Ecosystem Assessment

Elizabeth Siddon[1], Stephani Zador[2], and Kerim Aydin[2]

[1]Auke Bay Laboratories, Alaska Fisheries Science Center, NOAA Fisheries
[2]Resource Ecology and Fisheries Management, Alaska Fisheries Science Center, NOAA Fisheries
Contact: elizabeth.siddon@noaa.gov
Last updated: November 2018

The primary intent of this assessment is to summarize and synthesize climate and fishing effects (historical and future) on the eastern Bering Sea shelf and slope regions from an ecosystem perspective. The Ecosystem Status Reports of the Groundfish Stock Assessment and Fishery Evaluations (SAFE) provide 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 the ecosystem effects 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 and a prognosis of how fish stocks are expected to fare, given concurrent information on ecosystem status. To perform this synthesis, a blend of data analysis and modeling is required annually to assess current ecosystem status in the context of historical and future climate conditions.

Recap of the 2017 Ecosystem State

Some ecosystem indicators are updated to the current year (2018), while others can only be updated to the previous year (or earlier) due to the nature of the data collected, sample processing, or modeling efforts. Therefore, some of the "new" updates in each Ecosystem Status Report reflect information from the previous year. Below is a complete summary of 2017 that includes information from both previous and current indicators. The next section (Current Conditions: 2018) provides a summary of the 2018 ecosystem state based on indicators updated this year.

In 2017, sea ice extended over the eastern Bering Sea shelf and created an extensive, although narrow, cold pool over the middle domain (see p. 59). Interestingly, sea level pressure patterns set up persistent winds from the south that prevented sea ice formation in the Gulf of Anadyr creating an unusual retraction of ice extent over the northwestern shelf. As a result, the northwestern Bering Sea responded more similarly to a "warm year", whereas ice coverage over the southern middle domain lead to more moderate conditions in the southeast. Over the southeastern shelf, latent heat from the previous warm stanza (2014–2016) was off-set by the narrow, but extensive,

cold pool that resulted in average water column temperatures at mooring M2 at the southern end of the eastern Bering Sea shelf.

The narrow cold pool was centered over the middle domain while the inner domain remained anomalously warm and is thought to have acted as a wide corridor for species' movement between the southeastern and northeastern Bering Sea. Indications of a "warm year" response during 2017 in the north included observations of crab as well as adult Walleye pollock and Pacific cod in the northern Bering Sea. Genetic work conducted on Pacific cod collected in the northern Bering Sea in 2017 showed that the NBS cod grouped strongly with spawning samples from Pervenets and Pribilof canyons and Unimak Pass, suggesting population coherence across the southeastern and northern shelf regions (p. 40). While these species might typically move south during winter, the environmental cues (i.e., sea ice, cold pool) did not occur during winter 2016–2017, therefore we anticipated observations of pollock and Pacific cod, for example, from northern communities during winter 2017–2018 (see Current Conditions: 2018 below).

Productivity across the system, as indicated by zooplankton distributions, reflected increased productivity in the north with significantly higher abundances of small and large copepods near St. Matthew Island. Over the southeastern shelf, 2017 estimates of small and large copepod abundances were below that of 2016, while euphausiid abundances were comparable. Groundfish condition subsequently declined from 2016 to 2017 for all species (except Arrowtooth flounder) and may be a leading indicator of poor overwinter survival and potential for smaller stocks in 2018. Indicators demonstrated that the mean lifespan, overall length, and biomass of the groundfish community have remained relatively stable over the time series. However, these indicators are very sensitive, and small changes in mean length or mean age can be quite significant and indicative of ecosystem shifts. For example, mean length increased in 2002–2005 and again in 2014–2016. The fish community is dependent on previous year-classes that are maturing, and low recruitment during these warm stanzas results in an increase in mean length. This trend could have important consequences for the fishery.

