Lesson Plan: Climate Change Impacts on Blue King Crabs

GRADE LEVEL
9-12; can be adapted to different age levels

FOCUS QUESTION
How is climate change affecting blue king crabs in the Bering Sea?

LEARNING OBJECTIVES
Students will learn about the impacts of climate change on blue king crabs from an ecosystem perspective. Students will also learn to relate concepts through concept mapping. Students will connect different components of understanding to complete the activity, relating environmental changes to the impact that has on blue king crabs.

MATERIALS
- 6 large pieces of butcher paper – enough for one per 3-4 person group
- Markers – dark/thick enough to be visible on butcher paper
- Concept mapping keyword lists for each group

TEACHING TIME
One hour - adaptable

KEYWORDS
Climate change
Bering Sea Ice
Climate Variability

BACKGROUND INFORMATION
Range and Current Status
Blue king crabs (*Paralithodes platypus*) range throughout the Gulf of Alaska and the Bering Sea along the Siberian coast and in the Bering Strait. The populations of blue king crabs are very insular, inhabiting widely separated islands and fjord-like inlets in "pockets," or disjunct populations. They inhabit the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and outer parts of the Norton Sound. In the Bering Sea, blue king crabs inhabit St. Matthew Island and the Pribilof Islands (ADFG, 2014). For the purpose of this lesson plan, we will be focusing specifically on the Eastern Bering Sea populations of blue king crabs located around St. Matthews Island and the Pribilof Islands.

In the early 1980s, the commercial fishery stocks of red king crab (*Paralithodes camtschaticus*) crashed, so the similar blue king crab became more popular (AFCS). Not long after the increase in blue king crab catches, however, the blue king crab populations also saw a huge decline in numbers. The fishery for blue king crabs near the Pribilof Islands was closed in 1988 due to low abundances, and the fishery near St. Matthew declined soon thereafter, and was closed in 1999 (Herter, 2011; ADFG, 2014). Despite the closure of the blue king crab fishery, the Pribilof Island population has not recovered. The Pribilof Island blue king crab fishery has been considered overfished since 2002, with little to no recruitment to the population since 1995 (Low, 2008). The St. Matthew Island blue king crab fishery has also been considered overfished since 1998, but during the 2009-2010 fishing season the St. Matthews population was large enough to allow for fishing (Low, 2008; Herter, 2011).

Basic Biology
It is important to compare red king crab and blue king crab life history traits because they have very similar ranges and yet they often don't co-occur, or inhabit regions together. This is likely a result of increases in water temperature following the most recent period of glaciation (Somerton, 1985). The insular distribution of blue king crabs may be a direct result of temperature stress on the crabs, or an indirect result of the changing temperatures that expanded the range of warm water competitors and predators. Blue king crabs may be adapted for colder waters compared to red king crabs. Hypotheses for the difference in distribution between red and blue king crabs include differences in optimum temperature for reproduction, competition with the red king crab for resources, exclusion by predators, and habitat requirements of juveniles (Somerton, 1985; ADFG, 2014).

Blue king crabs use both the open ocean and sea floor of the Bering Sea throughout their life history. After hatching, king crabs are free floating larvae that feed initially on phytoplankton and then on zooplankton as they grow larger (Donaldson, 2005). The larval crabs pass through four stages (about 10-14 days each), and one non-feeding glaucothoe phase (about 40 days), before metamorphosing into the first juvenile stage and becoming a benthic bottom dweller for the remainder of their lives. The larval stages lasts for 2 to 3 months for red king crabs, and 3.5 to 4 months for blue king crabs depending on temperature (Armstrong et al, 1985; AFCS).

