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Implementation Plan for Loss of Sea Ice (LOSI) Program

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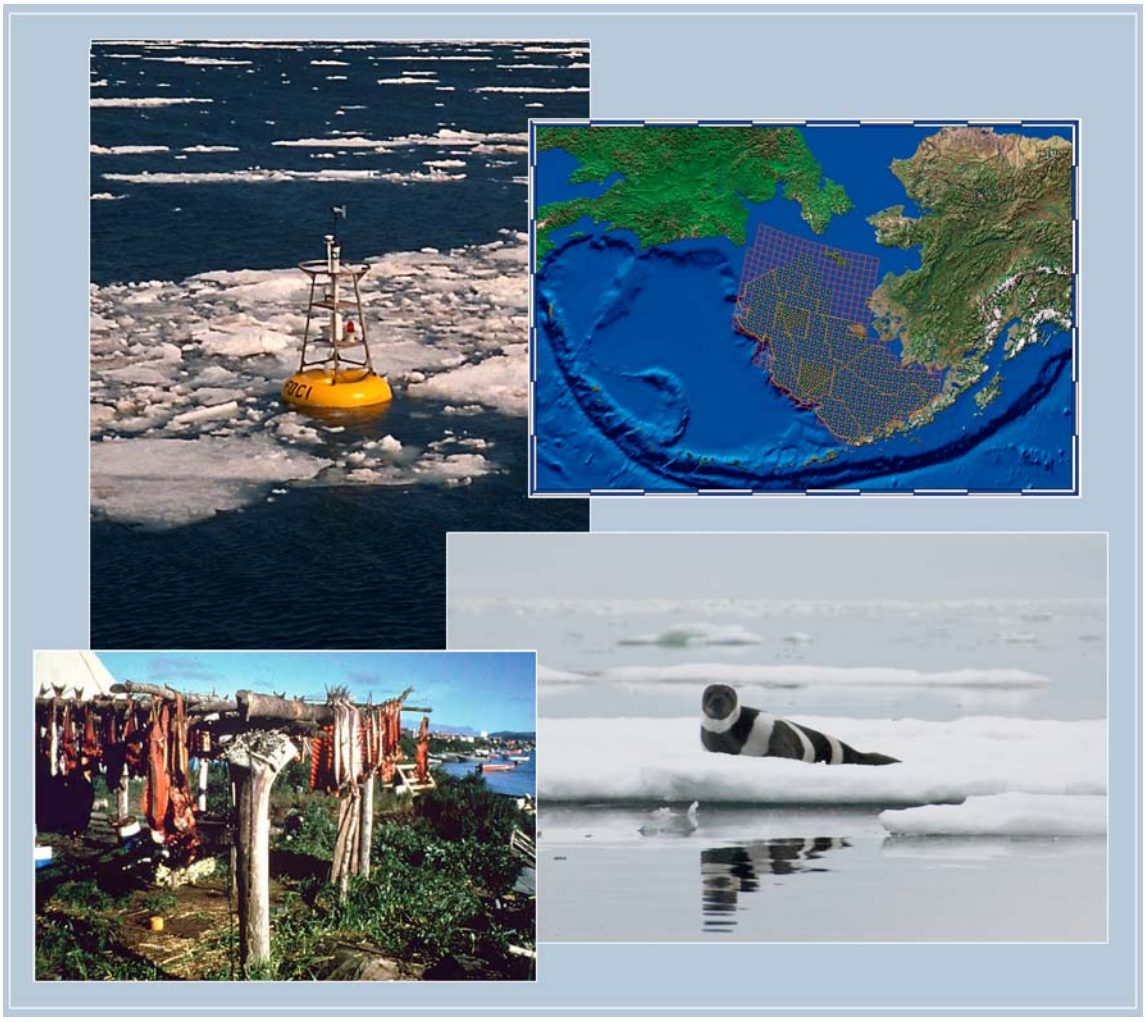
Implementation Plan for Loss of Sea Ice (LOSI) Program

by

A. B. Hollowed, R. P. Angliss, M. F. Sigler, B. A. Megrey, and D. H. Ito



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EXECUTIVE SUMMARY

Ice is the defining feature characterizing the seasonal physical and biological environment of the Bering Sea. As in other ecosystems throughout the world, the Bering Sea is warming. Areas of the Bering Sea that historically were seasonally ice-covered are now totally ice-free throughout the year. Recent observations indicate that the depth-averaged temperature of the eastern Bering Sea is increasing. Results of the Arctic Climate Impact Assessment indicate that climate change will have profound impacts on managed species in the Bering Sea. Scientists expect that in the next 50 years, these shifts will alter the spatial distribution and abundance of managed species in the Bering Sea, resulting in major changes to the Alaskan economy and the Bering Sea ecosystem. We anticipate geographic redistribution of important commercial fishes and their fisheries, redirection of larval fish transport pathways, reduction of prey resources around marine mammal and seabird rookeries, and the establishment of new biological interactions.

A research program targeting impacts of loss of sea ice is needed to study this unprecedented change within the historical record. Without a program in place now, the opportunity to monitor these changes will be forfeited, and NOAA will be far less able to meet agency responsibilities for management of fish and marine mammal species. Thus the Loss of Sea Ice (LOSI) program provides a permanent, long-term research program directed at determining the impacts of the loss of sea ice in the Bering and Chukchi Seas.

The LOSI program was developed with the goal to gather information to enhance scientists' ability to understand the influence of physical processes on the Bering Sea ecosystem dynamics and to accurately predict the biological and economic consequences of shifts in ocean conditions resulting from loss of sea ice. Understanding the mechanisms underlying behavioral responses of managed species to shifts in ocean conditions is a first step toward the development of predictive models that will forecast long-term responses of living marine resources to climate-induced shifts in regional forcing. Identifying and understanding climate-influenced ecosystem-related shifts is critical for fisheries management because the nationally important Bering Sea commercial fisheries (> 40% of the U.S. catch) are located primarily within the southern Bering Sea.

The LOSI program will utilize a multi-disciplinary approach including combinations of field studies, modeling, technology development, and retrospective studies. Three independent but interrelated research themes are proposed that focus research on loss of sea ice in different regions and seasons.

1. Theme 1: Winter -- This theme would enhance forecast capabilities through a focus on winter pre-conditioning and the influence of winter ocean conditions on the spawning distribution of crab, walleye pollock, Pacific cod, and rock sole.
2. Theme 2: Spring -- This theme would enhance forecast model capabilities through a focus on ice edge processes including the development of the spring bloom and the foraging behavior and movement of ice-dependent seals.
3. Theme 3: Summer -- This theme seeks to improve knowledge of stock status and trends through expanded assessments and comparative approaches with focus on benthic pelagic coupling.

Research targeted at each of these themes will enable Alaska Fisheries Science Center (AFSC) scientists to develop a comprehensive understanding of the response of living marine resources to loss of sea ice.

The LOSI program plans to address three major areas of scientific:

- What are the external forcing functions that link global and regional climate processes to the physical oceanography of the eastern Bering Sea?
- How does variability in the physical aspects of the marine system affect ecosystem processes and structure?
- How can spatial and temporal scales be integrated to permit forecasting how changes in climate will affect the productivity and sustainability of the marine ecosystems of the eastern Bering Sea?

In collaboration with cooperative scientific partners the LOSI program plans to focus research on the following hypotheses:

- Climate change is influencing the temporal and spatial distribution of sea ice and the quality (e.g., structure) of sea ice in the Bering Sea.
- Changes in the spatial and temporal distribution of sea ice and its quality (structure) influence the volume, spatial extent, and quality of ocean habitats in the Bering Sea.
- Shifts in the volume, spatial extent, and structure of ocean habitats influence the distribution, abundance, and structure of fish, shellfish, and marine mammal communities in the Bering Sea.

Six key scientific issues and research questions for the LOSI program were identified. The key research questions to be addressed by the LOSI program are as follows:

- Are the distributions (range, spawning, and breeding locations) and abundances of species in the Bering Sea ecosystem changing? If so, is this in response to the loss of sea ice?
- Are the physical and chemical attributes of the ecosystem changing? If so, is this in response to loss of sea ice?
- Is lower trophic level production (quantity and form) changing? If so, is it in response to loss of sea ice?
- What are the principal processes controlling energy pathways in the Bering Sea? What is the role of sea ice in these processes?
- What are the linkages between sea ice and vital rates of living marine resources in the Bering Sea?
- What are the economic and sociological impacts of a changing ecosystem on the communities of the Bering Sea? What are the impacts on other users?

The following field and modeling activities are examples of the types of opportunities for expanded research that could be supported by a LOSI program.

- Expand existing surveys to monitor apparent northern migration of managed fish and shellfish species.
- Assess the status of ice-dependent seal species.

- Assess impacts of sea ice on the growth, maturity, and feeding of managed fish, shellfish, and marine mammal species.
- Develop an understanding of the processes controlling the changes in key vital rates and movements of ice-dependent seals, shellfish, and fish.
- Forecast distribution and abundance of managed fish, shellfish, and marine mammal species.
- Assess the economic and sociological impacts of sea ice change on the commercial and subsistence fisheries of the Bering Sea.
- Collect oceanographic data from survey vessels and ships of opportunity.

The underlying theme connecting these studies will be the development of spatially explicit models capable of forecasting seasonal shifts in the distribution, abundance, growth, and reproductive success of managed species and the societal impact of these changes. A multi-agency, multi-disciplinary research approach is required to achieve this goal. The NOAA LOSI implementation plan represents a piece of this larger research effort. The implementation plan described below complements ongoing AFSC research by providing targeted funds to help develop the Center's ability to forecast the potential ecological and economic effects of climate change on the Bering Sea.

LOSI plans to use the following criteria to assist them in selecting key species for research:

- The species exhibits a life history characteristic that will be directly influenced by loss of sea ice.
- There is information available to allow researchers to compare current conditions with past conditions.
- The species likely plays an important role in subarctic or Arctic ecosystems and thus necessitates collection of a baseline level of abundance to assess impact.
- The species plays a major role in controlling energy pathways within the Bering or Chukchi Seas.
- Responses of the species to loss of sea ice will have direct economic impacts on commercial fishing or subsistence harvests.

Using these criteria, the following candidate species are considered: walleye pollock, Pacific cod, yellowfin sole, rock sole, flathead sole and Bering flounder, Greenland turbot, Pacific herring, chum and Chinook salmon, Arctic char, snow crab, bowhead whales, gray whales, and ringed, ribbon, bearded, and spotted seals.

In summary, the LOSI program was developed to enhance our understanding of processes on subarctic and Arctic ecosystem dynamics for the purpose of accurately predicting the biological and economic consequences of loss of sea ice. Rapidly changing climactic conditions require timely implementation of this effort. Otherwise the opportunity to monitor these changes will be forfeited, and NOAA will be far less able to meet agency responsibilities for management of fish and marine mammal species in this important region.