Declines in forage fish quality and quantity have cascading effects for piscivorous-feeding seabirds and marine mammals. For example, the reproductive success of cliff-nesting seabirds at both St. Paul and St. George Islands was poor in 2017, with the exception of nearshore-feeding red-faced cormorants (*Phalacrocorax urile*). Despite the moderation of environmental conditions in 2017, seabird foraging conditions did not appear to recover. However, the number of seabirds caught incidentally in EBS fisheries in 2017 declined; northern fulmars, shearwaters, and gulls were the most common species caught (p. 162). Additionally, estimated age-1 natural mortality for pollock, Pacific cod, and Arrowtooth flounder (based on the CEATTLE model) remained at elevated levels in 2017.

Other indications of a decline in system-wide productivity include juvenile Chinook salmon (*Oncorhynchus tshawytscha*), Togiak herring, and crab stocks. First, juvenile Chinook salmon abundance in the northern Bering Sea was below the long-term average in 2017; this has important implications for abundance-based bycatch caps for Chinook in the pollock fishery because low juvenile abundance leads to reduced bycatch caps 3–4 years in the future. Second, in 2017, the abundance of Togiak herring was estimated to be 55% of the most recent 10-year aerial survey average and 59% of the most recent 20-year aerial survey average (p. 99). Lastly, in 2017, crab catches declined significantly for all species, particularly tanner crab (p. 184).

Maintaining adequate prey has important implications for upper trophic level species and other

ecosystem components. Maintaining species diversity increases ecosystem stability as species have differential responses to environmental variability. Total CPUE from the bottom trawl survey peaked in 2014 due to increased pollock catches, but declined slightly in 2015–2017. Species richness remained high along the 100m isobath while diversity was highest over the middle domain. Cooler water temperatures in 2017 resulted in a substantial southeastward shift, in contrast to a more moderate response to similar cooling in 2006.

Current Conditions: 2018

This year's assessment will highlight ecosystem conditions and responses in the northern Bering Sea (NBS) and southeastern Bering Sea (SEBS) independently, but recognizing that species responses to recent conditions (i.e., sea ice, cold pool extent, water temperatures) have emphasized the connectedness of the two regions and that they function as one ecosystem: the eastern Bering Sea.

With contributions from (in alphabetical order): Steve Barbeaux, Peter Boveng, Lyle Britt, Catie Bursch, Lauren Divine, Martin Dorn, Janet Duffy-Anderson, Lisa Eisner, Anne Hollowed, Kirstin Holsman, Jim Ianelli, Chad Jay, Dave Kimmel, Sasha Kitaysky, Bob Lauth, Kathi Lefebvre, Paul Lehman, Maggie Mooney-Seus, Carina Nichols, Emily Osborne, Jim Overland, Heather Renner, Patrick Ressler, Gay Sheffield, Phyllis Stabeno, Jeremy Sterling, Grant Thompson, Jim Thorson, and Andy Whitehouse.

Northern Bering Sea
2018 was extraordinarily different in the NBS than in the past experience of scientists visiting the region or in the oral histories of local residents.

Physical conditions
A composite of unusual weather events during the winter of 2017/2018 resulted in an unprecedented near-complete lack of sea ice in the NBS. Several climatic forces occurred that resulted in the warm conditions: (i) residual heat maintained above-average water temperatures that caused delayed freeze-up (e.g., the Chukchi remained ice-free into January 2018, ice arrived late (March) and departed early (April)), (ii) a large and persistent high-pressure system from February through April over the Aleutian Islands and southern Bering Sea, which shifted the position of the Aleutian Low Pressure System (ALPS) northwest over Siberia, and (iii) highly unusual winds from the southwest that brought warm air over the Bering Sea and prevented sea ice from forming until March.

2018 marks the lowest ice year on record for the eastern Bering Sea while the Chukchi Sea was the warmest on record. Bottom temperatures in the northern Bering Sea were 1°C to 2°C rather than <-1°C, and no cold pool formed. Historically, salinity and temperature contributed equally to the vertical stratification of the water column in the northern Bering Sea. In 2018, salinity in May was vertically uniform, with no evidence of high (>32) salinities from brine rejection. The lack of salinity structure resulted in weaker vertical stratification, permitting greater vertical mixing. Warming of the surface waters started ~May 13 and some thermal stratification began ~May 15 (data from mooring M8 located at 62.194°N 174.688°W).

