NOAA Coastal Ocean Program

Fiscal Year 1999 Implementation Plan

for

SOUTHEAST BERING SEA CARRYING CAPACITY

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Introduction

Background

The Bering Sea ecosystem is among the most productive of high-latitude seas, with large biomasses of fishes, birds and mammals. This productivity is important to the U.S. economy. Fish and shellfish constitute almost 5% of the world and 40% of the U.S. fisheries harvest. Walleye pollock (*Theragra chalcogramma*), salmon, halibut, and crab generate over 2 billion dollars each year in fisheries revenue and provide a major source of protein. At present, some Bering Sea fisheries, such as pollock, appear not to be overexploited, although there have been major changes in abundance over the last thirty years. Populations of several species, such as king crab and Greenland turbot, however, are at near historical lows. The collapse of the New England cod fishery, perhaps due to over-exploitation, has called attention to potential human impacts on the Bering Sea.

The relative importance of natural cycles and exploitation in explaining variability in abundance is a key management issue for the Bering Sea. In addition to perturbations created by human activities, environmental factors are seldom stable and are subject to large-scale fluctuations. For example, the production of new organic matter, which provides the basis for exploitable fish populations and all other higher trophic level animals, is greatly affected by environmental factors. The past three decades were marked by dramatic changes in abundance for many groups of upper-trophic level species. Populations of some piscivorous seabirds, such as murres and kittiwakes, underwent significant declines. Similarly, estimates of Steller sea lions and northern fur seals showed a declining trend, particularly in the 1980s. Biomass of adult pollock decreased during the 1970s, increased in the 1980s, and has approached a median value in the 1990s. These upper-trophic level predators all use juvenile pollock as a food source. We have witnessed unprecedented changes in the Bering Sea ecosystem over the past two years. Rare blooms of coccolithophorid phytoplankton have occurred, and the abundance of jellyfish has risen dramatically. These documented changes in the biological and physical elements of this system have occurred at the same time as financially catastrophic returns of some Bering Sea salmon runs and high mortality of some apex predators. Previous to this, stakeholders, public officials, and research scientists have publicly warned that the Bering Sea ecosystem was showing signs of stress. It is within this context that SEBSCC operates. It is the only currently funded project that is committed to long-term monitoring and analysis of biophysical conditions over a broad range of habitats in the southeastern Bering Sea. As such, SEBSCC's work is invaluable in understanding the mechanisms that are changing the ecosystem. We do not understand the fragility of the present state of the ecosystem. Pollock, however, plays a singularly important role, and its population historically has varied over a wide range.

Southeast Bering Sea Carrying Capacity (SEBSCC) supports studies of the Bering Sea ecosystem with a focus on pollock. SEBSCC developed a conceptual model wherein juvenile pollock are a nodal species in the ecosystem. Juvenile pollock utilize the high primary and secondary productivity and provide food for the pelagic upper trophic level species, including adult pollock. By nodal, we imply that a large fraction of the system energy flow passes through this species population. We focus on pollock in terms of their linkages to other species. We

seek to understand interspecific overlaps in feeding habits through various stages of life history, including energy flow into and out of the pollock population. We identify synchronized increases or decreases in biomass at different trophic levels that may indicate the co-influence of factors. Project researchers study change in distribution and intensity of secondary productivity as a basis for change in year-class strength. The project examines pollock as a key to the large-scale changes in productivity of the Bering Sea over the last three decades. As a presently abundant resource, pollock provides an important measure of the status of the ecosystem.

Build Sustainable Fisheries is the first goal listed in the Strategic Plan of the National Oceanic and Atmospheric Administration (NOAA). SEBSCC meets the requirement of the Advance Fisheries Prediction element of the Strategic Plan. The Bering Sea is a major ecosystem and economic resource where there is large year-to-year variability in pollock recruitment and upper-trophic-level abundance that is not well understood. To advance understanding, SEBSCC uses a proven NOAA-academic-international partnership, effective in providing scientific leadership and delivery of information to management. Information from SEBSCC contributes toward the work of the North Pacific Fishery Management Council (NPFMC) and International Convention on Conservation and Management of Pollock Resources in the Central Bering Sea. Results increase understanding of the response of the pollock population to changes in environmental conditions and allow evaluation of alternate management approaches taking into account such responses. Results from indicial models relating to short-term forecast of pollock recruitment will be incorporated into stock assessments used by the Alaska Fisheries Science Center (AFSC) to recommend allowable biological catch (ABC) estimates to the Council. Other research results involving factors influencing horizontal and vertical distribution of juvenile pollock to upper trophic level predators assist Council decisions regarding restriction of fishing around marine mammal rookery areas. The NPFMC has moved in the direction of ecosystem management, and information provided by SEBSCC expedites this effort by improving knowledge of the role of pollock in the southeastern Bering Sea ecosystem. Focus on the response of the system, and in particular juvenile pollock, to changes in forcing provides a context for management in a changing environment.

Goal

SEBSCC's goal is to increase understanding of the southeastern Bering Sea ecosystem, to document the role of juvenile pollock and factors that affect their survival, and to develop and test annual indices of pre-recruit (age-1) abundance.

