Understanding Ecosystem Processes in the Bering Sea: First Year Field Highlights from the BEST-BSIERP Partnership

By Michael F. Sigler[1] and H. Rodger Harvey[2]

In 2007, the North Pacific Research Board (NPRB) and the National Science Foundation (NSF) entered into a historic partnership to support a comprehensive $52 million investigation of the eastern Bering Sea ecosystem. This "Bering Sea Project" integrates two research programs, the NSF Bering Ecosystem Study (BEST) and the NPRB Bering Sea Integrated Ecosystem Research Program (BSIERP). Their common goal is to understand how climate change is affecting the Bering Sea ecosystem and the consequences of these changes on lower trophic levels for fish, seabirds, marine mammals, and ultimately people. The BEST-BSIERP Bering Sea Project is a 6-year study of the Bering Sea ecosystem, from the benthos and the atmosphere to human communities, and everything in between. Nearly a hundred principal scientists are linked through a vertically integrated process and modeling program. Field research began in 2007 and reached full speed the following year, with at-sea sampling conducted from February through September 2008. The Bering Sea winter ice cover reached a 30-year high in 2008, and Alaska shivered through a cold and wet spring and summer. In this article, we present a few select observations from the first complete field year and highlight some of the new results.

Three Major Research Themes

The Bering Sea Project consists of three major research themes.

Control of Production in a Changing Environment. Production research examines the timing and duration of seasonal production and what ecosystem components benefit; for example, benthic components versus pelagic. Sea ice covers much of the eastern Bering Sea shelf each winter; the extent of sea ice and the timing of its retreat dominate production effects. The Oscillating Control Hypothesis has suggested how multiyear runs of cold or warm years may switch control of the Bering Sea pelagic ecosystem between "top down" and "bottom up" as production is aligned (or not) with their major euphausiid and zooplankton consumers.

Competition Among Consumers. Competition research examines how major beneficiaries of production compete and how this race influences the short-term (3-5 years) and medium-term (10-30 years) winners. For example, the study tests the predictions that short-term winners (planktivorous fish including juvenile walleye pollock) will eventually be outcompeted by medium-term winners (humpback and fin whales).

Location Matters. Location research examines how climate-driven changes in the spatial distribution of production may affect place-based foragers. For example, murres, kittiwakes, and northern fur seals are central-place foragers that bear and nurture their young on the Pribilof Islands. If their prey is displaced northward due to ocean warming, their reproductive success is expected to falter. Baleen whales depend on concentrated prey that may shift northward with climatic shifts, causing the whales to expend more energy.

Five Principal Hypotheses

The Bering Sea Project addresses a range of research questions which fall under five principal hypotheses.

Physical Forcing Affects Food Availability. Climate-induced changes in physical forcing will modify the availability and partitioning of food for all trophic levels through bottom-up processes.

Ocean Conditions Structure Trophic Relationships. Climate and ocean conditions influencing water temperature, circulation patterns, and domain boundaries impact fish reproduction, survival and distribution, the intensity of predator-prey relationships, and the location of zoogeographic provinces through bottom-up processes.

Ecosystem Controls Are Dynamic. Later spring phytoplankton blooms resulting from early ice retreat will increase zooplankton production, thereby leading to increased abundances of piscivorous fish (walleye pollock, Pacific cod, and arrowtooth flounder) and a community controlled by top-down processes with several trophic consequences.

Location Matters. Climate and ocean conditions influencing circulation patterns and domain boundaries will affect the distribution, frequency, and persistence of fronts and other prey-concentrating features and, thus, the foraging success of marine birds and mammals largely through bottom-up processes.

[1] Alaska Fisheries Science Center, NMFS, NOAA, Juneau, Alaska.
[2] University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, Maryland.