OVERVIEW

The impetus for the Loss of Sea Ice (LOSI) program stemmed from recent observations that the depth-averaged temperature of the eastern Bering Sea is warming (Overland and Stabeno 2004) and results of the Arctic Climate Impact Assessment (ACIA) that indicate that climate change will have profound impacts on managed species in the Bering Sea (ACIA 2005, Grebmeier et al. 2006). Scientists expect that in the next 50 years, these shifts will alter the spatial distribution and abundance of managed species in the Bering Sea, resulting in major changes to the Alaskan economy and the Bering Sea ecosystem (Schumacher et al. 2003, ACIA 2005, Stabeno et al. 2006). A research program targeting impacts of loss of sea ice on living marine resources is needed to study this unprecedented change within the historical record. Without a program in place now, the opportunity to monitor these changes will be missed, and the National Oceanic and Atmospheric Administration (NOAA) will be far less able to meet agency responsibilities for management of fish and marine mammal species.

Planning for the LOSI program in the Bering Sea was initiated by a series of intra- and inter-agency workshops held in Seattle, Washington. These workshops brought together an interdisciplinary group of scientists to discuss and review ideas for implementing research on the effects of climate on sea ice formation in the Bering Sea and its associated impact on living marine resources and habitat. The core elements of a joint Alaska Fisheries Science Center (AFSC) / Pacific Marine Environmental Laboratory (PMEL) LOSI program were outlined in a proposal developed in April 2005 by the Fisheries-Oceanography Coordinated Investigations (FOCI) program and elaborated in reports on workshops conducted by the AFSC's Habitat and Ecological Processes (HEPR) program in June 2005, September 2005, and May 2006. The recognition that efforts to understand the role of sea ice in the Bering Sea ecosystem would require an inter-agency coordinated effort employing the unique capabilities of each contributing agency also led to the formation of the Bering Sea Interagency Working Group (BIAW) representing the North Pacific Research Board (NPRB), the National Science Foundation's Bering Sea Ecosystem Study (BEST), the U. S. Geological Survey (USGS), the U. S. Fish and Wildlife Service (USFWS), the Alaska Ocean Observing System (AOOS), the Alaska Fisheries Science Center (AFSC), the University of Alaska Fairbanks (UAF), the U.S. Arctic Research Commission (USARC), and NOAA's PMEL (BIAW, 2006). The role of the AFSC in the LOSI program evolved from internal discussions within the AFSC and discussions during BIAW meetings.

The LOSI program was developed to improve our understanding of the influence of physical processes on the Bering Sea ecosystem dynamics in order to predict the response of the living marine resources in the Bering Sea to climate variability. Addressing ecosystem-related shifts is critical for fisheries management because the nationally important Bering Sea commercial fisheries (> 40% U.S. catch) are located primarily within the southern Bering Sea and protected species such as gray whales forage in the northern Bering and Chukchi Seas during summer. The goal of the LOSI program is to gather information to enhance our ability to accurately predict the biological and economic consequences of shifts in ocean conditions resulting from loss of sea ice. Understanding the mechanisms underlying behavioral responses of managed species to shifts in ocean conditions is a first step towards the development of predictive models to forecast long-term responses of living marine resources to climate-induced shifts in regional forcing. Consistent with the HEPR program mission, the LOSI program will utilize a multi-disciplinary approach including combinations of field studies, modeling, technology development, and retrospective studies.

Three independent but interrelated research themes are proposed that focus research on loss of sea ice in different regions and seasons. The winter theme would enhance forecast capabilities through a focus on winter pre-conditioning and the influence of winter ocean conditions on the spawning distribution of crab, walleye pollock, Pacific cod, and rock sole. The spring theme would enhance forecast model capabilities through a focus on ice edge processes including the development of the spring bloom and the foraging behavior and movement of ice-dependent seals. The summer theme seeks to improve knowledge of stock status and trends through expanded assessments and comparative approaches with focus on benthic pelagic coupling. Research targeted at each of these themes will enable AFSC scientists to develop a comprehensive understanding of the response of living marine resources to loss of sea ice.

PHYSICAL OCEANOGRAPHIC SETTING

The shelf region of the eastern Bering Sea (EBS) is characterized by three major oceanographic domains (Macklin and Hunt 2004). The boundaries of these domains are characterized by the location and intensity of the inner and outer fronts (Fig.1). The inner, middle, and outer domains are further subdivided by a north-south zoogeographic partition. The annual extent of the cold pool is a prominent feature of the middle domain. The cold pool is a large body of cold water (< 2° C) that forms from annual sea ice melts. In recent years, the cold pool has retreated to the northern portion of the middle domain. The inner domain is characterized as being well mixed due to tidal effects and local freshwater runoff. The region is characterized by prolonged summer production (Stabeno and Hunt 2002). This highly productive zone attracts fish as a nursery ground and is particularly important for many flatfish species and Pacific herring. The outer domain of the Bering Sea is bounded by a northward flowing slope current (Fig. 2) that creates a local greenbelt of production (Springer et al. 1996). The region is utilized by a variety of pelagic marine fish for summer foraging.

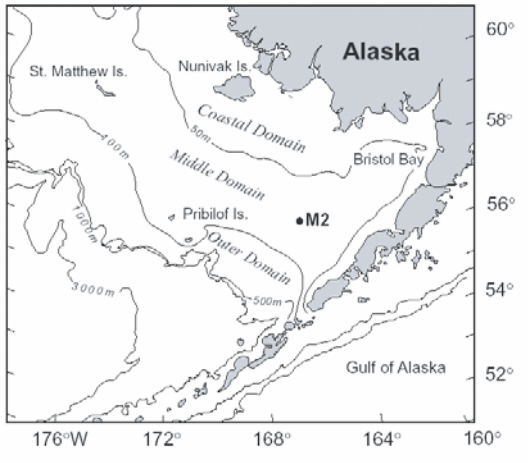

Figure 1. Southeastern Bering Sea showing isobaths and domains. (Macklin and Hunt 2004)

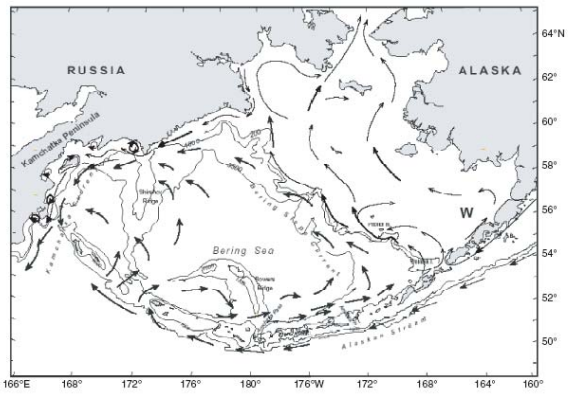

Figure 2. Schematic of major currents in the Bering Sea. From Stabeno et al. (1999).

The oceanography of the EBS is influenced by the location and intensity of winter storm tracks. Simulation models suggest that the southern side of the Arctic front will be the region of greatest alteration due to global climate change (ACIA 2005). The position and intensity of storm tracks

are controlled by global teleconnection patterns. Three patterns are particularly important in the Bering Sea: the Arctic Oscillation (Overland et al. 1999), the Pacific Decadal Oscillation (Mantua et al. 1997), and the recently discovered Victoria pattern (Bond et al. 2003). Shifts in atmospheric forcing influence sea water circulation, the mixed layer depth, and the extent of ice coverage, all of which influence the rich biological resources of the Bering Sea.

There is compelling evidence that ocean conditions are changing in response to shifts in climatic conditions (Bond et al. 2003). Persistent climatic shifts appear to be altering the heat content of the water column leading to changes in the timing of sea ice formation, the duration and extent of sea ice formations and the thickness of sea ice (Hunt et al. 2002). Of particular importance for the LOSI program, climate impacts the timing of shifts in storm activity and solar heating, which in turn, determine the timing of the spring ice edge bloom (Hunt et al. 2002). Climate shifts can also influence cross-shelf wind forcing altering the transport pathways in the Bering Sea. Bond and Adams (2002) examined wind patterns in the Bering Sea and showed that the 1980s were characterized by strong cross-shelf advection, while the 1990s were characterized by northwesterly wind forcing.

EVIDENCE OF IMPACTS ON MANAGED SPECIES

Shifts in the physical characteristics of the Bering Sea appear to be impacting living marine resources (Mueter and Litzow, in review). The EBS shelf represents the primary migratory corridor for several pelagic fish species including walleye pollock (Overland and Stabeno 2004). Wind-induced shifts in advective pathways influence the survival of larval flatfish and larval walleye pollock (Westpestad et al. 1997, Wilderbuer et al. 2002). The northward retreat of the cold pool apparently influences the spatial distribution of fish and shellfish. Retrospective studies of walleye pollock distributions show that adult pollock avoid cool ocean temperatures and move to the outer domain in years when the cold pool extends into the southern region of the middle domain (Fig. 3) (Kotwicki et al. 2005). Spencer (per. comm.[1]) examined the distribution of flatfish in the Bering Sea and noted that the distributions of rock sole and flathead sole were correlated with the distribution of the cold pool. Ernst et al. (2005), Orensanz et al. (2005a), and Orensanz et al. (2005b) demonstrated that the cold pool influences the distribution of snow crabs in the Bering Sea. Climate-induced changes in the distribution of bottom temperature, ocean fronts, and thermocline depth may influence pollock growth and survival by altering the availability of zooplankton prey (Swartzman et al. 1994, 2002, 2005).

Changes in the Bering Sea marine mammals also have been observed. Gray whales have shifted their distributions northward, apparently in response to decreases in sea ice and declines in their preferred prey on the ocean floor (Grebmeier et al. 2006, Moore et al. 2003). In addition, ice-dependent seals (ringed, spotted, bearded, and ribbon seals) require ice for parts of their life history (molting and pupping) and there is concern that these animals are being forced away from suitable feeding grounds as the ice retreats. These changes to the ecosystem have clear implications for subsistence harvests in Alaskan Native communities that have functioned in much the same way for much of recorded history.

[1] Dr. Paul Spencer, Alaska Fisheries Science Center, NMFS-NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

RELATIONSHIP TO NOAA'S STRATEGIC PLAN

The LOSI program is a cross-cutting program that is responsive to NOAA's Ecosystem and Climate Strategic Goals. Within the Ecosystem Goal, the LOSI program is particularly responsive to two of NOAA's sub-goals: Ecosystem Observations and Ecosystem Research. Within the Climate Goal, the LOSI program is responsive to the Climate and Ecosystem sub-goal. Within the Ecosystem Observations sub-goal, the LOSI program will draw from the following Ecosystem Capabilities:

1. Fishery monitoring and assessment.
2. Protected species monitoring, assessment, and forecast.
3. Ecosystem monitoring, assessment, and forecast.
4. Economic socio-cultural surveys and assessment.

COORDINATION WITH ONGOING NOAA PROGRAMS

The LOSI program will build on current research by other NOAA programs. This matrix approach encourages collaboration across NOAA line agencies. In particular, the LOSI program will utilize climate forecasts produced by NOAA's PMEL and National Center for Atmospheric Research (NCAR). LOSI will utilize projections of sea ice retreat developed by the National Weather Service's Climate Prediction Center. Analysis of water column properties data and simulated ocean current modeling will be conducted as part of the LOSI program in collaboration with ongoing research conducted by PMEL, AFSC, and the GLOBEC synthesis program.