Objectives

SEBSCC has both scientific and programmatic objectives that enable attainment of the project goal. Scientific objectives are to

1. investigate influences of climate variability on the Bering Sea ecosystem,
2. determine what limits population growth on the Bering Sea shelf,
3. identify effects of oceanographic conditions on biological distributions, and
4. understand environmental influences on primary and secondary production regimes.

As a schedule to implement objectives, SEBSCC defined two ~2-year research phases or cycles and a final 2-year period of synthesis. Scientific pursuits during phase I followed four approaches -- modeling, monitoring, process-oriented studies and, retrospective analysis -- to

examine biophysical domains, juvenile pollock productivity, and relationships between them and the ecosystem of the southeastern Bering Sea. SEBSCC engages agencies, groups, and investigators with broad ecological interest in the southeast Bering Sea. The team for the first research cycle lasting from 1996 through 1998 investigated the ecology of juvenile pollock and sources and fate of nutrients in the southeastern Bering Sea.

Following review by the Technical Advisory Committee in early 1998, SEBSCC modified its objectives and began to recruit a science team for the second research cycle, 1999-2000. A key challenge for SEBSCC during this phase is to understand how recent physical changes in the eastern Bering Sea affect the food web and food supply to higher trophic level animals. Thus, the focus of SEBSCC in fiscal years 1999 and 2000 is to use synthesis/modeling, monitoring and process studies to determine how such physical changes affect

5. the availability of nutrients on the Bering Sea shelf and
6. the relation of juvenile walleye pollock to top predators.

Programmatic objectives insure that SEBSCC is socially and scientifically responsible and responsive:

7. support a specific goal to provide critical knowledge needed for formulating policy and management of resources of the southeast Bering Sea ecosystem;
8. build partnerships and encourage multidisciplinary cooperative efforts among research scientists within the academic community, NOAA, and other agencies interested in the SE Bering Sea; and
9. provide an open process in establishing research objectives and proposal selection to foster quality and diversity.

To help achieve these objectives SEBSCC maintains scientific communication through monthly principal investigator meetings, Senior Investigators Council meetings, working group meetings, annual science workshops, and the SEBSCC Home Page at http://www.pmel.noaa.gov/sebscc/.

FY 1998 Annual Report

Progress

SEBSCC had four objectives for fiscal year 1998:

1. complete modeling, monitoring, and retrospective studies begun in FY 1996 and process studies begun in FY 1997;
2. prepare for the second research cycle (1999-2000);
3. begin synthesis of ecosystem dynamics;
4. progress in determining index of pre-recruit pollock abundance.

Fifteen research components involving 23 investigators were funded during phase I of SEBSCC. All three modeling components have accomplished significant portions of their research but are not yet complete. Model investigators have submitted plans for completing their work during the coming fiscal year. Of the two monitoring components, one was completed (except for a manuscript) last year, and the other has completed observations through 1998. Analyses are not yet available for 1998, as data from moorings and September cruises have not

all been returned for processing. Most of the six process studies also rely on 1998 data. They have completed observations but have not yet completed their analyses. One of the four retrospective studies, an examination of natural scales of variability using sediments from cores, was unable to locate a suitable southeastern Bering Sea site and has withdrawn. Another study, hoping to find a correlation between lactating fur seal foraging success and historical abundance of pollock, has found a negative result. Many of the components have publications in press or in preparation.

The project began to prepare for phase II research during the first quarter of the year. SEBSCC principal investigators, project managers, technical advisors, and invited Bering Sea experts met for a two-day workshop on December 15-16, 1997 at the Battelle Seattle Conference Center, Seattle, Washington. The workshop featured status reports on 14 research components within SEBSCC's scientific approaches of modeling, monitoring, retrospective analysis, and process studies. Time was allocated after each report for questions and discussion by all attendees. Additionally, senior investigators, project managers, and technical advisors were able to present their impressions of the project, and there was discussion of Future Directions and Field Operations. Project managers and technical advisors met in a closed session on December 16 to discuss tuning SEBSCC to take best advantage of the second research cycle. Suggestions included eliminating the scientific approach called retrospective analysis and creating a new one called synthesis that would include modeling. It was further suggested that SEBSCC seek to supply information needed by modelers of upper-trophic levels and juvenile pollock survival. Based in part on information from these meetings, project managers in February published an announcement of opportunity for phase II research, with proposals due April 30. Twenty-four proposals were received and reviewed by peers and the Technical Advisory Committee. A change in policy within DOC General Counsel has delayed further action toward forming a research team for 1999-2000. COP was informed by DOC General Counsel after the original deadlines for proposals that the announcement had to appear in the Federal Register before any selections were made. COP has drafted the Federal Register notice and circulated it for approval, and the project will move forward with selections as soon as possible under the constraints of the Federal Register notice.