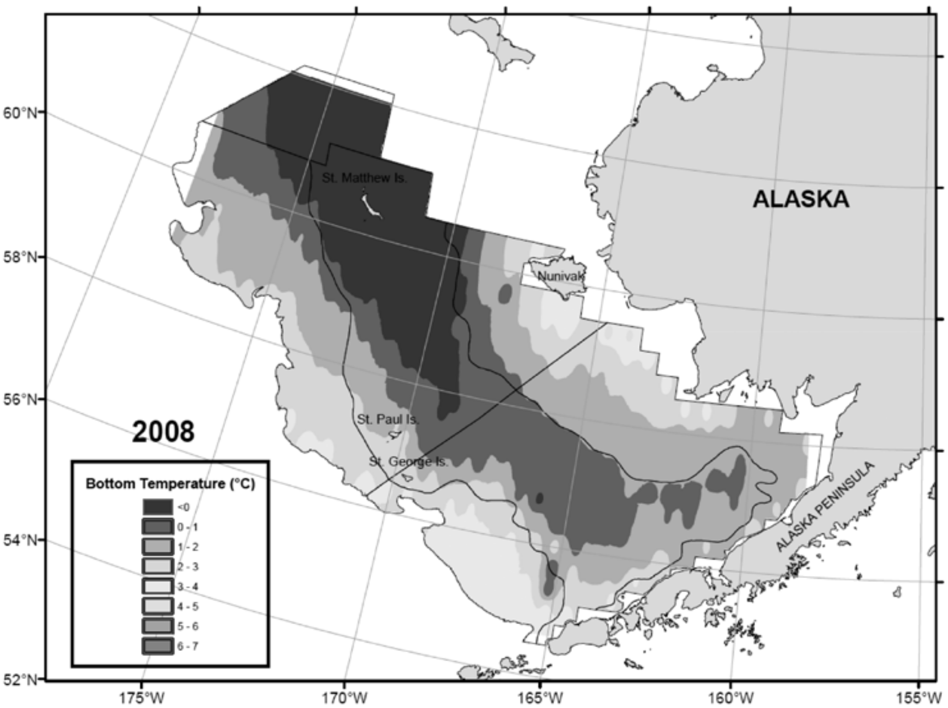

Figure. 1. Bottom temperatures in June and July 2008 measured during the southeast Bering Sea bottom trawl survey.

Commercial And Subsistence Fisheries Reflect Climate. Climate-ocean conditions will change and, thus, affect the abundance and distribution of commercial and subsistence fisheries.

2008 - A First Take

The Bering Sea Project consists of 43 unique studies which are linked together by the five principal hypotheses. As a starting point towards realizing the project's goal of developing an integrated, predictive model encompassing the Bering Sea shelf ecosystem, scientists working in each study phrased their key result for 2008 as a headline to facilitate the identification of connections between study results and to inform ongoing synthesis and modeling efforts. Though still early in the overall project, some obvious connections between individual studies already have emerged. Four examples are reported here, organized by the relevant hypothesis. The full set of headlines is available on the web at bsierp.nprb.org/results/headlines.html.

H1 Physical Forcing Affects Food Availability: Distinct Northern And Southern Bering Sea Eastern Shelf Ecosystems Are Initialized By Seasonal Ice And Maintained By Tides And Cross-Shelf Transport

Observations in 2008 revealed a remarkably cold year with the most extensive and persistent ice over the southern Bering Sea shelf in more than three decades. This resulted in an extensive cold pool of water (<2°C) that covered virtually the entire middle shelf (Fig. 1). Temperatures measured at four biophysical moorings revealed cold temperatures along the 70-m isobath with bottom temperatures (the cold pool) remaining below 2°C through September and surface temperatures remaining below 9.5°C throughout the summer. This cold pool is a principal ocean structure influencing marine processes in the Bering Sea.

While the three cross-shelf domains (coastal, middle, and outer shelves) in the Bering Sea are well known, the north-south transition is poorly understood because of the very limited amount of north-south sampling of the eastern shelf, a distance of approximately 1,000 km, prior to 2005. And while the initialization of the distinct northern and southern ecosystems by seasonal ice cover has been noted previously, the recognition that the north-south structure is strongly modified by a combination of cross-shelf advection and tides has recently arisen based on results from studies during 2007 and 2008.

During summer a transition between the northern and southern shelf ecosystems occurs south of St. Matthew Island (~lat. 60N°) independent of position and timing of maximum ice extent. The northern shelf is characterized by fresher surface water and colder bottom waters. Over the southern shelf there is a very weak, vertical gradient in salinity, while over the northern shelf, salinity and temperature contribute equally to the vertical density gradient. Major food-web pathways differ between the northern and southern Bering Sea eastern shelf. Pelagic species decrease, and infauna and epifauna increase northward in the Bering Sea (Fig. 2), with consequences for how loss of sea ice will affect the dominant biota in each region (pollock and other pelagic predators in the southern Bering Sea and gray whales and other benthic foragers farther north).

These results are based on studies led by Phyllis Stabeno and Calvin Mordy of the Pacific Marine Environmental Laboratory (PMEL), Terry Whitledge of the University of Alaska (UA), Jeff Napp and Bob Lauth of the Alaska Fisheries Science Center (AFSC), and Jackie Grebmeier and Lee Cooper of the University of Maryland (UM).

H2 Ocean Conditions Structure Trophic Relationships: Ice Algae Are Important Food For Copepods And Krill In The Early Spring

Massive blooms of ice algae were observed at all studied Bering Sea locations in March to May 2008. The biomass of sea ice communities was mostly concentrated in the lowermost 2-5 cm of ice floes. Maximum values exceeded 2 mg Chl/l in these bottom layers (Fig. 3) and were thus up to five orders of magnitude higher than water column values. Dominant meiofauna taxa in these layers were rotifers and nematodes. Late April and early May 2008 data showed a substantial increase in the vertical particle flux in sediment traps deployed in 5-20 m depth, likely caused by release of organic material from the melting ice.