Biological responses
The near-complete lack of sea ice over the northern Bering Sea shelf created an absence of ice

algae to 'seed' productivity. At St. Matthew Island, the bloom began quite late (approximately June 12; ∼1 month delay), and because stratification was weak (due to lack of salinity component), nutrients were still being mixed into the surface layer. The abundance of small copepods was similar to 2017, but the abundance of large copepods was an order of magnitude lower and abundance of juvenile euphausiids was near zero. In addition, survey scientists noted that the large copepods were predominantly *Eucalanus bungii*, which is not a lipid-rich species. In fact, estimates of lipid content for large copepods and juvenile euphausiids were low. Based on the diets of auklets and the low nesting success of thick-billed murres, which also eat large zooplankton, it seems large lipid-rich zooplankton, that are a critical component of seabird and pollock diets, were in low supply.

Bottom trawls, surface trawls, and acoustic surveys again documented the presence of Pacific cod and pollock in the NBS. When sampled in July 2018, Pacific cod were 'fat' and 'healthy' and anecdotal observations were that stomachs were 'full of *Opilio*'. Based on bottom trawl survey results, more than 50% of the overall estimated biomass of Pacific cod in the eastern Bering Sea (northern and southern components) was found in the northern Bering Sea. With half of the biomass in the northern survey area, stock assessment models for 2019 will include NBS data for the first time.

In contrast, pollock estimated biomass in the northern Bering Sea declined by 14% from 2017 to 2018. Pollock to the east of St. Lawrence Island were in 'poorer condition' while pollock sampled north of St. Lawrence Island were 'plump and healthy' (B. Lauth, pers. obs.). Initial on-board examination of pollock stomachs showed that fish were consuming polychaete worms, indicating they were feeding on the bottom. Preliminary lab-based diet analyses of Pacific cod and pollock indicated prey composition was similar to that of diets observed from the inner domain of the southeastern Bering Sea.

Ice seal distributions were dramatically impacted by the lack of sea ice over the northern Bering Sea shelf and retraction of the ice edge. In 2018, during a spring research survey, the nearest ice edge over the eastern Bering Sea shelf was between St. Lawrence Island and Norton Sound, about 375 km to the northeast of where it was found during 2014 and 2016 surveys. Ice seals (particularly ribbon seals) were unusually scarce with no evidence that they moved northeast or into Norton Sound following the ice edge; it remains unknown where they went and whether their reproduction was compromised by the lack of sea ice in their typical breeding grounds. Spotted seal pups weighed less than in recent years, indicating poor condition, and continuing a declining trend in body condition and blubber thickness from 2014 to 2016 to 2018. More walrus and bearded seals were seen than typical, likely because the survey was farther north in areas where these species are more prevalent. Walrus, which are benthic foragers, consume a wide range of prey items, but mostly clams, snails, and polychaete worms. Studies of walrus stomach contents indicate that fish are typically a very small part of their diet. Recent population modeling suggests the population has undergone as much as a 58% decline since the early 1980s. The cause of the decline is unknown, but may have been the result of the population reaching carrying capacity coupled with high walrus harvest levels in the late 1970s-early 1980s. Large numbers of dead marine mammals were found along the shorelines from north of Bering Strait, throughout Norton Sound, and on St. Lawrence Island. In July, an exceptionally large number of humpback whales was present off the north shore of St. Lawrence Island.

A seabird die-off event, unprecedented in terms of spatial and temporal scale, occurred in 2018. Large numbers of seabirds (mainly murres) washed ashore from Bering Strait southward through Norton Sound, and along the shores of St. Lawrence Island. The die-off event continued, albeit at

a slow pace, into August. On St. Matthew Island there was evidence of an earlier, year-old large die-off of seabirds. Crested auklets were reported dead from at-sea surveys. To date, starvation is the only identified cause of death.

The historical diet composition of the affected seabirds suggests that large, lipid-rich zooplankton may have been in short supply in 2018. Least and crested auklets specialize on large copepods (least auklets: *Calanus marshallae/glacialis* at St. Matthew Island and *Neocalanus plumbchrus/flemingeri* at St. Lawrence Island), euphausiids (crested auklets), and sometimes the large amphipod, *Themisto libellula*. Thick-billed murres and shearwaters take euphausiids, amphipods, and forage fish while common murres take mostly forage fish.

