Ecosystem Assessment

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Introduction

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

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

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

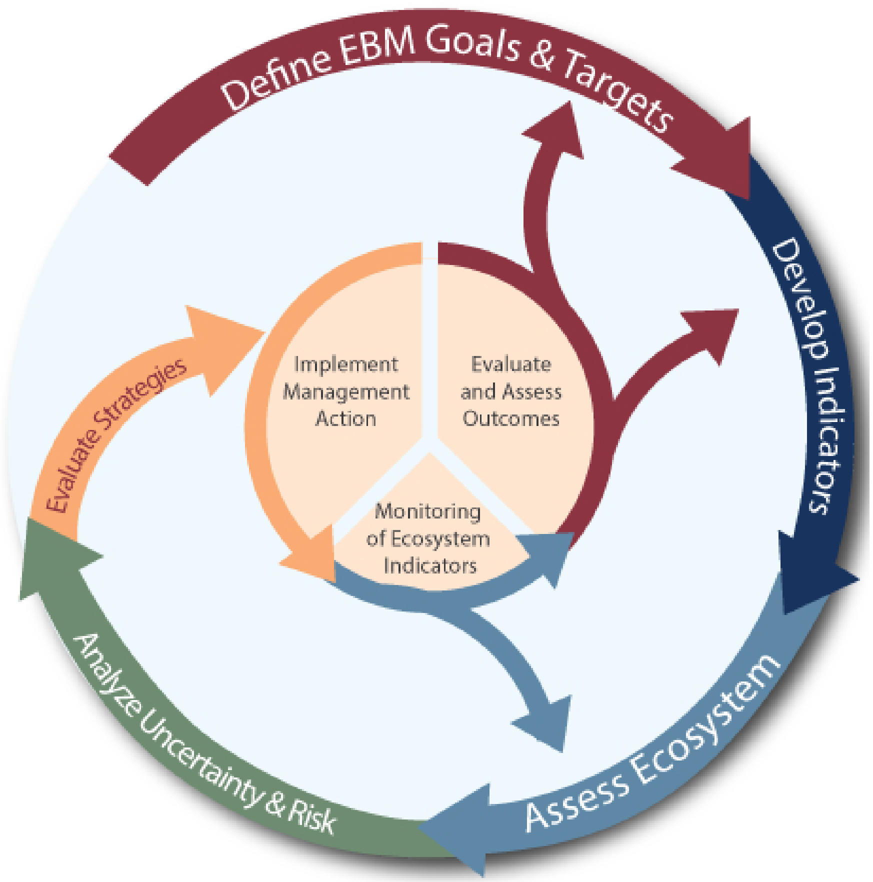


Figure 7: The IEA (integrated ecosystem assessment) process.

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

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

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

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

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

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

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

Hot Topics

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

Hot Topics: Arctic

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

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

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

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

Hot Topics: Eastern Bering Sea

Chum salmon distribution, diet, and bycatch

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

Increased sightings of dead birds at sea

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

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

Hot Topics: Gulf of Alaska

Too warm for larval walleye pollock survival in 2015?

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

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

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

Very few age-0 pollock in late summer, 2015

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

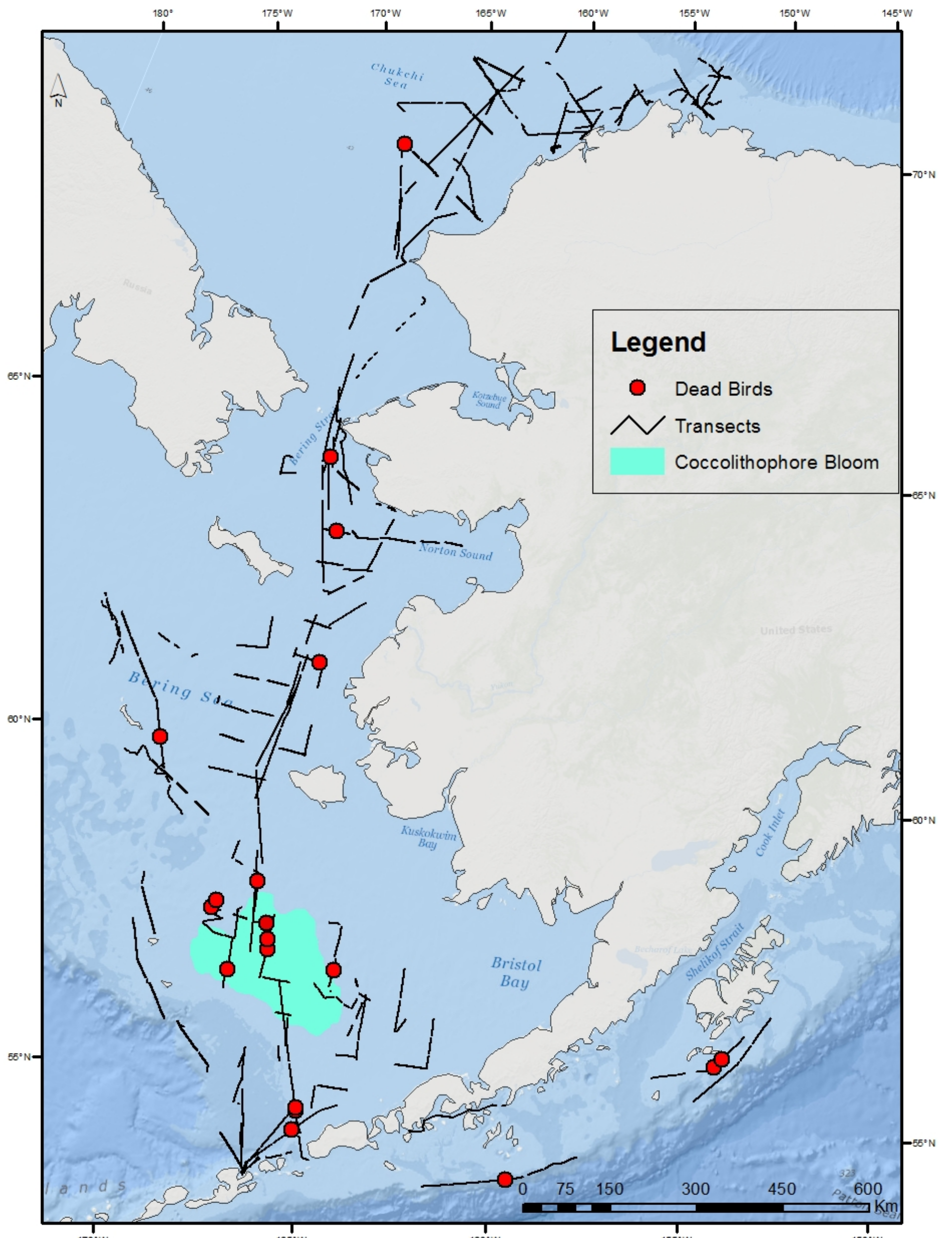


Figure 8: Dead birds observed during surveys from July through September 2015. A coccolithophore bloom is delineated in light blue.

