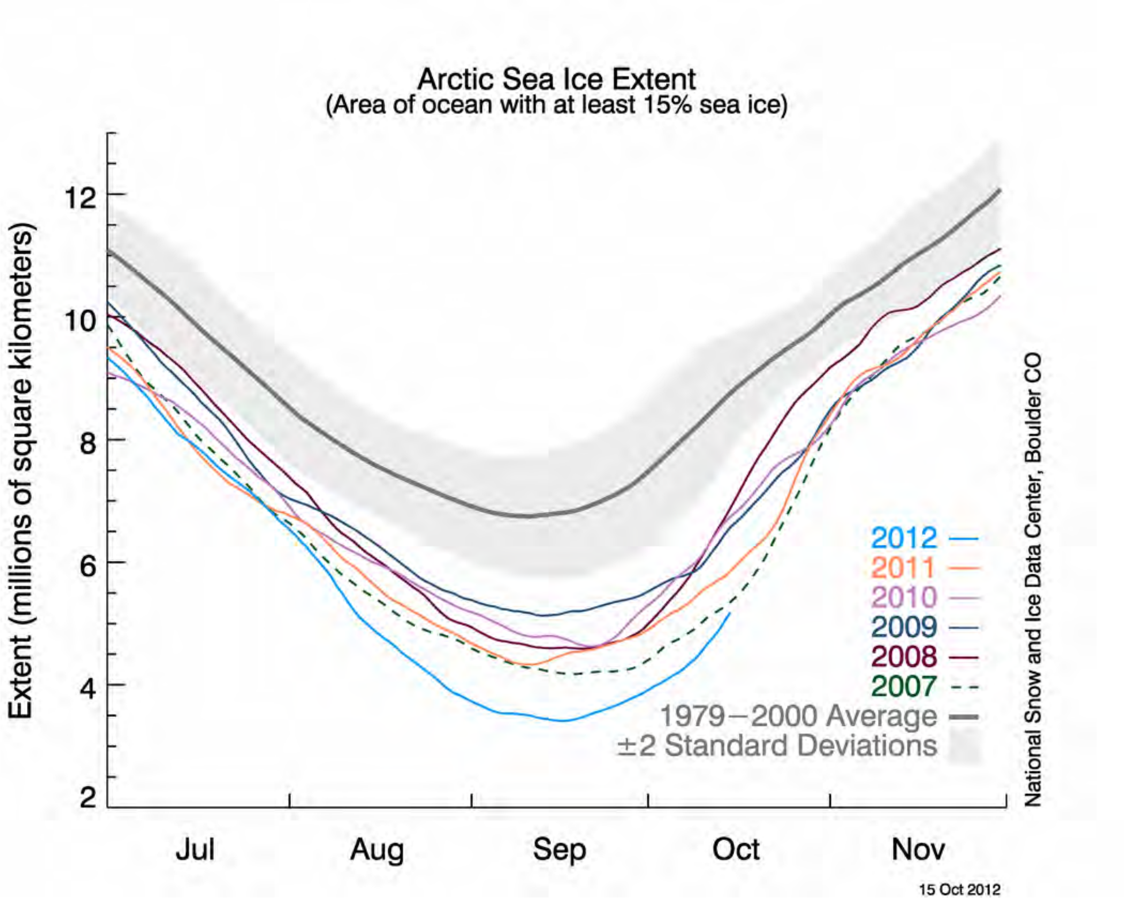


Figure 6: Arctic sea ice extent as of October 15, 2012, along with daily ice extent data for the previous five years. 2012 is shown in blue, 2011 in orange, 2010 in pink, 2009 in navy, 2008 in purple, and 2007 in green. The gray area around the average line shows the two standard deviation range of the data. Figure from National Snow and Ice Data Center (`http://nsidc.org/arcticseaicenews/`).

Effects of record low sea ice minima on selected marine mammals: During the summer, Pacific walrus use the sea ice as a platform to haulout and rest between foraging excursions at offshore feeding areas. Pacific walrus forage on the seafloor for clams and other invertebrates (Fay, 1982) in waters generally less than 80 m depth (Fay and Burns, 1988). Record low sea ice coverage in recent summers has left the ice edge farther to the north over deeper water, beyond the shallow continental shelf waters, where walrus prefer to forage. There, the water is too deep for walrus to forage optimally and this has forced high numbers of walrus to haulout and rest on the Chukchi Sea coast in Alaska and to forage in waters within range of shore (Jay and Fischbach, 2008; Garlich-Miller et al., 2011). Prior to 2007, Pacific walrus were not known to haulout in large aggregations on the Chukchi Sea coast in Alaska (Fischbach et al., 2009). It is not yet known if these recent shore-based aggregations of Pacific walrus are placing elevated predation pressure on nearby prey populations or if concentrating walrus near shore is forcing them to consume suboptimal prey (Jay and Fischbach, 2008; Garlich-Miller et al., 2011).

Polar bears are among the most sensitive marine mammals to climate change in the Arctic (Laidre et al., 2008). They are dependent on sea ice as a platform to hunt from and may also use sea ice as a form of transportation, and to occasionally construct maternity dens. Declines in sea ice can reduce the availability of their primary prey, ice seals, and lengthen the portion of the year when polar bears have to fast while stranded on land or on thick multi-year ice over the deep water of the central Arctic (Regehr et al., 2010). Declining body condition in the Hudson Bay population of polar bears has been correlated with reductions in the duration of sea ice coverage (Stirling et al., 1999). And in the southern Beaufort Sea, declining polar bear survival is associated with an increasing number of ice free days over the continental shelf (Regehr et al., 2010). Lengthening of the ice free season and the related nutritional stress has also been implicated in recent observations of cannibalism (Amstrup et al., 2006; Stone and Derocher, 2007). Interactions between polar bears and people that resulted in the bears being killed for human safety increased from 1993 to 1998 (Schliebe et al., 2006). The increasing duration of the ice free season is suspect for this rise in human-bear interactions, in part due to the increased nutritional stress experienced by the bears during this time and the greater amount of time spent on land increasing the likelihood of human-bear encounters (Stirling et al., 1999; Schliebe et al., 2006; DeBruyn et al., 2010). Though polar bears are capable of swimming long distances (Durner et al., 2011; Pagano et al., 2012), record low summer sea ice coverage and rough seas has been suggested as a possible cause for recent polar bear drownings (Monnett and Gleason, 2006). The increasing energetic demands of swimming over greater distances in expanding areas of ice free water may also result in body mass loss and declining body condition (Durner et al., 2011; Pagano et al., 2012).

Ice Seal and Walrus Unusual Mortality Event Update

The Unusual Mortality Event (UME) observed for ice seals and walrus during 2011 appears to have waned. No ice seals or walrus were reported with symptoms this summer. It is currently unknown whether the UME is nutritionally or environmentally driven. Laboratory analysis has not indicated any specific disease agent or process. Affected animals have tested negative for Avian/Bird influenza.

Text from the Diseased Ice Seals webpage at `http://alaskafisheries.noaa.gov/protectedresources/seals/ice/diseased/default.htm`: **June 25, 2012 update:** In 2011, over 100 seal strandings were reported. Approximately 60% of animals were alive or moribund (near death) and approximately 40% were found dead. In 2012, Native subsistence hunting communities have documented over 40 seals (primarily adult bearded and ringed seals) with clinical signs, namely: hair loss, weakness, unresponsiveness to human approach, skin sores, or some combination thereof. As the Alaska Native subsistence bearded seal harvest in the Bering Strait region precedes hunting in the Chukchi and Beaufort Sea, all seal reports for 2012 have been from the Bering Strait region.

Pacific walruses are less affected and cases tend to involve juveniles and subadults. There have been no reports of widespread illness or mortality in subsistence harvested walruses in 2012. In 2011, approximately 6% of the herd hauled out at Point Lay in September had round skin ulcers or sores throughout their bodies; the majority looked healthy. There have been few reports of skin wounds in Pacific walruses from the Bering Strait region or Bristol Bay, and high definition photos from Round Island haulouts have been reviewed and support this as well.

Based on review of pathologic findings to date, we believe that there are two categories of disease in ice seals related to this UME (referred to as case type 1 and type 2 below). All animals consistently feature abnormal hair loss due to lack of regrowth (alopecia or baldness) or persistence of old coats. Old hair is distinguishable from developing hair by its dull, yellowish or sun bleached appearance.

Case Type 1: animals have varying degrees of hair loss or baldness and otherwise seem healthy. Ringed seals with these signs have been reported by subsistence communities from the Bering Strait and North Slope for many years, but not in great numbers. However, in 2011 reports from hunters indicated a significant increase in the number of affected animals.

Case Type 2: animals appear/act sick. They have skin sores, often around the eyes, snout, and hind flippers. Hunter and biologists observations indicate that many of the affected seals are easily approachable/remain hauled out on land for prolonged periods of time.

Affected walruses feature a very distinctive pattern of small ulcers or skin sores widely distributed across the body. Sores tend to be the same size and fresh (new) lesions may ooze bloody fluid. Walruses normally have many scars and cuts, so it can be difficult to determine whether they are cases.

Hot Topics: Eastern Bering Sea

Commerical King Salmon Fisheries Failures

In September the Department of Commerce declared commercial king salmon fisheries in the Yukon and Kuskokwim rivers and Cook Inlet (Gulf of Alaska) failures after extrememly low returns over the summer. ADF&G reports that the 2012 Kenai River run appears to be the worst on record (`http://www.adfg.alaska.gov/sf/FishCounts/index.cfm?ADFG=main.kenaiChinook#RunSummary`). Commericial fishermen are eligible for federal disaster relief. Poor returns are also having a negative impact on subsistence fishermen, particularly along the Yukon and Kuskokwim rivers. Salmon experts, including scientists and fishermen, discussed a state-requested draft salmon research plan during a 2-day Alaska Chinook Salmon Symposium. The two leading hypotheses for the reduced runs are climate change and fishing. Recommendations included studying factors affecting early ocean survival, climate change, ocean acidification, marine pollution, and interactions between wild king salmon and hatchery fish. The state expects to have a research plan in place in December to address some of these questions.

Hot Topics: Aleutian Islands

Area-Specific Exploitation Rates of BSAI Blackspotted/Rougheye Rockfish

A recent analysis of spatial concentration of blackspotted/rougheye rockfish harvest relative to abundance indicates that exploitation rates for the western Aleutian Islands have been at or above $U_{F40\%}$ (defined as the exploitation rate for each year which would result in from applying a fishing rate of $F40\%$ to the estimated beginning year numbers at age) each year from 2004-2012, with the exception of 2011. Bering Sea/Aleutian Islands blackspotted/rougheye are taken as bycatch, and the fishery is thus obtaining higher catches in the western Aleutian than would be expected from the spatial distribution of survey biomass estimates. One potential explanation is that the spatial association between blackspotted/rougheye and targeted species (mostly Pacific ocean perch) differs between the western Aleutian Islands and other Aleutain Island subareas. Alternatively, it is also possible that the survey abundance in the western Aleutians is an underestimate of the true abundance due to spatial differences in survey catchability and availability. Additional detailed spatial data will be required to evaluate these hypotheses. See the Aleutian Islands ecosystem assessment for further detail (this document, p. 59).

Hot Topics: Gulf of Alaska

Anomalous Conditions in 2011

Widespread seabird reproductive failures and increased prevalence of nutrient-deficient ("mushy") halibut during summer 2011 were early indicators that foraging conditions for upper trophic-level predators were poor in the Gulf of Alaska (GOA) that year. Both diving and surface-foraging seabirds experienced poor reproductive success and in some cases complete failure, particularly in the western GOA. Affected colonies from west to east include: (1) Aiktak Island, near Unimak Pass; (2) Chowiet Island, in the Semedi Islands near Chignik on the Alaska peninsula; (3) East Amatuli Island, in the Barren Islands at the mouth of lower Cook Inlet, and (4) Middleton Island, south of Prince William Sound. Much of the reproductive failure occurred early in the breeding season during the egg stage. ADF&G reported increased prevalence of "mushy" halibut syndrome (see Hot Topics in the 2011 Ecosystem Considerations report and the following Hot Topic in this document) in smaller halibut caught mainly in the lower Cook Inlet area. Fisherman reported catches of affected fish during the summer, which waned by September. The cause is believed to be nutritional deficiency.

Direct sampling of low trophic level zooplankton and small fish provides supporting evidence of poor food supply for upper trophic predators during 2011. Continuous Plankton Recorder sampling through the GOA recorded very low zooplankton biomass in the Alaskan shelf region south of the Kenai Peninsula between April and September 2011 (this document, p. 123), potentially indicating poor food supply for planktivorous small fish such as age-0 pollock. To the south, the region offshore of British Columbia (BC) recorded average zooplankton biomass. The opposite pattern was observed in 2010, when zooplankton biomass was average in the Alaskan shelf region and below average in the offshore BC region. Gulf of Alaska small mesh trawl surveys conducted annually by the AFSC and ADF&G showed below average eulachon, juvenile pollock and herring catch rates in 2011 (this document, p. 133). Eulachon and herring had been at or above average in 4 and 3 of the previous five years, respectively. Surface trawls conducted in 2011 as part of the first year of the GOA Integrated Ecosystem Research Project caught few age-0 marine fish in both the western and eastern GOA (this document, p. 135). The winter Shelikof Strait acoustic survey in early 2012 recorded few age-1s (2011 year class)(Table 1.13 in GOA pollock stock assessment). The estimated abundance of 9-16 cm pollock was well below average but also below the median ranked abundance in 28 years of surveys.

It is unclear whether these anomalies were climate driven. Data from Argo profiling floats, used for diagnosing the sub-surface physical properties of the GOA region indicated that the poleward branch of the Alaska Current in the southeastern portion of the Gulf declined considerably from its peak in the winter of 2009-10 through summer 2011. It then increased markedly from summer into fall of 2011, and after declining over the course of the winter, again increased from spring into summer 2012 (see 2011 Ecosystem Considerations report and this document, p. 71). At a larger scale the state of the North Pacific atmosphere-ocean system reflected the influences of the back-to-back La Niñas during 2010-11 and 2011-12 winters (see 2011 Ecosystem Considerations report and this document, p. 71). The PAPA Trajectory Index (PTI), which provides an annual index of near-surface water movement variability based on the trajectory of a simulated surface drifter released at Ocean Station PAPA, generally fan out northeastwardly toward the North American continent (this document, p. 96). The 2010/2011 endpoint for January 2011 was east of the release site and the southernmost endpoint since the early 1990s. The current (5-year averaged) PTI trend remains consistent with a return to conditions associated with the preceding "cold" regime. It may thus be a harbinger of a decadal-scale reduction in regional productivity.

Reoccurrence of "Mushy" Halibut Syndrome

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.

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.

A Preliminary Assessment of the Alaska Arctic

Contributed by Andy Whitehouse[1] and Stephani Zador[2]

[1]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington
[2]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA

Rationale to include the Alaska Arctic

In recognition of the changing climatic and ecological conditions in the Arctic, the Council and the National Marine Fisheries Service implemented the Arctic Fishery Management Plan (FMP) in 2009. The Arctic FMP prohibits commercial fishing in the Arctic management area until such a time that a sufficient amount of information becomes available to support the implementation of a sustainable fishery, and outlines the criteria and process for authorization of any future commercial fisheries. The intent of adding the Alaska Arctic to the Ecosystem Considerations chapter is to provide an overview of general ecosystem information that may form the basis for more comprehensive future Arctic assessments that would be useful for fishery managers making decisions on the authorization of new fisheries. Consistent with ecosystem assessments of the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands, we intend for the future Arctic assessments to include a list of indicators that directly address ecosystem-level processes and attributes that can inform fishery management advice by communicating indicator history, current status, and possible future directions.

The area considered the Alaska Arctic for the purposes of this report includes the entire Arctic management area (NPFMC, 2009). Additionally, we propose the inclusion of the northern Bering Sea, which at present is not included in the eastern Bering Sea ecosystem assessment (Figure 7). The northern Bering Sea is widely regarded as having an ecosystem that is physically and biologically distinct from the southeastern Bering Sea (Grebmeier et al., 2006; Mueter and Litzow, 2008; Stabeno et al., 2010, 2012). A recent analysis of the biology and oceanography of the Bering, Chukchi, and Beaufort seas identified the northern Bering (north of St. Lawrence Island) and Chukchi seas as a single, distinct biogeographic province (Sigler et al., 2011). Studies of groundfish distribution in the northern and eastern Bering Sea have similarly identified a change in groundfish community composition with latitude (Cui et al., 2009; Stevenson and Lauth, 2012). Thus, there is sufficient evidence to support including the northern portions of the Bering Sea (> approx. 60°N) in an Arctic assessment. This will create a continuum of assessed areas throughout the marine waters of Alaska and will not cause any disruption or alteration to the existing northern boundary of the eastern Bering Sea assessment area.

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 six lowest annual sea ice minima over the satellite record (1979-present) occurring in the last 6 years, 2007-2012 (Comiso, 2012; Stroeve et al., 2012)(`http://nsidc.org`). A recent reconstruction of Arctic sea ice cover over the last 1,450

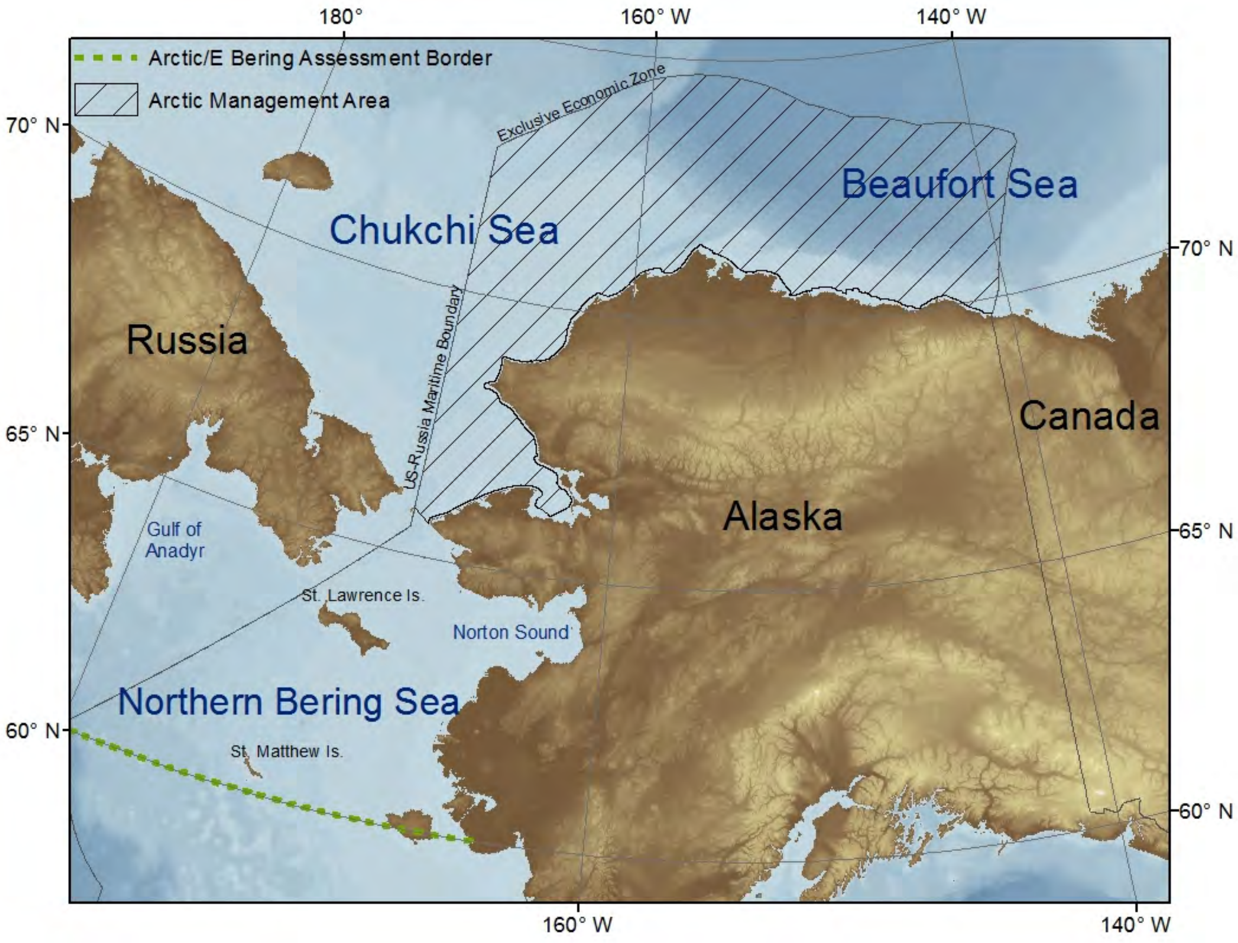


Figure 7: The proposed Alaskan Arctic assessment area, encompassing the northern Bering Sea, Chukchi Sea, and Beaufort Sea, within US territorial waters. The existing Arctic management area is filled with hatched lines.

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, 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 0C. 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 and Lowry, 1983; Ljungblad et al., 1986; Moore et al., 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, 1982; Hunt, 1991), preying on ice-associated invertebrates and Arctic cod (Bradstreet, 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 and the affect 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 and 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). In the Chukchi and Beaufort seas snow crab are a dominant benthic species, however they are seldom found to grow to a commercially viable size, greater than 78 mm carapace width (CW) (Frost and Lowry, 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 (78 mm CW) 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), and the northern Bering Sea again in 2010 (Lauth, 2011). 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 and Lowry, 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, 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 and Lowry, 1983; Barber et al., 1997; Norcross et al., 2010; Rand and Logerwell, 2011).

Gaps and needs for future Arctic assessments

There is an immediate need to convene Arctic experts to identify a list of indicators and corresponding time series data that will best capture ecosystem components and trends that would be of value to fishery managers. Several biomass indices are presently used as indicators in the ecosystem assessments of the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska. Times series data to support similar indices in the Alaska Arctic are lacking. The identification of available data sets would provide important first steps at indicator development and would provide critical help in identifying future indicator needs.

Potential indicators

Climate Index: The Arctic Oscillation (AO) index (`www.cpc.ncep.noaa.gov`) is a candidate indicator that tracks climate patterns in the Arctic and offers some capacity to predict the presence and extent of Arctic sea ice (Rigor et al., 2002). The AO describes the dominant pattern in sea-level pressure over the Arctic region (Figure 8)(Thompson and Wallace, 1998). A positive AO phase is associated with low pressure dominating over the polar region and with the development of a counter-clockwise anomaly in sea ice circulation in the eastern Arctic (Eurasian Arctic), which results in increased transport of sea ice out of the Arctic into the north Atlantic and decreased transport of ice from the Beaufort Sea into the Chukchi Sea (Rigor et al., 2002; Rigor and Wallace, 2004; Stroeve et al., 2011). In general, the positive phase of the AO is associated with the loss of thick multi-year ice, which in turn promotes the development of thinner first year ice (Rigor et al., 2002). The thinning of sea ice preconditions it for greater summer melt, resulting in reduced September sea ice extent (Maslanik et al., 2007; Serreze et al., 2007; Stroeve et al., 2012). During a negative AO phase, sea-level pressure is higher than normal, and the sea ice tends to have a clockwise motion, which favors the retention and thickening of Arctic sea ice.

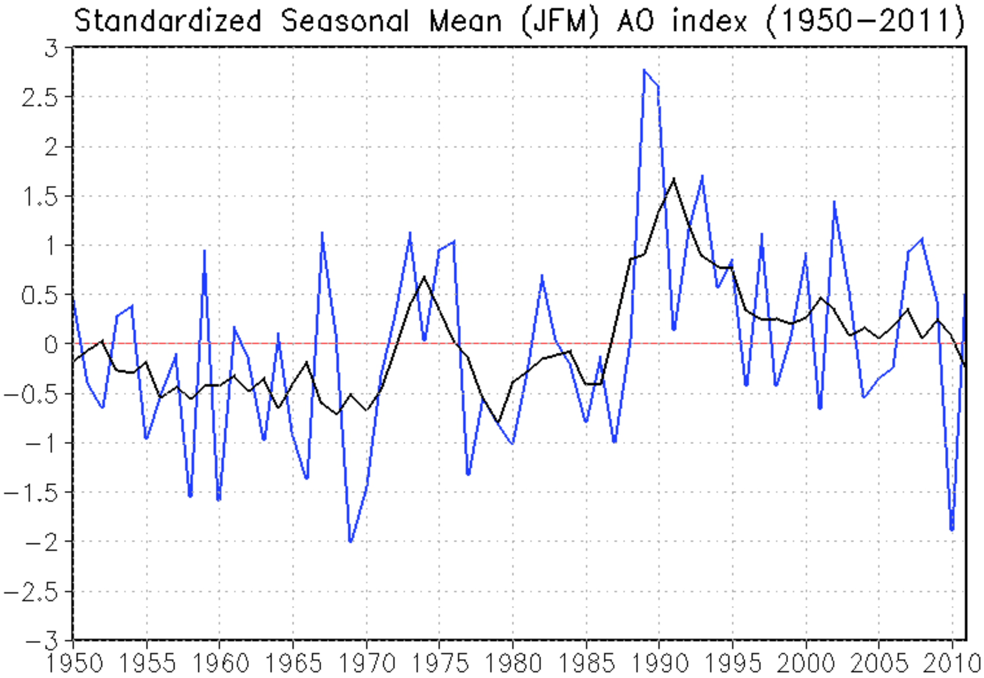


Figure 8: The standardized seasonal mean (Jan, Feb., Mar.) Arctic oscillation index (blue line) from 1950 through 2011. The black line represents the standardized five year running mean of the index. Image source: NOAA/National Weather Service/Climate Prediction Center, `http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml`.

The capacity of the AO to predict sea ice conditions has recently fallen under some scrutiny as the negative phase of the AO observed during the winter of 2009/10 failed to result in the retention of sea ice during the following summer, but rather resulted in the fourth lowest September sea ice minima in the satellite record (Stroeve et al., 2011). This observed lack of sea ice retention in 2010 has been partly attributed to changes in the wind field resulting in lower retention of sea ice in the Beaufort Gyre, an overall thinning of Arctic sea ice (Kwok et al., 2009), and a general rise in Arctic temperatures rendering the sea ice more susceptible to summer melt (Serreze et al., 2009; Stroeve et al., 2011).

Sea Ice Index: The September sea ice index (`http://nsidc.org/data/seaice_index/`) tracks the status and trend of September sea ice coverage for the entire Arctic (Figure 9). The end of the melt season and the annual minimum in total Arctic sea ice coverage occurs in September (Stroeve et al., 2012). As an indicator, the September sea ice index may serve to compliment the AO index and provide a means to evaluate the predictive capacity of the AO index. Much recent discussion in the primary literature and in the popular media has centered on whether the Arctic has passed a tipping point (Wassmann and Lenton, 2012). The term "tipping point" is generally taken to mean a critical threshold or variable value, beyond which an abrupt change takes place, altering the system qualitatively (Lenton et al., 2008). Tipping points as a threshold, may mark the transition between multiple alternative stable states but are not necessarily points of no return, leading to irreversible change (Lenton, 2012). For the Arctic, much of this discussion has centered on observed declines in sea ice coverage and thickness, and whether or not the Arctic is now headed towards, or has already passed a tipping point (e.g., overall warming) leading to a largely ice-free summer state (Lindsay and Zhang, 2005).

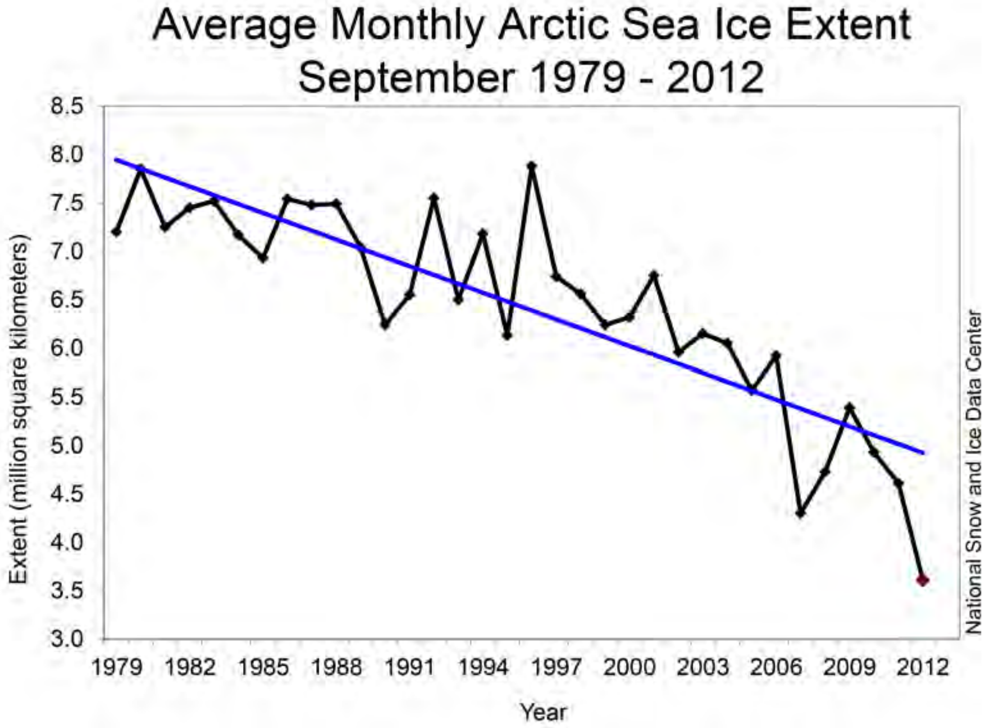


Figure 9: The average September sea ice extent over the years 1979 to 2011, with the linear trend line. Image source: National Snow and Ice Data Center, `http://nsidc.org/arcticseaicenews/category/analysis/`.

Primary Production Time Series: Arctic sea ice coverage has declined over recent decades (Meier et al., 2007; Stroeve et al., 2007; Comiso et al., 2008) and this has exposed an increasing area of open water to solar radiation. Recent increases in Arctic annual primary production since the late 1990's have been attributed to increases in the duration of the phytoplankton growing season and increases in open water area associated with sea ice loss (Arrigo et al., 2008; Pabi et al., 2008). Further declines in Arctic sea ice coverage are expected through the rest of the century (Boe et al., 2009; Wang and Overland, 2009; Douglas, 2010) and these continued declines are expected to result in further increases in Arctic primary production (Arrigo and van Dijken, 2011). Suitable time series of in situ estimates of primary production are not presently available and the development of a primary production index would provide a means to track any continued changes in the primary production regime in the Alaska Arctic. Satellite estimates of primary production may be spotty due to persistent cloud cover, and may be confounded by the presence of chromophoric dissolved organic matter (CDOM, compounds that appear the same as phytoplankton chlorophyll a to satellite viewing), and may underestimate production due to the presence of a subsurface chlorophyll maximum (Arrigo and van Dijken, 2011; Matsuoka et al., 2011). However, recent analysis of satellite data (Sea-viewing Wide Field-of-view Sensor, SeaWiFS) has offered some hope, indicating it may be possible to account for these inaccuracies (Arrigo and van Dijken, 2011).

Eastern Bering Sea Ecosystem Assessment

Stephani Zador[1] and the Eastern Bering Sea Ecosystem Synthesis Team: Sarah Gaichas[1], Phyllis Stabeno[2], Jeff Napp[1], Lisa Guy[3], Kerim Aydin[1], Anne Hollowed[1], Patrick Ressler[4], Nick Bond[3], Troy Buckley[1], Jerry Hoff[4], Jim Ianelli[1], Tom Wilderbuer[1], Lowell Fritz[5], Diana Evans[6], Martin Dorn[1], Pat Livingston[1], Franz Mueter[7], Robert Foy[4], Ed Farley[8], Sue Moore[2], Stephani Zador[1]

[1]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[2]Pacific Marine Environmental Lab, National Marine Fisheries Service, NOAA
[3]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington
[4]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[5]National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[6]North Pacific Fisheries Management Council
[7]University of Alaska Fairbanks, 17101 Point Lena Road, Juneau, AK 99801
[8]Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA

Editor's note: This year, we present an update to the full eastern Bering Sea assessement based on the ten ecosystem indicators chosen in 2010 and shown in Figure 1. For details about the selection and definition of the indicators see Zador and Gaichas (2010). We also present an evaluation of predictions from last year's assessment.

Summary

Conditions in the eastern Bering Sea in 2012 returned to the cold patterns of 2007-2010 that were favorable for lower trophic level production with extensive sea ice, early spring blooms, and moderately high concentrations of euphasiids and large copepods for planktivorous feeders. These conditions moderated in 2011 with warmer bottom temperatures and less extensive maximum ice extent and cold pool. However, the surface temperature was much lower than average, reflecting the unusually cold atmospheric conditions during summer 2011. The cool summer contributed to the continuation of multi-year sequential cold ocean temperatures, which in 2012 included the most extensive cold pool area of the recent decade and the latest ice retreat (along with 2009) in more than two decades.

The cold summer conditions in the eastern Bering Sea may translate to increased energy density of age-0 pollock during fall 2012, which favors their overwintering survival. However the very cold spring in 2011 experienced by the 2011 year class of pollock leads to a prediction of below average abundances of age-3 pollock in 2014.

The summer *Calanus* copepod time series showed an increase in abundance in 2011 relative to 2010, but remained below the 2009 peak. 2011 was the fourth year that concentrations remained well above average, following patterns also seen in fall zooplankton abundance during cold years. This suggests that prey availability for planktivorous fish, seabirds, and mammals continued to be high during the summer of 2011. Zooplankton indices for 2012 are currently unknown.

Jellyfish, primarily *Chrysaora melanaster*, remain abundant, although peak abundances observed in fall 2010 and summer 2011 declined by fall 2011 and summer 2012. An earlier increasing jellyfish biomass trend in the eastern Bering Sea was linked to a period of climatic transition from warm to moderate conditions, with a sharp decline in biomass at the transition back to a period of very warm conditions. The moderate winter of 2010/2011 seemed like it could have been the beginning of a transition out of the cold pattern seen for the previous 4 - 5 years, although the unusually cold summer and following cold winter did not allow these conditions to persist. Jellyfish biomass has also been linked to prey availability. Increased jellyfish abundance may indicate an increased source of mortality on their zooplankton and small fish prey.

Biomass estimates of four fish foraging guilds (apex predators, pelagic foragers, benthic foragers, and motile epifauna) were updated this year based entirely on survey estimates; past years included estimates from stock assessments. However, overall patterns within the foraging guilds remained similar. Since the mid-1990s, the apex predator and pelagic forager series seem to be correlated and in phase with each other. Both show increasing trends in past five years. It is hypothesized that cold conditions and high primary production could result in conditions that deliver food to both benthic and pelagic food webs. Unknown is whether or not top-down control (predation) will eventually occur once the biomass of these two guilds builds to a particular level (e.g. Oscillating Control Hypothesis).

Top-down control continues to be a concern in the ecosystem, particularly with the long term increase in arrowtooth flounder. Arrowtooth generally avoid areas with cold bottom temperatures during summer, with the result that their distribution and predatory impacts increase across the shelf during warm years. Reductions in the extent of the cold pool, as occurred during summer 2011, may have facilitated their expansion onto the shelf as seen during the warm years of 2003-2005. However, the extensive cold pool of 2012 would likely contribute to reduced estimated abundance on the shelf.

Seabirds and northern fur seals breeding on the Pribilof Islands are representative of the air-breathing central place piscivorous foragers in the eastern Bering Sea. The reproductive success of thick billed murres at St. George was just above the long-term mean (1977-2012), a substantial increase from the record low reproductive success they experienced in 2011. This suggests that foraging conditions were favorable for piscivorous seabirds. This assumption is supported by patterns in a multivariate Pribilof Island seabird index. The temporal trend in first principal component (PC1) increased from 2011, indicating earlier hatch dates and higher reproductive success for common murres and St. Paul thick-billed murres. The temporal trend in the second principal component (PC2) continued the nearly annual trend reversal with the 2012 value showing an increase from the previous year and indicating an increase in kittiwake and St. George Island thick-billed murre reproductive success.

Estimates of northern fur seal pup production in the Pribilof Islands are available 1 - 2 years after the surveys because of the bienniel survey and data analysis schedules. Thus it is difficult to assess their current response to ecosystem conditions. However, the most recent data in 2010 confirmed a continuation of their overall decline. The breeding populations of the western stock of Steller sea lions, meanwhile, continue to respond differently despite the fact that both fur seals and sea lions forage extensively in the southeast Bering Sea. Pup counts at rookery sites have either declined or have stabilized in the western and central Aleutian Islands but have shown an increase in the eastern Aleutian Islands (see Aleutian Islands ecosystem assessment for more detail, p. 59).

Evaluation of 2011 predictions

In this section we provide an evaluation of predictions from the 2011 eastern Bering Sea assessment. The most important aspects of the physical environment in the eastern Bering Sea during 2011 was considered the combination of the cool fall 2010 temperatures and a newly seen cold summer that did not allow the multi-year sequential continuation of cold ocean temperatures to come to an end. This certainly proved to be the case as the cold conditions in 2012 further lengthened the multi-year cold pattern. Early formation of sea ice was predicted and confirmed, and early 2012 conditions led to extensive sea ice and very late retreat.

Overall food availability for planktivorous species was considered to be high in 2010 based on the euphausiid biomass index and thus the survival of this year classes of fishes was predicted to be potentially better than average. The *Calanus* copepod time series which extends through 2011 follows the same above average trend. Although a full evaluation of this prediction is not currently possible, there is some indication that this may hold true. In evaluating sea temperatures to determine year class strength for groundfishes, conditions suggest continued improvement for the overwintering survival of pollock and cod from age-0 to age-1 in the Bering Sea. The 2011 temperature change index value and cold year models predict above average abundances of age-3 pollock in 2013.

The rapid increase in jellyfish biomass to peak values in fall 2010 and summer 2011 led to the prediction that there could be increased mortality on jellyfish prey such as zooplankton and small fish. The increase in the summer *Calanus* copepod abundance seen in 2011 relative to 2010 does not support this. The effects of possible increases in jellyfish predation on small fish are currently unknown.

The numbers of northern fur seal pups born at St. Paul Island in 2010 was estimated to drop by approximately 8.8% from 2008 estimates. This is consistent with the declining trend observed since the mid-1990s. By contrast, the 2010 pup production estimate for St. George Island is 1.0% less than the estimate in 2008. The overall decrease in pup production for St. Paul and St. George Islands combined from 2008 to 2010 is approximately 7.6%. Since 1998, St. Paul Island has declined at an annual rate of 5.5% and on both Pribilof Islands at an annual rate of 4.9%, down from the 6% annual decrease anticipated during the 2011 assessment which had incorporated available data through 2008. We will be able to evaluate the predicted declining trend with the 2012 data in next year's assessment.

Gaps and needs for future EBS assessments

Climate index development: We plan to develop 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. 187). 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 (in press) 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 Wilderbuer (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

Stephani Zador[1] and the Aleutian Islands Ecosystem Assessment Team: Kerim Aydin[1], Steve Barbeaux[1], Nick Bond[2], Jim Estes[3], Diana Evans[4], Dave Fraser[5], Lowell Fritz[6], Stephen Jewett[7], Carol Ladd[8], Elizabeth Logerwell[1], Sandra Lowe[1], John Olson[9], Ivonne Ortiz[1], John Piatt[10], Chris Rooper[11], Paul Wade[6], Jon Warrenchuk[12], Francis Weise[13], Jeff Williams[14], Stephani Zador[1] Additional data provided by Michael Martin[11]

[1]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[2]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington
[3]Long Marine Laboratory, University of California at Santa Cruz
[4]North Pacific Fisheries Management Council
[5]IMARIBA West, Port Townsend, WA
[6]National Marine Mammal Lab, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[7]University of Alaska Fairbanks
[8]Pacific Marine Environmental Lab, NOAA
[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 present an update to the full Aleutian Islands assessement based on the ecosystem indicators chosen in 2011 and depicted in Figures 2, 3, 4, and 5. For details about the selection and definition of the indicators see Zador (2011). New this year we also present an evaluation of predictions, updates on indicator development, and an update to recommendations from last year's assessment.

Summary

The Aleutian Islands ecosystem assessment is presented by three ecoregions. The ecoregions were defined based upon evidence of significant ecosystem distinction from the neighboring ecoregions. The ecosystem assessment team concluded that developing an assessment of the ecosystem at this regional level would also 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 10). 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. 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.These are briefly defined here and in more detail later in the document (Figure 10). The Western Aleutian Islands ecoregion spans 170° to 177°E. These are the same boundaries as the North Pacific Fishery Council fishery management unit 543. The Central Aleutian Islands ecoregion spans 177°E to 170°W. This area encompasses the North Pacific Fishery Council fishery management units 542 and 541. The Eastern Aleutian Islands ecoregion spans 170°W near Samalga Pass to False Pass at 164°W.

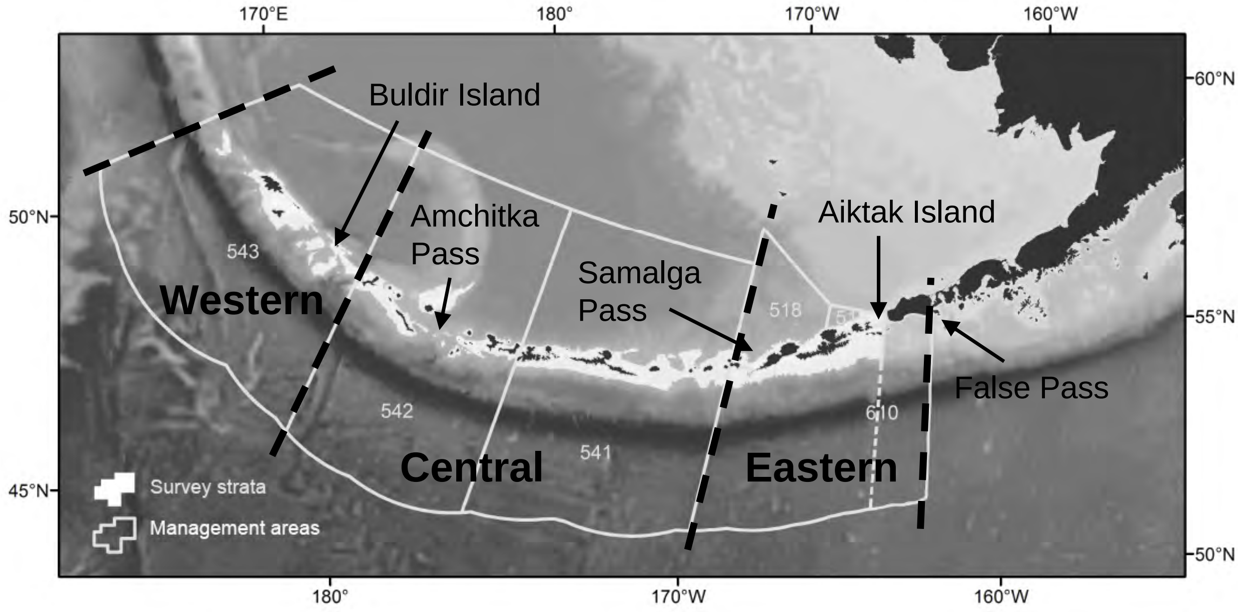


Figure 10: The three Aleutian Islands assessment ecoregions. Seabird monitoring islands are indicated by arrows.

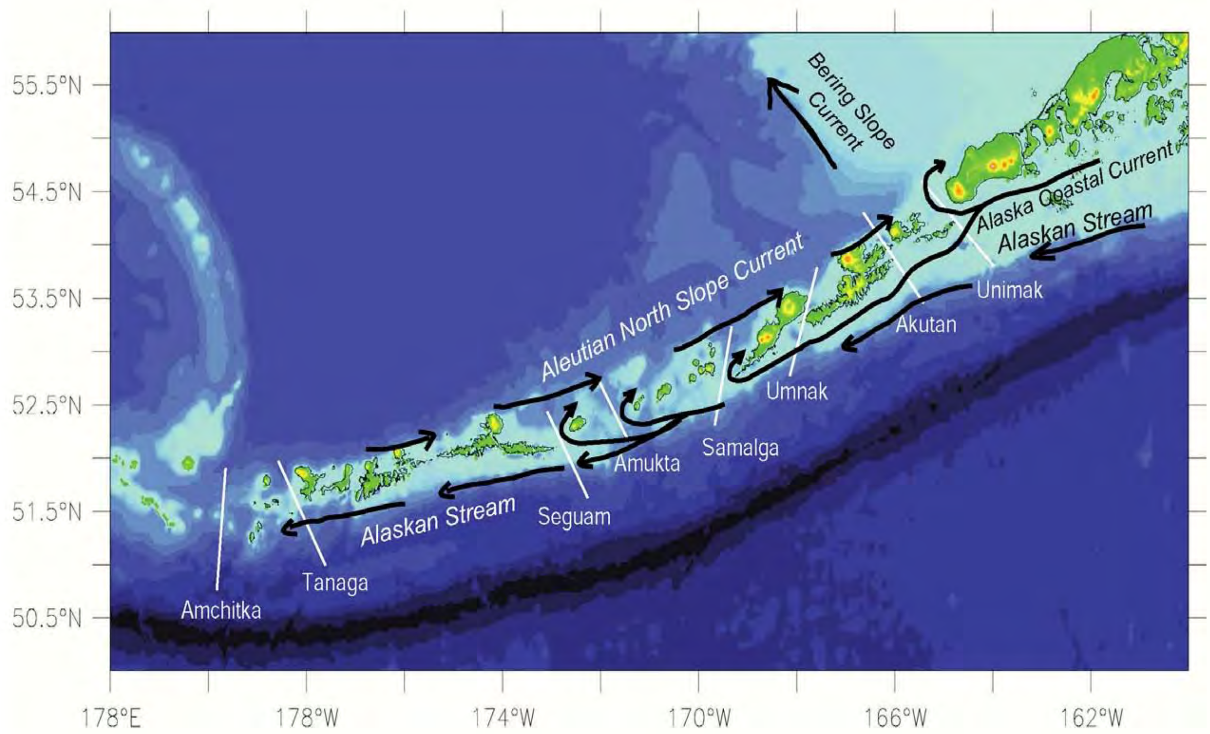


Figure 11: Ocean water circulation in the Aleutions. Currents are indicated with black lines. Passes are indicated with white lines. Image from Carol Ladd.

Most of what we can say about the Aleutians Islands ecosystem is based upon biological trends. There are large gaps in knowledge about the local physical processes and, as a result, their impact on biological processes. These gaps are largely due to geographic reality. For example, persistent cloudiness precludes obtaining comprehensive satellite-derived data. Also, the sheer distances involved in surveying the island chain make comparing west-east trends in indicators such as bottom temperature difficult because of the difference in timing of oceanographic surveys across the region. Differences in survey timing may also affect detection of biological patterns, but biological indicators such as fish or sea lion abundances are more integrative indicators than a specific physical indicator such as bottom temperature that they may be responding to and thus are less sensitive to survey timing. Also, the extensive nearshore component of the ecosystem, narrow shelf relative to the entire ecosystem, as well as strong oceanographic input mean that some metrics commonly used as ecosystem indicators in other systems may not be as informative in the Aleutians. Therefore, our synthesis of ecosystem indicators will by necessity include speculation.

The Aleutian Islands ecosystem experienced persistent westerly winds and very cold water temperatures during summer 2012. The westerly wind anomalies prevailed for much of the past year. Anomalies in this sense tend to suppress the northward transport through Unimak Pass and perhaps also the Aleutian North Slope Current. Eddy energy in the region has been low in the past two years, but a particularly strong eddy formed south of Amutka Pass this spring. Water column temperatures were the lowest overall compared with seven other surveyed years (1994, 1997, 2000, 2002, 2004, 2006, 2010). These cool temperatures may have influenced the lower abundance estimates of some species such as Atka mackerel, pollock, and arrowtooth flounder.

The largest total biomass of both fish apex predators and pelagic foragers is located in the central ecoregion, the region with the largest shelf area under 500m (Figure 12). The lowest apex predator biomass is located in the western ecoregion, whereas that of pelagic foragers is found in the eastern ecoregion. This pattern has been constant since 1991, though individual species groups fluctuations do not necessarily follow the same behavior. Both western and central ecoregions have a larger total biomass of pelagic foragers compared to that of apex predators, while in the eastern ecoregion the largest total biomass alternates between both guilds. Total pelagic foragers biomass is primarily driven by Pacific Ocean perch (POP) and Atka mackerel, however this is not the case across regions. POP biomass has been increasing (rebuilding) since 1991 with the difference between POP and Atka mackerel biomass gradually decreasing over the years. In the eastern ecoregion, where pollock is more abundant, both Atka and mackerel used to be the dominant biomasses but here too POP has been gradually increasing. There seems to be a trend towards an overall gradual shift from shallow foragers (Atka and pollock mostly between 100-200 m) to rockfish (northern rockfish / POP, >300m). Shallow pelagic foragers seem to have a lower availability to survey gear than rockfish during particularly cold water years like 2012. This may be affecting arrowtooth flounder too in the eastern ecoregion. These three species explain most of the changes in total biomass for both indices.

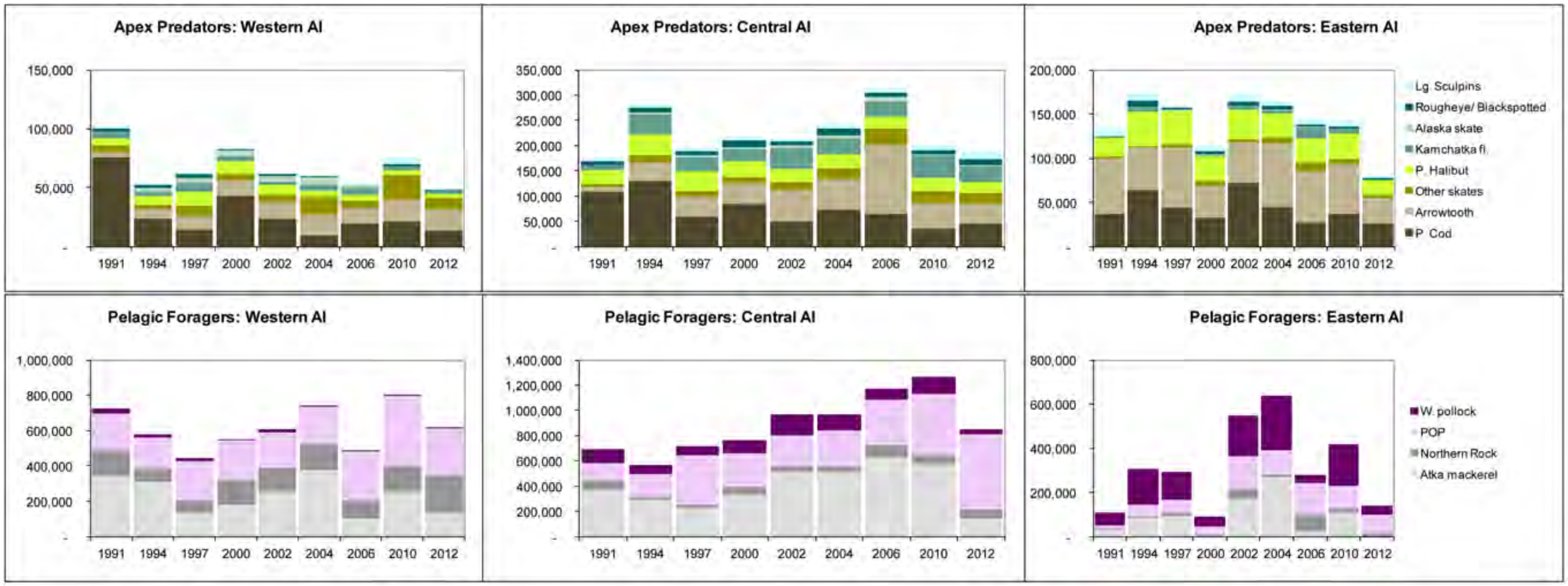


Figure 12: Estimated biomasses of fish apex predators and pelagic foraging guilds aggregated by Aleutian Islands ecoregions.

Reproductive success of planktivorous auklets increased in 2012, but has shown an overall declining trend in the past five years, possibly indicating a return to average zooplankton foraging conditions compared with the above average reproductive years of 2007-2009. In general, school enrollments numbers in the Aleutian Islands region have shown no recent trends, possibly indicating that communities with year-round residents that experience direct interactions with the ecosystem through residential and subsistence activites are stable.

Western Ecoregion In the western ecoregion specifically, reproductive success of planktivorous auklets, serving as indicators of zooplankton production, increased in 2012. This may indicate a return to average zooplankton foraging conditions compared with the above average reproductive years of 2007-2009. Forage fish trends as indicated in tufted puffin chick meals have varied. In general, *Ammodytes* (sand lance) have been more common since 2000 whereas gadids have been less common, although there is high interannual variability. The numbers of hexagrammids varied among years, but show a decreasing trend in the past five years. The pelagic fish foraging guild biomass has decreased since the last survey in 2010, likely influenced by the record cold water temperatures influencing catchability. Pollock, Pacific Ocean perch, and Atka mackerel contributed to this trend; whereas northern rockfish increased. The decrease in the fish apex predators foraging guild apparent in the 2012 trawl survey is driven by Pacific cod, skates and large scuplins, reversing the increasing trend in this foraging guild observed in 2010. The most recent counts of otters show no trend, in contrast to the steep decline during the early 2000s, possibly indicating stability for this keystone species of the nearshore environment. Steller sea lions continue their decades-long decline in this ecoregion, although at a slower rate. Between 1991 and 2008, non-pup counts declined 81%, or at a rate of -10% per year. The population appears to be continuing to fare poorly. Causes for the declining trend are topics of active research on these apex piscivores whose diet consists primarily of commercially-fished species. The amount of area trawled declined dramatically last year due to recent measures aiming at increasing protection for Steller sea lions.

Central Ecoregion Recent trends in planktivorous auklet reproductive success in the central ecoregion are unknown. Forage fish trends as captured by puffins are also not available from this ecoregion because puffins are not as numerous and nests are not monitored regularly. The pelagic fish foraging guild biomass declined overall since the last survey in 2010, reversing an increasing trend since 1994. Most of the decline can be attributed to Atka mackerel, although Pacific Ocean perch biomass has increased. The slight decline in fish apex predator biomass is largely driven by arrowtooth and Kamchatka flounders. The most recent counts of sea otters continue to decline, possibly indicated poor conditions in the nearshore environment for this species. Counts of non-pup Steller sea lions in 2011 continued to decline. The recent counts are more than one standard deviation below the long term mean. While the rate of decline is occuring at a lower rate compared to that in the western ecoregion, there is a still concern for these apex piscivores. Enrollment in Aleutian village schools has shown no trend in recent years, following a decline since peak enrollment in 2000.

Eastern Ecoregion Planktivorous auklets are not as numerous in the eastern ecoregion as in the central and western ecoregion and are not monitored in the Eastern ecoregion. Forage fish trends have varied in tufted puffin chick meals. In general, *Ammodytes* (sand lance) and gadids have shown opposite trends. *Ammodytes* were more common from 1998 to 2008, and have shown a declining trend in the last five years. Gadids were more common through the 1990s and have been increasing recently. Hexagrammids are uncommon in puffin chick meals in this region. These patterns suggest puffins are responding to changes in forage fish availability. All fish groups fluctuate widely in this area, which has the lowest total biomass of pelagic foragers relative to the other ecoregions. The fish pelagic forager biomass declined to the lowest value since 2002. Pollock and Atka mackerel contributed to this trend. Fish apex predator biomass declined to the lowest in the time series. All species groups declined since the last survey in 2010. In contrast to the other ecoregions, non-pup counts of Steller sea lions remained high in 2011. Counts were largely stable through the 1990s, but increased at a rate of 3% per year between 2000 and 2008. School enrollment has fluctuated in this ecoregion, but has shown no overall trend in the past five years. In contrast to the other ecoregions, non-pup counts of Steller sea lions increased 21% overall between 1991 and 2008. Counts were largely stable through the 1990s, but increased at a rate of 3% per year between 2000 and 2008, indicating favorable conditions for these piscivores. School enrollment has fluctuated in this ecoregion, but has shown no overall trend in the past five years.

Indicator Development

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

This section describes notable changes in the indicators from the last assessment. The time series of reproductive success of least and crested auklets that is used as an indicator of zooplankton productivity has changed slightly. The U.S.F.W.S., which collects the data and produces the values, undertook a reanalysis of historical data that resulted in minor changes to the values of the reproductive success time series that we follow. We included the new, corrected time series in this assessment. The forage fish indicators as represented by proportions of *Ammodytes*, gadids, and hexagrammids in tufted puffin chick diets were incomplete last year. These data have been reanalyzed and recently made available in numeric form. Thus, the data we include are complete through 2011, but show the proportion of fish in chick diets by number rather than biomass, which the team originally selected. The biomass data are expected to become available in the next year, so we plan to replace the current proportion by number data with biomass data in the 2013 assessment. Sea otter counts could not be updated this year due to unfavorable weather conditions during the 2012 field season.

Evaluations predictions and updates to recommenations

In 2011, based on the negative correlation between the strength of the Aleutian Low and planktivorous seabird productivity (Bond et al., 2011), we correctly anticipated continued favorable reproductive conditions for planktivores.

Among the Gaps and Needs listed in the first assessment, the team identified the lack of a regional analysis of stock exploitation rates. The next section reports on a recent analysis of spatial exploitation rates of rockfish.

Area-Specific Exploitation Rates of BSAI Blackspotted/Rougheye Rockfish

Contributed by Paul Spencer
Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: paul.spencer@noaa.gov

Introduction: The purpose of this report is to consider the potential impacts of this disproportionate harvesting upon the population by estimating area-specific exploitation rates and comparing them to exploitation rates which would result from current fishing reference points. This analysis is also motivated by the recent Aleutian Islands Ecosystem Assessment, which has indicated that substantial variability exists among ecoregions within the Aleutian Islands for several ecological characteristics. The Aleutian Islands Ecosystem Assessment Team identified regional analysis of stock exploitation rates as a gap in the current assessment and a need for future assessments, in part based on the spatial variability. In addition, the BSAI and GOA Groundfish Plan Teams have recently been requesting analyses of stock structure in order to assess spatial management practices for assessed groundfish stocks. Part of this evaluation consists of an examination of the spatial harvest patterns. For example, stocks with relatively low harvest rates that are not spatially concentrated may pose little issues regarding the impact of fishing, whereas harvest patterns that are spatially concentrated relative to the spatial scale of population structure could pose conservation risks to the population.

In 2010, a stock structure report for BSAI blackspotted/rougheye rockfish indicated that the spatial scale of population structure was estimated to be not larger than 500 km. Beginning in 2011, the BSAI ABC was partitioned in two areas - the western and central Aleutian Islands, and the eastern Aleutian Islands and the eastern Bering Sea area. Additional information presented in the 2010 indicated that a large portion of the catch of blackspotted/rougheye (∼40%) occurs in the western Aleutian Islands, which accounts for a relatively small portion (∼10%) of the estimated abundance from BSAI area.

Methods: The spatial concentration of harvest relative to abundance was evaluated by calculating area-specific exploitation rates from 2004 to 2012. For each year and subarea, exploitation rates were obtained by dividing the yearly catch by the estimate of biomass at the beginning of the year. The subarea biomass for each year was obtained by partitioning the estimated biomass at the beginning of the year (obtained from 2012 BSAI blackspotted/rougheye stock assessment) into the subareas. The biomass estimates from the 2012 stock assessment are assumed to be the best available information on the biomass time series, and using the results from the 2012 assessment can be considered a "retrospective" look at past exploitation rates. For each year, a weighted average of the subarea biomass from the three most recent surveys Aleutian Islands and eastern Bering Sea slope trawl survey (weights of 4, 6, and 9, with recent surveys higher weights) was computed, and the proportions from these averages were used to partition the biomass into subareas. Catches of blackspotted/rougheye were obtained from the Catch Accounting System database.

To evaluate to the potential impact upon the population, exploitation rates were compared to various measures of stock productivity. A common measure of stock productivity is the estimated natural mortality rate (M), which (for Tier 5 stocks) forms the basis for the acceptable biological catch (ABC) and overfishing level (OFL) fishing rate reference points of Fabc = 0.75*M and Fofl = M. Because BSAI blackspotted/rougheye are managed as a Tier 3 stock, the Fabc and Fofl reference points are based on conserving 40% and 35% of the lifetime spawning stock biomass produced per recruit for an unfished stock, and these reference points reflect maturity, fishery selectivity, and size at age. For comparison with the subarea exploitation rates, the exploitation rate for each year that would result from applying a fishing rate of F40% to the estimated beginning-year numbers was computed, and this rate is defined as $\mathrm{U}_{\mathrm{F40\%}}$.

Results: Exploitation rates for the western Aleutian Islands (WAI) have been at or above M in 2004, 2006, and from 2008-2010, ranging between 1.00 to 1.94 times the M value of 0.03 (Figure 1a). The exploitation rate for the WAI has exceed 0.75*M for each year from 2004-2010, and has exceeded $\mathrm{U}_{\mathrm{F40\%}}$ in all years from 2004 -1012 except 2011. The values of $\mathrm{U}_{\mathrm{F40\%}}$ are similar to 0.75*M, and have decreased slightly in recent years because a large portion of the catch weight is derived from relatively young fish where the fishery selectivity (and thus fishing mortality) is relatively low. The 2011 WAI catch of 46 t is the lowest since 2007, lowering the ratio of exploitation rate/$\mathrm{U}_{\mathrm{F40\%}}$ ratio to 0.49. However, the 2012 catch (through Oct 6) in the WAI has increased to 66 t. The exploitation rates from 2004-2012 for the other subareas do not exceed $\mathrm{U}_{\mathrm{F40\%}}$ with the exception of the EBS in 2010 and 2011.

Catches in WAI from 2004-2012 appear to be decreasing, with the two highest catches occurring in 2004 and 2006 (Figure 1b). This could potentially be explained by a combination of the fishery improving their avoidance of blackspotted/rougheye rockfish bycatch, and also a potential reduction in population size. Discerning a true population trend in the WAI is hindered by the relatively high coefficient of variation, which has averaged 0.44 from the 1991-2012 surveys. However, the point estimates of biomass in this area are consistent with a decline in abundance, as the average biomass from the 1991-1997 surveys was 3,156 t and the average from the 2000-2010 surveys was

1,059 t. In the 2012 survey, the biomass estimate was further reduced to 335 t. High catches in the WAI also occurred in the mid-1990s (Spencer and Rooper, 2012), consistent with the trend in survey biomass estimates.

The high exploitation rates in the WAI reflect that the fishery is obtaining higher catches than would be expected from the spatial distribution of survey biomass estimates. Given that the catch of blackspotted/rougheye rockfish is obtained as bycatch in the POP fishery rather than directed fishing, one would expect that the survey data and the bycatch data would be similar. One potential explanation is that the spatial association between blackspotted/rougheye and targeted species (mostly Pacific ocean perch) differs between the western Aleutian Islands and other Aleutain Island subareas. Alternatively, it is also possible that the survey abundance in the WAI is an underestimate of the true abundance due to spatial differences in survey catchability and availability. Additional detailed spatial data will be required to evaluate these hypotheses.

The spatial scale of expected dispersal distance between generations of blackspotted rockfish in the Aleutian Islands, obtained from genetic data, is estimated to not exceed 500 km (Spencer and Gharrett, 2010), which is comparable to the length of the WAI subarea. Given that the generation time of BSAI blackspotted rockfish is estimated is approximately 53 years, a depletion of abundance on spatial scale of $\sim$500 km would not be expected to be replenished quickly from the dispersion of fish from neighboring areas

Gulf of Alaska

This report does not include a current ecosystem assessment of the Gulf of Alaska. A workshop is planned for 2013, during which a new Gulf of Alaska Ecosystem Assessment team will develop an assessment following the procedure and format of the EBS and AI assessments.

Conclusions

Climate Monitoring climate variability is necessary to understanding changes that occur in the marine environment and may help predict potential effects on biota. La Niña conditions developed again in the winter of 2011/1012, following on the heels of the same pattern the year before. North Pacific climate patterns reflect a continuation of a negative sense to the Pacific Decadal Oscillation (PDO). ENSO indices for the tropical Pacific indicate a warming trend for the first half of 2012; the models used to forecast ENSO are indicating outcomes for the winter of 2012-13 ranging from near neutral to a weak-moderate El Niño. These large-scale climate patterns influence important Alaskan marine features such as the size and location of the cold pool in the Bering Sea. In the summers of 2006-2012, the extent of the cold pool increased from low values observed during 2000-2005. Changes in the cold pool size and location may affect the distribution of some fish species and may also affect stratification, production, and community dynamics in the Bering Sea. Observed changes in the physical environment in the Bering Sea may be, in part, responsible for the increased zooplankton biomass observed in the last three or four years. The increased zooplankton biomass may have positive effects on zooplanktivorous fish, such as juvenile walleye pollock, in the Bering Sea. It is apparent that many components of the Alaskan ecosystems respond to variability in climate and ocean dynamics. Predicting changes in biological components of the ecosystem to climate changes, however, will be difficult until the mechanisms that cause the changes are understood (Minobe, 2000).

Habitat It is difficult to assess the effects of fishing on habitat and structural epifauna. Increased knowledge of habitat disturbance as a function of fishing intensity would improve our ability to assess this objective. Also, it would be beneficial to have improved knowledge of the importance of structural epifauna as habitat for different species and life stages of fish, estimates of structural epifauna population abundance and distribution, particularly in areas currently untrawlable with standard survey gear, the relationship between physical factors such as sediment type, bathymetry, and oceanography and the abundance and distribution of structural epifauna.

Diversity Measures of diversity are subject to bias and we do not know how much change in diversity is acceptable (Murawski, 2000). Furthermore, diversity may not be a sensitive indicator of fishing effects (Livingston et al., 1999; Jennings and Reynolds, 2000). We, therefore, attempted to look at a variety of indicators for the diversity objective. EBS species richness has increased since 1995 and this has been attributed to subarctic species spreading into the former cold pool area as the extent of the cold pool has decreased over recent decades (Mueter and Litzow, 2008). Species diversity in the EBS, however, has been relatively low in recent years, compared to the 1990s, which suggests that species remain patchily distributed such that a given haul may be dominated by one or a few species. With regards to size diversity of fish in the Bering Sea, unlike other marine ecosystems, there has not been a linear decreasing trend in groundfish size or abundance during 1982-2006 (Boldt et al., 2008). No groundfish species is overfished or subject to overfishing; however, Pribilof Island blue king crab are considered overfished. These indices, however, apply only to fish and invertebrate species. There are eight endangered and five threatened marine mammal and seabird species in Alaska. One of those endangered species is the western stock of Steller sea lions, of which, the adult females may be experiencing declines in reproductive rates since the early 1990s (Holmes and York, 2003; Holmes et al., 2007). The number of northern fur seal pups born on the Pribilof Islands and Bogoslof Island show opposite trends, which can not be explained by immigration/emigration, or large-scale spatio-temporal environmental changes in the North Pacific Ocean. Further research is needed to improve our understanding of diversity indices and what causes some of these trends.