Concomitantly, reproductive failures and poor reproductive success (mainly murres and kittiwakes) were observed by community members, subsistence eggers, and scientists. Those birds that did nest, nested very late. On St. Lawrence Island, murre eggs that were laid late were still hatching in September. There were also indications of lower nesting success for least and crested auklets: ~30% fewer least auklet burrows were occupied, although those birds that did nest appeared to be reproducing successfully. Crested auklets that laid eggs also seemed to be doing well, though perhaps with a somewhat greater rate of egg abandonment. Community members reported very few auklets (only 20 least auklets observed) and surprisingly low numbers of puffins attending cliffs. Horned puffins were observed around the north end of Sevuokuk Mountain in late September with bill-loads of fish, perhaps reflecting very late nesting this year.

All murre reproductive effort failed north of St. Matthew Island, such that murres did not produce chicks, which is exceptional, and prior to the 2016 heatwave, widespread murre reproductive failures had not been observed. In fact, low numbers of common murres attended cliffs and very few eggs were laid (subsistence eggers reported difficulty finding eggs). Likewise, for thick-billed murres, there was very low cliff attendance and almost no eggs laid. Black-legged kittiwakes also had a near-complete reproductive failure, with <10% of nests fledging young (although not that unusual, these birds have been failing for the past 5 years). In contrast, cormorants did well. Of interest was the first observation of red-legged kittiwakes nesting on St. Matthew Island.

Harmful Algal Blooms (HABs)

As a result of warming sea surface temperatures, species of algae known to produce harmful toxins, commonly referred to as harmful algal blooms (HABs), are becoming more widespread and prevalent in the Arctic. A 2018 coordinated research effort in the Pacific Arctic Sector centered around the Bering Strait Region has made progress towards improving our baseline understanding of HABs species abundance, distribution, and toxin presence in this region. A total of six HABs oceanographic research cruises worked together to collect HABs data across the northern Bering and Chukchi Seas at more than 340 stations. Synthesized research results show concentrations of one HABs species in particular, *Alexandrium* spp., which is associated with paralytic shellfish poisoning as well as a second less abundant species, *Pseudo-nitzschia*, which is responsible for amnesiac shellfish poisoning. Research missions found no positive toxicity or significant HAB cell counts south of the strait in the northern Bering Sea (June-September), however high concentrations of HABs cells (*Alexandrium* spp.) were found in the Chukchi Sea in August and a positive toxicity test was also recorded in June.

Alexandrium spp. cells have the unique ability to form "cysts", which are a dormant phase of this species' cells that harden and rest on the seafloor until environmental conditions are right for the cell to bloom or grow. A survey of cysts in seafloor sediments found dormant cells of

Alexandrium spp. across the entire shelf of the northern Bering and Chukchi Seas. Especially high concentrations were found offshore of Ledyard Bay and some sample sites had some of the highest cyst concentrations observed in the entire global ocean.

Contributed by Emily Osborne
Program Manager, Arctic Research Program
NOAA Office of Ocean and Atmospheric Research

Local Knowledge and Traditional Knowledge
Gay Sheffield (Alaska Sea Grant Marine Advisory Agent in Nome, Alaska) recounted observations from community members in the northern Bering Sea. In Nome, large Pacific cod (1 m) were caught in crab pots and the unusual occurrence of king salmon being caught on rods from the Nome beach. There were record returns of pink and silver salmon, which came in strong and early; sockeye returns were not as great. Halibut fishing off Savoonga was 'really great'.

Subsistence hunters for crested and least auklet fledglings usually get ∼30-40/day. In 2018, a hunter stopped after he pulled 13 dead fledglings and no live ones. An Elder on St. Lawrence Island said "when there is no dirty ice, there is less food for the krill, and consequently, no food for the birds." At Sledge Island in Norton Sound, 50-70% of murres were missing from cliffs and those that were there were not laying eggs; local people were stunned and there was a complete lack of harvest. There were dead and emaciated murres, shearwaters, and crested auklets in Nome and on St. Lawrence Island.