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

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

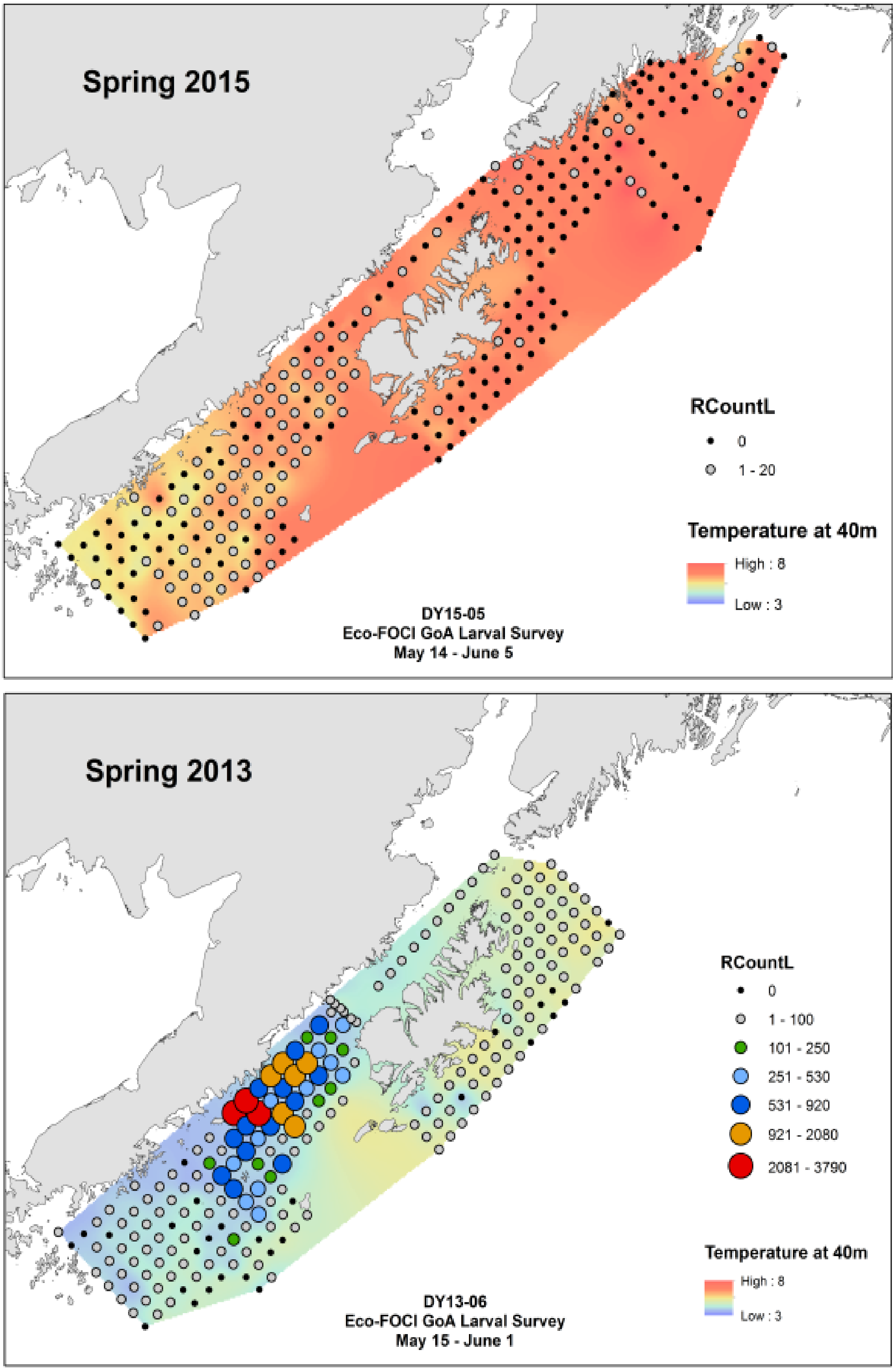


Figure 9: Temperatures and larval walleye pollock abundances as determined at sea in 2015 (top) and 2013 (bottom). 2015 was much warmer with many fewer larval pollock observed.