Grazing experiments were conducted on the U.S. Coast Guard icebreaker *Healy* using dominant mesozooplankton (copepods and euphausiids) to determine carbon-specific grazing rates on water column phytoplankton, ice algae, and microzooplankton, as well as egg production experiments with reproductively active copepod species. Feeding and reproduction of the copepod *Calanus marshallae*, an important shelf species, were closely tied to food concentration (Fig. 4). Ice algae were an important food

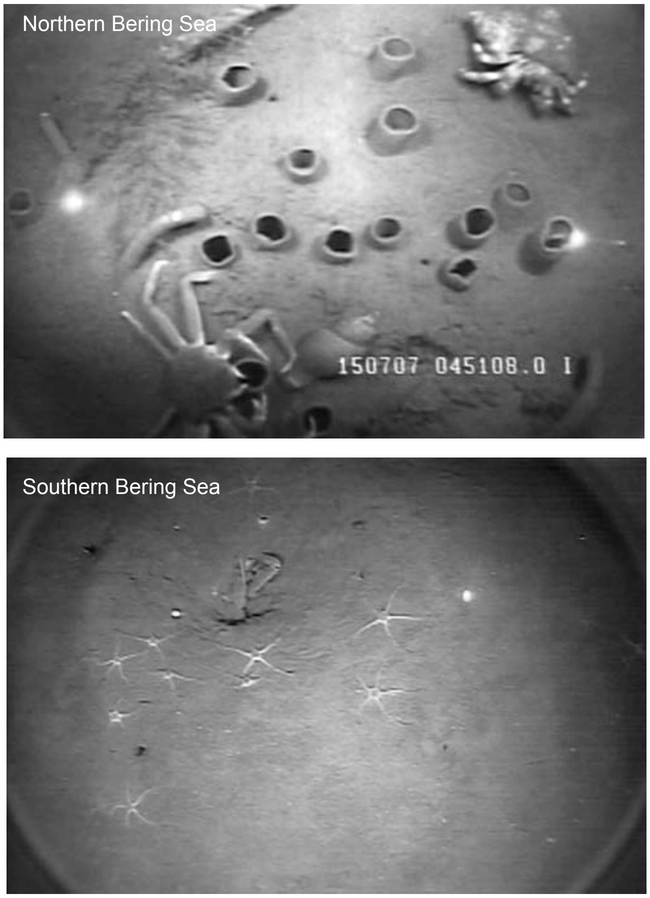

Figure 2. Infauna and epifauna on the eastern Bering Sea shelf.

source for most zooplankton, including krill, and helped to jump-start the reproductive season.

Phytoplankton, ice algae, and microzooplankton were all important food sources for mesozooplankton; however, significant differences in prey preferences were observed between species. Ingestion rates increased with increasing food concentration, with an apparent lower threshold concentration observed for euphausiids but not for copepods. Heterotrophic protists and copepods likely contribute to the summer diets.

These results are based on studies led by Rolf Gradinger, Bodil Bluhm, and Katrin Iken (UA); Bob Campbell of the University of Rhode Island; Carin Ashjian of the Woods Hole Oceanographic Institution; Evelyn Lessard of the University of Washington (UW); Rodger Harvey (UM); and Evelyn and Barry Sherr of Oregon State University (OSU).

H3 Ecosystem Controls Are Dynamic: Prewinter Energy Reserves Are Critical For The Overwinter Survival Of Young Pollock

Recent analyses help us understand why overwinter survival of young walleye pollock was poor during 2001-05. A window of optimum stability for pollock survival may have been exceeded during those summers with unprecedented high temperatures (Fig. 5). Survival of young walleye pollock in the eastern Bering Sea usually is higher during warm years with an early ice retreat, particularly if predator abundance and, hence, predation mortality is also low. Conversely, survival is reduced if the onset of thermal stratification is delayed, suggesting that warm conditions are generally more favorable to pollock survival than cool conditions. However, the recent warm period from 2001 to 2005 produced few age-1 pollock despite abundant age-0 pollock the previous summer and fall. While age-0 pollock were abundant in these warm years, they had low lipid reserves going into winter (Fig. 6) and, therefore, likely suffered high overwintering mortalities. Such low energy densities during those warm years may have resulted from the almost complete lack of large zooplankton species (in particular *Calanus marshallae*, whose copepodites during May of 1995-99 were greatest in years of most southerly ice extent) on the shelf and the predominance of smaller, less desirable prey in pollock diets. Changes in nutrient supply likely reduced primary production in warm years and may have resulted in a shift from large zooplankton, such as *C. marshallae*, to small zooplankton species. Age-0 pollock that had grown to a relatively large size during the spring and early summer were unable to find sufficient large prey to store enough energy for the winter, resulting in poor overwinter survival.

These results are based on studies led by Franz Mueter, Gordon Kruse, and Nicola Hillgruber (UA); Ed Farley, Ron Heintz, Lisa Eisner, Janet Duffy-Anderson, Ann Matarese, Jeff Napp, Chris Wilson, Stan Kotwicki, Alex De Robertis, Patrick Ressler, and Anne Hollowed (AFSC); and Ned Cokelet (PMEL).

H4 Location Matters: In A Year Of Low Pollock Availability, Kittiwakes Flew Long Distances To Feed On Myctophids, And Murres Ate Euphausiids In The Pribilof Canyon

Historical information suggests that kittiwakes and murres forage in a relatively even distribution around the Pribilof Islands and consume pollock as a primary prey. To investigate the current "patch dynamics" of seabird species breeding at the Pribilof Islands, location (GPS) loggers were fitted to Black-legged Kittiwakes and Thick-billed Murres nesting on the Pribilof Islands, and nestling diets were measured. In the surrounding waters, feeding seabirds were collected to determine adult diets, and prey abundance was measured using hydroacoustics combined with midwater trawling.