Several components have begun synthesis of results to deduce the state of the ecosystem. Several hypotheses are contained at the end of the next section. At the upcoming SEBSCC PI meeting (October 24, 1998), project scientists will contrast the environment of the Bering Sea shelf and slope from observations made during 1996, 1997, and 1998 to understand the strong interannual variability in the ecosystem. The meeting will also foster discussion on SEBSCC model simulations comparing circulation, its effect on pollock survival, and upper-trophic-level interactions in the southeastern Bering Sea for warm and cold years to determine the influence of interannual variability in the ecosystem, and provide results of SEBSCC biophysical models.

With these hypotheses of ecosystem status come candidates for a pollock survival index. These are mentioned in the next section, and this subject, too, will be explored more fully at the upcoming meeting.

Scientific Accomplishments and Other Outcomes

FY 1998 was of particular interest as it followed the anomalous 1997 season. SEBSCC was the major scientific observer of this anomaly, and results determined from 1997 data are becoming available.

Monitoring

Monitoring demonstrated that the anomalously warm sea surface temperature signal observed in the Bering Sea resulted from regional wind mixing and heat exchange with the atmosphere rather than by propagation of an oceanic anomaly from the equator. As occurred in recent years, an early spring diatom bloom was associated with sea ice. By the end of April 1997, chlorophyll concentrations had decreased to pre-bloom values. During April winds were unusually weak, and these conditions persisted through August. One striking wind mixing event, however, did occur in mid-May. The impact of this storm was to mix the upper 40-45 m, thereby making nutrients from the lower layer available in the upper water column. This reduced the reservoir of nutrients typically found throughout the summer in the lower layer. The storm also weakened the pycnocline, which permitted further depletion of nutrients. This likely occurred through a vertical flux of nutrients across the pycnocline to the surface and net photosynthesis below the mixed layer throughout the summer. An examination of heat content revealed that it was similar to that in the previous year. The heat, however, was concentrated in a shallow mixed layer. The extreme sea surface temperature anomalies appeared to be due primarily to the lack of winds rather than to increased solar radiation resulting from reduced cloud cover. This warm upper layer extended over portions of the coastal domain into waters as shallow as 30 m. In general, the coastal domain waters are mixed. One consequence was that the transition between coastal and middle shelf water was poorly defined and tens of kilometers wider than previously reported. The changes in structure likely affected the usual biophysical dynamics that result in primary and secondary production throughout summer. While biophysical processes likely accounted for much of the nutrient depletion on the shelf, a change in the flux from source waters may have exacerbated this situation. Observations of temperature and salinity versus depth collected along a slope/shelf transect showed that during spring 1997, transport in both the Aleutian North Slope Current and the Bering Slope Current was unusually large. Moored current records from the Aleutian North Slope Current revealed consistent flow, supporting the inference of steady, strong flow. How the enhanced strength of these currents affects shelf/slope exchange is not known. The flux of oceanic water through Bering Canyon is a source of nutrients for the shelf. Satellite tracked drifters revealed that little or no onshelf flow occurred there as well.

To establish a basis for ecosystem observations this year, moorings were deployed at standard SEBSCC sites in the southeastern Bering Sea during February. It was noted that Bering Sea ice had retreated north of mooring 2. Measurements at this mooring showed a cold, fresh water surface layer and warmer, more saline water at the bottom. In spring, four cruises investigated shelf and slope waters during the period April 14 to June 19. The purpose of these cruises was to examine the spring phytoplankton bloom and its associated physical, chemical, and biological oceanographic processes. During the cruises, moorings were recovered and deployed at sites 2, 3, 4, and 6. Scientists conducted biological and physical sampling using net tows and CTD casts at and between mooring sites. Spring conditions were well documented. Inflow into the Bering Sea occurred on the western side of Amchitka Pass, rather than the eastern. A large clockwise eddy that lasted at least 3 to 4 weeks interrupted the Bering Slope Current. Temperatures in the southeastern Bering Sea were warmer than previous years, and there was more storm activity. The level of thermal stratification was less pronounced (the shelf was well mixed to 80m through May) as a result. A recognizable spring phytoplankton bloom had not started by mid May, and by the end of the season, no spring bloom was evident in either the middle or outer shelf domains. Anomalous conditions prevailed again this summer with a second year's coccolithophore bloom over the Bering Sea shelf from Bering Strait to the Pribilof

Islands. Jellyfish were abundant on the outer and middle shelf, but less prevalent in the inner domain. As an indicator of unusual circulation, the NSF Inner Front cruise during June caught offshore euphausiids at the outer ends of their Cape Newenham and Nunivak Island lines. Participants on the July *Oshoro Maru* cruise reported that the distribution of pollock seems low this year relative to the last four years. They also reported the continuation of the coccolithophore bloom north of St. Paul Island. In mid August shelf water was still warm, but by early September storm winds had deepened the mixed layer, and the water was colder than at the same time last year. Sea bird abundance was low, and those sampled were under weight. Birds sampled on the Pribilofs in August were also undersized and there were signs of reproductive failure. The coccolithophore bloom extended from Nunivak Island to the Pribilof Islands and to mooring site 2. Bristol Bay and the coastal regions were not affected. Shelf waters were rich in nutrients, and there were significant zooplankton as opposed to last year when coccolithophores dominated. During mid September the bloom was still prevalent, and project scientists sampled on either side of a front separating typical Bering Sea water from bloom water. The front was located north of St. George Island.