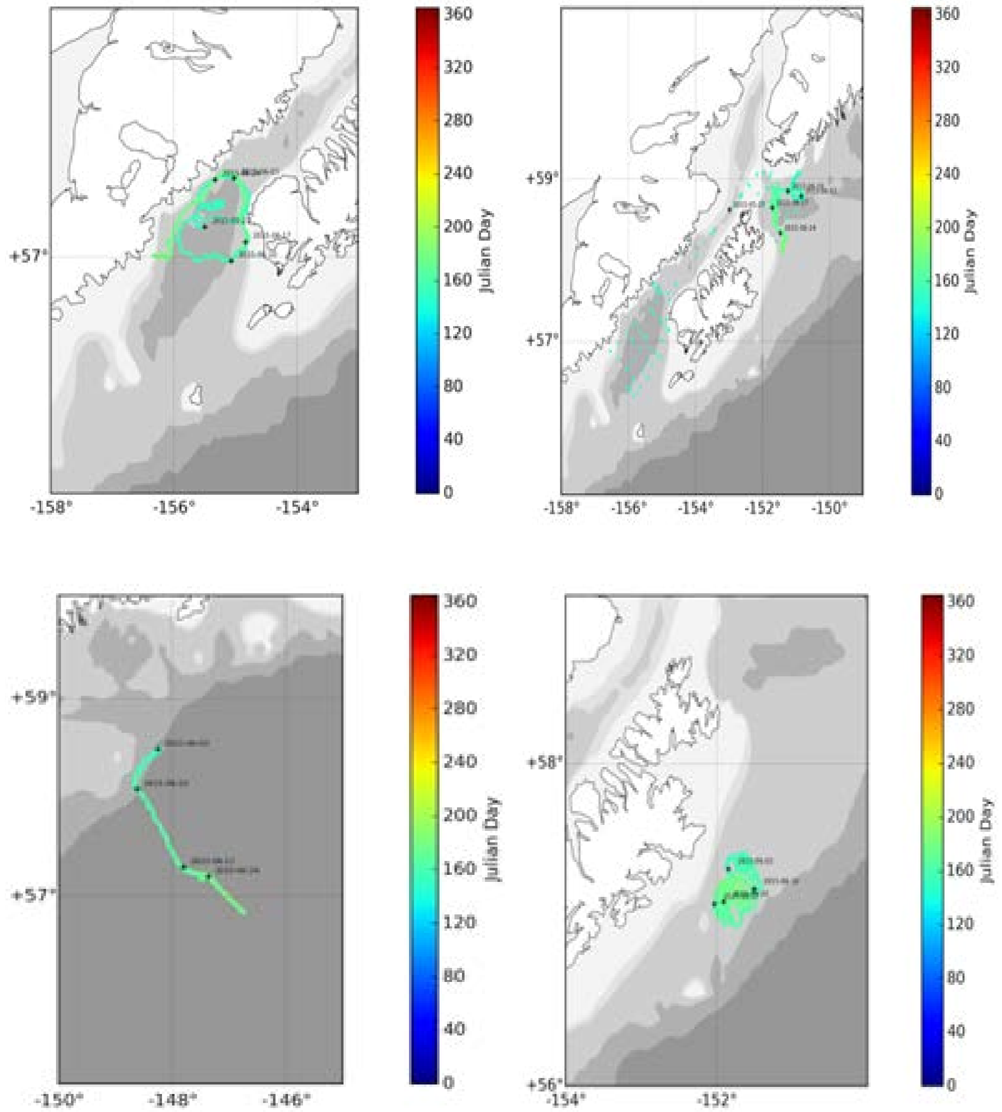


Figure 10: Trajectories of satellite-tracked drifters deployed during the EcoFOCI Late Larval Survey in 2015. Trajectories indicate anomalous circulation patterns over the GOA shelf in 2015.

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

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

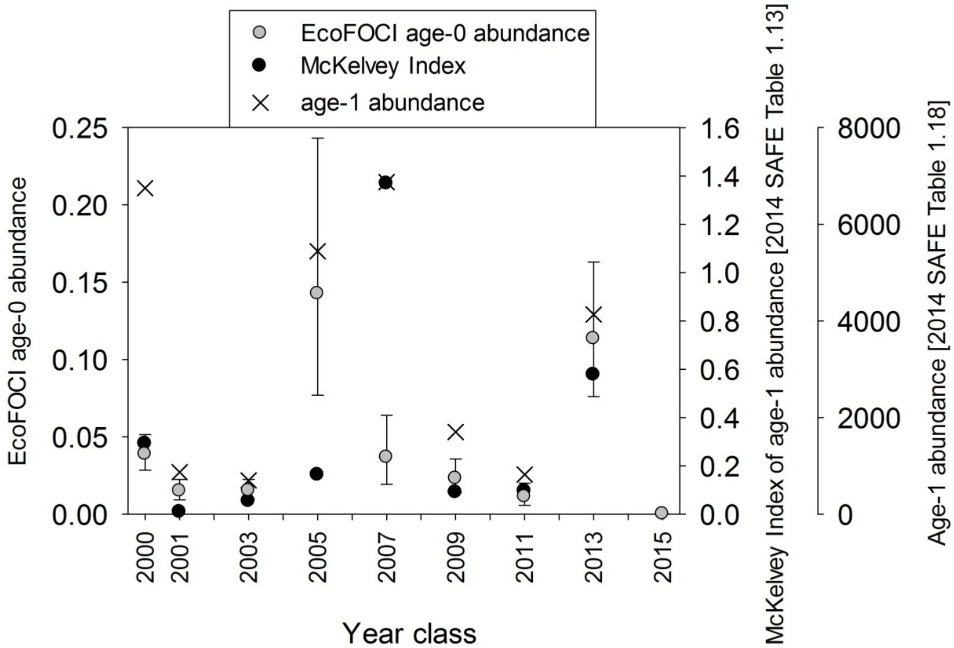


Figure 11: Abundance of year-classes of pollock measured as age-0's during late summer (Eco-FOCI, mean +1 SE), winter age-1 (McKelvey Index), and estimated as age-1 in the GOA pollock stock assessment (Dorn et al., 2014)