Gaps in knowledge There are gaps in understanding the system-level impacts of fishing and spatial/temporal effects of fishing on community structure and prey availability. Validation and improvements in system-level predator/prey models and indicators are needed along with research and models focused on understanding spatial processes. Improvements in the monitoring system should include better mapping of corals and other benthic organisms, development of a system for prioritizing non-target species bycatch information in groundfish fisheries, and identification of genetic subcomponents of stocks. In the face of this uncertainty, additional protection of sensitive or rare ecosystem components such as corals or local spawning aggregations should be considered. Improvements in understanding both the nature and direction of future climate variability and effects on biota are critical. An indicator of secondary production or total zooplankton availability would improve our understanding of marine ecosystem dynamics and in prediction of groundfish recruitment and survival.

Ecosystem Status and Management 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 are not maintained are excluded from this 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))
NOAA/PMEL, Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: nicholas.bond@noaa.gov
Last updated: August 2012

Summary: The state of the North Pacific atmosphere-ocean system during 2011-2012 reflected the combination of a response to La Niña and intrinsic variability. The Aleutian low was weaker than usual in the winter of 2011-12, and the sea level pressure was higher than normal in the eastern portion of the basin for the year as a whole. Cooler than normal upper ocean temperatures prevailed in the eastern portion of the North Pacific and warmer than normal temperatures occurred in the west-central and then central portion of the basin. This pattern reflects a continuation of a negative sense to the Pacific Decadal Oscillation (PDO). The ENSO indices for the tropical Pacific indicate a warming trend for the first half of 2012; the models used to forecast ENSO are indicating outcomes for the winter of 2012-13 ranging from near neutral to a weak-moderate El Niño.

Regional Highlights:

West Coast of Lower 48. This region experienced conditions during 2011-2012 that mostly resembled those during past periods of La Niña and negative PDO. The waters near the coast tended to be mostly cool, with varying salinity, relative to normal. The cooler waters were accompanied by a greater preponderance of sub-arctic than sub-tropical zooplankton than usual, except for during fall

2011 (B. Peterson, NOAA/NWFSC). There was a rather late start to the upwelling in spring 2012, and the winds have tended to be somewhat less upwelling favorable than usual north of 40°N. Additional information on the state of the California Current system is available at `www.pacoos.org` and `http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/bb-midyear-update.cfm`.

Gulf of Alaska. The data from Argo profiling floats, available at `http://www.pac.dfo-mpo.gc.ca/science/oceans/Argo/Alaska-Argo-eng.htm`, are useful for diagnosing the sub-surface physical properties of this region. Based on the gradient in dynamic height from Argo, the poleward branch of the Alaska Current in the southeastern portion of the Gulf increased markedly from summer into fall of 2011, and after declining over the course of the winter, again increased from spring into summer 2012. These changes from season to season are consistent with the winds, as can be deduced from the SLP anomaly patterns shown in Figs. 1b-4b. The mixed layer depths in the Gulf were shallower than usual during the winter of 2011-2012 but by early summer 2012 were near their seasonal norms.

Alaska Peninsula and Aleutian Islands. Westerly wind anomalies have prevailed in this region for much of the past year. Anomalies in this sense tend to suppress the northward transport through Unimak Pass and perhaps also the Aleutian North Slope Current. A possible implication is a reduced supply of nutrients onto the southern Bering Sea shelf, but the importance of this mechanism is poorly known.

Bering Sea. The Bering Sea shelf experienced another relatively heavy ice year, especially in terms of maximum ice extent. The weather was punctuated by periods of unusually frigid temperatures at around the first of the year, the end of January and much of March. Westerly wind anomalies occurred during spring, which resulted in a late ice retreat from the southern shelf, but not to extent of some recent years, notably 2010. Unlike a year ago, the summer of 2012 has been relatively calm. This has resulted in a relatively thin (∼10 m) mixed layer that rapidly warmed in June through July, especially in the north. The water at depth is still cold and the onset of the fall storms should result in rapid cooling near the surface. The combination of El Niño expected this winter and a continuation of reduced ice cover in the central Arctic (more on this below) should yield a lighter ice year for the Bering in 2013.

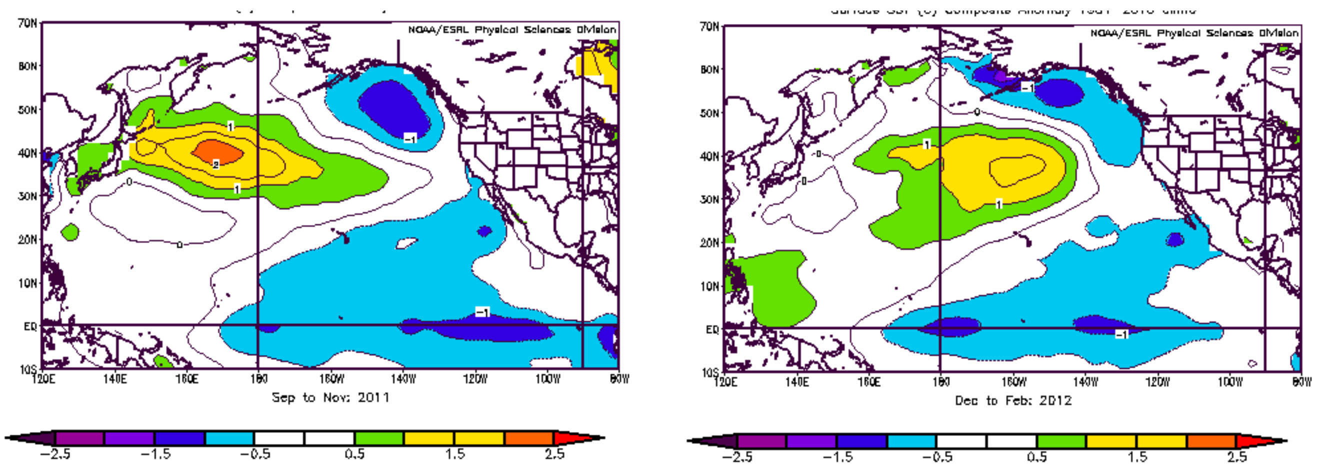
Arctic. The tendency for reduced sea ice cover in the Arctic during the summer has continued into 2012. The distribution of the arctic sea ice in early August 2012 differs somewhat from recent years. Specifically, high ice concentrations have persisted in the Chukchi and in the western portion of the Beaufort Sea. The extent to which this ice will melt back during the remainder of summer depends on the weather of August and September. If the ice pack retreats to well north of Alaska, as it has in recent summers, there should again be a delay the development of ice in marginal seas such as the Bering Sea during the following cold season.

Sea Surface Temperature and Sea Level Pressure Anomalies

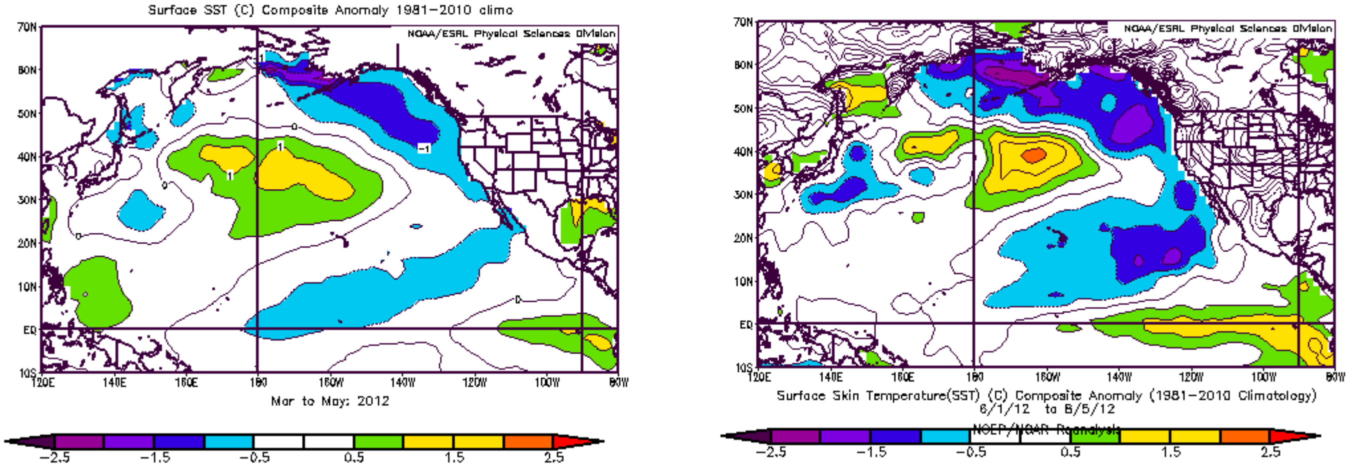
Contributed by N. Bond (UW/JISAO))
NOAA/PMEL, Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: nicholas.bond@noaa.gov
Last updated: August 2012

Description of indices: The state of the North Pacific from autumn 2011 through summer 2012 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 NOAAs Extended Reconstructed SST analysis; the SLP data are from the NCEP/NCAR Reanalysis project. Both data sets are made available by NOAAs Earth System Research Laboratory at `http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl`.

Status and trends: In an overall sense, the climate forcing of the North Pacific during the year of 2011-12 was dominated by the response to a weak-moderate La Niña that developed in late summer of 2011 and waned in spring 2012. The autumn (Sep-Nov) of 2011 included weak to moderate negative SST anomalies in the northern and eastern North Pacific, and moderate to strong positive SST anomalies in the central and western North Pacific in a band between 30° and 50°N. Cooler than normal SSTs occurred in the central and eastern tropical Pacific in association with the re-development of La Niña (Figure 13a). The corresponding pattern of anomalous SLP included negative anomalies north of 50°N from eastern Siberia into central Canada and positive anomalies in the central north Pacific (Figure 14a). This pattern corresponds with westerly wind anomalies from roughly 40° to 50°N across most of the North Pacific.

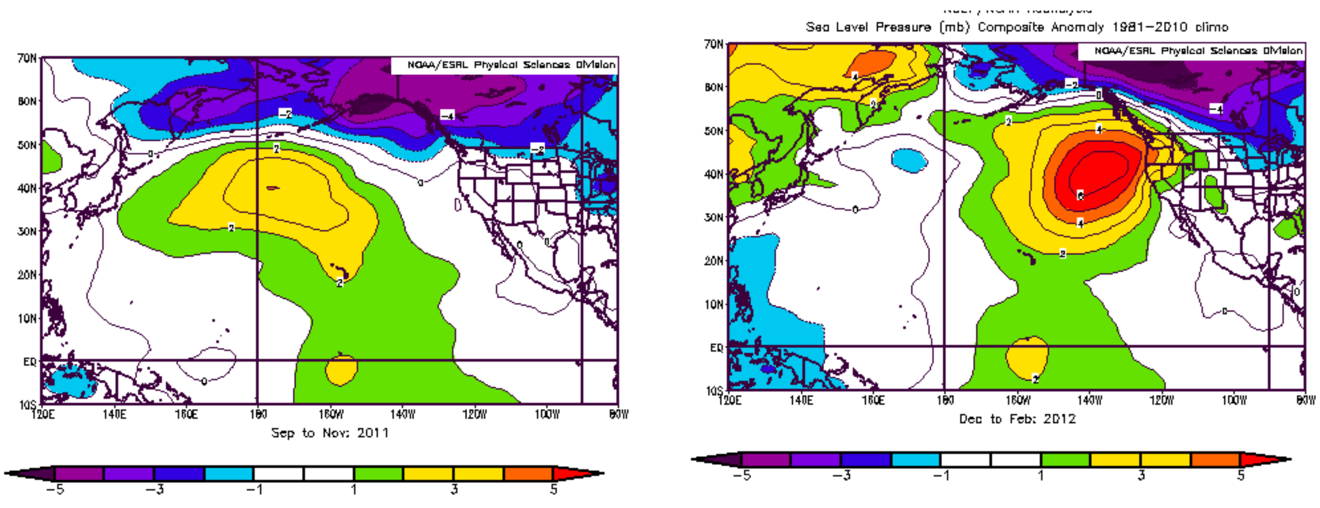


(a) Autumn (b) Winter

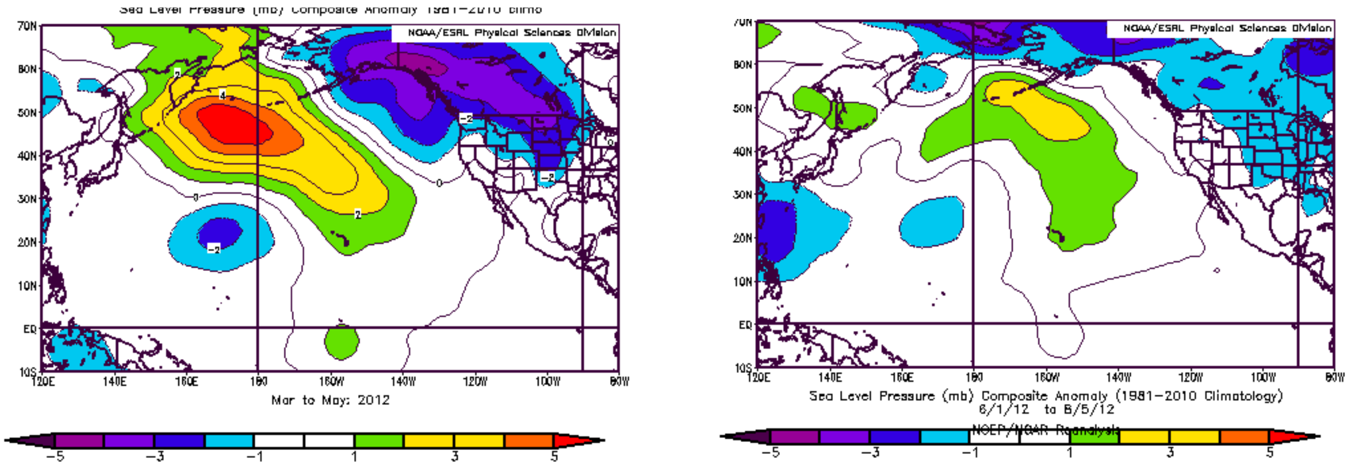


(c) Spring (d) Summer

Figure 13: SST anomolies for autumn (September-November 2011), winter (December 2011 -February 2012), spring (March - May 2012), and summer (June - August 2012).



(a) Autumn (b) Winter



(c) Spring (d) Summer

Figure 14: SLP anomolies for autumn (September-November 2011), winter (December 2011 -February 2012), spring (March - May 2012), and summer (June - August 2011).

The pattern of anomalous SST during winter (Dec-Feb) of 2011-12 (Figure 13b) resembled its counterpart during the previous fall. There was some modest cooling, relative to seasonal norms, in the eastern Bering Sea, and continuation of La Niña in the tropical Pacific. The anomalous SLP during winter 2011-12 was dominated by a large high (¿6 mb) centered near 40°N, 140°W 14b). This anomaly was located well to the southeast of its usual location during La Niña. The anomalous SLP pattern shown in Figure 14b indicates anomalous westerlies in the mean for the Bering Sea and Gulf of Alaska and anomalous upwelling along the coast of California. This promotes the delivery of cold air of Siberian origin to the Bering Sea and Gulf of Alaska; the higher than normal pressure west of California meant suppressed storminess in the far eastern North Pacific and below normal precipitation for the western US.

The distribution of SST in spring (Mar-May) of 2012 (Figure 13c) indicates a continuation of colder than normal temperatures in Alaskan waters and anomalous warmth in the central North Pacific. There was a marked decline in La Nia in the tropical Pacific, with positive anomalies developing in the far eastern portion of the coast of South America. The concomitant SLP anomaly map (Figure 14c) indicates high pressure centered just south of the Aleutians, which is a more typical response to La Nña than was observed during the previous season. Anomalous low pressure extended from Alaska into western and central Canada. This set-up brought about an anomalous flow of cold air from the northwest across the Bering Sea and Gulf of Alaska, ultimately producing a cold and wet spring for the Pacific Northwest.

The pattern of anomalous SST in summer (Jun-Aug) 2012 (Figure 13d) featured the continued warming of the eastern tropical Pacific relative to seasonal norms. Negative anomalies persisted in a horseshoe pattern extending form the Bering Sea to the west coast of the US and curving back towards the southwest to the dateline. Warm water remained in the central North Pacific north of the Hawaiian Islands. This pattern represents a negative expression of the Pacific Decadal Oscillation (PDO), as further discussed below. The distribution of anomalous SLP (Figure 14d) included a band of positive anomalies stretching from the southeastern Bering Sea to the southeast into the central-eastern North Pacific. Relatively low pressure occurred from far eastern Siberia across Alaska across Canada. The gradients in the SLP anomalies, and hence anomalous winds, were weak in many regions, e.g., along the west coast of North America. This is typical for the summer season, when atmospheric circulation anomalies tend to be lower in amplitude compared to other times of the year.

Climate Indices

Contributed by N. Bond (UW/JISAO))
NOAA/PMEL, Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: nicholas.bond@noaa.gov
Last updated: August 2012

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 2002 through spring 2012 are plotted in Figure 15.

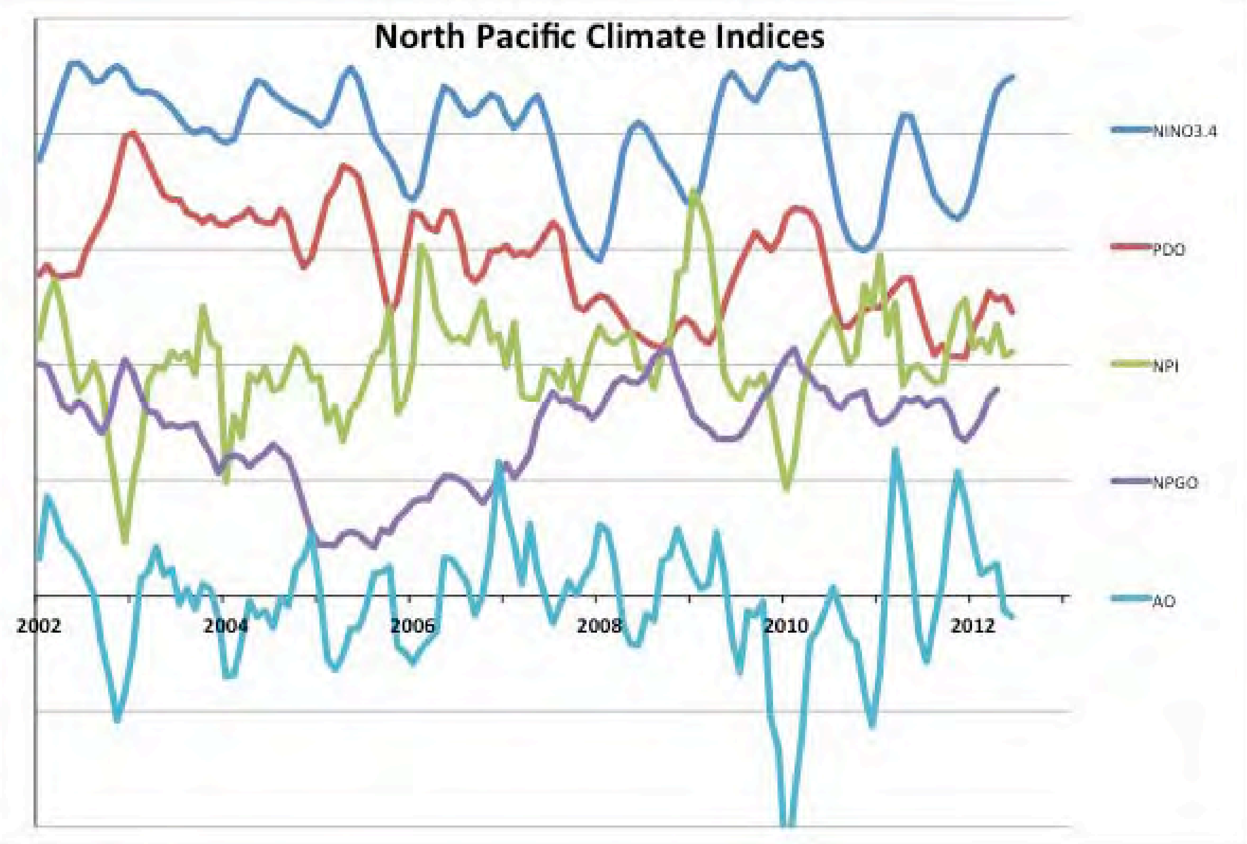


Figure 15: Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 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 state of the North Pacific atmosphere-ocean system reflected the influences of ENSO during 2011-12. The Aleutian Low tends to be weaker during La Niña winters, and while this was the case to an extent, the SLP anomalies during the past year (Fig. 2b) featured a positive anomaly center displaced to the southeast from its average location near 50°N, 160°W. Note that while ENSO is dominated by year-to-year variability it also varies on multi-year time scales. In particular, it was in a predominantly positive state from 2002 through 2005, and a negative state from late 2007 through early 2012, with La Niña present during four of the last five winters. As of summer 2012, recent warming in the tropical Pacific has transitioned ENSO into a positive state. The projections of the dynamical and statistical models used to forecast ENSO are discussed in the last section of this overview.

The PDO has manifested a largely downward trend since the winter of 2002-03. This reflects a multi-year shift from relatively warm to cool water in an arc extending from the Bering Sea through the Gulf of Alaska to along the west coast of North America, and SST anomalies of the opposite sign in the western and central North Pacific. There has been a return towards a more neutral state since late 2011, at least in part due to the influence of ENSO on the PDO through the formers impacts on the atmospheric circulation over the North Pacific. The potential predictability of the PDO appears to be largely associated with its connection to ENSO.

The NPI is a commonly used measure of the strength of the Aleutian Low. The prominence of its short-term variability can be attributed to the nature of the North Pacific atmospheric circulation, which undergoes substantial fluctuations on short time scales (days) as well as years to decades. Note the negative correspondence with the NINO3.4 index in general. That being said, the NPI had a rather muted response to ENSO during the past La Niña.

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 Gulf of Alaska and the southern portion of the California Current (Di Lorenzo et al., 2008). It has been in a positive state since 2007, which projects on stronger than normal flows in both the Alaska Current portion of the Subarctic Gyre and the California Current. It has been suggested that the NPGO may influence ENSO through its association with the strength of the trade winds in the sub-tropical eastern Pacific, but the mechanisms behind this potential linkage are poorly understood.

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. During periods of positive AO, cold air outbreaks to mid-latitudes are suppressed. The AO had a record negative value during the winter of 2009-10; it was also strongly negative during the early portion of the winter of 2010-11. The overall sense of the AO was positive during the winter of 2011-12 and since has been in a near neutral state. There are no reliable forecast tools at present for seasonal prediction of the AO, but there is some tendency for it to be in a negative state during El Niño.

Seasonal Projections from the National Centers for Environmental Prediction (NCEP)

Contributed by N. Bond (UW/JISAO)
NOAA/PMEL, Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: nicholas.bond@noaa.gov
Last updated: August 2012

Description of index: Seasonal projections from the NCEP coupled atmosphere-ocean forecast system model (CFS) for SST are shown in Figure 16.

Status and trends: These projections of 3-month average anomalies indicate systematic declines in the magnitudes of the cold anomalies in the northeastern and southeastern portions of the basin, and of the warm anomaly centered near 40°N and the dateline. Changes of this nature imply a transition to a near neutral state for the PDO and are consistent with the changes in SST anomalies that have occurred during previous El Niños. Note that for the tropical Pacific itself, that the CFS is predicting some increase in the intensity of the warm anomalies, i.e., the development of a weak-moderate El Niño over the remainder of 2012. A slow decrease in the amplitude of El Niño is forecast during late winter 2013. The CFS is also forecasting a stronger than normal Aleutian Low, that is, negative SLP anomalies, for the winter of 2012-13 (not shown). The scenario described here resembles that of three years ago. A moderate El Niño developed over the summer and fall of 2009

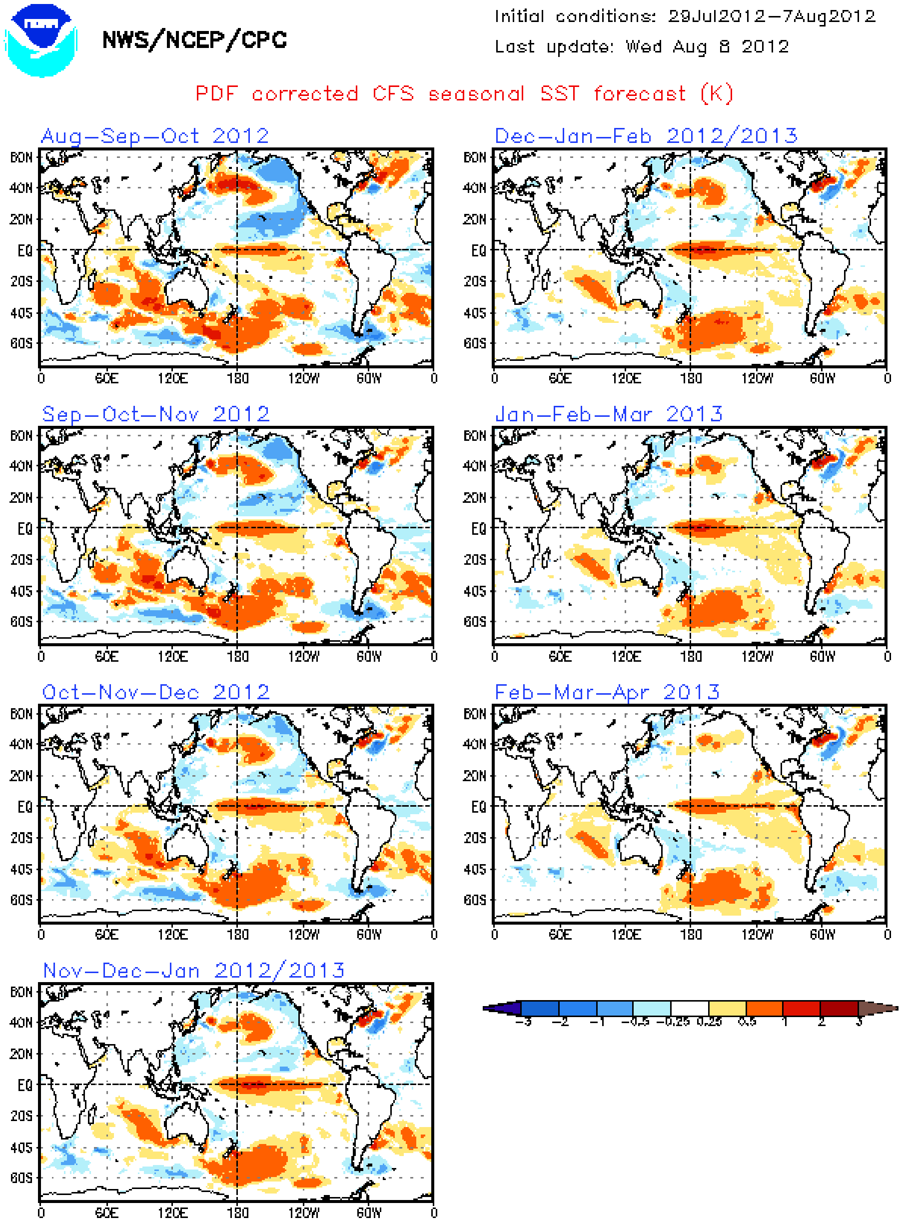


Figure 16: Seasonal forecast of SST anomalies from the NCEP coupled forecast system model for August 2012 through April 2013.

after the back-to-back La Niñas of 2007-08 and 2008-09; the presently developing El Niño event is occurring with similar precursor conditions. The CFS forecasts for late 2009 through summer 2010 were reasonably accurate; there is the expectation that the present CFS forecasts will also have value. The CFS predictions for El Niño are supported by the consensus of the predictions from a variety of dynamical and statistical approaches used by modeling centers towards forecasting ENSO.

Implications Based on not just the SST predictions shown in Figure 16, but also other forecast fields, it is likely that there will be a warming of Alaskan waters over the next 2-3 seasons, relative to the mostly cooler than normal temperatures that have prevailed over the last 5 years.

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)
Contact: james.e.overland@noaa.gov
Last updated: expected August 2012

Summary. *After the unusual sequence six years of warm winter-spring temperatures (2000-2005), four years of cold temperatures (2007-2010)and a cool summer in 2011, winter-spring 2012 returned to continue the cold sequence with a vengeance. The January-June near surface air temperature anomalies in the southeastern Bering Sea were -3^{o}C, and the individual anomaly in January was -8^{o}C and that for March was -6^{o}C. Cold temperatures related to sea level pressures being particularly low in the Gulf of Alaska; thus the cold temperatures were associated more with the location of Pacific Ocean-wide meteorological conditions than processes directly over the Bering Sea. Summer had near normal conditions. Bering Sea ocean temperatures remained cold and sea ice remained extensive, similar to 2008 and 2010. The cold pool for summer 2012 had the most extensive area of the recent decade.*

Air temperatures and sea level pressure. Surface air temperatures are easily measured and provide an available long term measure of the state of the climate. Winter and spring surface air temperatures in 2012 on St. Paul Island returned to the sequence of cold years after the neutral winter-spring conditions in 2011 (Figure 17). Winter and spring during 2012 was colder than normal in all months, centered in the SE Bering Sea (Figure 18), while the northern Bering Sea is part a continued Arctic warming that has lasted a decade. Air temperature anomalies for the individual months of January were -8 C and that for March was -6 C. Sea level pressure (SLP) in winter-spring 2012 over the greater North Pacific (Figure 19) shows a low pressure in the Gulf of Alaska, the signature of meteorological conditions that promote northeast winds over the Bering Sea and cold anomalies in the southeastern region (Overland et al. 2012). Summer had near normal to slightly cool conditions (Figure 20).

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 2012, 2008 and 2010 (Figure 21) are close to record extents, not seen since the early 1970s, and contrast to the warm years of 2000-2005 (except 2002). Steady northeast winds throughout winter and spring 2012 contributed to the major extent which lasted into May.

Ocean temperatures. Along with cold air temperatures and extensive sea ice, ocean temperatures at the M2 mooring site were sharply lower in winter 2012 similar to 2006 through winter 2010 compared with 2000-2005 (Figure 22). The cold pool (Figure 23), 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 for summer 2012 was again prominent and represented the most extensive area in the sequence of recent cold years.

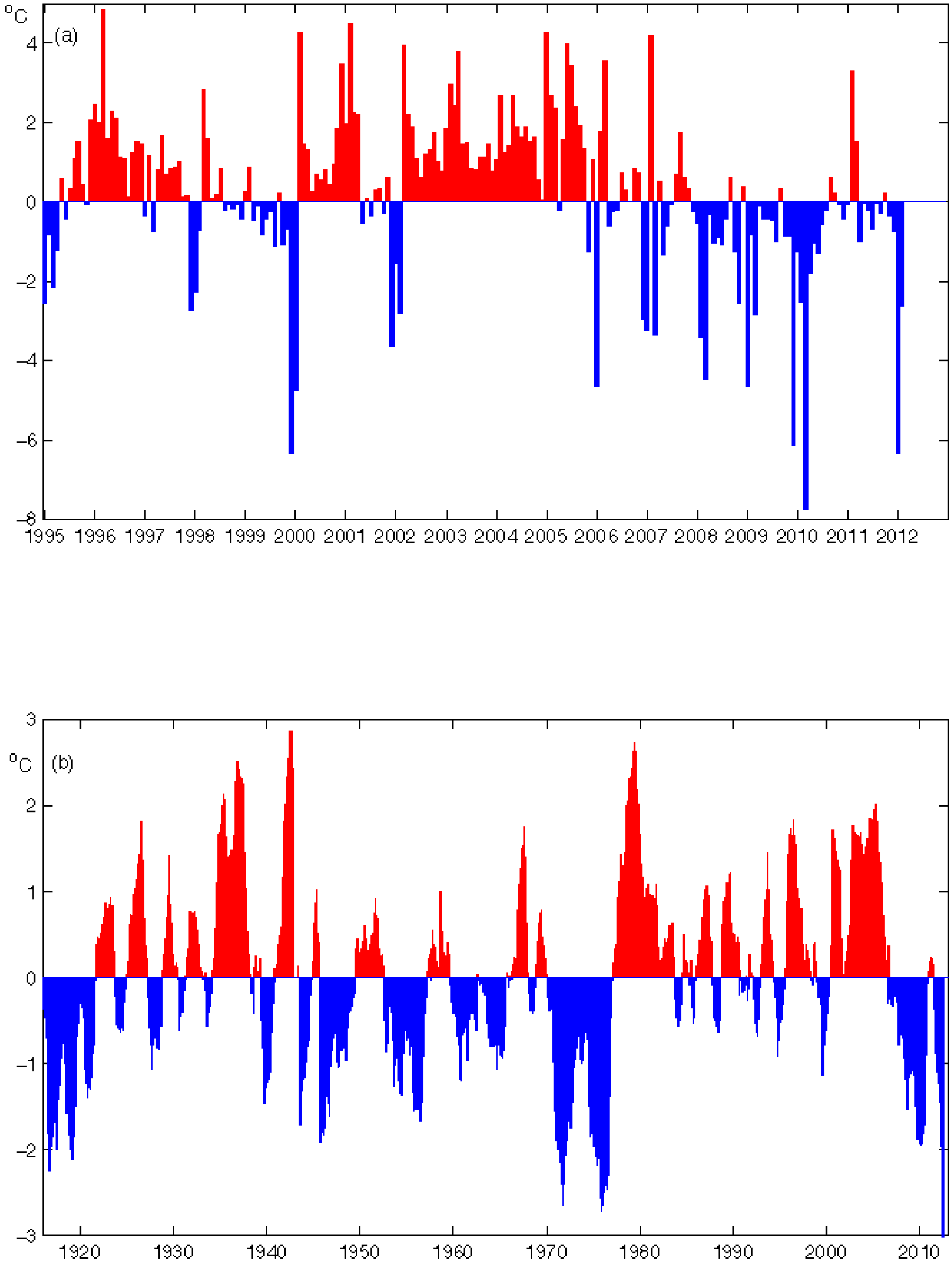


Figure 17: Mean monthly surface air temperatures anomalies in St. Paul, Pribilof Islands, a) unsmoothed, January 1995 through April 2012, and b) smoothed by 13-month running averages, January 1916 through April 2012. The base period for calculating anomalies is 1961-2000.

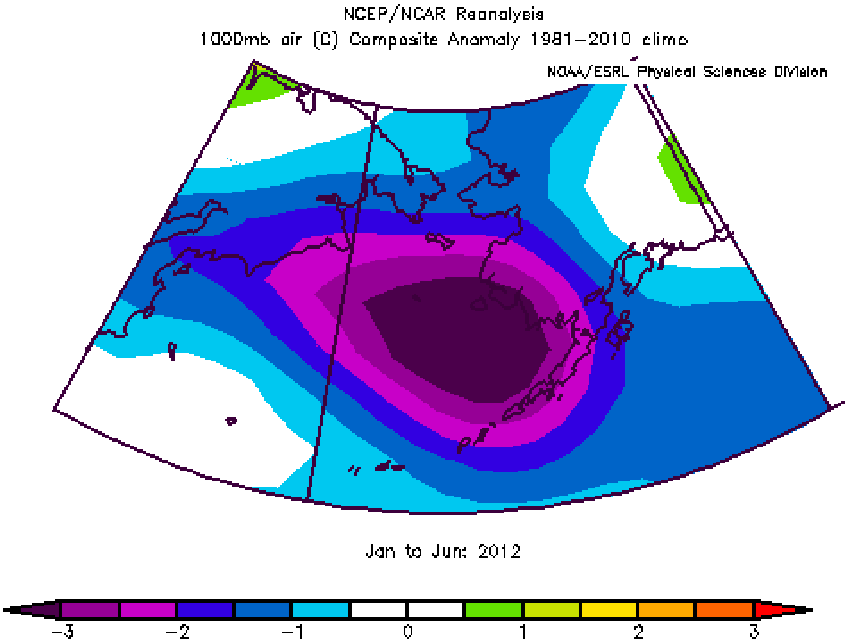


Figure 18: Surface air temperature anomaly over the greater Bering Sea region for Winter-Spring 2012. All individual months resemble the composite.

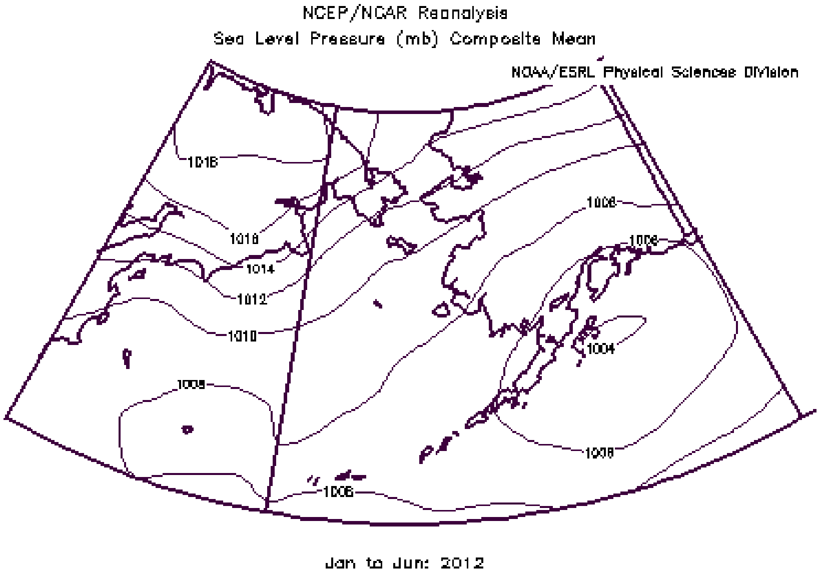


Figure 19: Sea level pressure (SLP) for January through June 2012. Note the center of the Aleutian low is centered in the Gulf of Alaska, east of its climatological location.

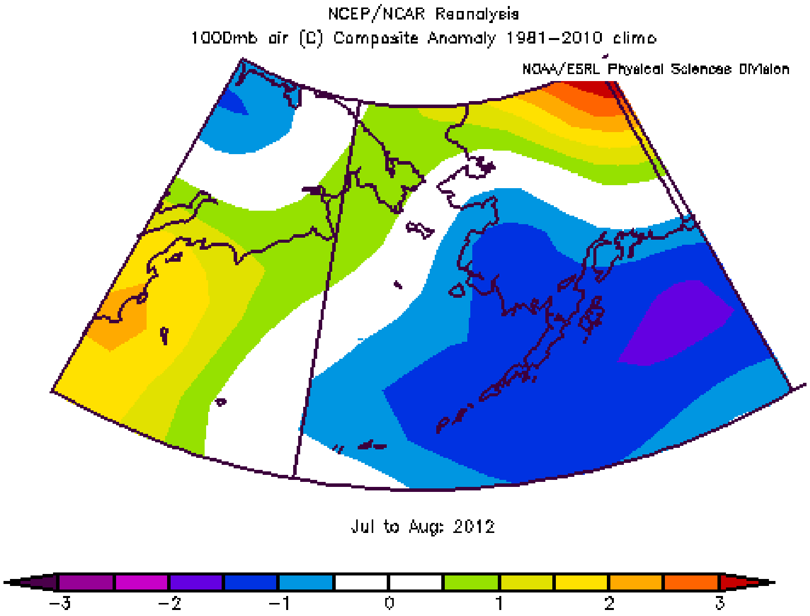


Figure 20: Surface air temperature anomaly over the greater Bering Sea region for July-August 2012.

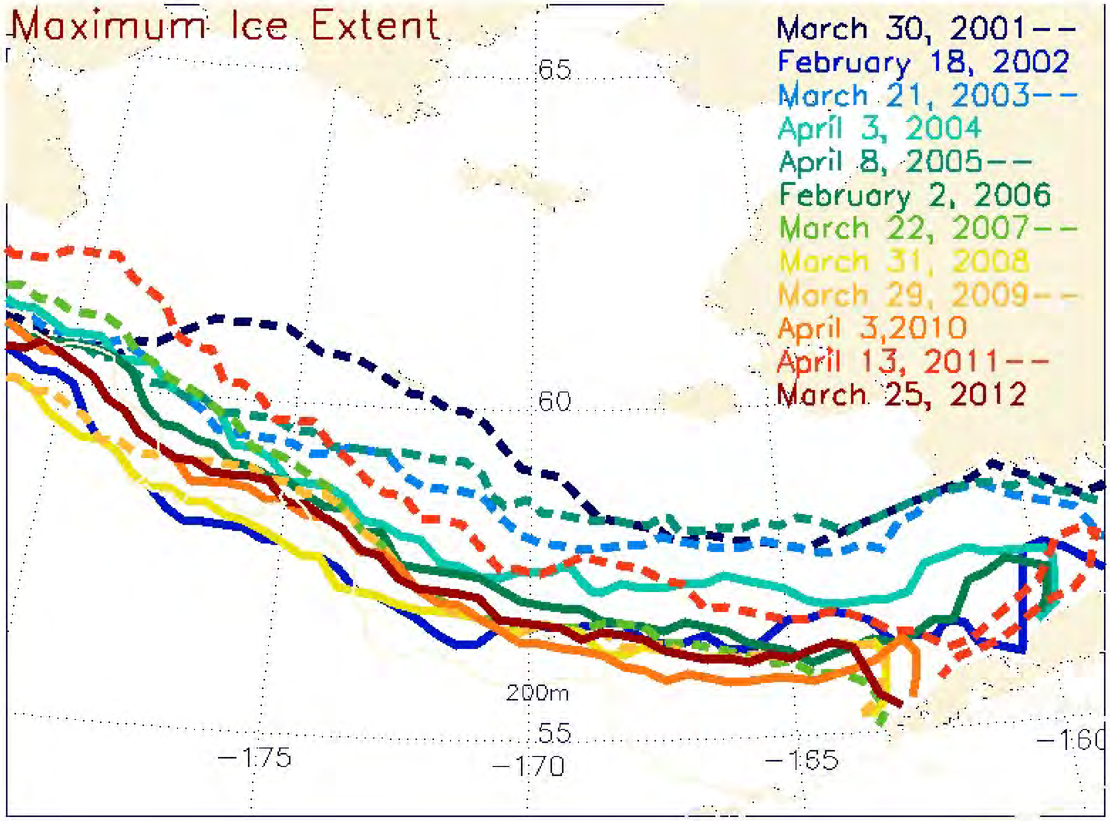


Figure 21: Recent springtime ice extents in the Bering Sea. Ice extent in 2006 through 2010 exceed the minimums of the early 2000s (except for 2002).

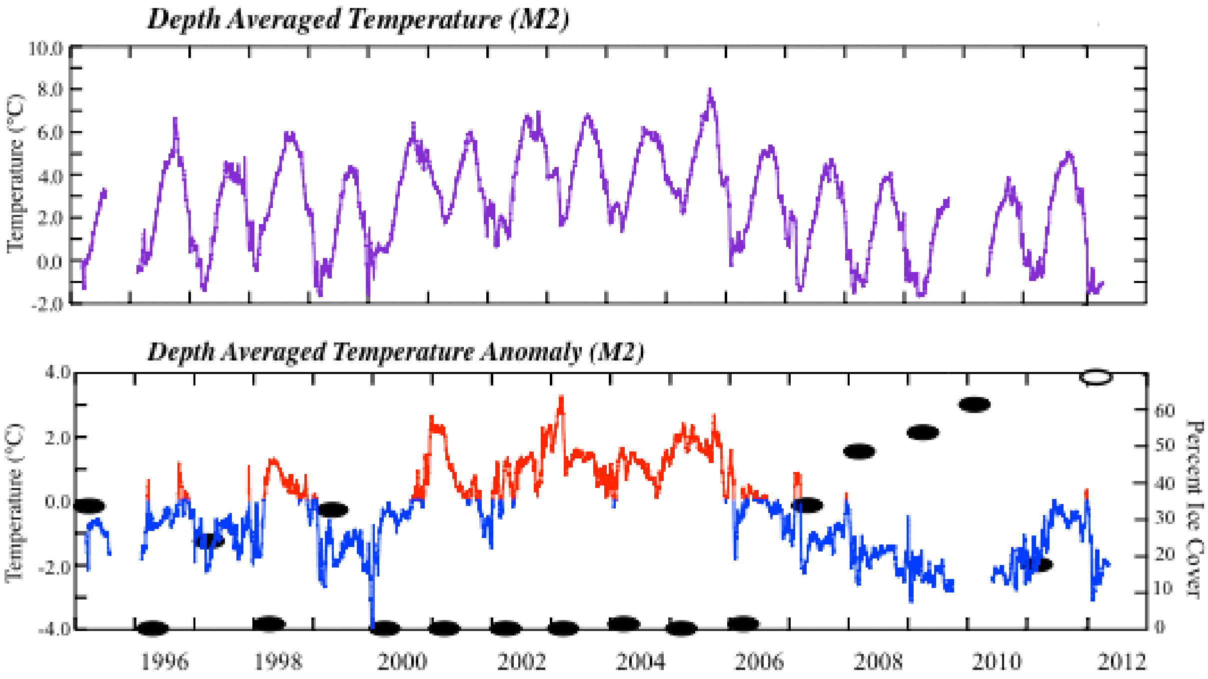


Figure 22: Depth averaged temperatures and temperature anomalies measured at Mooring 2, 1995-2012 in the southeast Bering Sea (C). Ellipses show the amount of sea ice in the vicinity of M2 during March and April.

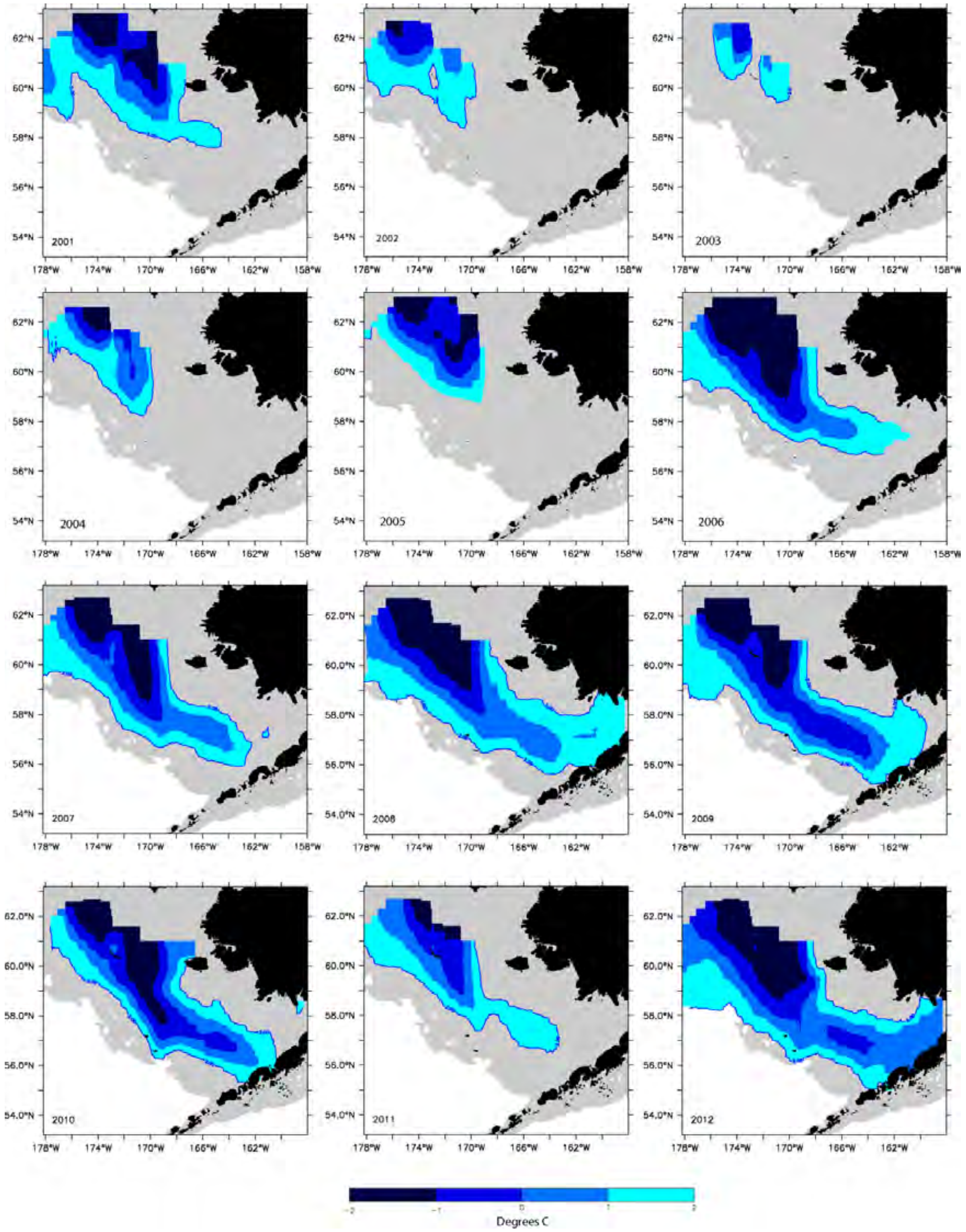


Figure 23: Cold Pool locations in southeast Bering Sea from 2001 to 2012. The year 2012 has the maximum southeastward extent of the cold pool of the decade.

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
Contact: jerry.hoff@noaa.gov
Last updated: October 2011

Description of index: The annual AFSC bottom trawl survey for 2012 started on 29 May and finished on 6 August.

Status and trends: The average surface temperature, 4.8°C, was slightly lower than 2011 (5.0°C) and still much lower than the long-term mean of 6.3°C (Figure 24). The average bottom temperature in 2012 was 1.0°C which was much colder than 2011 (2.4C) and lower than the grand mean from 1982 to 2012 of 2.3°C. The 'cold pool', usually defined as an area with temperatures <2°C, extended down the middle shelf to the Alaska Peninsula and into Bristol Bay similar to other years when bottom temperatures were below the grand mean (Figure 23).

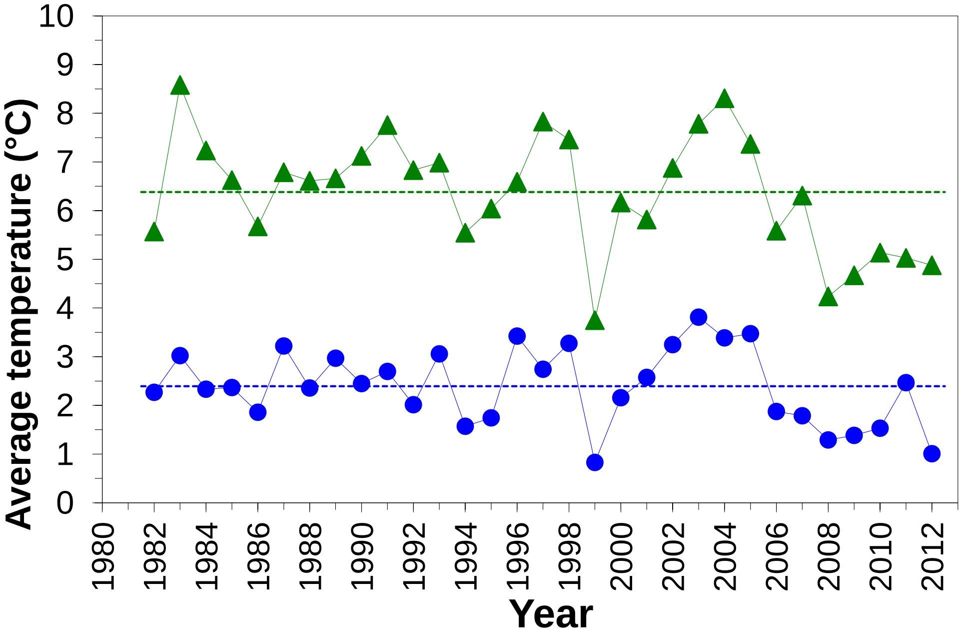


Figure 24: Average summer surface (open circles) and bottom temperatures (solid circles) (°C) of the eastern Bering Sea shelf collected during the standard bottom trawl surveys from 1982-2011. Survey water temperatures for each year were weighted by the proportion of their assigned stratum area.

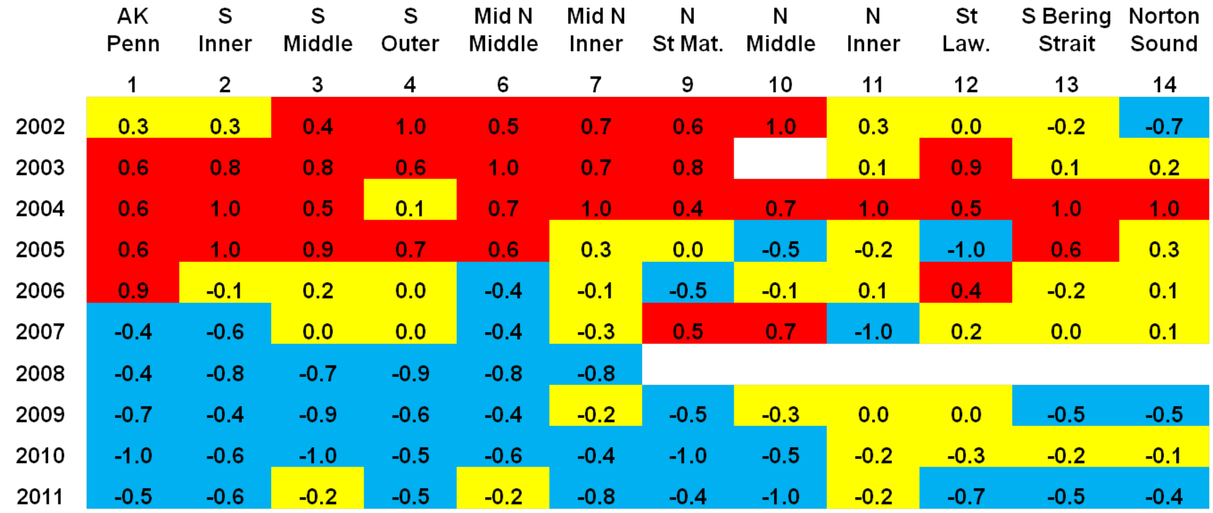
Factors influencing observed trends: Warm and cold years are the result of interannual variability in the extent, timing, and retreat of sea ice in the EBS shelf. During cold years, sea ice extent is further south and sea ice retreat occurs later.

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).

Variations in Temperature and Salinity During Late Summer/Fall 2002-2011 in the Eastern Bering Sea - BASIS

Contributed by Lisa Eisner, Kristen Cieciel, and Jeanette Gann, Auke Bay Laboratory, National Marine Fisheries Service, NOAA
Contact: lisa.eisner@noaa.gov
Last updated: August 2012

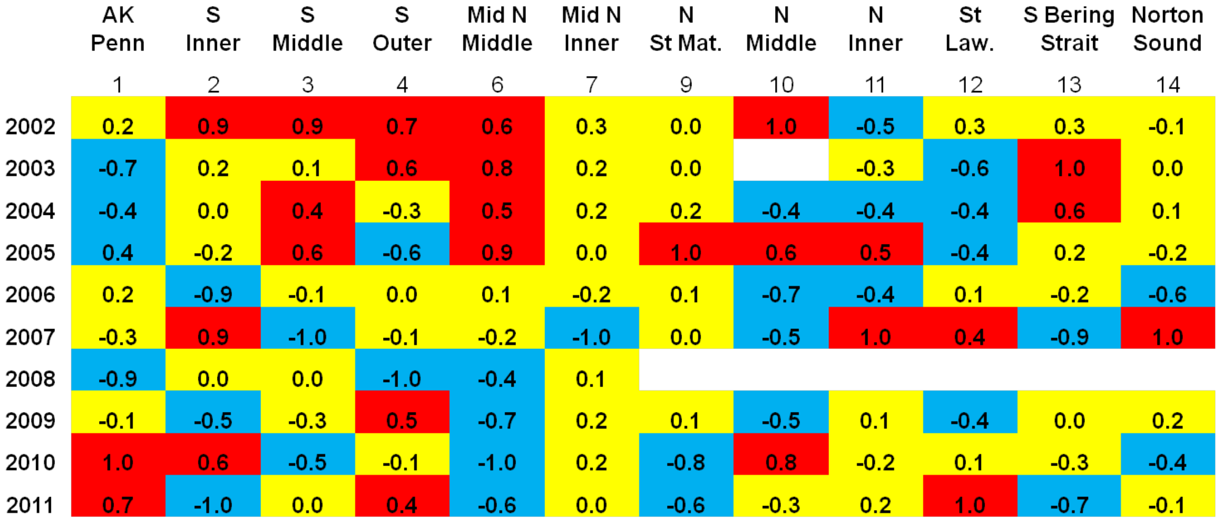
Description of index: Oceanographic and fisheries data have been collected across the eastern Bering Sea (EBS) shelf during fall 2002-2011 for a multiyear fisheries oceanography research program, Bering-Aleutian Salmon International Survey (BASIS). Stations were located between 54°N and 70°N, at 6̃0 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. Normalized anomalies of mean water column temperature (T) and salinity (S) were computed for 2002-2011 for regions defined by the Bering Sea Integrated Ecosystem Research Program (BSIERP, Ortiz et al. In review) (Figures 25, 26, 27). Contour maps of bottom temperatures for 2003-2010 and bottom salinities for 2003-2009 for the EBS are shown in Figures 28 and 29.



	AK Penn 1	S Inner 2	S Middle 3	S Outer 4	Mid N Middle 6	Mid N Inner 7	N St Mat. 9	N Middle 10	N Inner 11	St Law. 12	S Bering Strait 13	Norton Sound 14
2002	0.3	0.3	0.4	1.0	0.5	0.7	0.6	1.0	0.3	0.0	-0.2	-0.7
2003	0.6	0.8	0.8	0.6	1.0	0.7	0.8		0.1	0.9	0.1	0.2
2004	0.6	1.0	0.5	0.1	0.7	1.0	0.4	0.7	1.0	0.5	1.0	1.0
2005	0.6	1.0	0.9	0.7	0.6	0.3	0.0	-0.5	-0.2	-1.0	0.6	0.3
2006	0.9	-0.1	0.2	0.0	-0.4	-0.1	-0.5	-0.1	0.1	0.4	-0.2	0.1
2007	-0.4	-0.6	0.0	0.0	-0.4	-0.3	0.5	0.7	-1.0	0.2	0.0	0.1
2008	-0.4	-0.8	-0.7	-0.9	-0.8	-0.8						
2009	-0.7	-0.4	-0.9	-0.6	-0.4	-0.2	-0.5	-0.3	0.0	0.0	-0.5	-0.5
2010	-1.0	-0.6	-1.0	-0.5	-0.6	-0.4	-1.0	-0.5	-0.2	-0.3	-0.2	-0.1
2011	-0.5	-0.6	-0.2	-0.5	-0.2	-0.8	-0.4	-1.0	-0.2	-0.7	-0.5	-0.4

Figure 25: Water column temperature normalized anomalies (-1 to 1) by BSIERP region, BASIS data, mid Aug-Sept, 2022-2011. Red = anomalies 0.4 to 1 (highest temp.), yellow = -0.3 to 0.3, blue = -1 to -0.4.

Status and trends: Mean water column temperatures in the south Bering Sea (BSIERP regions 2, 3, 4 and 6) were warmer in 2002-2005 than in 2006-2011 (Figure 25). The northern Bering Sea regions (regions 9, 10, 11, 12) did not show consistent trends, but were generally warmer in 2002-2004 compared to later years. As described in the section, Summer Bottom and Surface Tem-



	AK Penn 1	S Inner 2	S Middle 3	S Outer 4	Mid N Middle 6	Mid N Inner 7	N St Mat. 9	N Middle 10	N Inner 11	St Law. 12	S Bering Strait 13	Norton Sound 14
2002	0.2	0.9	0.9	0.7	0.6	0.3	0.0	1.0	-0.5	0.3	0.3	-0.1
2003	-0.7	0.2	0.1	0.6	0.8	0.2	0.0		-0.3	-0.6	1.0	0.0
2004	-0.4	0.0	0.4	-0.3	0.5	0.2	0.2	-0.4	-0.4	-0.4	0.6	0.1
2005	0.4	-0.2	0.6	-0.6	0.9	0.0	1.0	0.6	0.5	-0.4	0.2	-0.2
2006	0.2	-0.9	-0.1	0.0	0.1	-0.2	0.1	-0.7	-0.4	0.1	-0.2	-0.6
2007	-0.3	0.9	-1.0	-0.1	-0.2	-1.0	0.0	-0.5	1.0	0.4	-0.9	1.0
2008	-0.9	0.0	0.0	-1.0	-0.4	0.1						
2009	-0.1	-0.5	-0.3	0.5	-0.7	0.2	0.1	-0.5	0.1	-0.4	0.0	0.2
2010	1.0	0.6	-0.5	-0.1	-1.0	0.2	-0.8	0.8	-0.2	0.1	-0.3	-0.4
2011	0.7	-1.0	0.0	0.4	-0.6	0.0	-0.6	-0.3	0.2	1.0	-0.7	-0.1

Figure 26: Water column salinity normalized anomalies (-1 to 1) by BSIERP region, BASIS data, mid Aug-Sept, 2022-2011. Red = anomalies 0.4 to 1 (highest salinity), yellow = -0.3 to 0.3, blue = -1 to -0.4.

peratures - Eastern Bering Sea, the location of the cold pool (<2°C), extended further southward as the climate cooled (Figure 28) and was seen in similar locations as the June-July bottom trawl surveys. Mean water column salinities in the south Bering Sea middle domain (regions 3 and 6) were higher in warm years (2002-2005) than in cold years (2006-2011) with greatest differences observed in region 6, near mooring M4 (Figure 26). Spatial plots of bottom salinity also show the decreasing salinity from warm to cold years (2003 to 2009) in the area near M4 (Figure 29). In the northern Bering Sea regions and other southern regions, salinity showed interannual variations, with no apparent trends between warm and cold years (Figure 26).

Factors influencing observed trends: Sea ice during winter and spring extended further to the south as the climate cooled (see section, Eastern Bering Sea Climate - FOCI, p.). The cold pool, results from deep cold water formed during ice melt, and thus extends further to the south in years with higher sea ice coverage in the southern Bering Sea. The cold pool is always present in the north Bering Sea since ice covers this region each year. The lower bottom salinities near the coast (Figure 27) indicate major freshwater input from the Yukon and Kuskoquim rivers. Variations in salinity 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.

Implications: The variations of temperature and salinity between BSIERP regions indicate that water mass properties vary considerably both spatially 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 middle domain (Coyle et al., 2011).

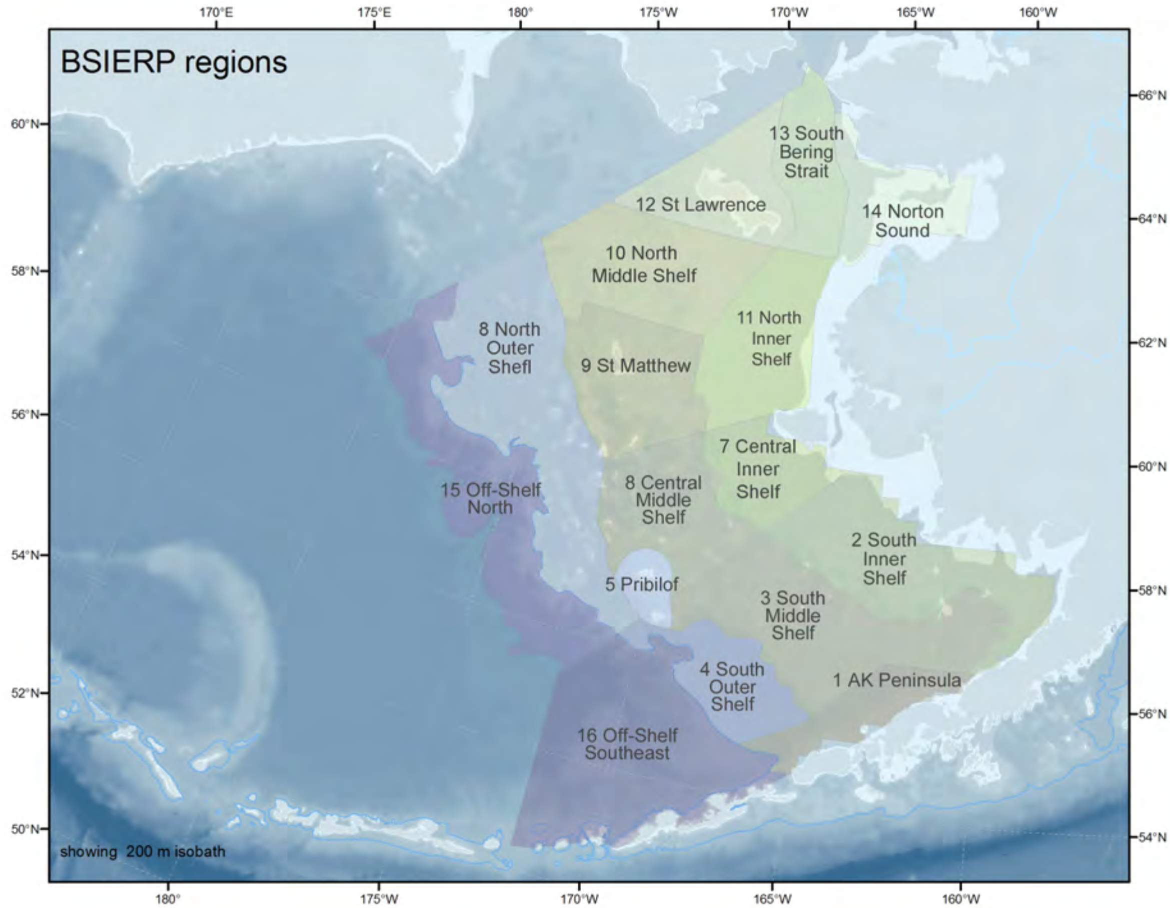


Figure 27: Map of Bering Sea Integrated Ecosystem Research Program (BSIERP) regions 1-16 (Ortiz et al. In review).