Beginning in February, residents in shoreside communities reported walruses were harvested off St. Lawrence Island, a time when they are not typically accessible. The walruses were 'fat and in good condition'. In early June, there were reports of exceptionally high numbers (i.e., 50) of dead seals on beaches (primarily young bearded seals) along the north side of St. Lawrence Island and 48 beach-cast ice seals (bearded, ringed, and sub-adult spotted seals) near Wales. The seals appeared to have poor body condition and empty stomachs. There were also reports of seal strandings, reports of sick/dead seals out of normal range, and seals were absent or unusually scarce in the Port Clarence area.

Southeastern Bering Sea
Physical conditions
In the southeastern Bering Sea, the timing of the spring bloom was a bit late, but otherwise conditions were typical of a low-ice year with above-average water temperatures and complete lack of a cold pool. Similar to the northern Bering Sea, the southeastern shelf experienced reduced strength of water column stratification due to the lack of salinity component. These weakly stratified waters are easily disrupted by storms.

Biological responses
At mooring M2 (located at the southern end of the eastern Bering Sea shelf) a small phytoplankton bloom began May 25, approximately 1 week after stratification. While this timing is delayed, it is not unprecedented for the southeastern shelf. In early spring, small copepods and large copepods were in low abundance. Large copepod lipid values were <5% body weight (though this is not surprising) while those sampled near Unimak Pass had higher lipid values (∼10%). Evidence of increased production (phytoplankton, zooplankton, pollock) around Unimak Pass likely resulted from on-shelf flow through Bering Canyon and/or transport of Alaska Coastal Current waters from the Gulf of Alaska. During the late spring larval survey, small copepod abundances increased to one

of the highest levels recorded while large copepod abundances were similar to the historical average. However, copepod mortality may be increased due to the decreased biomass of the phytoplankton bloom and inability to sustain nauplii.

Euphausiid furcilia had very low abundances on both spring surveys, which was not unprecedented in a warm year. The acoustic survey indicated that euphausiid densities remain low; this high quality prey have become less available in 2012–2018. Thus, delayed production gave rise to a low quality zooplankton prey base over the entire shelf. Reduced energy transfer from the prey base to the top-level predators likely contributed to poor body condition and observed mortality events (i.e., seabirds and mammals).

Larval pollock production was similar to other warm years: high abundances with the distribution shifted eastward. However, the poor prey base may result in reduced growth of juvenile fish and higher overwinter mortality. Survey scientists noted that larvae 'seemed long and skinny'. It is unlikley that juvenile pollock will be able to utilize cold water refugia due to a well-mixed water column over the shelf and absence of a cold pool. The bottom trawl survey indicated that Pacific cod and pollock abundances were below the long-term mean. Pacific cod abundance was lower, but biomass was higher (fewer, larger fish). Additionally, there was no evidence of pollock recruitment, with low age-1 numbers and abundance dominated by the 2012 year class. Age-1 pollock abundance has been low since 2014.

Northern fur seal pup production at St. Paul Island was ∼6% less than 2016. Pup production has been declining at St. Paul Island at an approximate annual rate of 4.0% since 1998. Anecdotal reports suggest smaller or skinnier pups at some rookeries on St. Paul Island. The estimated St. George pup production is approximately 5% greater than 2016 with no unusual pup mortality, but shows no significant trend since 1998.

At the Pribilof Islands, seabird nesting was delayed, and/or unsuccessful. Seabird reproduction was poor, as expected for a warm year with little sea ice. For example, black-legged kittiwake reproductive success failed completely, indicating prey for these surface-foraging birds was likely not sufficient for them to successfully rear chicks. On St. George Island, common murres experienced the latest mean hatch ever recorded and thick-billed murres experienced their 2nd latest hatch date. Productivity values were mediocre and fewer birds than normal were attending cliffs or laying eggs.