During the juvenile stage of life, the king crabs molt frequently, growing several millimeters with each molt (Donaldson, 2005). As early juveniles, blue and red king crabs are small and rather defenseless, and this stage of life is characterized by the highest mortality of the benthic stage because the crabs are too small to escape predation (Donaldson, 2005). For this reason, habitat is crucial to blue king crab survival. Juvenile blue king crabs are limited to near shore areas around the Pribilof Islands because they are dependent on the intact shell that is found on the bottom (Armstrong et al, 1985). This varied bottom material consisting of shell, gravel, and rocks provides habitat rarely found elsewhere in the Bering Sea (Palacious, 1985). The juvenile blue king crabs likely inhabit the shell, rocky, cobble bottom as a means of protection; red king crabs have differing juvenile body morphology with long spines and exhibit a podding behavior, both of which may provide protection (Armstrong et al, 1985). The podding behavior is characterized by red king crabs touching and piling on top of one another in a large ball – possibly for protection from predators (Donaldson, 2005). This podding behavior has not been observed in blue king crabs.

In addition to the habitat, it is important to consider the coloration of each of these species: red king crab juveniles are red, and thus in the ocean might not be visible due to the depth red light penetrates so they might be able to survive in the open (Widder, 2004), while blue king crab juveniles are mottled and patchy, with large variation in their color pattern, potentially hiding them well amongst the shell and cobble bottom.

King crabs are frequently preyed upon by many species of fish in the Bering Sea, as well as by cannibalistic larger king crabs (Donaldson, 2005; AFCS). Predators of king crabs include: Pacific cod, halibut, yellowfin sole, flathead sole, arrowtooth flounder, octopus, walleye Pollock, herring, Sockeye salmon, scuplins, Irish lords, skates, and snailfish.

King crabs themselves feed on a variety of organisms, depending on size and location. As early stage larvae, king crabs prefer *Thalassiosira* spp., a diatomaceous phytoplankton (Mantua & Hare 2002; Alexander, 1981; Aydin, 2007; Stevens, 2006; Stevens, 2008; Zheng, 2008). King crabs are omnivorous and are opportunistic feeders, meaning will eat almost anything available on the ocean floor. This includes worms, clams, mussels, snails, brittle stars, sea stars, sea urchins, sand dollars, barnacles, crabs, other crustaceans, fish parts, sponges, and algae (Donaldson, 2005; AFCS).

Juveniles continue to grow and molt (shed the old shell and form a new one) frequently until they reach adulthood or sexual maturity, characterized by reproductive readiness. Molting is an essential part of growth that occurs during many stages of the crab life cycle; because crabs have an exoskeleton, in order to grow larger crabs must first shed the old shell and then they will be able to grow a new, larger shell. King crabs reach maturity between 5-7 years of age. Adult blue king crabs migrate annually from nearshore (shallow) to offshore (deeper). In winter blue king crabs migrate to shallow waters, and eggs hatch in spring. Because there is no way to determine the age of a king crab, the average lifespan is unknown (ADFG, 2014).

Blue king crab reproduction occurs when the male blue king crab grasps the female blue king crab, and he will transfer the sperm to her eggs. After fertilization of 50,000 to 200,000 eggs, the eggs are held in the abdomen of the female blue king crab for a little over a year (12-14 months) before hatching. Female blue king crabs have a biennial reproductive cycle, meaning they reproduce every two years. This biennial cycle may be due to the inability of the female blue king crab to produce fully developed ovaries in one year, possibly as a result of the energy requirements for annual ovary development or other factors (ADFG, 2014; Jensen et al, 1989; Jensen et al, 1985). In contrast, red king crabs reproduce annually – on a 12 month cycle – and several days after eggs of one cycle hatch, the female red king crab molts, mates and begins carrying another clutch of eggs (Donaldson, 2005).

Links to Climate

Biological communities in the Bering Sea are inextricably linked to physical oceanographic and climate processes. Climate variability in the Bering Sea is heavily influenced by the strength and position of the Aleutian Low atmospheric low pressure system (Aydin & Mueter, 2007). It is important to mention here that the ecosystem in the Bering Sea is incredibly complex and it is not fully understood how frequent climate variability and large scale climate cycles affect the biological communities in the Bering Sea (Aydin & Mueter, 2007).