Aleutian Islands

Eddies in the Aleutian Islands - FOCI

Contributed by Carol Ladd, NOAA/PMEL
Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: carol.ladd@noaa.gov
Last updated: July 2012

Description of index: 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

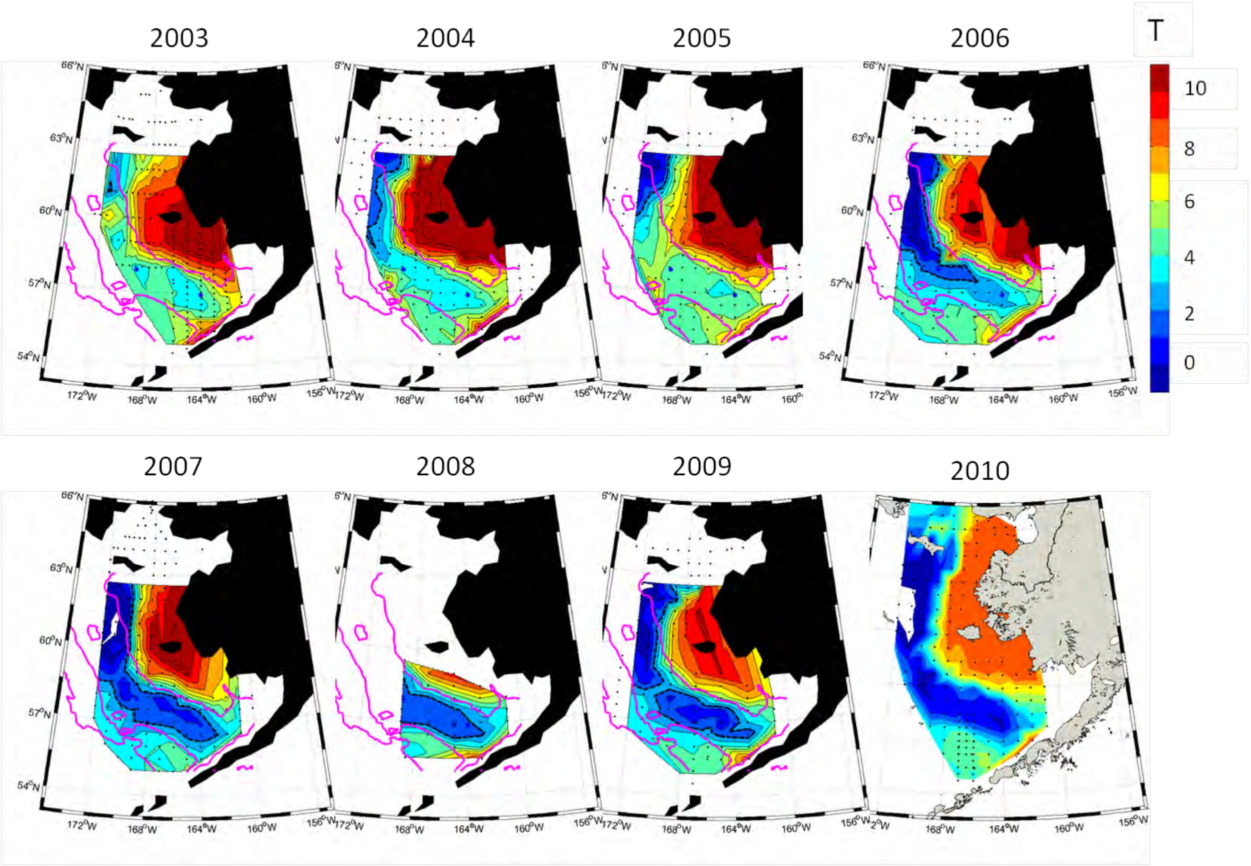


Figure 28: Contours of bottom temperature for mid-Aug to Sept, 2003-2010. Black dots are station locations.

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 30) 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 31) 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).

Status and trends: Particularly strong eddies were observed south of Amukta Pass in 1997/1998, 1999, 2004, 2006/2007, 2009/2010, and summer 2012. Eddy energy in the region was low from the spring of 2010 through early 2012, but recent data shows the existence of an eddy in the region beginning in late April 2012.

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

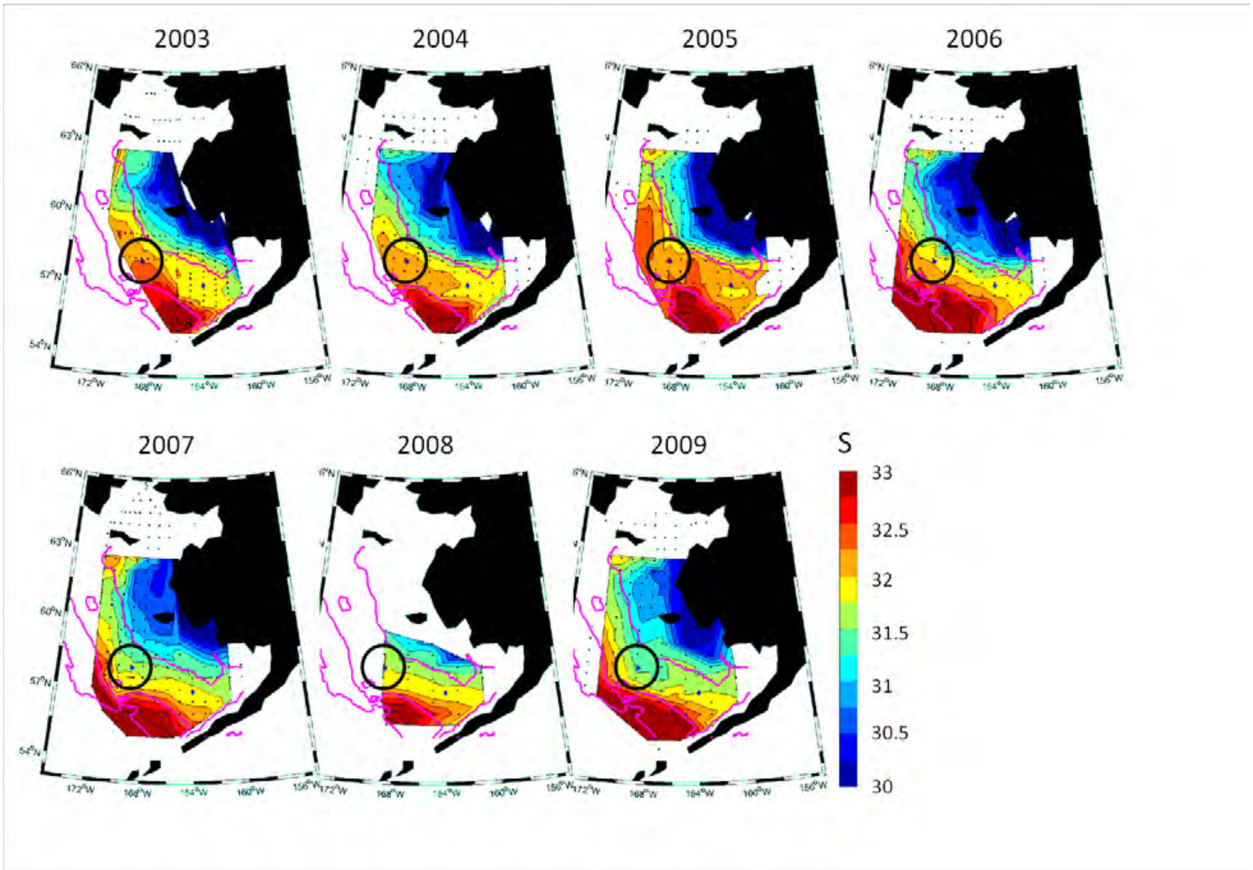


Figure 29: Contours of bottom salinity for mid-Aug to Sept, 2003-2009. Black dots are station locations. Circle shows location of mooring M4.

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 2012

Description of index: The oceanography of the Aleutian Islands is shaped in large part by three major currents running along the archipelago and strong tidal forces in the passes between islands (Hunt and Stabeno, 2005). The Alaska Coastal Current (Schumacher et al., 1989; Reed, 1987) flows westward along the south side of the Aleutians from the Gulf of Alaska to Samalga Pass. The Alaskan Current also flows westward along the southern shelf break of the Aleutians to Amchitka Pass where some of the water flows northward to serve as the source water for the Aleutian North Slope Current. The remainder of the Alaskan Current continues westward in a series of meanders and eddies to bathe the western Aleutians. The Alaska Coastal Current is warmer and fresher than the Alaskan Current and these differences contribute greatly to the chemical and physical properties of the water flowing through the passes of the Aleutian Islands. The Aleutian North Slope Current flows eastward along the north side of the Aleutians from Amchitka Pass.

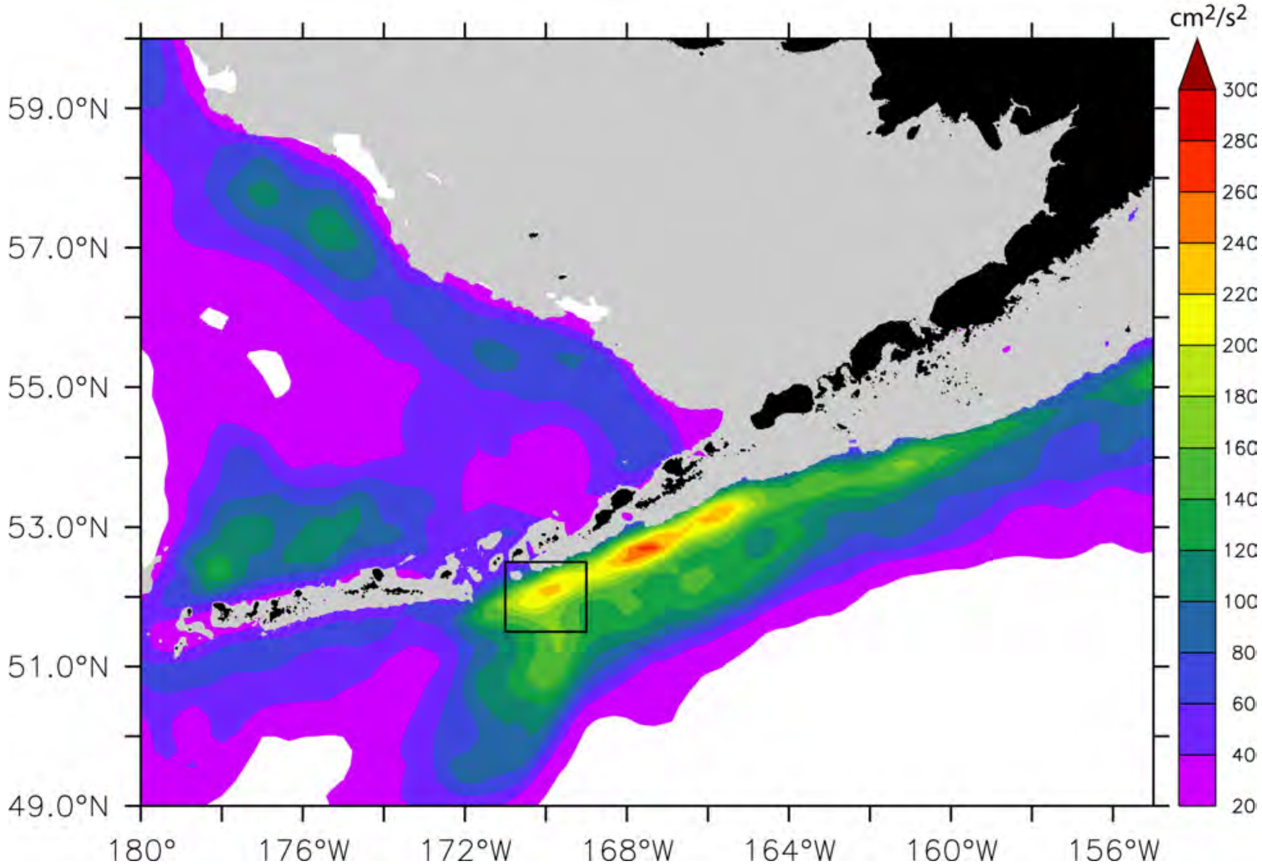


Figure 30: Eddy Kinetic Energy averaged over October 1993 - October 2011 calculated from satellite altimetry. Square denotes region over which EKE was averaged for Figure 31.

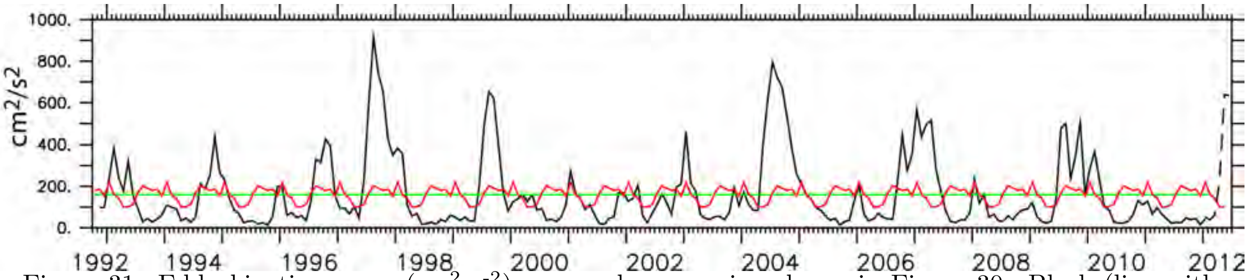


Figure 31: Eddy kinetic energy (cm^2 s^{-2}) averaged over region shown in Figure 30. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product). Red: seasonal cycle. Green (straight line): mean over entire time series.

Water temperature data have been routinely collected on NMFS survey bottom trawl hauls since 1994 using micro-bathythermographs attached to the headrope of the trawl. Prior to that, temperature data were routinely collected near trawl haul sites using expendable bathythermographs, although these earlier data were not used in this analysis. Groundfish assessment survey periods have ranged from early May to late September and sampling has usually progressed from east to west, but notable exceptions exist especially for the earliest three surveys involving Japanese vessels (1980, 1983, and 1986) and for the 2002 and 2006 surveys. These differences in sampling patterns in time and space complicate inter-annual comparison due to the strong relationship between date of collection and water temperature at all depths throughout the survey area.

Water temperature data during trawl descent (the period between when the doors were dropped until the center of the footrope touched the bottom) were used to estimate water temperatures at depth. Average Water temperature was estimated at each of several depths from 3 meters to the deepest depth of each tow. Depth increments were much finer at shallower depths to capture the rapid changes in water temperatures often seen in these depths. In order to account for the seasonal differences in water temperatures and make inter-annual comparisons more meaningful, an attempt was made to remove the effect of date of collection on water temperature, in effect standardizing temperatures to an approximate median date (July 10) for most AI surveys. This was achieved by using generalized additive modeling techniques to model the effects of date on temperature at each depth interval. The model was then used to estimate the temperature at the standard date (July 10) at the same depth and the residuals of the original model were added to the prediction for the final estimate. The estimated temperatures were binned into ½ degree longitude by depth increments and mean temperature in each increment was calculated.

Status and Trends: Some common features are notable for all years, including warmer surface temperatures east of Amukta Pass (170 ° 30' W), between Seguam Pass (173° W) and Amchitka Pass (179° W) and west of Buldir Pass (175° E)(Figure 32)). The influence of these warmer surface temperatures generally extends to about 100 m, although in the warmest years it can reach 200 m. Cooler temperatures at depths greater than 100 m appear consistently around Seguam Island (172° 30' W), and this seems to be a particularly striking feature in colder than average years (e.g., 2000). Cooler temperatures at depths greater than 100 m are frequently a predominant feature west of 175° E, although in cooler years this area of cooler water extends as far east as Amchitka Pass.

Water temperatures have varied considerably during the eight survey years reported with 2012 producing some of the coldest temperatures of the series. The pattern of cooler temperatures observed in 2012 was similar to that observed in 2000 which had previously been considered the coldest year in the series. During the 2000 survey, cooler surface temperatures were observed throughout the survey area and waters deeper than 100 m were dominated by colder water in the western Aleutians, particularly west of 180°. In addition to the cooler surface waters recorded in 2012, the thermocline was shallower than in previous years and cooler temperatures in waters deeper than 100 m were not limited to the waters west of Amchitka Pass but extended across the entire survey area. In retrospect, Aleutian Island waters were warmer in 1997 than in any other year in the time series both at the surface and at deeper depths. Temperatures in 2004 were also quite warm with a similar temperature pattern to 1997, although deeper waters in the extreme western Aleutians were cooler than in 1997.

Factors causing the trend: The data presented here show a snapshot of water temperatures collected during bottom trawl surveys in the Aleutian Islands. 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 phenomena such as storm events, tidal current velocity and/or direction and eddies.

Implications: The strength and persistence of eddies is believed to play a major role in mediating the transport of both heat and nutrients into the Bering Sea through the Aleutian passes (Maslowski et al., 2008). This phenomenon likely has large impacts on both the Aleutian Islands and the Bering

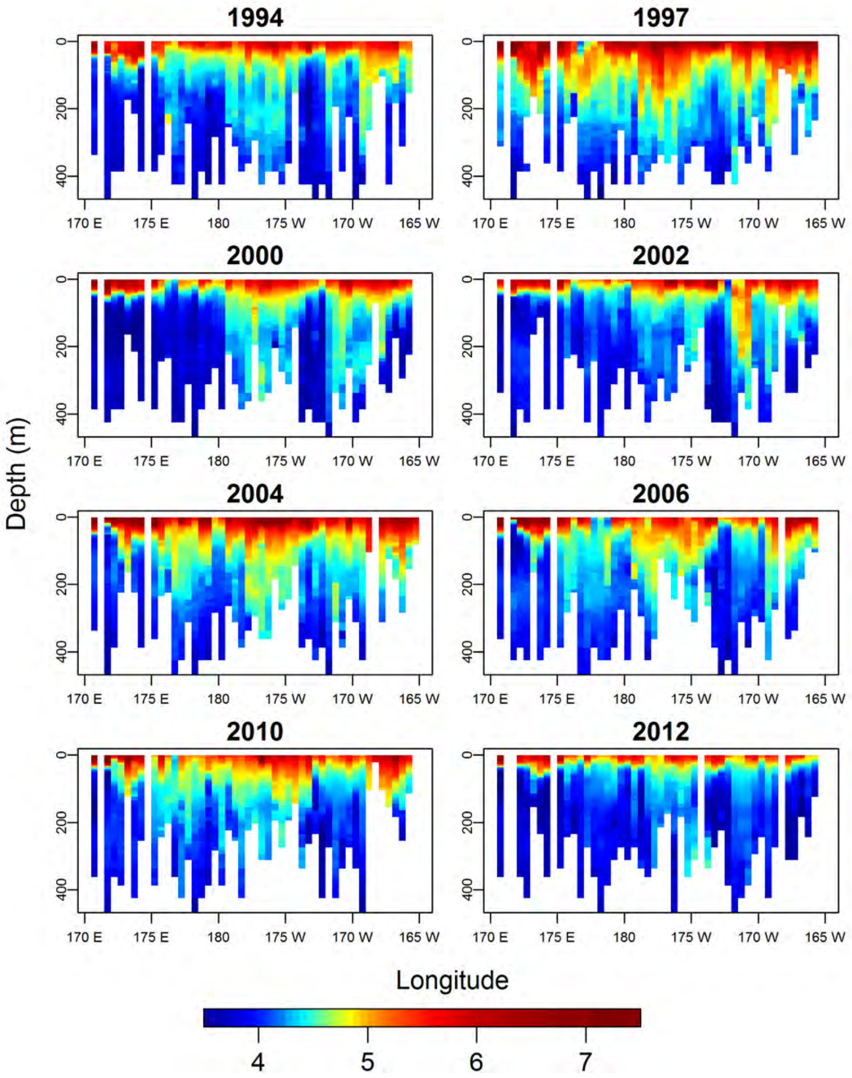


Figure 32: Date adjusted temperature profiles by ½ degree longitude intervals for years 1994-2012.

Sea ecosystems. The cool temperatures of 2012 may have influenced the low abundance estimates of some species such as Atka mackerel and walleye pollock.

Gulf of Alaska

Eddies in the Gulf of Alaska - FOCI

Contributed by Carol Ladd, NOAA/PMEL
Building 3, 7600 Sand Point Way NE, Seattle, WA 98115-6349
Contact: carol.ladd@noaa.gov
Last updated: July 2012

Description of index: Eddies in the northern Gulf of Alaska have been shown to influence distributions of nutrients (Ladd et al., 2009, 2005, 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 occur more often after 1997 than in the period from 1993 to 1997. Ladd (2007) extended that analysis and found that, in the region near Kodiak Island, eddy energy in the years 2002-2004 was the highest in the altimetry record (1993-2006).

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 (merged TOPEX/Poseidon, ERS-1/2, Jason and Envisat; (Ducet et al., 2000). A map of eddy kinetic energy in the Gulf of Alaska averaged over the altimetry record (updated from Ladd (2007)) shows four regions with local maxima (labeled a, b, c and d in Figure 33). 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 33). By averaging EKE over regions c and d (see boxes in Figure 33), we obtain an index of energy associated with eddies in these regions (Figure 34).

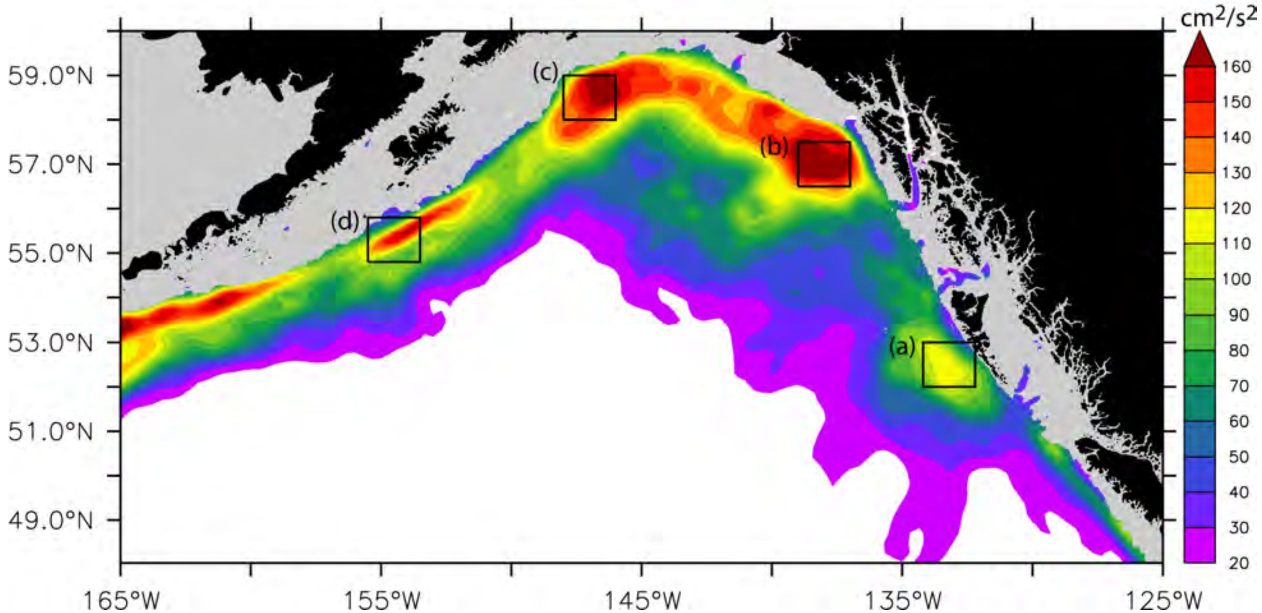


Figure 33: Eddy Kinetic Energy averaged over October 1993-October 2011 calculated from satellite altimetry. Regions (c) and (d) denote regions over which EKE was averaged for Figure 34.

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 and 2012. The summer 2012 EKE is calculated from near-real-time altimetry data which has lower quality than the delayed time data and may be revised. EKE

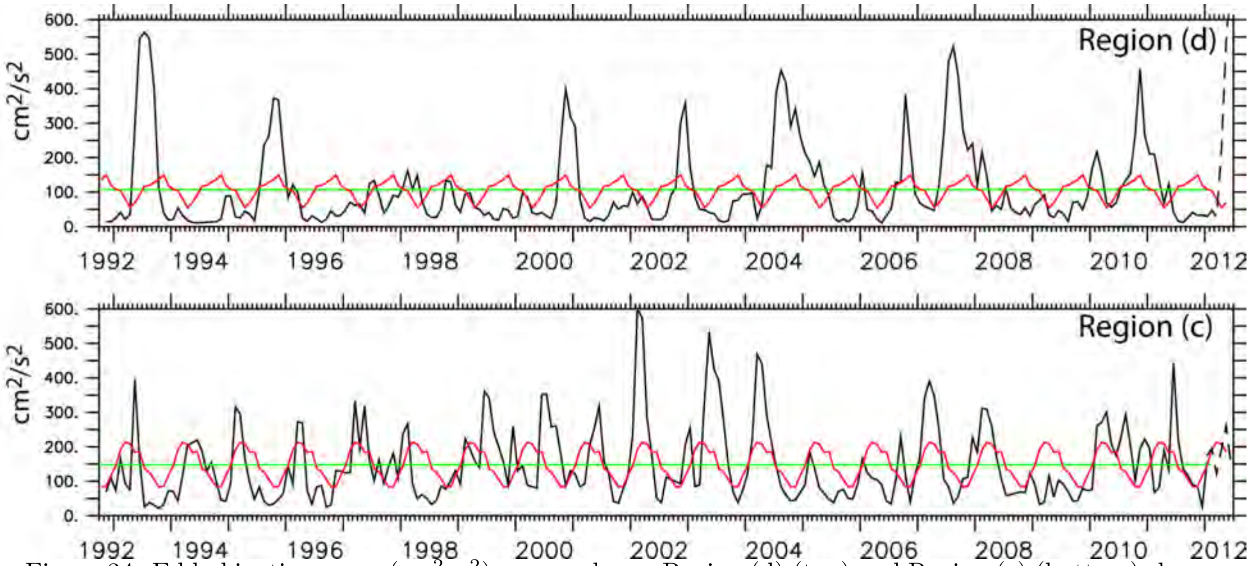


Figure 34: Eddy kinetic energy (cm^2 s^{-2}) averaged over Region (d) (top) and Region (c) (bottom) shown in Figure 33. Black (line with highest variability): monthly EKE (dashed part of line is from near-real-time altimetry product which is less accurate than the delayed altimetry product), Red: seasonal cycle. Green (straight line): mean over entire time series.

was approximately average in region (c) for the first six months of 2012.

Factors causing observed trends: In the eastern Gulf of Alaska, interannual changes in surface winds (related to the Pacific Decadal Oscillation and El Niño) modulate the development of eddies (Combes and Di Lorenzo 2007). In the western Gulf of Alaska, variability is related both to the propagation of eddies from their formation regions in the east and to intrinsic variability.

Implications: EKE may have implications for the ecosystem. Phytoplankton biomass was probably more tightly confined to the shelf during 2009 due to the absence of eddies, while in 2007, 2010 and 2012 (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, and 2012 (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). The altimeter products were produced by the CLS Space Oceanography Division (AVISO, 2012).

Ocean Surface Currents - Papa Trajectory Index

Contributed by William T. Stockhausen and W. James Ingraham, Jr. (Retired)
Resource Ecology and Fishery Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: william.stockhausen@noaa.gov
Last updated: August 2012

Description of index: 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 35). 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 2011.

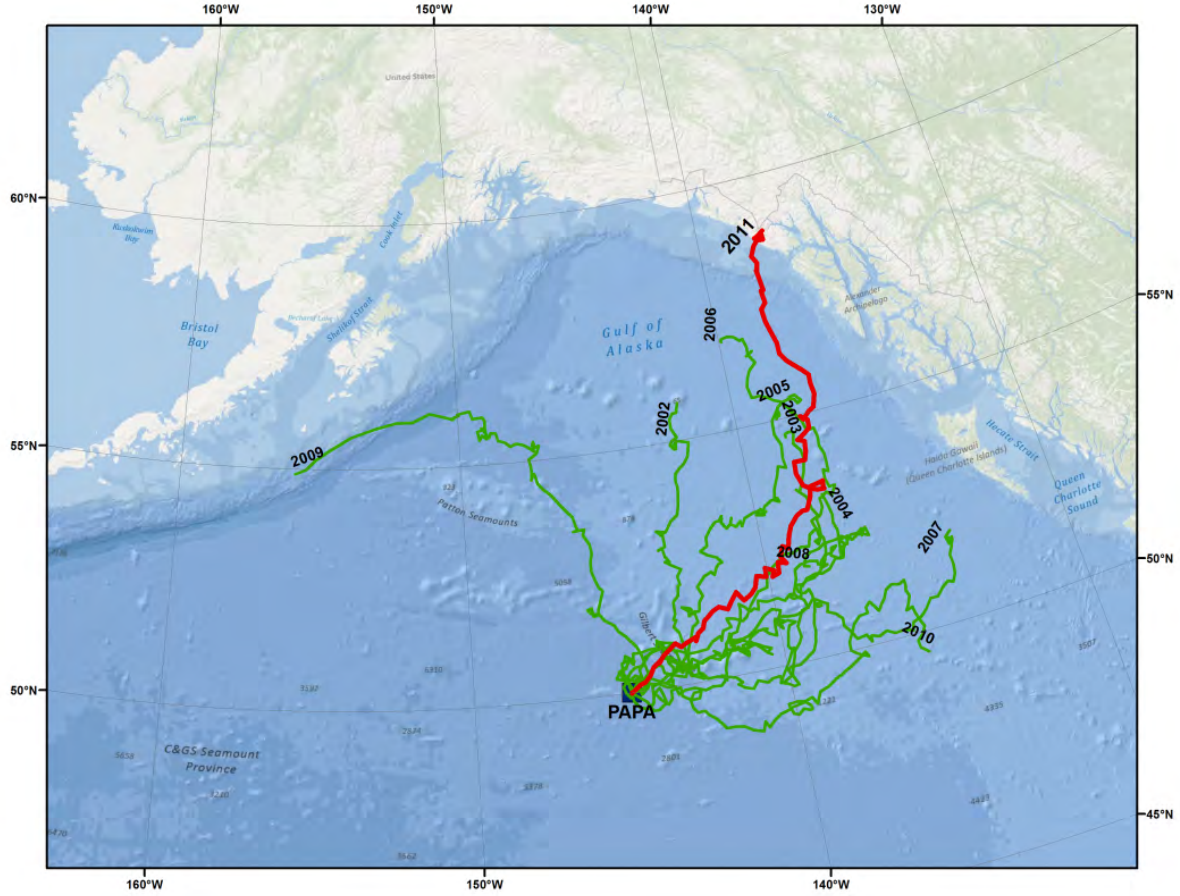


Figure 35: Simulated surface drifter trajectories for winters 2002-2012. End points of 90-day trajectories for simulated surface drifters released on Dec. 1 at Ocean Weather Station PAPA are labelled with the year of the release (50°N, 145°W).

Status and trends: In general, the trajectories fan out northeastwardly toward the North American continent (Figure 35). The 2009/2010 trajectory was an exception and resulted in the westernmost trajectory endpoint for the entire set of model runs (1902-2012). This trajectoy is, however, consistent with the atmospheric conditions that existed during the winter of 2009-2010 (N. Bond, 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 PTI time series (Figure 36), 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 2010/2011 and 2011/2012 was the largest since 1994. However, such swings are not uncommon over the entire time series.

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 36), 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. This indicates a return to conditions (at least in terms of surface drift) similar to those prior to the 1977 environmental regime shift.

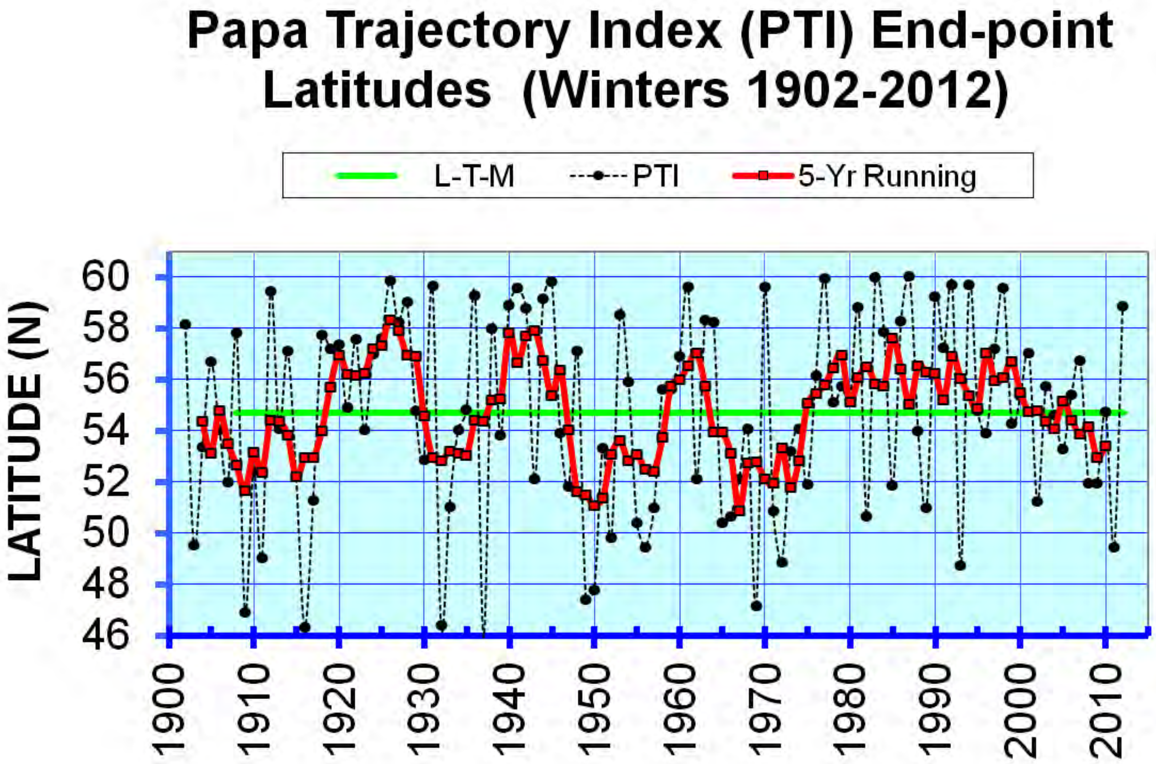


Figure 36: Annual, long-term mean (green line) and 5-year running mean (red line and squares) of the PAPA Trajectory Index time-series (dotted black line and points) for 1902-2012.

Factors causing 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.

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 (*Theragra 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 substantially larger than the mean for 2011-12, its current (5-year averaged) trend remains consistent with a return to conditions associated with the preceding "cold" regime. It may thus be a harbinger of a decadal-scale reduction in regional productivity.

Gulf of Alaska Survey Bottom Temperature Analysis

Contributed by Michael Martin, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: Michael.Martin@noaa.gov
Last updated: October 2011

Gulf of Alaska surveys are conducted in alternate even years. For most recent data, see the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Habitat

Area Disturbed by Trawl Fishing Gear in the Eastern Bering Sea

Contributed by Angie Greig, Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: angie.greig@noaa.gov
Last updated: July 2012

Description of index: 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 1990-2011. 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 37a). 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 37b).

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 decrease in 2009-2010. 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 Observed 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 38).

As of 1999 only pelagic trawls can be used in the Bering Sea pollock fisheries. To check to see if

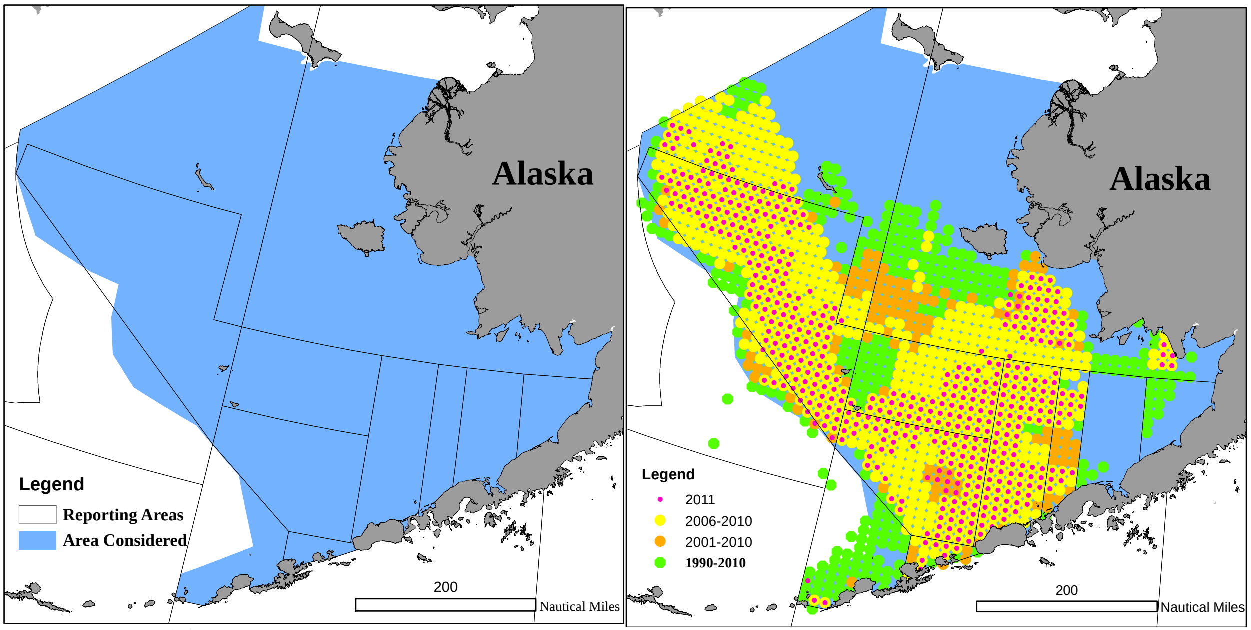


Figure 37: (a) Map of Eastern Bering Sea area considered when estimating percent area potentially disturbed by trawl fishing gear. (b) Map of 400 square kilometer cells with some trawling in cumulative time periods. Cells with fewer than 3 vessels are not shown

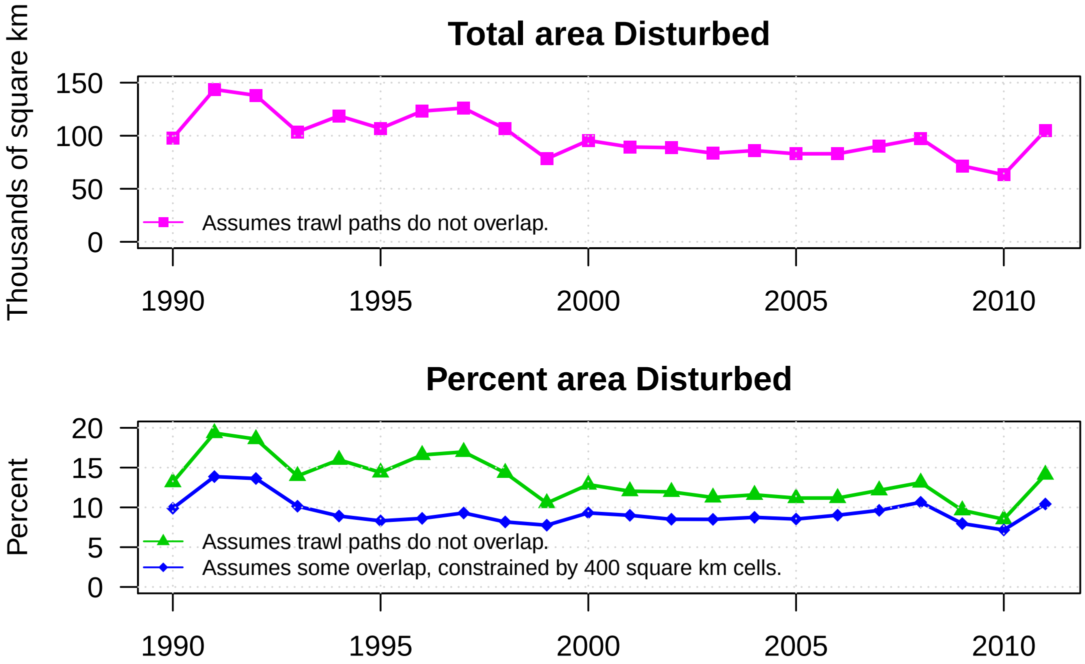


Figure 38: Total maximum potential area disturbed (assuming no spatial overlap of trawls), and the percent area disturbed. The green line, representing percent area disturbed, sums the area disturbed assuming no spatial overlap of trawl hauls in a year, thus providing an upper limit to the estimate of area disturbed. The 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.

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 structural epifauna biota in the areas fished, and management changes that result in spatial changes in fishing effort.

Structural Epifauna - Bering Sea

Contributed by Robert Lauth and Gerald Hoff, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: jerry.hoff@noaa.gov
Last updated: October 2012

Description of index: 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 1982-2012. 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 39).

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 - Aleutian Islands

Contributed by Chris Rooper, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: chris.rooper@noaa.gov
Last updated: October 2012

Description of index: Structural epifauna groups considered to be Habitat Area of Particular

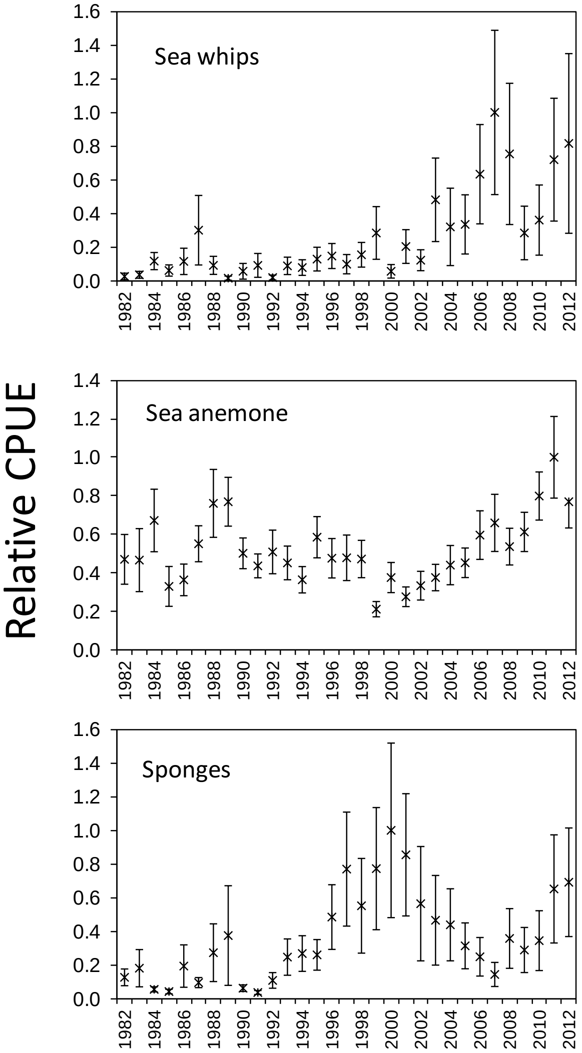


Figure 39: Relative CPUE trends of structural epifauna from the RACE bottom trawl survey of the eastern Bering Sea shelf, 1982-2012. Data points are shown with standard error bars.

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 Aleutian Islands (AI). For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (±) was weighted proportionally to the CPUE to get a relative standard error.

Status and trends: A few general patterns are clearly discernible (Figure 40). Sponges are caught in most tows in the Aleutians west of the southern Bering Sea. Interestingly, the frequency of occurrence of sponges in the southern Bering Sea is relatively high, but sponge abundance is much lower than other areas. The sponge estimates for the 1983 and 1986 surveys are much lower than other years, probably due to the use of different gear, including large tire gear that limited the catch of most sponges. Stony corals are commonly captured outside of the southern Bering Sea and their abundance appears to be highest in the central and eastern Aleutians. Soft corals are caught much less frequently and the survey likely does not provide a reliable estimate of soft coral abundance. Sea anemones are also common in survey catches but abundance trends are not clear for most areas. Sea pens are much more likely to be encountered in the southern Bering Sea and eastern AI than in areas further west. Abundance estimates are low across the survey area and large apparent increases in abundance, such as that seen in the eastern AI in 1997, are typically based on a single large catch. There was a decline in CPUE for sponges, stony corals, and anemones from the 2010 survey to the 2012 survey, but trends have been generally inconsistent or level since 2000 for most species and areas.

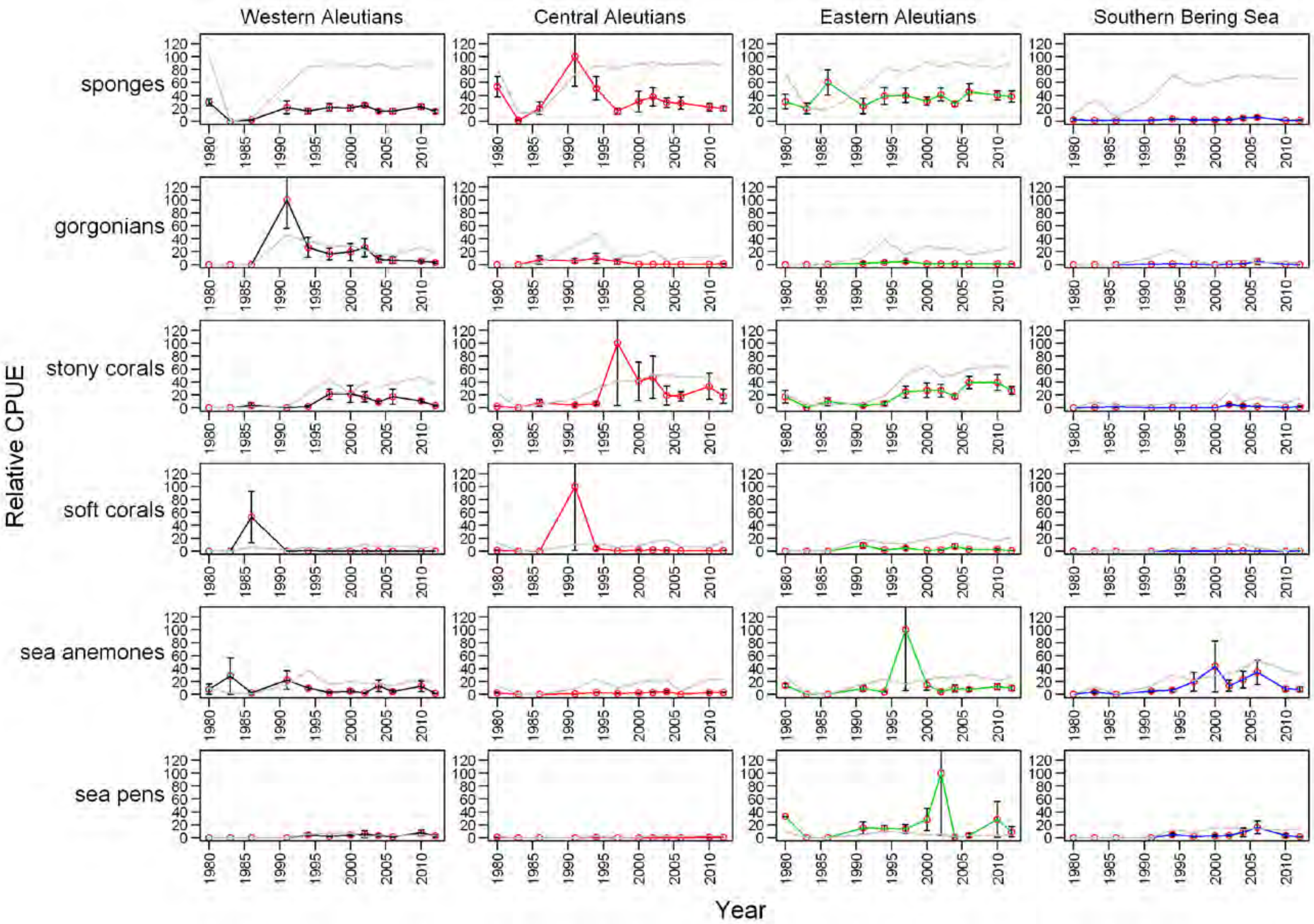


Figure 40: Mean CPUE of HAPC species groups by area from RACE bottom trawl surveys in the Aleutian Islands from 1980 through 2012. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches. The Western, Central, and Eastern Aleutians correspond to management areas 543, 542, and 541, respectively. The Southern Bering Sea corresponds to management areas 519 and 518.

Factors influencing observed trends: The 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 1991 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.

Structural Epifauna - Gulf of Alaska

Contributed by Michael Martin, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: Michael.Martin@noaa.gov
Last updated: October 2011

Gulf of Alaska surveys are conducted in alternate even years. For most recent data, see the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Nutrients and Productivity

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

Contributed by Lisa Eisner, Kristin Cieciel, Jeanette Gann
Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: lisa.eisner@noaa.gov
Last updated: August 2012

Description of index: BASIS conducted fisheries oceanography surveys in the eastern Bering Sea, mid-August to late September, for three warm (2003-2005) followed by six cold (2006-2011) years. Variations in chlorophyll a (chla) were used to evaluate spatial and interannual variations in total phytoplankton biomass and size structure (an indication of phytoplankton species). The percent large phytoplankton (>10 μm / total chla) were determined from discrete water samples collected with Niskin bottles and filtered through GFF and 10 μm filters. Integrated and mean chla values were estimated from CTD fluorescence profiles, calibrated with discrete chla samples. Chla data were averaged over the top 50 m of the water column or to the bottom for shallower stations. Water column stability was estimated over the top 70 m or to the bottom for shallower stations (Simpson et al., 1978). Wind speed cubed data were obtained from NCEP reanalysis (courtesy of Nick Bond). Spatial variations are shown for integrated chla, mean chla, ratio of large assemblages to total (>10

μm/total chla) and stability for 2003-2009 combined (Figure 41). Interannual variations in size structure are shown for the north and south Bering Sea Middle shelf (50-100 m station depths) (Figure 42). August wind speed cubed (u^{*3}), a measure of wind mixing, and mean chla over the top 50 m are shown for 2003 -2009 in the south Bering Sea Middle shelf (Figure 43). Anomalies of temperature, wind, stability, mean chla and size fraction ratios are shown for the south Bering Sea Middle shelf for summer to early fall 2003-2009, 2010 or 2011 (Table 3).

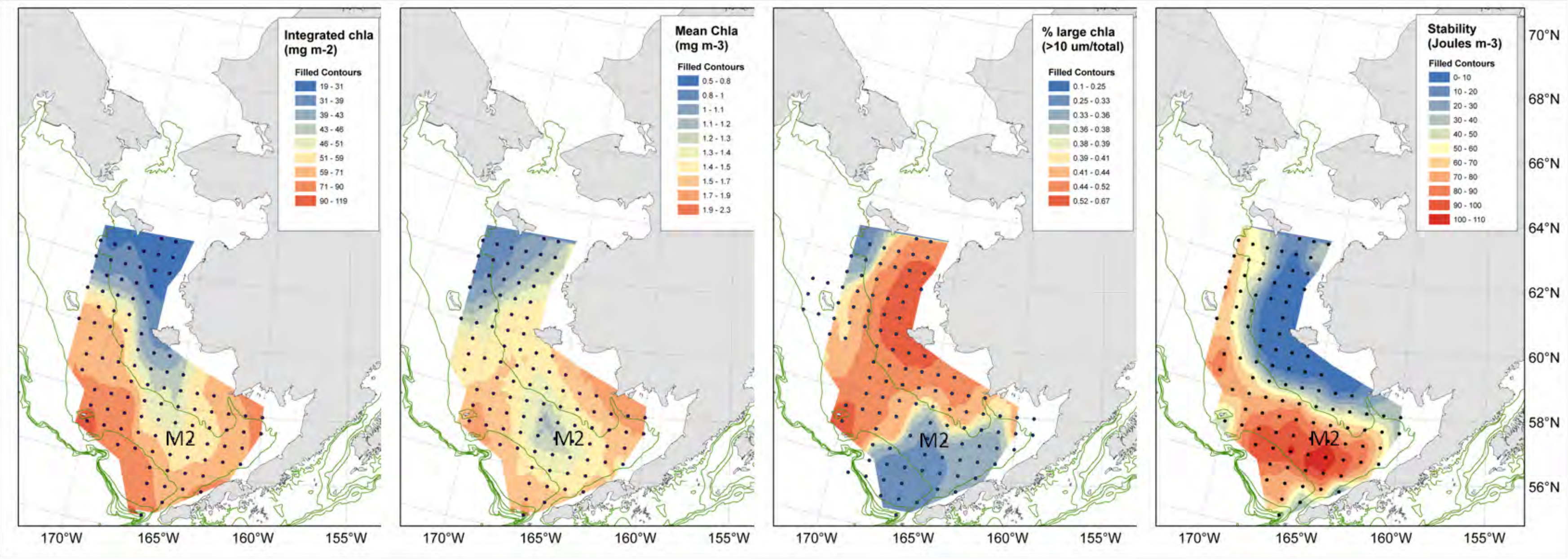


Figure 41: Spatial variations for integrated chla (mg m-2), mean chla (mg m-3), ratio of large assemblages to total (>10 μm /total chla) averaged over top 50 m, and stability (J m-3) averaged over top 70 m for 2003-2009 combined.

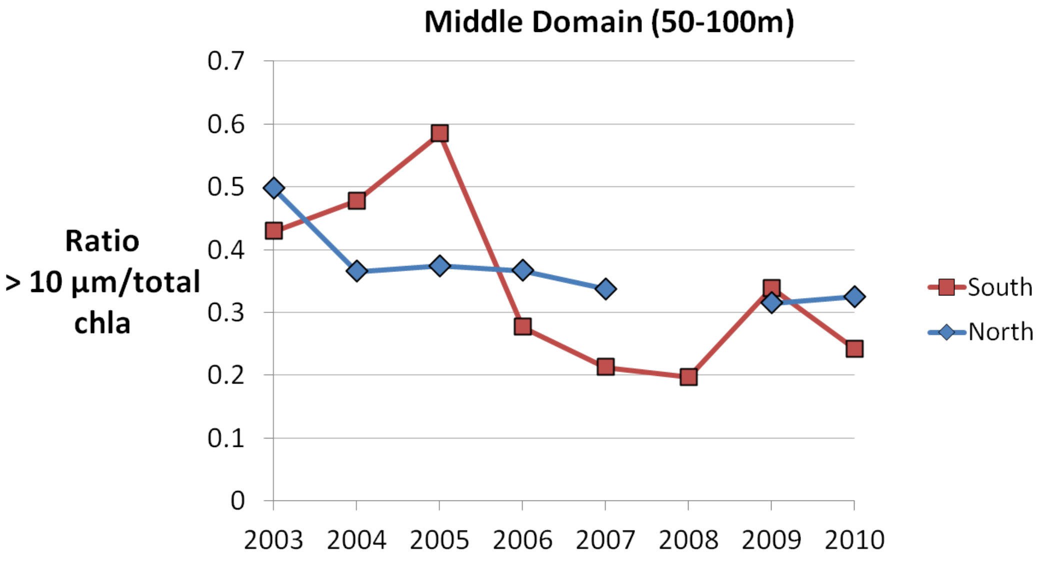


Figure 42: Ratio of large assemblages to total (>10 μm /total chla) in Middle Domain in the north (60 - 63°N) and south (54.5 - 59.5°N) Bering Sea for 2003-2010.

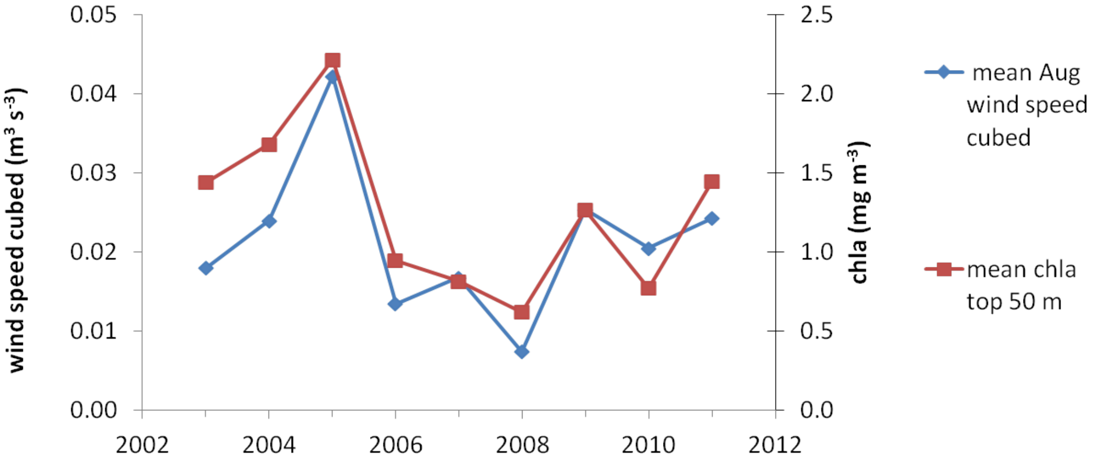


Figure 43: Interannual variations in mean August wind speed cubed (u^{*3}) at mooring M4 and mean chla over the top 50 m (Aug-Sept) for the south Bering Sea Middle shelf for 2003-2011.

Status and trends: Highest phytoplankton biomass was observed in the Outer shelf near the Pribilof Islands, and in the south Inner shelf. Lowest biomass was observed in the north Bering and SE Middle shelf (in a region of high stability). Larger phytoplankton were seen on the Inner shelf and near the Pribilofs. Smaller phytoplankton were seen on the SE Middle shelf (an area of lower total chla), and in the Outer shelf (an area of higher total chla). In the south Bering Sea, phytoplankton biomass and mean size of assemblages were higher in warm (03-05) than in cold (06-09) years on the Middle shelf. This trend was not observed in the north Bering Sea.

Factors influencing trends: Water column stability, wind and temperature may influence interannual and spatial variations in phytoplankton biomass. For the SE Middle shelf, a positive association was observed between August wind mixing and mean chla in the top 50 m (Figure

Table 3: Anomalies (calculated for 2003-2009, 2010, or 2011) for the south Bering Sea Middle shelf for mean water column T, stability over top 70 m, mean chla and ratio of large (>10 μm) to total chla over top 50 m (Aug-Sept) from BASIS data, and wind speed cubed (u^{*3}) near mooring M4 (Aug) from NCEP data. Positive indicates above average and negative below average values.

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Water column T	1	0.7	1	0	-0.2	-0.7	-0.7	-0.9	-0.2
Wind speed cubed	-0.2	0.1	1	-0.4	-0.2	-0.7	0.2	0	0.1
Stability	-0.7	-0.3	-0.2	-0.6	1	0.6	0.2		
Chla mean top 50 m	0.2	0.4	1	-0.3	-0.4	-0.6	0	-0.5	0.2
Large chla	0.4	0.6	1	-0.3	-0.6	-0.6	0	-0.4	

43).Deep nutrient-rich waters can be mixed to the surface to fuel production of large assemblages during periods of high winds and low water column stability. And phytoplankton growth may be enhanced at higher temperatures, depending on species. For example, the highest chla and largest size fractions were seen in 2005, during a period with high winds, average stability and high water column temperature (Table 3). While, the lowest chla and smallest size fractions were seen in 2008, during a period with low winds, high stability and low water column temperature. Spatially, low chla and small phytoplankton assemblages were seen in the area of highest stability, in the SE Middle shelf near mooring M2.

The greater variation in size structure in the south compared to the north may be related to the greater interannual variation in winter ice extent and subsequent effects on ecosystem dynamics in spring and summer (Stabeno et al., In press).

Implications: Phytoplankton dynamics determine the amount and quality of food available to zooplankton and higher trophic levels, and are thus important to ecosystem function. For example, larger phytoplankton assemblages may lead to shorter food webs and a more efficient transfer of energy to sea birds, fish and marine mammals. Data will be used to characterize interannual and spatial variation in primary production and ecosystem processes during the critical late summer/ fall period prior to the over-wintering of key forage fish (e.g. juvenile pollock, cod, salmon).

Trends in Surface Carbon Uptake by Phytoplankton During Late Summer to Early Fall in the Eastern Bering Sea

Contributed by Jeannette Gann, Lisa Eisner, and Kristin Cieciel
Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: jeanette.gann@noaa.gov
Last updated: August 2012

Description of index: Primary production experiments were carried out aboard ship during late summer/early fall as a means to help understand the flow of energy from plankton to fish. Autumn is a critical time for young forage fish to increase body mass for winter survival. Production experiments were performed during the Bering Aleutian Salmon International Surveys (BASIS) during August Sept, 2006-2011. Water samples were collected at surface (<10m, 50% light) depths, inoculated with $NaH^{13}CO^3$, covered with screen to simulate the 50% light level, and incubated in a polycarbonate tank at surface seawater temperatures for 6 daylight hours encompassing solar noon. Samples were then filtered through a GF/F filter and frozen at -80°C until analyzed for isotope ratios of $^{13}C/^{12}C$ by the University of Alaska Fairbanks stable isotope laboratory. Water samples were analyzed for chlorophyll a and inorganic nutrients at the same station and depth as the experimental stations.

Surface carbon (^{13}C) uptake rates (ug $L^{-1}h^{-1}$) by phytoplankton were normalized to chlorophyll a concentrations and compared across years (2006-2011, excluding 2008), oceanographic domains (inner 0-50 m, and middle 50-100 m), and North-South regions ($\leq$60°N$\geq$) using Kruskall Wallis non-parametric tests. Yearly comparisons in uptake of ^{13}C by phytoplankton were made only for the southeast Bering shelf (SEBS) due to insufficient data in the northeast Bering shelf (NEBS) during 2007.

Status and trends: Temporal trends in surface carbon uptake rates over the SEBS (inner and middle domains combined) remain relatively invariable from 2006-2011 with an exception during 2007, where median ^{13}C uptake rates decreased by a factor greater than 5 ($P = 0.008$) (Figure 44). The 2007 chlorophyll a surface concentrations, and silicate concentrations at the experimental stations were also significantly lower compared with other years ($P = 0.038$ and $P = 0.015$) (Figures 45 and 46). Inorganic nitrogen and phosphate levels did not vary significantly during the years studied. No significant differences were seen in uptake rates of carbon between north and south regions of the eastern Bering Sea during 2006-2011 ($P \geq 0.05$), nor were any significant differences seen between inner and middle oceanographic domains ($P \geq 0.05$).

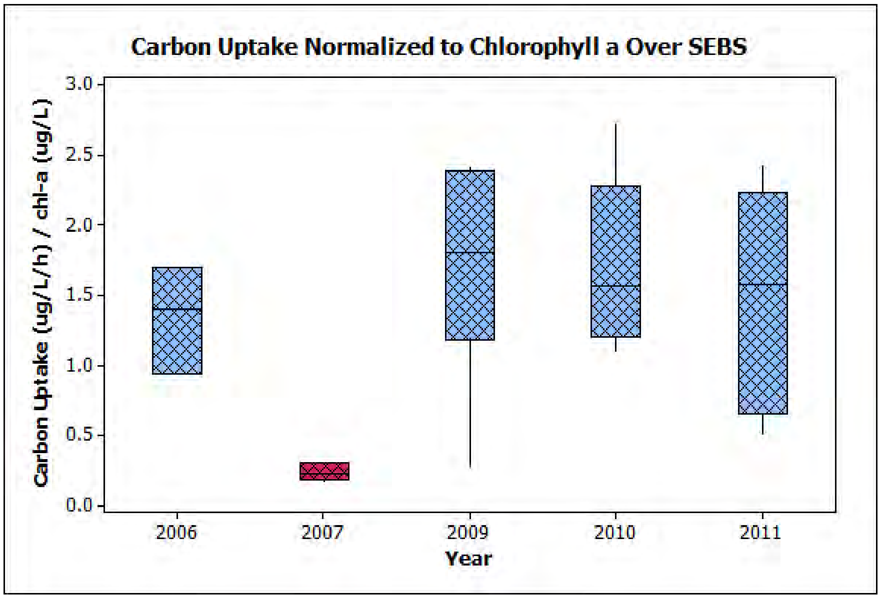


Figure 44: Surface carbon uptake normalized to chlorophyll a concentrations over the southeast Bering Shelf (SEBS) showing a significant drop (in red) in 2007 uptake rates compared with other years. Single outlier removed from 2007 dataset.

Factors causing observed trends: Significant decreases in both chlorophyll a concentrations and carbon uptake rates during 2007 may have been due to: lower than normal silicate concentrations, high water column stability (Coyle et al., 2011), or species changes in phytoplankton community.

Implications: Significant decreases in phytoplankton carbon uptake and chlorophyll biomass dur-

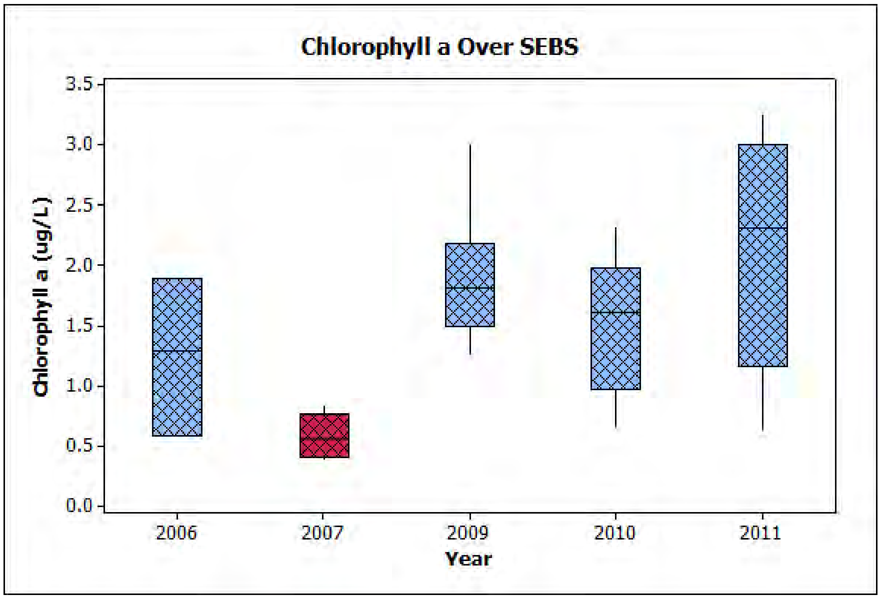


Figure 45: Surface chorophyll a concentrations at production stations over the southeast Bering Shelf (SEBS) showing a significant drop (in red) in 2007. Single outlier removed from 2007 dataset.

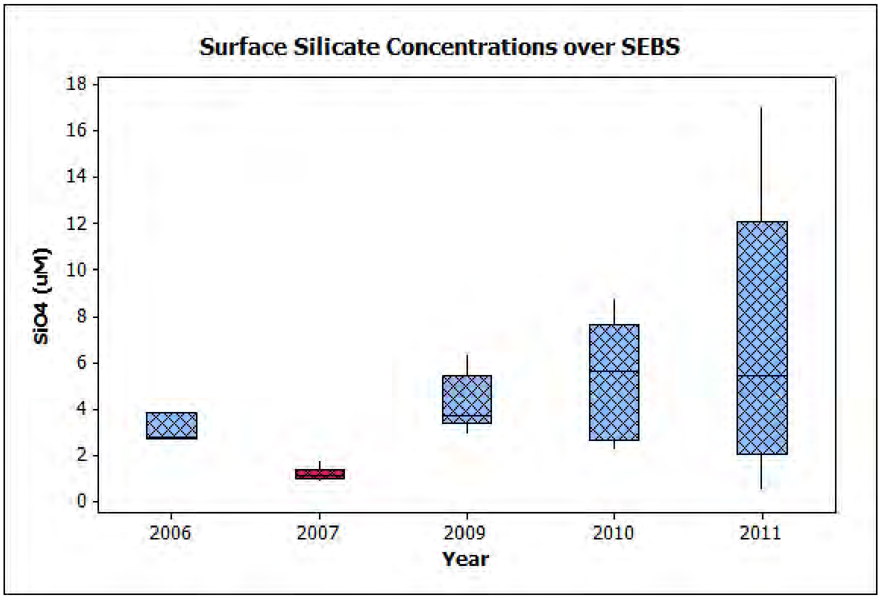


Figure 46: Silicate concentrations at production stations over the southeast Bering Shelf (SEBS) showing a significant drop (in red) during 2007. Single outlier removed from 2007 dataset.

ing late summer/early fall will negatively impact energy flow to higher trophic levels. Low food availability to young forage fishes during this time of year may make overwintering difficult and following year recruitments could suffer.