In 2008, few pollock were consumed by kittiwakes and murres at the Pribilof Islands; instead, concentrations of kittiwakes fed on myctophids off the shelf southwest of the islands, and murres fed on euphausiids around the Pribilof Canyon. At-sea diet collections of Black-legged Kittiwakes revealed that about 90% of the undigested prey in their stomachs was myctophids, in agreement with the unexpected finding from location data that Black-legged Kittiwakes

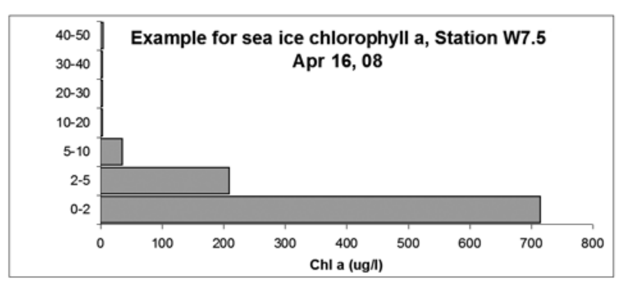

Figure 3. Sea ice algal pigment concentrations. (50 cm to 0 cm, ice-water interface.) Example from Station W7.5, 16 April 2008.

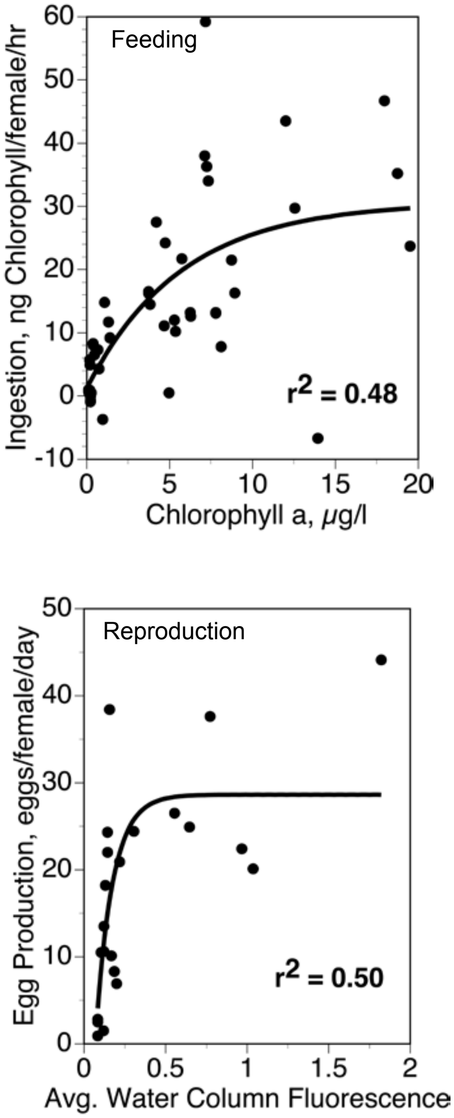

Figure 4. Relationship of copepod (*Calanus marshallae*) feeding and reproduction to food concentration.

foraged relatively far away from the islands over deep water past the shelf break (Fig. 7). While a diet dominated by myctophids is typical for Red-legged Kittiwakes nesting on the Pribilof Islands, it is not typical for Black-legged Kittiwakes, which generally feed more on juvenile pollock, Pacific sand lance, and fish processor offal. The at-sea collections of Thick-billed Murres indicated reliance on a much different forage base; about 90% of the undigested prey was euphausiids. Patches of euphausiids and age-0 pollock were found in acoustic surveys near the Pribilof Islands, but no age-1 pollock was detected.

Combining the at-sea diet data, the location data, the nestling diet data from on colony, and the prey abundance data, an emergent message is that no age-1 pollock were available as prey, nor were age-1 pollock found in the diet of kittiwakes and murres nesting on the Pribilof Islands in 2008. This led to nutritional stress for those piscivorous seabirds attempting to raise young (Fig. 8), fitting the cold-year pattern found in previous cold years of increased nutritional stress in piscivorous seabirds.

These results are based on studies led by David Irons, Kathy Kuletz, Vernon Byrd, and Heather Renner of the U.S. Fish and Wildlife Service (USFWS); Dan Roby, Rosana Paredes, Kelly Benoit-Bird, and Scott Heppell (OSU); Andrew Trites of the University of British Columbia (UBC); and Sasha Kitaysky (UA).

The Alaska Fisheries Science Center's Role in the Project

The AFSC plays an important role in the Bering Sea Project. AFSC scientists in collaboration with other scientists from NOAA and academia lead studies covering oceanography, ichthyoplankton, fish, and marine mammals. NOAA provides in-kind funding for substantial research infrastructure that is integral to the Bering Sea Project, particularly standard AFSC surveys. For example, abundance and condition of pollock cohorts are tracked through time by the AFSC's spring and summer ichthyoplankton surveys, the early fall surface trawl survey, and the following summer acoustic survey. In several cases, this infrastructure is enhanced by funding from the NPRB and NSF. AFSC scientists also provide scientific leadership for the project: Janet Duffy-Anderson serves as Ichthyoplankton Lead Principal Investigator (PI); Nancy Friday serves as Whale Lead PI; Anne Hollowed serves as as Fish Lead PI; and Mike Sigler serves as BSIERP Lead PI and cochair of the BEST-BSIERP Science Advisory Board. In addition, Phyllis Stabeno of PMEL serves as Oceanography Lead PI.