One example of the complexity of the interactions between climate and biological communities is the Pacific Decadal Oscillation (PDO), a pattern of large-scale, interdecadal climate variability. In 1976/1977, there was a shift in the climate system from a "cool" PDO phase to a "warm" PDO phase, and there was also a shift in a crustacean dominated ecosystem to an ecosystem dominated by flatfish, cod, and pollock (Mantua & Hare, 2002). As a result of the shift in climate, sea ice extent decreased and Bering Sea temperature warmed slightly. There has since this time been more PDO shifts, but it is unclear how the ecosystem responded, and crab populations are still struggling.

The physical oceanography of the Bering Sea is dynamic and complex (Figure 1, 2). The continental shelf is located in the eastern portion of the Bering Sea, and is characterized by varying layers of water from the surface to the sea floor between the coastal edge of Alaska and the continental shelf edge (Armstrong et al, 1987). Deep, cool nutrient-rich water from below the continental shelf seeps up onto the shelf, forming a deep layer of cold water. Above this deep, cold layer are typically two layers: a middle cool layer, and a top mixed layer. The upper layer varies in nutrient availability, and is typically biologically productive because nutrient-rich deep water is mixed by both winds and tides, and is brought up from below the continental shelf, providing nutrients to the phytoplankton so they can thrive (Stabeno, 2008). The mixed layer varies in depth based on the wind speed that causes the mixing, less mixing often causes stratification (usually harder to mix) of the different layers. In winter, the winds typically blow strongly from the north, while in summer the winds are weaker from the south (Armstrong et al, 1987; Stabeno, 2008). According to Zheng and Kruse (2000), strong mixing of ocean layers occurs during strong Aleutian Low pressure systems, and this may inhibit growth of the diatoms *Thalassiosira* spp. that are favored by king crab larvae.

According to Stabeno et al. (2008), the southeastern Bering Sea has experienced about 3 degrees Celsius warming over the last decade. This relatively small increase in temperature has had a dramatic impact on physical processes and mechanisms in the Bering Sea, such as sea ice extent and thickness. Sea ice is intricately connected to atmospheric and ocean conditions, and often reflects the high degree of variability in the Bering Sea (Figure 3, 4).

Timing of sea ice melt is an essential factor in larval crab success. The timing of sea ice melt – in addition to nutrient availability and sunlight availability – determines what species of phytoplankton are dominant and when the spring phytoplankton bloom occurs, in turn affecting the survival of crab larvae and supporting the entire Bering Sea ecosystem (Zheng and Kruse, 2000; McNutt). If the time of the phytoplankton bloom changes, organisms relying on phytoplankton and zooplankton will be negatively affected due to the lag time and spatial and temporal mismatch between predators and their prey (Mantua & Hare, 2002). According to Aydin & Mueter (2007), an earlier ice melt in spring typically results in lower phytoplankton biomass during the bloom. If the ice retreats before there is sufficient light availability, the phytoplankton bloom will be delayed until there is enough light and the water column is stabilized so the phytoplankton remain near the surface.

Early stage larval king crab larvae rely on the diatom *Thalassiosira* spp. for food, and these diatoms typically thrive on the edge of sea ice. If there is variability in ocean conditions or sea ice retreat, the dominant phytoplankton community also varies. This is crucial when thinking about climate impacts on king crabs because there is such a small time frame (several days) for the larval king crabs to find food before they die. Thus there is huge potential for there to be a mismatch in not only time but also location (due to currents) between the larval king crabs and their food source (Mantua & Hare, 2002). According to Low (2008), if survival to adulthood is less than natural mortality, the population will continue to decline – even without fishing pressure! Fluctuations in crab populations are linked to recruitment variability, which is at its greatest during the larval stage because the larval crabs are powerless against the currents and variability in their food sources (Low, 2008).

Climate variability can affect marine ecosystems through direct and indirect pathways. Direct impacts could be characterized by climatic and the resulting ocean habitat changes affecting the ability for certain species to live in its typical range (can expand, shrink, or geographically shift the range). Indirect impacts include the physical environment changes leading to changes in species interactions, such as predation or competition (Mantua & Hare, 2002).

