Rime of the Bering Sea Mariners

WENDEE HOLTCAMP

From albatross to zooplankton, the multidisciplinary Bering Sea Project explores how climate change is affecting this important ecosystem.

I arrive in the *RV Thompson*'s pilot house just in time. It's day six of the final month-long cruise of the Bering Sea Project, a six-year, $52-million, multidisciplinary program to study how climate change is affecting the Bering Sea ecosystem, and ship life already feels monotonous. But when I enter the pilot house, Brian Hoover is excitedly pointing at something out the oversized windows. "That," says Hoover, a graduate student from Moss Landing Marine Lab, "is one of only 3000 short-tailed albatrosses in the world." I see a sturdy gray-black juvenile with a bulbous, pink bill, soaring on the wind, its long wings outstretched.

Ever since Samuel Taylor Coleridge published *The Rime of the Ancient Mariner* in 1798, the albatross has represented a burden one must bear. The famous tale, in which a man kills one of the legendarily auspicious birds and is cursed to wear it around his neck, could easily have been set in the subarctic Bering Sea, with its near-constant mist and clouds, frigid temperatures, and notoriously stormy weather. Living as a mariner for weeks at a time requires its own kind of penance, yet it's the price biologists pay to study the intricacies of a place that sustains not only seabirds but also our own hungry appetites.

The Bering Sea yields half of the commercial seafood caught in the United States annually: primarily walleye pollock, but also Pacific cod, Atka mackerel, halibut, flounder, and salmon, not to mention the king and snow crabs made famous by the Discovery Channel TV series, *Deadliest Catch*. Pollock alone brings $1 billion annually to the US economy, the largest single-species fishery in the country. Although the Marine Stewardship Council certified pollock as a sustainable fishery in 2005, the species' population has since dropped. Despite Alaska pollock's sustainable label, Greenpeace placed the species on its red list of fish to avoid, blaming overfishing for its decline. In addition, the National Marine Fisheries Service (NMFS) just issued an emergency closure of Atka mackerel and Pacific cod fisheries in the Western Aleutians to stem the precipitous drop in endangered Steller sea lions—80 percent since the 1960s—though the action didn't affect the pollock fishery. With the planet warming, scientists are rushing to understand this commercially important Bering Sea ecosystem so they can predict what may happen in the future.

One of only 3000 short-tailed albatrosses in the world this juvenile soars on the wind in the Bering Sea, where albatross numbers have increased in recent years. Photograph: © Wendee Holtcamp.

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A partnership between the National Science Foundation (NSF) and the North Pacific Research Board (NPRB), since 2007 the Bering Sea Project has funded 100 principal investigators on 43 projects to study how climate affects everything from birds in the air to critters on the seafloor, and, of course, fishes in the sea. The project involves not just biologists but also marine chemists, economists, social scientists, and ecosystem modelers, working both independently and in concert to put together pieces of a large and perplexing puzzle.

Seabird spotting

Our expedition set off in mid-June from Dutch Harbor, Unalaska Island, one of the Aleutian Islands, before crisscrossing the eastern Bering Sea, heading northwest. The bird team, part of the US Fish and Wildlife Service (FWS) Seabird Observer Program, scouts sky and sea while transiting between stations, and when the ship stops, other scientists collect mainly three things: ocean water, seafloor sediment, and marine organisms. Day in and day out, we see nothing but a handful of tiny, scattered islands amid the vast, endless waves.

After leaving, we encounter a tyrannous storm, followed by nonstop fog, so we feel giddy at our good fortune of seeing the short-tailed albatross, a welcome diversion from the common birds—murres, kittiwakes, fulmars—and from general sea ennui. Keeping an eye on the horizon, Hoover and his colleague Sarah Jennings chat with me about seabirds and their work as observers.