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

Unusual Mortality Event for Marine Mammals

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

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

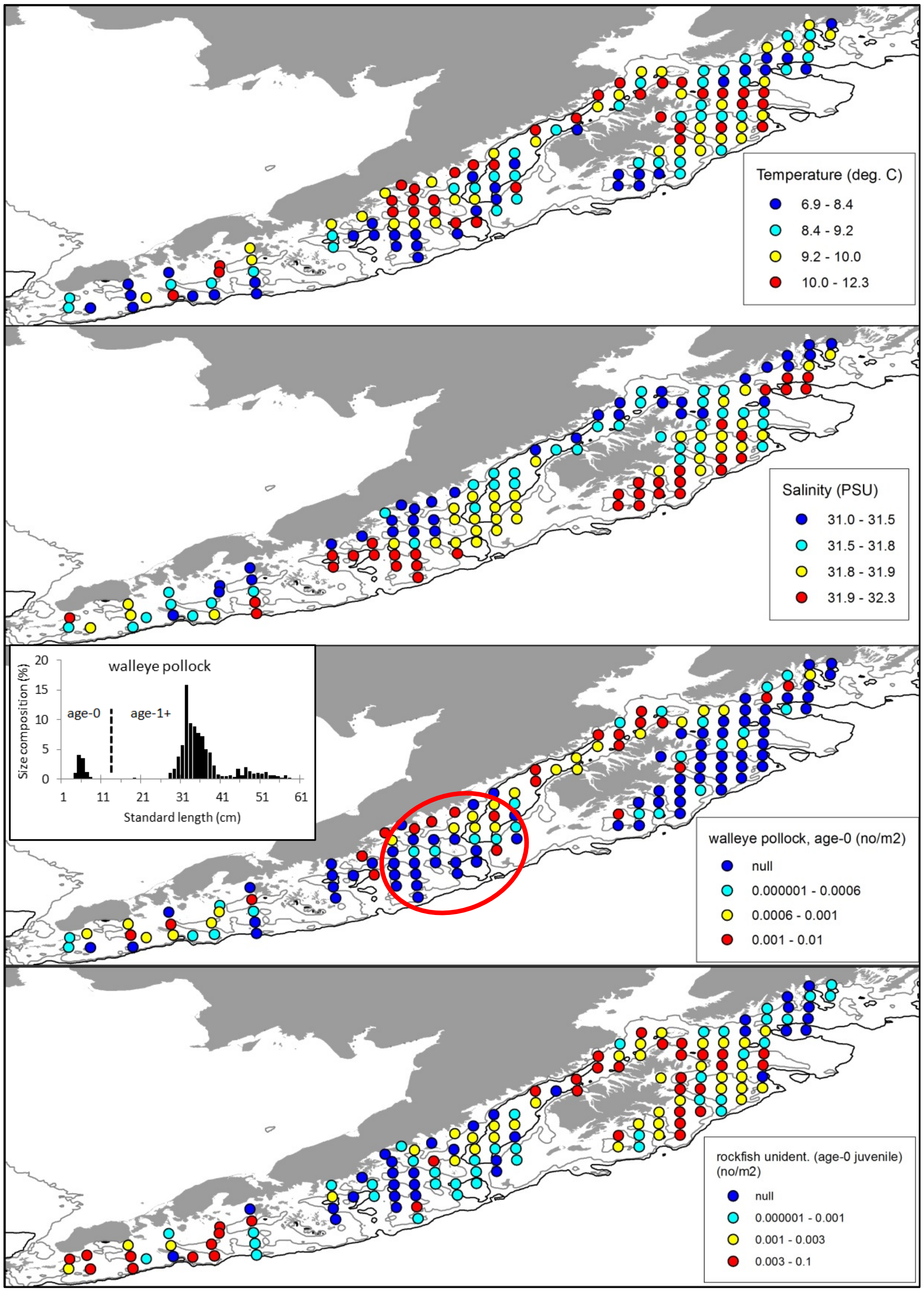


Figure 12: Geographic distributions of water temperature and salinity, measured at 40-m depth, and abundance estimates of two groups of age-0 juvenile fishes: walleye pollock and rockfishes during August-September 2015. For walleye pollock, the age-0 portion of the pollock population is identified on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

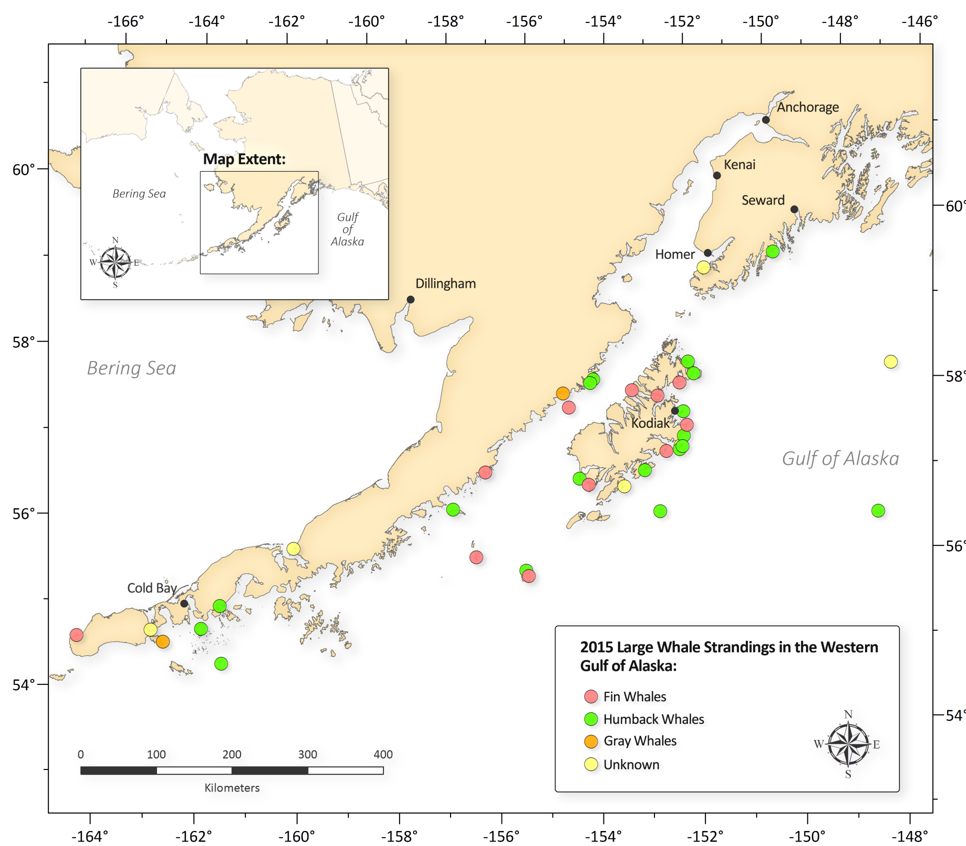


Figure 13: 2015 large whale stranding locations in the Western Gulf of Alaska through October 2, 2015 (`http://www.nmfs.noaa.gov/pr/health/mmume/large_whales_2015.html`)