The future

Because blue king crabs are habitat specialists in the sense that they rely on the rocky, cobble, shell habitat around the Pribilof Islands and St. Matthew Island, if the water temperature is too high or if food resources cannot support blue king crabs, they will not survive. An important point to mention here is that human additions of carbon dioxide are not only causing global temperatures to increase, but the carbon dioxide is also causing the oceans to become more acidic, which is also affecting Bering Sea ecosystems and blue king crabs. For more information about ocean acidification, start here: http://apps.seattletimes.com/reports/sea-change/2013/sep/11/alaska-crab-industry/

There are projects developing techniques the ability to raise blue king crabs and red king crabs in hatcheries, and examining if hatchery-reared crab could be used to supplement the population. Crabs are too long lived and cannibalistic to grow to harvestable size in a hatchery, but there are programs researching possible restoration and population supplement by cultivating juveniles in the lab, then releasing them into the wild (Carroll, 2012).

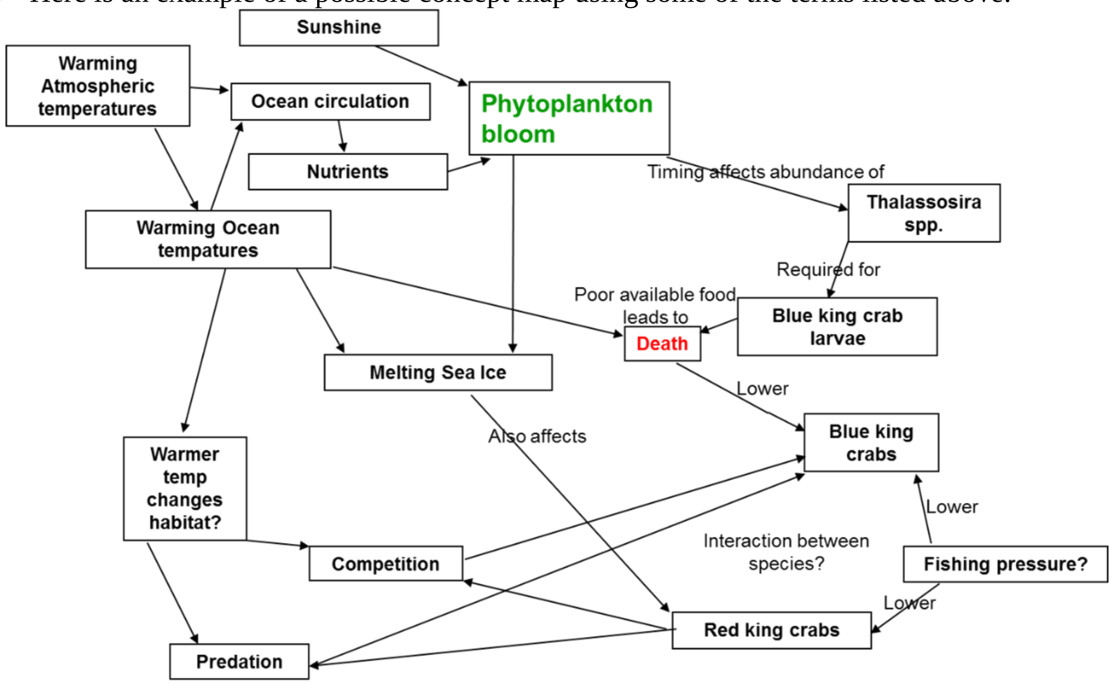
As for mitigating the effects of melting sea ice and rising temperatures, that requires drastic international cooperation and policy agreements to combat climate change, and to stop emission of carbon dioxide. The endangered king crab fisheries are closed to fishing and hopefully they will eventually begin to recover.