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
Contact: jamal.moss@noaa.gov
Last updated: August 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Zooplankton

Bering Sea Zooplankton

Contributed by Jeffrey Napp[1], Patrick Ressler[1], Phyllis Stabeno[2] and Atsushi Yamaguchi[3]
[1]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[2]Pacific Marine Environmental Lab,, NOAA
[3]Hokkaido University, Japan
Contact: jeff.napp@noaa.gov
Last updated: October 2012

Description of index: Ressler et al. (2012) computed abundance and biomass of adult and juvenile euphausiids on the middle and outer shelf of the eastern Bering Sea, using acoustic and Methot trawl data from 2004-2010 surveys of midwater pollock (Honkalehto et al. 2010). Estimated euphausiid density (no. m^3) along acoustic survey transects was averaged over the water column and then across the surveyed area to produce the mean estimates shown in the plot for each year. Error bars are 95% confidence intervals computed from geostatistical estimates of relative estimation error (Petitgas 1993).

Stabeno et al. (2012) computed the abundance of *Calanus* spp. (all copepodite stages) on the middle shelf of the eastern Bering Sea from summer net tows on multiple vessels (1981; PROBES, 1998 - 2008; T/S Oshoro Maru and 2009-2011; AFSC RACE Groundfish Assessment cruises). Shown are the mean and standard error. Raw data were fourth root transformed before calculation of the summary statistics and then back transformed before plotting.

Status and trends: Both series show a large increase since 2001-2005 ("warm years" according to Stabeno et al., accepted), with the copepod increase lagging that for euphausiids (Figure 47). Both series showed a smaller decline in 2010 but remained well above 2001-2005 levels. The *Calanus* spp. series showed a slight increase in 2011, but remained below the 2009 peak.

Factors influencing observed trends: The areas of the Bering Sea shelf sampled for copepods and euphausiids were not exactly the same, but we assume that the interannual variability in mean density indicated in the plot is correctly represented for both groups of animals, and that these groups are reasonable proxies for the trend in density of all large copepods and euphausiids on the Bering Sea shelf.

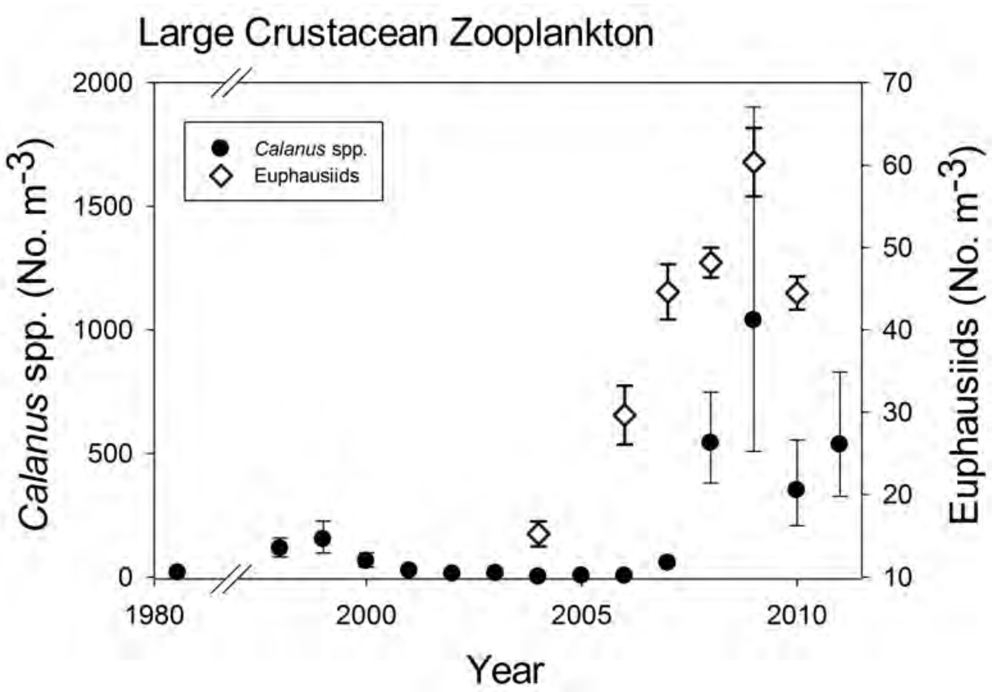


Figure 47: Estimated density of *Calanus* copepods and euphausiids (No. m^{-3}) in the eastern Bering Sea 1980-2011.

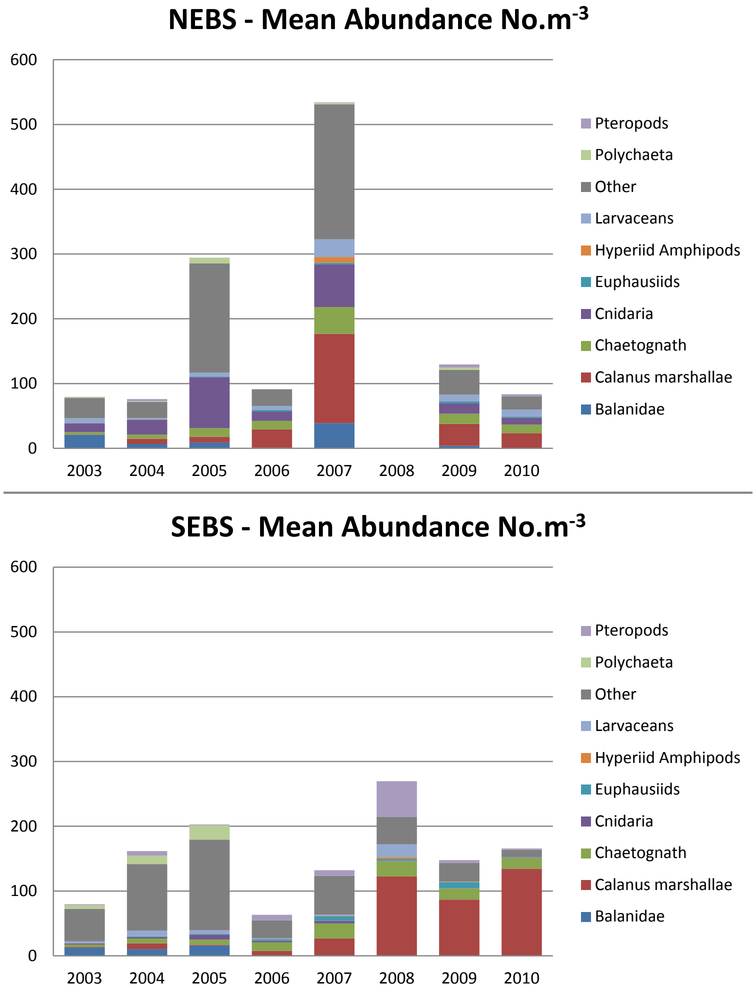
Implications: These two main groups of large crustacean zooplankton are important in the Bering Sea ecosystem and in the diet of many predators. For example, ecosystem modeling indicates that the biomass densities of euphausiids and copepods in the Bering Sea are of the same order (Aydin et al. 2007a, p. 77; Aydin and Mueter, 2007, Fig. 3) and that they are of comparable importance in the diet of walleye pollock (Aydin et al. 2007a, p. 51). In 2011, the MACE acoustic/trawl summer survey was in the Gulf of Alaska, however the concentrations of *Calanus* spp. were comparable to other cold years. This suggests that prey availability for planktivorous fish, seabirds, and mammals continued to be high during the summer of 2011.

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]
[1]Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[2]Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, P.O. Box 757220, Fairbanks, AK
Contact: alex.andrews@noaa.gov
Last updated: October 2012

Description of index: Abundances of large zooplankton were estimated for all Bering-Aleutian Salmon International Survey (BASIS) stations in the Inner and Middle Domains (bottom depths ¡ 100 m) collected during mid-August - early October, 2003-2010. Zooplankton samples were collected during daylight hours with oblique bongo tows from near bottom to surface using a 505 μm mesh. Samples were preserved in 5% formalin and counted to lowest identifiable taxonomic level by the Morski Instytut Rybacki Plankton and Identification Center (Szczecin, Poland) for 2003-2004, by the University of Alaska Fairbanks for 2005-2008, and by Auke Bay Laboratories for 2009-2010 following procedures outlined in Coyle et al. Coyle et al. (2008). Mean abundances (number per m^3) by year of large zooplankton are shown for the northern (60-63.75°N) and southern (55-59.75°N) Bering Sea for warm (2003-2005) and cold (2006-2010) years (Figure 48).

Status and trends: In warm years, the large copepod, *Calanus marshallae*, was in lower abundance than in cold years. Increases were observed first in the northern Bering Sea in 2006 and in the southern Bering Sea in 2007 (Figure 48). When available, *C. marshallae* is an important prey item for age-0 pollock (Moss et al., 2009) and comprised an average of 40% by wet weight in 2008 in the southern Bering Sea (Coyle et al., 2011). Although not depicted here, euphausiids also increased in abundance in the Middle Domain in cold years (2008 and 2009) compared to warm years (2004)(Coyle et al., 2011; Hunt et al., 2011). Increases in energy density of age-0 pollock during cold years (Heintz et al., this document, p. 127) may be associated with increases in *C. marshallae* and euphausiids on the eastern Bering Sea shelf.


NEBS - Mean Abundance $No.m^{-3}$

SEBS - Mean Abundance $No.m^{-3}$

Figure 48: Mean abundance of large zooplankton collected with oblique bongo tows (505 μm mesh) on the Bering Sea shelf (<100 m) during BASIS surveys in the northern (top panel) and southern (bottom panel) Bering Sea.

North-south variations in large zooplankton were also observed, with more Cnidaria present in the northern Bering and more polychaeta (in warm years) and pteropods in the southern Bering Sea (Figure 48). Salmon diets reflect these spatial variations in zooplankton with Cnidaria important in juvenile chum salmon diets in the northern Bering Sea.

Factors influencing observed trends: Survival and growth of early life stages of *C. marshallae* may be related to cold spring temperatures (Baier and Napp, 2003). Lower temperatures on the shelf during summer also may lower metabolic rates such that less food is required to sustain growth. During cold years, *C. marshallae* were concentrated in the Middle Domain in regions where the cold pool was observed (BASIS unpublished data).

Implications: Age-1 pollock recruitment was higher in two of the cold years, 2006 and 2008, suggesting that an increase in large zooplankton in the water column and diets of age-0 pollock may lead to increases in energy density and over-winter survival of pollock during their first winter (Heintz et al., this document, p. 127). In addition, during cold years, large zooplankton may serve as alternative prey for larger predators, such as juvenile salmon, that would otherwise be focusing on age-0 pollock as their major prey source (Coyle et al., 2011). Thus, potential reductions in the abundance of large zooplankton (*C. marshalle* and euphausiids) on the eastern Bering Sea shelf during warm years may lead to poor survival and reduced recruitment of age-1 pollock.

Jellyfish - 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
Contact: jerry.hoff@noaa.gov
Last updated: October 2012

Description of index: The time series of jellyfish (principally *Chrysaora melanaster*) was updated for 2011 (Figure 49). Relative CPUE was calculated by setting the largest biomass in the time series to a value of 1 and scaling other annual values proportionally. The standard error (±1) was weighted proportionally to the CPUE to produce a relative standard error.

Status and trends: Jellyfish relative CPUE in 2012 was was down slightly from 2011, 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 2009-2011.

Factors influencing observed trends: 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: The ecological implications of increases in jellyfish biomass and links between jellyfish biomass and biophysical indices are discussed by Brodeur et al. (2002, 2008).

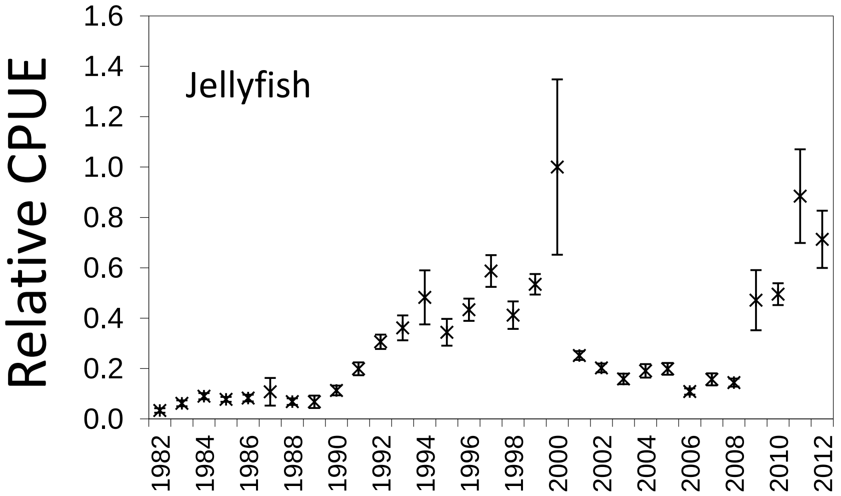


Figure 49: AFSC eastern Bering Sea bottom trawl survey relative CPUE for jellyfish during the May to August time period from 1982-2012.

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

Contributed by Kristen Cieciel, Jeanette Gann, and Lisa Eisner, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: kristin.cieciel@noaa.gov
Last updated: August 2012

Description of index: Jellyfish sampling was incorporated aboard the BASIS (Bering Aleutian Salmon International Surveys) vessels beginning in 2004 and will continue through 2012. 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 (Inner Domain <50m, Middle Domain 50m-100m, Outer Domain ≥100m) 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 Shelf Domain. Of the six species sampled, *Chrysaora melanaster* had the highest weight per unit effort (kg) for all years.

Status and trends: In 2011 total jellyfish biomass decreased by almost half compared to the previous year. However, for the first time since sampling started in 2004, the biomass was recorded higher in the north than in the south (Figure 50). During 2010, combined jellyfish species biomass nearly doubled compared to the previous highs of 2004 and 2005. Notable declines in jellyfish species compostion were observed for all taxa except *C. melanaster* starting in 2006 and continuing through 2011 (Figure 51)suggesting that the trend for the region has shifted from multiple species to a single species dominant catch. In 2008 our station grid was significantly reduced. However, comparisons with past years using the same survey area as 2008 indicate similar trends in species composition and distribution patterns.

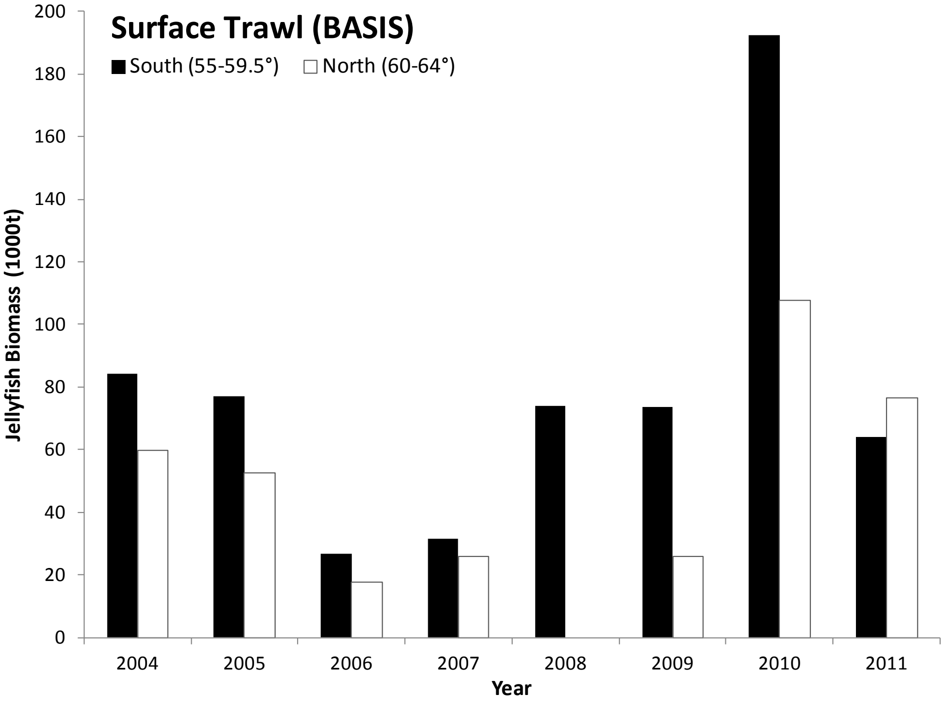


Figure 50: Total jellyfish biomass (1000 t) by year. Includes combined species caught in surface trawls in the Eastern Bering Sea during August-October. Biomass was calculated using average effort per survey area in km^2 by year.

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).

Long-term Zooplankton Trends in Icy Strait, Southeast Alaska

Contributed by Molly Sturdevant, Emily Fergusson, and Joe Orsi, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: molly.sturdevant@noaa.gov
Last updated: August 2012

Description of index: The Southeast Coastal Monitoring (SECM) project of Auke Bay Laboratories, AFSC, has collected zooplankton and temperature data during fisheries oceanography surveys

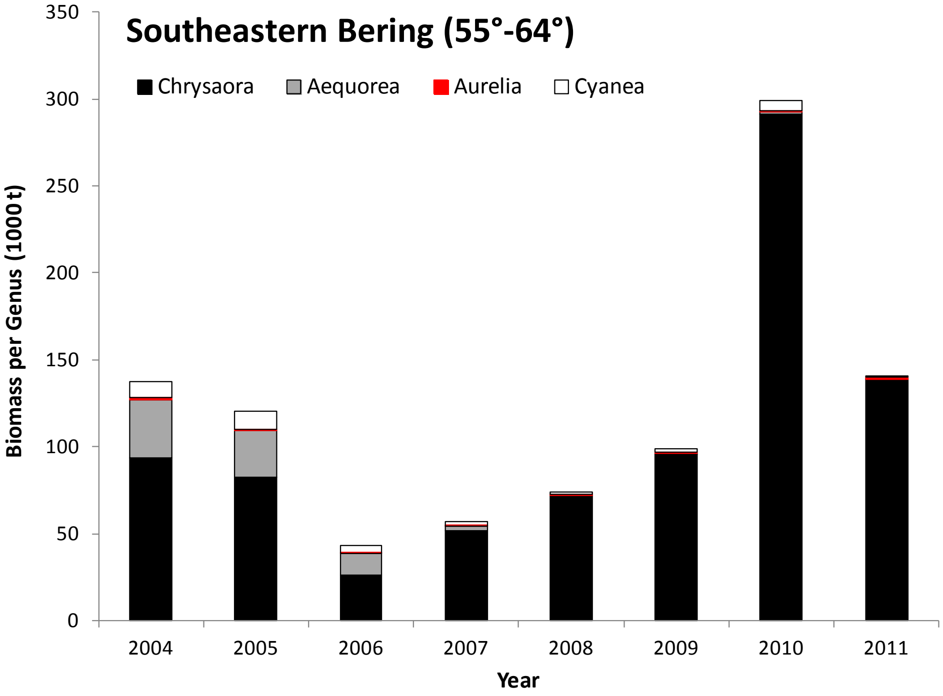


Figure 51: BASIS surface trawl Biomass (1000t) by genus for 2004-2011 in the Eastern Bering Sea during August -October. Biomass was calculated using average effort per survey area in km^2 by year.

annually since 1997 (Orsi et al. 2012; `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-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-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*) anticipated to return the following year (Sturdevant et al. 2004; Orsi et al. 2004, 2009, 2012; Sturdevant et al. 2012). 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 longterm trends for temperature and zooplankton in Icy Strait. The temperature data was an index of the 20-m upper water column and was linked to a climate metric, the El Niño/La Niña-Southern Oscillation (ENSO) Multivariate ENSO Index (MEI) (Wolter 2012). The temperature index was computed from CTD data at 1-m increments for 8 stations in Icy Strait ($\geq$ 160 monthly observations per year). The MEI Index data used was the mean for 12 months beginning in September of the year prior to the sample year, to capture the lag effect of propagating ocean-atmospheric teleconnections from the equatorial Pacific Ocean. Zooplankton total density (number -3) and percent composition were computed from 333-μm bongo net samples collected at 4 stations ($\leq$ 200 m depth) (Park et al. 2004). Anomalies were computed as deviations from

Table 4: Zooplankton longterm mean total density (numbers^{-3}) and percent composition for taxa important in fish diets by month in Icy Strait, Southeast Alaska. 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) from 1997-2011. Values are references for the 0-lines shown in Figure 53 anomalies.

	Total organisms	% Large calanoids	% Small calanoids	% Euphausiid larvae	% Larvaceans	% Pteropods	% Amphipods	% Decapod larvae	% Other
May	1682	35	47	5	6	<1	<1	<1	6
June	1711	25	58	6	4	2	<1	<1	4
July	1223	15	73	11	3	<1	3	<1	4
August	853	16	74	1	2	<1	3	<1	4

the longterm monthly mean values. These indices may help to explain variation in prey fields for diverse fish communities.

Status and trends: Monthly temperatures ranged from approximately 7°C to 10.5°C for the 20-m upper water column. Anomalies did not exceed these means by more than ± 1.4°C (Figure 52, top) and their direction was usually consistent within a year. The annual temperature index was significantly correlated with the MEI (Figure 52, bottom). Overall, 9 years were characterized as warmer than average (9.3°C), typically with positive MEI values; conversely, 6 years were characterized as colder than average, typically with negative MEI values. However, for the most anomalous years, all 4 months were warm (2003 and 2005) or cold (2002, 2006, and 2008; Figure 52, top). In contrast, moderately warm or cold years had unique months of temperature reversal. For example, the warm years of 2001, 2004, and 2010, were actually colder than average in May, June, and July, respectively.

Longterm mean zooplankton density peaked in May and June at approximately 1,700 organisms per m^{-3}, and declined 50% by August (Table 4). Density anomalies were strongly negative from 1997-2005, strongly positive in 2006-2009, then reversed in both 2010 and 2011 (Figure 53, top left). Total density showed little correspondence with annual temperature trends, with both positive and negative anomalies in both warm and cold years.

Zooplankton was numerically dominated by calanoid copepods, including small species ($\leq$ 2.5 mm Total length, TL; $\leq$ 74% composition; primarily Pseudocalanus spp.) and large species (> 2.5 mm TL; $\leq$ 35% composition; primarily *Metridia* spp.) (Table 4). Five other taxa important in fish diets (Sturdevant et al. 2004, 2012) contributed minor numerical percentages. Small and large calanoids typically deviated by 10-20% from the longterm average, with inverse monthly anomalies that indicated different seasonalities (Figure 53). However, these composition anomalies varied from year to year, suggesting different innate timing cues. For example, both 2005 and 2010 were warm years, but positive temperature anomalies were sustained in 2005 (when both large and small calanoid trends reversed abruptly in July), compared to 2010 (when synchronous negative anomalies were sustained for all months). The unusual pattern in 2010 occurred when total zooplankton densities were near average and two other prey taxa showed strongly positive anomalies (euphausiid larvae and larvaceans). Such changes could lead to mismatched timing of prey fields for planktivorous fish.

Factors influencing observed trends: Our research in SEAK over the past 15 years describes annual trends in temperature, prey fields, and other biophysical factors (Orsi et al. 2012). We

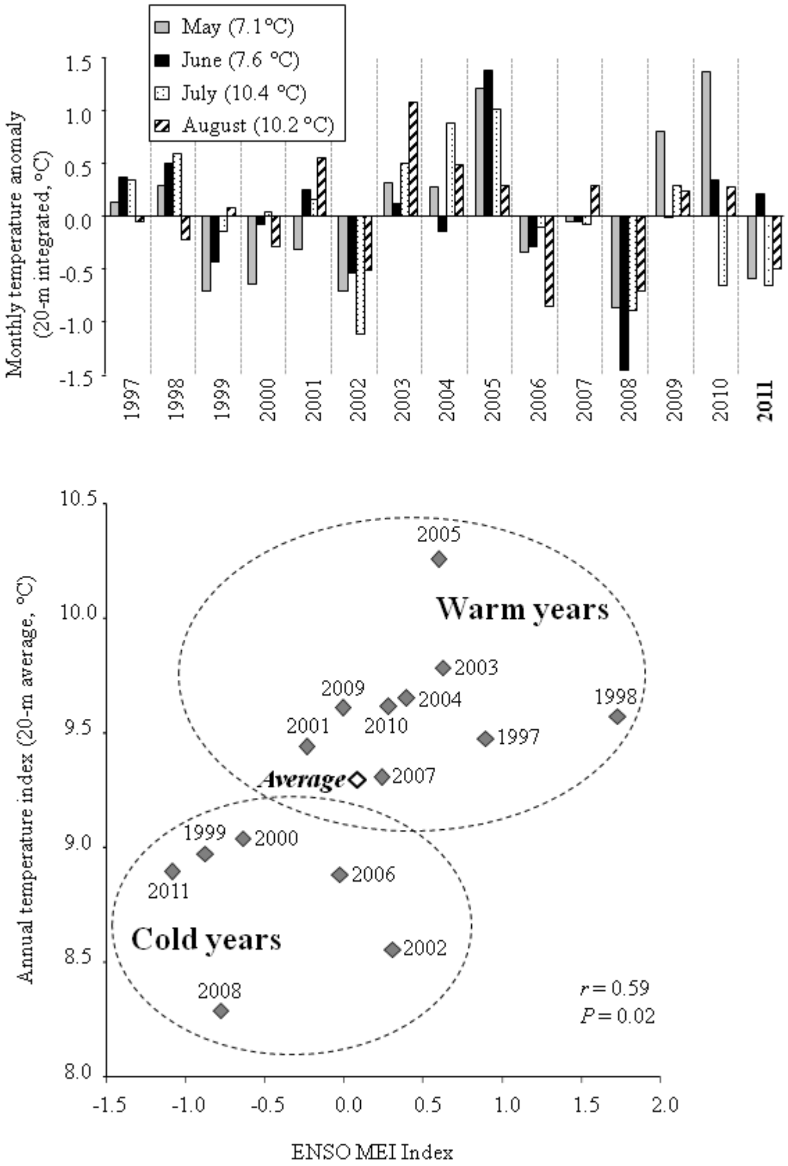


Figure 52: Marine climate relationships for the northern region of Southeast Alaska from the SECM 15-year time series, 1997-2011. Upper panel: mean monthly temperatures (°C, 20-m integrated water column) in Icy Strait; lower panel: correlation of mean annual temperature (°C, 20-m integrated water column) with the Multivariate ENSO Index (MEI), showing warm-versus-cold years. Longterm mean temperatures are indicated in the key.

documented a link between local marine temperatures and a multivariate, basin-scale climate index (MEI) (Sturdevant et al. 2012). 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

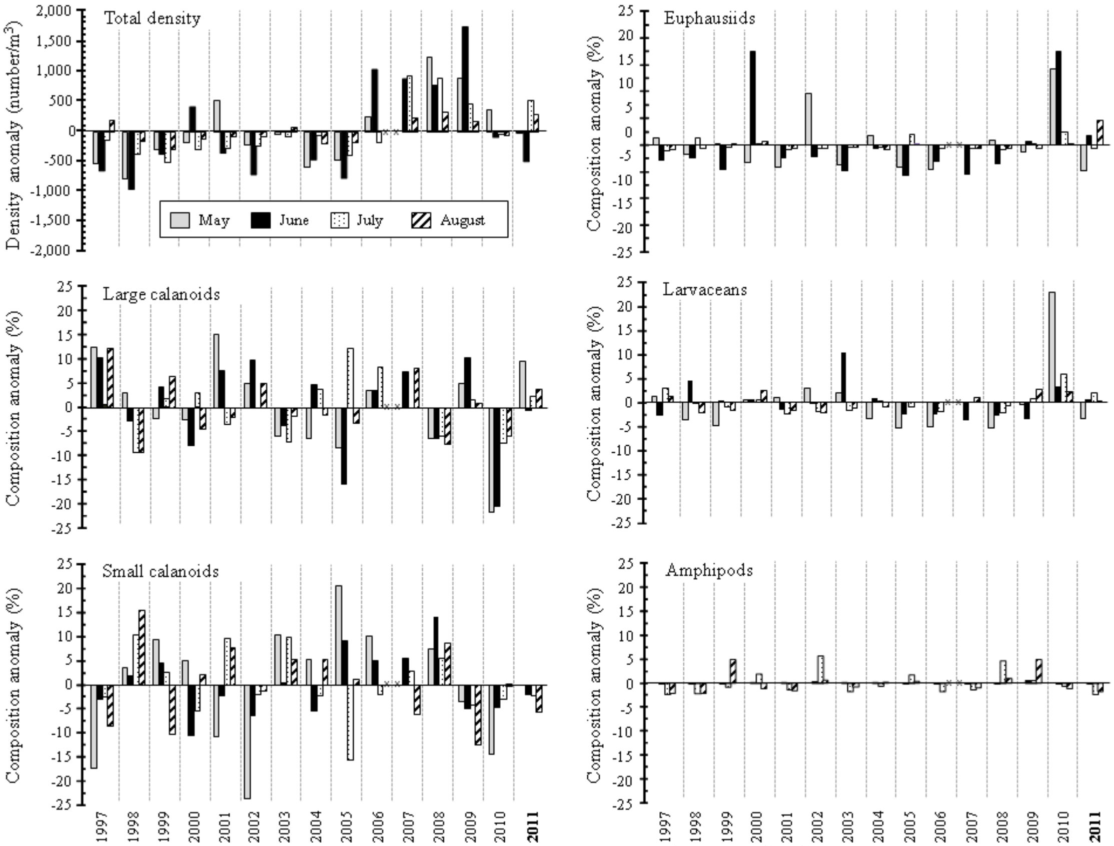


Figure 53: Zooplankton density and composition anomalies for the SECM 15-yr time series from Icy Strait, Southeast Alaska, 1997-2011. Longterm monthly means are indicated by the 0-line (values given in Table 4). Data (shaded bars) are deviations for total density (number/m^3; top left panel), and percent numerical composition of taxa important in fish diets. No samples were collected in August 2006, and the May 2007 night time values were omitted (denoted by x).

these responses could depend on the monthly timing, magnitude, and duration of temperature anomalies in warm or cold years. Therefore, a simple annual temperature index may not explain shifts in abundance and composition of these prey fields, particularly at broad taxonomic scales.

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 Southeast Alaska, large copepods with long life spans were thought to be more sensitive to climate fluctuation than small copepods (Park et al. 2004). In the Bering Sea, changes in energy flow led to poor recruitment of juvenile salmon and pollock when diets shifted between warm (2003-2006) and cool (2006-2009) years in response to zooplankton and temperature shifts (Coyle et al. 2011). Conversely, in the Strait of Georgia, although juvenile salmon diet composition did not show dramatic interannual shifts between 1997-2002, feeding intensity and fish size increased and survival was greater after the 1998 climate shift (Beamish et al. 2004). In dynamic ecosystems such as SEAK (Weingartner et al. 2008), 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. No climate effect on planktivorous fish diets was found in SEAK (Sturdevant et al. 2012). 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 (Downtown and Miller 1998; Francis et al. 1998).

Continuous Plankton Recorder Data from the Northeast Pacific

Contributed by Sonia Batten, Sir Alister Hardy Foundation for Ocean Science
Contact: soba@sahfos.ac.uk
Last updated: August 2012

Description of indices: Continuous Plankton Recorders (CPR) have been deployed in the North Pacific routinely since 2000. Two transects that originate in the Strait of Juan de Fuca are sampled seasonally. One is sampled monthly (Apr-Sept) and terminates in Cook Inlet; the second is sampled 3 times per year, follows a great circle route across the North Pacific, and terminates in Japan. Several indicators are now routinely derived from the CPR data and updated annually. They include indicators of mesozooplankton (1) biomass, (2) phenology (timing), and (3) community.

Mesozooplankton biomass and mean copepod community size are estimated for three regions. The eastern-most region has the best sampling resolution as both transects intersect here. This region has been sampled up to 9 times per year with some months sampled twice. Regions to the west are sampled only 3 times per year. Regions to the north are sampled 5-6 times per year.

The calanoid copepod *Neocalanus plumchrus* is a dominant component of the spring mesozooplankton in the subarctic North Pacific and Bering Sea. Because N. plumchrus normally has a single dominant annual cohort, its seasonal timing can be indexed from measurements of total population biomass or by following progressive changes in stage composition. The eastern North Pacific (offshore BC region in Figures 54 and 55) is sampled by both transects, giving sufficient sampling resolution to determine the timing of the peak of *Neocalanus plumchrus*. Further information on these indices can be found in Batten and Mackas (2009).

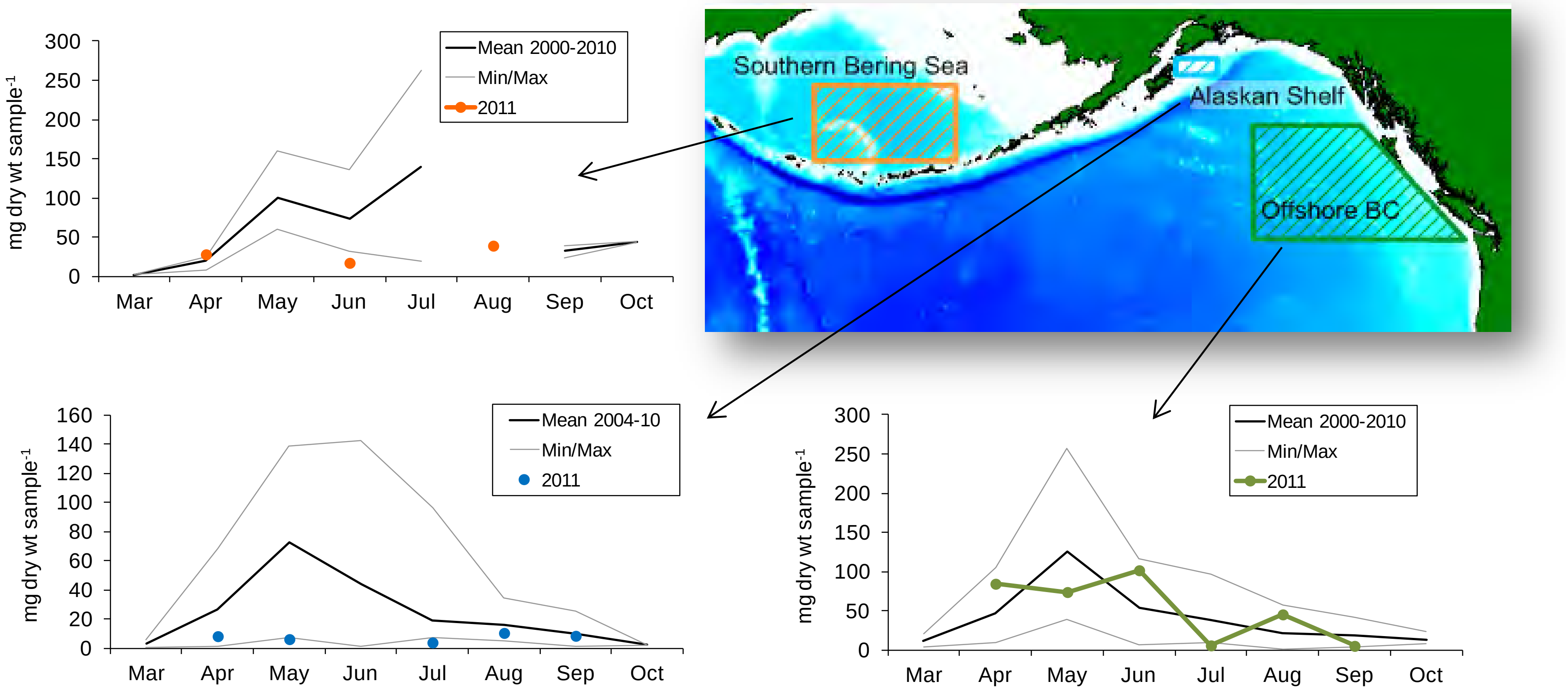


Figure 54: Mean (black lines), minimum and maximum (grey lines) monthly mesozooplankton biomass for the NE Pacific CPR sampling of the regions shown above right (2000 to 2010 except Alaskan Shelf regions where time series extends from 2004 to 2010), together with monthly data for 2011 overlaid as points.

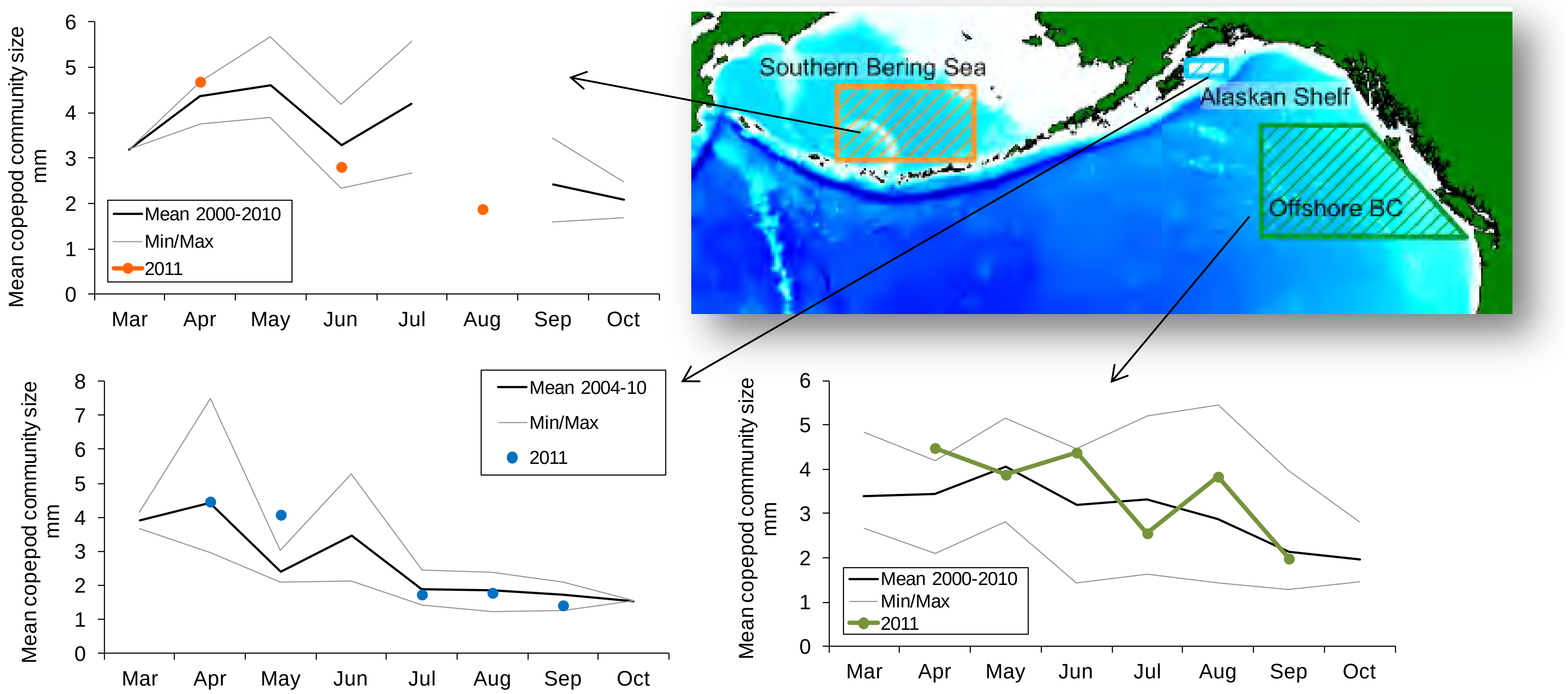


Figure 55: Mean (black lines), minimum and maximum (grey lines) copepod community size for the NE Pacific CPR sampling of the regions shown above right (2000 to 2010 except Alaskan Shelf regions where time series extends from 2004 to 2010), together with monthly data for 2011 overlaid as points.

Status and trends: Monthly mesozooplankton biomass estimates from three regions are shown in Figure 54, with 2011 data overlaid for comparison with previous years. Mesozooplankton biomass was apparently low in both the Alaskan shelf and southern Bering Sea regions in 2011 while the oceanic Northeast Pacific showed a late and extended biomass peak.

Time series of the day of the year when peak biomass is projected to have occurred and the length of the season (defined as the number of days between the 25th and 75th percentile of cumulative biomass) are shown in Figure 56. Note that the date could not be calculated for 2008 as sampling did not begin until May, when the copepodites were too advanced. In 2011, values were towards the middle of the range seen in the time series, slightly earlier and shorter than in 2010.

Mean monthly copepod community size for each region is shown in Figure 55 (for method of calculation see (Richardson et al., 2006)). All three regions have the largest copepods in the spring/summer when the larger subarctic species are dominant. Mean size declines into late summer and fall when smaller species become more abundant and the large species are in diapause at depth. Values from 2011 were similar to the long term mean for the southern Bering Sea and Alaskan shelf, suggesting that the low biomass was not the result of an absence of a particular group of copepods. The data for the northeast Pacific show that larger species were present later into summer than average, consistent with cool La Niña conditions delaying their development.

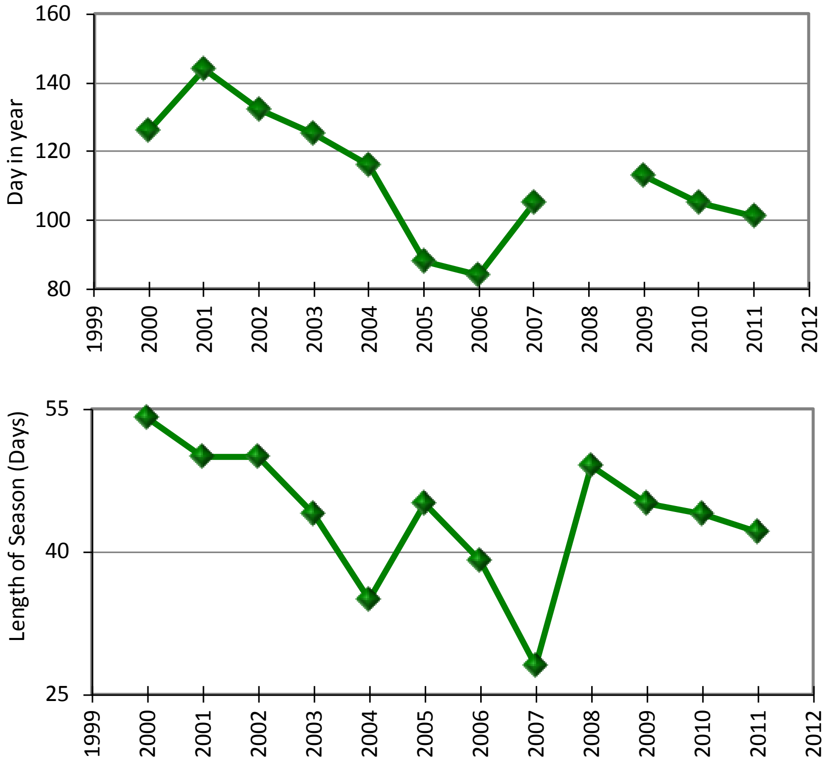


Figure 56: Day of the year when peak biomass of *Neocalanus plumchrus* occurred (based on stage composition, when 50% population was at copepodite stage 5), upper panel. Lower panel shows the length of the season calculated as the number of days between the 25th and 75th percentile of cumulative biomass.

Factors causing observed trends: Changes in ocean climate can affect each of these indicators. Previous studies have shown interdecadal and latitudinal variation in seasonal developmental timing, with peak biomass occurring earlier in years and places with warmer upper ocean temperatures Mackas et al. (1998); Batten et al. (2003); Mackas et al. (2007).

Implications: Each of these variables is important to the way that productivity is passed through zooplankton to higher trophic levels. Changes in community composition (e.g. prey size) may reflect changes in the nutritional quality of the zooplankton to their predators. Changes in ocean climate can affect the availability of zooplankton to their predators.

Forage Fish

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

Contributed by Ron Heintz, Ed Farley, and Elizabeth Siddon, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: ron.heintz@noaa.gov
Last updated: August 2012

Description of index: Average Energy Content (AEC) is the product of the average individual mass and energy density (i.e. kJ/fish) of YOY pollock collected from BASIS surveys. Average individual mass is estimated at sea from the mean individual mass of YOY pollock in each haul weighted by catch of YOY pollock. The average energy density of YOY pollock is estimated in the laboratory using fish collected at random from each haul and is also weighted catch. The product of the two averages represents the total energy content of the average YOY pollock for a given year.

The analytical procedures for measuring energy density follow strict protocols. Fish are retained from each haul during the BASIS survey, frozen and shipped to Auke Bay for analysis. Catch records are examined to identify the number of fish to process from each haul so that at least 50 fish are processed. Fish are dried, homogenized and combusted in our bomb calorimeter. Along with each batch of 15 samples we combust two samples of benzoic acid and a reference material to verify the accuracy of our methods. In addition, one of the samples is duplicated to verify that the precision of our estimates is within 3%.

Status and trends: Energy density (kJ/g) and mass (g) of YOY pollock have been measured annually since 2003. Over that period energy density has varied with the thermal regime in the Bering Sea. Between 2003 and 2005 the southeastern Bering Sea experienced warm conditions characterized by an early ice retreat. Ice retreated much later in the years following 2006 and 2006 was intermediate. The transition between the warm and cool periods is clearly observed in plot relating energy density to collection year (Figure 57). Plotting energy density for each year reveals this transition; energy density increases from values near 3.6 kJ/g in 2003-2005 to values near 5.0 kJ/g in 2008-2011. In contrast, the size of the fish has been less influenced by thermal regime. In the warm years mass averaged 2.0 g compared with 2.3 g in the cold years.

Contrasting the AEC of YOY pollock with year class strength in the age-structured stock assessment (ASA) suggests the condition of pollock prior to their first winter predicts their survival. The AEC of YOY pollock between 2003 and 2010 accounted for nearly 80% of the variation in the number

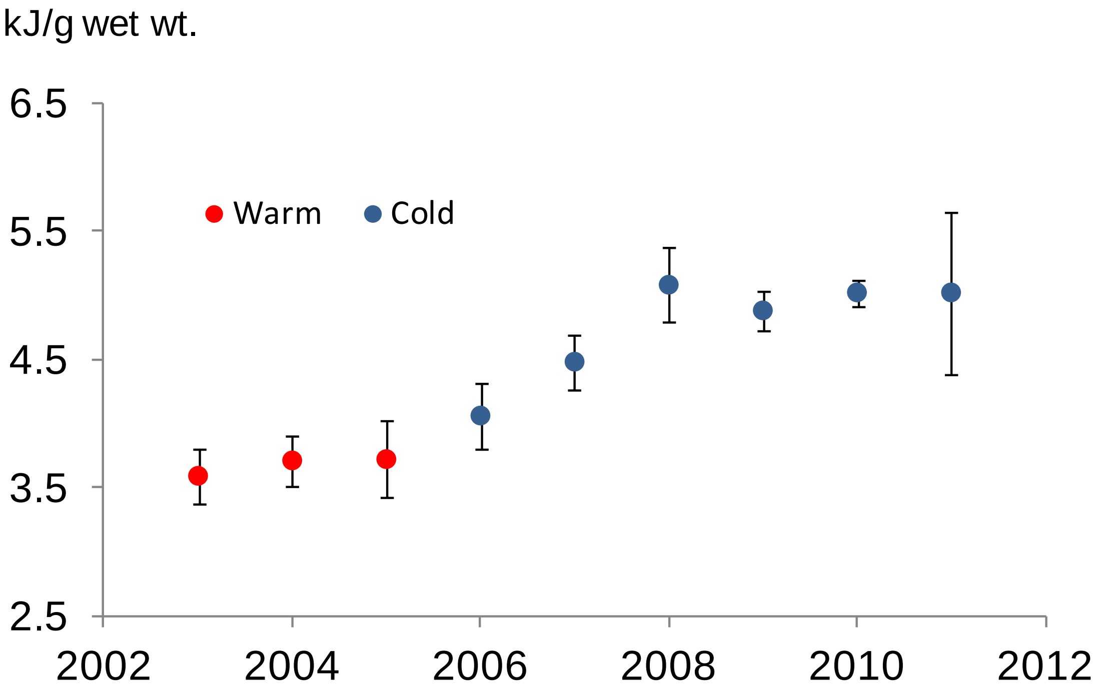


Figure 57: Annual changes in the average energy density of age-0 pollock sampled by surface trawl during BASIS surveys.

of age-1 recruits per spawner (Figure 58). In 2011 the AEC of YOY pollock remained high (12.0 kJ/fish) suggesting the number of age-1 recruits per spawner should continue to be above the overall median level in 2012.

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. Their success at exploiting this window likely depends on water temperatures, prey quality and foraging costs. Cold years appear to be associated with greater densities of euphausiids, medium and large copepods in the middle domain (Hunt et al. submitted). These species are higher in lipid affording 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). Consequently, conditions associated with cold conditions lead to improved condition of YOY pollock prior to winter.

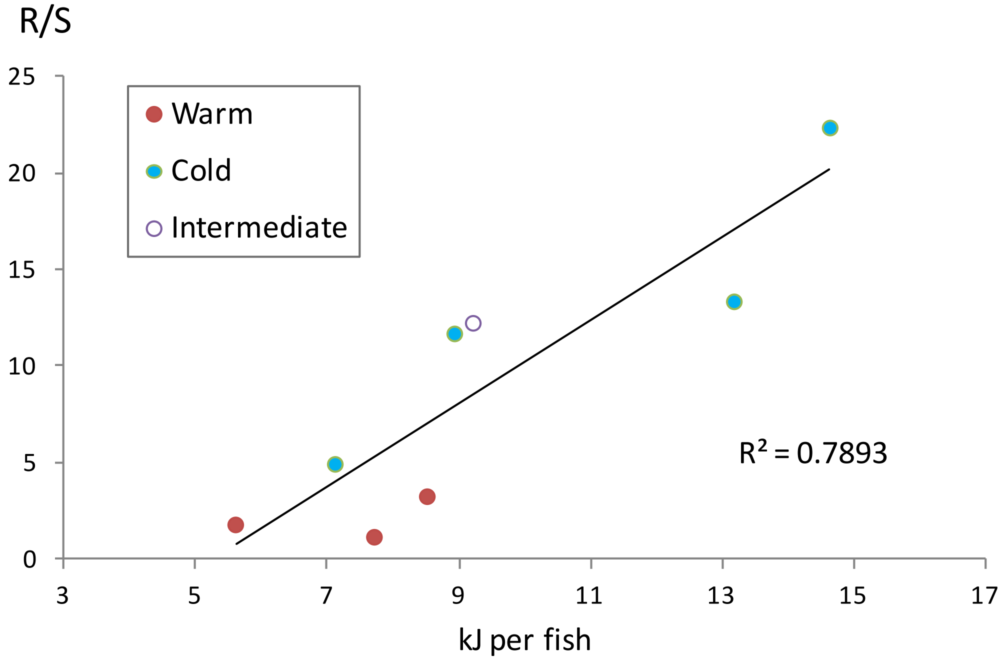


Figure 58: Relationship between average energy content (AEC) of individual age-0 pollock and the number of age-1 recruits per spawner as shown in the 2011 stock assessment (Ianelli et al. 2011).

Implications: The current data indicate that recruitment to age-1 should continue to be strong so long as summer conditions remain cold. A return to warm conditions in the Bering Sea is likely to result in reduced recruitment of pollock. BASIS data indicate warm conditions may support growth and survival of YOY pollock during the first few months of their lives, but they create suboptimal conditions for provisioning fish for winter.

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
Contact: ed.farley@noaa.gov
Last updated: October 2012

Description of index: Catch per unit effort (CPUE; km^2) for capelin, age 0 Pacific cod, Pacific herring, age 0 walleye pollock and juvenile sockeye salmon are provided for the northeastern (NEBS; stations north of 60N) and southeastern Bering Sea (SEBS; stations south of 60N; Figure 59). CPUE data are from BASIS surface trawl operations (surface to 25 meters) spread across a systematic grid along the eastern Bering Sea shelf (Figure 59). BASIS is a fish and oceanographic survey conducted in the eastern Bering Sea from mid-August to October. Effort in km^2 was calculated as: (1) distance towed (km) =ACOS(COS(RADIANS(90-Lat1)) *COS(RADIANS(90-Lat2)) +SIN(RADIANS(90-Lat1)) *SIN(RADIANS(90-Lat2)) *COS(RADIANS(Long1-Long2))) *6371; where Lat1, Lat2, Long1 and Long2 are recorded start and stop lat long locations for each

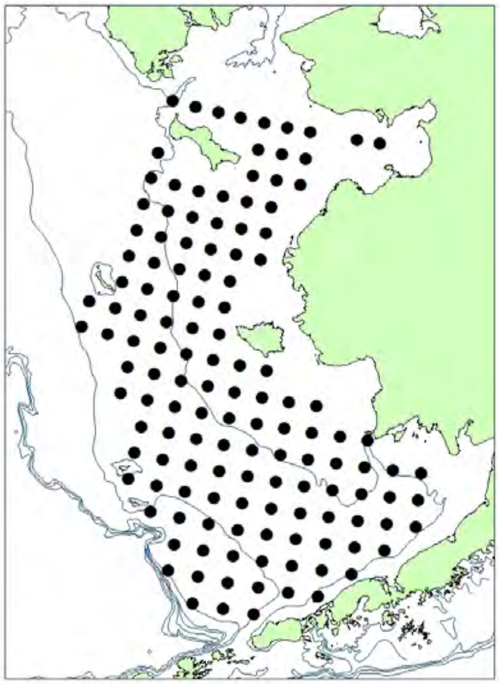


Figure 59: BASIS survey grid on the eastern Bering Sea shelf.

trawl; (2) distance towed was multiplied by the recorded or average horizontal spread of the rope trawl during tow operations; (3) the average catch of each species was equal to their total catch divided by the number of stations within the southeastern or northeastern Bering Sea; and (4) average CPUE (km^2) was equal to the average catch divided by average effort within each region by year.

Status and trends: The CPUE of capelin increased in both the NEBS and SEBS after 2008, whereas the CPUE Age 0 walleye pollock in surface waters declined in both regions (Tables 5, 6 and Figures 60, 61). The CPUE of age 0 Pacific cod was low in all years for the NEBS region and has varied in the SEBS region with the highest CPUE occurring during 2011. Herring CPUE has declined in the SEBS after 2007 but has varied over time in the NEBS with highest CPUE occurring during 2002 to 2006. Juvenile sockeye salmon CPUE was highest in the SEBS region with highest CPUE during 2005 and 2007.

Factors influencing observed trends: The survey occurred during warm and cold climate states. The eastern Bering Sea ecosystem productivity can vary among climate states, potentially impacting survival of marine species (Hunt et al., 2011; Coyle et al., 2011). Forage fish distribution (spatial extent and depth) can also vary depending on sea temperature and location of cold pool (Hollowed et al., 2012; Farley et al., 2011; Moss et al., 2009).

Implications: *What are the implications or impacts of the observed trends on the ecosystem or ecosystem components?* Capelin are an important forage fish for marine mammals and other fish species. Our survey observations suggest that the increase in capelin occurred near the 50m

Table 5: Catch per unit effort (number per km^2) of capelin, age 0 Pacific cod, age 0 walleye pollock, Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon International Survey along the **northeastern** Bering Sea shelf. * preliminary data.

Year	Capelin	Age 0 Pollock	Age 0 Pacific cod	Herring	Juvenile sockeye salmon
2002	386.1	7971	0.1	5776.3	3.8
2003	348.9	1367.6	10.5	2655.3	2.3
2004	147.8	13690.8	0.7	14504.7	18.1
2005	587.1	27150.5	0.4	6627.2	0.8
2006	85	268.8	2.9	4902.1	0.2
2007	491.4	85.8	14.8	2381.2	6.9
2008					
2009	3192.9	118	0	1114.3	1.8
2010	12611.3	27.4	0	4433	1
2011	3210.7	188.9	0.3	4432.9	0
2012*	10437.5	0.3	0.6	1538	0.4

Table 6: Catch per unit effort (number per km^2) of capelin, age 0 Pacific cod, age 0 walleye pollock, Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon International Survey along the **southeastern** Bering Sea shelf. * preliminary data.

Year	Capelin	Age 0 Pollock	Age 0 Pacific cod	Herring	Juvenile sockeye salmon
2002	0.9	17543.4	604.6	957.1	285.6
2003	13	59569.9	14.6	172.4	270.2
2004	5.7	116390.2	57.8	233.2	173.1
2005	60.7	89922.6	653.8	1123	518.2
2006	55.2	13815	822.3	238	62.3
2007	440.3	5278.3	68.8	357.2	296.9
2008	31.9	8616.8	161.9	68.1	59.9
2009	1031.6	105.4	1	97.1	150
2010	7184.7	1255.7	448.7	9.7	112.8
2011	2040.7	2867.3	4393.7	20.6	42.3
2012*	6143.8	1698	204.9	4.1	95.7

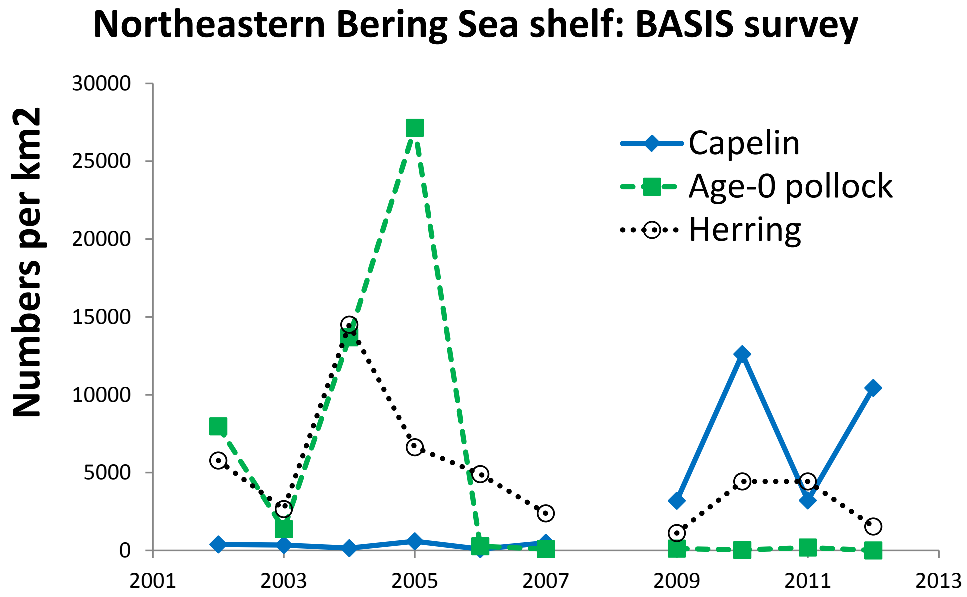


Figure 60: Catch per unit effort (number per km^2) of capelin, age-0 Pacific cod, age-0 walleye pollock , Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon Internatinoal Survey along the northeastern Bering Sea shelf. 2012 data are preliminary.

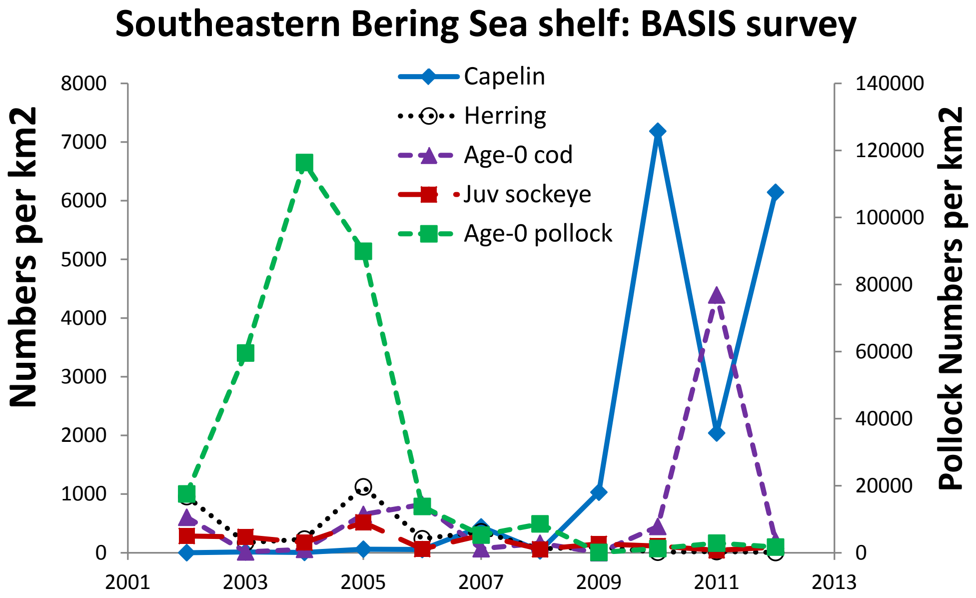


Figure 61: Catch per unit effort (number per km^2) of capelin, age-0 Pacific cod, age-0 walleye pollock , Pacific herring, and juvenile sockeye salmon during the August to September, 2002 to 2012 Bering Aleutian Salmon Internatinoal Survey along the southeastern Bering Sea shelf. 2012 data are preliminary.

isobaths (inner domain), and we observed an increase in whale activity in this region starting in 2008 and continuing through 2012. Whales were not observed during survey operations in this region (inner domain) of Bering Sea prior to 2008. *What do the trends mean?* Acoustic assessment of fish below 15m depth was added to the BASIS research survey during 2008 to present. Data from acoustic/midwater trawl suggest the downward trend in age 0 walleye pollock CPUE in surface waters is likely related to their shift in vertical distribution (deeper) during the cool period (Parker-Stetter et al. in review). Variation in distribution of age 0 Pacific cod was summarized in Hurst et al. 2012. *Why are they important?* Forage fish are key components of the eastern Bering Sea ecosystem for marine mammals, birds, and other commercial fish species. *How can this information be used to inform groundfish management decisions?* Currently, the PIs produce annual indices of age-0 pollock energy density, which is included in the Ecosystem Chapter of the NPFMC Groundfish Stock Assessment and Fishery Evaluation Report (e.g. pp. 124-126 in Zador (2011)), but these indices, to date, have not been used directly in the fisheries management process. We plan to test the hypothesis that the energy content and abundance of age-0 pollock during late summer predict overwintering survival to age-1 and thus year class strength. We plan to evaluate the impact that juvenile energy content at the end of the growing season and acoustic estimates of abundance for age-0 pollock from Bering Aleutian Salmon International Survey (BASIS) research has on stock recruitment estimates within the eastern Bering Sea pollock stock assessment (Ianelli et al., 2011). Data from BASIS have been used to connect climate change and variability to ecosystem productivity and age-0 walleye pollock fitness and recruitment to age-1 (Hunt et al., 2011; Coyle et al., 2011; Heintz, in press).

Gulf of Alaska Small Mesh Trawl Survey Trends

Contributed by Dan Urban, Kodiak Laboratory, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: dan.urban@noaa.gov
Last updated: August 2011

Description of index: Smallmesh trawl surveys of the nearshore Gulf of Alaska have been conducted by the Alaska Fisheries Science Center and Alaska Department of Fish and Game using standard methods since 1972 (n = 13,223 hauls). The most recent survey occurred in September and October of 2011 (n = 135 hauls) in the bays around Kodiak Island, the Shelikof Strait and in Pavlof Bay on the south side of the Alaska Peninsula. The smallmesh survey results are presented as fish and invertebrate CPUEs (kilograms captured per kilometer towed ± SD).

The CPUE time series was used to calculate two indices. First, gulf-wide anomalies from the long-term mean CPUE of pink shrimp *Pandalus borealis*, juvenile pollock ($\leq$ 20 cm) *Theragra chalcogramma*, eulachon *Thaleichthys pacificu*, and Pacific herring *Clupea pallasi* are reported. These species were selected because they are key prey items of many commercial species. The timing, location, and gear used on the smallmesh survey provides a unique opportunity to collect information on these forage species.

The second index uses the increased spatial variance in the catch of Pacific cod and their prey in Pavlof Bay as a leading indicator of an approaching, abrupt community reorganization such as the well-documented community reorganization of 1976/77 (Litzow et al., 2008; Anderson and Piatt, 1999; Mueter and Norcross, 2000). Developing methods that would allow for the early detection of impending ecosystem transition could allow managers to take steps to help prevent ecosystem collapse (Peterson et al., 2003). The coefficient of variation of the log (cod:prey) CPUE ratio is used here as the measure of spatial variance following methods of Litzow et al. (2008). Prey species used include those that are vulnerable to top-down control by cod (capelin *Mallotus villosus*, pink shrimp, coonstripe shrimp *Pandalus hypsinotus*, humpy shrimp *P.goniurus*, and sidestripe shrimp *Pandalopsis dispar*). Sequential t tests for the analysis of regime shifts (STARS, available at: `www.beringclimate.noaa.gov/regimes/index.html`, Rodionov and Overland (2005)) was used to test for statistically significant shifts between alternate states.

Status and trends: Forage species catch rates remain at low levels, one to two orders of magnitude lower than peak values observed in the 1970s and early 1980s (Figure 62). Eulachon, which in recent years has had the highest catch rates of the time series, decreased in 2011 to a rate below the long-term average. Forage species catch rates are not uniform across the region, however. For example, both pink shrimp and juvenile pollock were captured in all bays surveyed but catch rates varied widely both between bays and within bays. The 2011 catch rate for pink shrimp in Pavlof Bay was 1.01 ± 2.60 kg km^{-1}, while in inner Marmot Bay it was 21.12 ± 34.70 kg km^{-1}. Juvenile pollock catch rates ranged from 7.37 ± 7.40 kg km^{-1} in Uyak Bay on the west side of Kodiak Island (one haul catching nearly 19 kg km^{-1}) to <0.005 ± 0.008 kg km^{-1} in Ugak Bay on the east side of Kodiak.

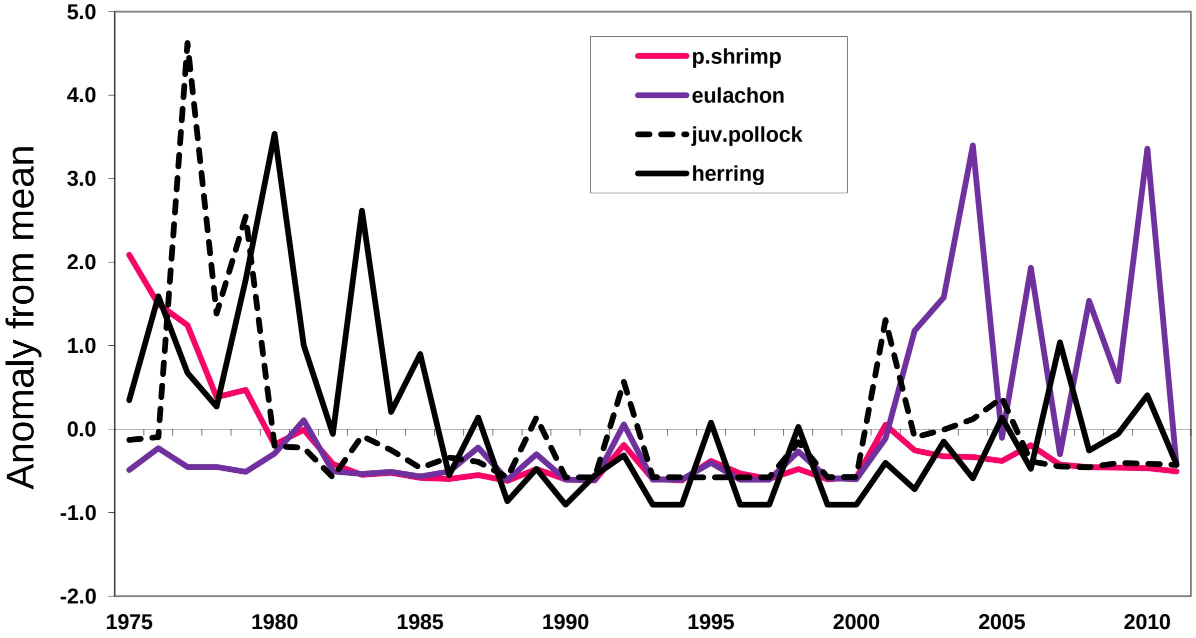


Figure 62: Anomalies from the long-term mean of forage species CPUE (kg km^{-1}) in the Gulf of Alaska, 1972-2011.