Process studies

SEBSCC's process studies have shed light on conditions leading to pollock hatching and the sequential blooms of phytoplankton and zooplankton that form the basis for the food web. Pollock egg development studies showed that Bering Sea eggs develop faster at low water temperatures than do Gulf of Alaska eggs, but Bering Sea eggs are found higher in the water column. Thus Bering Sea pollock eggs are more vulnerable to wind-driven advection but, because of their shorter development time, are less prone to predation. Sediment trap samples provided a history of lower-trophic conditions for pollock from April 1997 through February 1998. Spring samples were abundant in diatoms. By early summer sediments were primarily zooplankton. There was a secondary diatom bloom in mid to late summer that was recorded by the traps. However, coccolithophores did not appear in samples until late September. Then, the large numbers of coccoliths sampled by the traps, suggests that there was little grazing of the vast coccolithophore summer bloom. By winter, the traps were collecting resuspended sediments from storm mixing or nothing at all. It is interesting that during the fall, sediment traps collected a quantity of organic matter that was comparable in magnitude to that collected during spring. Because only 1997 data are available, it is not clear whether the fall maximum was linked to the unusual coccolithophorid bloom, or whether fall conditions result in substantial sinking particulate material in more normal years as well.

Retrospective studies

Retrospective studies determined that interannual variations in the wintertime atmospheric forcing are considerable. These variations are well correlated with the duration of sea ice, and in particular, the southernmost extent of sea ice. Interannual variations in the latter have correlation coefficients of 0.64 and 0.72 with the winter-average net surface heat fluxes and meridional wind stresses, respectively. Striking interannual variations have also been documented in the atmospheric forcing during the spring and summer. Interannual variations in sea surface temperature tendency during May through July are correlated about equally with the net surface heat fluxes (largely due to variations in low cloud cover) and a combination of wind mixing and Ekman pumping. The latter are important because of their impacts on the depth of the mixed layer. Based on the net heat fluxes at the surface, and the fraction of these fluxes that go towards

heating the mixed layer, estimates have been made in the rate of heating below the pycnocline. The years with a persistent cold pool (e.g., the early 1970s, 1995) typically had about 30 W m-2 less heating below the mixed layer than those without a cold pool. This result indicates the importance of the dynamics of the mixed layer and pycnocline for establishing the stratification that can insulate the cold pool from the summer heating.

The seasonal sea ice index was updated through 1997 and 1998. Sea ice extended across the shelf beyond 57° 30'. The unusual occurrence of a coccolithophore bloom during 1997 led to further analysis of sea ice characteristics that may help us understand the physical conditions that exist during, and preceding, such an unusual bloom. We found that in spring, sea ice retreated 2.5 degrees of latitude within one week. Sea ice retreat of at least 2.5 degrees in one week has occurred 10 times in the previous 26 years, but never before coupled with the late timing of May 22. In 1998 we are again observing a large coccolithophore bloom on the shelf, and again this spring we witnessed a rapid retreat of ice of 3 degrees latitude. However, the timing was earlier, falling within the average time of mid-April. Perhaps the previous years bloom influenced the dominance of coccolithophores on the shelf.

Modeling and synthesis

SEBSCC modeling advanced during 1998. One application is an eddy-resolving circulation model of the southeastern Bering Sea. This model is intended for use as input to a suite of biological models focusing on walleye pollock and higher trophic levels. Much of the research during 1998 focused on the implementation of a free-surface, primitive equation, eddy-resolving model at 4-kilometer resolution with both tidal and subtidal forcing. Presently, the model reproduces the observed tidal residual circulation around the Pribilof Islands, while replicating the Aleutian North Slope Current, the Bering Slope Current, and the shallow inflow through Unimak Pass. SEBSCC's spatial model of upper-trophic level interactions has completely parameterized a multispecies virtual population analysis (MSVPA) model. It characterizes the predation interactions between major groundfish populations and one marine mammal predator, northern fur seal, in the eastern Bering Sea for the time period 1979-1995. This model will provide starting values of juvenile walleye pollock abundance and estimates of prey suitability for the full spatial model.

The project has begun to synthesize information. One hypothesis thus far reasonably well supported is that oceanographic conditions are controlled by climate/weather fluctuations. During winters with a strong and eastward displaced Aleutian low (most often accompanying an El Niño), the Bering Sea shelf is warm and the cold pool is small. During winters with a weak and westward-displaced Aleutian low (most often accompanying La Niña), the Bering Sea shelf is cool and the cold pool is large. However, a climate-driven physical regime shift occurred on the Bering Sea shelf in the mid to late 1970s. Since the regime shift, El Niño-driven Aleutian lows have moved so far to the east that winds actually come off Alaska and cause the Bering Sea ice to advance as in 1998. The regime shift in the physical environment was largely responsible for the changes in fish populations on the Bering Sea shelf that occurred in the mid-late 1970s. The physical conditions occurring after the regime shift have persisted to some extent, but the biological response was short lived. Only one pollock year class was strongly affected, but that year class supported the pollock fishery for years.