BIOPHYSICAL MOORINGS

Biophysical moorings have been maintained on the southeastern Bering Sea shelf at four sites: M2 (56.9°N, 164.1°W) since 1995; M4 (57.9°N, 168.9°W) since 1996; and M5 (59.9°N, 171.7°W) and M8 (62.2°N 174.7°W) since 2004. The Bering Sea Project will continue these measurements for 3 years (2008-10). The moorings and ancillary observations along the 70-m isobath are core to the long-term observations on the Bering Sea shelf. All four moorings are deployed on the 70-m isobath. Key findings about the regional ecosystem (the Oscillating Control Hypothesis (OCH), timing of spring bloom, and stability in the nutrient supply) have resulted from data collected by these moorings. Data from M2 has quantified the warming that occurred over the southern shelf during 2001-05 and the marked cooling in 2007-08. The project continues the time series of temperature, salinity, fluorescence, currents, nitrate, and oxygen at four mooring sites and zooplankton abundance at M2 and possibly M4 on the Bering Sea shelf. Additionally, during late spring and summer, a surface mooring (two if ice permits) will be deployed to measure meteorological variables (air temperature, humidity, barometric pressure, wind velocity, and solar radiation). The surface moorings provide real-time reporting of selected data. Data from these moorings are also critical to model verification. Products include mixed layer depth, heat content, temperature, position of the transition between southern pelagic-dominated shelf and northern benthic-dominated shelf, advection, nutrient supply, and timing of the spring phytoplankton bloom. The biophysical moorings study is a continuation of a long-term partnership between the AFSC, PMEL, NPRB, and the NOAA program North Pacific Climate Research and Ecosystem Productivity (NPCREP).

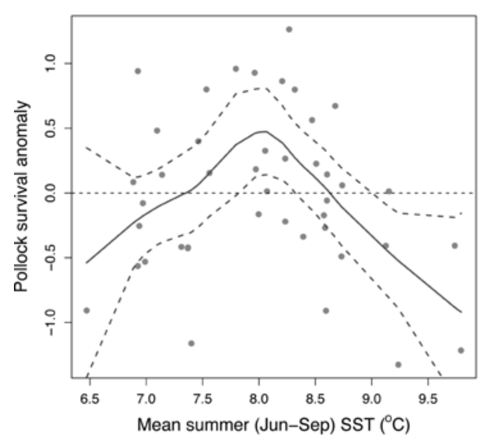

Figure 5. The relationship between pollock survival anomalies and mean summer sea surface temperature (SST) on the eastern Bering Sea shelf as estimated by nonparametric regression with 95% confidence band.

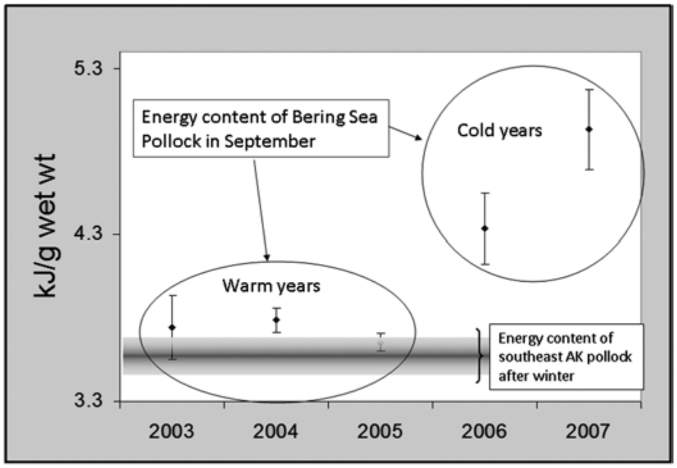

Figure 6. Age-0 pollock energy content in warm years vs. cold years.

The biophysical moorings study is led by Phyllis Stabeno (PMEL), Jeff Napp (AFSC), and Terry Whitledge (UA).

ICHTHYOPLANKTON SURVEYS

The ichthyoplankton surveys study examines seasonal linkages between spring spawning areas, early summer distribution patterns, and late summer/early fall occurrences for three key fish species in the eastern Bering Sea: walleye pollock, Pacific cod, and arrowtooth flounder. Studies will be based on a series of cruises conducted in spring, summer, and fall 2008-10. Biotic and abiotic data from these cruises will provide a better understanding of the potential effects of hydrographic variations on rearing conditions and on transport, dispersal, and distribution of early life stages of these key marine fish species in the eastern Bering Sea. The ichthyoplankton surveys study is led by Janet Duffy-Anderson, Ann Matarese, Jeff Napp, and Lisa Eisner (AFSC) and Nicola Hillgruber (UA).