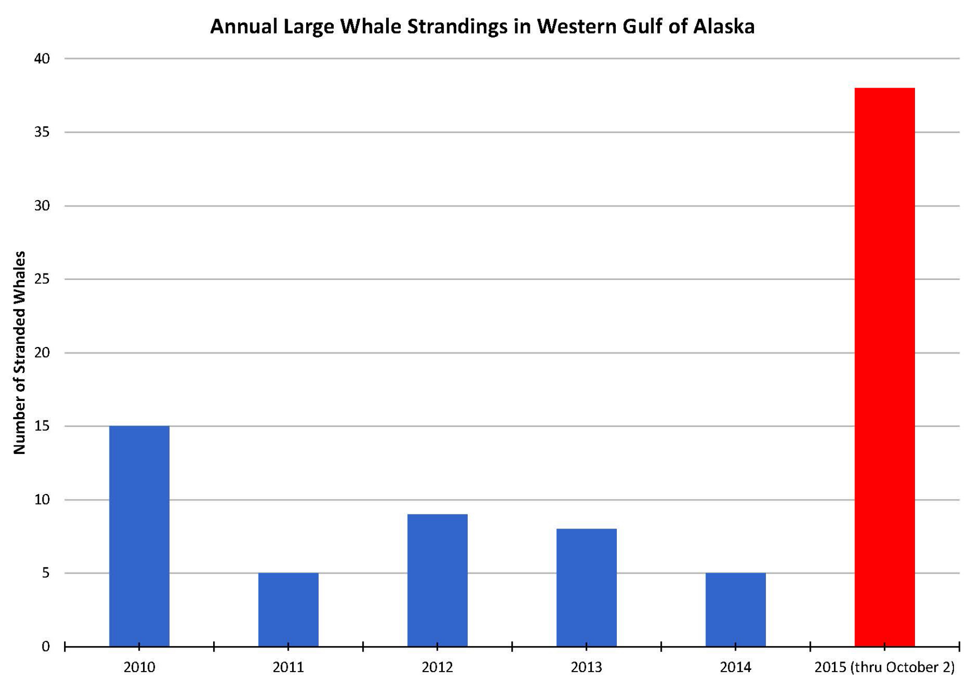
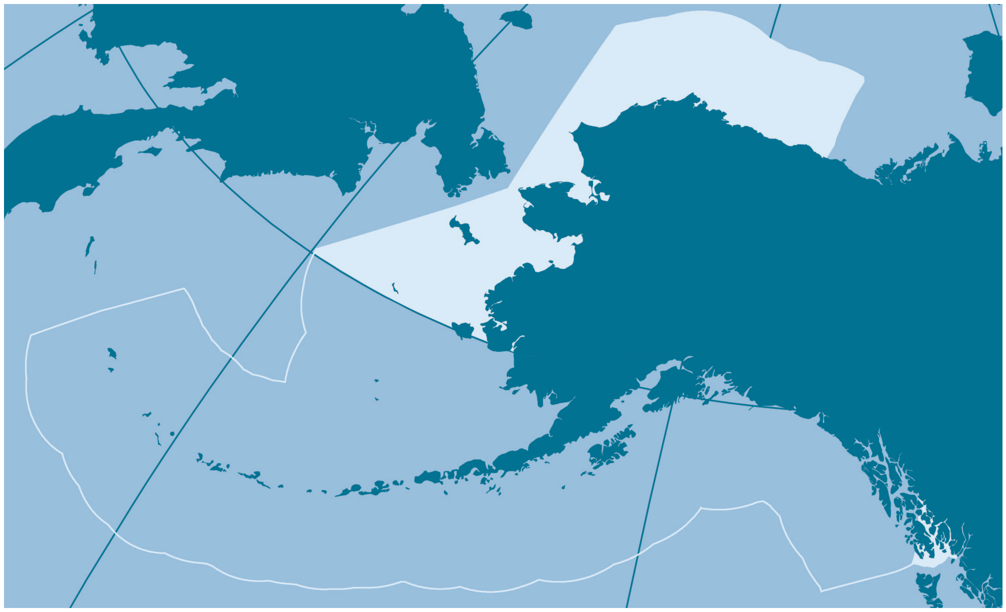


Figure 14: 2015 large whale stranding numbers in the Western Gulf of Alaska through October 2, 2015 (http://www.nmfs.noaa.gov/pr/health/mmume/large_whales_2015.html)



Preliminary Assessment of the Alaska Arctic

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

Defining the Alaska Arctic assessment area

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

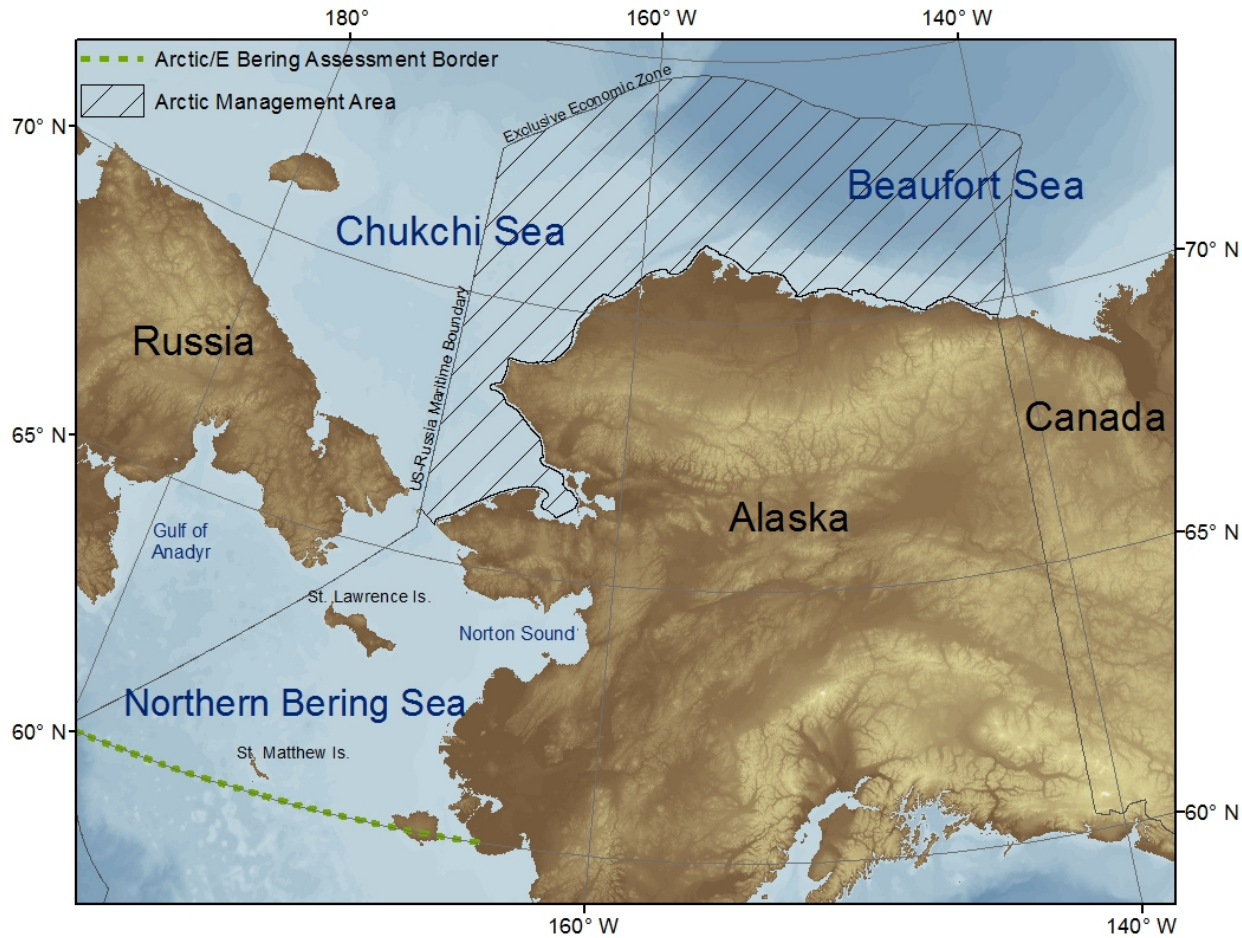

Figure 15: The proposed Arctic assessment area in Alaska, encompassing the northern Bering Sea, Chukchi Sea, and Beaufort Sea, within US territorial waters. The existing Arctic management area is filled with hatched lines.