A second, but less tested, hypothesis is that oceanographic conditions, particularly temperatures, limit the growth of some populations. In cold years with an extensive cold pool, pollock are forced off the shelf on to the outer shelf. Pollock recruitment is reduced because of

lower egg hatch, and concentration of adult pollock result in increased cannibalism. In warm years with a small cold pool, pollock recruitment is enhanced because of higher egg hatch, and the dispersal of pollock results in decreased cannibalism. Within a year or so, the population catches up so that cannibalism balances egg hatch. This may have been the mechanism that caused the pollock fluctuations over the regime shift.

One hypothesis has been refuted. Because lactating northern fur seals prey primarily on pollock, it was thought that an indication of foraging success as determined from fur seal teeth would correlate with observed pollock abundance. SEBSCC research does not show a strong direct link.

We have identified several more features of the ecosystem that are candidate indices of status of the Bering Sea. Among these are:

1. extent of ice and its influence on the timing of the phytoplankton bloom and hence the succession of bottom-up mechanisms that must match in time and space the needs of first feeding pollock larvae,
2. wind which influences the ecosystem through mixing (mixed layer depth was markedly shallow in summer 1997) and by advection as direct wind-driven flow. The latter may increase the separation between early life history stages and their cannibalistic parents, since recent evidence suggests that many larvae over the shelf may be in water depths less than 10 m. The timing of storms also play a role in the intensity of stratification over the middle shelf and the depletion of nutrients in the cold pool.
3. concentration of nutrients retained in the bottom layer of the middle shelf (essential for prolonged production at the inner front),
4. species composition of phytoplankton (e.g., rare coccolithophorid blooms),
5. location, strength and stability (eddies) of the Aleutian North Slope Current and Bering Slope Current system that affects advection of nutrients and pollock larvae onto the shelf, and
6. increased presence of previously low abundance biota (e.g., jellyfish and coccolithophores).

Applications from Funded Projects

Products developed

SEBSCC has refined the ability to discern various types of plankton from acoustic scattering data. An existing plankton identification algorithm was modified for 120 kHz and 38 kHz data. New analytical comparisons of acoustic images to bent cylinders and elongated spheres allow identification of euphausiids and copepods.

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Worldwide Web presentations

SEBSCC has published information on the Worldwide Web through the SEBSCC Home Page located at URL http://www.pmel.noaa/sebscc/. Research updates, notices of meetings, a publication list, personnel rosters, and addresses of related web sites are included in SEBSCC's offering.

Besides programmatic news, SEBSCC has underwritten development of a Bering Sea and North Pacific Ocean Theme Page at http://www.pmel.noaa.gov/bering/. This theme page serves as a common source for research activities pertaining to the Bering Sea and North Pacific Ocean. It supports multiple program interests based on the physical, chemical, biological and fisheries oceanography of this unique geographic area. This resource is intended to serve as a reference for the numerous programs and investigators working in this area.

Also developed for SEBSCC and other researchers is the Bering Sea Biophysical Metadatabase (http://www.pmel.noaa.gov/bering/mdb/), an on-line tool to locate data holdings that pertain to SEBSCC's interests.

Collaborations

SEBSCC is a unique administrative partnership between a state university and two federal agencies. These partners are the University of Alaska Fairbanks, the AFSC of the National Marine Fisheries Service (NMFS), and the Pacific Marine Environmental Laboratory (PMEL) of the Office of Oceanic and Atmospheric Research (OAR). SEBSCC's research team blends the talents of scientists from five universities -- University of Alaska Fairbanks, University of California Irvine, University of Washington, Rutgers University, University of Texas at Austin -- and two federal agencies (NMFS, OAR).

National collaboration is attained through cooperative research with other NOAA Bering Sea programs -- NMFS Bering Sea stock assessment, Fisheries-Oceanography Coordinated Investigations (FOCI), and Arctic Research Initiative (ARI) -- and with the NSF's Inner Front Study. Two cruises aboard the UNOLS vessel *Alpha Helix* addressed common objectives of SEBSCC and NSF Inner Front. International collaboration with Japanese and Korean scientists established under NOAA Coastal Ocean Program's Bering Sea FOCI are continuing with SEBSCC. Project scientists took part in a research cruise aboard the Japanese fishery research vessel *Oshoro Maru* from July 18 to August 1.

SEBSCC is participating in development of an interagency plan to research the Bering Sea ecosystem. A consortium of organizations and institutions has assembled under the leadership of NOAA, Alaska Department of Fish and Game, and the Department of the Interior to promote research coordination and data sharing. SEBSCC scientists assumed a role of leadership in drafting a science plan for research on the Bering Sea ecosystem. The interagency Organizing

Committee has adopted the Bering Sea and North Pacific Ocean Theme Page as the Internet vehicle for sharing of plans and information. The Bering Sea Biophysical Metadatabase was selected as the interagency database.