Initiating a LOSI research program in the North Pacific and Bering Sea is timely because of the coincidental development of an international research program in response to the International Polar Year focus in 2007 and 2008 and the associated formation of the Ecosystem Studies of Sub-Arctic Seas (ESSAS) program. The ESSAS program encourages coordinated research on climate change in Arctic regions around the globe to maximize the use of research funds and ensure the data are collected in a manner that will allow regional comparisons. The ESSAS program is a cooperative research program sponsored by the national research programs of the seven member nations (Norway, Greenland, Canada, Russia, England, Iceland, and the United States).

The LOSI research program complements NOAA's Stock Assessment Improvement Plan (SAIP) for fish and marine mammals. The SAIP programs were developed to address the nationwide need to expand research on improving fishery-dependent and fishery-independent data needs for stock assessments including food-web interactions, differences in life history, and trophic effects. Expansions of the SAIP program will support: a) continued fishery-dependent and fishery-independent surveys, b) the collection and analysis of food habits information, c) annual or semi-annual population assessments, and d) the collection and analysis of key life history parameters. Some research supported by the LOSI program may improve these efforts by providing detailed information on the response of species to climate-induced shifts in environmental variables such as light, temperature, or salinity that could influence fish selectivity or availability. The SAIP program will continue to support the development and improvement of whole ecosystem models and multispecies models. The LOSI program will enhance this effort by providing detailed information on behavioral responses of managed species to climate shifts and the development of functional relationships between environment and recruitment or growth of managed species.

The LOSI program also complements smaller ongoing NOAA research programs including Fisheries and the Environment (FATE) and Advanced Technology. FATE targets research on the development of ecosystem indicators and incorporation of ecosystem indicators into stock assessments. The LOSI program will complement the ongoing activities of FATE by providing field data collections to assess the predictive power of ecosystem indicators at local scales. The LOSI program will complement the Advanced Technology program by providing platforms for testing and developing new technology. In particular, it is likely that acoustic technologies will be used in the LOSI research program. It is also likely that FATE investigators will work with Advanced Technology experts to design sampling systems to improve data collection and ecosystem assessment that could be used in the LOSI research program.

The LOSI program will also supplement NOAA's Climate Regimes and Ecosystem Productivity (CREP) programs and National Science Foundation's BEST program. The CREP and BEST programs target research at processes linking ocean production and climate variability. The LOSI program will build on these efforts by providing expanded surveys and life history information on managed species at the Arctic and sub-arctic boundary. Furthermore, the CREP and BEST programs target lower trophic level production and early life history stages of managed fish species. The LOSI program builds on this research by providing more realistic representations of the interactions occurring at higher trophic levels. Models developed by the CREP, BEST, and LOSI programs will ultimately be coupled.

This initiative also complements ongoing efforts to understand the effects of fishing on essential fish habitat (EFH). AFSC is likely to conduct research targeting habitat mapping, recovery rates, and behavioral response of fish to benthic disturbance. The LOSI program will enhance these programs by encouraging the collection and analysis of environmental information and food habits during these cruises.

CENTRAL SCIENTIFIC ISSUES

The BIAW plans to focus research on the following hypotheses:

- Climate change is influencing the temporal and spatial distribution of sea ice and the quality (e.g., structure) of sea ice in the Bering Sea.
- Changes in the spatial and temporal distribution of sea ice, and the quality (structure of sea ice), influence the volume, spatial extent, and quality of ocean habitats in the Bering Sea.
- Shifts in the volume, spatial extent, and structure of ocean habitats influence the distribution, abundance, and structure of fish, shellfish, and marine mammal communities in the Bering Sea.

The BIAW identified six key scientific issues and research questions for the LOSI program. As is the case with large interdisciplinary research programs, the research activities usually needed to address these questions include monitoring, retrospective analyses, development of models, process studies, development of advanced observational systems, and data management. The key research questions to be addressed by the LOSI program are as follows:

1. Are the distributions (range, spawning, and breeding locations) and abundances of species in the Bering Sea ecosystem changing? If so, are they in response to the loss of sea ice?

2. Are the physical and chemical attributes of the ecosystem changing? If so, are they in response to loss of sea ice?

3. Is lower trophic level production (quantity and form) changing? If so, is it in response to loss of sea ice?

4. What are the principal processes controlling energy pathways in the Bering Sea? What is the role of sea ice in these processes?

5. What are the linkages between sea ice and vital rates of living marine resources in the Bering Sea?

6. What are the economic and sociological impacts of a changing ecosystem on the communities of the Bering Sea? What are the impacts on other users?

It is assumed that the research conducted to answer the six questions above will need to include sampling to assess whether modifications to essential habitats were occurring in response to changes in physical and chemical attributes of the ecosystem (see key research question 2 above).

The BIAW agreed that in principle, the NPRB Integrated Ecosystem Research Program (IERP) for the Bering Sea will fund process-oriented research targeted at all six key questions. The NOAA LOSI program and the research activities of the USGS and USFWS will target key research questions 1, 5, and 6. The National Science Foundation's BEST program will target key research question 3. The AOOS program, PMEL and USARC will address question 2. CREP programs will focus research on key research questions 2, 3, and 4. While the members agreed to these research foci, the BIAW strongly encourages collaboration among agencies and synthesis of projects across questions for a more holistic view of the ecosystem and more accurate predictions of the impact of changing climate on the ecosystem.

The following field and modeling activities are examples of the types of opportunities for expanded research that could be supported by a LOSI program.

1. Expand existing surveys to monitor apparent northern migration of managed fish and shellfish species.
2. Assess the status of ice-dependent seal species.
3. Assess impacts of sea ice on the growth, maturity, and feeding of managed fish, shellfish, and marine mammal species.
4. Develop an understanding of the processes controlling the changes in key vital rates and movements of ice-dependent seals, shellfish, and fish.
5. Forecast distribution and abundance of managed fish, shellfish, and marine mammal species.
6. Assess the economic and sociological impacts of sea ice change on the commercial and subsistence fisheries of the Bering Sea.
7. Collect oceanographic data from survey vessels and ships of opportunity.

The underlying theme connecting these studies will be the development of spatially explicit models capable of forecasting seasonal shifts in the distribution, abundance, growth, and

reproductive success of managed species and the impact of these changes on society. A multi-agency, multi-disciplinary research approach is required to achieve this goal. The NOAA LOSI implementation plan represents a piece of this larger research effort. The implementation plan described below complements ongoing AFSC research by providing targeted funds that will enhance AFSC development of an ability to forecast the ecological and economic effects of climate change on the Bering Sea.

FUNDING HORIZON

In 2005, AFSC developed a NOAA budget proposal outlining a plan for a LOSI program. This plan called for an initial funding allocation in 2008 of $ 2.2 million with a ramp to $ 4 million by 2012. As of July 2006, NOAA planners are reviewing a revised budget proposal (revised June 2006) for a range of annual funding from $1.7 – 4 M starting in 2009. Due to this uncertainty, we provide plans for a research program that will require modest supplements to the AFSC annual budget in 2007 and 2008 with plans for an expanded program in 2009.

KEY SPECIES

If the LOSI program focuses research on a select group of key species, HEPR plans to use the following criteria to assist it in selecting target species for research:

- The species exhibits a life history characteristic that will be directly influenced by loss of sea ice.
- There is information available to allow researchers to compare current conditions with past conditions.
- The species likely plays an important role in subarctic or Arctic ecosystems and thus necessitates collection of a baseline level of abundance to assess impact.
- The species plays a major role in controlling energy pathways within the Bering or Chukchi Seas.
- Responses of the species to loss of sea ice will have direct economic impacts on commercial fishing or subsistence harvests.

Using these criteria, several candidate species for study emerged (see below). In the near-term, research will target crab, walleye pollock, Pacific cod, rock sole, Pacific salmon, ice-dependent seals, gray whales, and the species they impact or species that impact them. The LOSI program is intended to be a permanent program; therefore, the complete list of candidate species is listed below. It is anticipated that the choice of target species selected will change over time.

Walleye pollock: Walleye pollock are closely studied by the AFSC's Resource Ecology and Fishery Management (REFM) Division's Status of Stocks and Multispecies Assessment (SSMA), Age and Growth, and Resource Ecology and Ecosystem Modeling (REEM) programs; Auke Bay Laboratories' (ABL) Bering Aleutian Salmon International Study (BASIS) program; and Resource Assessment and Conservation Engineering (RACE) Division's Fisheries-Oceanography Coordinated Investigations (FOCI) and Midwater Assessment and Conservation Engineering (MACE) programs. Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for this species. It is likely that pollock will shift their distribution in response to changes in oceanography. A large amount of the energy flow in the Bering Sea passes through pollock. Pollock fisheries target roe during the winter months; therefore, commercial fishing

operations will provide additional information on the location of spawning locations. Shifts in the distribution of this species will have direct economic impacts and potential impacts on the foraging success of sea birds and pinnipeds.

Pacific cod: Pacific cod are closely studied by REFM's SSMA, Age and Growth, and REEM programs and RACE's Groundfish Assessment program. Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for this species. It is likely that Pacific cod will shift their distribution in response to changes in oceanography. Tagging studies have been initiated to evaluate movement rates and shifts in habitat use. A large amount of the energy flow in the Bering Sea passes through Pacific cod. Shifts in the distribution of this species will have direct economic impacts and potential impacts on the foraging success of sea birds and pinnipeds.

Yellowfin sole: Yellowfin sole are closely studied by REFM's SSMA and Age and Growth programs and RACE's Groundfish Assessment program. Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for this species. It is likely that yellowfin sole will shift their distribution in response to changes in oceanography. A large amount of the energy flow in the Bering Sea passes through the yellowfin sole stock as it is one of the dominant benthic species in the EBS. Yellowfin sole nursery grounds are in the inner front region while their foraging regions are in the middle and outer shelf domains. This juxtaposition of habitat use will allow researchers an opportunity to compare responses to changes in coastal regions due to freshwater input as well as changes to the ocean conditions in the middle and outer domain species. Shifts in the distribution of this species will have direct economic impact.

Rock sole: Rock sole are closely studied by REFM's SSMA and Age and Growth programs and RACE's FOCI and Groundfish Assessment programs. Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for this species. It is likely that rock sole will shift their feeding and spawning distributions in response to changes in oceanography. Rock sole nursery grounds are in the inner shelf domain while their foraging regions are in the middle shelf domain. This juxtaposition of habitat use will allow researchers an opportunity to compare responses to changes in coastal regions due to freshwater input as well as changes to the ocean conditions in the middle domain species. Rock sole fisheries target roe; therefore, commercial fishing operations will provide additional information on the location of spawning locations. Shifts in the distribution of this species will have direct economic impact.

Flathead sole and Bering flounder: Flathead sole and Bering flounder are morphometrically similar species that are geographically partitioned. Bering flounder is commonly encountered in the northern Bering Sea while flathead sole is more common in the middle shelf and southern Bering Sea. Both species appear so much alike that they are managed as a single complex. Flathead sole are closely studied by REFM's SSMA and Age and Growth programs and RACE's FOCI and Groundfish Assessment programs. Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for this species. It is likely that flathead sole will shift their feeding and spawning distributions in response to changes in oceanography. Following the impact of this juxtaposition of habitat use on Bering flounder will allow researchers an opportunity to compare responses to the ocean conditions in the southern and northern regions of the Bering Sea. Shifts in the distribution of this species will have direct economic impact.