LEARNING PROCEDURE

1) Show your students the video “The Bering Sea” in the series Polar Palooza: http://passporttoknowledge.com/polar-palooza/pp06healy01.php. This video provides a great introduction to sea ice interactions with ecosystems. Ask your students to take notes on the video, how do organisms interact with sea ice? How is climate change impacting sea ice?
    a. Video “The Bering Sea” Can be downloaded here http://passporttoknowledge.com/polar-palooza/pp09a.php
2) Have your students talk to their neighbor for 5 minutes following the video, comparing notes and filling in gaps.
3) Depending on the background of your students, you may or may not decide to give your class a brief ten minute lecture about king crab biology basics and Bering Sea processes, and the effects of climate change on the Bering Sea.
4) If your students are unfamiliar with Concept Mapping, take a minute or two to explain the idea. Encourage the students to be creative with their maps and connections.
    a. The goal of this activity is to create a web of concepts about the relationships between climate change and the impact on blue king crabs.
    b. A simple way to explain this concept would be to draw an example on the board with a main circle or box, and different circles connected to the main via lines representing a relationship.
    c. If you are unfamiliar with Concept Mapping, it is a great technique for visualizing relationships. Stanford provides a great “Concept Mapping” article here: http://www.stanford.edu/dept/SUSE/SEAL/Reports_Papers/Vanides_CM.pdf
        - Background information can be found at this site: http://www.inspiration.com/visual-learning/concept-mapping
        - Here is a lesson plan about Concept Mapping that may provide a nice background http://www.activateevolution.ca/GettingAround/educators/pdf/LessonPlan2.pdf
5) Group the students into groups of 3-4. Give each group one piece of butcher paper – the larger the better.
6) Give each group a list of “Concept Mapping Keywords” and explain that while this list is useful and the terms should be included in their concept maps, it is also not exhaustive and creativity is encouraged! Challenge the students to think about terms not on the list, and include them in their concept maps.
    a. “Concept Mapping Keywords”:
        - Carbon dioxide in the atmosphere
        - Sun, solar energy
        - Climate change
        - Atmospheric temperature
        - Ocean temperature
        - Bering Sea sea ice
            - Extent of sea ice, timing of retreat
        - Phytoplankton
            - Diatoms –*Thalassosira* spp.
        - Zooplankton
        - Blue king crabs
            - Larvae
            - Juveniles

- Adults
- Red king crabs
- Competition
- Predation
- Habitat
- Ocean circulation

7) Have the students discuss in groups how changes in climate might affect blue king crabs. Make a concept map of the relationship between the physical oceanographic processes of the Bering Sea and the biological ecosystem processes, including impacts of climate change.
   a. Here is an example of a possible concept map using some of the terms listed above:



EVALUATIONS

- Have your students right a short reflection paragraph on a piece of paper, collect these at the end of class. Based on the concept maps and the paragraphs reflecting, you should get an idea of how your students are learning.

EXTENSIONS

- Research could be an excellent follow up to the Concept Mapping activity, and could provide the students an opportunity to learn more about some aspect of climate change impacts on ecosystems. This is an excellent lesson plan extension, with a video that you could use in your lesson. The lesson plan offers a research opportunity for your students, writing proposal and research questions about climate change affecting the Bering Sea ecosystems, and then conducting research to answer their questions. This could be done in groups or individually.
  - Alaska Sea Grant Bering Sea lesson plan: http://seagrant.uaf.edu/marine-ed/curriculum/grade-8/investigation-3.html
  - Video series: http://passporttoknowledge.com/polar-palooza/pp06healy01.php

FOR MORE INFORMATION

- The Climate Literacy and Energy Awareness Network (CLEAN) has a network of available activities and extensions available for free, and has many great lesson plans about climate change if you are interested in taking a more broad approach. http://cleanet.org/clean/literacy/index.html
  - Here is an activity teaching the students to graph the extent of sea ice in the Arctic, very practical and skill based. http://cleanet.org/resources/41790.html
- PBS lesson plan on global warming, this could be a great place to start if your students have not been exposed to the information before. (Might be a bit dated, from 2007) http://www-tc.pbs.org/now/classroom/global-warming-lesson-plan.pdf