FY 1999 Implementation Plan

Background

The Bering Sea remains one of our country's most valuable marine areas. Pollock, salmon, halibut, and crab generate over 2 billion dollars a year in fisheries revenue and provide a major source of protein. The overwhelming dominance of pollock in the Bering Sea suggests that this species currently plays a singularly important role in this ecosystem. We do not understand the factors controlling the stability of the Bering Sea ecosystem, and there are several indications of ongoing change that cause concern. The anomalous conditions observed during the summer and fall of 1997 and 1998 indicate how quickly the ecosystem can change in response to forcing.

SEBSCC postulates that a large fraction of the Bering Sea ecosystem energy passes through the pollock population. Juvenile pollock respond to and potentially affect primary and secondary production through grazing. They also influence the availability of food for upper trophic level species, including adult pollock, seabirds and marine mammals. Pollock provide an important measure of the condition of the present ecosystem, and may be an indicator of changes in the Bering Sea over the last three decades and in the future. The SEBSCC program is designed to improve our understanding of the Bering Sea ecosystem; the results of this endeavor will directly assist fishery and resource managers.

SEBSCC has amassed two full seasons of observations on the ecosystem of the southeastern Bering Sea. In order to address questions of pollock survival and their role in the ecosystem, we have observed processes and conducted retrospective studies. These already have enabled development of hypotheses and suggestions of candidates for a pollock survival index. For the next two years of the project, we will extend our understanding of interannual variability by continuing monitoring and process studies, and synthesizing information from these studies in the context of a potential shift in the ecology of the Bering Sea.

Objectives

Complete and synthesize phase I research

Because of the duration of the field season, the need to transfer results to other components, and lags in modeling progress, some phase I research is not yet complete. Investigators are committed to completing their tasks and have submitted revised schedules. A significant step in synthesizing phase I research will take place at the October 1998 Principal Investigators meeting. Three topics form the basis for the meeting. The first is interannual variability in the ecosystem from the contrasting environments observed during 1998, 1997, 1996, and before. The second is the influence of interannual variability in the ecosystem from observations, retrospective studies and model simulations comparing circulation, its effect on pollock survival and upper trophic level interactions in the southeastern Bering Sea during warm and cold years. The third topic is environmental factors that are candidates for inclusion in an index of juvenile pollock survival.

Fisheries-Oceanography Coordinated Investigations (FOCI), a NOAA program conducting Bering Sea research with SEBSCC, is hosting an International Workshop on Recent Conditions in the Bering Sea. Participants (many from SEBSCC) in this workshop will share observations

of anomalous conditions, integrate this information, suggest causal mechanisms, and discuss implications for the future of the ecosystem.

Begin phase II research

During the first quarter of the year, SEBSCC managers and technical advisors will help COP select the research team for the second research cycle. For phase II research, SEBSCC has two objectives. The first is to examine how changes in on-shelf transport of nutrients impact pelagic food webs. This includes determination of how timing, duration, magnitude and species composition of primary, secondary, and forage fish production affect food availability for higher trophic levels. The second objective is to determine how climate variability influences the spatial overlap of pollock of different life stages, and how the availability of juvenile pollock to predators affects pollock survival rate. Although the team of researchers has not yet been selected to address these objectives, project management has determined the approach to be used.

Approach

SEBSCC phase II uses three scientific approaches to achieve its objectives. The first is monitoring. Monitoring includes broad-scale studies such as shipboard surveys, multi-disciplinary mooring observations, drifters and analysis of regional satellite data. Shipboard studies help to determine the distribution and abundance of target organisms in relation to their physical environment. The aim of broad-scale studies is to provide the basis for interannual comparison of the population processes and their coupling to the physical structure and variability of the environment. The second approach is the study of specific processes. Process studies are nested within the broad-scale observations to investigate biological, physical, and biophysical actions that contribute to understanding of ecosystem interactions. They also provide information necessary to develop and parameterize biophysical models. The final approach is synthesis: Synthesis begins to assemble results generated by the project and historical data to investigate the biological, physical, and geographical structure of food webs and the influence of climatic variation. Synthesis includes development of theoretical, statistical, and numerical models.

Milestones for FY 1999 (with the fiscal year's quarter after which they are projected to be completed) are

1. Convene annual SEBSCC Principal Investigators meeting (Q1).
2. Complete assembly of phase II research team (Q1).
3. Complete SEBSCC mooring deployment cruise (Q2).
4. Complete SEBSCC cruises to monitor the biophysical environment associated with the spring bloom of phytoplankton (Q3).
5. Complete SEBSCC report on Phase I research that includes descriptions of a coupled, 3-D circulation and individual-based model, and a spatial model of upper trophic interactions (Q4).
6. Complete two SEBSCC cruises to monitor the ecosystem associated with age-0 pollock of the Pribilof Islands habitat and to recover and deploy moorings (Q4).
7. Contrast 1999 environmental conditions with previous years to further develop age-0 pollock survival index (Q4).