Greenland turbot: Greenland turbot are a cold-adapted species closely studied by REFM's SSMA and Age and Growth programs and RACE's Groundfish Assessment program. Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for this species. It is likely that Greenland turbot distribution will shift to the north in response to changes in

oceanography. Tagging studies have been initiated to evaluate movement rates and shifts in habitat use.

Pacific herring: Pacific herring is a wide ranging species found in the Bering Sea. They are managed by the Alaska Department of Fish and Game (ADFG). Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for the Togiak spawning population. It is likely that Pacific herring will expand their distribution to the north in response to changes in oceanography. Shifts in the availability of prey resources during summer months can directly impact the winter survival of this species.

Chum and Chinook salmon: Chum and Chinook salmon are wide ranging species that are found in the southern and northern regions of the Bering Sea. They are managed by ADFG and form the basis of an important subsistence harvest. It is likely that this research will continue to be funded in 2007 and 2008. Long time series of data exist for salmon spawning in this region. Juvenile Pacific salmon are among the forage species targeted by the ABL's Ocean Carrying Capacity (OCC) program. It is likely that Pacific salmon distribution will expand to the north in response to changes in oceanography. Interactions between this species and other anadromous fishes such as Arctic char are likely to increase.

Arctic Char: Arctic char are present in North American waters in both anadromous (seagoing) and nonanadromous (freshwater resident) forms. This species is an important element of the diet for Native communities in western Alaska. Arctic char inhabit polar regions, and some species displacement may occur if chum and Chinook salmon distributions expand to the north.

Snow Crab: Snow crab is a closely studied species of REFM's SSMA and REEM programs and the RACE's Kodiak Laboratory. Research likely will continue to be funded in 2007 and 2008. Long time series of data exist for this species. It is likely that snow crab distribution will shift in response to changes in oceanography. Shifts in the distribution of this species will have direct economic impact.

Bowhead Whales: The western Arctic stock of bowhead whales migrates annually from wintering areas in the Bering Sea to summer foraging areas in the Beaufort Sea. This species is pagophilic and strongly associated with sea ice most of the year. The AFSC's National Marine Mammal Laboratory (NMML), Cetacean Assessment and Ecology Program (CAEP), in cooperation with Alaska's North Slope Borough (NSB), is currently planning a 5-year field study (2007-11) of the distribution and foraging behavior of bowhead whales in the western Beaufort Sea. This study will include oceanography, prey sampling (primarily for copepods and similar feeding targets for whales), and year-round acoustic monitors to detect whale presence. In addition, CAEP is supporting stock structure studies of bowheads found in waters around Alaska (Rugh et al. 2003).

***Right Whales*:** Right whales are studied by NMML's CAEP program. The eastern North Pacific right whale population likely numbers under 100 animals and is critically endangered. This species is currently found in the inner, middle and outer domains of the Bering Sea from April to November (Wade et al. 2006). This species does not associate with sea ice, and if the trend of sea ice retreat continues, the distribution of the species may shift to the north. Studies on North Pacific right whales by NMML and the Southwest Fisheries Science Center over the past few years have focused on determining the distribution of the few remaining animals found on the Bering Sea shelf (Wade et al. 2006). It is likely that a small amount of support will enable NMML to continue to investigate distribution in 2006 and 2007, but funds are likely to be insufficient to attempt to correlate distribution with prey resources.

Gray whales: The Eastern North Pacific stock of gray whales is studied by NMML's CAEP program. Most of these gray whales migrate annually from Mexico and California to feeding areas in the Bering, Chukchi, and Beaufort Seas. A long time series of abundance information exists (1967-2001, Rugh et al. 2005), and correlations between ice cover and changes in abundance have been made (Rugh et al. 2001). The preponderance of gray whales have recently been documented to shift their feeding area from the Chirikov Basin (south of the Bering Strait) to the southern Chukchi Sea (Moore et al 2003), and some individual gray whales have been recorded acoustically throughout the winter in the Beaufort Sea near Barrow, Alaska (Moore et al. 2006). Gray whale distribution may be affected by sea ice distribution in one of two ways. Receding sea ice may alter how early in the season ice-free areas are available for foraging (Perryman et al. 2002), which would result in increased population growth. In contrast, if lack of sea ice results in a lower carbon flow to the benthos and changes in the distribution of the cold pool, then the benthic community composition in historical foraging areas will change, and gray whales may disperse to areas where the benthic community supports the ampeliscid amphipods favored as prey. Gray whale presence can be used as a proxy for indicating the presence of active benthic or epibenthic communities, particularly amphipods.

Ringed, Ribbon, Bearded, and Spotted Seals: Ringed, ribbon, bearded, and spotted seals are collectively known as "ice seals". Ice seals are studied by NMML's Polar Ecosystem Program (PEP). Ice seals are critically important subsistence harvest resources for Alaska Natives. The distributions and densities of ice seals are highly sensitive to suitable sea ice conditions because they rest on sea ice for molting and pupping; some species (ringed, bearded, and ribbon seals) are not known to haul out on land, so drastic changes in sea ice extent may eliminate a resource (ice) needed for species survival. Changes in sea ice extent have been non-uniform; therefore, the effects on seals are likely to occur on regional scales and affect some local populations more than others. Ribbon seals may be particularly sensitive to changes in sea ice extent because they may have a preference for ice that occurs over certain bottom types, and because at least some seals travel very far during the summer to forage along the Aleutian Islands. A small amount of support will allow limited studies on bearded and ribbon seals in 2006 and 2007, but substantial new funds will be needed to progress towards obtaining good information on abundance, distribution, or stock structure for these and the other species. Although a time series does not exist for these seals, at least two seal species (ringed, bearded) may be locally or regionally abundant, and they are known to play a major role in the Arctic ecosystem.

ONGOING AFSC RESEARCH ACTIVITIES

The LOSI program proposes to supplement information collected during ongoing echo integration-trawl (EIT) surveys, Bering Sea groundfish and crab bottom trawl surveys, and BASIS surveys in the EBS. The information will enable investigators to determine the factors affecting the distribution of walleye pollock, Chinook salmon, chum salmon, rock sole, Pacific cod, snow crab, ice-dependent seals, gray whales, and the species that they prey on, or species that prey on them.

Physical sampling

PMEL, through funding from the FOCI and CREP programs, is likely to continue ongoing oceanographic research in the Bering Sea. During the last 10 years, researchers at PMEL have deployed over 300 drifters in the Gulf of Alaska and Bering Sea (http://www.pmel.noaa.gov/foci/drifters/efoci_drifterData.html). Many of these drifters are

advected northward in the Bering Slope Current or along the 100-m isobath. Such drifters provided critical information on deriving maps of mean transport over the Bering Sea basin (Stabeno and Reed 1994) and shelf. As part of NOAA's CREP program, it is planned that ~20 drifters will be deployed each year in the southeastern Bering Sea for the next 4-5 years. All data is available in near real time. The LOSI investigators will be able to utilize trajectories from these drifters both to assist in ground truthing the model results (see Hermann and Stabeno 1996) and will also provide information on the advection of larval finfish and shellfish in our study area.

Eddies are common features along the eastern shelf break of the Bering Sea. These are large diameter (> 100 km), deep (> 1,500 m) features that not only impact the flow patterns along the shelf break, but often attract foraging marine mammals. The best way to determine the position and trajectory of these eddies is through the use of satellite-altimetry data (e.g., Ladd et al. 2005). Scientists from PMEL provide expertise to merge and interpret data from Jason-1 and ENVISAT satellites downloaded from Aviso (http://www.aviso.oceanobs.com).

Acoustic Surveys

AFSC has conducted echo integration-trawl (EIT) surveys since 1979 (1979, 1982, 1985, 1988, 1991, 1994, 1996, 1997, 1999, 2000, 2002, 2004 and 2006; Fig. 4). EIT surveys have been conducted from the NOAA ship *Miller Freeman* intermittently since 1979 to estimate pollock in midwater from near surface to within 3 m of bottom (Honkalehto et al. 2002). This survey typically occurs during the months of June and July. The surveys follow parallel transects uniformly spaced 20 nautical miles (nmi) apart (Fig. 5). Continuous surface temperature and conductivity data are collected from the ship's flow-through water intake. Water column profiles are taken at each trawl location using a trawl-mounted temperature probe.

In all survey years, fish distributions were assessed using EIT survey techniques during daylight hours aboard ship. The survey methods are similar to those used during other routine EIT surveys (Traynor et al. 1990, Williamson and Traynor 1984). Abundance of adult pollock, juvenile pollock, euphausiids, and other sound scatterers are measured from estimates of acoustic backscattering (S_A; defined in MacLennan et al. 2002). Trawl hauls are conducted when significant acoustic signs are encountered to determine the length and species composition of the acoustic layer. The trawls used to sample midwater acoustic sign types included: a multiple opening and closing (MOCNESS) net that allows sampling of discrete acoustic layers; large, midwater Aleutian wing trawl (AWT); and occasionally, a smaller midwater Marinovich trawl. A poly Nor'eastern (PNE) bottom trawl may be used to sample acoustic fish sign near the bottom.

In 2006, acoustic backscatter will be continuously collected with calibrated echosounders at 18, 38, 120, and 200 kHz along the ship's trackline. The 120 and 200 kHz backscatter, which are sensitive to noise effects at the ranges encountered on this survey, will be noise corrected following a procedure based on that of Watkins and Brierley (1996). Walleye pollock backscatter will be identified based on echosign morphology and will be ground-truthed with targeted trawl hauls using established EIT procedures (e.g., Honkalehto et al. 2002).

Beginning in 2006, krill aggregations will be identified from the remaining backscatter by exploiting the strong frequency-dependence (~10-20 dB or 10-100-fold differences in intensity in the 18-200 kHz range) of krill volume backscatter (Stanton et al. 1996), which differentiates them from other important scatterers including North Pacific fish assemblages (Gauthier and Horne 2004). Targeted hauls with a Methot trawl will be conducted to ground-truth the accuracy of this method. Research to establish simple and robust frequency-dependent criteria for krill backscatter based on analysis of ground-truthed backscatter from acoustic backscatter from NOAA acoustic surveys in Alaska is

currently underway. Preliminary results of this work as well as previous field work in the North Pacific (Miyashita 1997, McKelvey and Wilson, in press) gives us confidence that we will be able to reliably separate krill from other backscatter.

Acoustic Sampling from Ships of Opportunity

In January 2002 the AFSC, in cooperation with the commercial fishing industry and the Pollock Conservation Cooperative Research Committee, began the Opportunistic Acoustic Data (OAD) program to collect, process, and store acoustic data from selected factory trawlers participating in the southeastern Bering Sea Alaska pollock fishery. Although these data were not collected on a systematic grid, their broad temporal extent combined with a high spatial resolution facilitates investigations on the distribution and behavior of fished aggregations. Three-dimensional kriging has been used to produce snapshots of Alaska pollock distributions over the fishing season. Fleet movement and effort was tracked using vessel monitoring system (VMS) data and on-board observer catch data. Integration of these data allows an unprecedented look at four-dimensional distributional changes in Alaska pollock aggregations and how aggregation behavior is reflected in the dynamics of the fishing fleet.