SEASONAL BIOENERGETICS

The seasonal bioenergetics study will relate the energy phenology of young-of-the-year (YOY) and juvenile pollock, Pacific cod, and arrowtooth flounder to seasonal changes in their distribution and abundance. Fish will be collected seasonally and analyzed to determine their energy, lipid, and protein content. In addition, growth will be monitored by examining their RNA and DNA content. In particular, the seasonal energy content and allocation will be examined for four year classes of pollock and cod and three year classes of age-0 arrowtooth flounder. The latter group will depend on availability to surface and midwater gear. Seasonal changes in energy content will be compared with acoustically determined estimates of abundance to understand the relative importance of energetic bottlenecks in the recruitment of these species. These data will be used to test the hypotheses that energetic demands during metamorphosis limit recruitment of YOY pollock, cod, and arrowtooth flounder. In addition, the hypotheses that energetic demands limit winter survival of pollock and cod will also be tested. Finally, laboratory studies will be performed to understand the relationships between growth and metabolic demand to water temperature. The seasonal bioenergetics study is led by Ron Heintz (AFSC).

ACOUSTIC SURVEY

The AFSC's Resource Assessment and Conservation Engineering (RACE) Division conducts biennial acoustic-trawl surveys to monitor pollock abundance. Normally, AFSC acoustic pollock surveys occur biennially (e.g., 2006, 2008, and 2010). In-kind funding by the AFSC allows an additional survey in 2009. These surveys are an integral part of the Bering Sea Project and provide distribution and abundance information on pollock and euphausiid abundance, characterization of physical oceanography, and a research platform for several other studies. The acoustics survey study is led by Chris Wilson (AFSC).

BOTTOM TRAWL SURVEY

The RACE Division conducts annual bottom (benthic) trawl surveys to monitor the condition of the eastern Bering Sea continental shelf epibenthos. These surveys are an integral part of the Bering Sea Project and provide information on groundfish and shellfish abundance and distribution and oceanographic conditions to other PIs in the Bering Sea Project. The bottom trawl survey study is led by Bob Lauth (AFSC).

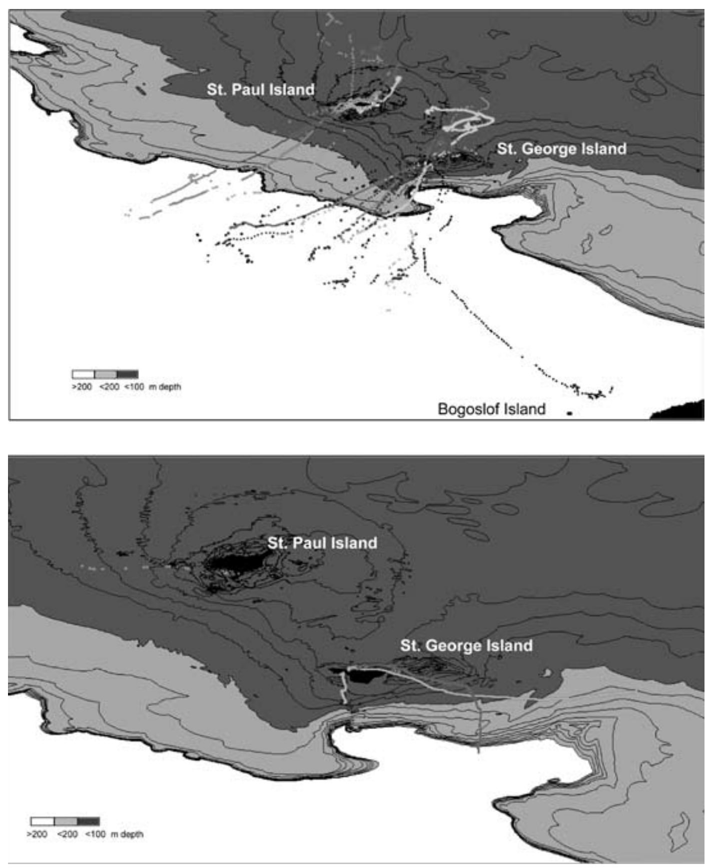

Figure 7. At-sea GPS tracks of chick-rearing Black-legged Kittiwakes at St. Paul (N = 18) and St. George Islands (N = 18) during July 2008 (top). At-sea GPS tracks of chick-rearing Thick-billed Murres at St. Paul (N = 2) and St. George Islands (N = 6) during August 2008 (bottom).