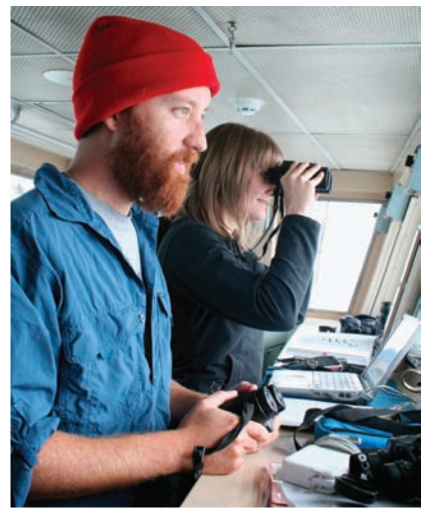
Testament to the rarity of the short-tailed albatross, this is only Hoover's fifth observation of one over the past two years. Kathy Kuletz, a FWS biologist who is the principal investigator for the observer program, has seen only one in her 30 years of seabird surveys. The critically endangered species once numbered more than 5 million but plummeted to fewer than 50 by the 1940s because the birds were clubbed to death for their feathers. They breed on two islands off the coast of Japan and began their slow recovery only after they and their nesting habitat were protected.

Today, short-tailed albatrosses remain vulnerable from long-line fishing. The fish- and squid-eating birds attempt to grab hooked fish bait on the wing, but they often get hooked and eventually drown. Jennings's boss at Washington Sea Grant, Ed Melvin, is a pioneer in designing long-line gear that has substantially reduced albatross bycatch in Alaska. Just four bycatch deaths of the endangered short-tailed albatross within two years causes serious trouble for the $300-million long-line industry—an immediate review of the fishery by NMFS, which some say could temporarily shut down the fishery. Two have already been killed this year, the first since 1998.

Most of what is known about seabirds comes from studies at their breeding colonies, but by placing observers on ships throughout the Bering Sea, biologists can learn where many species feed. "Albatrosses seem to hug the shelf break tightly in every cruise," Hoover tells me. Scientists call this region where Alaska's broad continental shelf drops off to a miles-deep ocean floor the "green belt" because rich algae blooms occur here, fueling the region's immense biological productivity.

Kuletz and colleagues mapped sightings for all three albatross species found here over the past 30 years (black-footed and Laysan albatrosses are not endangered), and most occurred along the shelf break. Albatrosses have not only increased their numbers in the Bering Sea but have also begun foraging farther north during their seasonal forays here. What could be driving this shift?

"Most likely, changes in prey," answers Kuletz. "As the persistence of ice cover changes, prey distribution and abundance will change, thus affecting seabird distribution." Temperature rise causes ice cover to decline in winter, affecting the distribution of seabirds' prey. In the past three years, observers have surveyed more than 70,000 kilometers, documenting more than 300,000 marine birds of 74 species, although just 10 species make up 90 percent of the birds. "Seabirds are excellent indicators of ecosystem health," Kuletz says. By looking at foraging patterns of birds that breed elsewhere, such as albatrosses, as well as birds that nest on islands



Keeping an eye on the horizon, Brian Hoover, from Moss Landing Marine Lab, and Sarah Jennings, of Washington Sea Grant, look for birds in the sky and on the sea as part of their work for the Seabird Observer Program. Photograph: © Wendee Holtcamp.

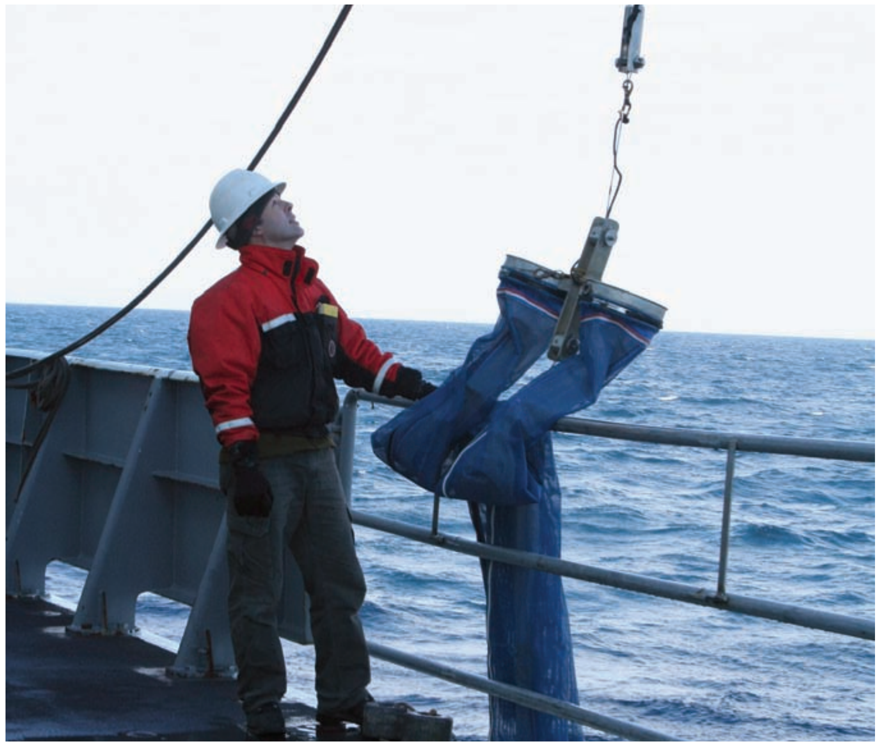
Long-line fishing continues to threaten fish- and squid-eating birds. Short-tailed albatrosses attempt to grab fish bait on the wing but get hooked and eventually drown. Newly designed long-line gear, pioneered by Ed Melvin, of Washington Sea Grant, has substantially reduced albatross bycatch in Alaska. Photograph: Greg Brusseau.