In June 2002 all vessels participating in the fishery were required to carry an operational VMS. The VMS reports the vessels position to the nearest 0.001 degree every 15 minutes via satellite. In addition, NMFS requires factory trawlers participating in this fishery to carry two certified fisheries observers during all fishing operations. The observers collect trawl location and time, total catch weight, catch composition, and Alaska pollock length and weight samples from every trawl haul. Otoliths for age samples are collected from selected hauls. Both the VMS and observer databases are stored on an ORACLE database managed by the AFSC.

Bottom Trawl Surveys

NMFS Groundfish Crab Trawl surveys have been conducted on chartered fishing vessels since 1979 (Acuna and Kotwicki 2004). This survey typically occurs during the months of June and July. Water column profiles have been taken at each trawl location using a trawl-mounted temperature probe. In 2004, NMFS extended its survey to the region to the northwest to include samples as far north as St. Lawrence Island (Fig. 6, Table 1).

In all survey years, fish distributions will be assessed using standard bottom trawl survey techniques during daylight hours. The survey is based on a systematic 20 × 20 nm grid using an 83/112 Eastern trawl with steel V-doors. Abundance of groundfish and crabs will be measured using area swept techniques (Acuna and Kotwicki 2004). Fish will be measured, sexed, and sampled for stomach contents, maturity stage, and otoliths.

The station grid for this survey will be extended north to include 26 additional stations to obtain a baseline of physical and biological data for the LOSI program (Fig. 6). NMFS will also augment the trawl survey by taking zooplankton samples at the beginning and end of each day.

BASIS Near-Surface Trawls

AFSC has conducted BASIS cruises annually since 2002. NOAA BASIS cruises have been conducted using either chartered fishing vessels or NOAA research vessels. In August 2006, the research was conducted on the NOAA ship *Oscar Dyson*. This ship is equipped to collect continuous surface temperature and salinity data from the ship's water intake system. Conductivity temperature depth (CTD) profiles were taken at each station (Fig. 7, Table 1). Surface fronts will be identified from the continuous temperature records, and water column properties will be evaluated from the CTD profiles.

Age and Growth Analysis of Fish

AFSC has conducted age determinations of biological samples collected from fishery-dependent and fishery-independent sampling programs. These age determinations will be continued and will form the basis for an analysis of seasonal and spatial differences in size at age of managed species.

Food Habits Analysis

AFSC has conducted food habits analysis of biological samples collected from fishery-dependent and fishery-independent sampling programs. These diet analyses will be continued and will form the basis for an analysis of seasonal and spatial differences in food habits of managed species.

Modeling

The AFSC has a large analytical staff devoted to the development of next generation stock assessment and ecosystem models. A central element of this ongoing research is the development of spatially explicit models that will track and forecast seasonal movements of fish and shellfish. It is likely that investigators will continue to work on these models and that they will provide important advice regarding the design and implementation of LOSI sampling programs.

The PMEL staff in collaboration with scientists at the University of Washington's Joint Institute of Ocean and Atmospheric Science (JISAO) will continue to conduct research on the development and refinement of ocean circulation models and predictive climate models of subarctic and Arctic ecosystems.

Whale Surveys – Aerial and Vessel

Whale distribution on the southeast Bering Sea shelf has been documented by vessel surveys (Southwest Fisheries Science Center (SWFSC) 1999 and 2002 right whale survey (LeDuc et al. 2001, LeDuc 2004), NMML Alaska Cetacean Ecosystem (ACE) cruise 2004 and 2005, SWFSC SPLASH humpback whale survey 2004 (Wade et al. 2006)) and aerial surveys (SWFSC right whale surveys 1998-2000 (LeDuc et al. 2001), 2002) (e.g., Appendix Fig. 2-1). All surveys have been geographically limited because of the target species: usually right whales. Cetacean data collected during the pollock stock assessment surveys in 1997, 1999, 2000, 2002, and 2004 show broad species-specific patterns of distribution for fin, humpback and North Pacific right whales (Moore et al. 2000, 2002; Tynan 2004). However, dedicated cetacean surveys that allow the collection of biological data and additional oceanographic and prey data are required to interpret seasonal and interannual variability, and to effectively include large whales as top-level predators in Bering Sea ecosystem models. Currently, funding is not available to conduct these types of studies.

Whale Surveys – Passive Acoustics

To augment visual surveys, passive acoustic monitoring for large whale calls was initiated in the southeastern Bering Sea in 2000 (Moore et al. 2006). Autonomous recorders were deployed in locations selected to maximize detection of North Pacific right whale calls while also monitoring productive middle-shelf waters for calls from fin and humpback whales. Provisional analyses have shown that right whale calls occur from May through November, with the greatest number of calls recorded in September and October. One key result from the middle-shelf deployments was the discovery that distance to calling right whales can be estimated from call-component arrival times (Wiggins et al. 2004), which potentially could support calculations of calling whale density. In 2004, the acoustic survey was extended to the shelf break in the eastern Bering Sea and analyses of data from these deployments is underway. Of note, in 2006 three PMEL-type autonomous recorders [http://www.pmel.noaa.gov/vents/acoustics/ whales/bioacoustics.html] will

be deployed at PMEL mooring sites: M2, M4 and M5, made possible by support from the North Pacific Research Board (NPRB). Because a follow-on proposal was not funded, this will be the last deployment of recorders in the Bering Sea unless support can be generated in FY07.

Table 1. -- Summary of AFSC cruise activity in the Bering Sea in 2006

Vessel	Months	Survey Area	Survey Type
Thompson	Apr.	EBS shelf – ice edge processes NPCREP	Ichthyoplankton
Miller Freeman	Apr.	EBS shelf – ice edge processes	Acoustic - trawl
Charter	Apr./May	Central BS	Acoustic, ice seal visual/tagging
Miller Freeman	May	EBS shelf (FOCI)	Ichthyoplankton
Charter	May/Jun.	Aleutian Is./Pribilof Is.	Killer whale abundance/distribution/tagging
Charter	2 Jun. – 30 Aug.	Aleutian Islands	Longline
Oshoro Maru	Jun.	EBS shelf	Plankton
Charter	May – Jul.	EBS Shelf	Bottom trawl
Oscar Dyson	Jun. – Jul.	EBS shelf	Acoustic -trawl
Oscar Dyson	Jul.	EBS shelf	Right whale abundance/distribution
Charter	May – Jul.	AI Shelf	Bottom trawl
Cooperative agreement	Jul.	AI shelf (FIT)	Atka mackerel tagging
Charter	May or Aug.	Kenai – E. Aleutians (nearshore)	Mark-resights of Steller sea lions
Oscar Dyson	Sep.	EBS shelf (BASIS)	Near surface trawl
Miller Freeman	Sep.	EBS shelf	Fall ichthyoplankton

Table 2. -- Summary of expected 2007 AFSC cruise activity in the Bering Sea

Vessel	Months	Survey Area	Survey Type
Oscar Dyson	Feb.	Bogoslof	Acoustic/trawl
Oscar Dyson	May	EBS shelf – NMML	Acoustic/trawl
Oscar Dyson	May	EBS shelf – ice edge processes (NPCREP)	Ichthyoplankton
Charter	2 Jun. – 30 Aug.	Bering Sea	Longline
Charter	May – Jul.	EBS Shelf	Bottom trawl
Charter	May – Jul.	GOA Shelf	Bottom trawl
Cooperative agreement	Jul.	AI shelf (FIT)	Atka mackerel tagging
Charter	May or Aug.	Kenai – E. Aleutians (nearshore)	Mark-resights of Steller sea lions
Oscar Dyson	Sep.	EBS shelf (BASIS)	Near surface trawl
Oscar Dyson	Apr./May	Central BS	Acoustic, ice seal visual/tagging
Charter	Summer	Western Beaufort Sea	Oceanographic/zooplankton sampling, bowhead whale distribution

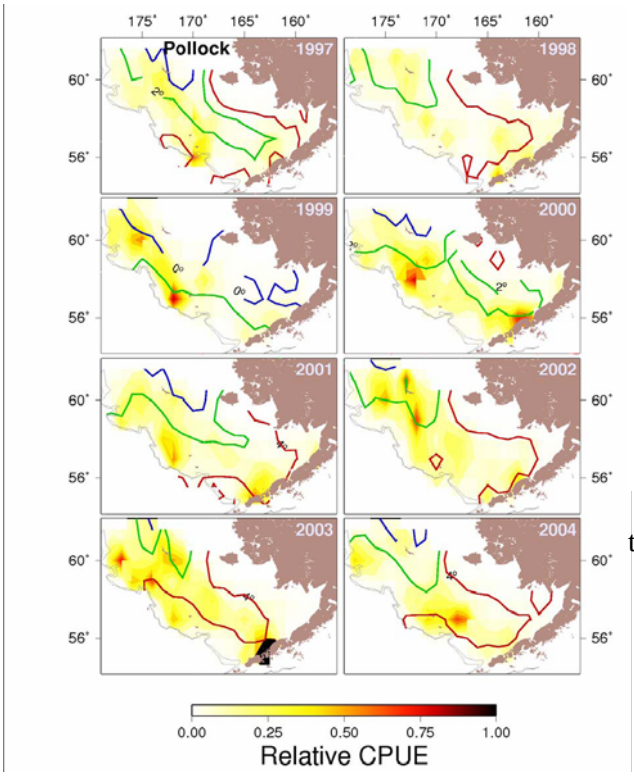

Figure 3. -- EBS pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º Celsius for 1997-2004. Station locations are depicted by the dots.

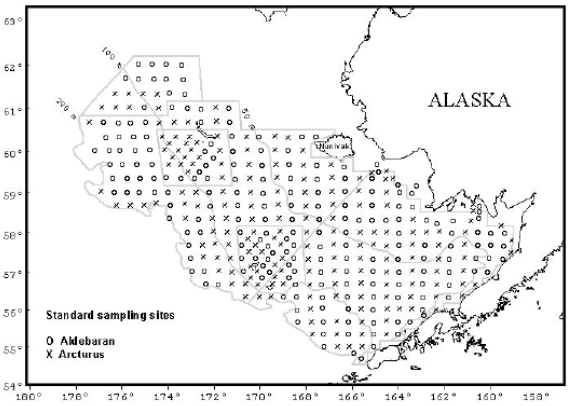

Figure 4. --Standard and special study stations sampled during the 2003 eastern Bering Sea bottom trawl survey, and stratifications used for analysis of data.

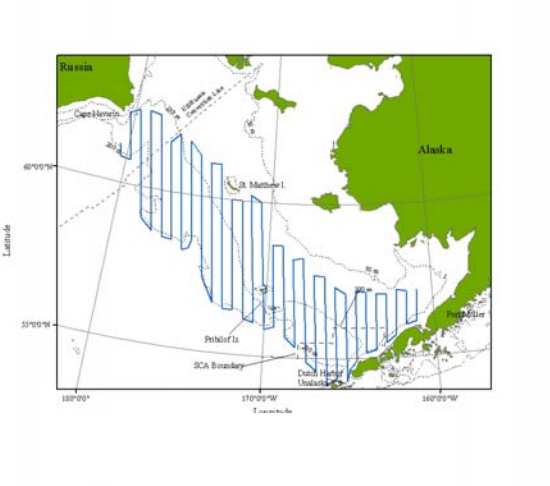

Figure 5. --Echo integration-trawl survey tracklines.