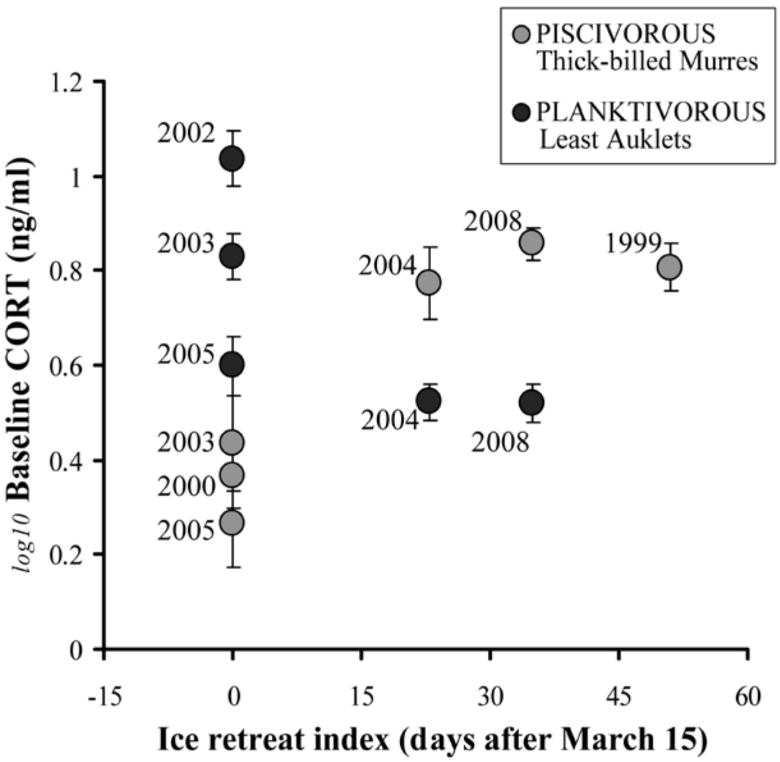

Figure 8. Nutritional stress (as represented by circulating corticosterone values) observed for planktivorous seabirds (Least Auklet, gray circles) and piscivorous seabirds (Thick-billed Murre, black circles) with later ice retreat on St. Paul Island.

SURFACE TRAWL SURVEY

The AFSC's Auke Bay Laboratories conduct annual surface trawl surveys which provide information for commercially important fish species and forage fish species (walleye pollock, Pacific cod, Pacific herring, Pacific sand lance, capelin) to determine their relative abundance, distribution, size, diet, and energetic status prior to winter. These surveys are an integral part of the Bering Sea Project and will provide the information on forage fish species abundance as well as a research platform for other studies. The surface trawl survey study is led by Ed Farley (AFSC).

SURFACE TRAWL SURVEY ACOUSTICS

The surface trawl survey acoustics study extends sampling through the water column by adding an acoustics and midwater trawling component to the surface trawl survey. This study will quantify forage fish (e.g., juvenile pollock, capelin and Pacific herring) distributions on portions of the eastern Bering Sea shelf and examine how oceanography and environment may influence forage fish distribution, abundance, and ultimately affect apex predator distribution and abundance. The surface trawl acoustics study is led by John Horne (UW) and Ed Farley (AFSC).

POLLOCK AND COD DISTRIBUTION

The pollock and cod distribution study combines retrospective analysis of ichthyoplankton distributions with historical wintertime fisheries data to examine the relationship of spawning time and location to fixed and labile landscape and environmental features. These analyses will be used to create species spawning distribution models using nonlinear regression analysis. Field data collections incorporating spatially and temporally referenced maturity data collected by observers, roe quality data collected from the commercial fisheries records, and temperature-at-depth data collected by commercial fishing vessel net sensors will be assimilated in the models. The results of the study will be used to evaluate the alternative hypotheses that 1) there is environmental flexibility in gadid spawning locations versus fixed sites, or 2) there are species or stock-related differences in this spawning strategy. A portion of this study also extends to adult-stage distribution during winter months when walleye pollock spawn. An important question that needs to be answered in order to better understand the potential effects of climate change on pollock populations is whether adult pollock select winter habitat based on location or on oceanographic conditions or both. This study employs nonlinear regression analysis of fisheries-dependent (observer) data in conjunction with satellite-derived oceanographic data to assess differences in pollock biology and distribution between years with contrasting environmental conditions. The pollock and cod distribution study is led by Lorenzo Ciannelli (OSU) and Kevin Bailey (AFSC).

FUNCTIONAL FORAGING RESPONSE

The functional foraging study is aimed at distinguishing between temperature-related and prey density-related responses of juvenile and adult pollock, a nodal species in the eastern Bering Sea food web. Understanding these biological responses will help predict ecosystem responses to projected reduced production, increased overlap between piscivores and forage fishes, and increased abundance of piscivores due to predicted warming of the climate. The specific functional forms and relationships measured between predator and prey will become a critical component of the FEAST model (described below). The functional foraging study is led by Kerim Aydin, Troy Buckley, and Ed Farley (AFSC).

FORAGE FISH DISTRIBUTION AND OCEAN CONDITIONS

The forage fish distribution and ocean conditions study focuses on the importance of considering the effect of ocean forcing on fish and euphausiids at different spatial and temporal scales. The study objective is to understand the response of fish (including forage fish) and euphausiids to shifts in the characteristics of ocean habitat and to use that understanding to model the impacts of climate change on their spatial and temporal distribution. The study focuses on spatial patterns of walleye pollock, euphausiids, myctophids, Pacific cod, arrowtooth flounder, and capelin. The study will simultaneously sample ocean habitat conditions during acoustic midwater trawl surveys and groundfish and shellfish bottom trawl surveys during summer and on commercial fishing vessels during summer and winter in order to understand the relation between pollock, euphausiids, Pacific cod, arrowtooth flounder, myctophid, and capelin distributions and ocean habitat. A major product will be seasonal movement rules for fish that will be used in spatial models of the Bering Sea ecosystem. The forage fish distribution and ocean conditions study is led by Anne Hollowed, Steve Barbeaux, Patrick Ressler, Chris Wilson, and Stan Kotwicki (AFSC) and Phyllis Stabeno and Ned Cokelet (PMEL).