Local and Traditional Knowledge
Bristol Bay
Unusual observations of adult pollock behavior were reported from community members as well as subsistence and commercial fishers from Bristol Bay in summer 2018. Sightings of pollock swimming 'with their heads out of the water' and 'behaving odd' were reported. Adult pollock were reported to have washed up on shore in high numbers, and pollock were reported to have been caught in subsistence set nets during the salmon fishery (both near Pilot Point, Ugashik River, and from the Nushagak District). "Traditionally, it is unusual to see pollock in the salmon season in Bristol Bay" (Catie Bursch, fisher, pers. comm.).

Efforts to capture the breadth of these events resulted in phone calls and emails from additional commercial fishers from Bristol Bay. Fishers reported dead fish ashore in late May in numbers that were "many, many more than other springs" (Tyler Sterling, fisher, pers. obs.). Reports continued through early July of pollock 'floating belly-up, but alive' and 'half swimming, half floating'. A local fisher who has been fishing near Pilot Point for 40 years described the events as "unusual".

"I first remember seeing pollock swimming along the surface in the shallows in early July in Nushagak district. We caught a few in our gillnet, but mostly saw them swimming. I also have a friend who setnets in Ekuk; she said they saw one swimming in the shallows near their site and heard reports of similar things from others who setnet near there. We stopped to go beachcombing along the coast between Ugashik and Egegik on July 25th. There were dead pollock dried up everywhere along the beach (I would guess a dead fish every 20 feet or so). Some of the guys I was with have fished the area for decades–they were mentioning how they had never seen anything like it." (Carina Nichols, fisher, pers. comm.).

Catie Bursch, a commercial fisher from Pilot Point, sent samples to NOAA Fisheries in Juneau, Alaska. Sample processing is still underway, but the fish were "definitely skinny compared to average weights by year/size from NOAA's bottom trawl survey" (B. Lauth, pers. comm.). Stomach contents included Caridea shrimp, gammarid amphipods, and other fish, which "seems pretty typical for Bristol Bay" (K. Aydin, pers. comm.). Stomach and intestine samples were processed for PSP toxins (i.e., saxitoxin) at the NWFSC/WARRN-West Program. All samples contained low but detectable levels of PSP, confirming that an exposure risk was present in the food web. Therefore, PSP toxins could have played a role in the unusual behaviors and mortality events observed in Bristol Bay, although it is important to note that the levels were well below the seafood safety regulatory limit and therefore were not a risk for human consumption (K. Lefebvre, pers. comm.). Samples taken for isotope and condition analyses are still being processed.

Aleut Community of St. Paul Island
The Ecosystem Conservation Office (ECO) reported that St. Paul Island community members noted how 'quiet' the cliffs were in May 2018; birds should have been returning and starting their nests. Although birds arrived around the usual time of year, they did not engage in typical nest building activities. In fact, red- and black-legged kittiwakes gathered nest-building materials a month late. Residents were unable to collect subsistence murre eggs because there were none on the cliffs during the egging season (June). Across multiple seabird species, eggs were laid a month later than usual and community members were monitoring cliffs to observe whether fledging would also occur late.

Least auklets have been declining since 2015; no auklets have been subsistence harvested in the last two years due to declining breeding colonies. Elders in St. George recall how abundant least auklets were in 1940s–1970s. Similarly, red-legged kittiwake hunting has been declining in part due to concerns about the population decline. Residents continue to take low numbers of kittiwakes for subsistence, but only to provide to Elders who request it.

In early July 2018, approximately 50 fresh-dead northern fulmars, shearwaters, and murres were collected on beach surveys. All necropsies revealed the birds died of starvation. This marks the third year that birds have washed ashore in poor body condition. Elders on both St. Paul and St. George have cited shifting prey distributions and a 'lack of food' as the reason behind declining populations. Community members continue to speak of a lack of food in both summer and winter as the cause for die-offs, population declines, and reduced productivity and fledgling success.

Subsistence fishermen have reported that they have to go out more often (spend more time on the water) and further (cover more distance from the shore) from the St. Paul harbor to catch enough halibut for their families to get through the winter. ECO continues to receive reports from subsistence fishermen that very few halibut have been caught in what used to be considered 'traditional rich fishing grounds'. Residents refer to warm water temperatures in recent years as

the reason driving a lack of food in the region: "fish have all moved north to find colder waters and sea ice".