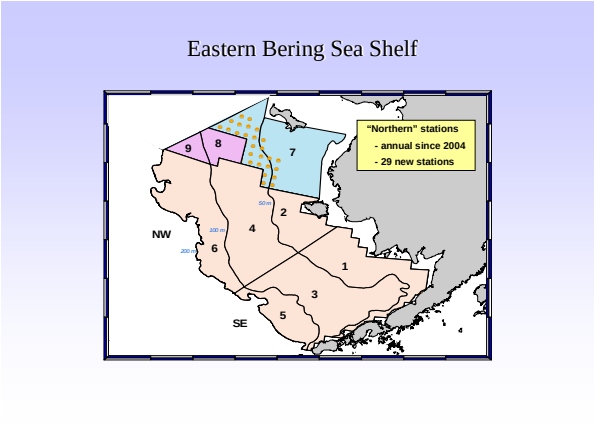

Figure 6. --Standard and special study stations sampled (in blue) during the 2004 and 2005 eastern Bering Sea bottom trawl survey, and stratifications used for analysis of data.

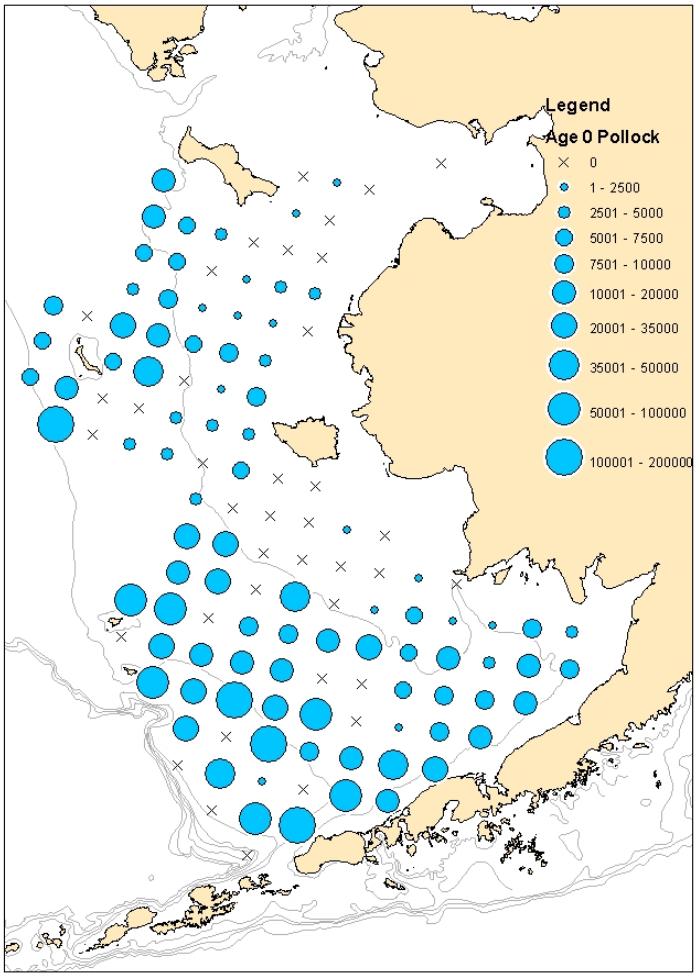

Figure 7. -- Distribution of age-0 pollock observed in Bering Aleutian Salmon International Study (BASIS) cruise in 2004.

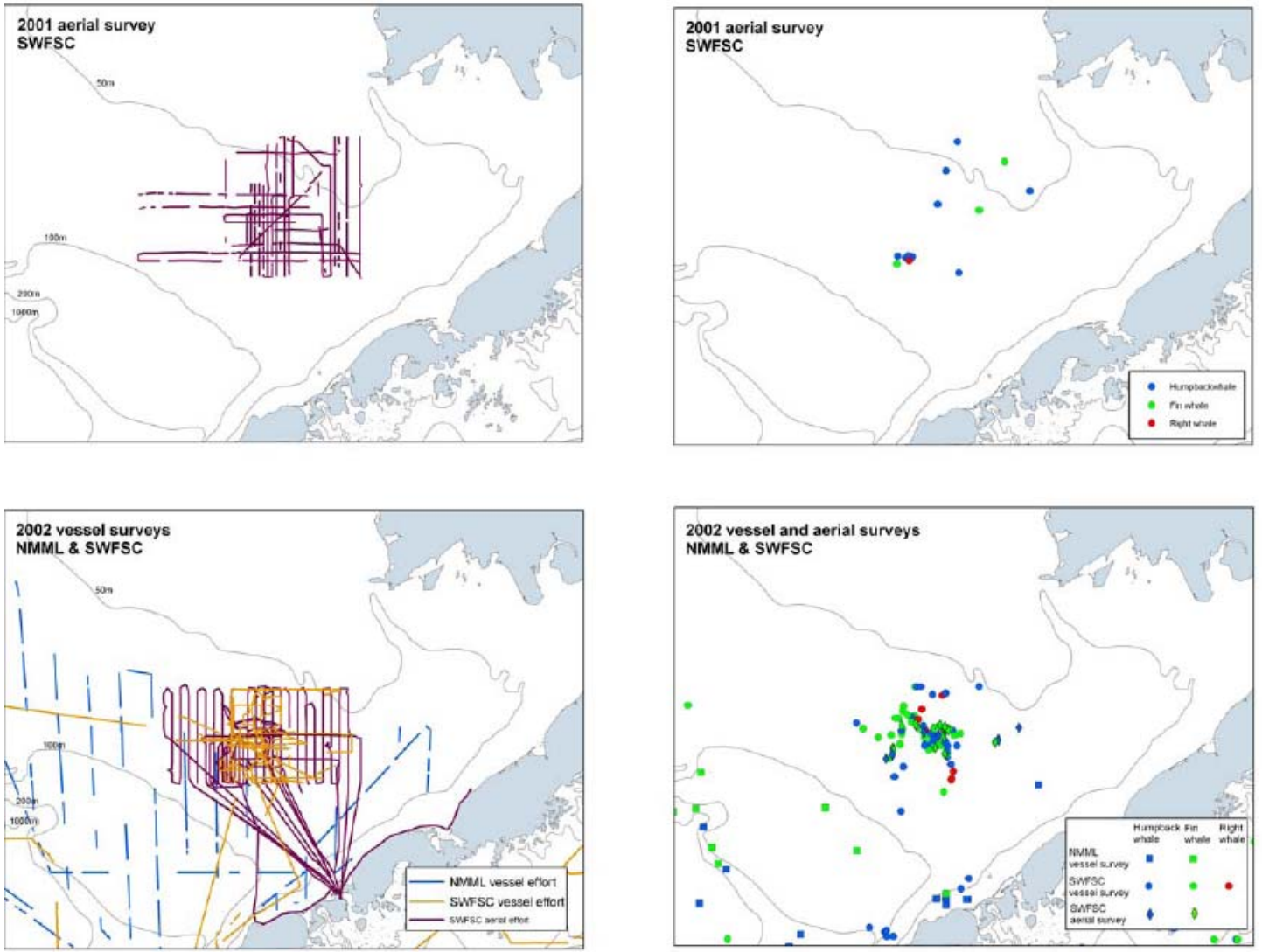

Figure 8.-- Track lines (left panels) and locations of whale sightings (right panels) for National Marine Mammal Laboratory and Southwest Fisheries Science Center surveys in 2001 and 2002. Species are coded by color: humpback (blue), fin (green), and right whale (red).

RESEARCH RECOMMENDATIONS

On 3 May 2006, the HEPR team convened a workshop to develop an implementation plan for a permanent, long-term research program directed at determining the impacts of the loss of sea ice on the Bering and Chukchi Seas (Appendix 1-3). The HEPR team provided a draft implementation plan and list of research activities that might be considered by participants when considering an implementation program for LOSI (Appendix 2). Workshop participants were encouraged to discuss the ideas within the constraints of $1 million and $4 million dollar funding scenarios. Two breakout groups (see Appendix 1) discussed approaches to combining the proposed activities into research programs. Under the $1 million funding constraint, the groups recommended that research be focused on three themes. The Winter Theme will enhance forecast capabilities through a focus on winter pre-conditioning for oceanographic models and the influence of winter ocean conditions on the spawning distribution of commercial species (e.g., crab, pollock, Pacific cod, and rock sole). The Spring Theme will enhance forecast model capabilities through a focus on ice edge processes, and foraging and movement of ice-dependent seals; and the Summer Theme will enhance knowledge of stock status and trends through expanded assessments and comparative approaches with focus on benthic pelagic coupling. Under the $1 million constraint, it was recommended that research be focused on one of the three themes to ensure that the predicted outcomes are attained given the expected funding level. At the $4 million funding horizon, research on one or more themes would be possible.

A brief description of the themes follows. It should be noted that the funding amounts listed were intended to be a guide to form the integrated research proposal. The actual funding level will be dependent on the proposals submitted in 2009.

Winter Theme *- Enhanced forecast capabilities through a focus on winter pre-conditioning and the influence of winter ocean conditions on the spawning distribution of commercial species (crab, pollock, Pacific cod, and rock sole).*

The objective of this theme is to assess the impact of climate on ocean conditions in the Bering Sea and the influence of these climate-induced changes on the timing and distribution of spawning of major managed species, and its influence on fish production and communities that depend on fish. This research theme stemmed from the observation that knowledge of winter ocean conditions is crucial to understanding and forecasting ecosystem conditions in the Bering Sea and Arctic and the potential economic impact of these conditions. The project calls for an interdisciplinary research program involving field and modeling activities designed to enhance our ability to monitor winter ocean conditions and to assess the response of commercially important species and protected resources to these conditions. This research theme targets key research questions 1, 2, and 5 and would contribute to improved model forecasts for key research questions 2, 3 and 6 (see Central Research Issues). An added reason to focus research on the winter season is that shifts in the distribution of spawning pollock and Alaskan crab will have the greatest economic impact on the fishing community because of the high commercial value of crab and roe fisheries. Extensive use of ships of opportunity is proposed to reduce costs.

The methods proposed for this theme include a combination of ocean monitoring and process studies to inform the development of coupled biophysical ocean circulation models, spatial models of adult fish responses to climate, and bioeconomic models. Oceanographic conditions would be monitored by deploying satellite tracked drifters, collecting water column properties from ships of opportunity, and the collecting underway sea surface conditions by deploying

SeaChests (a system that includes a thermosalinograph and intake water temperature sensor, dissolved oxygen sensor, chlorophyll fluorometer, GPS receiver, single-board data acquisition computer, boxes in which the gear is mounted, and miscellaneous plumbing and electronic/electrical equipment) on ships of opportunity. Sea ice conditions would be monitored using satellite images.

Responses of commercially important fish (initially Tanner crab, snow crab, and Pribilof blue king crab, Pribilof red king crab, Pacific cod, walleye Pollock, and rock sole) to observed ocean conditions would be monitored through enhanced collection of the maturity stage from roe fisheries, collection of pollock distributions through collection of acoustic backscatter from ships of opportunity, and deployment of a combination of archival and coded wire tags to assess fish movement. Oceanographic models would be used to forecast expected patterns of larval dispersal from spawning sites.