WHALE BROAD-SCALE DISTRIBUTION

The whale broad-scale distribution study will estimate density and abundance of cetaceans in the survey area of the AFSC acoustic survey. The study will model cetacean distribution data and density estimates in terms of oceanographic and bathymetric variables and prey distribution and density to investigate cetacean habitat characteristics and to create predictive models of cetacean distribution. All analyses will focus on fin and humpback whales, but other cetaceans will be included as sample sizes permit. The whale broad-scale distribution study is led by Nancy Friday, Phil Clapham, Sue Moore, and Alex Zerbini (AFSC).

TOP PREDATOR HOT SPOT PERSISTENCE

The top predator hotspot persistence study will quantify the distributions of pelagic forage fish and determine whether apex predators are associated with locations where prey concentrations persisted across years (hot spots). Seabird and cetacean foraging locations from at-sea visual surveys will be analyzed in relation to prey type and abundance data. The top predator hotspot persistence study is led by Mike Sigler, Chris Wilson, and Nancy Friday (AFSC) and Kathy Kuletz (USFWS).

FORAGE/EUPHAUSIID ABUNDANCE IN SPACE AND TIME (FEAST MODEL)

The forage/euphausiid abundance in space and time study will implement a spatially-explicit forage fish/pollock 3-D model based within a physical oceanography model (ROMS), which communicates directly with a biological oceanography model and allows for behaviors such as aggregation at fronts. This approach allows for depletion of primary and secondary production by all higher trophic levels, hence a simultaneous treatment of both top-down and bottom-up effects in the ensemble runs, with euphausiids and pollock as the key interface between controlling mechanisms. The scale for the grid is 10 km and covers the Bering Sea shelf. The FEAST model will have several subcomponents, developed separately, and finally integrated. The components include forage species (spatial distribution of prey fields); Pacific cod/arrrowtooth flounder/salmon (pollock predators modeled within FEAST); birds/mammals (forage fields and forage success); and economics (spatial fishing choice model). The forage/euphausiid abundance in space and time study is led by Kerim Aydin (AFSC) and Andre Punt (UW).

INTEGRATE ECONOMIC AND ECOLOGICAL MODELS OF POLLOCK AND COD

This study integrates economic models of pollock and cod into the ecological model FEAST. The model will help us understand how changing climate-ocean conditions will affect the abundance and distribution of commercial and subsistence fisheries. This study is led by Mike Dalton (AFSC) and Andre Punt (UW).

SPATIALLY EXPLICIT ECONOMIC MODEL OF POLLOCK AND COD

The spatially explicit economic model of pollock and cod study will model how fishing effort is likely to change in the Bering Sea cod and pollock fisheries under changing environmental conditions. These models will be constructed both directly, through the inclusion of spatially-explicit environmental data into existing models, and indirectly, through the inclusion of spatial predictions of fish abundance from FEAST or other BSIERP-related models. This study will allow us to model how field research conducted on the Bering Sea ecosystem will translate into changes in fishing effort. The spatially explicit economic model of pollock and cod study is led by Alan Haynie (AFSC).

MANAGEMENT STRATEGY EVALUATION

The management strategy evaluation study involves using the FEAST model as an "operating model" from which simulated data are generated to test currently developed methods (i.e., single species stock assessments, multispecies statistical model (MSM), and Ecosim). Models from the range currently available for the Bering Sea, including single species-assessments with correlative recruitment indices, multispecies models, and whole ecosystem models will be tested. In addition, autocorrelative biomass dynamics/network models and nonlinear correlative models will be tested as "null" models for determining the added value of the more mechanistic approaches. The study will attempt to evaluate management strategies in an ecosystem context. The metrics for evaluating the success of the two assessment models will be the accuracy and precision of key model outputs such as recruitment and biomass when they are fit to data generated from the operating (FEAST) model. The aim will be to provide information about the skill of each model in determining past and current states as well as the success of each model when predicting future states from current states. When combined with management decision rules, success will be defined as the ability to keep fish populations and yields above a reference point determined from the operating model and the ability to achieve high economic returns. The management strategy evaluation study is led by Jim Ianelli (AFSC) and Andre Punt (UW).

Conclusion

Pollock, Pacific cod, flatfish, Pacific halibut, crab, and Pacific salmon are abundant in the Bering Sea and form a powerful economic engine for fishing communities. Whales, seals and seabirds flock there from afar to feed on these prolific fisheries—some staying year round, others migrating there to feed and mate. Climate change and reduced ice cover could significantly impact the Bering Sea ecosystem. We seek to understand the mechanisms that create and sustain this highly productive ecosystem and how they may be altered over time as our climate changes. The Bering Sea Project provides the most comprehensive investigation of the Bering Sea ecosystem to date. Field research and modeling will continue in 2009 and 2010 and will be followed by analysis and reporting in 2011 and 2012. Ecosystem modeling will link climate, physical oceanography, lower and upper trophic levels, and economic outcomes, and attempt to predict the impacts of climatic change on the Bering Sea ecosystem. This research would not be possible without the efforts of nearly one hundred principal scientists.

The results reported in this article are preliminary, subject to change, and should not be cited without permission of the authors.

Additional Reading

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