- NOAA has several lesson plans available about light penetration in the ocean, which might be a great supplement if the point is confusing to your students. Here is the link to the overview page: http://oceanexplorer.noaa.gov/facts/red-color.html
  - Grades 9-12: http://oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_blinded.pdf
  - Grades 5-6: http://oceanexplorer.noaa.gov/explorations/02hudson/background/edu/media/hc_bright_red.pdf
- Here is a comprehensive lesson plan option for climate change impacts on the Artic. http://iclimate.org/ccc/Files/arctic.pdf
- Here are some great videos about decreasing sea ice in Alaska, it provides a nice background of the extent sea ice in the Artic and Bering Sea. An awesome introduction to climate change, or a break during a discussion about sea ice and the effects on ecosystems. The videos include interviews with expert scientists, as well as Alaskan Native peoples.
  - Faces of Climate Change: Introduction: http://vimeo.com/19581877. This gives a great introduction to climate change, through the lens of Alaska, in the Bering Sea and Arctic.
  - Faces of Climate Change: Life on the Ice: http://vimeo.com/19583516. This video provides an overview of biological communities that rely on sea ice.
  - Faces of Climate Change: Disappearing Sea Ice: http://vimeo.com/19583956. The video briefly discusses albedo and sea ice, as well as climate variability in the Bering Sea.
- Here is another great 7 minute video from the Woods Hole Oceanographic Institution about Bering Sea ice and ecosystems. It provides an introduction to primary production following ice melt in springtime, and describes the impact of climate change on sea ice. Discusses Pollock impacts, but similar discussion could be had about king crabs. http://www.whoi.edu/oceanus/viewArticle.do?id=63566
- This is an amazing page of interactive activities and explanatory pages from the Woods Hole Oceanographic Institution. http://www.whoi.edu/oceanus/interactives
  - One great interactive page is the "Light in the Ocean," which explains how light affects the ocean biologically and physically.
  - Also, for a bit about Ocean Acidification, use the "How Animals Build Their Shells" activity
- Here is an interactive resource about sea ice extent http://earthobservatory.nasa.gov/Features/WorldOfChange/sea_ice.php

NATIONAL SCIENCE EDUCATION STANDARDS

- Content Standard C: interdependence of organisms, and behavior of organisms
- Content Standard F: natural resources, natural and human-induced hazards, and environmental quality

ACKNOWLEDGMENTS

This lesson plan was created by Alexandra Doty for a project with the UW School of Aquatic and Fishery Sciences. Special thanks to the project team, David and Jan Armstrong, P. Sean McDonald, and Chris Long, as well as Emily Runnells and Joseph Bizzarro. Funds for these materials were provided through a subaward from the North Pacific Research Board. For questions or comments, please contact Alexandra Doty at dotya@uw.edu.