throughout the Bering Sea, she and other Bering Sea Project scientists have begun documenting how changes in ocean temperatures have had domino effects through the food web.

Zooplankton soup

In mid-June, the sea ice had only just melted for the year, leaving behind a "cold pool" as a footprint of the previous winter. The salt in seawater allows it to freeze well below 0 degrees Celsius, and *Deadliest Catch* rightly calls the Bering Sea crab fishery one of the world's most dangerous jobs. We're slightly safer on such a big ship, but no one goes on deck without a bright orange life vest.

I join Russian biologist Alexei Pinchuk on the back deck as he samples zooplankton just after sunset, which comes around midnight this time of year. A marine scientist at the University of Alaska's Seward Marine Center, he has been following changes in the community composition of zooplankton between warm and cold years. I watch as Pinchuk hauls a CalVET net, which resembles a giant pair of pants, over the starboard side of the ship, lowering it down to just above the seafloor with a winch. He hauls it back up, sprays down the paired nets, and washes the creatures inside into containers—zoop soup.



University of Alaska-Fairbanks Seward Marine Center oceanographer Alexei Pinchuk deploys a CalVET net, which resembles a giant pair of pants, over the starboard side of the ship, lowering it to just above the seafloor with a winch. He hauls it back up, sprays down the paired nets, and washes the "zoop soup" inside into containers. Photograph: © Wendee Holtcamp.

Zooplankton may seem uninteresting without a microscope, but when Pinchuk shows me his catch under low magnification, I'm impressed by the "lowly" invertebrates. These are all organisms that drift, unable to propel themselves against currents, and include larval forms of species—fish, octopus, jellyfish, squid—as well as animals that live their whole lives as plankton, such as crustaceous amphipods, copepods, and krill. To the untrained eye, larval cephalopods resemble alien heads, krill look like diminutive shrimp, and amphipods like tiny pill bugs.

Under higher magnification, microplankton, such as diatoms and ciliates, become visible and are interesting to watch. Diane Stoecker, a biology professor at University of Maryland's Center for Environmental Science, conducts grazing studies on board to determine how much algae the microzooplankton eat. She gets excited about mixotrophs, microzooplankton that consume phytoplankton and instead of digesting their chloroplasts use them to photosynthesize. Out of curiosity I ask whether microzooplankton poop, and to my surprise, she finds dinoflagellate poop under the microscope to show me. "Micropoop," she says with a pleased grin.

As we take turns looking through the microscope, Pinchuk talks about changes in the region, some of which he's seen firsthand, having worked in the area since the 1980s. The Bering Sea experienced a "regime shift" in the late 1970s that led to warmer ocean temperatures for the better part of three decades. Pollock numbers surged, but the population moved north, along with snow crabs, walruses, gray whales, and other organisms. The northward shift came with costs: It meant some commercially harvested species were moving into Russian waters, and fishers had to go farther afield from the main fishing port in Dutch Harbor, requiring more fuel. At the same time, endangered Steller sea lion numbers plummeted, and other species' numbers declined as well, including northern fur seals, Pacific cod, and some fish. The years 2001–2005 had the warmest ocean temperatures on record in the Bering Sea.