The decline of northern fur seals is also apparent to Elders, adults, and youth. Community members comment how thin and sickly female fur seals are and Elders report 'low pup numbers' and 'no yearlings or two-year-olds returning'. These reports come from individuals who experienced the commercial harvest days. This knowledge is reflected in subsistence harvests today; harvests have a more somber tone in recent years. Subsistence harvests represent the importance of securing seal meat to provide food security for winter.

The Pribilof Islands are also experiencing crowberry (or moss berry) failure. Crowberries are a source of fiber and stored for use during the winter months when fresh foods are scarce. In 2018, a complete lack of berries occurred, potentially causing a food security issue for the community.

Please also see the Noteworthy contribution "Better Off Dead" about a rat on St. Paul Island that poses a potentially catastrophic threat to breeding seabirds (p. 40).

Contributed by Lauren Divine (Aleut Community of St. Paul Island), with contributions from J. Erickson, G. Fratis, Sr., S. Lekanof, P. Melovidov, Z. Melovidov, J. Merculief, M. Merculief, and P. Pletnikoff

Forecasts and Predictions

Climate projections for the Chukchi Sea have impacts on the eastern Bering Sea in terms of residual heat and timing of ice formation ("freeze up"). The Chukchi Sea has been freezing up, on average, one day later each year since 1980 whereas the timing of freeze up in the northern Bering Sea has been random. Currently, the Chukchi Sea is colder than this time in 2017, which may affect the timing of freeze up and the potential for export of heat to the northern Bering Sea. If no ice forms over the eastern Bering Sea shelf this coming winter 2018–2019, summer conditions in 2019 may be much warmer due to stored heat content.

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 October of each year run through July of the following year using the Bering10k ocean and plankton model forced by seasonal atmospheric predictions produced by the NOAA/NCEP Climate Forecast System (CFS).

The Bering10k 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 calibrated using repeated hindcasts of the region covering the period 1972–2017.

A particular metric of interest is the summer cold pool, the proportion of the summer bottom trawl survey area below a particular temperature. Figure 2 shows the cold pool with limits of ≤0°C, ≤1°C, and ≤2°C. Shown are bottom trawl survey data, Bering10k hindcast results for 1982–2018, and Bering10k 9–month ahead predictions. The most recent prediction, made in October 2018, is shown for summer (July) 2019. The Bering10K model successfully predicted a transition from