General ecosystem information

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

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

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

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

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

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

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

Species of commercial interest

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

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

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

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

Gaps and needs for future Arctic assessments

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

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

Potential indicators

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

Climate

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

Figure 2:

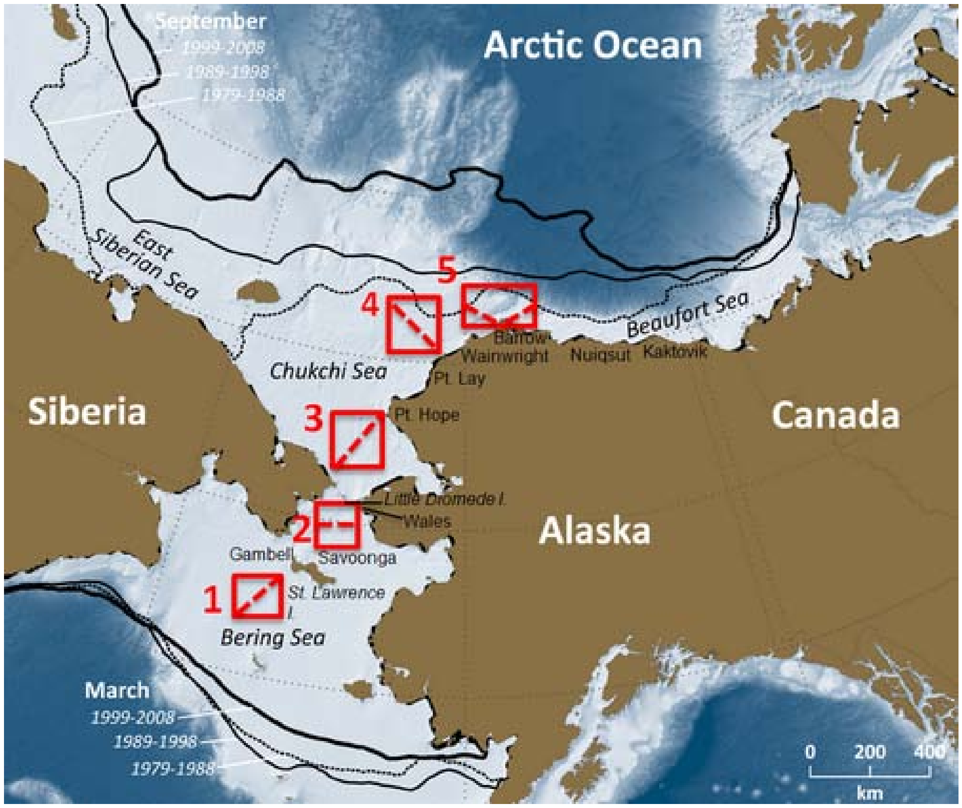

Figure 16: The Distributed Biological Observatory (DBO) in the Alaska Arctic. The red boxes are regional areas selected for observation and the dashed lines are the sampling transect lines. Figure from `http://www.arctic.noaa.gov/dbo/index.html`.

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

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

Plankton

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

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- *Zooplankton species composition and biomass.* Zooplankton species of Arctic and subarctic (Pacific) origin are present in the Chukchi Sea (Lane et al., 2008; Hopcroft et al., 2010;

