

## 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 planktivorous 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 ~ 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.

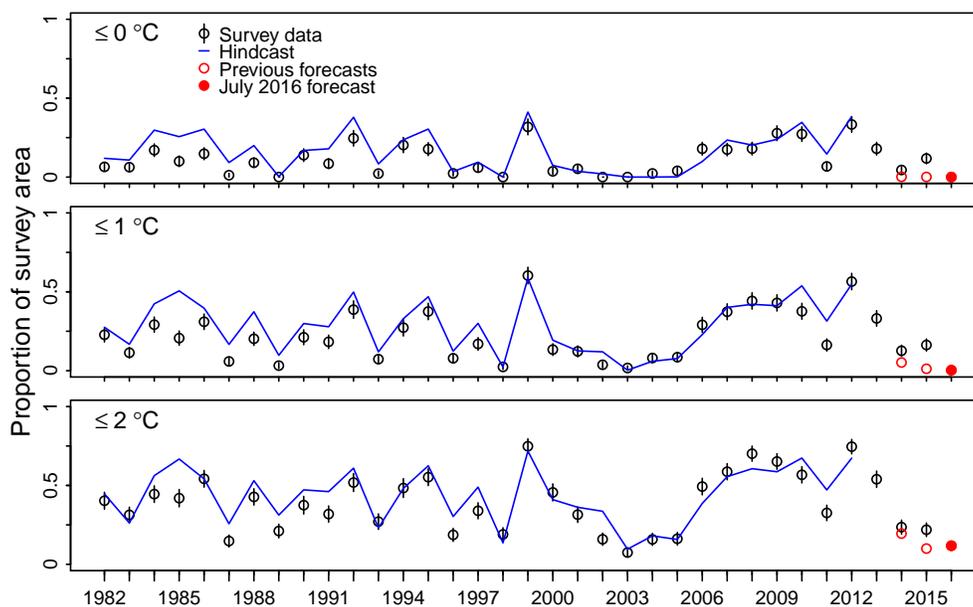


Figure 17: The eastern Bering Sea cold pool with limits of 0°C, 1°C, and 2°C. Shown are BTS survey data, ROMS hindcast results 1982-2012, and ROMS 9-month ahead predictions. The most recent prediction, made in October 2015, is shown for summer 2016.

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. Biennial 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)).

<b>Model</b>	<b>Application</b>	<b>Issue</b>	<b>Example reference</b>
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	