RESOURCES

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FIGURES

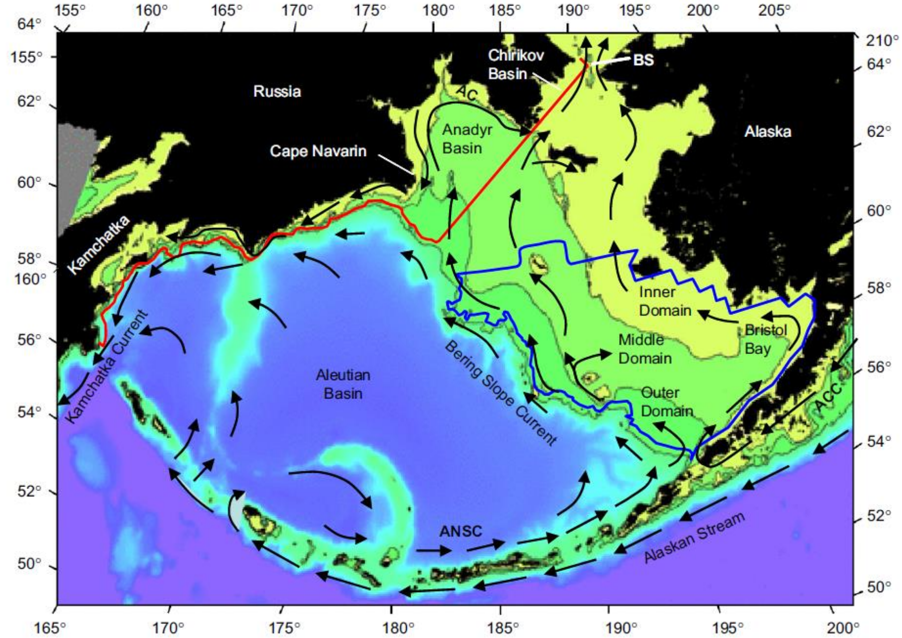

Figure 1. The Bering Sea, with boundaries of the southeast Bering Sea shelf (EBS, blue line), and the western Bering Sea shelf (WBS, red line). Isobaths shown are 50m (between inner and middle domains), 100m (between middle and outer domains) and 200m (between outer domain and slope/basin). Schematic of major currents based on Stabeno et al. (1999). AC: Anadyr Current, ACC: Alaska Coastal Current, ANSC: Aleutian North Slope Current, BS: Bering Strait. (Source: Dave Armstrong)

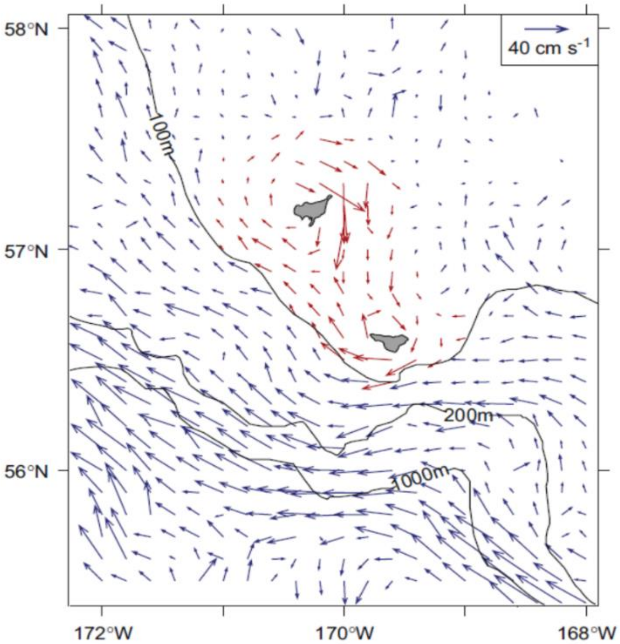

Figure 2. Red arrows are Pribilof domain circulation, (Stabeno et al, 2008).