And then something shifted, some unknown elixir of atmospheric and sea-level pressure, throwing the system into reverse. It's very likely that a swing

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in the Pacific Decadal Oscillation, which can exhibit rapid changes in sea surface temperatures that last for several years in a row, was under way. The warming trend flip-flopped in 2006, with progressively cooler years thereafter. During 2007–2010, the region experienced the four coldest years since recordkeeping began in the 1970s.

Most marine animals have limits to the temperature range in which they can function. They get less oxygen to their tissues when the ambient temperature is too high or too low, and their enzymes do not work properly. To survive, vertebrate species that moved north may have migrated with the temperature shifts in their environment, or they could have followed the zooplankton, since the distributions of most planktonic species are also linked to temperature. For example, Pinchuk discovered that a cold-weather Arctic amphipod has invaded the Bering Sea during the last three years. "They haven't been seen here since the 1970s," he says. These large, fatty invertebrates provide a high-energy food source that seabirds, pollock, and other marine organisms consume. The analyses done in the next two years may yet show what ecosystem-wide impacts these population shifts have had.

Zooplankton are organisms that drift, unable to propel themselves against currents, and include larval forms of many species—octopus (top left), pollock (top right), and squid (bottom left)—as well as animals that live their whole lives as plankton, such as Sea angels which are tiny gastropods (bottom right). Photographs: © Tracy Shaw.

Oscillating control

Changes to one part of the food web inevitably cascade throughout. And that's where the multidisciplinary Bering Sea Project mariners come in, to tackle the climate change puzzle. George Hunt has spent the better part of three decades studying seabirds in the Bering Sea and is, in many ways, the scientific mastermind behind the entire project. "If you talk to my fish colleagues, I'm a bird guy who dabbles in fisheries, but if you talk to my bird colleagues, they'll say I am a fish guy who doesn't do birds anymore," jokes Hunt, now a biology professor at the University of Washington. "I'm curious about how things are connected."

After much deliberation, Hunt and his colleagues came up with an idea that put the whole ecosystem in perspective. The oscillating control hypothesis, the first theoretical framework for the region, was published in 2002. At its core, this food-web theory attempts to predict pollock recruitment, since they are the "money fish," both for their commercial value and because they provide food for marine mammals and seabirds, but it also makes predictions about everything from benthic invertebrates to seabirds. In brief, the theory posits that the food web fluctuates between being regulated by predators, or top-down forces, and food supply, bottom-up regulation. The key is temperature: The timing of ice melt and its associated spring algae bloom affects everything else in the food web.

If the Bering Sea experiences a cold spring, the sea ice melts later, but it results in an early spring algae bloom. Algae thrive in the freshwater layer coming off the melting sea ice. Zooplankton don't rev up their engines as quickly in colder waters, so instead of the abundant algae being eaten, much of it dies and sinks to the ocean floor, with more energy flowing to the creatures there, such as brittle stars, polychaete worms, bivalves, and crabs. (This explains why the farther north one goes in the Bering Sea, the more abundant the benthic fauna is.) A reduced zooplankton population limits growth of "forage fish," small species like young pollock, which limits larger fish and seabirds, the web's apex predators. In the cold system, the pollock population is limited by food supply, allowing plankton-eating seabirds and marine mammals to prosper, freed from competition with larger fish for (albeit limited) zooplankton food.

In warmer years, sea ice melts earlier, when darkness still blankets much of the day. Late winter storms send algae deep undersea, where there isn't enough light. Eventually, the sun warms the sea's uppermost layer, in which algae bloom. Zooplankton prospers during warm years, consuming more algae, and less of the algal biomass sinks to the seafloor. The abundant zooplankton feeds small and medium-sized "forage fish," which in turn leads to a boom in survival and reproduction of top predators, such as larger pollock, Pacific cod, and seabirds. And here is where the oscillations kick in.

After a few warm years in a row, pollock become so abundant that they start to eat their own kind. "If the pollock population builds up and you start to have a lot of top-down impact on the young, that limits recruitment," explains Hunt. An eventual shift to cold conditions would restore the bottom-up control.