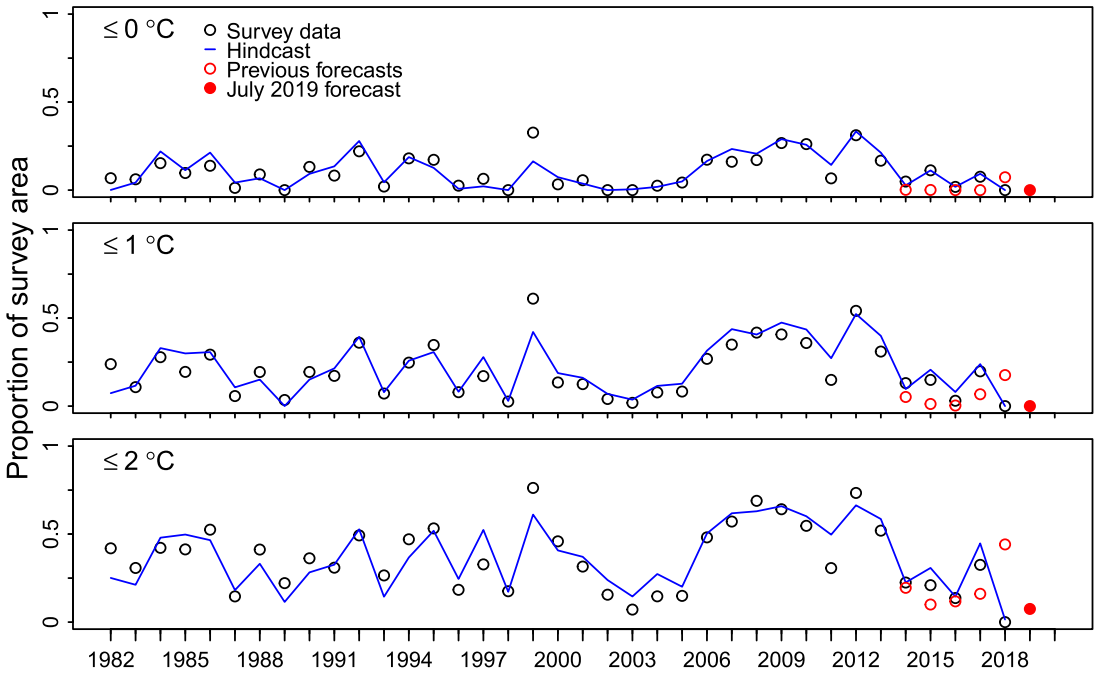

Figure 2: The eastern Bering Sea cold pool with limits of ≤0°C, ≤1°C, and ≤2°C. Shown are bottom trawl survey data, ROMS hindcast results 1982–2018, and ROMS 9–month ahead predictions. The most recent prediction, made in October 2018, is shown for summer (July) 2019.

cold to warm conditions between 2013 and 2014, and continued warm conditions were predicted successfully for three more years, through summer 2017. The prediction made in 2017 for 2018 was for cooling (returning towards average), however this prediction was substantially incorrect as anomalous atmospheric conditions (p. 59) greatly impeded the formation of ice in 2017–2018 and led to the smallest cold pool on record. The predictions for summer 2019 are for **continued warm conditions substantially similar to 2014–2018.**

Pollock Recruitment Predictions

The EBS Ecosystem Status Report includes several leading indicators of pollock recruitment that give, in some cases, contradictory results. 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. Additional research is underway to assess these indicators over longer time periods. Survival and recruitment success of juvenile pollock are driven, in part, by bottom-up processes. The abundance, species composition, and quality of zooplankton prey resources are governed by large-scale oceanographic processes and vary between warm and cold climate stanzas. For example, the abundance of large zooplankton (e.g., *Calanus marshallae*) is greater in cold years when above-average pollock recruitment to age-3 has been observed. Below we track available predictions for several recent year classes of pollock (2015–2017):

2015 year class: The 2015 pollock year class appears **slightly below-average** (Ianelli et al., 2017). Indicators that support below-average or intermediate recruitment include:

- Large zooplankton abundance was low, therefore would predict **below-average recruitment**
- Biophysical indices (chum salmon growth, temperature, predator abundance) predicted **below-average recruitment**
- Age-0 pollock diet energy density predicted **intermediate recruitment**
- Average energy content predicted **intermediate recruitment**

In contrast, the following indicators predicted above-average recruitment:

- The Temperature Change Index predicted above-average recruitment
- Surface silicic acid concentrations predicted above-average recruitment

The EBS had warm conditions in 2015, although age-0 pollock may have utilized the cold pool as a refuge which may act as a buffer against recruitment declines for this year class (Duffy-Anderson et al., 2017).

2016 year class: The 2016 pollock year class also appears **slightly below average** (Ianelli et al., 2017). Indicators that support below-average or intermediate recruitment include:

- The Temperature Change Index predicted **below-average recruitment**
- Average energy content predicted **intermediate recruitment**

In contrast, the following indicators predicted above-average recruitment:

- Surface silicic acid concentrations predicted **above-average recruitment**

2016 marked the 3rd consecutive year of above-average warmth over the eastern Bering Sea shelf and zooplankton communities appeared qualitatively and quantitatively low. However, pollock appear to have mitigated against dramatic recruitment declines. Possible mechanisms include utilizing high productivity waters associated with the strong, northerly cold pool as a refuge, or by exploiting alternative prey (i.e., euphausiids) over the southern shelf (Duffy-Anderson et al., 2017).

2017 year class: No assessment estimate available for the 2017 pollock year class.

- Average energy content predicts **average recruitment** to age-1
- The Temperature Change Index predicts **average recruitment** to age-3