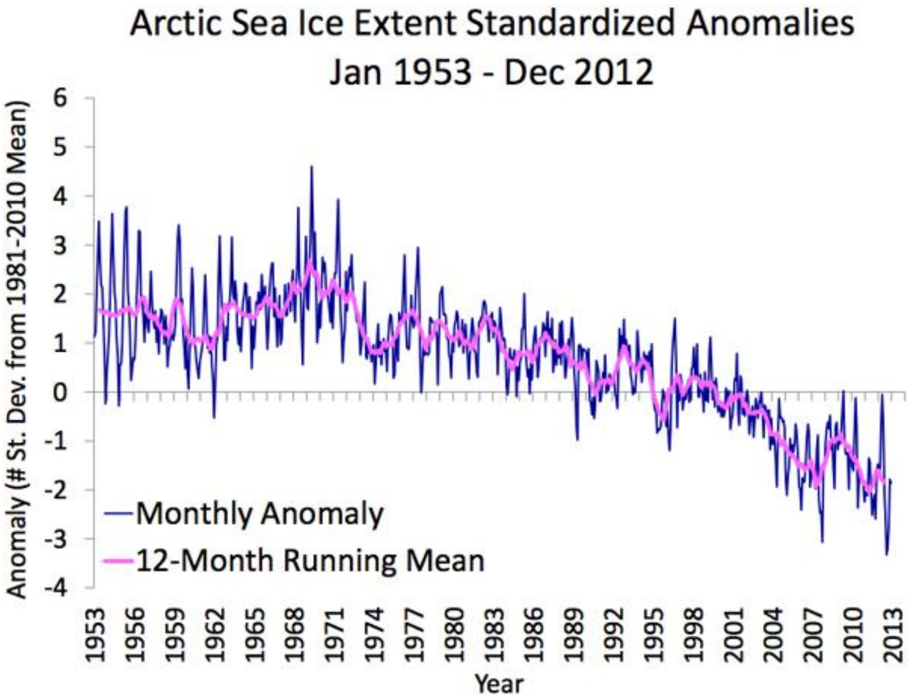

Figure 3. Mean sea ice anomalies from 1953-2012. Anomalies are departure from the mean for the Northern Hemisphere. Image by Walt Meier and Julienne Stroeve, National Snow and Ice Data Center, University of Colorado, Boulder. (Source: http://nsidc.org/cryosphere/sotc/sea_ice.html)

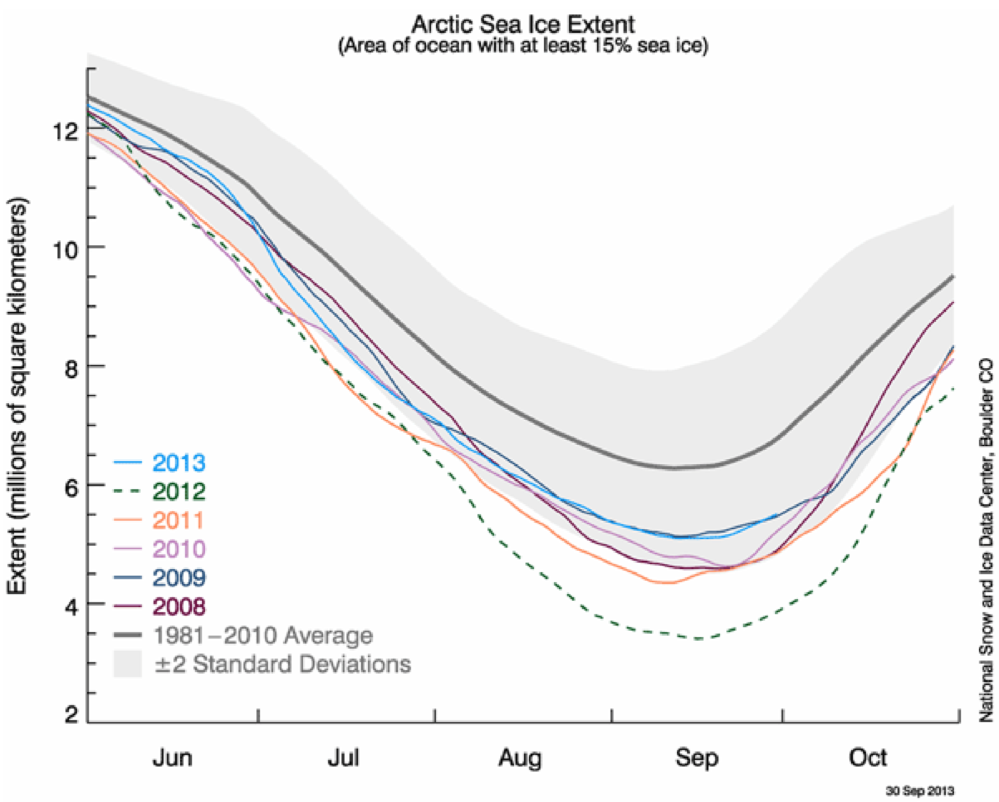

Figure 4. Five-day averages for Arctic sea ice extent (area of ocean with ice concentration of at least 15 percent) for the long-term mean (1981-2010), and the years 2008 through 2013. The 2012 minimum dropped to 3.61 million square kilometers, and experienced a rapid freeze-up after reaching its minimum. The 2013 minimum was 5.10 million square kilometers, the sixth lowest in the satellite record. Image provided by National Snow and Ice Data Center, University of Colorado, Boulder. (Source http://nsidc.org/cryosphere/sotc/sea_ice.html)