The STARS analysis of the cod:prey ratio in Pavlof Bay detected increased spatial variability surrounding the period of the community reorganization of 1976/77 (Figure 63) but did not detect the weaker shift in 1998/99 (Overland et al., 2008; Litzow, 2006). Qualitatively, however, these shifts can be seen in the CPUE anomalies of the forage fish (Figure 62). An impending shift in the marine community was not indicated by the STARS analysis including the 2011 data.

Factors causing observed trends: Climate forcing on the marine community has often been implicated in explaining changes in community organizations. Large transitions are not, however, uniform within the community (Duffy-Anderson et al., 2005), as seen in recent eulachon abundance

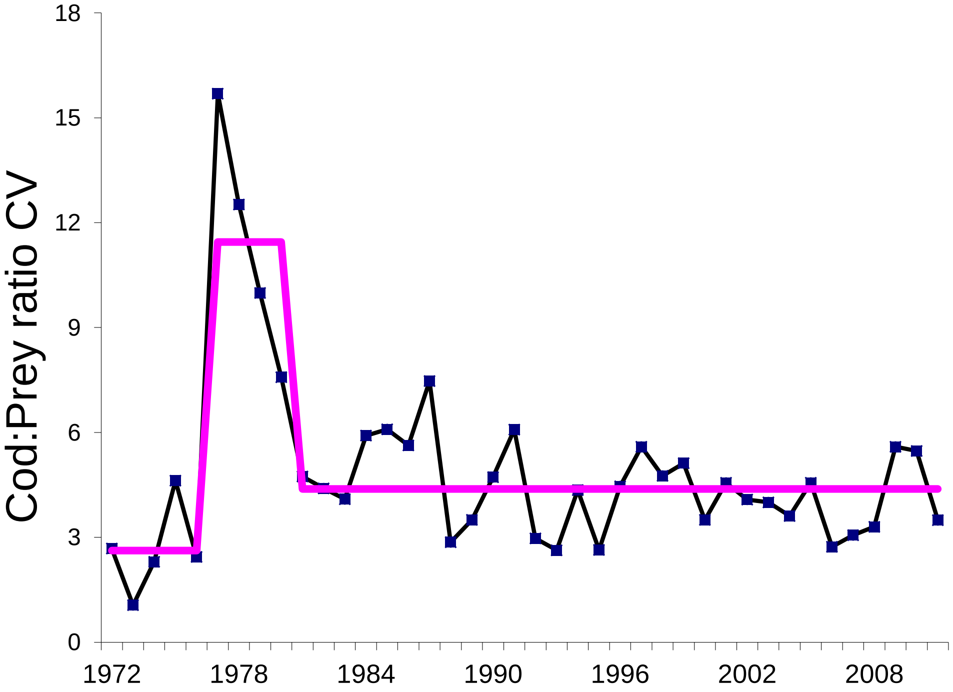


Figure 63: Time series of spatial variance in the cod:prey ratio (coefficient of variation in CPUE log + 10 ratio) in Pavlof Bay (line and squares) as adapted from Litzow et al. (2008). Heavy line indicates distinct states in the times series as defined by sequential t tests for analysis of regime shifts (STARS, $p = 0.03$, l = 5, H = 2).

levels, and may involve different time lag periods for different species (Overland et al., 2008). Changes to the cod:prey ratio and input parameters to the STAR algorithm may be necessary to better capture phase transitions in the GOA that are weaker than the 1976/77 event.

Implications: While the community changes in the marine ecosystem caused by the environmental changes of 1976/1977 appeared strong and widespread across the GOA, the Pacific Decadal Oscillation has not recently had as a dramatic effect (Bond et al., 2003; Litzow, 2006; Mueter et al., 2007), limiting its value as a predictive tool for groundfish managers. Linkages between ocean climate and the marine ecosystem are still important (Di Lorenzo et al., 2008) but improving our understanding of the changing ocean environment requires continued careful monitoring of the physical and biological systems.

Regional Distribution of Juvenile Salmon and Age-0 Marine Fish in the Gulf of Alaska

Contributed by Jamal H. Moss, Wyatt Fournier, and Stacy K. Shotwell, Auke Bay Laboratories, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 17109 Pt. Lena Loop Rd., Juneau, Alaska
Contact: jamal.moss@noaa.gov
Last updated: August 2012

Description of index: Regional distribution of juvenile salmon and age-0 marine fish inhabiting surface waters of the Gulf of Alaska (GOA) are reported in terms of CPUE (30 min surface trawl). These data were collected as part of the Gulf of Alaska Integrated Ecosystem Program (GOA Project) during summer (July-August) 2011. In coming years (2012-2013), summer distributions for both the southeastern and central regions of the GOA will be reported. Juvenile salmon are the most abundant nekton in number and biomass in shelf waters during summer months. They prey upon on larval fish, age-0 marine fish, and plankton, and interannual estimates of abundance may be used as an index of potential predation pressure on these organisms. An index of age-0 marine fish may be combined with other sources of biophysical indices and offer insight into mechanisms influencing recruitment of commercially harvested species.

Status and trends: Data reported in 2011 is the first installment of an impending time series, and thus there are no interannual trends to report at present. However, within year spatial patterns were apparent, with the highest CPUE of juvenile salmon in the central GOA and the mouth of Cross Sound (Figure 64). Catches of age-0 marine fish were relatively low, with most rockfish located off the shelf in the southeast and arrowtooth flounder on the shelf and in the central regions (Figure 65).

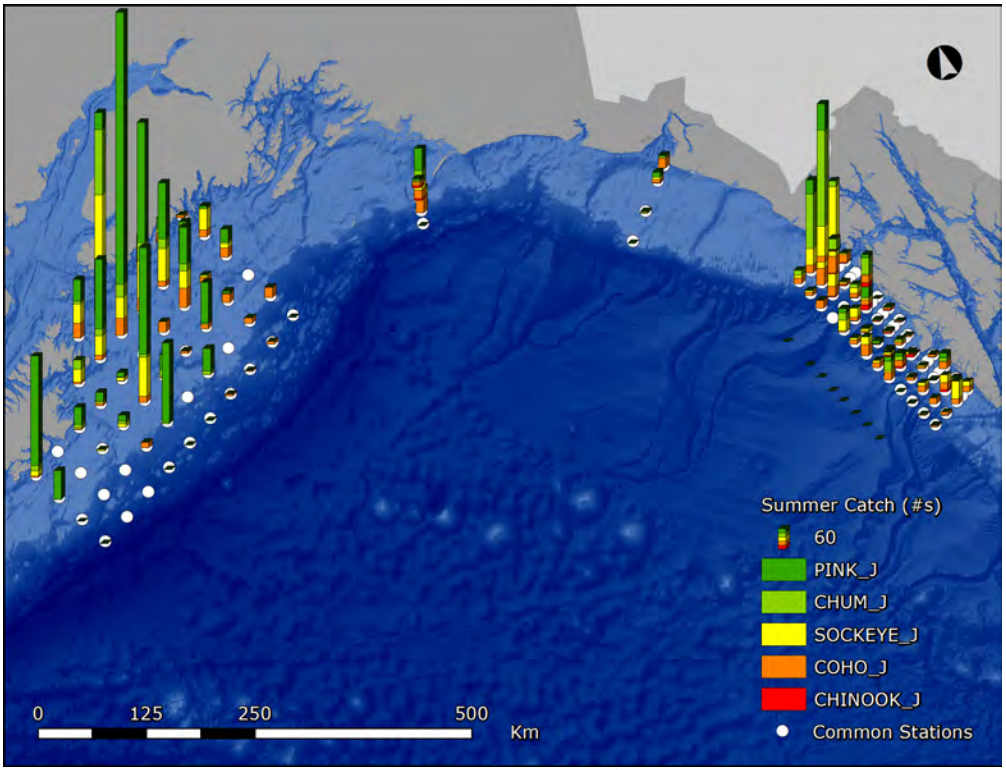


Figure 64: Distribution of juvenile salmon in the Gulf of Alaska during summer months in 2011.

Factors influencing observed trends: None at this time.

Implications: None to report at this time.

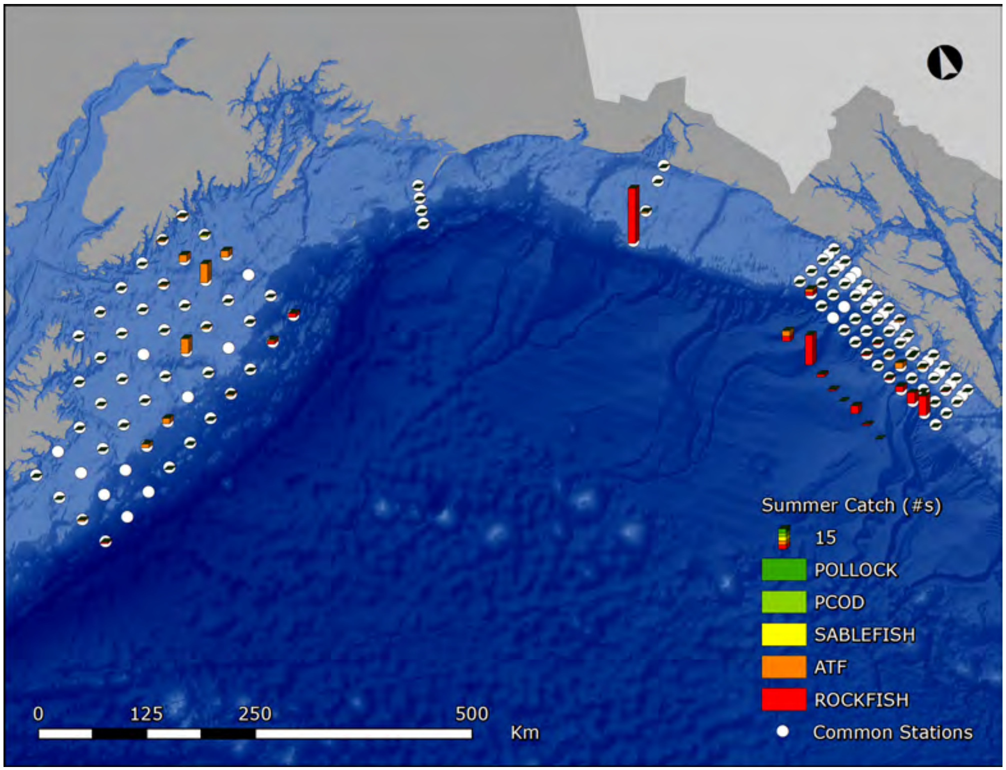


Figure 65: Distribution of age-0 marine fish in the Gulf of Alaska during summer months in 2011.

Herring

Togiak Herring Population Trends

Contributed by Greg Buck, Alaska Department of Fish and Game
Contact: gregory.buck@alaska.gov
Last updated: October 2012

Description of index: 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.

Status and trends: The largest biomass observed in Togiak District of Bristol Bay occurred in 1979 when 239,022 tons was estimated while the minimum biomass occurred in 1980 with 68,686 tons (Figure 66). In 2012 we observed 167,738 tons which is 116% of the most recent 10-year average and 114% of the 20-year average (Buck, in prep).

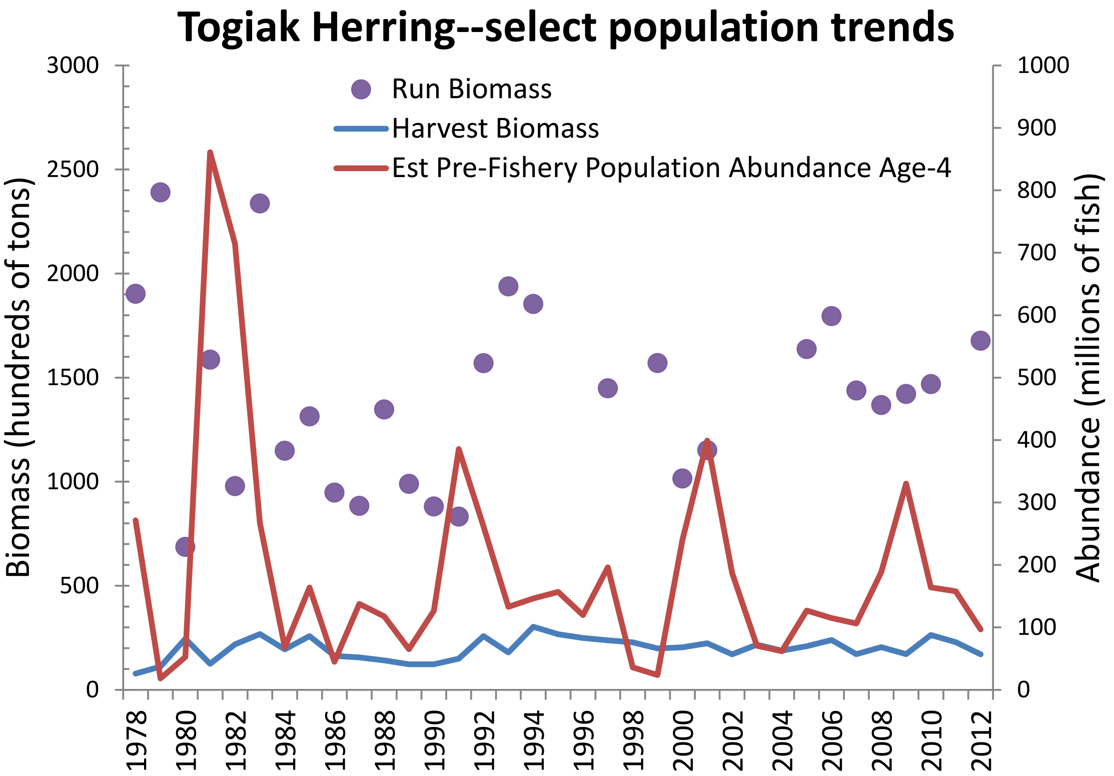


Figure 66: Observed total run and harvest biomass (hundreds of tons) with estimated abundance of age 4+ herring (millions of fish), for Pacific herring in Togiak District of Bristol Bay, Alaska 1978 - 2012.

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 in recent years. The sac roe fishery harvested 17,021 tons in 2010 which is 82% of the 10-year average and 79% of the 20-year average.

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. We consider this population healthy and sustainable at current harvest levels.

Prince William Sound Pacific Herring

Contributed by Steve Moffitt, Alaska Department of Fish and Game
Contact: steve_moffitt@fishgame.state.ak.us
Last updated: October 2008

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Southeastern Alaska Herring

Contributed by Kyle Hebert and Sherri Dressel, Alaska Department of Fish and Game, Commerical Fisheries Division, P. O. Box 110024, Juneau, AK 99811-0024
Contact: kyle.hebert@alaska.gov
Last updated: October 2012

Description of index: 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. Limited spawning occurs at other locales throughout southeastern Alaska. Little stock assessment activity occurs at these locations other than aerial surveys to document the miles of spawn along shoreline. Spawning at the nine primary sites for which regular assessments are conducted have probably accounted for 95-98% 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 (Figure 67). Since 1980, through 2011, several stocks show at least moderate increasing trends, with four of the nine primary, surveyed locations (Sitka Sound, Hoonah Sound, Seymour Canal, and Craig) exhibiting a pronounced trend of increasing biomass, and one area (Kah Shakes/Cat Island) exhibiting a pronounced downward trend. Since 1998, the southeastern Alaska spawning herring biomass estimate has been above the long-term (1980-2011) median of 87,296 tons. Although the long-term trends in most spawning areas are increasing, an apparent decrease in biomass was observed between 2010 and 2011 for some areas, including Tenakee Inlet and Hobart Bay. Nevertheless, the 2010 and 2011 estimates of spawning biomass, combined for the entire region, were the two highest in the 32-year time series (Figure 68). Since 1980, herring biomass near Sitka has contributed between 37% and 72% (median: 55%) of the total estimated annual biomass among the nine surveyed spawning locations. Excluding the Sitka biomass from a combined estimate, southeastern Alaska herring biomass has been above the 25-year median of 40,985 tons in every year since 1998, except for 2000.

Estimated abundance of total age-3 herring recruits (mature and immature) has varied greatly among and within stocks over time (Figure 67). The number of age-3 recruits has been estimated for Seymour Canal, and Sitka for most years since 1980; for Craig in every year since 1988; and for West Behm Canal, Ernest Sound, Hobart Bay-Port Houghton, and Hoonah Sound for most years

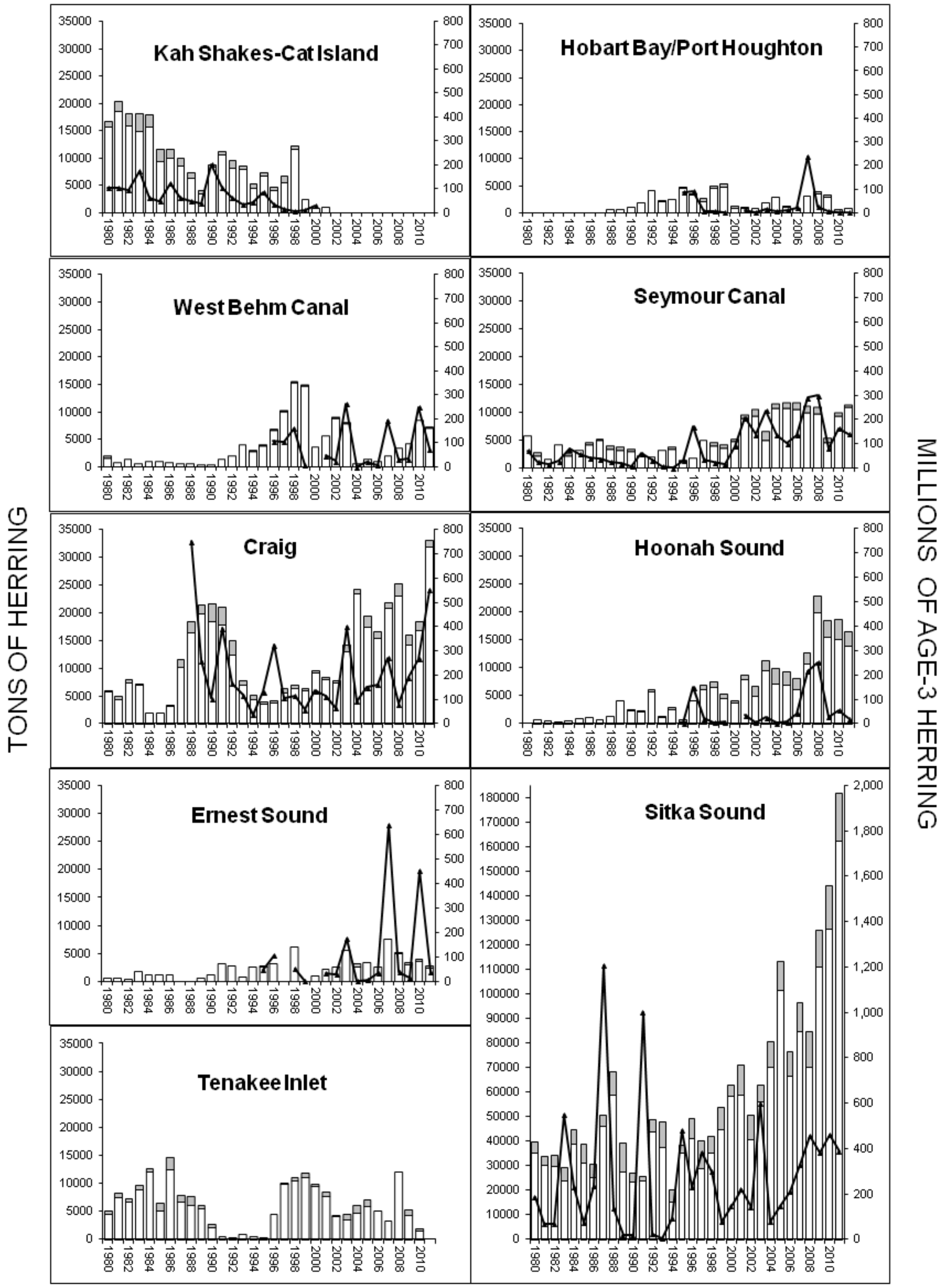


Figure 67: Estimated post-fishery mature herring biomass (white bars in tons), catch (gray bars in tons) and age-3 recruitment to mature population (black line) at nine major spawning locations in southeastern Alaska, 1980-2011. Estimates of recruitment for Tenakee Inlet were unavailable by time of publication.

since 1995. An oscillating recruitment pattern with strong recruit classes every three to five years is apparent 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

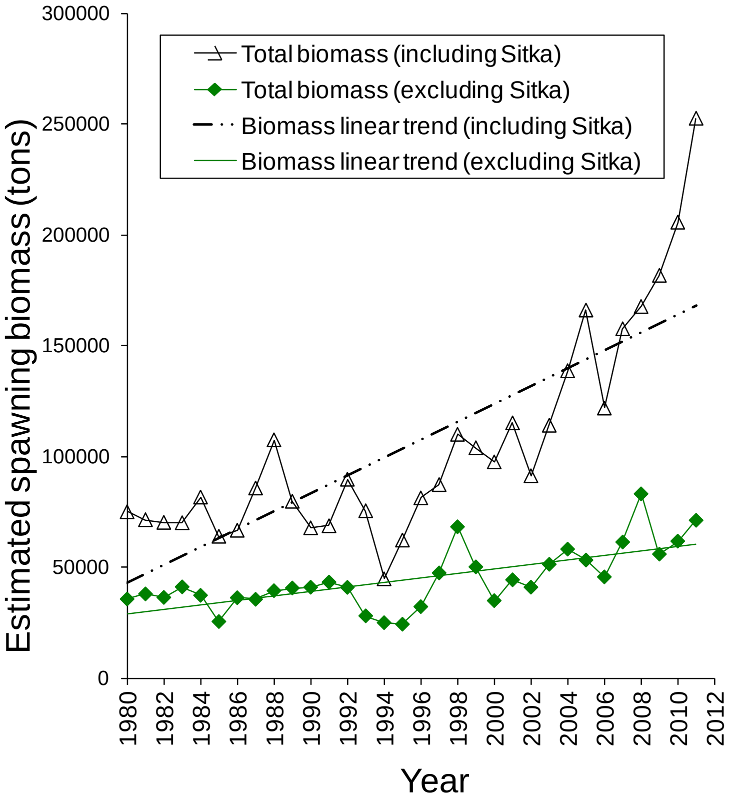


Figure 68: Estimated combined annual mature herring biomass (including and excluding Sitka) at major southeastern Alaska spawning areas, 1980-2011.

in the 1980s and early 1990s changed to more consistent, intermediate recruit abundances in the mid-1990s through 2011.

Factors influencing observed trends: The generally increasing long-term trends of biomass observed for many herring stocks in southeastern Alaska, particularly over the past 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, for the period 1980-1998, survival has been estimated to be 57%, while for the period 1999-2011 survival is estimated at 79%. Similar shifts in survival have been estimated for the Craig and Seymour Canal stocks. These shifts in survival coincide with time periods of change in ocean conditions, as indexed by the Pacific Decadal Oscillation (PDO).

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 a few areas in 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 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 to spawning grounds within the Annette Island

Reserve, bordering Revillagigedo Channel. In Lynn Canal spawning area reasons for the decline are unclear but may have been influenced by a number of factors including commercial harvest, increased predation by marine mammals, and development 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, at most areas, has varied roughly in proportion to forecast biomass (Figure 68). The high abundance of mature herring observed at many spawning areas is a positive sign for short-term future commercial fishery opportunities in the region. 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.

Salmon

Historical and Current Alaska Salmon Trends

Contributed by Andy Whitehouse[1] and Todd Tenbrink[2]
[1]Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington, Seattle WA [2]Resource Ecology and Fishery Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: andy.whitehouse@noaa.gov
Last updated: August 2012

Description of index: 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 (e.g., Eggers and Carroll (2012)).

Pacific salmon in Alaska are managed in four regions based on freshwater drainage basins, Southeast, Central (encompassing Prince William Sound, Cook Inlet, and Bristol Bay), Arctic-Yukon-Kuskokwim, and Westward (Kodiak, Chignik, and Alaska peninsula (`http://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmonareas`). 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 generally fluctuated over the last 35-40 years (Figure 69). According to ADF&G, total salmon commercial harvests from 2011 totaled 177.1 million fish, approximately 26.4 million less than the preseason forecast of 203.5 million. ADF&G is forecasting a decrease in the total commercial catch to 132.1 million fish in 2012, due to an expected decrease in the number of pink salmon. Projections for 2013 will not be available until February 2013.

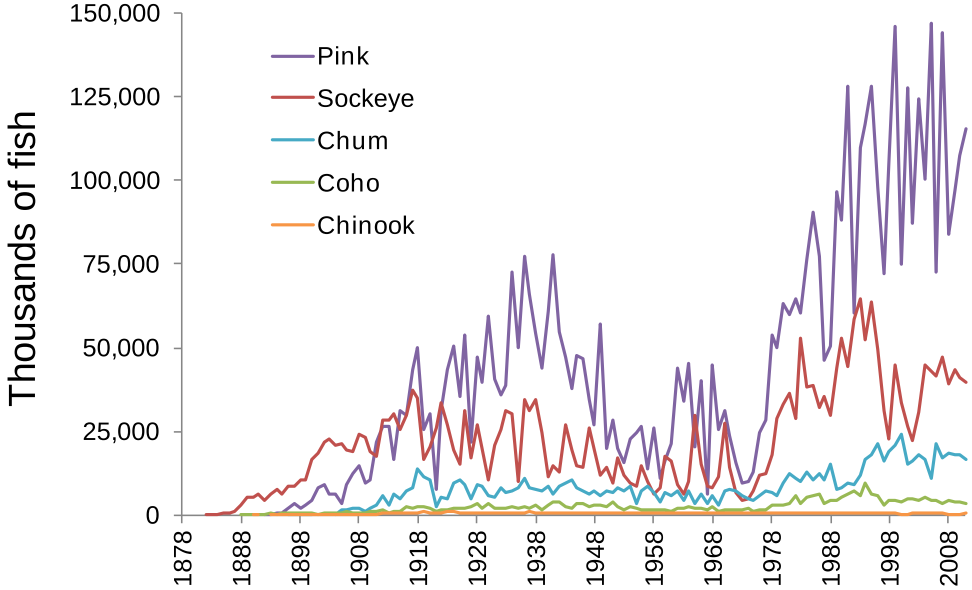


Figure 69: Alaskan historical commercial salmon catches and ex-vessel values. 2011 values are preliminary. (Source: ADF&G, `http://www.adfg.alaska.gov`. ADF&G not responsible for the reproduction of data.)

Bering Sea. Chinook salmon production for many stocks in the Yukon River has been declining in recent years. The Chinook harvest for 2011 in the Arctic-Yukon-Kuskokwim region was considerably below average and no commercial periods targeting Chinook salmon were allowed during the 2011 summer season in the Yukon Area. In Bristol Bay, the 2011 Chinook harvest was below average in every district. In the Kuskokwim Area, Chinook salmon abundance was poor and only 4 of 10 escapement goals were met. The coho catch in Bristol Bay was 85% below the recent 20 year average, with the majority of the catch in the Togiak District. Chum salmon catches in Bristol Bay, depending on the district, have been above or below the 20 year average. In the past, chum salmon in the Yukon River have been classified as stocks of concern (Eggers, 2003). The preliminary estimate of the 2011 fall run of Yukon River chum salmon is estimated to be above the upper end of the preseason forecast range (605,000-870,000 fish), and the fall chum salmon harvest (238,979 fish) was the highest since 1995.

Recruitment for most Bristol Bay sockeye salmon stocks was moderate to strong in the 1980s and into the mid-1990s. Beginning with the 1973 brood year (>1979 return year) of Bristol Bay sockeye salmon, the number of returning adults produced from each spawner showed a dramatic increase across most stocks (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. Bay-wide forecasts have been fairly accurate in recent years, although forecasts to individual rivers have been less accurate. Historically, total runs to Bristol Bay have been highly variable, but in recent years, 2004-2010, sockeye salmon runs have been well above the long term mean (Figure 70). The 2011 run of 30.3 million fish was close to the long-term average of 30.6 million, but 21% below the forecasted run size. The run size forecasted for 2012 Bristol Bay sockeye is 32.3 million fish.

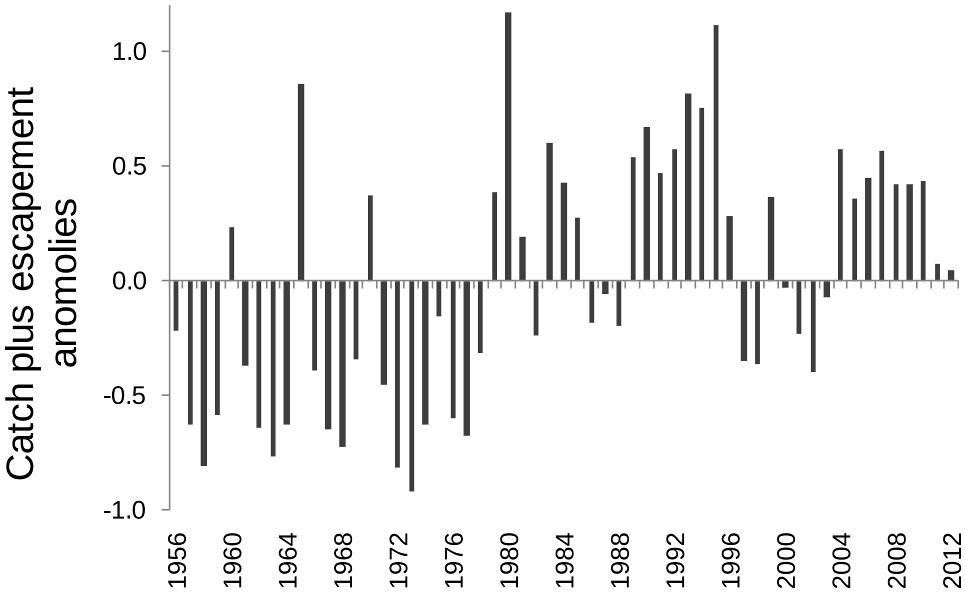


Figure 70: Historical catch plus escapement anomalies of Bristol Bay sockeye salmon, 1956-2011. Data provided by Charles Brazil (ADF&G). Note: the value for 2012 is preliminary and subject to revision.

Gulf of Alaska. In southeast Alaska and the Yakutat region, 2011 harvests totaled 73.6 million fish, which was 35% above the 54.4 million average harvest over the most recent ten years and well above the long-term average since 1962 of 38.6 million fish. In the Central region, the Prince William Sound fishing area harvests the majority of the total catch. In 2011, pink salmon comprised 85% of the Prince William Sound commercial salmon harvest. The purse seine commercial common property fishery (CPF) harvest of 26.9 million pink salmon was the tenth highest since 1971. 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. Commercial Chinook salmon fisheries occur in Copper River and the Southeast Alaska troll fishery. Catches in this fishery declined in the late 1990s. The 2011 catch of 346,000 Chinook was just below the recent ten-year harvest average of 349,000. Coho fisheries in Central and Western Alaska are not fully developed, but the harvest of 2.3 million in 2011 was just above the recent 10 year average of 2.1 million. Directed chum salmon fisheries occur on hatchery runs in Prince William Sound and Southeast Alaska. The 2011 harvest of 10.7 million chum salmon in Southeast Alaska and Yakutat regions was above the long-term average of 5.4 million fish (1962-2009) and equivalent to the most recent 10 year average of 9.6 million fish.

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. Hatchery pink salmon marine survival in 2007 (2005 brood year) was the second highest recorded during the 1977-2009 time period. Marine survival in 2010 (2008 brood year) is at an all-time high since 1977 (Figure 71).

Factors causing observed trends: Bering Sea chum salmon are generally caught incidentally to other species and catches may not be good indicators of abundance. Directed commercial chinook salmon fisheries occur in the Yukon River and Nushagak management District in Bristol Bay. In all

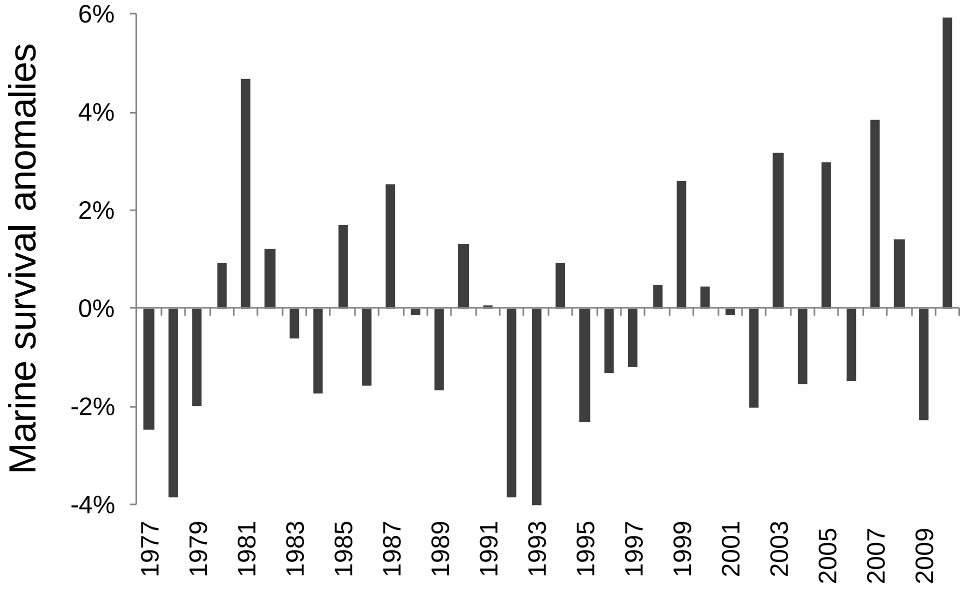


Figure 71: Marine survival of Prince William Sound hatchery pink salmon by year of return (brood year +2 years). Data reproduced from Botz et al. (2012).

other areas 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 variable may be affected differently depending upon climate conditions, for example, so more diverse sets of populations provide greater overall stability (Schindler et al., 2010).

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).

Prince William Sound pink salmon run strength is established during early marine residence (Cooney and Willette, 1997). Diet and food availability may be factors that influence growth rates during this early marine residence period. Willette and Cooney (1991) found that productivity of pink salmon in southeast Alaska are sensitive to fry-year spring time temperatures.

Implications: Directed salmon fisheries are economically important for the state of Alaska. Salmon have important influences on Alaskan marine ecosystem through their predatory impacts and as sources of prey for species such as Steller sea lions.

Forecasting Pink Salmon Harvest in Southeast Alaska

Contributed by Joe Orsi, Emily Fergusson, Molly Sturdevant, and Alex Wertheimer
Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: joe.orsi@noaa.gov
Last updated: August 2012

Description of index: An objective of the Alaska Fisheries Science Center (AFSC), Auke Bay Laboratories (ABL) Southeast Alaska Coastal Monitoring (SECM) project `http://www.afsc.noaa.gov/abl/msi/msi_secm.htm` is to understand the effects of climate and ocean on year class strength of salmon and ecologically-related species in Southeast Alaska (SEAK). Since 1997, the SECM project has collected a time series of data using surface trawls and oceanographic instruments in coastal SEAK which has allowed an annual index of ecosystem metrics to be constructed and used for pre-season pink salmon (*Oncorhynchus gorbuscha*) forecast models. Pink salmon are an ecologically and economically important species in SEAK ($ 92.5 M in 2011) that do not lend themselves to traditional sibling or stock assessment models because of their brief ocean life history. Consequently, adult returns are notoriously difficult to forecast; their 2-year life history with one ocean winter precludes the use of younger returning age classes to predict cohort abundance. Thus, an SECM pink salmon pre-season forecast model was developed to aid fishery managers and to help better understand mechanisms in play in the Gulf of Alaska ecosystem.

Status and trends: Since 1960 in SEAK, pink salmon year-class success has varied widely, with harvests ranging from 3 to 78 million fish annually. This variability may result from dynamic ocean conditions that affect juveniles. Therefore, the SECM approach has been to sample 4-65 km offshore along coastal localities in the vicinity of Icy Strait on monthly research surveys. Oceanographic sampling is conducted in May, June, July, and August, while surface trawling for epipelagic fish species is conducted in the latter three months. The SECM data has also been used to describe epipelagic fish assemblages in the Alaska Coastal Current compared to the California Current, to define Essential Fish Habitat for Pacific salmon in the U.S. Exclusive Economic Zone of Alaska, and to document life history patterns of threatened and endangered salmon stocks off SEAK. For the pink salmon forecasting, SECM data is used with other regional and basin-scale data sources to construct an ecosystem matrix of input and response variables.

Researchers in the SECM project have provided forecasting information to stakeholders of the pink salmon resource of SEAK since 2004, enabling them to anticipate the harvest with more certainty than previous forecasting methods have allowed (`http://www.afsc.noaa.gov/abl/msi/msi_sae_psf.htm`). In 7 of the past 8 years, these forecast estimates have deviated from the actual harvests by an average of only 7% (Figure 72). Data from juvenile pink salmon catches (CPUE) are also shared with the Alaska Department of Fish and Game (ADF&G) to help refine their SEAK pink salmon harvest forecast that is developed by a different method.

Factors influencing observed trends: Selected ecosystem metrics associated with SEAK adult pink harvest over the 15-year SECM time series are shown in Figure 73 below. Subsets in the value ranges for each metric are color-coded, with the 5 highest in green, the 5 lowest in red, and the 5 intermediate values in grey. Metrics to the right of the response variable column for SEAK pink harvest are ordered by declining significance (increasing "P-value" = declining significance); the corresponding correlation coefficient "r" and "P-value" are shown below each metric. Note that in addition to CPUE, 3 other variables are significantly correlated with harvest (peak migration

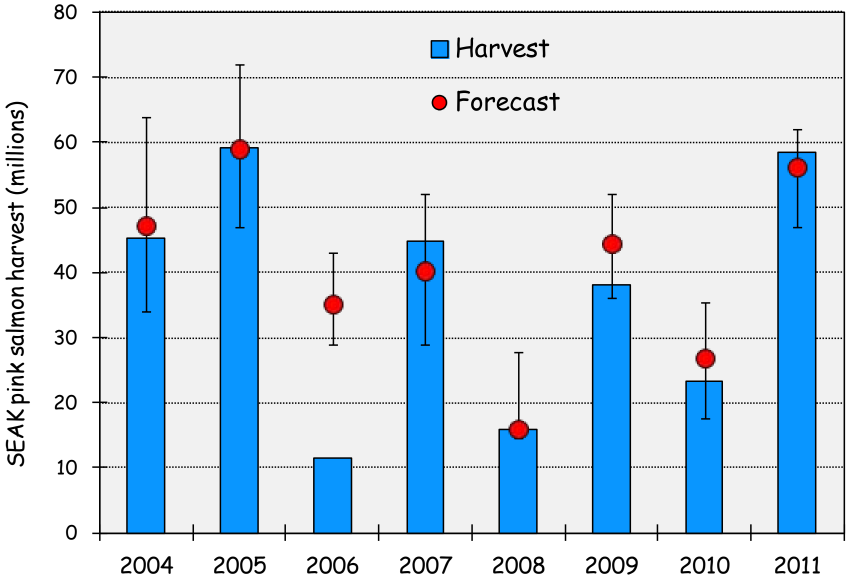
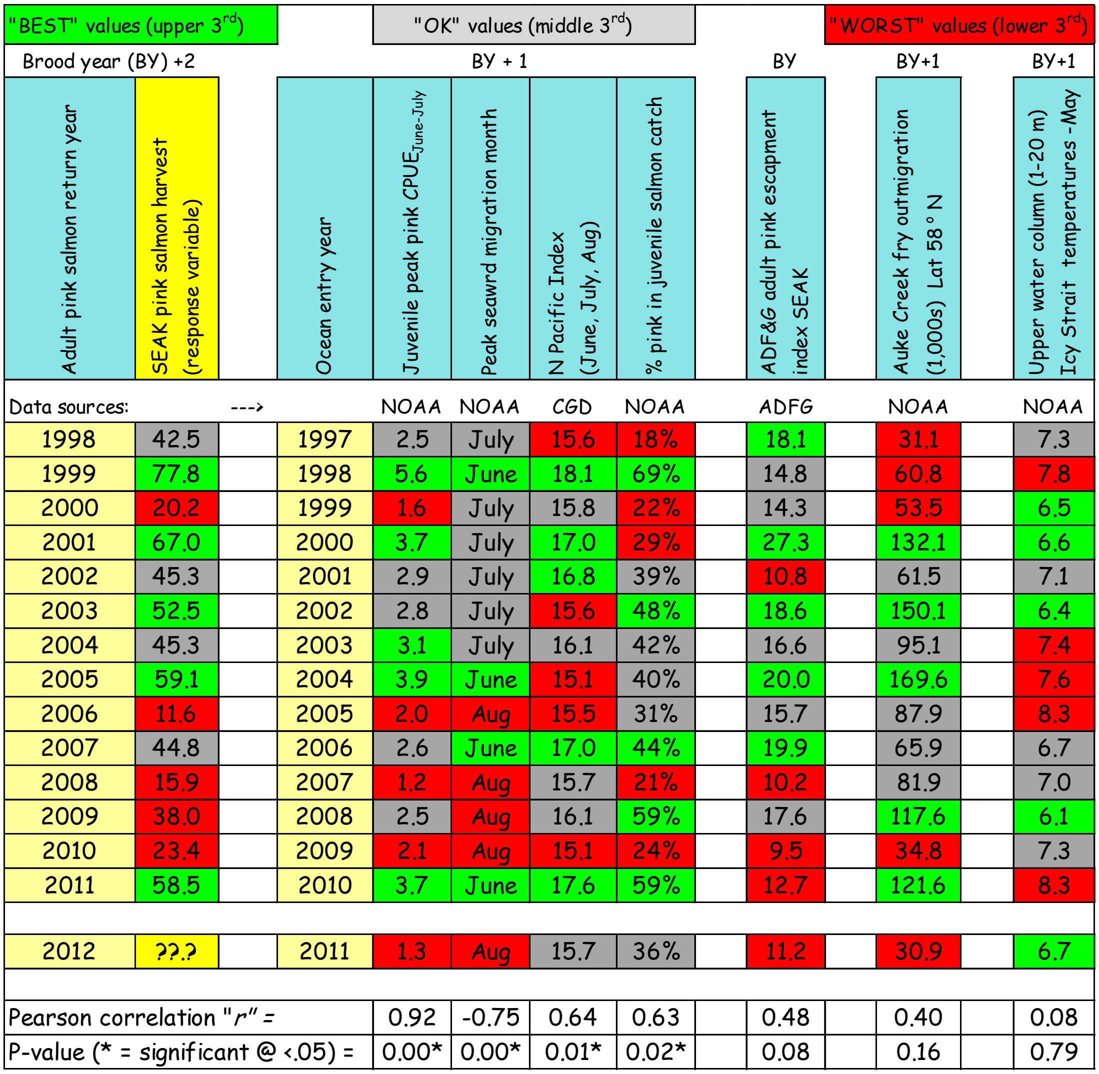


Figure 72: Previous Southeast Alaska (SEAK) pink salmon forecast model predictions (with 80% confidence intervals) and harvests.

month, NPI, and %pink in catch) and suggest a low to intermediate pink harvest in 2012. Although not significantly correlated with SEAK harvest, the low SEAK pink escapement index for the adult parent year and the low Auke Creek fry production for the juvenile year corroborate the low juvenile CPUE from trawl catches. May 20-m temp was not significantly correlated with harvest, but has served as an important secondary parameter to explain the error in the CPUE and harvest regression model.

Implications: Additional evidence from SECM research and other indicators suggested a low pink harvest for SEAK in 2012. The strongest sign was that the 2011 peak juvenile pink CPUE was the second lowest on record. Over the 15-year SECM time series, both the ADF&G escapement index for the pink salmon parent year (2010) in SEAK and subsequent wild pink salmon fry production from Auke Creek in 2011 were the third lowest values. Also, ocean catch rates of juvenile pink salmon from two trawl surveys in the eastern Gulf of Alaska (GOA) were lower in 2011 than in 2010 (GOA Integrated Research Project and SECM sampling along the Icy Point transect).

Given the ecosystem conditions and SECM metrics sampled in 2011, the two best SECM forecast models for the 2012 SEAK pink salmon harvest are shown below in Table 7. Each forecast model value has an 80% bootstrap confidence interval shown in parentheses. The 2-parameter model was the best fit predictor for the relationship of the 15-year time series of SECM data parameters with subsequent SEAK pink salmon harvests from 1998 to 2011, based on the R^2 and AIC_c.



"BEST" values (upper 3rd) "OK" values (middle 3rd) "WORST" values (lower 3rd)

Brood year (BY) +2		BY + 1					BY	BY+1	BY+1
Adult pink salmon return year	SEAK pink salmon harvest (response variable)	Ocean entry year	Juvenile peak pink CPUE$_{June-July}$	Peak seawrd migration month	N Pacific Index (June, July, Aug)	% pink in juvenile salmon catch	ADF&G adult pink escapment index SEAK	Auke Creek fry outmigration (1,000s) Lat 58 ° N	Upper water column (1-20 m) Icy Strait temperatures -May
Data sources:	--->		NOAA	NOAA	CGD	NOAA	ADFG	NOAA	NOAA
1998	42.5	1997	2.5	July	15.6	18%	18.1	31.1	7.3
1999	77.8	1998	5.6	June	18.1	69%	14.8	60.8	7.8
2000	20.2	1999	1.6	July	15.8	22%	14.3	53.5	6.5
2001	67.0	2000	3.7	July	17.0	29%	27.3	132.1	6.6
2002	45.3	2001	2.9	July	16.8	39%	10.8	61.5	7.1
2003	52.5	2002	2.8	July	15.6	48%	18.6	150.1	6.4
2004	45.3	2003	3.1	July	16.1	42%	16.6	95.1	7.4
2005	59.1	2004	3.9	June	15.1	40%	20.0	169.6	7.6
2006	11.6	2005	2.0	Aug	15.5	31%	15.7	87.9	8.3
2007	44.8	2006	2.6	June	17.0	44%	19.9	65.9	6.7
2008	15.9	2007	1.2	Aug	15.7	21%	10.2	81.9	7.0
2009	38.0	2008	2.5	Aug	16.1	59%	17.6	117.6	6.1
2010	23.4	2009	2.1	Aug	15.1	24%	9.5	34.8	7.3
2011	58.5	2010	3.7	June	17.6	59%	12.7	121.6	8.3
2012	??.?	2011	1.3	Aug	15.7	36%	11.2	30.9	6.7
Pearson correlation "*r*" =			0.92	-0.75	0.64	0.63	0.48	0.40	0.08
P-value (* = significant @ <.05) =			0.00*	0.00*	0.01*	0.02*	0.08	0.16	0.79

Figure 73: Matrix of ecosystem metrics considered for pink salmon forecasting.

Groundfish

Gulf of Alaska Ichthyoplankton Abundance Indices 1981-2009s

Contributed by Miriam Doyle[1] and Kate Mier[2]
[1]Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, WA 98195; based at NOAA Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115
[2] Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: miriam.doyle@noaa.gov

Last updated: July 2012

Table 7: The two best SECM pink salmon forecast models for the 2012 SEAK harvest.

2012 SECM pink salmon forecast models	Adj. R^2	AIC_c	P	Prediction for 2012
(1-parameter) Peak CPUE	83%	99.3	<0.001	17.1 M (13-24)
(2-parameter) Peak CPUE+May20m temp	89%	95.9	<0.001	18.8 M (13-25)

Description of index: The Alaska Fisheries Science Center's (AFSC) Ichthyoplankton Database (IchBASE) includes data from collections in the Gulf of Alaska (GOA) from 1972 to the present and with annual sampling since 1981. 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 μm 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 late spring, May 18-June 6 (Figure 74). From this area and time, a subset of three decades of data has been developed into a time-series of ichthyoplankton species abundance (Doyle et al., 2009).

Historical trends in late spring abundance are presented for the most abundant larval taxa in the GOA, representing commercially and ecologically important species (Figure 75). The time-series extends from 1981 through 2009 with no data for 1984 and 1986. Abundance values are normalized over the time-series. Trends in abundance of these species (1981-2003) 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).

Status and trends: Coherent patterns and synchronicity in trends were observed among groups of species, and with the extension of the time-series through 2009, these similarities and synchronicities are maintained (Doyle and Mier, in press). For instance, Pacific cod, walleye pollock, and northern rock sole display a high degree of synchrony in abundance with periodic years of high abundance primarily during the 1990s and after 2005. Northern lampfish, arrowtooth flounder, and Pacific halibut show a pattern of enhanced abundance during the 1990s and 2004-2007 relative to the 1980s, 2000-03, 2008 and 2009. Interannual patterns for rockfish (*Sebastes* spp.), southern rock sole, and starry flounder are characterized by low to moderate abundance through most of the 1980s to mid-1990s, followed by some dramatic swings in abundance including occasional high anomalies in the second half of the time-series. Trends for these and other species are described further and analyzed statistically with non-metric multidimensional scaling (NMDS) ordination in Doyle et al. (2009) and Doyle and Mier (in press). The annual sampling for the GOA ichthyoplankton time-series ends in 2011 with plans for biennial sampling from 2013 onwards due to decreases in funding and ship time.

Factors causing observed trends: Synchronies and similarities in larval abundance trends through 2003, and in GAM model-generated links to time-series of environmental variables, reflect early life history variation among species (Doyle et al., 2009). Similarities in response to environmental forcing were apparent among species that display similarities in patterns of early life history

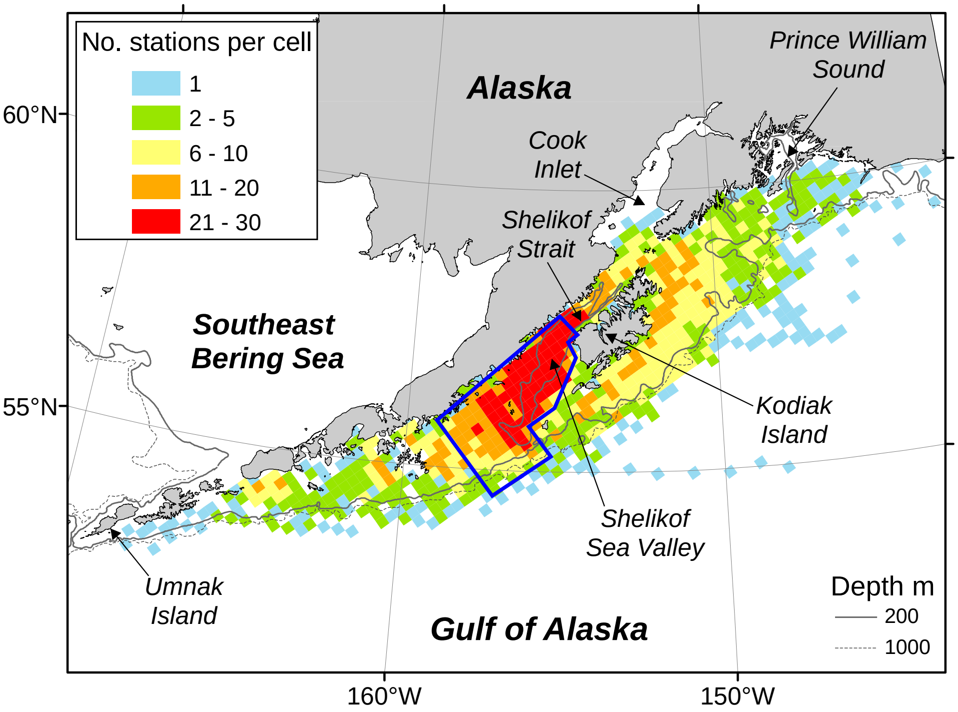


Figure 74: Distribution of ichthyoplankton sampling in the Gulf of Alaska by NOAAs Alaska Fisheries Science Center from 1972 through 2009 using a 60 cm frame bongo net. Sampling effort is illustrated by the total number of stations sampled in 20 km^2 grid cells over these years. A late spring time-series of mean abundance of ichthyoplankton species has been developed for the years 1981-2009, from collections in the polygonal area outlined in blue where sampling has been most consistent during mid-May through early June (Doyle et al., 2009).

exposure to the environment. 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. Further evidence of environmental exposure-response connections among GOA species is provided by a recent study that incorporates multiple early life history characteristics into a comparative analysis of early ontogeny exposure patterns (Doyle and Mier, in press). Species groups that emerged from this analysis were reflected in the NMDS ordination of the 1981-2009 larval abundance time-series. With the current extension of the ichthyoplankton time-series through 2011, and associated environmental variables, GAMs will be re-run as in Doyle et al. (2009) to investigate for consistency and variability in the established relationships between species (and groups of species) abundance and aspects of the GOA environment. For commercial populations, species-environment relationships will also be investigated using time-series of recruitment metrics. These new analyses will further illuminate mechanistic linkages and enhance the predictive potential with respect to species early life history response to varying environmental conditions. Syntheses of these results will be presented in future Ecosystem

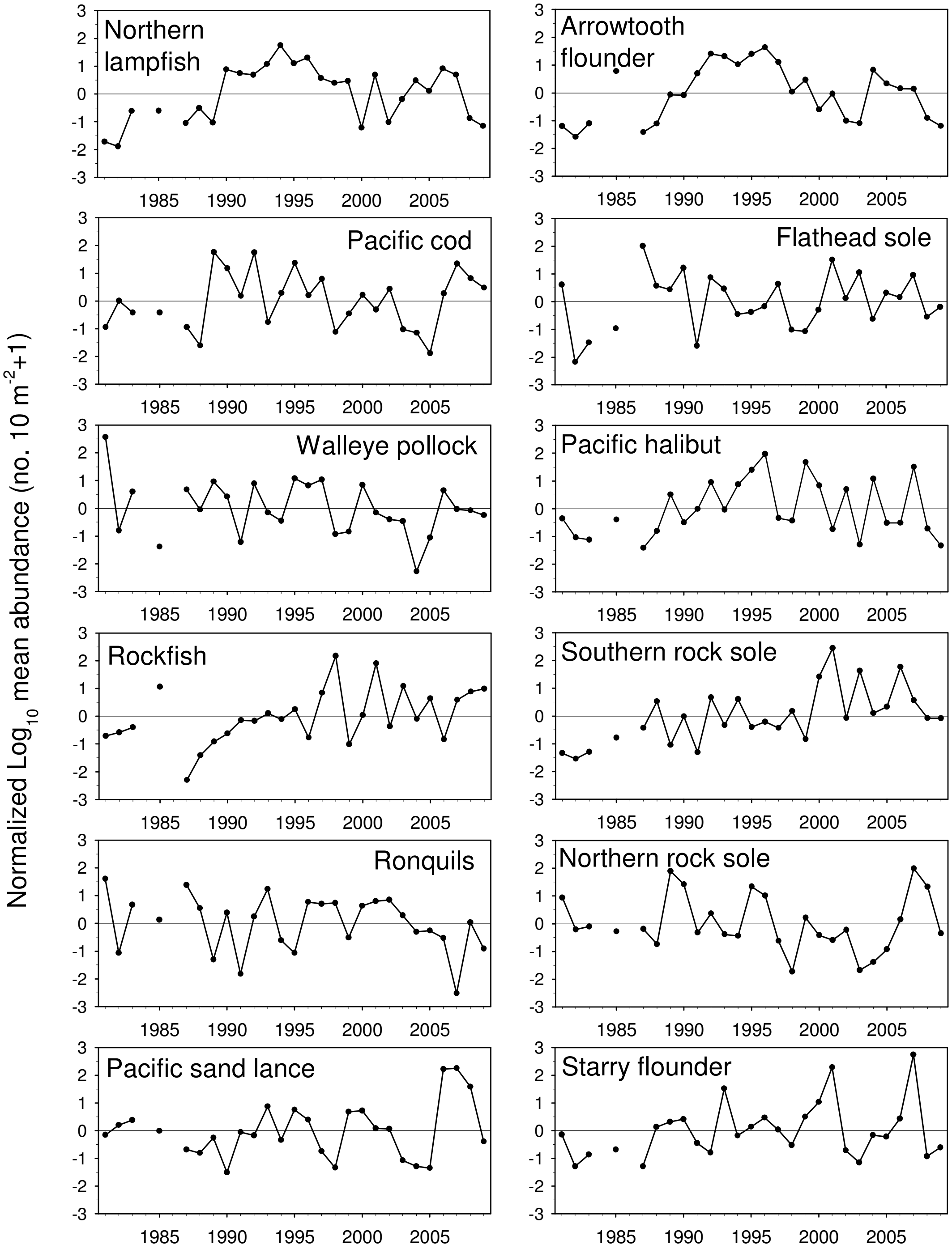


Figure 75: Interannual variation in late spring larval fish abundance for the most abundant species in the Gulf of Alaska. For each year, the larval abundance index is expressed as the log10 of mean abundance (no. 10 m^{-2}+1) standardized by the time-series mean and standard deviation.

Considerations reports.

Implications: Understanding ecological connections between the early ontogeny stages of fish and the pelagic environment contributes to the evaluation of vulnerability and resilience among GOA species early life history patterns to fluctuating oceanographic conditions. Analyses of these time-series also provides crucial information for the identification of environmental indicators that may have a broad-spectrum effect on multiple species early life history stages, as well as those that may be more species-specific in exerting control on early life history survival. Ongoing research addresses the hypothesis that we can utilize similarities in reproductive and early life history characteristics among species to identify (a) ecologically determined species groups that are pre-disposed to respond to environmental forcing in similar ways, and (b) plausible environmental predictors of early life history aspects of recruitment variation. The decrease in sampling frequency of GOA ichthyoplankton (from annual to biennial) is unfortunate as this is one of very few annual ichthyoplankton abundance time-series in the world that extends beyond 25 years. In association with climate and ocean time-series it can illuminate early life history mechanisms that influence recruitment, as well as provide critical information on likely response patterns among species to environmental fluctuations in the GOA. Biennial sampling seriously compromises our ability to assess such response patterns.

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
[1]Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Rd, Nanaimo, BC, Canada V9T 6N7
[2]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[3]International Pacific Halibut Commission
Contact: jennifer.boldt@dfo-mpo.gc.ca
Last updated: October 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Bering Sea Groundfish Condition

Contributed by Jennifer Boldt[1] and Jerry Hoff[2]
[1]University of Washington. Current address: Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Rd, Nanaimo, BC, Canada V9T 6N7
[2]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: jennifer.boldt@dfo-mpo.gc.ca
Last updated: October 2008

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

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

Contributed by Tom Wilderbuer and Jim Ingraham (retired), Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: tom.wilderbuer@noaa.gov
Last updated: October 2012

Description of index: Wilderbuer et al. (2002) 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 change 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 2012 (Figure 76).

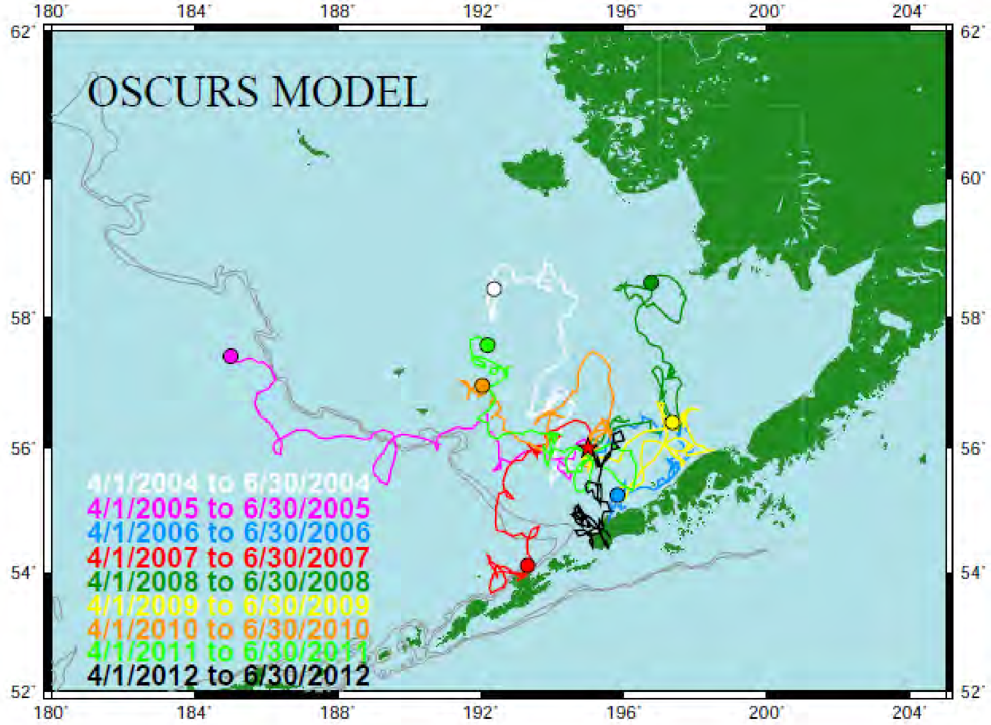


Figure 76: OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56°N, 164°W from April 1-June 30 for 2004-2012.

Status and trends: The 2012 springtime drift patterns do not appear to be consistent with years of good recruitment for winter-spawning flatfish. Five out of nine OSCURS runs for 2003-2011 were consistent with those which produced above-average recruitment in the original analysis, 2005, 2007 and 2009 being the exceptions. 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 and larval occurrence 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 2012 springtime drift patterns do not appear to be consistent with years of good recruitment for northern rock sole, arrowtooth flounder and flathead sole. The drift patterns in 2010 and 2011 are less clear in terms of classification relative to other years. In 2010 there were strong northerly winds for part of the spring which would suggest increased larval dispersal to Unimak Island and the Alaska Peninsula. In 2011 the pattern was more across-shelf in a northerly direction, opposite of 2010.

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

Contributed by Ellen Martinson, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Ted Stevens Marine Research Institute, 17109 Point Lena Loop Road, Juneau, Alaska 99801-8626
Contact: ellen.martinson@noaa.gov
Last updated: August 2012

Description of index: The temperature change (TC) index is a composite index for the pre- and post-winter thermal conditions experienced by pollock (*Theragra 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 77) 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). Less negative values represent a cool late summer during the age-0 phase followed by a warm spring during the age-1 phase for pollock.

Status and trends: The 2012 TC index value -5.56 is based on a cooler than average late summer in 2011 (8.65°C) followed by the coldest June temperature (3.09°C) recorded since 1948 (Figure 77). The TC index is positively correlated with subsequent recruitment to age-1 through age-6 based on abundance estimates from (Ianelli et al., 2011) (Figure 78). This relationship has improved over time (Table 8).

Factors causing observed trends: The age-0 pollock are more energy-rich in a year with a cooler late summer (Heintz, personal communication). 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). These conditions are assumed more favorable for the overwintering survival of pollock from age-0 to age-1.

Implications: In 2010, the TC index value of -6.00 was below the long term average of -4.58, therefore we expect below average numbers of pollock to survive to age-3 in 2012. In the future, the TC values in 2011 (TC=-4.23) and 2012 (TC=-5.56) indicate above average abundances of

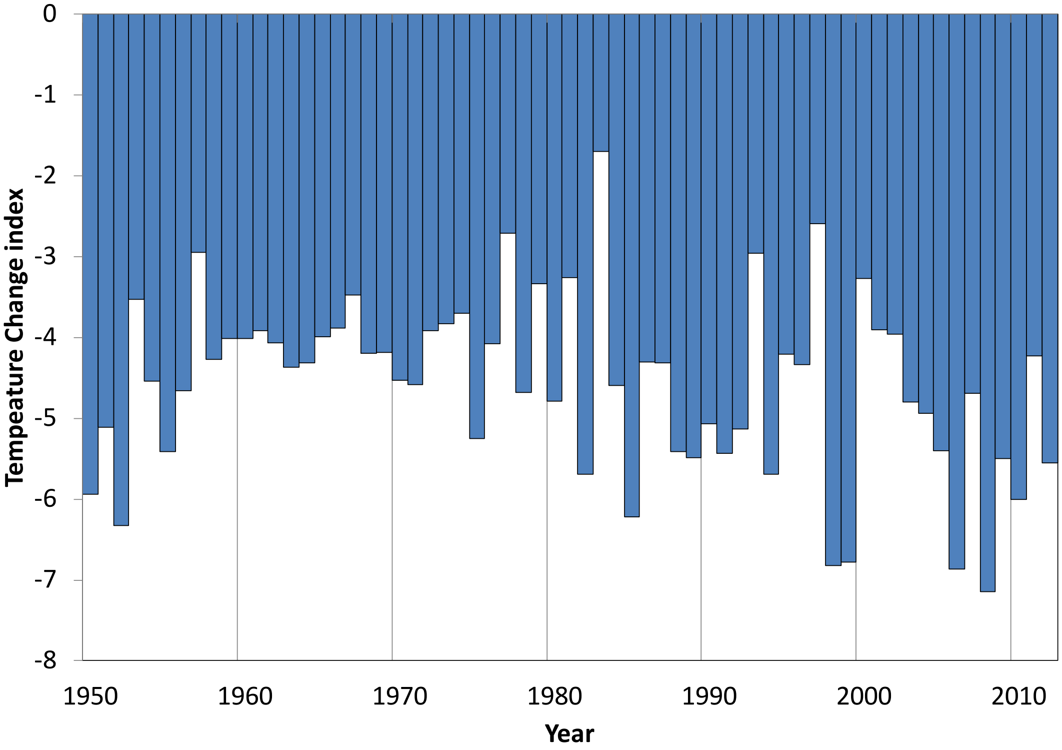


Figure 77: The Temperature Change index value from 1950-2012.