Proposed Budget

Presently the research team for FY 1999-2000 is unknown. Based on preliminary information, project management projects a tentative FY 1999 budget of ~$1,030K. Unused FY 1998 funds totaling ~$7K are included. It is anticipated that the FY 2000 budget will be ~$977K, bringing the two-year total to $2,007K.

The FY 1999 budget is divided into two parts: research and management. Research contracts (~$985K) support the first year of phase II research in synthesis, monitoring, and process-oriented studies of lower and upper trophic levels. Project management ($45K) will provide for PMT activities, a principal investigators' meeting, a council meeting, communications (including WWW development), and additional support for selection of round-two proposals. The following table shows a tentative SEBSCC budget for FY 1999.

SEBSCC FY 1999 Tentative Budget

Research		*~$985K*
Synthesis	~$150K	
Monitoring	~$350K	
Lower-trophic studies	~$205K	
Upper-trophic studies	~$280K	
Project Management		*$45K*
PI Meeting	$15K	
TAC Meeting	$10K	
Communications	$15K	
Research Council	$5K	
TOTAL		*~$1,030K*

Outlook

Annual Steps

Over its six-year lifetime, SEBSCC provides information to help assess resources of the Bering Sea in an ecosystem context. Two research cycles (the first lasting two and a quarter years, the second lasting two years) and a final 2-year period for component completion, synthesis, and survival index validation comprise SEBSCC's schedule. Throughout the duration of the project, an ecosystem focus will be the role of juvenile pollock in the Bering Sea, both as a consumer of energy from the bottom of the food chain and as a source of food to apex predators and other pollock. One goal is to develop an index of juvenile pollock abundance based on measurable ecosystem characteristics documented by retrospective and process studies and by data from biophysical platforms and annual spring through fall cruises. Steps to develop the

index are data collection, exploratory hypothesis testing, and development and testing of the index. In the final field year, 2001, cruises and moorings will be used to validate the index.

First research cycle products included a regional model of southeastern Bering Sea circulation with output to an individual-based model of pollock, and a spatial model of upper-trophic level interactions in the eastern Bering Sea. Satellite altimetry analysis contributed a census of eddy-like features. The drifter component has shed light on the dynamics responsible for eddy generation, evolution and influence on exchange of properties and material between the Bering Sea basin and shelf. Effects of local enhancement of primary productivity on higher trophic levels are better understood. SEBSCC has examined development of pollock eggs at water temperatures spanning the expected range. Results from this study are helping to tune the individual-based model of pollock and aiding understanding of temporal and spatial synchrony in the ecosystem. Moreover, phase I results are being synthesized, and from this synthesis the project is progressing with development of the survival index.

Phase II research continues the important monitoring that has made SEBSCC such a visible project in the Bering Sea and augments our knowledge of interannual variability. Process studies will refine ecosystem understanding and provide important rates to biophysical models. Synthesis and modeling will integrate the knowledge acquired by the project with existing information.

The final two years of the project (2001-2002) are used for research completion and synthesis. Participation will be through invited submission of work statements.

The SEBSCC budget stipulated initial year (FY 1996) funds of $0.5M and level funding of $1.0M from 1997 through 2000. In 2001, to include minimal field operations, project funding will ramp down to $0.7M, followed by $0.3M in 2002 for final synthesis. Inflation provides an additional downward financial ramp over the life of the project. We exploit that ramp by procuring capital equipment for monitoring at the start of the project, then shift to process studies, leading to synthesis, evaluation and validation, and information dissemination. The following timeline presents a schedule of major program elements for the duration of SEBSCC.

SEBSCC Timetable of Major Program Elements

	FISCAL YEAR						
	96	97	98	99	00	01	02
Workshop	*	*	*	*	*	*	*
Proposal Cycle	*		*		*		
Hypothesis Testing		I ---------- I					
Develop Survival Index			I---------- I				
Validate Survival Index						I---------- I	
Synthesis				I ---------- >			
Measurement Program							
Mooring Cruises	*	*	*	*	*	*	*
Ecology Cruises	*	*	*	*	*	*	*

Collaborative Planning

SEBSCC is a highly leveraged program. It is cooperative with other Bering Sea ecosystem programs such as Fisheries-Oceanography Coordinated Investigations (FOCI), Arctic Research Initiative and NSF Inner Fronts Study.. It works collaboratively with NMFS programs examining pollock resources and ecology of the Bering Sea. These include fishery acoustics, fish stock assessment, and marine mammal assessment. SEBSCC also collaborates with programs at the University and State of Alaska, EPA, Japan Far Seas Fisheries Laboratory, Ocean Research Institute of Tokyo University, Faculty of Fisheries, Hokkaido University, the Japanese Marine Science and Technology Center, Tokai University in Sapporo, Tohoku National Fisheries Institute, Korean Ocean Research and Development Institute and the Institute of Marine Biology, Far East Branch of the Russian Academy of Sciences. We also coordinate with inhabitants of St. Paul Island. Marine mammalogists from the AFSC, ornithologists from the University of California-Irvine, and bioacousticians from the Southwest Fisheries Science Center and Scripps Institute of Oceanography collaborate on ecosystem studies as begun by a sister project, Bering Sea FOCI, and continued by SEBSCC. Japanese and SEBSCC researchers coordinate Japanese summer cruises in the eastern Bering Sea. When combined with NOAA cruises, these allow several larval cohorts to be followed through their period of maximum mortality. There is ongoing University of Alaska Fairbanks and Hokkaido University collaboration on climate change and Bering Sea productivity. Japanese researchers (JAMSTEC) also are cooperating with University of Alaska scientists in research on the northern Bering Sea and Chukchi Seas in consort with Russian participants, and are providing financial support for

ship time. SEBSCC is considered a component of the PICES-GLOBEC Climate Change and Carrying Capacity (CCCC) Program.