Expected outcomes from the winter theme include refined climate scenarios to forecast future states of nature and improved forecasts of the response of commercially important fish species to shifts in ocean conditions. Baseline winter ocean conditions would improve simulated ocean current models by providing observations during the winter set-up phase. These conditions have a direct impact on ocean conditions in other seasons and would improve the accuracy of model predictions of the location of key ocean features and the intensity and location of ocean currents and fronts. Understanding the response of fish and shellfish to key oceanographic features would enable modelers to correctly predict the distribution of larvae and the expected dispersal mechanisms influencing survival during the early life history phase of key species. This information could be readily incorporated into individual-based models, stock assessments, and ecosystem models to enhance predictions of future production of key marine species.

Winter Theme Research Activities $1M funding horizon (see Appendix 2 for project descriptions)

- PMEL – Climate scenario and satellite image support and research (Appendix 2 Prj. 17; $60K)
- Drifter deployment (Appendix 2 Prj. 14; 15-20 for $150 K)
- CTD on ships of opportunity including crab pots (Appendix 2 Prj. 2; $35K)
- Deployment of SeaChests on ships of opportunity (Appendix 2 Prj. 1; $15 K)
- Acoustic sampling from ships of opportunity (Appendix 2 Prj. 5; $255 K, includes technician / analyst)
- Monitoring of spawning locations (Appendix 2 Prj. 9; $50 K)
- Forecast model development and analytical support (Appendix 2 Prj. 14 – 16; $135 K)
- Tagging studies (Archival and mark – recapture) (Appendix 2 Prj. 10; $300 K)

Spring Theme *- Enhanced forecast model capabilities through a focus on ice edge processes including the development of the spring bloom and the foraging behavior and movement of ice-dependent seals.*

The objective of the spring theme is to assess the impact of climate on the timing and intensity of the spring bloom, and the impact of sea ice quality on the foraging success of ice-dependent seals. This research program focuses on developing a comprehensive monitoring program that involves the use of an icebreaker and a NOAA research vessel during the early spring (March/April). This research theme targets key research questions 1, 2, 3 and 4 (see Central Scientific Issues).

Collection of information during this period was believed to be particularly critical because very little is known about biological processes that occur in ice-covered areas.

The methods proposed for this theme include a combination of monitoring and process studies. Monitoring activities include analysis of seasonal changes in water column properties from moorings and CTDs and underway surface temperature, nutrients, and fluorometery. LOSI will fund a mooring placed north of St. Matthew Island. Oceanographic conditions under the ice would be studied using an icebreaker. CTDs would be deployed from the side of the icebreaker in patches of open water left behind the ship. Sub-surface nutrient and fluorometery samples would be collected from water samples collected during CTDs. Surface ocean conditions will be collected from SeaChests on research vessels. This oceanographic data will be analyzed to assess the timing of the beginning of the meltback of the ice and its influence on the intensity of the spring bloom. As described in the Winter Theme, satellite image analysis for sea ice condition will be supported by the LOSI program. Shiptime would be devoted to focused local studies of the response of forage fish distributions relative to sea ice and the foraging behavior of ice-dependent seals. Fish and zooplankton distributions near the ice edge would be assessed using a NOAA research vessel equipped with a multifrequency ecosounder, mid-water trawls, and bottom trawls. The response of seals to shifts in forage fish availability will be assessed by local estimates of abundance and distribution as well as behavioral information regarding number of hours spent searching for and actively pursuing prey. Ice seal distribution and abundance would be assessed using line transect visual assessments from aerial surveys on helicopters dispatched from the icebreaker. Small boats would be deployed from the icebreaker to capture ice-dependent seals to collect vital statistics on animals and to attach satellite tags for behavioral studies. Additional information on spring distributions of seabirds and cetaceans could be obtained by deploying observers on the two ships scheduled for this experiment.

The proposed budget assumes that an icebreaker would be provided for at no cost to the government and it does not include a range-wide abundance assessment for ice-dependent seals. PMEL currently has dedicated UNOLS time on an icebreaker. Implementation of this project would require that NOAA negotiates an agreement for more icebreaker time. If an agreement cannot be reached it would cost approximately $11-48K/day (see details under $4M option). Ideally, the icebreaker would have a helicopter pad and offer the ability to work off the stern, and would be available for 15, or preferably 20, days each year.

Expected outcomes from the Spring Theme include refined understanding of the link between climate forcing and sea ice formation and extent and the influence of these processes on the timing and intensity of the spring bloom. The research conducted under the Spring Theme will improve our understanding of the potential impacts of loss of sea ice on ice-dependent seals.

Spring Theme Research Activities $1M funding horizon (see Appendix 2 for project descriptions)

- Icebreaker and acoustic surveys to assess response of forage fish to sea ice fronts ($300K; Prj. 11)
- Biophysical mooring deployment north of St. Mathew Island to assess timing and intensity of spring bloom (Appendix 2 Prj. 19; $75K)
- Ice seal tagging and foraging ecology (Appendix 2, Prj. 11; $250 K)
- Seabird monitoring and foraging ecology ($60K)
- Nutrient and zooplankton sampling to assess onset of spring bloom (Appendix 2 Prj. 2; $50K)
- Biophysical model development to assess the role of ice in annual production (Appendix 2 Prj. 14; $100K)
- Cetacean surveys during all cruises. (Appendix 2 Prj. 6; $30 K)

- Either conduct an independent survey for cetaceans in the Bering Sea or add significant ship time to the acoustic surveys so they could break transect to photo-id or biopsy cetaceans (Appendix 2 Prj. 6; $100K)

Summer Theme *- Enhanced knowledge of stock status and trends through expanded assessments and comparative approaches with focus on benthic pelagic coupling.*

This theme focuses research on the hypothesis that major food web pathways differ between the southern (subarctic biogeographic province) and northern (arctic biogeographic province) regions of the Bering Sea, with consequences for the dominant biota in each biogeographic province. In the subarctic biogeographic province, production appears to remain within the pelagic ecosystem and walleye pollock are the dominant tertiary consumer. In contrast in the arctic biogeographic province, tight coupling between pelagic productivity and the benthos benefits benthic foragers such as gray whales, walrus, and some seabird species. Seasonal ice cover and the resulting cold pool of seawater largely dictate the boundary of the subarctic biogeographic province. For example, pollock thermal preference excludes them from the arctic biogeographic province. Fur seals also avoid the cold pool, either due to energy considerations or foraging preferences (pollock can be an important diet item). This research theme targets key research questions 1, 2, and 4 (see Central Research Issues).

Activities proposed under this theme would include expanded summer surveys in the northern Bering Sea biogeographic province. Data would be collected to assess whether the area of the northern Bering Sea biogeographic province is contracting due to loss of seasonal sea ice in the Bering Sea. To understand and forecast loss of sea ice effects on fish and marine mammal abundance in the Bering Sea, we propose to study the summer cold pool and ecologically important sentinel species by expanding sampling of the southern Bering Sea and initiating sampling of the northern Bering Sea. The sentinel species include pelagic (walleye pollock) and benthic fish (Bering flounder and flathead sole), shellfish (Tanner crab), pinniped (ribbon seal, fur seal) and cetacean (gray whale) species. Our research approach is oceanographic sampling, multi-frequency acoustic surveys, bottom trawl surveys, visual and acoustic surveys for cetaceans, and forecasting of distribution and abundance of managed fish, shellfish, and marine mammal species.

This research theme focuses heavily on an expansion of existing surveys to include regions to the north. Information relevant to foraging habitat quality will be determined through underway ocean monitoring on NMFS surveys and expanded collections of nutrients, plankton, and zooplankton. The response of fish to changes in habitat quality (including prey availability) will be assessed through more detailed examinations of the spatial variability in diet of managed fish species. Cetacean monitoring will be accomplished through the deployment of acoustic listening lines that will track the migratory corridors used by gray whales.

Expected outcomes from the Summer Theme include information to develop stock assessments of subarctic and arctic species, improved understanding of processes controlling the summer habitat selection and the impact of these processes on fish condition. The project will provide an improved understanding of the major energy pathways in the northern and southern Bering Sea, and an improved understanding of the role of climate on these processes.

Summer Theme Research Activities $1M funding level (see Appendix 2 for project descriptions)

- Underway oceanography on ships of opportunity or survey charter vessels (Appendix 2 Prj. 1; $75K)
- 40 new BASIS stations in Chukchi Sea (Appendix 2 Prj. 3; $200 K)]
- 60 new Trawl stations to complete area 7 and add stations to the north. (Appendix 2 Prj. 3; $350K)
- Cetacean monitoring from ships of opportunity (Appendix 2 Prj. 6; $30K)
- Assessment of technologies needed to conduct aerial surveys for ice-dependent seals – and implementation of these surveys. (Prj. 11; $50K)
- Comparative studies and modeling of selected species (Appendix 2 Prj. 8 and 9; $50k)
- Acoustic monitoring lines for cetaceans (Appendix 2 Prj. 6; $120)
- Plankton and zooplankton sorting for BASIS survey and for the zooplankton samples collected from the summer trawl surveys (Appendix 2 Prj. 4; $180K)
- Summer food habits and bioenergetics of selected fish species (Appendix 2, Prj 7 and 12; $85K)

The following projects were suggested as priorities for funding at the $4M level:

Under the $4M funding level, all three research Themes could be funded. In addition, new projects involving laboratory and field studies could be conducted. The following are examples of the types of programs that could be added to those already listed under the winter, spring, and summer themes:

- Under the Summer Theme, the AFSC would fund a researcher to explore the best method for assessing ice-dependent seal abundance. The Spring Theme would provide local abundance estimates for ice-dependent seals. Under a fully funded program, the AFSC would attempt to implement a range-wide estimate of ice-dependent sea abundance. If it is determined that the best and safest method of assessing ice-dependent seal abundance is through aerial surveys deployed from icebreakers, then additional funds would be needed to charter an icebreaker for 20 days at 50k/day to work in the ice ($1M; other estimates were $11K/day for a Russian ship). It is anticipated that food habits and foraging behavior of ice seals would be conducted in conjunction with this project – (Appendix 2 Prj. 3 and 11; $600K).

- Under a fully funded program, NOAA would consider extending the shelf trawl survey to the north into the Chukchi Sea and to the east into Norton Sound (would take an additional 3 weeks for each) and add benthic grabs to assess benthic species composition and abundance (assumes funds for one permanent benthic ecologist and crew for additional charters). A fully funded summer program would include zooplankton and ichthyoplankton sampling twice daily during the survey of Area 7. The NPCREP program only covers processing of samples in the core sampling area. This information would be needed to determine the species composition of prey field (Appendix 2 Prj. 3 and 19; Total $750K, $500K for the survey and benthic ecologist, $250K for processing zooplankton samples and 1 FTE to verify and work up data.)

- Conduct a large-scale survey for cetaceans. Full suite of acoustic monitoring lines for cetaceans (Appendix 2 Prj. 6; $360K)

- The LOSI program requires surveys in a harsh environment. Some funds would be used to equip and maintain the icebreaker including modifications to allow for trawling. Other funds would be utilized to equip the research vessels used to perform winter and spring surveys with

advanced technology to maximize the information derived from days at sea. For example, the AFSC would purchase multiple frequency towed equipment to sample water column and PMEL would calibrate already-owned ADCPs to measure zooplankton. In addition, SeaChests might be deployed on fishing vessels to collect underway oceanography data.