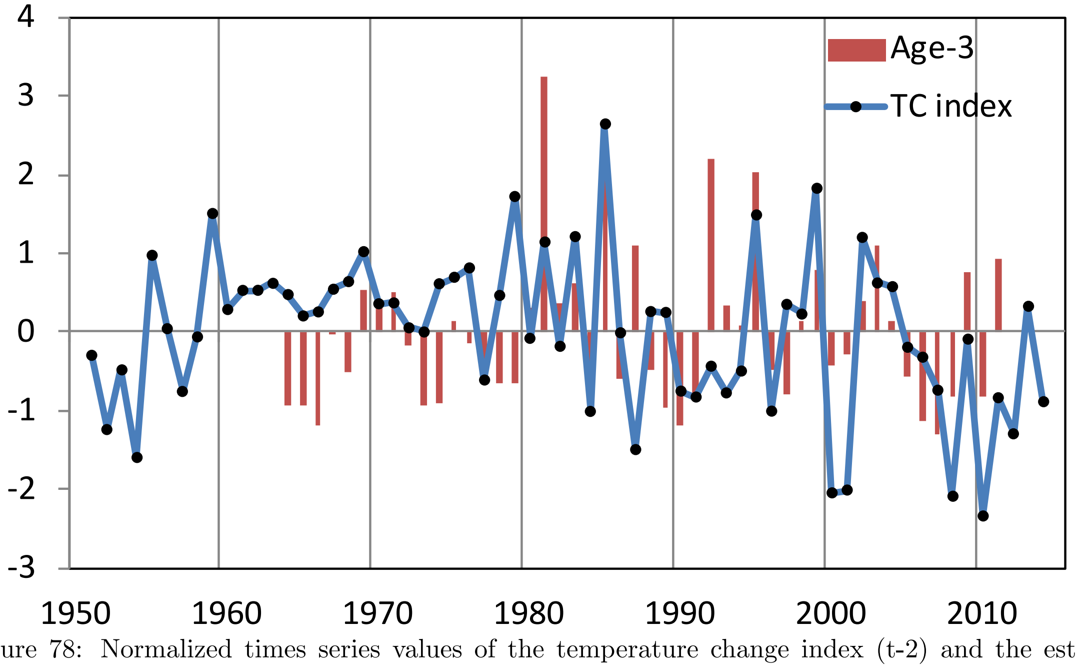


Figure 78: Normalized times series values of the temperature change index (t-2) and the estimated abundance of age-3 walleye pollock in the eastern Bering Sea (t).

age-3 pollock in 2013 and below average abundances of age-3 pollock in 2014.

Table 8: Pearson's correlation coefficient relating the temperature change index (t+x) to subsequent estimated year class strength of pollock (Age-x+1). Bold values are statistically significant ($p < 0.05$).

	Correlations					
TC Index Pollock	t Age-1	t+1 Age-2	t+2 Age-3	t+3 Age-4	t+4 Age-5	t+5 Age-6
1964-2011	**0.415**	**0.407**	**0.385**	**0.343**	**0.289**	0.281
1995-2011	**0.505**	**0.509**	**0.611**	**0.659**	**0.616**	**0.533**

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

Contributed by Chris Rooper, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: chris.rooper@noaa.gov
Last updated: October 2012

Description of index: 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 have been two statistically significant depth-related trends over the time series, as the distribution of both northern rockfish and shortspine thornyhead has been shallower in the most recent surveys of the Aleutian Islands (Figure 79). Northern rockfish have also shown a significant trend 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.

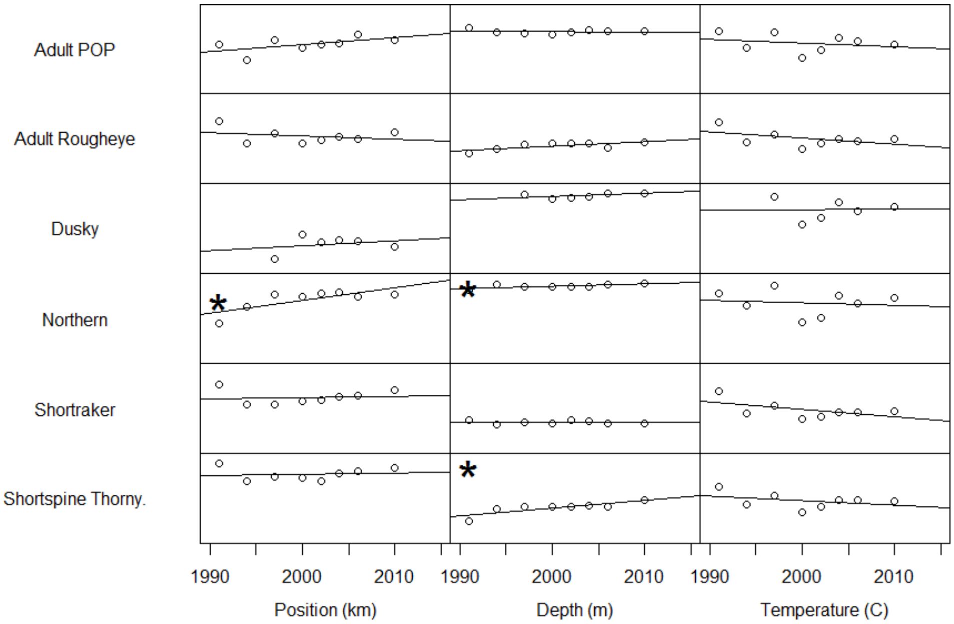


Figure 79: Plots of mean weighted (by catch per unit effort) distributions of six rockfish species-groups along three environmental variables in the Aleutian Islands. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance 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.

The depth distribution of rockfish in the Gulf of Alaska has remained constant for each species over time with the exception of shortraker rockfish (Figure 80). Changes in rockfish distribution with temperature have occurred over the time series, most notably since 2007 where there has been a constriction of the range of mean-weighted temperatures for rockfish. In past contributions, a shift in the distribution of rockfish to the eastern and SE areas of the Gulf of Alaska was noted; however, in the 2011 bottom trawl survey data this trend was ameliorated.

Factors causing observed trends: The observed changes in depth and spatial distributions for northern rockfish, shortraker 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 shortspine thornyhead and shortraker rockfish their depth range has become shallower while the temperatures occupied by the species have not changed in recent surveys.

It is unclear why the shift in rockfish distribution towards the eastern GOA and SE Alaska was not found in the 2011 survey data. It may also 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 position and temperature distributions of rockfish.

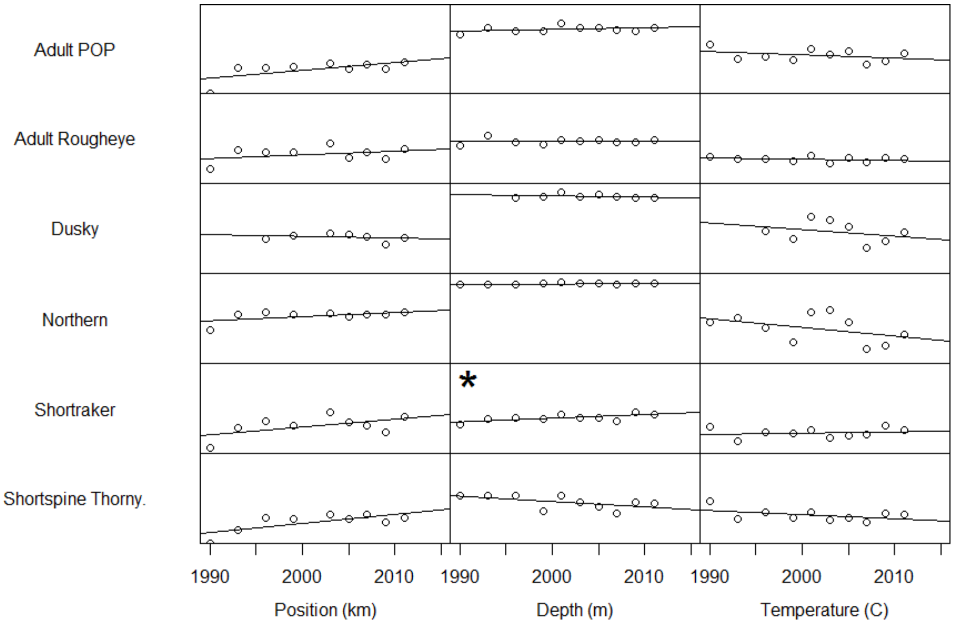


Figure 80: Plots of mean weighted (by catch per unit effort) distributions of six rockfish species-groups along three environmental variables in the Gulf of Alaska. Mean weighted distributions of rockfish species-groups are shown for A) position, B) depth, and C) temperature. Position is the distance 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

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]
[1]The Farallon Institute, PO Box 750756, Petaluma, CA 94975
[2]University of Tasmania, Private Bag 129, Hobart, TAS, 7001, Australia
[3]University of Alaska Fairbanks, 17101 Pt. Lena Rd., Juneau, AK 99801
[4]Alaska Fisheries Science Center, 301 Research Ct., Kodiak, AK 99615
Contact: malitzow@utas.edu.au
Last updated: January 2012

Description of index: Ecosystem models predict that key system parameters should exhibit increasing variability as resilience declines and a shift between alternate stable states approaches (Carpenter and Brock, 2006). Tracking system variability has received great attention as a possible tool for providing early warning of population collapse and ecosystem reorganization, although this technique has received little empirical evaluation to date (Scheffer et al., 2009). However, historical collapses in Alaskan crustacean fisheries were preceded by rising spatial variability in catches (Litzow et al. in prep.), providing empirical evidence that variance tracking may be a useful tool for detecting impending collapses in crustacean fisheries (Figure 81). In this contribution, we calculate contemporary trends in the spatial variability of catches (among ADF&G statistical areas) to make inferences about the resilience of five commercially exploited crab populations. Fisheries analyzed included Bristol Bay red king crab, Eastern Bering Sea Tanner and snow crab, and Kodiak and South Alaska Peninsula Tanner crab. The measure of variability that we use is the standard deviation of log-transformed catch data. Our analysis only includes years during which these fisheries were managed under limited entry or IFQs, as the transition from derby-style fisheries to limited entry/IFQs produced obvious changes in fleet behavior and catch statistics.

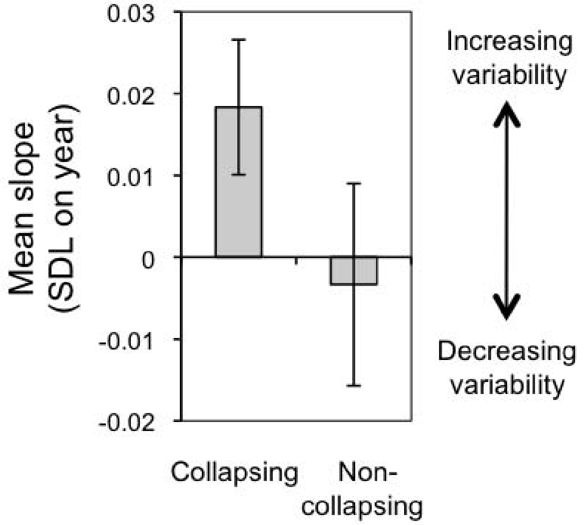


Figure 81: Trends in variability (SDL, standard deviation of log-transformed catch data) for historical crustacean catch data from the Bering Sea and Gulf of Alaska during the 1960s-2000s. Collapsing fisheries (n = 12) showed positive average slopes (i.e., increasing variability) prior to collapse, while non-collapsing fisheries (n = 2) did not show increasing variability. Differences in trend were statistically significant between the two groups (one-tailed P = 0.02). Error bars = 95% CI, figure redrawn from Litzow et al. (in prep.).

Status and trends: Only one of the five fisheries (Kodiak Tanner crab) showed a statistically significant increase in variability (one-tailed P = 0.03). Other fisheries showed either stable (EBS Tanner and snow crab) or declining (Bristol Bay red king crab and South Peninsula Tanner crab) variability (Figure 82).

Factors causing observed trends: The significant increase in catch SDL for the Kodiak Tanner crab fishery was largely driven by elevated variability in the 2011 season (Figure 82). The fishery expanded in this year: the GHL roughly doubled (1,490,000 pounds in 2011 compared to 700,000 pounds in 2010), and four sections of the Kodiak District were open to fishing compared with three sections in 2010 (Sagalkin, 2011; Sagalkin and Spalin, 2011). As a result of this expansion in the fishery, catches were reported from 21 statistical areas, compared with 15 in 2010. Four of these statistical areas produced catches below 20 pounds, and a fifth produced only 320 pounds, and these very low totals drove up variability (average catch among statistical areas was approximately 73,000 pounds). So while rising variability may generally signal impending population collapse, we conclude in this case that a more parsimonious explanation is the addition of low-catch statistical areas through expansion of the fishery. Conversely, persistent increases in variability in coming

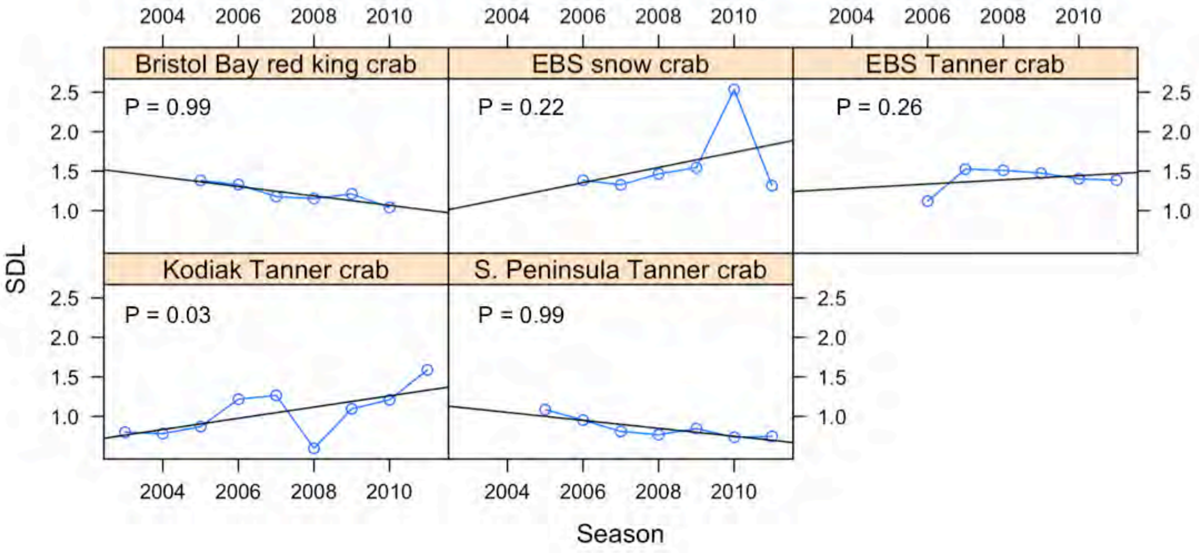


Figure 82: Current trends in spatial variability of catches for five crab fisheries in the Bering Sea and Gulf of Alaska. Fishing seasons are plotted to the calendar year including December for Bristol Bay red king crab, and to the year including January for all others. Black lines are best-fit linear trends, and P values are for one-tailed tests for increasing trends in SDL (standard deviation of log-transformed catch data).

years would be more likely to represent a decline in resilience of Kodiak Tanner crab populations.

Implications: Although the notion of rising variability prior to population collapses has a strong theoretical background, the use of "variance tracking" in a management context is in its infancy. However, patterns of rising variability did apparently distinguish collapsing from non-collapsing Alaskan crustacean fisheries in the past (Figure 81), so there is specific support for using changes in variability to monitor the status of crab stocks. Analysis of historical catch data shows statistically significant increases in variability up to five years prior to stock collapse, suggesting that this indicator may provide adequate warning for management action to avert an impending collapse (Litzow et al. in prep.). Presently, four of the five crab fisheries that we analyzed show no increases in the spatial variability of the catch, and thus are not showing patterns that might be consistent with declining resilience and an increased chance of sudden collapse. Two of these fisheries (Bristol Bay red king crab and South Peninsula Tanner crab) showed evidence of decreasing catch variability (Figure 82), which may indicate continuing development of these fisheries under the new limited entry/IFQ management systems. The fifth fishery (Kodiak Tanner crab) does show a statistically significant increase in variability, but, considering a plausible alternate explanation (addition of low-catch areas with fishery expansion in 2011), we conclude that this trend will be cause for concern only if it continues in future years.

Bering Sea/Aleutian Islands King and Tanner Crab Stocks

Contributed by Robert Foy, Kodiak Laboratory, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA

Contact: robert.foy@noaa.gov
Last updated: October 2010

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Miscellaneous Species - 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
Contact: jerry.hoff@noaa.gov
Last updated: October 2012

Description of index: "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 1982-2012. 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: With few exceptions, the trend in relative CPUE for all three species groups was very similar (Figure 83).

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

Contributed by Carrie Worton, Alaska Department of Fish and Game, 211 Mission Road, Kodiak, AK 99615
Contact: carrie.worton@alaska.gov
Last updated: August 2012

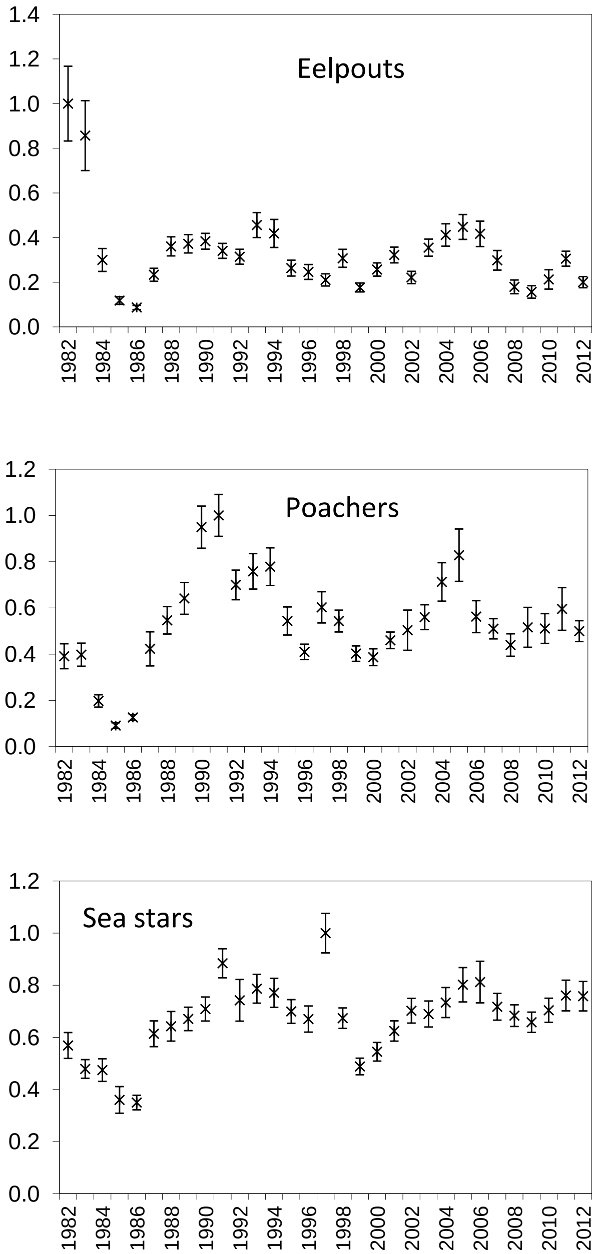


Figure 83: AFSC eastern Bering Sea bottom trawl survey relative CPUE for miscellaneous species during the May to August time period from 1982-2012.

Description of index: 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, 2010). 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 84) 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. Standardized anomalies, a measure of departure from the mean, for the survey catches 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*, and skates) using the method described by Link et al. (2002) (Figure 85). Bottom temperatures for each haul have been consistently recorded since 1990 (Figure 86).

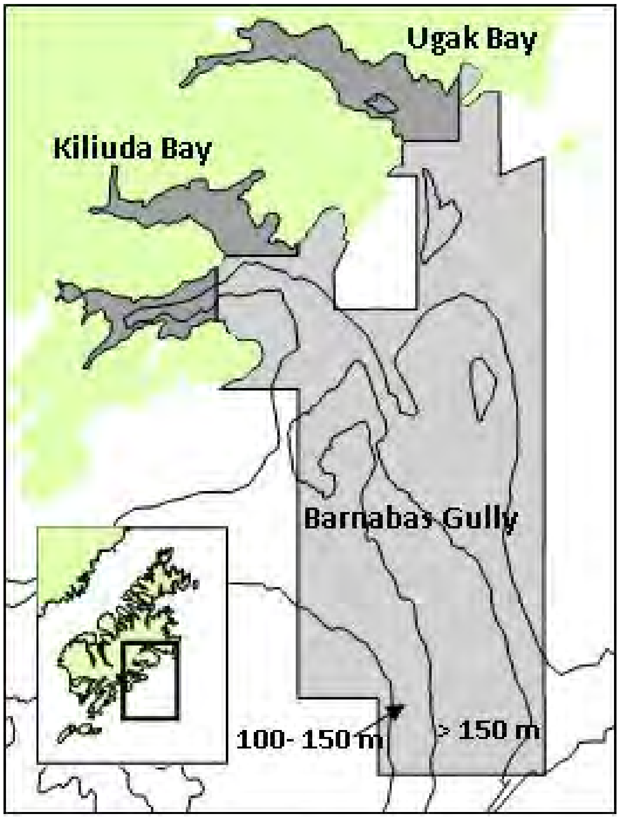


Figure 84: Adjoining survey areas on the east side of Kodiak Island used to characterize inshore (dark gray, 14 stations) and offshore (light gray, 33 stations) trawl survey results.

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 2011 from years of record high catches seen from 2002 to 2005.

Prior to the start of our standard trawl survey in 1988, Ugak Bay was the subject of an intensive seasonal trawl survey in 1976-1977 (Blackburn, 1977). Today, the Ugak Bay species composition is markedly different than in 1976. Red king crabs *Paralithodes camtschaticus* were the main component of the catch in 1976-1977, but now are nearly non-existent. Flathead sole, skate, and gadid catch rates have all increased roughly 10-fold. While Pacific cod made up 88% and walleye pollock 10% of the gadid catch in 1976-1977, catch compositions have reversed in 2011 with Pacific cod making up 17% of catch and walleye pollock 82%. Overall catches have decreased slightly in 2011 (Figure 87) with arrowtooth flounder, flathead sole, and Tanner crab predominating the catch for both inshore and offshore areas (Figure 87).

The increased catches are reflected in the wide distribution of positive values for the standardized anomalies in the recent past. In 2011, above average anomaly values for Tanner crabs, Pacific cod, and skates were recorded for both inshore and offshore areas, while arrowtooth flounder and

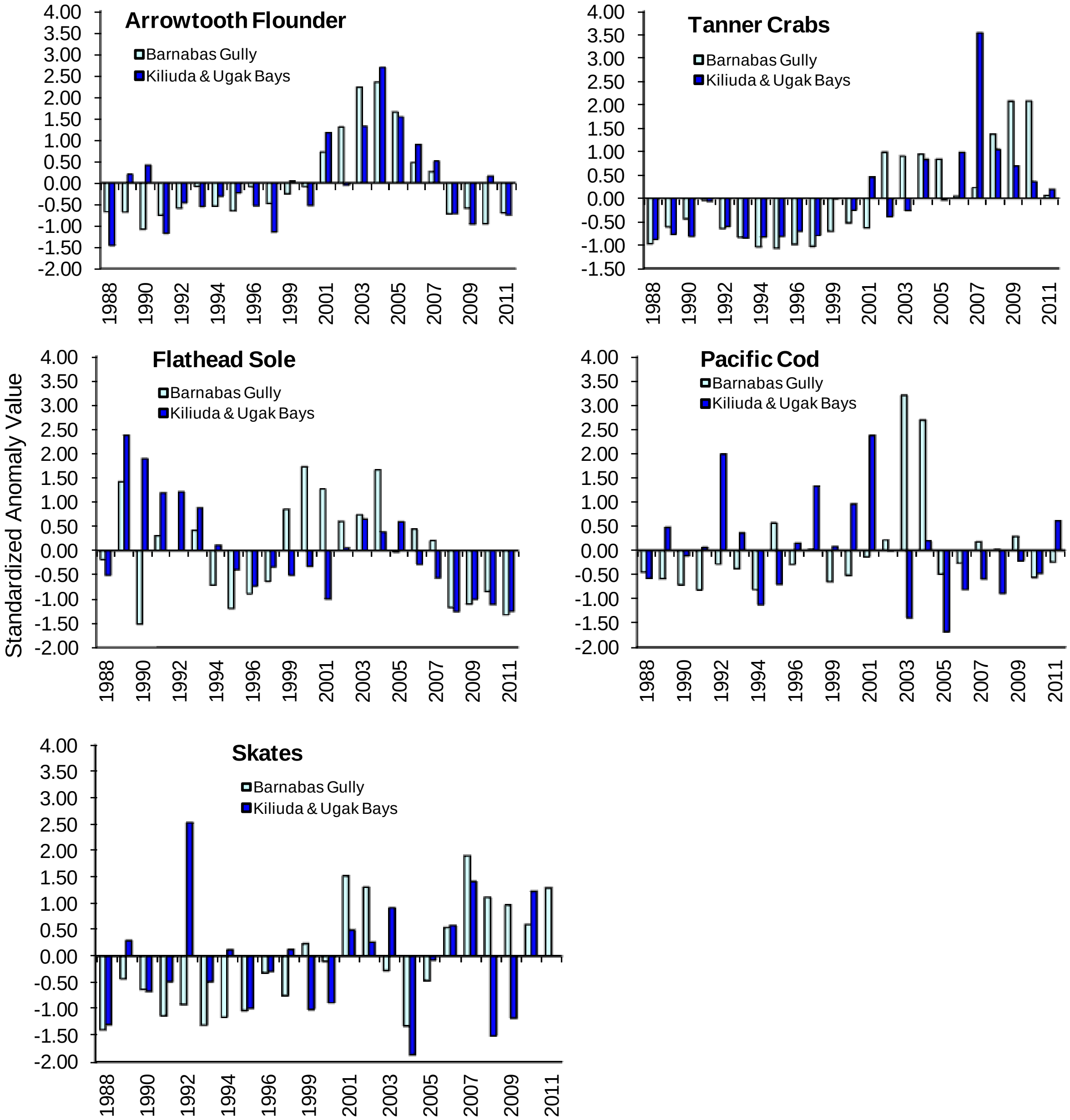


Figure 85: A comparison of standardized anomaly values for selected species caught from 1988-2011 in Kiliuda and Ugak Bays and Barnabas Gully during the ADF&G trawl surveys.

flathead sole values remain below average.

Temperature anomalies for both inshore, Kiliuda and Ugak Bays and offshore stations, Barnabas Gully, from 1990 to 2011, show similar oscillations with periods of above average temperatures corresponding to the strong El Niño years (1997-1998; Figure 86;`http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html`).

Factors causing observed trends It appears that significant changes in volume and composition

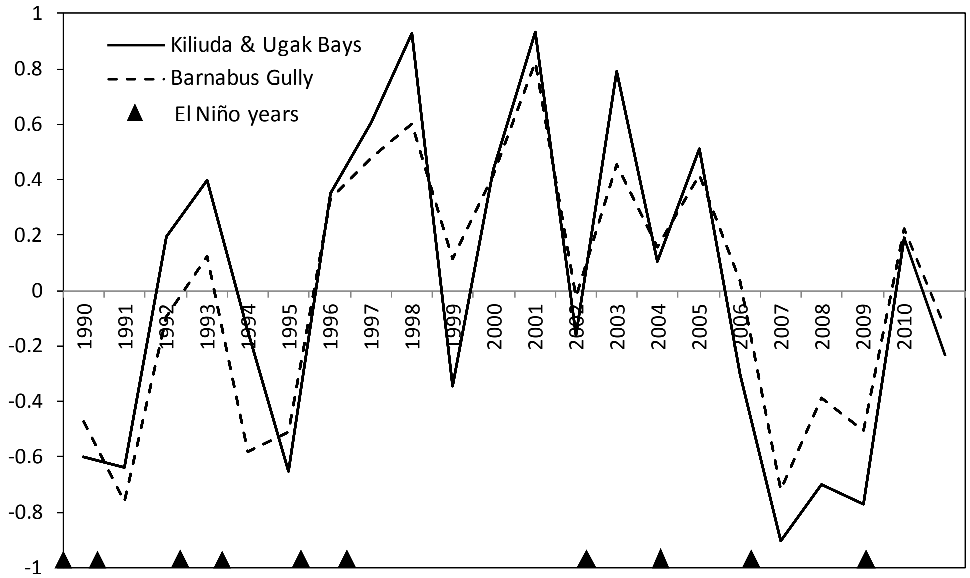


Figure 86: Bottom temperature anomalies recorded from the ADF&G trawl survey for Barnabas Gully and Kiliuda and Ugak Bays from 1990 to 2010, with corresponding El Niño years represented.

of the catches on the east side of Kodiak are occurring, but it is unknown if predation, environmental changes, or fishing effort are contributing to these changes. The lower overall catch from 1993 to 1999 (Figure 87) 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. The survey data is used directly 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 harvest guidelines.

Miscellaneous Species - Gulf of Alaska

Contributed by Michael Martin, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: Michael.Martin@noaa.gov

Last updated: October 2011

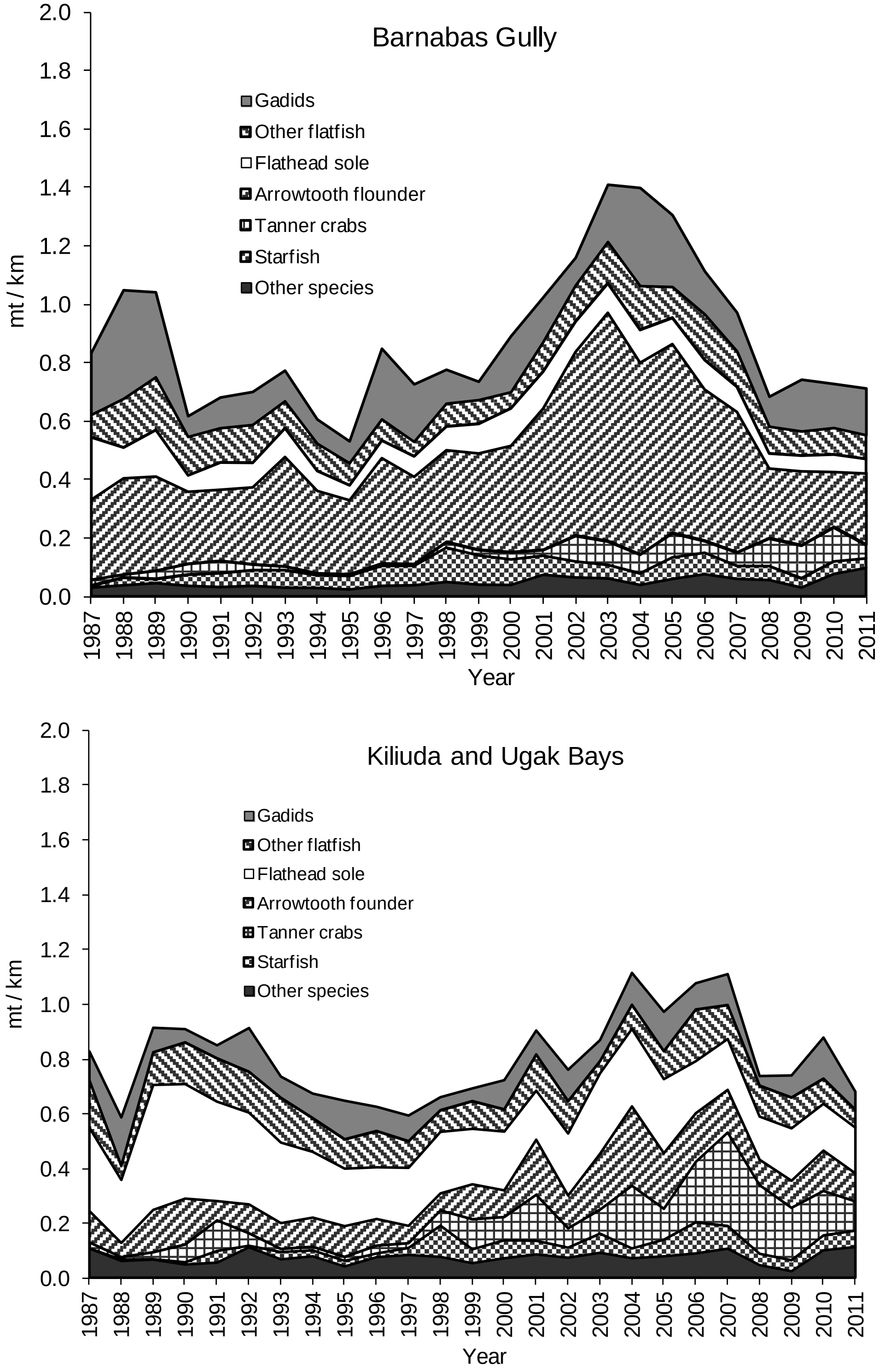


Figure 87: Total catch per km towed (mt/km) during the ADF&G trawl survey from adjacent areas off the east side of Kodiak Island, 1987 to 2011.

Gulf of Alaska surveys are conducted in alternate odd years. See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Lingcod Catches in the Gulf of Alaska

Contributed by Nicholas Sagalkin, Alaska Department of Fish and Game, 211 Mission Road, Kodiak, AK 99615
Contact: nick.sagalkin@alaska.gov
Last updated: September 2009

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Miscellaneous Species - Aleutian Islands

Contributed by Chris Rooper, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: chris.rooper@noaa.gov
Last updated: October 2012

Description of index: RACE bottom trawl surveys in the Aleutian Islands (AI) 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. Apparent abundance trends for a few of these groups are shown in Figure 88). For each species group, the largest catch over the time series was arbitrarily scaled to a value of 100 and all other values were similarly scaled. The standard error (±1) was weighted proportionally to the catch per unit effort (CPUE) to get a relative standard error.

Status and trends: Echinoderms are frequently captured in all areas of the AI surveys. Echinoderm mean CPUE is typically higher in the central and eastern AI than in other areas, although frequency of occurrence in trawl catches is consistently high across all areas. The lowest echinoderm CPUE has usually been in the southern Bering Sea. Jellyfish were generally more abundant in 2004 and 2006 than in other years and continued to be at low levels in 2012. The frequency of occurrence shows two distinct modes across all areas (1991-94 and 2004-06), although only in the western AI did this translate into higher abundance during the earlier period. The 2006 survey showed the highest level of jellyfish CPUE for all survey years, with a particularly large increase in the eastern AI. This change in abundance pattern is quite different from the eastern Bering Sea where peak abundances occurred in 2000 and 2011. Eelpout CPUEs have generally been highest in the central and eastern AI and have remained high since 1991 except for 2012 in the central AI. Poachers occur in a relatively large number of tows across the AI survey area, but mean CPUE trends are unclear.

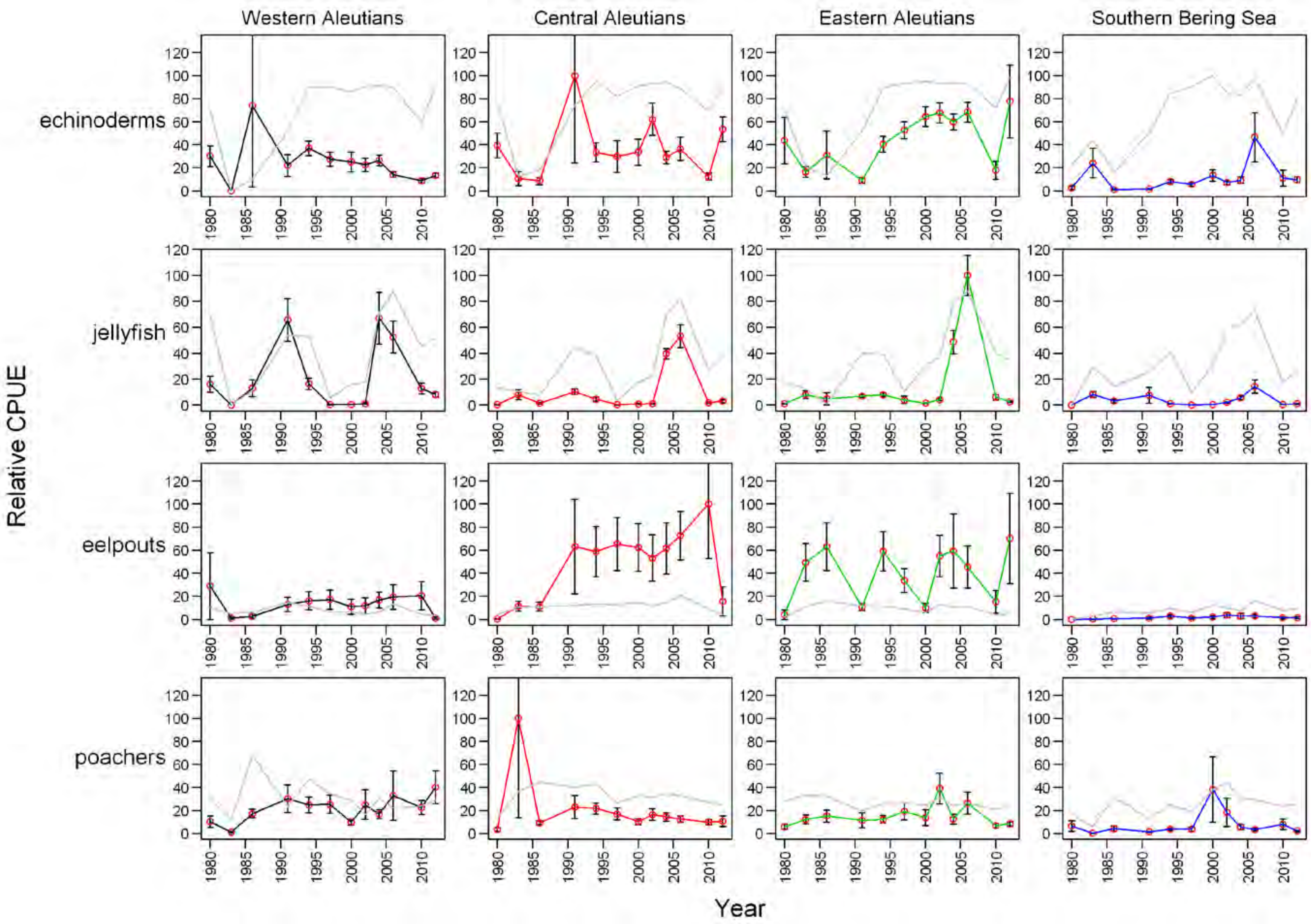


Figure 88: Relative mean CPUE of miscellaneous species by area from RACE bottom trawl surveys in the Aleutian Islands from 1980 through 2012. Error bars represent standard errors. The gray lines represent the percentage of non-zero catches. The Western, Central, and Eastern Aleutians correspond to management areas 543, 542, and 541, respectively. The Southern Bering Sea corresponds to management areas 519 and 518.

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 AI. The fishing gear used aboard the Japanese vessels that participated in all AI surveys prior to 1991 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: 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.

Seabirds

Multivariate Seabird Indices for the Eastern Bering Sea

Contributed by Stephani Zador
Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, WA
Contact: stephani.zador@noaa.gov
Last updated: October 2012

Description of index: 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. The most recent PCA includes 17 individual data sets spanning 1996 to 2012. St. Paul red-faced cormorant reproductive success could not be monitored in 2012, so we substituted the long-term mean value for this year. Removing the cormorant time series and repeating the PCA did not change the results meaningfully.

All data were standardized (mean of zero and unit variance) 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.

Status and trends: The PCA on the 17 yr annual time series (1996-2012) explained 64.8% of the variance in the data in the first two components (Figure 89). All seabird phenology, common murre and St. Paul thick-billed murre reproductive success time series were associated (loadings > 0.2) with PC1, which explained 41.6% of the total variance (Figure 90). All kittiwake reproductive success time series were strongly associated (loadings > 0.4) with PC2, which explained 23.2% of the total variance. With the addition of 2012 data, St. Paul thick-billed murre reproductive success and St. Paul black-legged kittiwake hatch dates were also associated with PC2, although not as strongly as the kittiwake reproductive success time series (loadings = 0.26 and 0.24, respectively). 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.

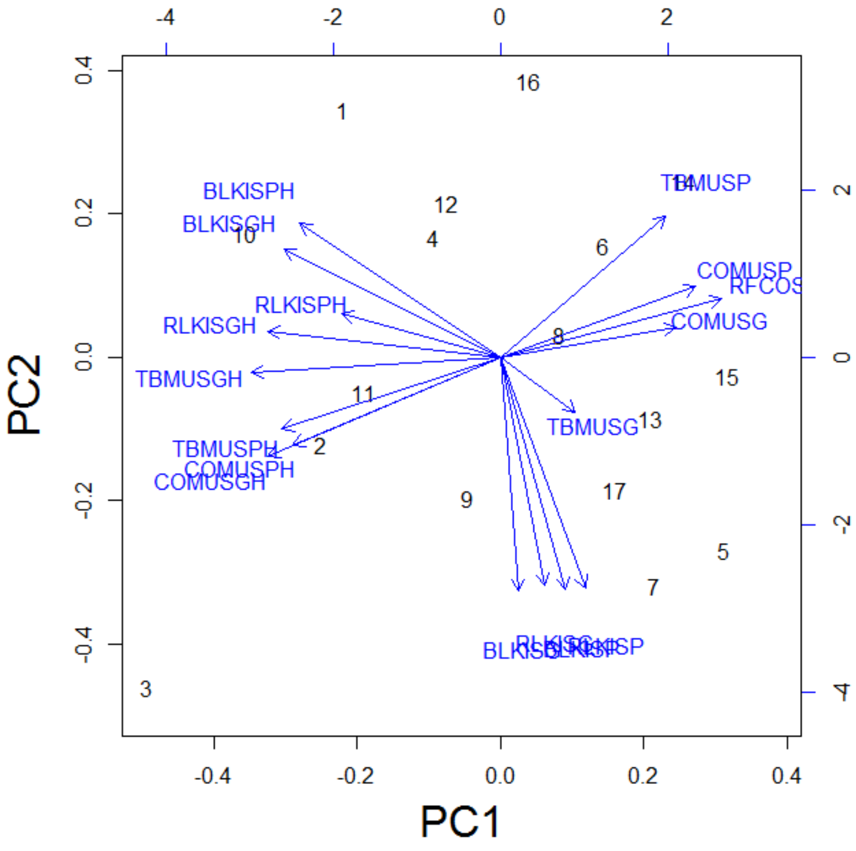


Figure 89: Biplot of the PC1 and PC2 values for each dataset in blue. The datasets are labeled in order with a 4-letter bird species code following American Ornithological Union convention (e.g., BLKI: black-legged kittiwake), a 2-letter island code (SP: St. Paul; SG: St. George), and H if it is a hatch date time series. Years in the 1996-2011 time series are depicted numerically in black.

The temporal trend in PC1 increased from 2011, indicating earlier hatch dates and higher reproductive success for common murres and St. Paul thick-billed murres (Figure 91). The temporal trend in PC2 continued the nearly annual trend reversal with the 2012 value showing an increase from the previous year and indicating an increase 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, in review). 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.

Implications: These results indicate that 2012 was a more successful year for Pribilof seabirds overall. These indices 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

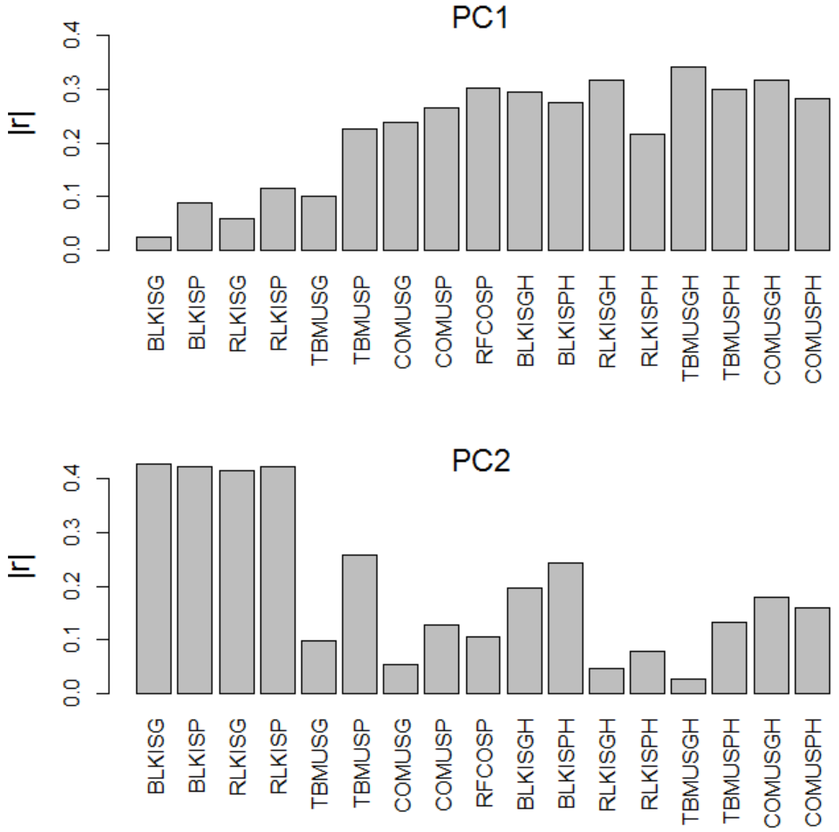


Figure 90: Loadings (absolute correlations) measuring the strength of association between individual time series and the first (PC1, top) and second (PC2, bottom) principal components.

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 indices and environmental conditions could help managers to anticipate ecosystem level effects of varying ecosystem states.

Seabird Bycatch Estimates for Alaskan Groundfish Fisheries, 1993-2011

Contributed by Shannon Fitzgerald
Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: shannon.fitzgerald@noaa.gov
Last updated: October 2012

Description of index: This report provides estimates 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 2011, updating the previously reported estimates from 1993 to 2006 (Fitzgerald et al., 2008). Gear types represented are demersal longline, pot, pelagic trawl, and non-pelagic

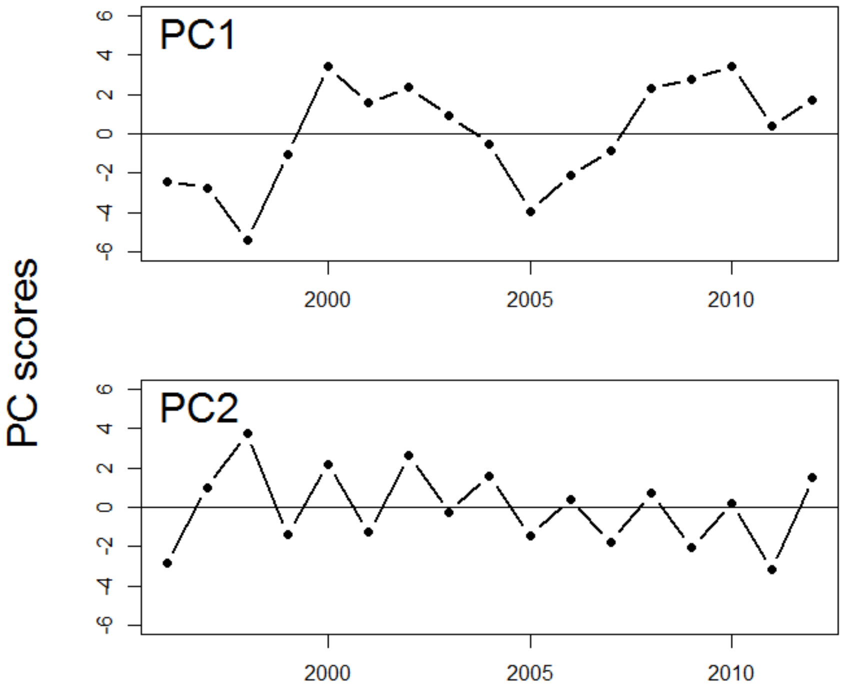


Figure 91: The value of PC1 (top) and PC2 (bottom) over time. Higher values of PC1 indicate earlier seabird hatch dates and higher cormorant and murre reproductive success (except for St. George thick-billed murres). Higher values of PC2 indicate higher kittiwake reproductive success, and new with the inclusion of 2012 data, St. Paul thick-billed murre reproductive success and St. Paul black-legged kittiwake hatch dates.

trawl. These numbers do not apply to gillnet, seine, troll, or halibut longline fisheries.

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), and (2) catch estimates provided by the NMFS Alaska Regional Office Catch Accounting System. The 2007 - 2011 bycatch estimates presented here are produced from the NMFS Alaska Regional Office Catch Accounting System (Cahalan et al., 2010). A figure is provided on seabird bycatch in the groundfish longline fisheries for 1993 through 2011, using results from the AFSC for 1993 through 2006 and the CAS from 2007 through 2011. Seabird bycatch in pot fisheries is minimal.

Status and trends: In the longline fishery, the 2011 numbers are 30% above the 2007-2010 average of 7,249. Bycatch in the longline fishery showed a marked decline beginning in 2002 due to the deployment of streamer lines as bird deterrents. Since then, annual bycatch has remained below 10,000 birds. The 2010 bycatch (3,704 birds) was the lowest estimated in this fishery overall, but the numbers increased to 8,914 in 2011, the second highest in the streamer line era. The increased numbers in 2011 are due to a doubling of the gull (*Larus* spp) numbers (1,084 to 2,206) and a 3-fold increase in Northern fulmar (*Fulmaris glacialis*) bycatch, from 1,782 to 5,848.

Total estimated seabird bycatch in all Alaskan groundfish fisheries are shown in Table 9. Northern fulmar are the most commonly caught in each year. Gulls and shearwaters, both combined species groups, were typically the second and third most commonly caught although shearwater bycatch was much reduced in 2011.

Albatross bycatch varied annually. The greatest numbers of albatross were caught in 2008. In 2011, 87.0% of albatross bycatch occurred in the GOA which accounts for only 18.5% of overall seabird bycatch. Of special interest is the endangered short-tailed albatross (*Phoebastria albatrus*). Since 2003, bycatch estimates were above zero only in 2010 and 2011, when 2 birds and 1 bird were incidentally hooked respectively. This incidental take occurred in the Bering Sea area. Also of note, the estimated number of black-footed albatross indicate over a 4-fold increase in bycatch, from 44 to 206. Although the black-footed albatross is not endangered (like its relative, the short-tailed albatross), it is considered a Bird of Conservation Concern by the U.S. Fish & Wildlife Service. This designation means that without additional conservation actions, these birds of concern are likely to become candidates for listing under the Endangered Species Act.

Factors influencing observed trends: The marked decline in overall numbers of birds caught as depicted in (Figure 92) after 2002 reflects the increased use of seabird mitigation devices. There are many factors that may influence annual variation in bycatch rates, including seabird distribution, population trends, prey supply, and fisheries activities. 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. A project is underway that addresses this issue.

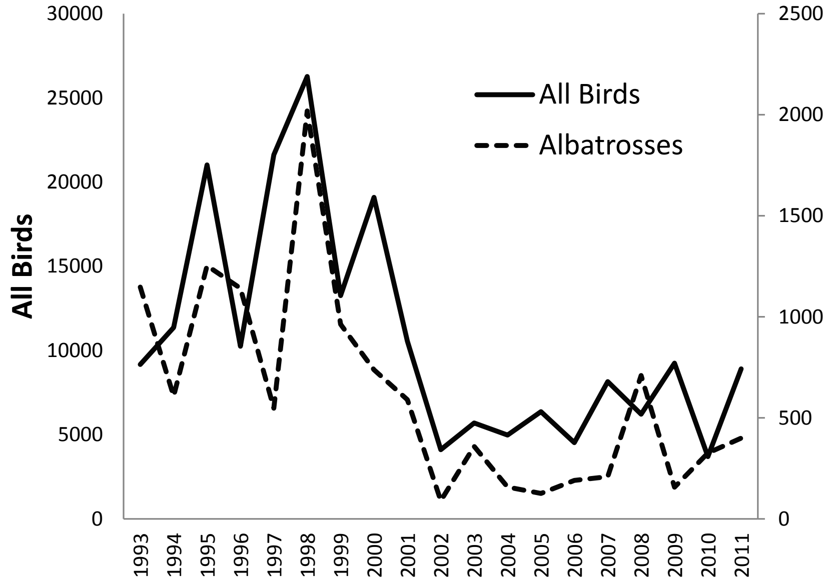


Figure 92: Total estimated seabird bycatch by year in the Alaskan demersal longline fishery derived by employing three methods: the Fish and Wildlife Service (Stehn et al., 2001), the National Marine Mammal Laboratory (Fitzgerald et al., 2008), and this preliminary report, using the Alaska Regional Office Catch Accounting System (Cahalan et al., 2010).

Implications: Seabird mitigation gear used on longline vessels can substantially reduce bycatch. Individual vessel performance varies, and further reduction of overall fleet averages may depend on targeted improved performance for a handful of vessels within the fleet. Additional methods, such as integrated weight longline gear, have been researched and shown to be effective (Washington Sea

Table 9: Total **estimated** seabird bycatch in Alaskan groundfish fisheries, all gear types and Fishery Management Plan areas combined, 2007 through 2011. 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
Unidentified Albatross	16	0	0	0	0
Short-tailed Albatross	0	0	0	15	5
Laysan Albatross	17	420	114	267	189
Black-footed Albatross	176	290	52	44	206
Northern Fulmar	4,581	3,426	7,921	2,357	6,214
Shearwater	3,602	1,214	622	647	199
Storm Petrel	1	44	0	0	0
Gull	1,309	1,472	1,296	1,141	2,208
Kittiwake	10	0	16	0	6
Murre	7	5	13	102	14
Puffin	0	0	0	5	0
Auklet	0	3	0	0	0
Other Alcid	0	0	105	0	0
Other Bird	0	0	136	0	0
Unidentified	509	40	166	18	259
Total	10,228	6,914	10,441	4,596	9,298

Grant Program). Continued collaboration with the longline industry will be important. Albatross bycatch in the Gulf of Alaska is generally higher than in other regions. With observer program restructuring and the deployment plan recommended by NMFS and approved by the North Pacific Fisheries Management Council, we will have a better sense of albatross bycatch issues within GOA-fisheries.

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 Alaska Marine Mammal stock assessment was released in May 2012 and can be downloaded at `http://www.nmfs.noaa.gov/pr/sars/region.htm`.

Steller Sea Lion (*Eumetopias jubatus*)

Contributed by Lowell Fritz and Rod Towell, National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: lowell.fritz@noaa.gov
Last updated: October 2010

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Northern Fur Seal (*Callorhinus ursinus*)

Contributed by Lowell Fritz and Rod Towell, National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: lowell.fritz@noaa.gov
Last updated: October 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Harbor Seals (*Phoca vitulina*)

Contributed by Peter Boveng and Josh London, National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: peter.boveng@noaa.gov
Last updated: October 2007

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Arctic Ice Seals: Bearded Seal, Ribbon Seal, Ringed Seal, Spotted Seal

Contributed by Michael Cameron, National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: peter.boveng@noaa.gov
Last updated: July 2009

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Bowhead Whale (*Balaena mysticetus*)

Contributed by Marcia Muto, National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: marcia.muto@noaa.gov

Last updated: August 2012

Description of index: All stocks of bowhead whales (*Balaena mysticetus*) were severely depleted by commercial whaling (Woodby and Botkin, 1993) and were classified as protected by the International Whaling Commission (IWC) under the 1946 International Convention for the Regulation of Whaling. The IWC currently recognizes the Okhotsk Sea, Spitsbergen, Eastern Canada-West Greenland, and Western Arctic stocks of bowhead whales (IWC, 2007). The Western Arctic stock, also known as the Bering Sea (Burns et al., 1993) or Bering-Chukchi-Beaufort Seas (Rugh et al., 2003) stock, is the only stock of bowheads in U.S. waters (Rugh et al., 2003; George et al., 2007; IWC, 2007). In the U.S., this stock is classified as endangered under the Endangered Species Act (ESA) of 1973 and depleted under the Marine Mammal Protection Act of 1972; thus, it is also considered a strategic stock. However, the Western Arctic stock has been increasing in recent years (George et al., 2004; Koski et al., 2010) and may be approaching its carrying capacity (Brandon and Wade, 2006).

Western Arctic bowheads generally migrate between wintering areas in the Bering Sea and summering areas in the eastern Beaufort Sea (Braham et al., 1980; Moore et al., 1993). Some bowheads are found in the Chukchi and Bering Seas in summer and are thought to be part of the expanding Western Arctic stock (Rugh et al., 2003).Systematic ice-based visual counts during this migration have been conducted since 1978 (Krogman et al., 1989; George et al., 2004).

Status and trends: A summary of the resulting abundance estimates, corrected for whales missed during the census (Zeh et al., 1993; Clark et al., 1996), is provided in Table 10 (Allen and Angliss, 2012) and Figure 93 (George et al., 2004); however, these estimates have not been corrected for a small, unknown portion of the population that does not migrate past Point Barrow during the survey (Allen and Angliss, 2012). The most recent population abundance estimate in 2004 of 12,631 (CV=0.2442) whales in the Western Arctic stock (excluding calves) was calculated from aerial photographic surveys of bowhead whales in 2003, 2004, and 2005 (Koski et al., 2010). The rate of increase indicates a steady recovery of the stock (George et al., 2004; Brandon and Wade, 2006; Koski et al., 2010).

Factors influencing observed trends: There are no observer program records of bowhead whale mortality incidental to commercial fisheries in Alaska. Historically, however, some bowheads have had interactions with crab pot gear. More recent NMFS Alaska Region stranding records have reported bowhead whale entanglements, including a bowhead that was found dead in Bristol Bay in 2003, with line (of unknown origin) around its caudal peduncle and both flippers, and a bowhead that was observed near Point Barrow in 2004 with fishing net and line around its head (Allen and Angliss, 2012).

Alaska Natives living in villages along the migration route of the Western Arctic stock of bowheads have hunted these whales for at least 2,000 years (Marquette and Bockstoce, 1980; Stoker and Krupnik, 1993), and the IWC has regulated subsistence takes since 1977 (IWC, 1978). Alaska Native, Russian, and Canadian Native currently practice subsistence harvest (Table 11). At its annual meeting in 2012, the IWC renewed the bowhead quota for the 6-year period from 2013 to 2018 (IWC 2012a, b); the quota includes up to 336 whales landed, with no more than 67 whales struck in any year (except that up to 15 unused strikes can be carried forward and added to the strike quota of subsequent years).

Table 10: (from Allen and Angliss (2012)). Summary of population abundance estimates for the Western Arctic stock of bowhead whales. The historical estimates were made by back-projecting using a simple recruitment model. All other estimates were developed by corrected ice-based census counts. Historical estimates are from Woodby and Botkin (1993); 1978-2001 estimates are from George et al. (2004) and Zeh and Punt (2004).

Year	**Abundance Estimate (CV)**
Historical estimate	10,400-23,000
End of commerical whaling	1,000-3,000
1978	4,765 (0.305)
1980	3,885 (0.343)
1981	4,467 (0.273)
1982	7,395 (0.281)
1983	6,573 (0.345)
1985	5,762 (0.253)
1986	8,917 (0.215)
1987	5,298 (0.327)
1988	6,928 (0.120)
1993	8,167 (0.017)
2001	10,545 (0.128)

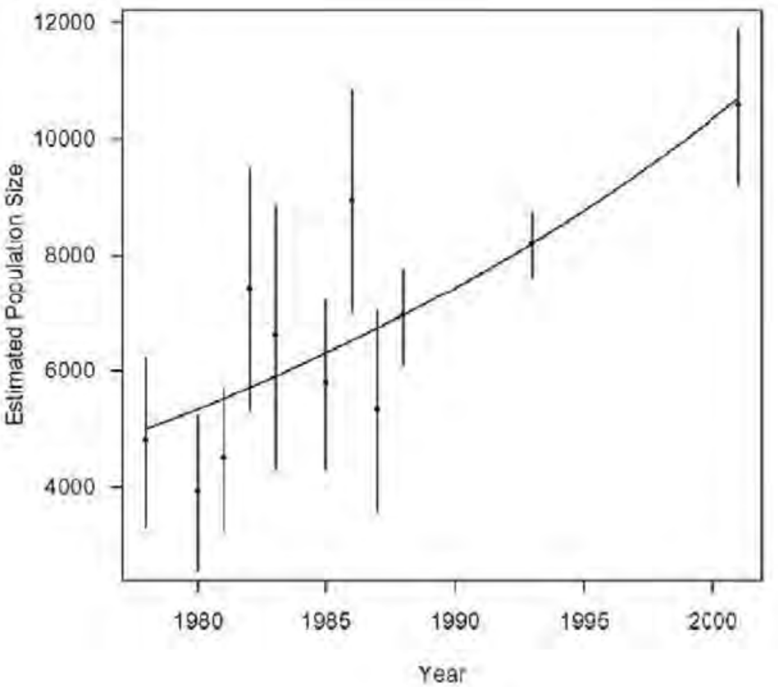


Figure 93: (George et al., 2004). Population abundance estimates for the Western Arctic stock of bowhead whales, 1977-2001, as computed from ice-based counts, acoustic locations, and aerial transect data collected during bowhead whale spring migrations past Barrow, Alaska. Error bars show +/- 1 standard error.

Table 11: Recent subsistence harvest estimates (Suydam et al. 2011, IWC 2011, Allen and Angliss 2012).

Years	Alaska Native	Russian subsistence	Canadian Natives
1974-2003	832		
1991			1
1996			1
1999		1	
2000		1	
2001		1	
2002		2	
2003		3	
2004	37	1	
2005	55	2	
2006	31		
2007	41		
2008	38	2	
2009	31		
2010	45	2	

Oil and gas development in the Arctic has the potential to impact bowheads through increased risks of exposure to pollution and to the sound produced by exploration, drilling operations, and increased vessel traffic in the area (Allen and Angliss, 2012). Past studies have indicated that bowheads are sensitive to sounds from seismic surveys and drilling operations (Richardson and Malme, 1993; Richardson, 1995; Davies, 1997) and will avoid the vicinity of active seismic operations (Miller et al., 1999), active drilling operations (Schick and Urban, 2000), and the resulting vessel traffic (Richardson et al., 2004). Each year since 1979, the U.S. Department of the Interior's Minerals Management Service (MMS) has funded and/or conducted aerial surveys of bowhead whales during their fall migration through the western Beaufort Sea in what is known as the Bowhead Whale Aerial Survey Project (BWASP). In 2007, as part of an Inter-Agency Agreement (IAA) between the MMS and NMFS, the National Marine Mammal Laboratory (NMML) took over the coordination of BWASP. Through a second IAA, the survey area has been expanded to include the northeastern Chukchi Sea as part of the Chukchi Offshore Monitoring in Drilling Area (COMIDA) project. The Aerial Surveys of Arctic Marine Mammals (ASAMM) project is a continuation of the BWASP and COMIDA projects. The goal of this project is to document the distribution and relative abundance of bowheads and other marine mammals in areas of potential oil and natural gas exploration, development, and production activities in the Alaskan Beaufort and northeastern Chukchi Seas. To facilitate mitigation of future oil and gas development along the migration route of the Western Arctic stock of bowheads, the multi-year (2007-2012) Bowhead Whale Feeding Ecology Study (BOWFEST), administered by NMFS and funded by the MMS, will estimate relationships among bowhead whale prey, oceanographic conditions, and bowhead whale feeding behavior in the western Beaufort Sea (Rugh et al., 2003). Aerial survey daily reports for the BWASP, COMIDA, and BOWFEST projects are available at `http://www.afsc.noaa.gov/nmml/cetacean/bwasp/index.php` and annual reports are available through NMML.

Implications: Describing implications for fisheries managers is difficult given the lack of population estimates after 2004. Subsistence harvest by Alaska natives has been relatively stable since that time (37-45 whales per year).

Ecosystem or Community Indicators

Indicators of Basin-scale and Alaska-wide Community Regime Shifts

Contributed by Mike Litzow[1,2] and Franz Mueter[3]
[1]Blue World Research, 2710 E. 20th Ave., Anchorage, AK 99508
[2]University of Tasmania, Private Bag 129, Hobart, TAS, 7001, Australia
[3]University of Alaska Fairbanks, 17101 Pt. Lena Rd., Juneau, AK 99801
Contact: malitzow@utas.edu.au
Last updated: August 2012

Description of indices: The first and second principal components (PCs) for 64 biology time series from Baja California to the Bering Sea allow basin-scale patterns of biological variability to be monitored (Hare and Mantua, 2000). We updated the Hare and Mantua biology time series for the years 1965-2008; too many values were missing after 2008 for PC analysis to be conducted. Our update included 35 Alaskan time series (19 from the Gulf of Alaska and 16 from the Bering Sea). Alaskan time series include recruitment estimates for groundfish (n = 15) and herring (n = 3) populations, log-transformed and lagged to cohort year; commercial salmon catches (n = 15), log-transformed and lagged to year of ocean entry; and measures of invertebrate abundance (n = 2). These indices are useful for monitoring possible biological responses to the negative Pacific Decadal Oscillation (PDO)/positive North Pacific Gyre Oscillation (NPGO) conditions that have persisted since 2007/08 (Figure 94).

Status and trends: There is some evidence that an abrupt change in leading axes of basin-scale biological variability occurred in 2008. Change in the PC1-PC2 phase space for all 64 northeast Pacific time series from 2007 to 2008 was significantly greater than the mean for all other year-to-year changes since 1965-66 ($t_{41} = 22.69$, $p < 0.0001$, Figure 95). However, this biological change was not evident at the scale of Alaska. While PC1 and PC2 for the Alaskan time series show some evidence of declining amplitude in recent years (Figure 96), STARS (sequential t-tests for analysis of regime shifts) found no evidence of recent, statistically significant shifts in either Alaskan PC time series ($L = 15$ years, $H = 6$ SD, autocorrelation accounted for with IP4N method, $P > 0.05$).

Factors causing observed trends: Coherent shifts in climate and biology time series in the northeast Pacific have traditionally been interpreted as evidence of a causal relationship, though the underlying climate-biology covariation has rarely been evaluated with formal hypothesis testing. The abrupt change in PC1 and PC2 for all 64 time series between 2007 and 2008 (Figure 95) is suggestive of a basin-scale biological response to recent cool temperatures and PDO-negative/NPGO-positive conditions in the northeast Pacific. The possibility of a return to persistent PDO-negative conditions has received recent attention in the literature (e.g., (Cai and van Rensch, 2012; Zwolinski and Demer, 2012)). However, we have no ability to predict either the behavior of the PDO or the biological response to large-scale climate fluctuations. Additionally, while we excluded recent recruitment estimates that were poorly supported by data from our analysis, there is some chance

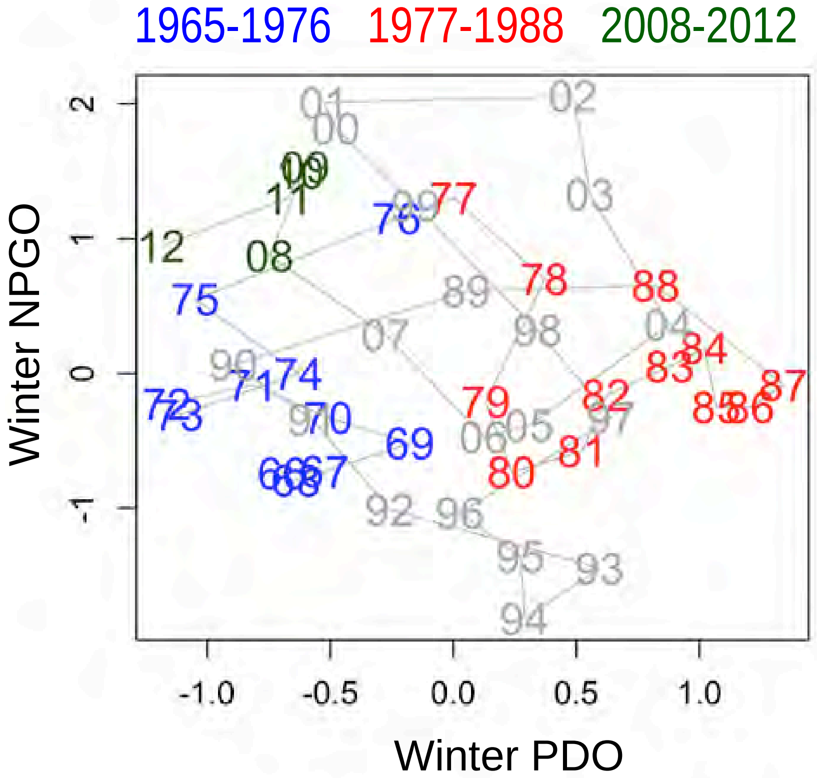


Figure 94: Winter (NDJFM) PDO-NPGO phase space, 1965-2012. Colors highlight recent years (2008-12) and two historical periods of strong PDO influence in the ecosystem (1965-77 and 1978-88). Plotted values are 3-year running means, except for 2012, which is a 2-year mean.

that the PC scores are subject to unquantified increases in variability in the most recent years of observation. Further years of observation will therefore be required before the persistence and true magnitude of the apparent shift in basin-scale patterns of biological variability can be known.