Projected Resource Issues

For FY 1999, SEBSCC will use an as-yet-undetermined vessel for February mooring work. The NOAA Ship *Miller Freeman* is anticipated to complete repairs in order to provide SEBSCC support during April and September. The UNOLS Ship *Wecoma* will provide support during May and June. There will be no SEBSCC cruises during July, although a few scientists may be invited to join the *Oshoro Maru*. Cruises need to coincide with ecosystem events such as the spring bloom and with larval and juvenile life stages of pollock.

Appendix 1. SEBSCC investigators funded during FY 1998

Investigator	Institution	Project title	FY98 award ($K)	Total award ($K)	End
Hinckley, Sarah, and Megrey, Bern	NOAA/AFSC	Individual-based modeling of walleye pollock in the southeast Bering Sea			1998
Hermann, Al	University of Washington				1998
Livingston, Pat and Hinckley, Sarah	NOAA/AFSC	A spatial model of upper-trophic level interactions in the Bering Sea			1998
Hermann, Al	University of Washington	Circulation modeling for the SE Bering Sea			1998
Stabeno, Phyllis	NOAA/PMEL				1998
Haidvogel, Dale	Rutgers University				1998
Musgrave, David	University of Alaska Fairbanks				1998
Schumacher, Jim and Stabeno, Phyllis	NOAA/PMEL	Monitoring and development of biophysical indices of the southeastern Bering Sea			1998
Brodeur, Ric and Napp, Jeff	NOAA/AFSC				1998
Hunt, George	University of California Irvine				1998
Cullen, John and Davis, Richard	Dalhousie Univ. (contract)				1998
Whitledge, Terry	University of Texas at Austin	Investigation of the origin and dynamics of nutrients on the southeast Bering Sea shelf in relation to dominant physical and biological processes			1998

Investigator	Institution	Project title	FY98 ($K)	Total ($K)	End
Henrichs, Susan	University of Alaska Fairbanks	Isotopic and biomarker composition of sinking organic matter in the southeast Bering Sea: indicators of food web structure			1998
Stabeno, Phyllis	NOAA/PMEL	Using optical measurements to explore the influence of mesoscale eddies on the interaction of lower and higher trophic levels in the southeast Bering Sea			1998
Swartzman, Gordie	University of Washington	High-resolution acoustic and juvenile pollock retrospective data analysis			1998
Brodeur, Ric	NOAA/AFSC				1998
Brodeur, Ric and Napp, Jeff	NOAA/AFSC	Habitat differences in frontal regions around the Pribilof Islands and their importance to juvenile pollock growth and survival in the Bering Sea			1998
Doyle, Miriam	University of Washington				1998
Francis, Robert	University of Washington				1998
Blood, Debbie	NOAA/AFSC	Low-temperature incubation of walleye pollock eggs from the southeast Bering Sea region			1998
Francis, Bob	University of Washington	Natural scales of variability in coastal marine ecosystems of the eastern Bering Sea			1998
Loughlin, Tom	NOAA/AFSC	Historical trends in the number of foraging trips made by lactating northern fur seals			1998
Niebauer, Joe	University of Alaska Fairbanks	The role of atmospheric forcing on the “cold pool” and ecosystem dynamics the Bering Sea shelf: a retrospective study			1998
Bond, Nick and Wyllie-Echeverria, Tina	University of Washington				1998

Investigator	Institution	Project title	FY98 ($K)	Total ($K)	End
Megrey, Bern and Wespestad, Vidar	NOAA/AFSC	A retrospective investigation into relationships between southeast Bering Sea pollock recruitment and biophysical correlates			1998

* funds returned to COP for FY 1999 SEBSCC spending

Summary by category	$K
Federal research funds	421.5
Academic research funds**	475.5
Federal administrative funds	44.8
TOTAL	941.8

** excluding funds returned to COP for FY 1999 SEBSCC spending

Appendix 2. Personnel

Project Management Team

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Appendix 3. Summary of recommendations from Project Management Team and Technical Advisory Committee deliberations

During the year, project managers and technical advisors decided that a key challenge for SEBSCC during phase II is to understand how recent physical changes in the eastern Bering Sea affect the food web and food supply to higher trophic level animals. Thus, the focus of SEBSCC in fiscal years 1999 and 2000 is to use synthesis/modeling, monitoring and process studies to determine how such physical changes affect the availability of nutrients on the Bering Sea shelf and the relation of juvenile walleye pollock to top predators.