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

Fish

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

Seabirds

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

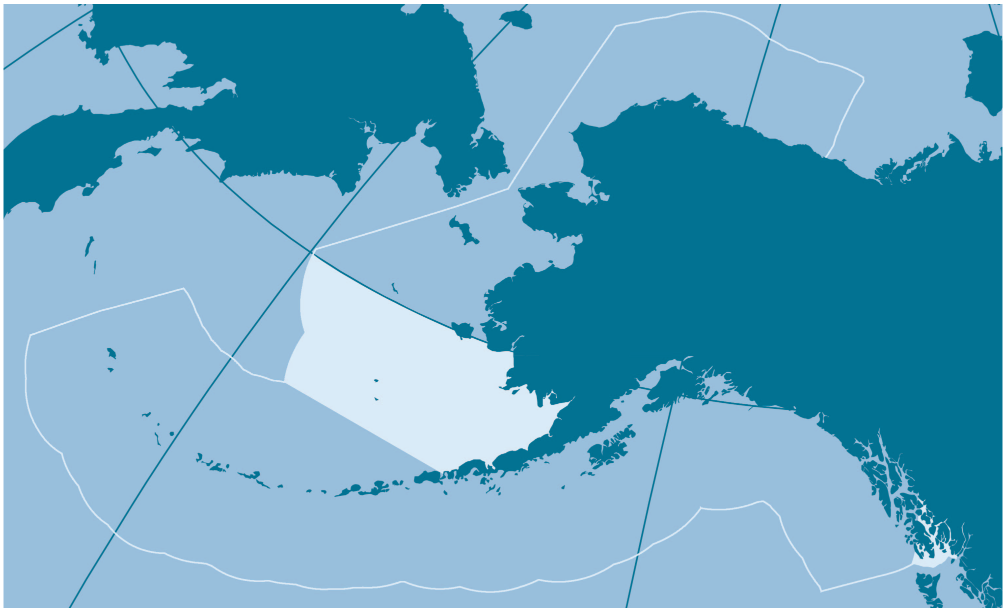
Marine mammals

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

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

Humans

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



Eastern Bering Sea Ecosystem Assessment

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Summary

Recap of the 2014 ecosystem state

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

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

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

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

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

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

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

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

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

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

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

Current conditions: 2015

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

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

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

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

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

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

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

Forecasts and Predictions

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

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

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

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

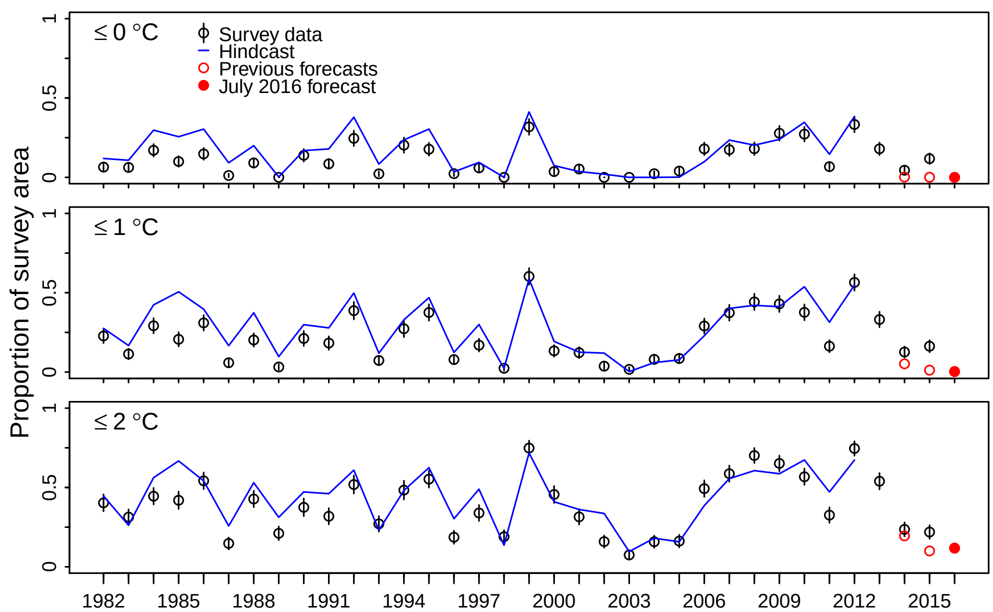


Figure 17: The eastern Bering Sea cold pool with limits of 0°C, 1°C, and 2°C. Shown are BTS survey data, ROMS hindcast results 1982-2012, and ROMS 9-month ahead predictions. The most recent prediction, made in October 2015, is shown for summer 2016.

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

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

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

Description of the Report Card indicators

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

Gaps and needs for future EBS assessments

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

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

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

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

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

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

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

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

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

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

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

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

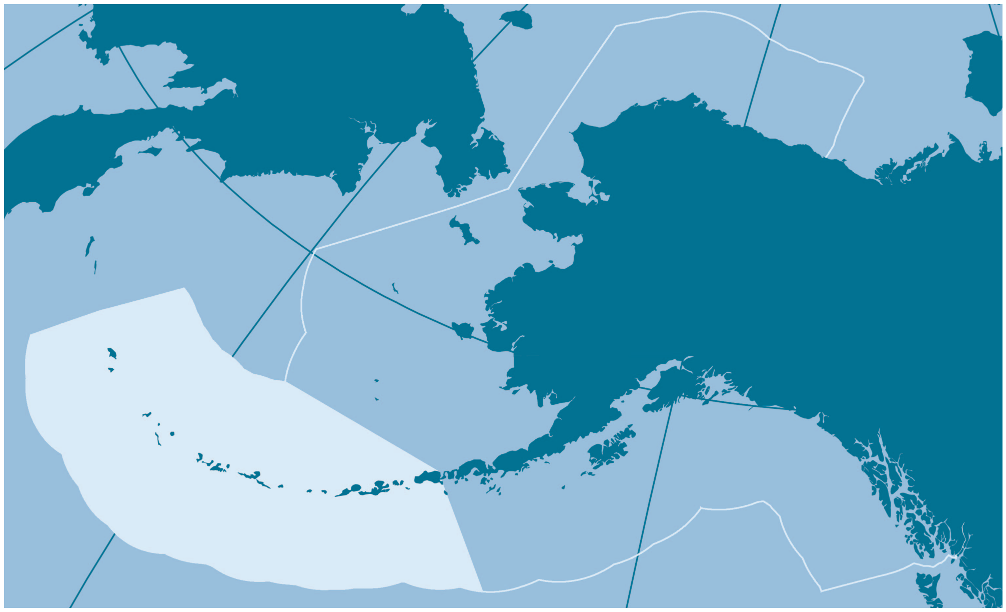
Integration with stock assessments: Integration of the stock assessments and this ecosystem assessment is an ongoing goal. During the 2010 meeting, the assessment team noted that dominant species often dictate the time trend in aggregate indicators. Several times the team strayed into conversations that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

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

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

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

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



Aleutian Islands Ecosystem Assessment

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

The Aleutian Islands ecosystem assessment area

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

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

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

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

Indicators

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

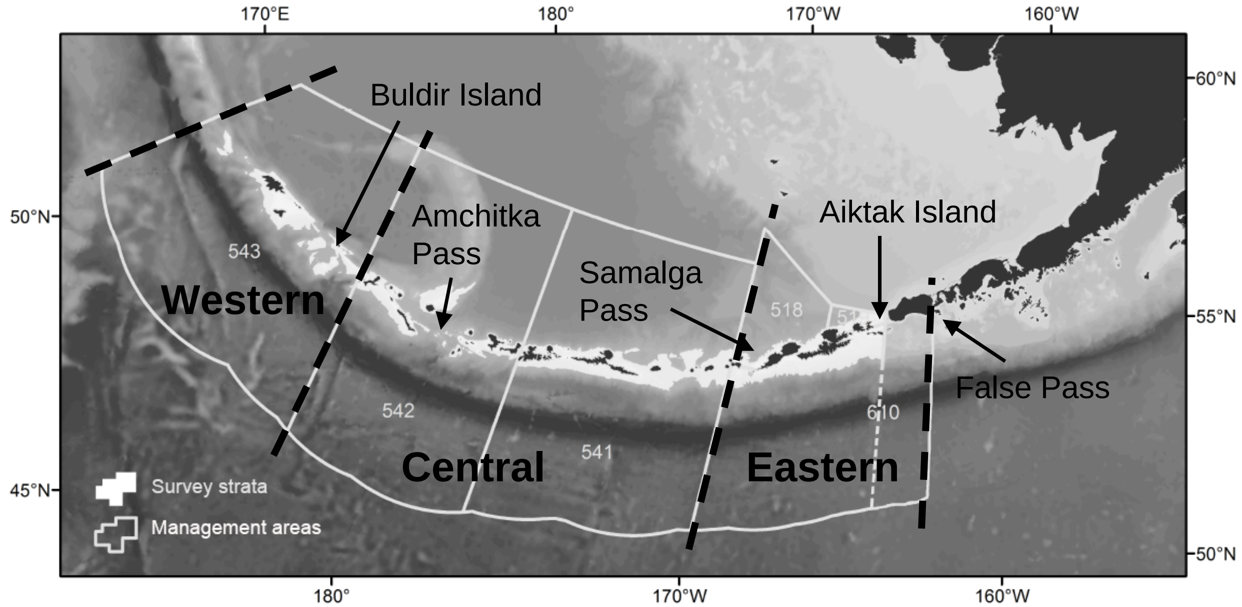


Figure 18: The three Aleutian Islands assessment ecoregions. Seabird monitoring islands are indicated by arrows.