While Alaska has experienced the lower coastal temperatures that have recently been observed in the rest of the northeast Pacific(Overland et al., 2012), PC1 and PC2 of Alaskan biology time series through 2008 do not show any evidence of abrupt change (Figure 96).

Implications: Abrupt, community-level biological changes that are spatially coherent at the scale of the northeast Pacific are rare events; only one (1976/77) has occurred during the time period of the Hare and Mantua dataset. However, though rare, these events are extremely disruptive to Alaskan fisheries. We found no evidence of recent abrupt biological change in Alaska, although the abrupt 2007-08 change in basin-scale data (Figure 95) suggests some possibility of ongoing changes across the northeast Pacific, possibly in response to a large change in the PDO-NPGO phase space between 2006 and 2008 (Figure 94). Lags in availability for many time series mean that community-wide patterns of biological variability during 2009-2012 cannot yet be evaluated.

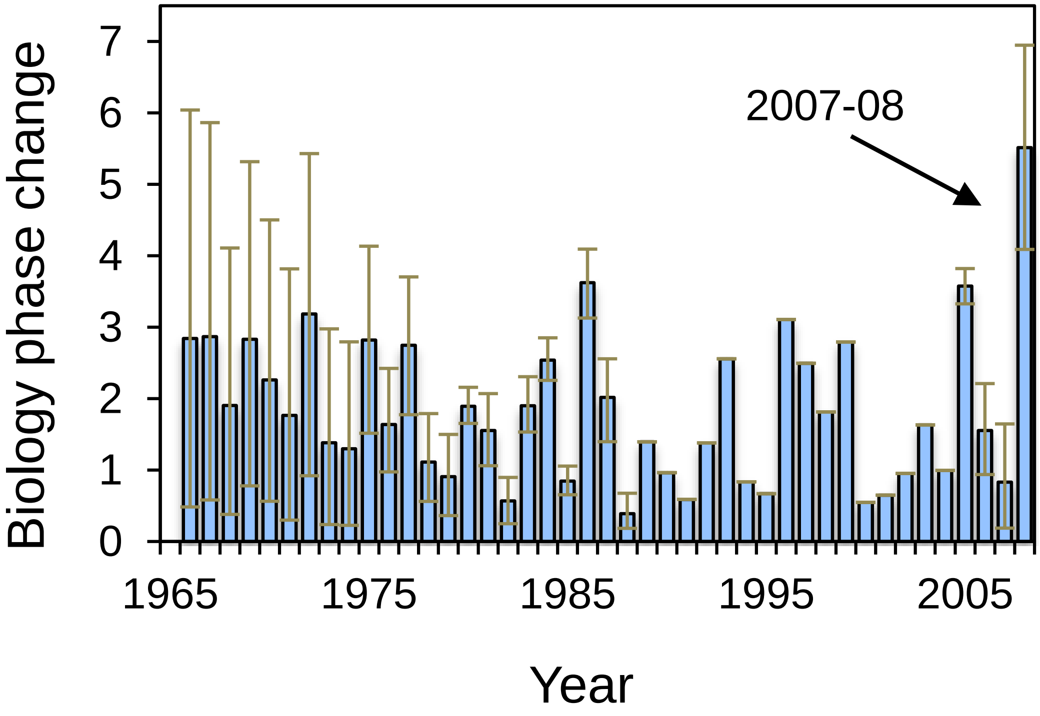


Figure 95: Total change in the PC1-PC2 phase space for 64 biology time series, Baja California to the Bering Sea, 1965-66 to 2007-08. Each column plots a year-to-year change in the phase space, calculated as the length of the hypotenuse joining PC1 and PC2 vectors. Error bars = 95% CI associated with estimating missing values. The 2007-08 change was 311% of the mean change for other years ($t_{41} = 22.69$, $p < 0.0001$).

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

Contributed by Franz Mueter, University of Alaska Fairbanks, 17101 Point Lena Road, Juneau, AK 99801
Contact: franz.mueter@uaf.edu
Last updated: October 2012

Description of index: The index provides a measure of the overall biomass of demersal and benthic fish and invertebrate species. We computed catch-per-unit-effort (CPUE in kg km^{-2}) of fish and major invertebrate taxa for each successful haul completed during standardized bottom trawl surveys on the eastern Bering Sea shelf (EBS, 1982-2012) and on the Gulf of Alaska shelf (GoA, 1990-2011). Total CPUE for each haul was estimated 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 = 11548, 5782, and 1529 hauls in the EBS, western GoA,

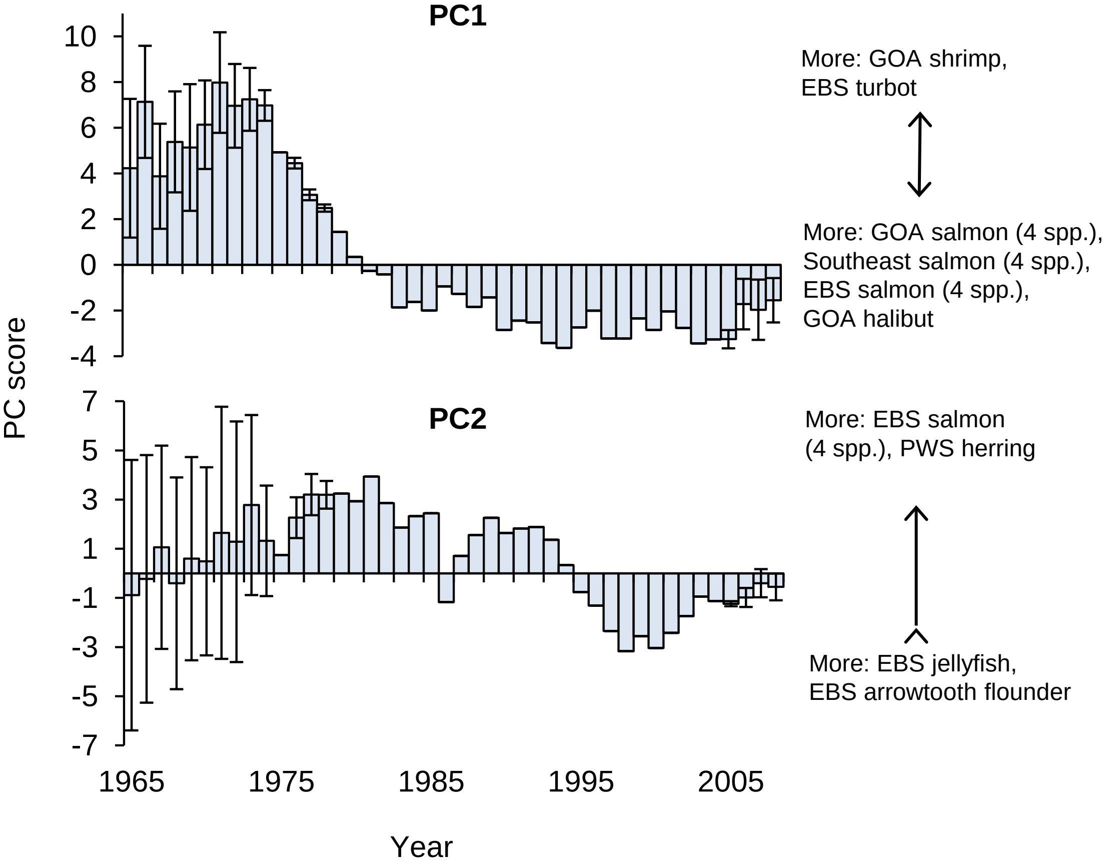


Figure 96: Time series of first two PC scores for 35 Alaskan biology time series, 1965-2008. Error bars = 95% CI associated with uncertainty through estimation of missing time series values; columns with no error bars indicate years with no missing values. Individual populations listed to the right of panels are time series showing strongest loading (≥ 0.2) on each PC score.

and eastern GoA, respectively) as smooth functions of depth, net width, and location (latitude / longitude in the EBS, alongshore distance and sampling stratum in the GoA) using Generalized Additive Models following Mueter and Norcross (2002). Hauls were weighted based on the area represented by each station. Although catches were standardized to account for the area swept by each haul we included net width in the model for the Bering Sea because of differences in catchability of certain taxa with changes in net width (von Szalay and Somerton, 2005) and because there was strong evidence that total CPUE tends to decrease with net width, all other factors being constant. The CPUE index does not account for gear or vessel differences, which are strongly confounded with interannual differences and may affect results prior to 1988 in the Bering Sea.

Status and trends: Total log(CPUE) in the western GoA varied over time with lowest abundances observed in 1999 and 2001 (Figure 97). Mean CPUE ranged from 101 kg/ha in 2001 to 138 kg/ha in 2003. The eastern GoA shows a significantly increasing trend (p 0.0139) from 55 kg/ha in 1990 to 70 kg/ha in 2011. Total log(CPUE) in the EBS shows an apparent long-term increase from 1982-2005, followed by a decrease from 2005 to 2009 and an increase in 2010 (Figure 98). Estimates of total mean CPUE ranged from 180 kg/ha in 1985 to over 370 kg/ha in 2003, decreasing to 225 kg/ha in 2005. 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).

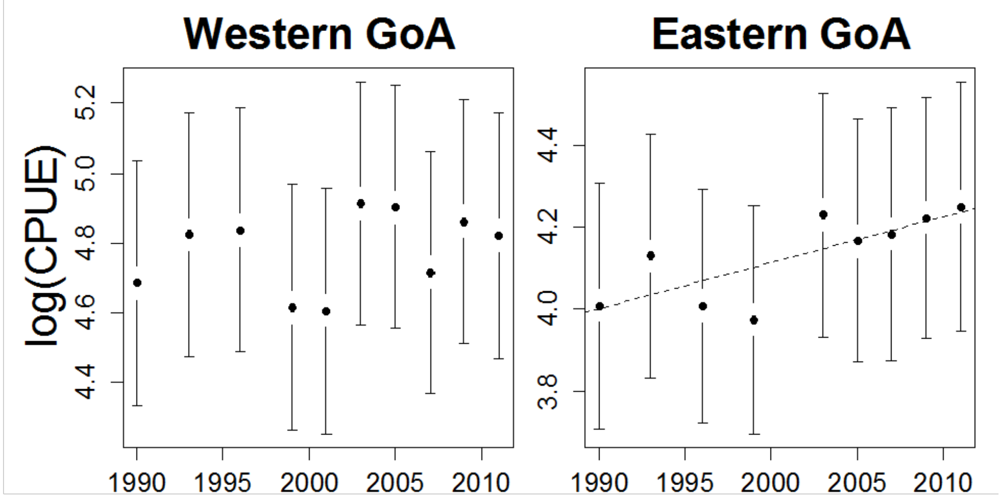


Figure 97: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from in the western Gulf of Alaska (west of 147°W) by survey year with approximate 95% confidence intervals. Estimates were adjusted for differences in depth and sampling locations (alongshore distance) among years. Linear trend in eastern GOA based on generalized least squares regression assuming 1st order auto-correlated residuals ($t = 3.258$, $p = 0.014$).

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 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. This reduction 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 spiny dogfish.

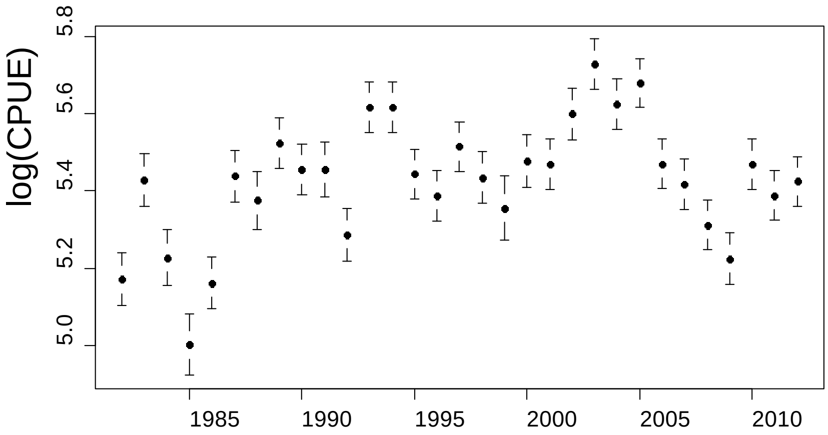


Figure 98: Model-based estimates of total log(CPUE) for major fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2012 in the Bering Sea with approximate pointwise 95% confidence intervals and linear time trend. Estimates were adjusted for differences in depth, day of sampling, net 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 ($t = 1.221$, $p = 0.232$).

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.

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
Contact: jerry.hoff@noaa.gov
Last updated: July 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Average Local Species Richness and Diversity of the Groundfish Community

Contributed by Franz Mueter[1], Jason Waite[1], and Robert Lauth[2]
[1]University of Alaska Fairbanks, 17101 Point Lena Road, Juneau, AK 99801
[2]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA

Contact: franz.mueter@uaf.edu
Last updated: October 2012

Description of index: This section provides indices of local species richness and diversity based on standard bottom trawl surveys in the eastern Bering Sea (EBS). We computed the average number of fish and major invertebrate taxa per haul (richness) and the average Shannon index of diversity (Magurran, 1988) by haul based on CPUE (by weight) of each taxon. Indices were based on 45 fish and invertebrate taxa that were consistently identified throughout all surveys since 1982 (Table 1 in Mueter and Litzow (2008), excluding Arctic cod because of unreliable identification in early years). Indices were computed following Mueter and Norcross (2002). Briefly, annual average indices of local richness and diversity were estimated by first computing each index on a per-haul basis, then estimating annual averages with confidence intervals across the survey area using a Generalized Additive Model that accounted for the effects of variability in geographic location (latitude/longitude), depth, date of sampling, and area swept. 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 2012 (Figure 99). The average number of species per haul increased by one to two species from 1995 to 2004 and has remained relatively high since then. The Shannon Index increased from 1985 through 1998, decreased sharply in 1999, and has been highly variable since then. Diversity was low in 2002/03, increased substantially in 2004, decreased through 2010, but was high in the last two years.

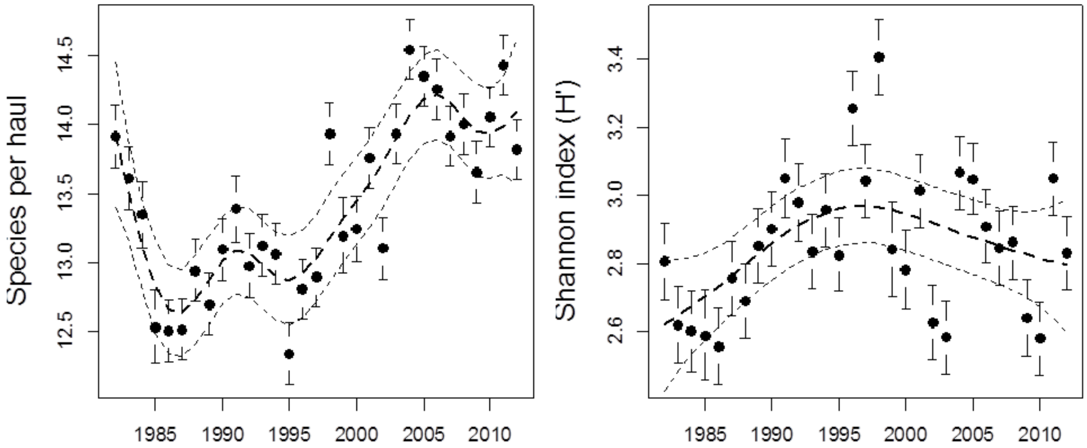


Figure 99: Model-based annual averages of species richness (average number of species per haul, dots), and species diversity (Shannon index) in the Eastern Bering Sea, 1982-2012, based on 45 fish and invertebrate taxa collected by standard bottom trawl surveys with pointwise 95% confidence intervals (bars) and loess smoother with 95% confidence band (dashed/dotted lines). Model means were adjusted for differences in area swept, depth, date of sampling, and geographic location.

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 (Figure 99) and spatial patterns in species diversity (Figure 100) 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). 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.

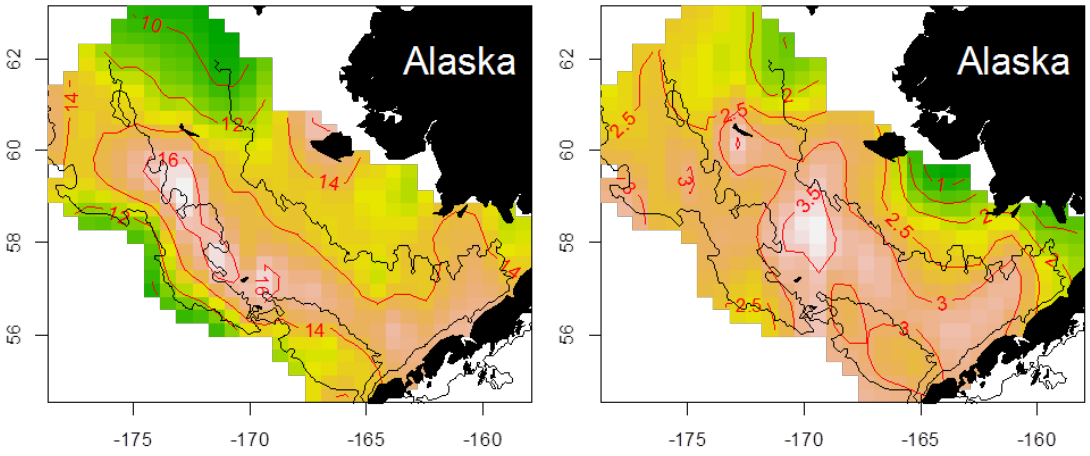


Figure 100: Average spatial patterns in local species richness (left, number of taxa per haul) and Shannon diversity in the Eastern Bering Sea. The 50 m, 100 m, and 200 m depth contours are shown as black lines. Note highest richness along 100 m contour, highest diversity on middle shelf.

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 responses of the groundfish community to projected climate warming. However, neither richness nor diversity were significantly correlated with bottom temperatures; richness was relatively high since 2004 spanning both a warm and cold period, while diversity varied greatly between years in the most recent cold period (2009/2010 vs. 2011/12).

Combined Standardized Indices of Recruitment and Survival Rate

Contributed by Franz Mueter, University of Alaska Fairbanks, 17101 Point Lena Road, Juneau, AK 99801
Contact: franz.mueter@uaf.edu
Last updated: August 2010

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Spatial Distribution of Groundfish Stocks in the Eastern Bering Sea

Contributed by Franz Mueter[1], Michael Litzow[2,3] and Robert Lauth[4]
[1]University of Alaska Fairbanks, 17101 Point Lena Road, Juneau, AK 99801
[2]Blue World Research, 2710 E. 20th Ave., Anchorage, AK 99508
[3]University of Tasmania, Private Bag 129, Hobart, TAS, 7001, Australia
[4]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: franz.mueter@uaf.edu
Last updated: October 2012

Description of index: 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 1982-2012 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 26 of the 27 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 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 101). This distribution was largely maintained through the recent cold years. Strong shifts in distribution over the 31 year time series remain evident even after adjusting for linear temperature effects (Figure 101). 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 102)). On average, there was a gradual shift to the north from 2001 to 2005, which reversed as temperatures cooled after 2006. In 2009, the average center of gravity temporarily shifted back to deeper waters but has been relatively shallow with little change in latitude since 2010.

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,

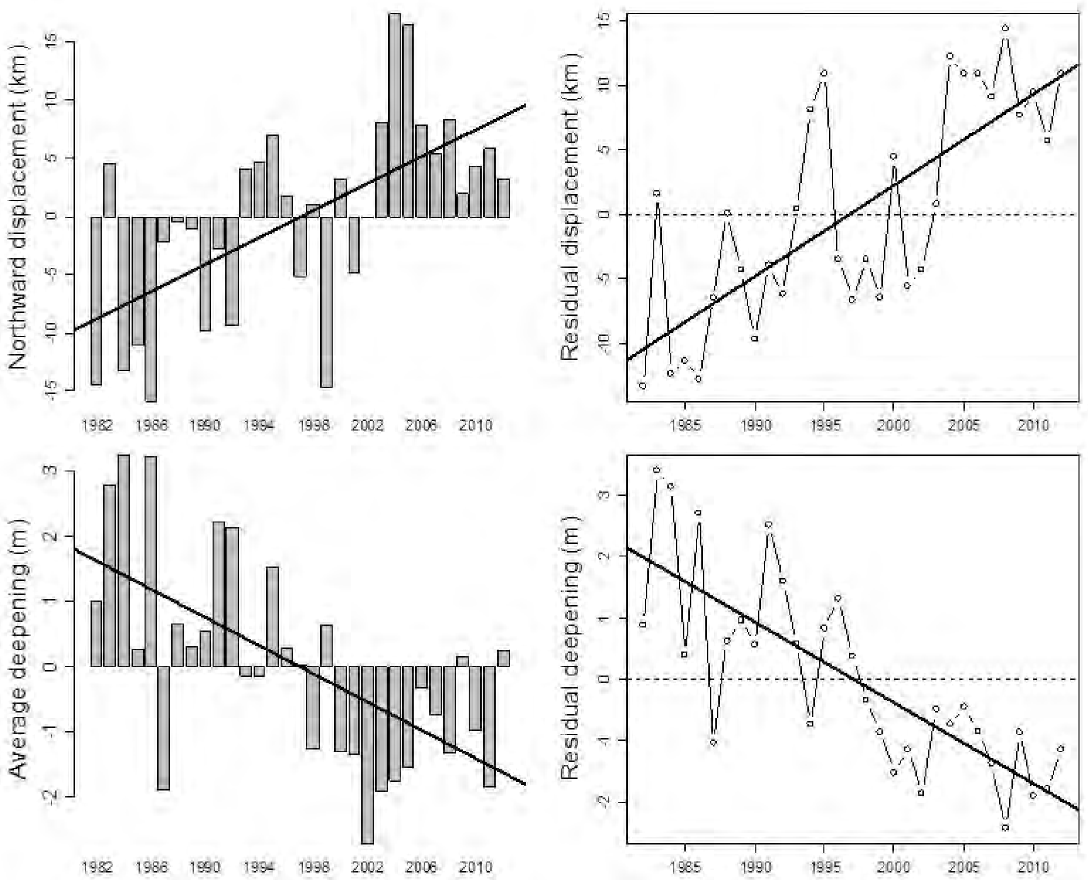


Figure 101: Left: Distributional shifts in latitude (average northward displacement in km from species-specific mean latitudes) and shifts in depth distribution (average vertical displacement in m from species-specific mean depth, positive indices indicate deeper distribution). Right: Residual displacement 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 weighted least-squares regression on annual average temperature with first-order auto-correlated residuals over time (Northward displacement: $R^2 = 0.24$, $t = 3.75$, $p < 0.001$; depth displacement: $R^2 = 0.25$, $t = -3.60$, $p = 0.001$). Solid lines denote linear regressions of residual variability over time (top: $R^2 = 0.57$, $t = 4.34$, $p < 0.001$; bottom: $R^2 = 0.61$, $t = -6.68$, $p < 0.001$).

2008). The reasons for residual shifts (Spencer, 2008) in combination with internal community dynamics (Mueter and Litzow, 2008). Unlike groundfish in the North Sea, which shifted to deeper waters in response to warming (Dulvy et al., 2008), the Bering Sea groundfish community shifted to shallower waters during the recent warm period (Figure 101). 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

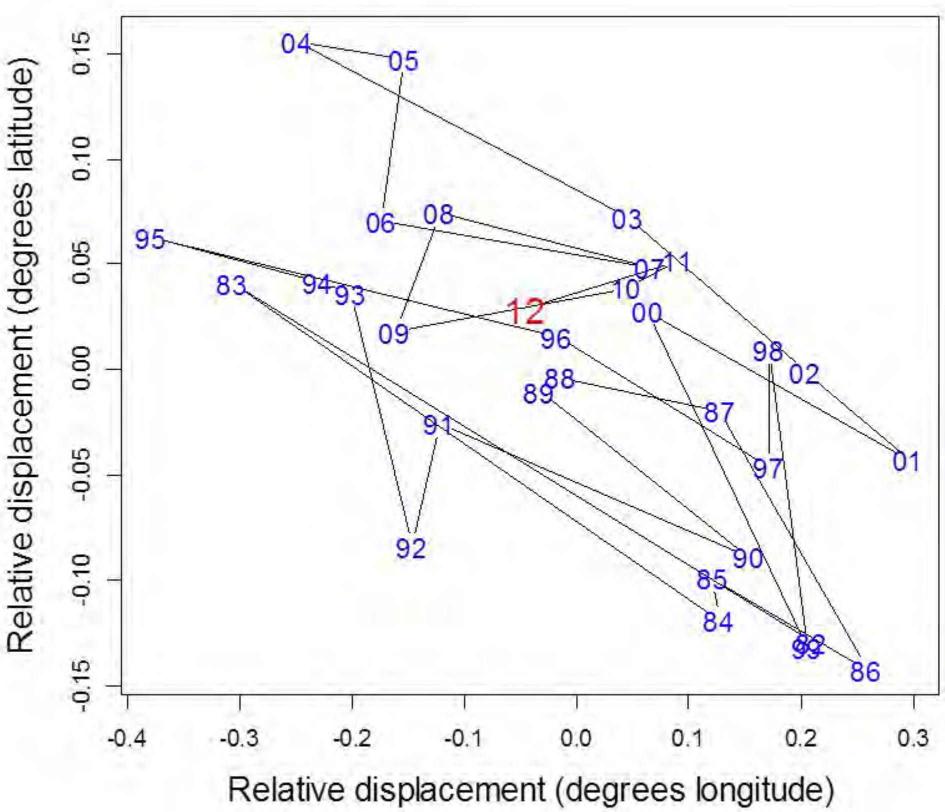


Figure 102: Average North-South and East-West displacement across 39 taxa on the eastern Bering Sea shelf relative to species-specific centers of distribution.

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.

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.

Ecosystem Goal: Maintain Diversity

Time Trends in Groundfish Discards

Contributed by Jean Lee and Terry Hiatt (retired), Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: jean.lee@noaa.gov
Last updated: July 2012

Description of index: Estimates of discards for 1994-2002 come from NMFS Alaska Region's blend data; estimates for 2003-10 come from the Alaska Region's catch-accounting system. It should be noted that although these sources provide the best available estimates of discards, the estimates are not necessarily accurate because they are based on visual observations by observers rather than data from direct sampling.

Status and trends: In 1998, the amount of managed groundfish species discarded in federally-managed Alaskan groundfish fisheries dropped to less than 10% of the total groundfish catch in both the Eastern Bering Sea (EBS) and the Gulf of Alaska (GOA) (Figure 103). Discard rates in the Gulf of Alaska have varied over time but were lower than average in 2010 and 2011. Discard rates in the Aleutian Islands (AI) dropped significantly in 1997, trended generally upwards from 1998 through 2003, and have generally declined over the last eight years. As in the EBS and the GOA, both discards and discard rates in the AI are much lower now than they were in 1996.

Factors causing observed trends: Discards in both the EBS and the GOA are much lower than the amounts observed in 1997, before implementation of improved-retention regulations. These decreases are explained by reductions in the discard rates of pollock and Pacific cod that resulted from regulations implemented in 1998 prohibiting discards of these two species. The decline in discards in both the AI and the EBS in 2008 is largely due to enactment of improved retention/utilization regulations by the North Pacific Fishery Management Council for the trawl head-and-gut fleet.

Implications: The management of discards in commercial fisheries is important for the obvious reason that discards add to the total human impact on the biomass without providing a benefit to the Nation.

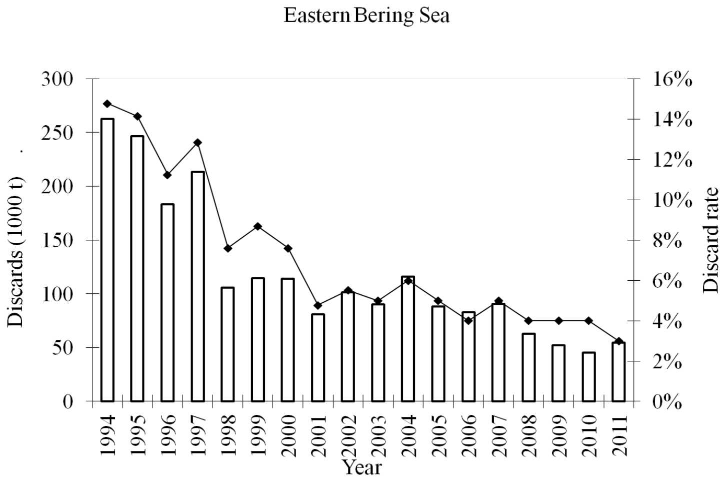
Time Trends in Non-Target Species Catch

Contributed by Andy Whitehouse[1], Sarah Gaichas[2], and Stephani Zador[3]
[1]Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington, Seattle WA, [2]Ecosystem Assessment Program, Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, Woods Hole MA, [3]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: sarah.gaichas@noaa.gov
Last updated: August 2012

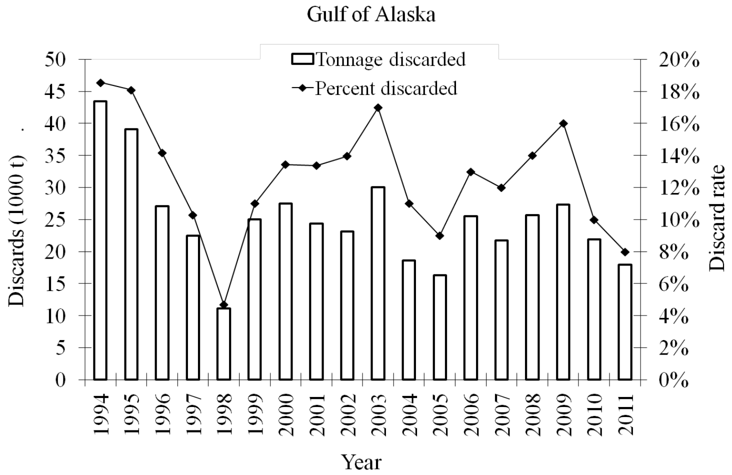
Description of index: We monitor the catch of non-target species in groundfish fisheries in the Eastern Bering Sea (EBS), Gulf of Alaska (GOA) and Aleutian Islands (AI) ecosystems (Figure 104). There are three categories of non-target species: 1) forage species (gunnels, stichaeids, sandfish, smelts, lanternfish, sand lance), 2) species associated with Habitat Areas of Particular Concern-HAPC species (seapens/whips, sponges, anemones, corals, tunicates), and 3) non-specified species (grenadiers, crabs, starfish, jellyfish, unidentified invertebrates, benthic invertebrates, echinoderms, other fish, birds, shrimp). Stock assessments have been developed for all groups in the other species (sculpins, unidentified sharks, salmon sharks, dogfish, sleeper sharks, skates, octopus, squid) category, so we do not include trends for "other species" here (see AFSC stock assessment website at http://www.afsc.noaa.gov/refm/stocks/assessments.htm).

Total catch of nontarget 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. From 1997-2002, these estimates were made at the AFSC using data from the observer program and the NMFS Alaska Regional Office. Catch since 2003 has been estimated using the Alaska Region's new Catch Accounting system. These methods should be comparable. 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. Until 2008, observer sample recording protocols prevented estimation of variance in catch; however, we are developing methods to estimate variance for 2008 on which will be presented in future reports.

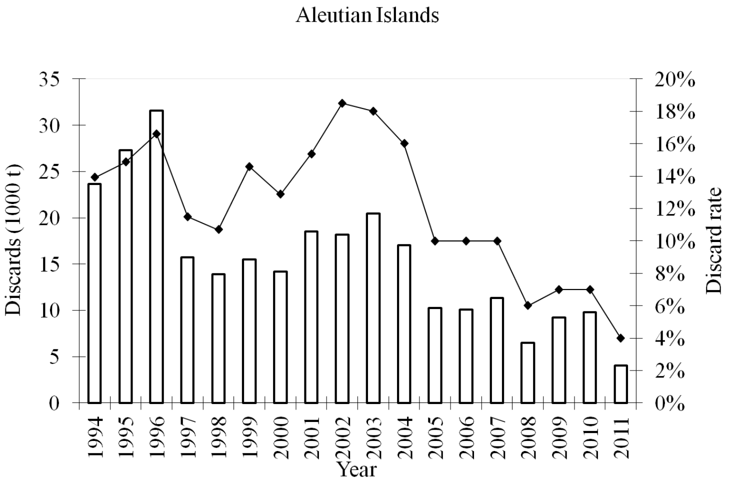
Status and trends: In all three ecosystems, non-specified catch comprised the majority of non-target catch during 1997-2011 (Figure 104). Non-specified catches are similar in the EBS and GOA, but are an order of magnitude lower in the AI. Catches of HAPC biota are highest in the EBS, intermediate in the AI and lowest in the GOA. The catch of forage fish is highest in the GOA, low in the EBS and very low in the AI.



(a) EBS



(b) GOA



(c) AI

Figure 103: Total biomass and percent of total catch biomass of managed groundfish discarded in the EBS, GOA, and AI areas, 1994-2011. (Includes only catch counted against federal TACS)

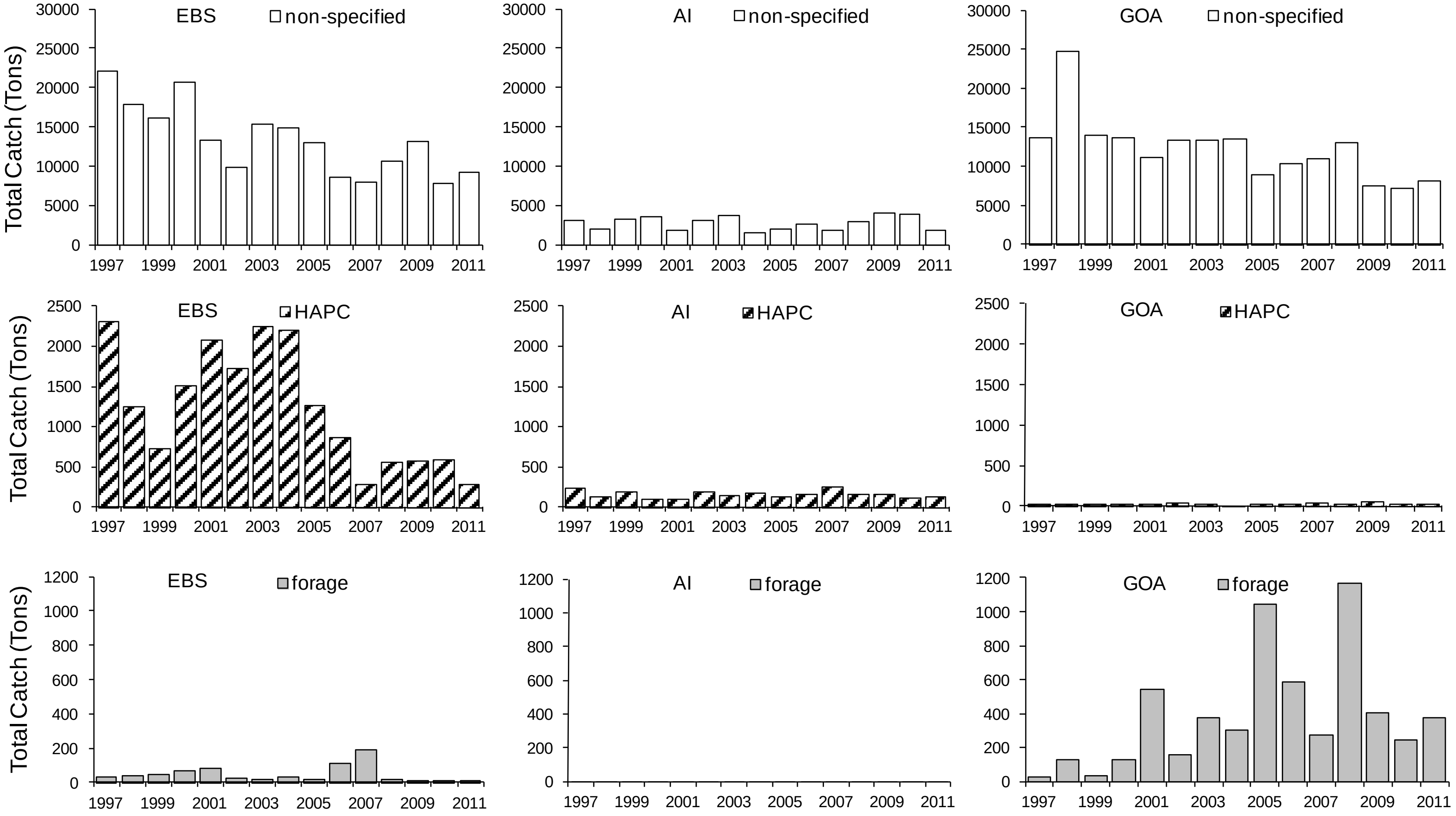


Figure 104: Total catch of non-target species (tons) in the EBS, AI, and GOA groundfish fisheries.

In the EBS, the catch of non-specified species appears to have decreased overall since the late 1990s. Scyphozoan jellyfish, grenadiers and sea stars comprise the majority of the non-specified catches in the EBS. The 2008-2009 and 2010-2011 increase in non-specified catch was driven by jellyfish. Grenadiers (including the Giant grenadier) are caught in the flatfish, sablefish, and cod fisheries. Jellyfish are caught in the pollock fishery and sea stars are caught primarily in flatfish fisheries. HAPC biota catch has generally decreased since 2004. Benthic urochordata, caught mainly by the flatfish fishery, comprised the majority of HAPC biota catches in the EBS in all years except 2009-2011, when sponges and sea anemones increased in importance. The catch of forage species in the EBS increased in 2006 and 2007 and was comprised mainly of eulachon that was caught primarily in the pollock fishery; however, forage catch decreased in 2008-2010. The forage catch increased again in 2011, primarily due to capelin and eulachon.

In the AI, the catch of non-specified species shows little trend over time, although the highest catches were recorded in 2009-2010. The non-specified catch dropped in 2010-2011, primarily due to a reduction in the catch of giant grenadiers. Grenadiers comprise the majority of AI non-specified species catch and are taken in flatfish and sablefish fisheries. HAPC catch has been similarly variable over time in the AI, and is driven primarily by sponges caught in the trawl fisheries for Atka mackerel, rockfish and cod. Forage fish catches in the AI are minimal, amounting to less than 1 ton per year, with the exception of 2000 when the catch estimate was 4 tons, driven by (perhaps anomalous) sandfish catch in the Atka mackerel fishery.

The catch of non-specified species in the GOA has been generally consistent aside from a peak in 1998 and lows in 2009 and 2010. Grenadiers comprise the majority of non-specified catch and they are caught primarily in the sablefish fishery. Sea anemones comprise the majority of the variable but generally low HAPC biota catch in the GOA and they are caught primarily in the flatfish fishery. The catch of forage species has undergone large variations, peaking in 2005 and 2008 and decreasing in 2006-2007 and 2009-2010. The catch of forage species increased in 2010-2011, primarily due to eulachon and other osmerids. The main species of forage fish caught are eulachon and they are primarily caught in the pollock fishery.

Factors causing observed trends: The catch of nontarget species may change if fisheries change, if ecosystems change, or both. Because nontarget 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 nontarget catch at may indicate ecosystem changes. Catch trends may be driven by changes in biomass or changes in distribution (overlap with the fishery) or both.

Implications: Catch of non-specified species is highest in the non-target category and has remained stable or possibly recently declined in all three ecosystems. Overall, the catch of HAPC and forage species in all three ecosystems is very low compared with the catch of target and non-specified species. HAPC species may have become less available to the EBS fisheries (or the fisheries avoided them more effectively) during the late 2000s. Forage fish may be more available to fisheries in the GOA during the 2000s.

Ecosystem Goal: Maintain and Restore Fish Habitats

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

Contributed by John Olson, Habitat Conservation Division, Alaska Regional Office, National Marine Fisheries Service, NOAA
Contact: john.v.olson@noaa.gov

Last updated: August 2012

Description of index: Many trawl closures have been implemented to protect benthic habitat or reduce bycatch of prohibited species (i.e., salmon, crab, herring, and halibut)(Figure 105). 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. For additional background on fishery closures in the U.S. EEZ off Alaska, see Witherell and Woodby (2005).

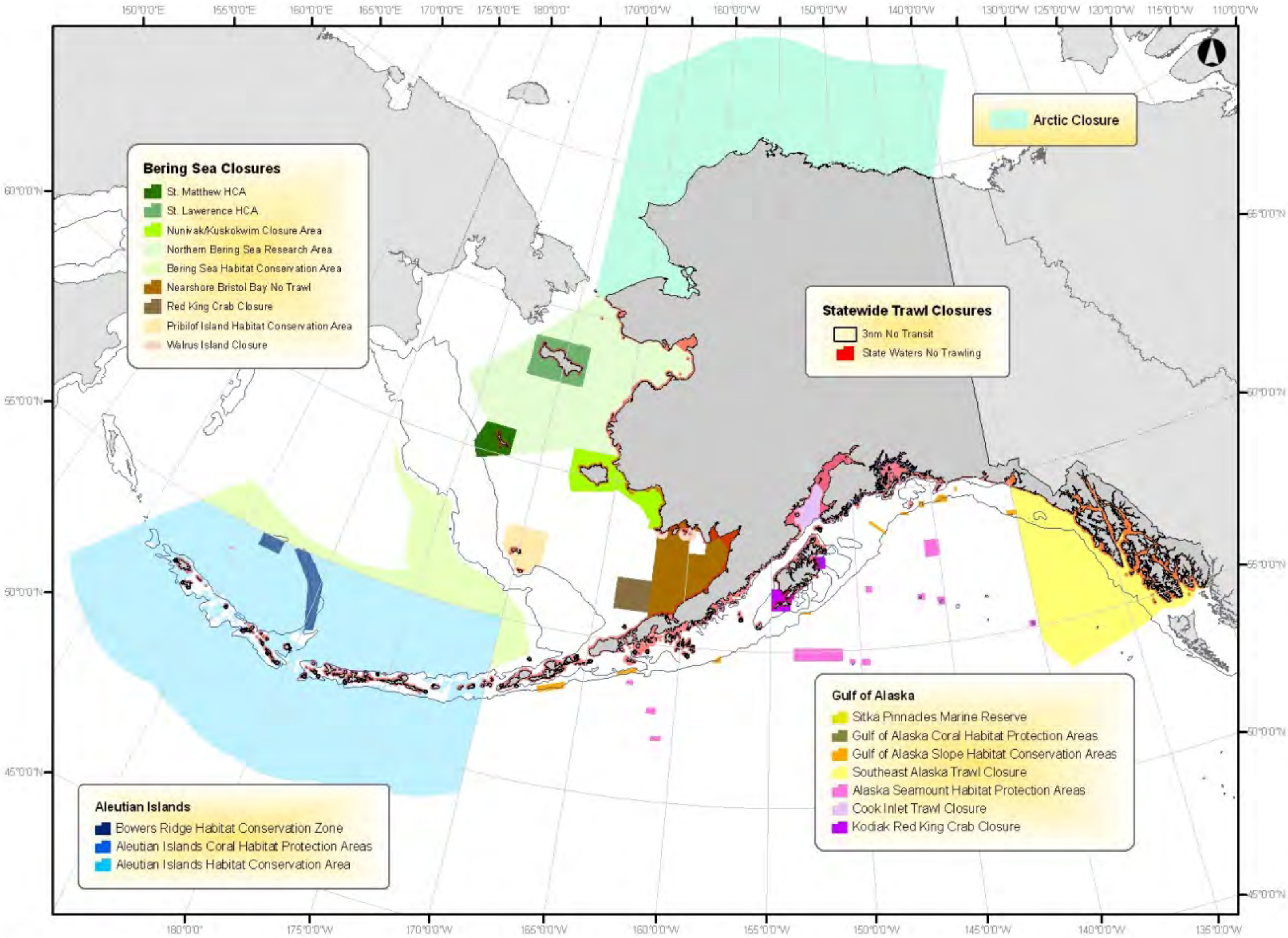


Figure 105: Year-round groundfish closures in the U.S. Exclusive Economic Zone (EEZ) off Alaska, excluding most SSL closures.

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 nm2 were closed on a seasonal basis. State waters (0-3 nmi) are also closed to bottom trawling in most areas. A motion passed the North Pacific Management Council in February 2009 which closed all waters north of the Bering Strait to commercial fishing as part of the development of an Arctic Fishery management plan. This additional closure adds 148,300 nm^2 to the area closed to bottom trawling year round.

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

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

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

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`

Hook and Line (Longline) Fishing Effort in the Gulf of Alaska, Bering Sea and Aleutian Islands

Contributed by John Olson, Habitat Conservation Division, Alaska Regional Office, National Marine Fisheries Service, NOAA
Contact: john.v.olson@noaa.gov
Last updated: October 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Groundfish Bottom Trawl Fishing Effort in the Gulf of Alaska, Bering Sea and Aleutian Islands

Contributed by John Olson, Habitat Conservation Division, Alaska Regional Office, National Marine Fisheries Service, NOAA
Contact: john.v.olson@noaa.gov

Last updated: October 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Groundfish Pelagic Trawl Fishing Effort in the Gulf of Alaska, Bering Sea and Aleutian Islands

Contributed by John Olson, Habitat Conservation Division, Alaska Regional Office, National Marine Fisheries Service, NOAA
Contact: john.v.olson@noaa.gov
Last updated: October 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

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

Contributed by John Olson, Habitat Conservation Division, Alaska Regional Office, National Marine Fisheries Service, NOAA
Contact: john.v.olson@noaa.gov
Last updated: October 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Ecosystem Goal: Sustainability (for consumptive and non-consumptive uses)

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

Contributed by Andy Whitehouse, Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington, Seattle, WA
Contact: andy.whitehouse@noaa.gov
Last updated: August 2012

Description of index: 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/statusoffisheries/SOSmain.htm`). 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

Table 12: Summary of status for FSSI and non-FSSI stocks managed under federal fishery management plans off Alaska, 2011.

Jurisdiction	Stock Group	Number of Stocks	Overfishing					Overfished				Approaching Over-fished Condi-tion
			Yes	No	Unk	Undef	NA	Yes	No	Unk	Undef	
NPFMC	FSSI	35	0	35	0	0	0	2	28	0	5	0
NPFMC	NonFSSI	29	0	21	6	1	1	0	4	4	21	0
	Total	64	0	56	6	1	1	2	32	4	16	0

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 230 FSSI stocks in the U.S., with a maximum possible score of 920. The value of the FSSI is the sum of the individual stock scores. In the Alaska Region, there are 35 FSSI stocks, and an overall FSSI of 140 would be achieved if every stock scored the maximum value, 4 (Tables 12 and13). Additionally, there are 29 non-FSSI stocks, two ecosystem component species complexes, and Pacific halibut which are managed under an international agreement (Tables 12 and 14).

Many species in Alaska are monitored as part of a group or complex, but are considered individually for the purposes of the report. The overfishing determination for the individual species is listed as "unknown", but the species' complex is determined to be "not subject to overfishing" based on the abundance estimates for the entire complex. This determination is applicable for some sharks, skates, sculpins, octopus, and squid complexes in the Gulf of Alaska (GOA) Groundfish FMP. In the Bering Sea-Aleutian Islands (BSAI) Groundfish FMP, similar determinations are made for some stocks in the sharks, skates, sculpins, octopus, rockfish, and flatfish complexes. For this year's chapter, groups previously reported in the larger "Other Species" complex, have been separated out into their respective assemblage units (e.g. Sculpin complex).

Status and trends: : As of June 30, 2011, no BSAI or GOA groundfish stock or stock complex is overfished and no BSAI or GOA groundfish stock or stock complex is being subjected to overfishing (Tables 12 and 13). Stocks that are considered overfished are Pribilof Island blue king crab and BSAI Tanner crab. The Pribilof Island blue king crab is on a continuing rebuilding plan (year 9 of 10-year plan) while the management required for the Tanner crab stock is to develop a rebuilding plan. The status of the Bering Sea snow crab rebuilding program has changed from rebuilding to rebuilt.

The current overall Alaska FSSI is 122.5 out of a possible 140, based on updates through June 2012(Table 13). This is a half point reduction from last year (the overall Alaska FSSI of 119 reported in last year's document should have been 123). The overall Bering Sea/Aleutian Islands score is 82 out of a possible maximum score of 92 (the overall BSAI possible maximum FSSI was incorrectly reported as 88 in last year's document). The BSAI groundfish score is 56 (including BSAI/GOA sablefish, see (g) in Box A) of a maximum possible 56 (the BSAI groundfish maximum possible score was incorrectly reported as 52 in last year's document) and BSAI king and Tanner crabs score 26 of a possible score of 36. The Gulf of Alaska groundfish score is 40.5 of a maximum possible 48 (excluding BSAI/GOA sablefish). Overall, the Alaskan total FSSI score increased from 2006 through 2010, then decreased slightly in 2011 and 2012 (Figure 106)

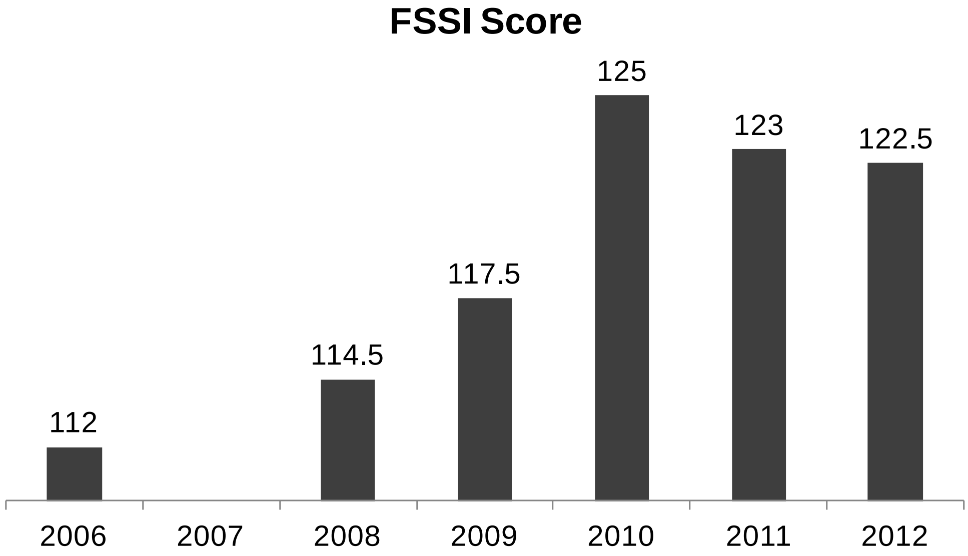


Figure 106: The trend in total Alaskan FSSI score from 2006 through 2012. All scores are the reported through the second quarter (June) of each year, and are retrieved from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm`. The maximum possible FSSI score is 140 in all years. Scores for 2007 were not available at the time of document preparation.

Factors causing observed trends: The total Alaskan FSSI dropped two points from 125 in 2010 to 123 in 2011. One point was lost because the biomass of the Pribilof Islands stock of red king crab dropped below 80% of B_{MSY}. The second point was lost for the Bering Sea southern Tanner crab stock becoming overfished.

From 2011 to 2012 another half point was lost in the total Alaskan FSSI. This was the net result of a two stocks each gaining a point, while a third stock lost points. One point was gained because the biomass of eastern Bering Sea pollock increased to a level at or above 80% of B_{MSY}. BSAI king and Tanner crabs also increased by one point because Bering Sea snow crab biomass increased to be at or above 80% of B_{MSY}. The FSSI score for GOA groundfish dropped by 2.5 points due to changes in the FSSI for the deep water flatfish complex. Following the recommendations of the most recent assessment report, the GOA deep water flatfish complex no longer has an indicator species, therefore an overfished determination can no longer be made, it is unknown whether they are approaching an overfished condition, and the ratio of B:BMSY is not estimated. The 2.5 point reduction in the GOA deep water flatfish complex FSSI offsets the two points gained by eastern Bering Sea walleye pollock and Bering Sea snow crab and explains the half point reduction in the total Alaskan FSSI.

Other 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 two rockfish complexes are because it is undefined whether these species are overfished, it is unknown if they are approaching an overfished condition, and the ratio of B:BMSY is not estimated.

Implications: The majority of Alaska groundfish fisheries appear to be sustainably managed. Two stocks or stock complexes are overfished (Pribilof Islands blue king crab and Bering Sea southern Tanner crab), no other stocks or stock complexes are approaching an overfished condition, and no stock or stock complex is subject to overfishing.

Table 13: FSSI stocks under NPFMC jurisdiction updated June 2012, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm`.

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/Bmsy	FSSI Score
Blue king crab - Pribilof Islands	No[a]	Yes	N/A	Rebuilding Program	Year 9 of 10	0.065	2
Blue king crab - Saint Matthews Island	No	No	No	N/A	N/A	2.204	4
Golden king crab - Aleutian Islands	No	Undefined	Unknown	N/A	N/A	not estimated	1.5
Red king crab - Bristol Bay	No	No	No	N/A	N/A	1.197	4
Red king crab - Norton Sound	No	No	No	N/A	N/A	1.739	4
Red king crab - Pribilof Islands	No1	No	Unknown	N/A	N/A	0.535	3
Red king crab - Western Aleutian Islands	No	Undefined	Unknown	N/A	N/A	not estimated	1.5
Snow crab - Bering Sea	No	No	No	Rebuilt	N/A	1.333	4
Southern Tanner crab - Bering Sea[b]	No	Yes	N/A	Rebuilding Program	N/A	0.321	2
BSAI Alaska plaice	No	No	No	N/A	N/A	2.04	4
BSAI Atka mackerel	No	No	No	N/A	N/A	1.692	4
BSAI Arrowtooth Flounder Complex[c]	No	No	No	N/A	N/A	3.156	4
BSAI Blackspotted and Rougheye Rockfish[d]	No	No	No	N/A	N/A	1.328	4
BSAI Flathead Sole Complex[e]	No	No	No	N/A	N/A	2.122	4
BSAI Rock Sole Complex[f]	No	No	No	N/A	N/A	2.057	4
BSAI Greenland halibut	No	No	No	N/A	N/A	2.714	4
BSAI Northern rockfish	No	No	No	N/A	N/A	1.615	4
BSAI Pacific cod	No	No	No	N/A	N/A	1.141	4
BSAI Pacific Ocean perch	No	No	No	N/A	N/A	1.627	4
Walleye pollock - Aleutian Islands	No	No	No	N/A	N/A	0.846	4
Walleye pollock - Eastern Bering Sea	No	No	No	N/A	N/A	1.034	4
BSAI Yellowfin sole	No	No	No	N/A	N/A	1.639	4
BSAI GOA Sablefish[g]	No	No	No	N/A	N/A	1.09	4

Table 13: FSSI stocks under NPFMC jurisdiction updated June 2012, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm`. (continued)

Stock	Overfishing	Overfished	Approaching	Action	Progress	B/Bmsy	FSSI Score
GOA Arrowtooth flounder	No	No	No	N/A	N/A	2.94	4
GOA Flathead sole	No	No	No	N/A	N/A	2.809	4
GOA Blackspotted and Rougheye Rockfish complex	No	No	No	N/A	N/A	1.492	4
GOA Deepwater Flatfish Complex[h]	No	Undefined	Unknown	N/A	N/A	not estimated	1.5
GOA Demersal Shelf Rockfish Complex[i]	No	Undefined	Unknown	N/A	N/A	not estimated	1.5
GOA Dusky Rockfish[j]	No	No	No	N/A	N/A	1.677	4
GOA Thornyhead Rockfish Complex[k]	No	Undefined	Unknown	N/A	N/A	not estimated	1.5
Northern rockfish - Western / Central GOA	No	No	No	N/A	N/A	1.851	4
GOA Pacific cod	No	No	No	N/A	N/A	1.198	4
GOA Pacific Ocean perch	No	No	No	N/A	N/A	1.302	4
GOA Rex sole	No	No	No	N/A	N/A	2.713	4
Walleye pollock - Western / Central GOA	No	No	No	N/A	N/A	1.004	4

Box A. Endnotes and stock complex definitions for FSSI stocks listed in Table 13, adapted from the Status of U.S. Fisheries website: http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm. **a** Fishery in the EEZ is closed; therefore, fishing mortality is very low. **b** The North Pacific Fishery Management Council was notified by the Alaska Regional Office on October 1, 2010 that Southern Tanner crab is overfished. The NPFMC has 2 years from this date to implement a rebuilding plan for Southern Tanner crab - Bering Sea. **c** The Arrowtooth Flounder Complex consists of Arrowotooth flounder only. Beginning in 2010, Kamchatka flounder was separated into its own assessment, so the arrowtooth flounder assessment now represents arrowtooth flounder only, but management will continue to be based on the "arrowtooth flounder" assemblage. **d** 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** 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. **h** The Deep Water Flatfish Complex consists of the following stocks: Deepsea Sole, Dover Sole, and Greenland Turbot. Prior to 2011, Dover sole was the indicator stock for the deep-water flatfish assemblage. However, the 2011 assessment contained a recommendation that the existing age-structured model be rejected, including using Dover sole as an indicator species. The deep-water flatfish complex therefore no longer has an indicator species and an overfished determination can no longer be made. The complex was not subject to overfishing in 2010. **i** 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. **j** Prior to 2011, dusky rockfish was the indicator species for the "pelagic shelf rockfish" complex. Now, however, dusky rockfish is assessed as a single stock and the remaining two members of the former "pelagic shelf rockfish" assemblage (yellowtail and widow rockfish) have been combined with the former "other slope rockfish" assemblage to create a new "other rockfish" assemblage. Overfishing was not defined in 2010 for the dusky rockfish stock per se, but the former pelagic shelf rockfish complex was not subject to overfishing. **k** The Thornyhead Rockfish Complex consists of the following stocks: Longspine Thornyhead and Shortspine Thornyhead. The overfishing determination is based on the OFL, which is computed using abundance estimates of Shortspine Thornyhead.

Table 14: Non-FSSI stocks, Ecosystem Component Species, and Stocks managed under an International Agreement updated June 2012, adapted from the Status of U.S. Fisheries website: `http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm`. See website for definition of stocks and stock complexes.

Stock	Jurisdiction	Overfishing	Overfished	Approaching
Golden king crab - Pribilof Islands	NPFMC	No	Undefined	Unknown
BSAI Octopus Complex	NPFMC	Unknown	Undefined	Unknown
BSAI Other Flatfish Complex	NPFMC	No	Undefined	Unknown
BSAI Other Rockfish Complex	NPFMC	No	Undefined	Unknown
BSAI Sculpin Complex	NPFMC	Unknown	Undefined	Unknown
BSAI Shark Complex	NPFMC	Unknown	Undefined	Unknown
BSAI Skate Complex	NPFMC	No	No	No
BSAI Squid Complex	NPFMC	No	Undefined	Unknown
BSAI Kamchatka flounder	NPFMC	Undefined	Undefined	Unknown
BSAI Shortraker rockfish	NPFMC	No	Undefined	Unknown
Walleye pollock - Bogoslof	NPFMC	No	Undefined	Unknown
GOA Atka mackerel	NPFMC	No	Undefined	Unknown
GOA Big skate	NPFMC	No	Undefined	Unknown
GOA Octopus complex	NPFMC	Unknown	Undefined	Unknown
GOA Squid Complex	NPFMC	Unknown	Undefined	Unknown
GOA Other Rockfish Complex	NPFMC	No	Undefined	Unknown
GOA Sculpin Complex	NPFMC	Unknown	Undefined	Unknown
GOA Shallow Water Flatfish Complex	NPFMC	No	No	No
GOA Shark Complex	NPFMC	Unknown	Undefined	Unknown
GOA Alaska skate Complex	NPFMC	No	Undefined	Unknown
GOA Longnose skate	NPFMC	No	Undefined	Unknown
GOA Shortraker rockfish	NPFMC	No	Undefined	Unknown
Walleye pollock - Eastern Gulf of Alaska	NPFMC	No	Undefined	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	Undefined	Unknown
Arctic cod - Arctic FMP	NPFMC	No	Unknown	Unknown
Saffron cod - Arctic FMP	NPFMC	No	Unknown	Unknown
Snow crab - Arctic FMP	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/NP,PFMC	Undefined	No	No

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
Contact: franz.mueter@uaf.edu
Last updated: July 2010

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Community Size Spectrum of the Bottom Trawl-Caught Fish Community of the Eastern Bering Sea

Contributed by Jennifer Boldt[1], Shannon Bartkiw[1], Pat Livingston[1], Jerry Hoff[2], and Gary Walters[2]
[1]Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
[2]Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: jennifer.boldt@dfo-mpo.gc.ca
Last updated: August 2008

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Ecosystem Goal: Humans are part of ecosystems

Fishing Overcapacity Programs

Contributed by Jessica Gharrett and Rachel Baker
Alaska Regional Office, National Marine Fisheries Service, NOAA, PO Box 21668 Juneau, AK 99802-1668
Contact: jessica.gharrett@noaa.gov or rachel.baker@noaa.gov
Last updated: August 2012

Overview: Overcapacity, wherein there is an excessive level of investment or effort relative to the available fisheries resources, is considered a problem in fisheries throughout the world. The problem is often manifested in short fishing seasons, increased enforcement and safety problems, and reduced economic viability for vessel owners and crew-members. Overcapacity can, under certain conditions, have grave implications for conservation as well.

The North Pacific Fishery Management Council (Council) and Congress have developed numerous tools and programs to address increasing effort in fully- or over-subscribed Alaskan fisheries. Some "traditional" tools have been refined to allowed more responsive management and avoidance of TAC overruns; for example, comprehensive and electronic reporting systems and broad observer coverage have improved the level of detail and timeliness of catch, discard, and landings information available to in-season managers. However, more significant has been development of management programs that limit the numbers of participants or that control size and/or effort of those participants.

Trends: Since the 1990s, the Alaskan management trend has been towards increasingly specific management, from more finely divided allocations (by season, area, gear, sectors), to capacity removal, to "rights-based" catch share management such as Community Development Quota (CDQ) allocations, cooperatives and individual quotas. Rights-based management has successfully addressed many ills typical of open access, as well as introducing some new issues. Alaskan programs have been designed to meet socioeconomic goals such as protecting the economic interests of historical participants and preventing excessive consolidation, in order to minimize negative impacts on fishery-dependent communities, while maintaining sustainable, economically viable fisheries. For example, recent Council catch share recommendations are intended to maintain active harvesting participation by quota holders, including "holder-on-board" provisions and revocation of privileges for latent participants. The Council also requested, and NMFS implemented, community purchase programs and loan programs to assist entry into the two major individual quota fisheries. Implementation of catch share management programs has enabled continued expansion of electronic reporting and observer coverage along with consideration of newer technologies such as video recording particularly for small vessel fleets. Catch share management also facilitated development of additional bycatch controls through implementation of quotas to address bycatch concerns while providing flexibility in bycatch use among participants. NMFS plans to expand cost recovery to additional catch share programs, under which landing fees help defray public costs of managing and enforcing dedicated access privileges. Finally, Federal and State management are increasingly coordinated to manage fisheries holistically, including bycatch, and throughout their range.

Text overviews (through mid-2010) of Alaskan limited access management programs can be found in 2010 Ecosystem Consideratins report (Zador and Gaichas, 2010). Additionally, a thorough review of Alaskan catch share programs and a document containing fleet profiles prepared by Council staff and are posted on its website, at `http://www.fakr.noaa.gov/npfmc/PDFdocuments/catch_shares/Fina_CatchShare_411.pdf` and `http://www.fakr.noaa.gov/npfmc/PDFdocuments/resources/FleetProfiles412.pdf`, respectively. For current management programs: program information; links to analyses, proposed, and final rules and current regulations; and application forms and reports including current issued permits, are posted on the NMFS, Alaska Region website: `http://www.alaskafisheries.noaa.gov/ram`. A variety of online constituent services are offered to foster industry self-determination and resource stewardship and support efficient and timely operations.

Following is a brief description of each major Alaskan capacity reduction permit program.

Vessel Moratorium Programs. License "Moratorium" programs for crab and groundfish (1996), and scallops (1997) fixed the number of harvesting vessels that could be deployed off Alaska and set limits on vessel and gear characteristics, operational types, and/or fishing areas. At the time these programs were replaced with License Limitation Permit (LLP) programs in late 1999, 1,864 groundfish and 653 crab vessel owners held moratorium fishing rights, and fewer than a dozen held Scallop Moratorium Permits.

Vessel License Limitation Programs. License Limitation programs (LLPs) established a fixed number of transferable harvesting licenses, with combinations of gear, area, species/fishery, vessel length, and operation type endorsements. Over time, the crab and groundfish programs have been re-implemented to remove latent effort and licenses, prevent "crossover" and "spillover" effects into other fisheries, and for groundfish, to add community benefit in form of issuance of licenses to eligible communities to help preserve and build fishery revenues. No new developments have occurred in the crab program since 2005 when the crab rationalization program catch share program replaced the requirement for an LLP for most fisheries. Residual LLP fisheries are managed by the State of Alaska. Currently, there are about 350 crab LLP permits, about half the number of vessels eligible to fish under the Moratorium. At present there are 1,839 LLP groundfish, and nine scallop licenses.

Capacity Reduction ("Buyback") Programs. Direct "Capacity Reduction" programs have been used to permanently retire vessels, licenses, fishery endorsements, and/or participation histories through monetary compensation ("buyback" programs), administered by the NOAA Fisheries, Financial Services Division. In addition, vessels may not be reflagged under any other nation. By 1998 statute, nine American Fisheries Act (AFA) catcher/processor vessels were removed by a combination of Agency funding and repayable industry loan, and were physically scrapped. In more recent programs, after a bid process programs approved by industry referenda have been funded by Government loans repayable through landing fees on program participants. The Crab Capacity Reduction Program (2004) removed 25 vessels and their histories. A subsequent statute authorizes buyback programs for four groundfish fishery subsectors, to be developed separately; a recent implementation removed three vessels and multiple licenses from the longline catcher-processor subsector, and a recent proposed addition to the latter would remove an additional latent license. The objective of the program is to achieve a permanent reduction of capacity to: increase post-reduction harvester's productivity, help financially stabilize the fishery, and help conserve and manage fishery resources.

Rights-based Management Programs. Rights-based management such as individual transferable quotas and dedicated allocations to cooperatives and industry "sectors" have increasingly being used to "rationalize" fisheries. Often, "sideboard" measures prevent "spillover" effects due to imposition of right-based programs.