Hunt approached the NSF for money to test his hypothesis but didn't get funding. Instead, a year later, the NSF asked him to consider developing a program for the Bering Sea, allowing others to test his hypothesis in a much more comprehensive way than one scientist alone could. Hunt agreed, chairing the science steering committee of what became known as the NSF Bering Ecosystem Study (BEST). He coordinated the development of BEST's science and implementation plans at a series of workshops between 2002 and 2005. In 2007, the NSF merged its program with NPRB's Bering Sea Integrated Research Program. The Bering Sea Project has undergone two rounds of proposals, funding such projects as how benthic invertebrates influence nutrient cycling, which the ship's chief scientist David Shull studies, as well as basic oceanographic surveys by NOAA (National Oceanic and Atmospheric Administration) scientists such as cochief scientist Nancy Kachel. And then there are the zooplankton, seabird, and marine mammal studies, among other projects.

The last few cold years have allowed Hunt, Pinchuk, and others to learn enough about the Bering Sea to revise the oscillating control hypothesis. It turns out that warmer water does not increase population size for all zooplankton, as the hypothesis originally predicted. Ken Coyle at the University of Alaska, Pinchuk, and Jeff Napp, at NOAA, found that in cold conditions, fatty krill, larger copepods, and the invading Arctic amphipods thrived, but they did not do as well in warm conditions, when small copepods abound. But small copepods are not nutritionally satisfying to larger fish and seabirds. Concurrent studies of pollock found the young of the year initially feed on the small copepods, but as they grow they require larger zooplankton, which are scarce in warm water. On top of that, the metabolism

University of Alaska (UA)–Juneau graduate students Wesley Strasburger and undergrad Elizabeth Siddon operate the MOCNESS (multiple opening/closing net and environmental sampling system), a net that captures larger-sized zooplankton than does the CalVET net. After dragging the device, with its nine tapering nets, behind the ship, they spray it down and collect the fish larvae, krill, and other pelagic zooplankton to be identified. Photograph: © Wendee Holtcamp.

of fish cranks up in warm water, and as a result, fish burn so much energy that they are unable to accumulate enough body fat to survive winter, and survival plummets. Two papers revising aspects of the hypothesis are forthcoming.

Climate puzzle

"What makes these collaborative programs particularly valuable are the multiyear and seasonal snapshots," Kuletz says. Principal investigators must share their data publicly so others can use it, and the final two years of the project are primarily for data analysis. Enough data have been collected for decades of discovery. "There will be years of work ahead as we put all our pieces together."

One of the most exciting aspects of the Bering Sea Project is its spatially explicit ecosystem model, FEAST (Forage/Euphausiid Abundance in Space and Time). FEAST uses data collected on krill (euphausiids), physical oceanography, and predators to predict how climate change may affect pollock, cod, flounder, and herring populations; endangered species; and the ecosystem. "The academic community is having a lot of debate these days on whether models like FEAST will one day wholly replace [single-species models]," says Kerim Aydin, a NOAA scientist working on the model. Currently, most fisheries set catch quotas by just looking at one species' population numbers, using what are called single-species stock assessment models. In the Bering Sea, that is changing as the North Pacific Fishery Management Council (NPFMC) embraces a more ecosystem-based management approach.

"In theory, the NPFMC and NOAA are mandated to use 'ecosystem-based management,'" Kuletz says. The Bering Sea fisheries are world renowned, not just for their bounty but also for their sustainability. In stark contrast to elsewhere—Atlantic tuna comes to mind—the council has always set catch quotas at, not above, scientists' recommendations, even when they've had to almost halve it. The 2010 pollock catch quota of 800,000 metric tons was down from 1.3 million just two years ago. "The council, and scientists involved in the process, are struggling to incorporate ecosystem-based approaches into stock assessment and harvest levels," Kuletz says. "It's cutting-edge work and still being developed."

According to NPRB Bering Sea Project manager Tom Van Pelt, ecosystem-level management is definitely a priority. "The Bering Sea Project is very much oriented towards providing the kind of information that will contribute to helping manage fisheries in an ecosystem-type approach." The first step is data collection.

Out on the frigid Bering Sea, the scientists aboard the *RV Thompson* watch the skies, haul nets, and collect water, mud, and critters for weeks before making a beeline for Dutch Harbor in mid-July. It takes a unique set of skills to brave the mariner's lifestyle of close quarters, confined spaces, and the isolation of being at sea. Unusual forms of entertainment arise, such as sending Styrofoam cups two miles undersea, creating a sticky-note haiku wall, painting faces with mud, staging a "Gumby" survival suit contest, and knitting. Yet these scientists, graduate students, and technicians have made science at sea bearable, and ecosystem management in the Bering Sea will be better for it.

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