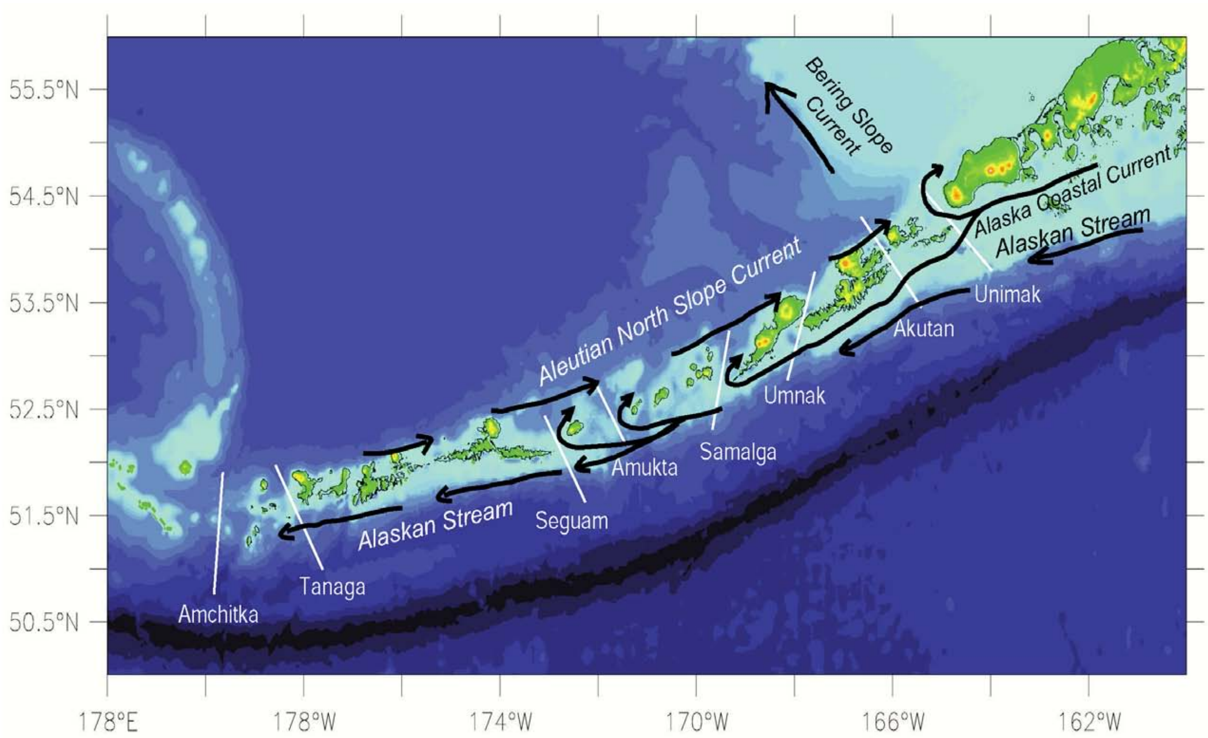


Figure 19: Ocean water circulation in the Aleutions. Currents are indicated with black lines. Passes are indicated with white lines. Image from Carol Ladd.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

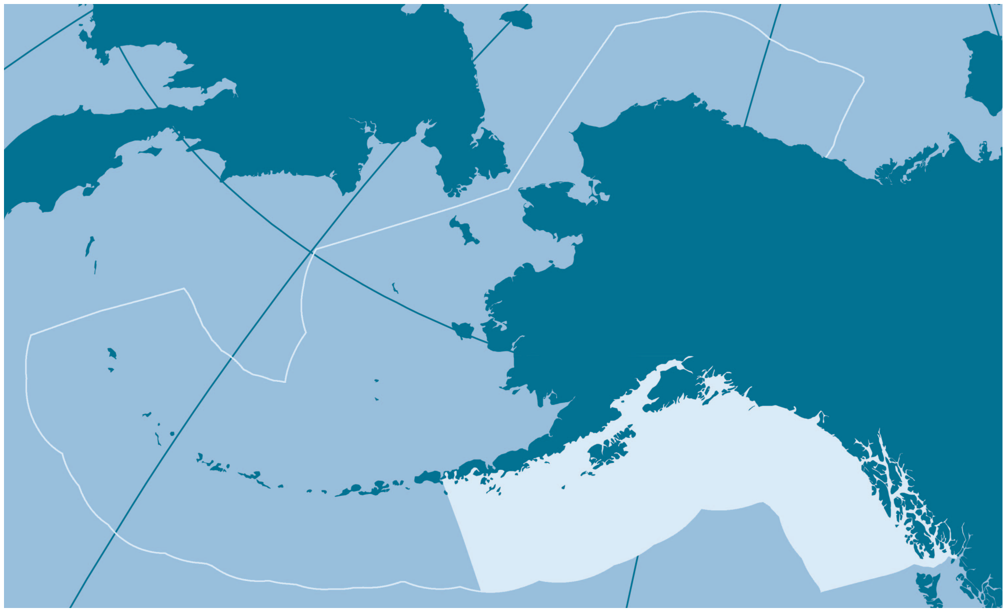
In our Aleutian Island ecosystem assessment, counts of adult and juvenile Steller sea lions at trend sites are used to indicate of the 'health' of apex piscivores whose diet consists primarily of commercially-fished species. The survey sites used in the assessment are:

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

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

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

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



Gulf of Alaska Ecosystem Assessment

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

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

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

Indicators

Top-ranked indicators were selected for each category: physical, plankton, benthic, forage fish, non-forage fish, seabirds, marine mammals, and humans. We include two physical and plankton indicators and one from each of the other categories. There is one set of indicators for the entire Gulf, although further refinement may include separate components to represent smaller scales such as west vs east. The final list on indicators in this report card includes:

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

Winter Pacific Decadal Oscillation

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

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

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

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

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

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

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

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

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

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

Current Environmental State

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

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

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

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

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