The following "rights-based" programs have been implemented in Alaska. An overview of these programs follows:

The **American Fisheries Act (AFA)** established by statute which harvesting and processing vessels could participate in Bering Sea/Aleutian Islands pollock fisheries, authorized pollock harvesting cooperatives, established allocations for inshore and offshore processing, and established allocations of pollock Total allowable Catch (TAC) to BS/AI communities eligible for a Community Development Quota program. Under the AFA, 109 catcher, 21 catcher-processor, and 3 mothership vessels and 8 inshore processors are authorized to participate; vessels may be replaced or (more recently) removed, and their histories reassigned. Six inshore-delivering vessel cooperatives are licensed and catcher-processor vessel owners formed a voluntary industry cooperative.

The first rights-based management program in Alaska was the **Individual Fishing Quota (IFQ)** program, which has been used to manage the halibut and fixed gear sablefish fisheries since 1995. Rather than limiting the number of harvesting vessels, this program grants quota holders the privilege of harvesting a specified percentage of the Total Allowable Catch (TAC) each year. The Council included, and has since added, numerous provisions that protect many pre-existing practices and provide additional operational flexibility while moving the bulk of the fishery toward a small vessel, owner-operator fleet. In addition, a Community purchase provision added in 2004 was intended as an opportunity to reverse the rapid attrition of quota from residents of small coastal communities through voluntary transfers. The IFQ program includes cost recovery. The number of QS holders has decreased from 4,829 and 1,054 for halibut and sablefish, to 2,637 and 841 respectively. Participating vessels decreased from 3450 to 1,051 for halibut; and 1,191 to 362 (sablefish). A history of IFQ development authored by the Council and detailed annual reports as well as transfer studies and community quota profiles can be found at: `http://www.alaskafisheries.noaa.gov/ram/ifqreports.htm`.

A similar program developed by the Council, **Crab Rationalization**, was implemented in 2005 by statute. This program includes allocations to Community Development Quota Groups; for one golden king crab species, an allocation to the community of Adak; and a complex quota system for harvesters and processors called the "three-pie voluntary cooperative program." The quota program provides benefits for historic license holder and crew harvesters and for processors, authorizes harvesting cooperatives, and provides protections for crab revenue in fishery-dependent communities, and is largely paid for by cost recovery. The initial eight fisheries were expanded to nine when after the first year the Chionoecetes bairdi Tanner crab (BST) fishery was divided into two fisheries for more accurate stock management. Crab QS or PQS was initially issued to 511 persons (490 received harvesting QS and 27 PQS), but through transfers this has increased to 524 holders (500 hold QS and 30 hold PQS, including a number of entities representing communities). Consolidation has occurred in the crab fisheries, due largely to widespread use of cooperatives. The Council has changed the rationalization program to address a number of issues, including those that relate to capacity in various sectors, to improving operational flexibility through on-line transfers and regional delivery exemptions; and has recommended or is considering requirements for quota holders to actively participate in harvesting. Detailed annual reports can be found at: `http://www.alaskafisheries.noaa.gov/sustainablefisheries/crab/crfaq.htm`

As a prelude to an overarching GOA rationalization program, NMFS, in response to a Congressional mandate and in consultation with the Council, developed a **demonstration quota program for Central Gulf of Alaska rockfishes**, later extended to five years. This program provided exclusive harvesting and processing privileges for a specific set of rockfish and associated species harvested incidentally to those rockfish in the Central GOA and was replaced in 2012 with a permanent regulatory program. Quota issuance was based on LLP license use and attached to those licenses; currently, 54 holders realize annual TAC (and in some cases, bycatch allocations) only through cooperatives or a shared limited access fishery.

Most recently, in a program implemented under statutory authority, NMFS attached quota to LLP licenses for historic participants in the non-AFA catcher/processor sector (**"Amendment 80"**). The quota may be used annually to provide dedicated allocations to harvesting cooperatives or pooled in a limited access fishery to meet the broad goals of: (1) improving retention and utilization of fishery resources by the non-AFA trawl catcher/processor; (2) allocating fishery resources among BSAI trawl harvesters in consideration of historic and present harvest patterns and future harvest needs; (3) authorizing the allocation of groundfish species to harvesting cooperatives and establishing a limited access privilege program (LAPP) for the non-AFA trawl catcher/processors to reduce potential GRS compliance costs, encourage fishing practices with lower discard rates, and improve the opportunity for increasing the value of harvested species; and (4) limiting the ability of non-AFA trawl catcher/processors to expand their harvesting capacity into other fisheries not managed under a LAPP. Currently, 24 persons hold Amendment 80 quota.

Sector allocations. NMFS implemented Council recommendations to the FMPs for the BSAI and GOA, which provides annual allocations of Pacific among jig, trawl, and fixed gear (hook-and-line and pot) subsectors. The recommended allocations were determined based on a set of historic participation criteria, with consideration for small boats and coastal communities dependent on the Pacific cod resource. The Council also recommended seasonal apportionments for jig and trawl gear and a hierarchy for reallocating projected unused allocations among the various sectors. The number of eligible persons subject to this Amendment would be reduced to the extent that prior capacity reduction programs first reduce the size of the fleet.

State-Federal Coordination: Parallel Waters Fisheries. In 2012, NMFS implemented a 2009 Council recommendation to limit access by federally-permitted pot and hook-and-line catcher processor vessels to the BSAI Pacific cod parallel State waters fishery and preclude those vessels from fishing past the end of the sector closures. The Council's action complements the December 2008 action by the Alaska Board of Fisheries that limits the size of vessels using hook-and-line gear in the BSAI Pacific cod parallel State waters fishery to 58 ft LOA. NMFS' action requires certain license endorsements for participation, and stays divestiture of some Federal permits or endorsements.

Arctic FMP. The Council recommended a new Fishery Management Plan for Fish Resources of the Arctic Management Area (Arctic FMP). Established in 2009, the Arctic FMP in intended to provide for sustainable management of commercial fishing in the Arctic Management Area. The Arctic FMP prohibits the expansion of commercial fishing in federal Arctic waters until researchers gather sufficient information to prevent adverse impacts of commercial harvesting activity on the ecosystem.

Guided Sport Halibut Management. The Charter Halibut Limited Entry Program halted entry into the guided sport fishery for International Pacific Halibut Commission (IPHC) areas 2C and 3A. This replaces management under a guideline harvest level (GHL), which had been exceeded for several years in each area. Under the program, NMFS issued Federal charter halibut permits (CHP) to historical participants based on required State logbook reporting and licensing. Eligible communities and military morale and welfare and recreational programs may request a limited number of free permits.

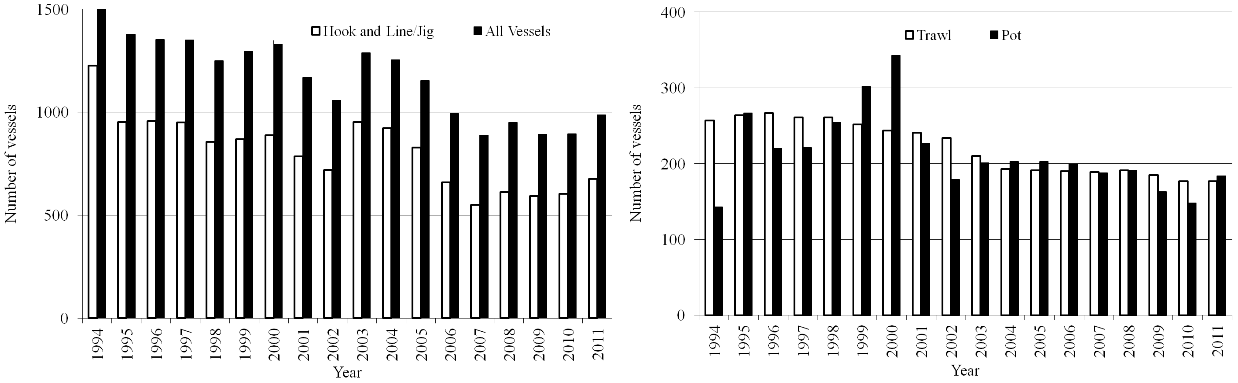
NMFS is drafting regulations to implement the Council's recommendation for an allocation system to replace the current GHLs for charter fisheries in Areas 2C and 3A with a "catch sharing plan". Under the plan the Council would request that the IPHC annually set a combined charter and setline catch limit to which the allocation percentage for each area automatically would be applied to establish domestic harvest targets for each sector. This proposal also included a "guided angler fish" (GAF), feature, under which holders of CHPs could purchase annual IFQ halibut from the commercial fishery for use in individual accounts, to support halibut retention by their clients.

Groundfish Fleet Composition

Contributed by Jean Lee, Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: jean.lee@noaa.gov
Last updated: July 2012

Description of index: Fishing vessels participating in federally-managed groundfish fisheries off Alaska principally use trawl, hook and line, and pot gear. Vessel counts in these tables were compiled from blend and Catch-Accounting System estimates and from fish ticket and observer data through 2011.

Status and trends: The pattern of changes in the total number of vessels harvesting groundfish and the number of vessels using hook and line gear have been very similar since 1994. Numbers have generally decreased since 1994 and were low in the past 5 years (2007-2011). The total number of vessels was 1,518 in 1994 and 987 in 2011 (Figure 107). Hook and line/jig vessels accounted for about 1,225 and 676 of these vessels in 1994 and 2011, respectively. The number of vessels using trawl gear decreased from 257 in 1994 to 177 in 2011. During the same period, the number of vessels using pot gear peaked in 2000 at 343, and decreased to 184 in 2011.



(a) Hook and Line, All vessels (b) Trawl, Pot

Figure 107: Number of vessels participating in the groundfish fisheries off Alaska by gear type, 1994-2010.

Factors causing observed trends: The increase, in 2003, in the number of hook-and-line/jig and pot vessels (and, thus, also in the total number of vessels) results from replacement of the old blend system with the Catch-Accounting System (CAS) as the official estimates of groundfish catch. The new CAS data include the Federal Fisheries Permit numbers of catcher vessels delivering both to motherships and to shoreside processors, making possible a more complete count of participating vessels. It should be noted that vessel counts before and after 2003 are not directly comparable due to the change in data source mentioned above. The increase in the number of vessels in 2011 relative to 2010 is primarily attributable to the entry of new jig-gear vessels targeting Pacific cod in the Gulf of Alaska.

Implications: Monitoring the numbers of fishing vessels is important to fisheries managers, because it provides big-picture measures of fishing effort, the level of capitalization in the fisheries, and the potential magnitude of effects on industry stakeholders caused by management decisions.

Distribution and Abundance Trends in the Human Population of the Bering Sea/Aleutian Islands

Contributed by Amber Himes-Cornell
Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: amber.himes@noaa.gov

Last updated: July 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

Distribution and Abundance Trends in the Human Population of the Gulf of Alaska

Contributed by Amber Himes-Cornell
Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA
Contact: amber.himes@noaa.gov

Last updated: July 2011

See the contribution archive at: `http://access.afsc.noaa.gov/reem/ecoweb/index.cfm`

References

Aagaard, K., and A. T. Roach. 1990. Arctic Ocean-shelf exchange: Measurements in Barrow Canyon. Journal of Geophysical Research-Oceans **95**:18163–18175.

(AFSC), A. F. S. C. 2010. Observer Sampling Manual for 2011. Available From: Fisheries Monitoring and Analysis Division, North Pacific Groundfish Observer Program. AFSC, 7600 Sand Point Way, NE.; Seattle WA; 98115. Technical report.

Allen, B. M., and R. P. Angliss. 2012. Alaska marine mammal stock assessments, 2011. NOAA Tech. Memo. NMFS-AFSC-234, 288 p., U.S. Dep. Commer.

Alverson, D., and N. Wilimovsky. 1966. Fishery Investigations of the Southeastern Chukchi Sea, pages 843–860 . U.S. Atomic Energy Commission, Oak Ridge, TN.

A'mar, Z. T., A. E. Punt, and M. W. Dorn. 2008. The Management Strategy Evaluation Approach and the fishery for walleye pollock in the Gulf of Alaska., pages 317–346 . Alaska Sea Grant College Program, University of Alaska Fairbanks.

Amstrup, S. C., and C. Gardner. 1994. Polar bear maternity denning in the Beaufort Sea. Journal of Wildlife Management **58**:1–10.

Amstrup, S. C., I. Stirling, T. S. Smith, C. Perham, and G. W. Thiemann. 2006. Recent observations of intraspecific predation and cannibalism among polar bears in the southern Beaufort Sea. Polar Biology **29**:997–1002.

Anderson, P. J. 2003. Gulf of Alaska small mesh trawl survey trends, In: J.L.Boldt (Ed.), Ecosystem Considerations for 2004. Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Reports. Technical report, North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Anderson, P. J., and J. F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series **189**:117–123.

Arrigo, K. R., D. K. Perovich, R. S. Pickart, Z. W. Brown, G. L. van Dijken, K. E. Lowry, M. M. Mills, M. A. Palmer, W. M. Balch, F. Bahr, N. R. Bates, C. Benitez-Nelson, B. Bowler, E. Brownlee, J. K. Ehn, K. E. Frey, R. Garley, S. R. Laney, L. Lubelczyk, J. Mathis, A. Matsuoka, B. G. Mitchell, G. W. K. Moore, E. Ortega-Retuerta, S. Pal, C. M. Polashenski, R. A. Reynolds, B. Schieber, H. M. Sosik, M. Stephens, and J. H. Swift. 2012. Massive Phytoplankton Blooms Under Arctic Sea Ice. Science **336**:1408–1408.

Arrigo, K. R., G. van Dijken, and S. Pabi. 2008. Impact of a shrinking Arctic ice cover on marine primary production. Geophysical Research Letters **35**.

Arrigo, K. R., and G. L. van Dijken. 2011. Secular trends in Arctic Ocean net primary production. Journal of Geophysical Research-Oceans **116**.

Atwood, E., J. K. Duffy-Anderson, J. K. Horne, and C. Ladd. 2010. Influence of mesoscale eddies on ichthyoplankton assemblages in the Gulf of Alaska. Fisheries Oceanography **19**:493–507.

AVISO. 2012. Map of sea level anomalies.

Aydin, K. Y., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling.

Baier, C. T., and J. M. Napp. 2003. Climate-induced variability in Calanus marshallae populations. Journal of Plankton Research **25**:771–782.

Barber, W. E., R. L. Smith, M. Vallarino, and R. M. Meyer. 1997. Demersal fish assemblages of the northeastern Chukchi Sea, Alaska. Fishery Bulletin **95**:195–208.

Barber, W. E., R. L. Smith, and T. J. Weingartner. 1994. Fisheries oceanography of the northeast Chukchi Sea final report. Technical report.

Batten, S., and D. L. Mackas. 2009. Shortened duration of the annual Neocalanus plumchrus biomass peak in the Northeast Pacific. Marine Ecology Progress Series **393**:189–198.

Batten, S., D. Welch, and T. Jonas. 2003. Latitudinal differences in the duration of development of Neocalanus plumchrus copepodites. Fisheries Oceanography **12**:201–208.

Blackburn, J. E. 1977. Demersal and Shellfish Assessment in Selected Estuary Systems of Kodiak Island. Technical report, Outer Continental Shelf Environmental Research Laboratory.

Bluhm, B. A., K. Iken, S. M. Hardy, B. I. Sirenko, and B. A. Holladay. 2009. Community structure of epibenthic megafauna in the Chukchi Sea. Aquatic Biology **7**:269–293.

Boe, J. L., A. Hall, and X. Qu. 2009. September sea-ice cover in the Arctic Ocean projected to vanish by 2100. Nature Geoscience **2**:341–343.

Boldt, J., S. Bartkiw, P. A. Livingston, J. Hoff, and G. Walters. 2008. Community size spectrum of the bottom trawl-caught fish community of the eastern Bering Sea. In: J.L.Boldt (Ed.), Ecosystem Considerations for 2009. Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Reports. Technical report, North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Bond, A. L., I. L. Jones, W. J. Sydeman, H. L. Major, S. Minobe, J. C. Williams, and G. V. Byrd. 2011. Reproductive success of planktivorous seabirds in the North Pacific is related to ocean climate on decadal scales. Marine Ecology Progress Series **424**:205–218.

Bond, N. A., and L. Guy. 2010. North Pacific Climate Overview In: S. Zador and S. Gaichas (Ed.), Ecosystem Considerations for 2010. Appendix C of the BSAI/GOA Stock Assessment and Fishery Evaluation Report. Technical report, North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Bond, N. A., J. E. Overland, M. Spillane, and P. Stabeno. 2003. Recent shifts in the state of the North Pacific. Geophysical Research Letters **30**.

Bradstreet, M. S. W. 1982. Occurrence, habitat use, and behavior of seabirds, marine mammals, and Arctic cod at the Pond Inlet ice edge. Arctic **35**:28–40.

Bradstreet, M. S. W., K. Finley, A. Sekerak, W. Griffiths, C. Evans, M. Fabijan, and H. Stallard. 1986. Aspects of the biology of Arctic cod (Boreogadus saida) and its importance in Arctic marine food chains. Technical report.

Braham, H. W., M. A. Fraker, and B. D. Krogman. 1980. SPRING MIGRATION OF THE WESTERN ARCTIC POPULATION OF BOWHEAD WHALES. Marine Fisheries Review **42**:36–46.

Brandon, J., and P. R. Wade. 2006. Assessment of the Bering-Chukchi-Beaufort Sea stock of bowhead whales using Bayesian model averaging. Journal of Cetacean Research and Management **8**:225–240.

Brickley, P. J., and A. C. Thomas. 2004. Satellite-measured seasonal and inter-annual chlorophyll variability in the Northeast Pacific and Coastal Gulf of Alaska. Deep-Sea Research Part Ii-Topical Studies in Oceanography **51**:229–245.

Brodeur, R., C. Mills, J. Overland, G. WAL-TERS, and J. Schumacher. 1999. Recent increase in jellyfish biomass in the Bering Sea: Possible links to climate change. Fish. Oceanogr **8**:286–306.

Brodeur, R., and D. M. Ware. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fisheries Oceanography **1**:32–37.

Brodeur, R. D., M. B. Decker, L. Ciannelli, J. E. Purcell, N. A. Bond, P. J. Stabeno, E. Acuna, and G. L. Hunt. 2008. Rise and fall of jellyfish in the eastern Bering Sea in relation to climate regime shifts. Progress in Oceanography **77**:103–111.

Brodeur, R. D., H. Sugisaki, and G. L. Hunt. 2002. Increases in jellyfish biomass in the Bering Sea: implications for the ecosystem. Marine Ecology-Progress Series **233**:89–103.

Burns, J. J. 1970. Remarks on the Distribution and Natural History of Pagophilic Pinnipeds in the Bering and Chukchi Seas. Journal of Mammalogy **51**:445–454.

Burns, J. J., J. J. Montague, and C. J. Cowles. 1993. The bowhead whale. Spec. Publ. No. 2. Society for Marine Mammalogy, Lawrence, KS.

Cahalan, J., J. Mondragon, and J. Gasper. 2010. Catch sampling and estimation in the Federal groundfish fisheries off Alaska. Technical report, U.S. Dep. Commer., NOA Tech. Memo. NMFS-AFSC-205, 42 p.

Cai, W. J., and P. van Rensch. 2012. The 2011 southeast Queensland extreme summer rainfall: A confirmation of a negative Pacific Decadal Oscillation phase? Geophysical Research Letters **39**:L08702.

Carpenter, S. R., and W. A. Brock. 2006. Rising variance: A leading indicator of ecological transition. Ecology Letters **9**:308–315.

Clark, C. W., R. Charif, S. Mitchell, and J. Colby. 1996. Distribution and behavior of the bowhead whale, Balaena mysticetus, based on analysis of acoustic data collected during the 1993 spring migration off POint Barrow, Alaska. Technical report.

Coachman, L. K., K. Aagaard, and R. B. Tripp. 1975. Bering Strait : the regional physical oceanography. University of Washington Press, Seattle.

Comiso, J. C. 2012. Large Decadal Decline of the Arctic Multiyear Ice Cover. Journal of Climate **25**:1176–1193.

Comiso, J. C., C. L. Parkinson, R. Gersten, and L. Stock. 2008. Accelerated decline in the Arctic Sea ice cover. Geophysical Research Letters **35**.

Condon, R. H., D. K. Steinberg, P. A. del Giorgio, T. C. Bouvier, D. A. Bronk, W. M. Graham, and H. W. Ducklow. 2011. Jellyfish blooms result in a major microbial respiratory sink of carbon in marine systems. Proceedings of the National Academy of Sciences **108**:10225–10230.

Cooney, R. T., and T. M. Willette. 1997. Factors influencing the marine survival of pink salmon in Prince William Sound, Alaska. In: (Emmett, R. L. and Schiewe, M. H.) Estuarine and ocean survival of northeastern Pacific salmon. NOAA Tech Memo NMFS-NWFSC-29 .

Cota, G. F. 1985. Photoadaptation of high Arctic ice algae. Nature **315**:219–222.

Cota, G. F., and R. E. H. Smith. 1991. Ecology of bottom ice algae: II. Dynamics, distributions and productivity. Journal of Marine Systems **2**:279–295.

Coyle, K. O., L. Eisner, F. J. Mueter, A. Pinchuk, M. Janout, K. Cieciel, E. Farley, and A. Andrews. 2011. Climate change in the southeastern Bering Sea: impacts on pollock stocks and implications for the Oscillating Control Hypothesis. Fisheries Oceanography **20**:139–156.

Coyle, K. O., A. Pinchuk, L. Eisner, and J. M. Napp. 2008. Zooplankton species composition, abundance and biomass on the eastern Bering Sea shelf during summer: the potential role of water column stability and nutrients in structuring the zooplankton community. Deep-Sea Research Part II **55**:1755–1791.

Coyle, K. O., and A. I. Pinchuk. 2002. Climate-related differences in zooplankton density and growth on the inner shelf of the southeastern Bering Sea. Progress in Oceanography **55**:177–194.

Cui, X. H., J. M. Grebmeier, L. W. Cooper, J. R. Lovvorn, C. A. North, W. L. Seaver, and J. M. Kolts. 2009. Spatial distributions of groundfish in the northern Bering Sea in relation to environmental variation. Marine Ecology-Progress Series **393**:147–160.

Davies, J. R. 1997. The impact of an offshore drilling platform on the fall migration path of bowhead whales: A GIS-based assessment. Ms.

DeBruyn, T. D., T. J. Evans, S. Miller, C. Perham, E. Regehr, R. Karyn, J. Wilder, and L. J. Lierheimer. 2010. Polar Bear Conservation in the United States, 2005-2009. IUCN, Gland, Switzerland and Cambridge, UK.

Di Lorenzo, E., N. Schneider, K. M. Cobb, P. J. S. Franks, K. Chhak, A. J. Miller, J. C. McWilliams, S. J. Bograd, H. Arango, E. Curchitser, T. M. Powell, and P. Riviere. 2008. North Pacific Gyre Oscillation links ocean climate and ecosystem change. Geophysical Research Letters **35**.

Divoky, G. J. 1976. Pelagic feeding habits of Ivory and Ross' gulls. Condor **78**:85–90.

Douglas, D. C. 2010. Arctic sea ice decline projected changes in timing and extent of sea ice in the Bering and Chukchi Seas. Technical report.

Doyle, M. J., and K. Mier. in press. A new conceptual framework for evaluating the early ontogeny phase of the recruitment process among marine fish species. Canadian Journal of Fisheries and Aquatic Sciences .

Doyle, M. J., S. J. Picquelle, K. L. Mier, M. Spillane, and N. bond. 2009. Larval fish abundance and physical forcing in the Gulf of Alaska, 1981-2003. Progress in Oceanography **80**:163–187.

Ducet, N., P. Y. Le Traon, and G. Reverdin. 2000. Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and-2. Journal of Geophysical Research-Oceans **105**:19477–19498.

Duffy-Anderson, J. K., K. M. Bailey, L. Ciannelli, P. M. Cury, A. Belgrano, and N. C. Stenseth. 2005. Phase transitions in marine fish recruitment processes. Ecological Complexity **2**:205–218.

Dulvy, N., S. Rogers, S. Jennings, V. Stelzenmuller, D. Dye, and H. Skjoldal. 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. Journal of Applied Ecology **45**:1029–1039.

Dunton, K. H., J. L. Goodall, S. V. Schonberg, J. M. Grebmeier, and D. R. Maidment. 2005. Multi-decadal synthesis of benthic-pelagic coupling in the western arctic: Role of cross-shelf advective processes. Deep-Sea Research Part Ii-Topical Studies in Oceanography **52**:3462–3477.

Durner, G. M., J. P. Whiteman, H. J. Harlow, S. C. Amstrup, E. V. Regehr, and M. Ben-David. 2011. Consequences of long-distance swimming and travel over deep-water pack ice for a female polar bear during a year of extreme sea ice retreat. Polar Biology **34**:975–984.

Eggers, D. M. 2003. Run Forecasts and Harvest Projections for 2003 Alaska Salmon Fisheries and Review of the 2002 Season. Juneau: Alaska Department of Fish and Game Regional Information Report No. 5J03-01. .

Eggers, D. M., and A. M. Carroll. 2012. Run Forecasts and Harvest Projections for 2012 Alaska Salmon Fisheries and Review of the 2011 Season.

Elliott, M. 2002. The role of the DPSIR approach and conceptual models in marine environmental management: an example for offshore wind power. Marine Pollution Bulletin **44**:iii–vii.

Fair, L. 2003. Bristol Bay sockeye salmon. In (Eggers, D. M.) Run Forecasts and Harvest Projections for 2003 Alaska Salmon Fisheries and Review of the 2002 Season. Juneau: Alaska Department of Fish and Game Regional Information Report No. 5J03-01. .

Fair, L. F., and A. Nelson. 1999. Southeast Chukchi Sea and Kotzebue Sound trawl survey, 1998. Technical report, Alaska Dept. of Fish and Game, Commercial Fisheries Division, AYK Region.

Farley, E., A. Starovoytov, S. Naydenko, R. Heintz, M. Trudel, C. Guthrie, L. Eisner, and J. Guyon. 2011. . Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. ICES Jour **68**:1138–1146.

Fay, F. H. 1982. Ecology and biology of the Pacific walrus, Odobenus rosmarus divergens Illiger. North American Fauna **74**:1–279.

Fay, F. H., and J. J. Burns. 1988. Maximal feeding depth of walruses. Arctic **41**:239–240.

Feder, H. M., N. R. Foster, S. C. Jewett, T. J. Weingartner, and R. Baxter. 1994. Mollusks in the northeastern Chukchi Sea. Arctic **47**:145–163.

Feder, H. M., and S. C. Jewett. 1978. Survey of the epifaunal invertebrates of Norton Sound, southeastern Chukchi Sea, and Kotzebue Sound. Technical report, Institute of Marine Science, University of Alaska.

Feder, H. M., S. C. Jewett, and A. Blanchard. 2005. Southeastern Chukchi Sea (Alaska) epibenthos. Polar Biology **28**:402–421.

Feder, H. M., S. C. Jewett, and A. L. Blanchard. 2007. Southeastern Chukchi Sea (Alaska) macrobenthos. Polar Biology **30**:261–275.

Fischbach, A., D. Monson, and C. V. Jay. 2009. Enumeration of Pacific walrus carcasses on beaches of the Chukchi Sea in Alaska following a mortality event, September 2009. Technical report.

Fischbach, A. S., S. C. Amstrup, and D. C. Douglas. 2007. Landward and eastward shift of Alaskan polar bear denning associated with recent sea ice changes. Polar Biology **30**:1395–1405.

Fitzgerald, S., M. Perez, and K. Rivera. 2008. Summary of Seabird Bycatch in Alaskan Groundfish Fisheries, 1993 through 2006. Technical report, North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

Frost, K. J., and L. F. Lowry. 1983. Demersal Fishes and invertebrates trawled in the northeastern Chukchi and western Beaufort seas, 1976-77. Technical report.

Frost, K. J., and L. F. Lowry. 1984. Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea, pages 381–401 . Academic Press, Orlando, FL.

Fujioka, J. T. 2006. A model for evaluating fishing impacts on habitat and comparing fishing closure strategies. Canadian Journal of Fisheries and Aquatic Sciences **63**:2330–2342.

Funk, F., L. Brannian, and K. Rowell. 1992. Age-Structured Assessment of the Togiak Herring Stock, 1978-1992, and Preliminary Forecast of Abundance for 1993. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J92-11, Juneau. .

Garlich-Miller, J., J. G. MacCracken, J. Snyder, R. Meehan, M. Myers, J. M. Wilder, E. Lance, and A. Matz. 2011. Status review of the Pacific walrus (Odobenus rosmarus divergens). Technical report.

George, J. C., H. P. Huntington, K. Brewster, H. Eicken, D. W. Norton, and R. Glenn. 2004. Observations on shorefast ice dynamics in arctic Alaska and the responses of the Inupiat hunting community. Arctic **57**:363–374.

George, J. C., S. Moore, and R. S. Suydam. 2007. Summary of stock structure reserach on the Bering-Chukchi-Beaufort Seas stock of bowhead whatles: 2003 - 2007. Technical report, International Whaling Commission.

Gosselin, M., M. Levasseur, P. A. Wheeler, R. A. Horner, and B. C. Booth. 1997. New measurements of phytoplankton and ice algal production in the Arctic Ocean. Deep-Sea Research Part Ii-Topical Studies in Oceanography **44**:1623–+.

Gradinger, R. R., and B. A. Bluhm. 2004. In-situ observations on the distribution and behavior of amphipods and Arctic cod (Boreogadus saida) under the sea ice of the High Arctic Canada Basin. Polar Biology **27**:595–603.

Grebmeier, J. M., and C. P. McRoy. 1989. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. III. Benthic food supply and carbon cycling. Marine Ecology-Progress Series **53**:79–91.

Grebmeier, J. M., C. P. McRoy, and H. M. Feder. 1988. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi seas. I. Food supply source and benthic biomass. Marine Ecology-Progress Series **48**:57–67.

Grebmeier, J. M., J. E. Overland, S. E. Moore, E. V. Farley, E. C. Carmack, L. W. Cooper, K. E. Frey, J. H. Helle, F. A. McLaughlin, and S. L. McNutt. 2006. A major ecosystem shift in the northern Bering Sea. Science **311**:1461–1464.

Hare, S. R., and N. J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography **47**:103–145.

Heintz, R. in press. Correlation between recruitment and fall condition of age-0 pollock (Theragra chalcogramma) from the eastern Bering Sea under varying climate conditions. Deep Sea .

Highsmith, R. C., and K. O. Coyle. 1992. Productivity of arctic amphipods relative to gray whale energy requirements. Marine Ecology-Progress Series **83**:141–150.

Hilborn, R., T. P. Quinn, D. E. Schindler, and D. E. rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences of the United States of America **100**:6564–6568.

Hill, V., and G. Cota. 2005. Spatial patterns of primary production on the shelf, slope and basin of the Western Arctic in 2002. Deep-Sea Research Part Ii-Topical Studies in Oceanography **52**:3344–3354.

Hinckley, S., B. A. Megrey, and T. W. Miller. 2009. Recruitment Prediction, pages 77–82 . H.C. Andersens Boulevard 44-46, 1553 Copenhagen V, Denmark.

Hollowed, A. B., K. Y. Aydin, T. E. Essington, J. N. Ianelli, B. A. Megrey, A. E. Punt, and A. D. M. Smith. 2011. Experience with quantitative ecosystem assessment tools in the northeast Pacific. Fish and Fisheries **12**:189–208.

Hollowed, A. B., S. J. Barbeaux, E. D. Cokelet, E. Farley, S. Kotwicki, P. H. Ressler, C. Spital, and C. D. Wilson. 2012. Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **6570**:230 – 250.

Holmes, E. E., L. W. Fritz, A. E. York, and K. Sweeney. 2007. Age-structured modeling reveals long-term declines in the natality of western Steller sea lions. Ecological Applications **17**:2214–2232.

Holmes, E. E., and A. E. York. 2003. Using age structure to detect impacts on threatened populations: A case study with steller sea lions. Conservation Biology **17**:1794–1806.

Hopcroft, R. R., K. N. Kosobokova, and A. I. Pinchuk. 2010. Zooplankton community patterns in the Chukchi Sea during summer 2004. Deep-Sea Research Part Ii-Topical Studies in Oceanography **57**:27–39.

Hovelsrud, G. K., M. McKenna, and H. P. Huntington. 2008. Marine mammal harvests and other interactions with humans. Ecological Applications **18**:S135–S147.

Hunt, G. L., K. O. Coyle, L. Eisner, E. Farley, R. Heintz, F. J. Mueter, J. M. Napp, J. E. Overland, P. Ressler, S. A. Salo, and P. Stabeno. 2011. Climate impacts on eastern Bering Sea food webs: A synthesis of new data and an assessment of the Oscillating Control Hypothesis. Ices Journal of Marine Science **68**:1230–1243.

Hunt, G. L., P. Stabeno, G. Walters, E. Sinclair, R. D. Brodeur, J. M. Napp, and N. A. Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. Deep-Sea Research Part Ii-Topical Studies in Oceanography **49**:5821–5853.

Hunt, G. L., and P. J. Stabeno. 2005. Oceanography and ecology of the Aleutian Archipelago: spatial and temporal variation. Fisheries Oceanography **14**:292–306.

Hunt, J., G. L. 1991. Marine birds and ice-influenced environments of polar oceans. Journal of Marine Systems **2**:233–240.

Huntington, H. P., C. Buckland, C. Elim, C. Koyuk, C. P. Lay, and C. Shaktoolik. 1999. Traditional knowledge of the ecology of beluga whales (Delphinapterus leucas) in the eastern Chukchi and northern Bering Seas, Alaska. Arctic **52**:49–61.

Ianelli, J. N. 2005. Assessment and fisheries management of eastern Bering Sea walleye pollock: is sustainability luck? Bulletin of Marine Science **76**:321–335.

Ianelli, J. N., T. Honkalehto, S. Barbeaux, S. Kotwicki, K. Y. Aydin, and N. Williamson. 2011. Assessment of the walleye pollock stock in the Eastern Bering Sea. Technical report, N Pac Fish Manage Council, 605 W 4th Ave, Anchorage, AK 99510.

IWC, I. W. C. 1978. Report of the Scientific Committee. Report of the International Whaling Committee **28**:38–92.

IWC, I. W. C. 2007. Report of the Scientific Committee, [Online]. Technical report.

Jay, C. V., and A. Fischbach. 2008. Pacific walrus response to Arctic sea ice losses. Technical report.

Jennings, S., and J. D. Reynolds. 2000. Impacts of fishing on diversity: from pattern to process, page 399 . Blackwell Science, Oxford.

Kelly, B. P. 1988. Ringed seal, Phoca hispida, pages 57–75 . Marine Mammal Commission, Washington, D.C.

Kelly, B. P., J. L. Bengtson, P. Boveng, M. Cameron, S. Dahle, J. Jansen, E. A. Logerwell, J. E. Overland, C. Sabine, G. Waring, and J. Wilder. 2010. Status review of the ringed seal (Phoca hispida). Technical report.

Kenyon, K. W. 1962. Notes on Phocid Seals at Little Diomede Island, Alaska. Journal of Wildlife Management **26**:380–387.

King, J. 2005. Report of the Study Group on Fisheries and Ecosystem Responses to recent regime shifts. PICES Scientific Report No. 28. Technical report.

Kinnard, C., C. M. Zdanowicz, D. A. Fisher, E. Isaksson, A. de Vernal, and L. G. Thompson. 2011. Reconstructed changes in Arctic sea ice over the past 1,450 years. Nature **479**:509–U231.

Kline, J., T. C. 2010. Stable carbon and nitrogen isotope variation in the northern lampfish and Neocalanus, marine survival rates of pink salmon, and meso-scale eddies in the Gulf of Alaska. Progress in Oceanography **87**:49–60.

Kline, T. C., J. Boldt, E. Farley, L. J. Haldorson, and J. H. Helle. 2008. Pink salmon (Oncorhynchus gorbuscha) marine survival rates reflect early marine carbon source dependency. Progress in Oceanography **77**:194–202.

Koski, W. R., J. Zeh, J. Mocklin, A. R. Davis, D. Rugh, J. C. George, and R. Suydam. 2010. Abundance of Bering-Chukchi-Beaufort bowhead whales (Balaena mysticetus) in 2004 estimated from photo-identification data. Journal of Cetacean Research and Management **11**:89–99.

Kotwicki, S., T. W. Buckley, T. Honkalehto, and G. Walters. 2005. Variation in the distribution of walleye pollock (Theragra chalcogramma) with temperature and implications for seasonal migration. Fishery Bulletin **103**:574–587.

Krogman, B., D. Rugh, R. Sonntag, J. Zeh, and D. Ko. 1989. ICE-BASED CENSUS OF BOWHEAD WHALES MIGRATING PAST POINT BARROW, ALASKA, 1978-1983. Marine Mammal Science **5**:116–138.

Kwok, R., G. F. Cunningham, M. Wensnahan, I. Rigor, H. J. Zwally, and D. Yi. 2009. Thinning and volume loss of the Arctic Ocean sea ice cover: 2003-2008. Journal of Geophysical Research-Oceans **114**.

Ladd, C. 2007. Interannual variability of the Gulf of Alaska eddy field. Geophysical Research Letters **34**.

Ladd, C., W. R. Crawford, C. Harpold, W. Johnson, N. B. Kachel, P. Stabeno, and F. Whitney. 2009. A synoptic survey of young mesoscale eddies in the Eastern Gulf of Alaska. Deep-Sea Research Part II **56**:2460–2473.

Ladd, C., N. B. Kachel, C. W. Mordy, and P. J. Stabeno. 2005. Observations from a Yakutat eddy in the northern Gulf of Alaska. Journal of Geophysical Research-Oceans **110**.

Ladd, C., C. W. Mordy, N. B. Kachel, and P. J. Stabeno. 2007. Northern Gulf of Alaska eddies and associated anomalies. Deep-Sea Research Part I-Oceanographic Research Papers **54**:487–509.

Laidre, K. L., I. Stirling, L. F. Lowry, . Wiig, M. P. Heide-Jrgensen, and S. H. Ferguson. 2008. Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. Ecological Applications **18**:S97–S125.

Lane, P. V. Z., L. Llins, S. L. Smith, and D. Pilz. 2008. Zooplankton distribution in the western Arctic during summer 2002: Hydrographic habitats and implications for food chain dynamics. Journal of Marine Systems **70**:97–133.

Lauth, R. R. 2011. Results of the 2010 eastern and northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. Technical report.

Lebida, R. C., and D. C. Whitmore. 1985. Bering Sea Herring Aerial Survey Manual. Alaska Department of Fish and Game, Division of Commercial Fisheries, Bristol Bay Data Report No. 85-2, Anchorage. .

Legendre, L., S. F. Ackley, G. S. Dieckmann, B. Gulliksen, R. Horner, T. Hoshiai, I. A. Melnikov, W. S. Reeburgh, M. Spindler, and C. W. Sullivan. 1992. Ecology of sea ice biota. 2. Global significance. Polar Biology **12**:429–444.

Lentfer, J. W., and R. J. Hensel. 1980. Alaskan Polar Bear Denning. Bears: Their Biology and Management **4**:101–108.

Lenton, T. M. 2012. Arctic Climate Tipping Points. Ambio **41**:10–22.

Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber. 2008. Tipping elements in the Earth's climate system. Proceedings of the National Academy of Sciences of the United States of America **105**:1786–1793.

Lindsay, R. W., and J. Zhang. 2005. The thinning of Arctic sea ice, 1988-2003: Have we passed a tipping point? Journal of Climate **18**:4879–4894.

Link, J. S., J. K. T. Brodziak, S. F. Edwards, W. J. Overholtz, D. Mountain, J. W. Jossi, T. D. Smith, and M. J. Fogarty. 2002. Marine ecosystem assessment in a fisheries management context. Canadian Journal of Fisheries and Aquatic Sciences **59**:1429–1440.

Litzow, M. A. 2006. Climate regime shifts and community reorganization in the Gulf of Alaska: how do recent shifts compare with 1976/1977? Ices Journal of Marine Science **63**:1386–1396.

Litzow, M. A., D. L. Urban, and B. J. Laurel. 2008. Increased spatial variance accompanies reorganization of two continental shelf ecosystems. Ecological Applications **18**:1331–1337.

Livingston, P. A., L.-L. Low, and R. J. Marasco. 1999. Eastern Bering Sea ecosystem trends, page 465 . Blackwell Science, Malden, MA.

Ljungblad, D. K., S. E. Moore, and D. R. VanSchoik. 1986. Seasonal patterns of distribution, abundance, migration and behavior of the western Arctic stock of bowhead whales, Balaena mysticetus in Alaskan seas. Rep. Int. Whal. Commn. Special Issue 8 pages 177–205 .

Lovvorn, J. R., L. W. Cooper, M. L. Brooks, C. C. De Ruyck, J. K. Bump, and J. M. Grebmeier. 2005. Organic matter pathways to zooplankton and benthos under pack ice in late winter and open water in late summer in the north-central Bering Sea. Marine Ecology-Progress Series **291**:135–150.

Lovvorn, J. R., S. E. Richman, J. M. Grebmeier, and L. W. Cooper. 2003. Diet and body condition of spectacled elders wintering in pack ice of the Bering Sea. Polar Biology **26**:259–267.

Lowry, L. F., K. J. Frost, and J. J. Burns. 1980. Feeding of bearded seals in the Bering and Chukchi seas and trophic interactions with Pacific walruses. Arctic **33**:330–342.

Mackas, D. L., S. Batten, and M. Trudel. 2007. Effects on zooplankton of a warmer ocean: Recent evidence from the Northeast Pacific. Progress in Oceanography **75**:223–252.

Mackas, D. L., R. Goldblatt, and A. Lewis. 1998. Interdecadal variation in development timing of Neocalanus plumchrus populations at Ocean Station P in the subarctic North Pacific. Canadian Journal of Fisheries and Aquatic Sciences **55**:1878–1893.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, N.J.

Marquette, W. M., and J. R. Bockstoce. 1980. HISTORICAL SHORE-BASED CATCH OF BOWHEAD WHALES IN THE BERING, CHUKCHI, AND BEAUFORT SEAS. Marine Fisheries Review **42**:5–19.

Martinson, E. C., H. H. Stokes, and D. L. Scarnecchia. 2012. Use of juvenile salmon growth and temperature change indices to predict groundfish post age-0yr class strengths in the Gulf of Alaska and eastern Bering Sea. Fisheries Oceanography **21**:307–319.

Maslanik, J. A., C. Fowler, J. Stroeve, S. Drobot, J. Zwally, D. Yi, and W. Emery. 2007. A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss. Geophysical Research Letters **34**.

Maslowski, W., R. Roman, and J. C. Kinney. 2008. Effects of mesoscale eddies on the flow of the Alaskan Stream. Journal of Geophysical Research-Oceans **113**.

Matarese, A. C., D. M. Blood, S. J. Picquelle, and J. L. Benson. 2003. Atlas of abundance and distribution patterns of ichthyoplankton from the northeast Pacific Ocean and Bering Sea ecosystems based on research conducted by the Alaska Fisheries Science Center (1972-1996). Technical report.

Matsuno, K., A. Yamaguchi, T. Hirawake, and I. Imai. 2011. Year-to-year changes of the mesozooplankton community in the Chukchi Sea during summers of 1991, 1992 and 2007, 2008. Polar Biology **34**:1349–1360.

Matsuoka, A., V. Hill, Y. Huot, M. Babin, and A. Bricaud. 2011. Seasonal variability in the light absorption properties of western Arctic waters: Parameterization of the individual components of absorption for ocean color applications. Journal of Geophysical Research-Oceans **116**.

McRoy, C. P., and J. J. Goering. 1974. The influence of ice on the primary productivity of the Bering Sea, pages 403–421 . Institute of Marine Science, University of Alaska Fairbanks.

Meier, W. N., J. Stroeve, and F. Fetterer. 2007. Whither Arctic sea ice? A clear signal of decline regionally, seasonally and extending beyond the satellite record. Annals of Glaciology **46**:428–434.

Methot, R. D. 2005. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. International North Pacific Fisheries Commission Bulletin **50**:259–277.

Miller, G. W., R. E. Elliot, W. R. Koski, V. D. Moulton, and W. J. Richardson. 1999. Whales, p. 5-1 to 5-109, page 390 . Report from LGL, Ltc. (King City, ON), and Greeneridge Sciences, Inc. (Santa Barbara, CA), for Western Geophysical (Houston, TX) and NMFS (Anchorage, AK, and Silver Spring, MD).

Minobe, S. 2000. Spatio-temporal structure of the pentadecadal variability over the North Pacific. Technical report, Pergamon-Elsevier Science Ltd. ISI Document Delivery No.: 368TZ Times Cited: 82 Cited Reference Count: 63.

Monnett, C., and J. S. Gleason. 2006. Observations of mortality associated with extended open-water swimming by polar bears in the Alaskan Beaufort Sea. Polar Biology **29**:681–687.

Moore, S. E., J. T. Clarke, and M. M. Johnson. 1993. Beluga distribution and movements offshore northern Alaska in spring and summer, 1980-84. Rep. Int. Whal. Commn. **43**:375–381.

Mordy, C. W., P. J. Stabeno, C. Ladd, S. Zeeman, D. P. Wisegarver, S. A. Salo, and G. L. Hunt. 2005. Nutrients and primary production along the eastern Aleutian Island Archipelago. Fisheries Oceanography **14**:55–76.

Moss, J., E. Farley, and A. Feldman. 2009. Spatial distribution, energetic status and food habits of eastern Bering Sea age-0 walleye pollock. Transactions of the American Fisheries Society **138**:497–505.

Mueter, F. J., J. L. Boldt, B. A. Megrey, and R. M. Peterman. 2007. Recruitment and survival of Northeast Pacific Ocean fish stocks: temporal trends, covariation, and regime shifts. Canadian Journal of Fisheries and Aquatic Sciences **64**:911–927.

Mueter, F. J., and M. A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecological Applications **18**:309–320.

Mueter, F. J., and B. L. Norcross. 2000. Changes in species composition of the demersal fish community in nearshore waters of Kodiak Island, Alaska. Canadian Journal of Fisheries and Aquatic Sciences **57**:1169–1180.

Mueter, F. J., and B. L. Norcross. 2002. Spatial and temporal patterns in the demersal fish community on the shelf and upper slope regions of the Gulf of Alaska. Fishery Bulletin **100**:559–581.

Murawski, S. A. 2000. Definitions of overfishing from an ecosystem perspective. ICES Journal of Marine Science **57**:649–658.

Niebauer, J. H., V. Alexander, and R. T. Cooney. 1981. Primary production at the eastern Bering Sea ice edge: The physical and biological regimes, volume 2, pages 763–772 . U.S. Dep. Commer., NOAA, Office of Marine Pollution Assessment, University of Washington Press, Seattle, WA.

NOAA. 2004. Programmatic Supplemental Environmental Impact Statement for the Alaska Groundfish Fisheries Implemented Under the Authority of the Fishery Management Plans for the Groundfish Fishery of the Gulf of Alaska and the Groundfish of the Bering Sea and Aleutian Islands Area. Technical report.

Noongwook, G., H. P. Huntington, J. C. George, N. V. Savoonga, and N. V. Gambell. 2007. Traditional knowledge of the bowhead whale (Balaena mysticetus) around St. Lawrence Island, Alaska. Arctic **60**:47–54.

Norcross, B. L., B. A. Holladay, M. S. Busby, and K. L. Mier. 2010. Demersal and larval fish assemblages in the Chukchi Sea. Deep-Sea Research Part Ii-Topical Studies in Oceanography **57**:57–70.

NPFMC. 2009. Fishery Management Plan for Fish Resources of the Arctic Management Area. Technical report, North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage AK, 99501.

NPFMC. 2011. Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Technical report, North Pacific Fishery Management Council, 605 W. 4th Ave 306, Anchorage, AK 99501.

Okkonen, S. R. 1996. The influence of an Alaskan Stream eddy on flow through Amchitka Pass. Journal of Geophysical Research-Oceans **101**:8839–8851.

Okkonen, S. R., G. A. Jacobs, E. J. Metzger, H. E. Hurlburt, and J. F. Shriver. 2001. Mesoscale variability in the boundary currents of the Alaska Gyre. Continental Shelf Research **21**:1219–1236.

Okkonen, S. R., T. J. Weingartner, S. L. Danielson, D. L. Musgrave, and G. M. Schmidt. 2003. Satellite and hydrographic observations of eddy-induced shelf-slope exchange in the northwestern Gulf of Alaska. Journal of Geophysical Research-Oceans **108**.

Orensanz, J. M., B. Ernst, and D. A. Armstrong. 2007. Variation of female size and stage at maturity in snow crab (Chionoecetes opilio) (Brachyura : Majidae) from the eastern Bering sea. Journal of Crustacean Biology **27**:576–591.

Osuga, D. T., and R. E. Feeney. 1978. Antifreeze glycoproteins from arctic fish. Journal of Biological Chemistry **253**:5338–5343.

Overland, J. E., S. Rodionov, S. Minobe, and N. Bond. 2008. North Pacific regime shirfts: Definitions, issues and recent transitions. Progress in Oceanography **77**:92–102.

Overland, J. E., M. Wang, K. R. Wood, D. Percival, and N. A. Bond. 2012. Bering Sea warm and cold events in a 95-year context. Deep-Sea Research II **65-70**:6–13.

Pabi, S., G. L. van Dijken, and K. R. Arrigo. 2008. Primary production in the Arctic Ocean, 1998-2006. Journal of Geophysical Research-Oceans **113**.

Pagano, A. M., G. M. Durner, S. C. Amstrup, K. S. Simac, and G. S. York. 2012. Long-distance swimming by polar bears (Ursus maritimus) of the southern Beaufort Sea during years of extensive open water. Canadian Journal of Zoology-Revue Canadienne De Zoologie **90**:663–676.

Parker-Stetter, S. L., J. K. Horne, and T. J. Weingartner. 2011. Distribution of polar cod and age-0 fish in the US Beaufort Sea. Polar Biology **34**:1543–1557.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature **421**:37–42.

Paul, J. M., A. Paul, and W. E. Barber. 1997. Reproductive biology and distribution of the snow crab from the northeastern Chukchi Sea, pages 287–294 . Bethesda, MD.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal Du Conseil **39**:175–192.

Peterson, G. D., S. R. Carpenter, and W. A. Brock. 2003. Uncertainty and the management of multistate ecosystems: an apparently rational route to collapse. Ecology **84**:1403–1411.

Piatt, J. F., and P. J. Anderson. 1996. Response of Common Murres to the Exxon Valdez oil spill and long-term changes in the Gulf of Alaska marine ecosystem. American Fisheries Society Symposium **18**:720–737.

Pickart, R. S., G. W. K. Moore, D. J. Torres, P. S. Fratantoni, R. A. Goldsmith, and J. Y. Yang. 2009. Upwelling on the continental slope of the Alaskan Beaufort Sea: Storms, ice, and oceanographic response. Journal of Geophysical Research-Oceans **114**.

Purcell, J. E., R. A. Hoover, and N. T. Schwarck. 2009. Interannual variation of strobilation by the scyphozoan Aurelia labiata in relation to polyp density, temperature, salinity, and light conditions in situ. Marine Ecology Progress Series **375**:139–149.

Quakenbush, L. T., R. J. Small, and J. J. Citta. 2010. Satellite tracking of western arctic bowhead whales. Technical report.

Quast, J. C. 1974. Density distribution of juvenile Arctic cod, Boreogadus saida, in the eastern Chukchi Sea in the fall of 1970. Fishery Bulletin **72**:1094–1105.

Rand, K. M., and E. A. Logerwell. 2011. The first demersal trawl survey of benthic fish and invertebrates in the Beaufort Sea since the late 1970s. Polar Biology **34**:475–488.

Ream, R. R., J. T. Sterling, and T. R. Loughlin. 2005. Oceanographic features related to northern fur seal migratory movements. Deep-Sea Research Part Ii-Topical Studies in Oceanography **52**:823–843.

Reed. 1987. Salinity characteristics and flow of the Alaska Coastal Current. Continental S **7**:573–576.

Regehr, E. V., C. M. Hunter, H. Caswell, S. C. Amstrup, and I. Stirling. 2010. Survival and breeding of polar bears in the southern Beaufort Sea in relation to sea ice. Journal of Animal Ecology **79**:117–127.

Richard, P. R., A. R. Martin, and J. R. Orr. 2001. Summer and autumn movements of belugas of the Eastern Beaufort Sea stock. Arctic **54**:223–236.

Richardson, A. J., A. W. Walne, A. G. J. John, T. D. Jonas, J. A. Lindley, D. W. Sims, D. Stevens, and M. Witt. 2006. Using continuous plankton recorder data. Progress in Oceanography **68**:27–74.

Richardson, W. J. 1995. Documented disturbance reactions, pages 241–324 . Academic Press, San Diego, CA.

Richardson, W. J., and C. I. Malme. 1993. Man-made noise and behavioral responses, pages 631–700 . Society for Marine Mammalogy, Lawrence, KS.

Richardson, W. J., T. L. McDonald, C. R. Greene, and S. B. Blackwell. 2004. Acoustic localization of bowhead whales near Northstar, 2001-2003: Evidence of deflection at high-noise times? p. 8-1 to 8-73, page 297 . Report from LGL, Ltd. (King City, ON), Greeneridge Sciences, Inc. (Santa Barbara, CA), and Western EcoSystems Technology, Inc. (Cheyenne, WY), for BP Exploration (Alaska), Inc., Anchorage, AK.

Rigor, I. G., and J. M. Wallace. 2004. Variations in the age of Arctic sea-ice and summer sea-ice extent. Geophysical Research Letters **31**.

Rigor, I. G., J. M. Wallace, and R. L. Colony. 2002. Response of sea ice to the Arctic oscillation. Journal of Climate **15**:2648–2663.

Rodionov, S., and J. E. Overland. 2005. Application of a sequential regime shift detection method to the Bering Sea ecosystem. Ices Journal of Marine Science **62**:328–332.

Rooper, C. N. 2008. An ecological analysis of rockfish (Sebastes spp.) assemblages in the North Pacific Ocean along broad-scale environmental gradients. Fishery Bulletin **106**:1–11.

Rugh, D., D. DeMaster, A. Rooney, J. Breiwick, K. Shelden, and S. Moore. 2003. A review of bowhead whale (Balaena mysticetus) stock identity. Journal of Cetacean Research and Management **5**:267–279.

Sagalkin, N. H. 2011. Fishery management plan for commercial Tanner crab fishery in the Kodiak District 2011/2012. Fishery Management Report 11-58, Alaska Department of Fish and Game, Anchorage, AK.

Sagalkin, N. H., and Spalin. 2011. Annual management report for shellfish fisheries in the Kodiak, Chignik, and Alaska Peninsula Areas, 2010. Fishery Management Report 11-43, Alaska Department of Fish and Game.

Sakshaug, E. 2004. Primary and secondary production in the Arctic Seas, pages 57–81 . Springer, Berlin; New York.

Scheffer, M., J. Bascompte, W. Brock, V. Brovkin, S. Carpenter, V. Dakos, H. Held, E. van Nes, M. Rietkerk, and G. Sugihara. 2009. Early-warning signals for critical transitions. Nature **461**:53–59.

Schick, R. S., and D. L. Urban. 2000. Spatial components of bowhead whale (Balaena mysticetus) distribution in the Alaskan Beaufort Sea. Canadian Journal of Fisheries and Aquatic Sciences **57**:2193–2200.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature **465**:609–613.

Schliebe, S., T. J. Evans, S. Miller, C. Perham, J. Wilder, and L. J. Lierheimer. 2006. Polar bear management in Alaska 2000-2004, pages 63–76 . IUCN, Gland, Switzerland and Cambridge, UK.

Schumacher, J. D., P. J. Stabeno, and A. T. Roach. 1989. Volume transport in the Alaska Coastal Current. Continental Shelf Research **9**:1071–1083.

Serreze, M. C., A. P. Barrett, J. C. Stroeve, D. N. Kindig, and M. M. Holland. 2009. The emergence of surface-based Arctic amplification. Cryosphere **3**:11–19.

Serreze, M. C., M. M. Holland, and J. Stroeve. 2007. Perspectives on the Arctic's shrinking sea-ice cover. Science **315**:1533–1536.

Sigler, M. F., M. Renner, S. L. Danielson, L. B. Eisner, R. R. Lauth, K. J. Kuletz, E. A. Logerwell, and J. Hunt, G. L. 2011. Fluxes, Fins, and Feathers Relationships Among the Bering, Chukchi, and Beaufort Seas in a Time of Climate Change. Oceanography **24**:250–265.

Simpson, J. G., C. M. Allen, and N. C. G. Morris. 1978. Fronts on the continental shelf. Journal of Geophysical Research-Oceans **83**:4607–4616.

Smith, T. G., M. O. Hammill, and G. Taugbol. 1991. A review of the developmental, behavioral and physiological adaptations of the ringed seal, Phoca hispida, to life in the Arctic winter. Arctic **44**:124–131.

Somerton, D. A. 1981. Regional variation in the size of maturity of two species of tanner crab (Chionoecetes bairdi and C. opilio) in the eastern Bering Sea, and its use in defining management subareas. Canadian Journal of Fisheries and Aquatic Sciences **38**:163–174.

Spalinger, K. 2010. Bottom trawl survey of crab and groundfish: Kodiak, Chignik, South Peninsula, and Eastern Aleutian Management Districts, 2009. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Management Report No. 05-48, Anchorage. Technical report.

Sparks, A., and W. Pereyra. 1966. Benthic Invertebrates of the Southeastern Chukchi Sea, pages 817–838 . U.S. Atomic Energy Commission, Oak Ridge, TN.

Spencer, P. D. 2008. Density-independent and density-dependent factors affecting temporal changes in spatial distributions of eastern Bering Sea flatfish. Fisheries Oceanography **17**:396–410.

Spencer, P. D., T. K. Wilderbuer, and C. I. Zhang. 2002. A mixed-species yield model for eastern Bering Sea shelf flatfish fisheries. Canadian Journal of Fisheries and Aquatic Sciences **59**:291–302.

Springer, A. M., and C. P. McRoy. 1993. The paradox of pelagic food webs in the northern Bering Sea-III. Patterns of primary production. Continental Shelf Research **13**:575–599.

Springer, A. M., C. P. McRoy, and M. V. Flint. 1996. The Bering Sea Green Belt: Shelf-edge processes and ecosystem production. Fisheries Oceanography **5**:205–223.

Springer, A. M., C. P. McRoy, and K. R. Turco. 1989. The paradox of pelagic food webs in the northern Bering Sea-II. Zooplankton communities. Continental Shelf Research **9**:359–386.

Stabeno, P., J. Napp, C. Mordy, and T. Whitledge. 2010. Factors influencing physical structure and lower trophic levels of the eastern Bering Sea shelf in 2005: Sea ice, tides and winds. Progress in Oceanography **85**:180–196.

Stabeno, P. J., E. Farley, N. B. Kachel, S. Moore, C. Modry, J. M. Napp, J. E. Overland, A. Pinchuk, and M. Sigler. In press. A comparison of the physics, chemistry, and biology of the northeastern and southeastern Bering Sea shelf. Deep Sea Research II .

Stabeno, P. J., J. Farley, E. V., N. B. Kachel, S. Moore, C. W. Mordy, J. M. Napp, J. E. Overland, A. I. Pinchuk, and M. F. Sigler. 2012. A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep-Sea Research Part Ii-Topical Studies in Oceanography **65-70**:14–30.

Stabeno, P. J., D. G. Kachel, N. B. Kachel, and M. E. Sullivan. 2005. Observations from moorings in the Aleutian Passes: temperature, salinity and transport. Fisheries Oceanography **14**:39–54.

Stehn, R. A., K. Rivera, S. Fitzgerald, and K. D. Wohl. 2001. Incidental catch of seabirds by longline fisheries in Alaska. Technical report, University of Alaska Sea Grant, AK-SG-01-01, Fairbanks.

Stevenson, D. E., and G. R. Hoff. 2009. Species identification confidence in the eastern Bering Sea shelf survey (1982-2008). AFSC Processed Rep. 2009-04, Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv.,, 7600 Sand Point Way NE, Seattle WA 98115.

Stevenson, D. E., and R. R. Lauth. 2012. Latitudinal trends and temporal shifts in the catch composition of bottom trawls conducted on the eastern Bering Sea shelf. Deep-Sea Research Part II-Topical Studies in Oceanography **65-70**:251–259.

Stirling, I., N. J. Lunn, and J. Iacozza. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic **52**:294–306.

Stoker, S. W. 1981. Benthic invertebrate macrofauna of the eastern Bering/Chukchi continental shelf, volume 2, pages 1069–1090 . U.S. Dep. Commer., NOAA, Office of Marine Pollution Assessment, University of Washington Press, Seattle, WA.

Stoker, S. W., and I. I. Krupnik. 1993. Subsistence whaling, pages 579–629 . Society for Marine Mammalogy, Lawrence, KS.

Stone, I. R., and A. E. Derocher. 2007. An incident of polar bear infanticide and cannibalism on Phippsoya, Svalbard. Polar Record **43**:171–173.

Stroeve, J., M. M. Holland, W. Meier, T. Scambos, and M. Serreze. 2007. Arctic sea ice decline: Faster than forecast. Geophysical Research Letters **34**.

Stroeve, J. C., J. Maslanik, M. C. Serreze, I. Rigor, W. Meier, and C. Fowler. 2011. Sea ice response to an extreme negative phase of the Arctic Oscillation during winter 2009/2010. Geophysical Research Letters **38**.

Stroeve, J. C., M. C. Serreze, M. M. Holland, J. E. Kay, J. Malanik, and A. P. Barrett. 2012. The Arctic's rapidly shrinking sea ice cover: a research synthesis. Climatic Change **110**:1005–1027.

Suydam, R. S. 2009. Age, growth, reproduction, and movements of beluga whales (Delphinapterus leucas) from the eastern Chukchi Sea. Ph.d. dissertation.

Thompson, D. W. J., and J. M. Wallace. 1998. The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. Geophysical Research Letters **25**:1297–1300.

Turnock, B. J., and T. K. Wilderbuer. 2009. Gulf of Alaska Arrowtooth Flounder Stock Assessment. Technical report, N Pac Fish Manage Council, 605 W 4th Ave, Anchorage, AK 99510.

von Szalay, P. G., and D. A. Somerton. 2005. The effect of net spread on the capture efficiency of a demersal survey trawl used in the eastern Bering Sea. Fisheries Research **74**:86–95.

Walsh, J. J., C. P. McRoy, L. K. Coachman, J. J. Goering, J. J. Nihoul, T. E. Whitledge, T. H. Blackburn, P. L. Parker, C. D. Wirick, P. G. Shuert, J. M. Grebmeier, A. M. Springer, R. D. Tripp, D. A. Hansell, S. Djenidi, E. Deleersnijder, K. Henriksen, B. A. Lund, P. Andersen, F. E. Mller-Karger, and K. Dean. 1989. Carbon and nitrogen cycling within the Bering/Chukchi seas: Source regions for organic matter effecting AOU demands of the Arctic Ocean. Progress in Oceanography **22**:277–359.

Wang, J., G. F. Cota, and J. C. Comiso. 2005. Phytoplankton in the Beaufort and Chukchi Seas: Distribution, dynamics, and environmental forcing. Deep-Sea Research Part Ii-Topical Studies in Oceanography **52**:3355–3368.

Wang, M. Y., and J. E. Overland. 2009. A sea ice free summer Arctic within 30 years? Geophysical Research Letters **36**.

Wassmann, P., and T. M. Lenton. 2012. Arctic Tipping Points in an Earth System Perspective. Ambio **41**:1–9.

Welch, H. E., M. A. Bergmann, T. D. Siferd, K. A. Martin, M. F. Curtis, R. E. Crawford, R. J. Conover, and H. Hop. 1992. Energy flow through the marine ecosystem of the Lancaster Sound Region, Arctic Canada. Arctic **45**:343–357.

Wespestad, V. G., L. W. Fritz, W. J. Ingraham, and B. A. Megrey. 2000. On relationships between cannibalism, climate variability, physical transport, and recruitment success of Bering Sea walleye pollock (Theragra chalcogramma). Ices Journal of Marine Science **57**:272–278.

Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. 2002. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography **55**:235–247.

Willette, T. M., and R. T. Cooney. 1991. An empirical orthogonal functions analysis of sea surface temperature anomalies in the North Pacific Ocean and cross correlations with pink salmon (*Oncorhynchus gorbuscha*) returns to southern Alaska. In: (White, B., and Guthrie, I.) Proceedings of 15th Pink and Chum Salmon Workshop. Pacific Salmon Commission pages 111–121 .

Williams, E. H., and T. J. Quinn. 2000. Pacific herring, (Clupea pallasi), recruitment in the Bering Sea and north-east Pacific Ocean, I: relationships among different populations. Fisheries Oceanography **9**:285–299.

Witherell, D., and Woodby. 2005. Application of marine protected areas for sustainable production and marine biodiversity off Alaska. Marine Fisheries Review **67**:1.

Woillez, M., J. Rivoirard, and P. Petitgas. 2009. Notes on survey-based spatial indicators for monitoring fish populations. Aquatic Living Resources **22**:155–164.

Wolotira, R. J., T. M. Sample, and M. Morin. 1977. Demersal fish and shellfish resources of Norton Sound, the Southeastern Chukchi Sea, and adjacent waters in the baseline year 1976. Technical report.

Woodby, D. A., and D. B. Botkin. 1993. Stock sizes prior to commercial whaling, p. 387-407, page 787 . Society for Marine Mammals, Lawrence, KS.

Woodgate, R. A., K. Aagaard, and T. J. Weingartner. 2005. A year in the physical oceanography of the Chukchi Sea: Moored measurements from autumn 1990-1991. Deep-Sea Research Part Ii-Topical Studies in Oceanography **52**:3116–3149.

Wyllie-Echeverria, T., and W. S. Wooster. 1998. Year to-year variations in Bering Sea ice cover and some consequences for fish distributions. Fisheries Oceanography **7**:159–170.

Zador, S. G. 2011. Ecosystem Considerations for 2012, Groundfish Stock Assessment and Fishery Evaluation Report. Technical report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Zador, S. G., and S. Gaichas. 2010. Ecosystem Considerations for 2011. Groundfish Stock Assessment and Fishery Evaluation Report.

Zeh, J. E., C. W. Clark, J. C. George, D. Winthrow, G. M. Carroll, and W. R. Koski. 1993. Current population size and dynamics, pages 409–489 . Society for Marine Mammalogy, Lawrence, KS.

Zeh, J. E., and A. E. Punt. 2004. Updated 1978-2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. Technical report, International Whaling Commission.

Zheng, J., F. Funk, G. H. Kruse, and R. Fagen. 1993. Evaluation of threshold management strategies for Pacific herring in Alaska. University of Alaska Fairbanks, Alaska Sea Grant College Program Report 93-02.

Zwolinski, J., and D. A. Demer. 2012. A cold oceanographic regime with high exploitation rates in the Northeast Pacific forecasts a collapse of the sardine stock. Proceedings of the National Academy of Sciences **109**:4175–4180.