- Data analysts would also be employed to analyze new and existing data. For example, PMEL currently has 10 years of ADCP data collected by moorings; this information could be analyzed after feasibility and QX/QA analysis. Over time, sufficient data will be available for the development of stock assessments for Arctic species. New funds will be needed to support these assessments including analysts to perform the assessments and age readers to process age samples. If fisheries develop for northern species, the observer program may also require additional funds to deploy observers and process data.

NEXT STEPS

The HEPR team will work with AFSC Leadership and National Marine Fisheries Service headquarters to seek funding to support research ideas outlined in this plan. It is anticipated that funding proposals will be submitted for the 2009 budget cycle. If successful, HEPR will seek integrated proposals from AFSC and PMEL to implement the plan in the spring of 2009.

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APPENDICES

APPENDIX 1

LOSI / HEPR Workshop Aggenda
3 May 2006, Traynor Room
Alaska Fisheries Science Center, Seattle, WA

09:00-09:20 Introductions and charge for workshop participants - Hollowed

09:20-10:30 Review of Draft Implementation Plan – Hollowed

- Time line for implementation
- Definitions: program augmentation versus permanent new programs
- Approve species and selection criteria
- Identify missing projects
- Review expected platforms of opportunity
- Set cost estimates for FTEs and Days-at-sea

10:10-10:30 Break

11:00-12:30 Breakout Session A and B – Megrey and Hollowed

12:30-1:30 Break for lunch

13:30-14:45 Resume breakout sessions A and B

14:45-15:00 Break

15:00-15:45 Compare breakout plans - Hollowed

15:45-17:15 Gap analysis for candidate plans

17:15 – 17:30 Meeting conclusions

Participants in Breakout Group A: (J. Duffy-Anderson, J. Ferdinand, N. Friday, R. Heintz, A. Hollowed, J. Ianelli, T. Hurst, J. Moss, J. Overland, P. Rigby, K. Shelden, M. Sigler, and F. Wiese)

Participants in Breakout Group B: (R. Angliss, K. Aydin, R. Felthoven, L. Logerwell, B. Megrey, D. Somerton, P. Stabeno, W. Stockhausen, C. Wilson)

APPENDIX 2

DESCRIPTION OF LOSI RESEARCH ACTIVITIES

Project 1 (Near surface underway sampling: Monitoring).

The project objective is to develop and sustain standard oceanographic sampling during ship-based surveys. New funds will be requested to augment EIT, bottom trawl, and near surface trawl survey platforms with continuous oceanographic observations that will help to identify specific processes or factors that may be influencing the spatial distribution, migration, growth, condition, and reproductive potential of euphausiids, fish, shellfish, ice-dependent seals, and whales. Supplementing existing platforms will enable researchers to develop a three-dimensional description of ocean habitats.

Project 2 (Water column properties sampling: Monitoring).

The project objective is to develop and sustain standard oceanographic sampling during ship-based surveys. In 2009, funds will be requested to augment EIT surveys with water column properties sampling with regular deployments using expendable bathythermographs (XBTs). Probes will be deployed at approximately 50 nmi spacing along each transect. Surface fronts will be identified from the continuous temperature records, and water column properties will be evaluated from the XBT and CTD profiles. Mixed layer depth will be estimated by the depth where the temperature difference between 1 m records was greatest. Information will be added to the existing water column properties database maintained by AFSC and PMEL. In addition, measurements of primary production will be expanded to all ship-based surveys.

Project 3 (Expand Bering Sea surveys to encompass northward movement of managed species: Monitoring).

Survey activity	**Annual Cost**
Expand annual groundfish survey to Area 7	$350K + 4 FTEs
Expand biennial acoustic survey to the northern limit of pollock	$100K
Surveys of ice-dependent seals	$600K
Chukchi Sea BASIS stations	$200K + 4 FTEs
Expand annual groundfish survey to northern Bering Sea	$750K + 1 FTE

Project 4 (Summer zooplankton sampling: Monitoring).

Zooplankton will be sampled using oblique tows of a CalVET net. Analysis of zooplankton samples will be completed by the Polish Plankton Sorting Center.

Project 5 (Acoustic sampling from ships of opportunity: Monitoring).

It is likely that shifts in oceanographic conditions will influence the spawning locations of selected species in the Bering Sea. The LOSI program will target research on species that are commercially fished during the winter months: snow crab, walleye pollock, Pacific cod, and rock sole. LOSI funds will be used to purchase additional data loggers and to expedite data processing and data management. The product of this effort will be improved information on the abundance and spatial distribution of pollock in seasons other than summer.

Project 6 (Sustain standard cetacean sighting and passive acoustic detection surveys: Monitoring, process).

Beginning in 2009, LOSI investigators will deploy a field team of three marine mammal observers on each EIT cruise of approximately 1 month in duration. Observers will adopt standard line transect protocols, maintaining a visual watch for cetaceans with 25x (Big Eye) binoculars from the ship's flying bridge. Cetacean sighting locations will be recorded on laptop computer, plotted relative to fronts, eddies, and prey aggregations, and then analyzed using DISTANCE sampling methods (Buckland et al. 2004) to calculate abundance. It is critical that observations for large whales be conducted coincident with hydrographic and prey sampling, such that spatial and temporal domains are coincident. Additional satellite-derived oceanographic data (sea surface temperature, height, and chlorophyll a) will be integrated, as possible, to aid in development of predictive models for large whale distribution and movement patterns in the southeastern Bering Sea.

Passive acoustic surveys for calls from large whales will be conducted. PMEL-type recorders (see Moore et al. 2006) will be deployed at PMEL mooring sites M2, M4, and M5. After recovery of the instruments, data will be analyzed for the number and types of calls by species, then correlated with oceanographic data available from the moorings, ships, and satellites (see NPRB proposal: Oceanographic correlates of the occurrence of endangered whales in the Bering Sea). Passive acoustics is a proven method for determining seasonal occurrence for large whales, including listed species (North Pacific right, fin, and humpback whales), sampling at spatial and temporal scales similar to oceanographic moorings. It is anticipated that results from the NPRB year-long deployment will be combined with data from 2000-05 recorder deployments, as well as visual data, to support ecosystem modeling in the southeastern Bering Sea.

Project 7 (Is it Food? Retrospective and monitoring).

The relationship between zooplankton abundance, feeding rates, and cannibalism will be examined through the collection and analysis of the food habits of pollock and co-occurring species in trawl hauls. Stomach samples will be fixed in formalin and later transferred to ethanol before being analyzed. Up to 1,250 samples will be analyzed in the lab and data will be prepared and presented in GIS format suitable to the project.

Foraging habitat for fish and crab species in the Bering Sea is dynamic and a product of thermal habitat, advective patterns, prey availability, and predation risk. Data on variation in these components over the last 25 years exists in AFSC databases; however, these data have never been pulled together to assess variation in foraging habitat quality over time. Explicitly mapping and quantifying seasonal foraging habitat and variation in habitat over time will provide a basis for developing migration models, determining critical habitat in relation to dynamic changes (e.g., as associated with water temperature), and predicting changes in habitat associated with long-term

thermal changes in the water column. The first phase of the project will be to develop maps of feeding rates and prey type from stomach contents analysis overlaid with the energetic costs of foraging as determined from bioenergetics models for flatfish, Pacific cod, and walleye pollock. These maps will be made for the range of observed conditions (e.g., "cold years" vs. "warm years"). These maps will be created so as to be readily available to other modeling efforts; for example, for coupling with spatially explicit lower trophic level production models and fish migration models. To the extent possible from current data, these maps will be seasonal to provide indications of foraging habitat during key time periods for determining fish survival. These maps will include the effects currently being investigated by REEM and Status of Stocks personnel of water column structure and stability on fish foraging rates. Later phases of the project will include improved laboratory analysis of fish growth and respiration rates, and integration with models indicated above. Concurrently, maps of fishing and predation pressure will be created for inclusion.

Project 8 (Comparative study of seasonal oceanography: Retrospective).

The EIT and BASIS surveys provide an opportunity to compare ocean features at the beginning and end of the summer. Funds will be requested to map and analyze ocean features observed from the BASIS cruises in August and ocean features observed in June and July from the EIT surveys.

Project 9 (Development of a conceptual model: Retrospective studies).

- Retrospective studies of fish distribution and diet relative to oceanographic features. Compare fish and whale distributions relative to zooplankton distributions and oceanographic factors.
- Develop measures of the volume of ocean habitat for fish and zooplankton.
- Compare ocean features between June-July (EIT) and August (BASIS) in 2002 -2006 to estimate seasonal variability in the location of features.
- Evaluate implications of climate change on future distribution and productivity of fish and marine mammals.

Analysis of the spatial distribution of major scatterers collected in the EIT surveys will be evaluated using the geographic information system (GIS) Arc INFO. Oceanographic variables used in the analysis are listed in Table 1.

Appendix Table 1. Existing data sources for retrospective studies.

Physical	Biological
Simulated current trajectories	Stock ID
Surface temperature	Catch composition
Mixed layer depth	Length frequency
Mixed layer temperature	Zooplankton distribution
Depth	CPUE
Satellite track drifters	Size at age
	Weight at age
	Movement rates
	Reproductive success/reproductive output
	Maturity schedule

Principal Investigators intend to fully cooperate with other investigators to fully utilize information on the biophysical processes influencing the distribution and abundance of marine resources in the EBS.

Scientists at the AFSC have constructed GIS applications for visualizing data collected by the AFSC and PMEL. Methods for extracting temperature at depth from water column profiles have been adapted for use in mapping applications. Detailed overlays of depth contours are available through a NMFS/PMEL water column properties database for Alaska waters. Routines have been written to display temperature profiles from selected stations.

Emergent properties of the distribution of major scatterers in the EBS revealed by the GIS will be tested using statistical methods. Principal components analysis will be used to isolate the most important modes of variability in the data. The relationship between the distribution of scatterers to prey fields, species composition of the diet, and physical factors will be explored using Generalized Additive Models (GAM; Hastie and Tibshirani 1990, Swartzman et al. 1994). GAM will be useful for the purposes of this study because nonlinear relationships between variables are allowed.

Project 10 (Movement studies of fish, shellfish, and marine mammal species: Process study).

Development of a core team of biologists dedicated to improving our understanding of the impact of climate change on shifts in distribution, migration, and habitat use in the Bering Sea. In the near-term biologists will target several species: walleye pollock, Pacific cod, and snow and Tanner crabs, and ice-dependent seals.

Pacific cod - Scientists require data to estimate movement rates of marine fish to support the development of spatially explicit models. The best method for obtaining these movement rates is through the use of mark recapture experiments. Scientists at the AFSC submitted a successful proposal to NPRB that will provide a design for tag deployment to assess Pacific cod movement. In 2008, LOSI funds will be used to initiate a new Pacific cod tagging program. Results from tagging experiments will be used in a spatially explicit stock assessment model for Pacific cod (see description in modeling section).

Walleye pollock - Scientists at the AFSC in collaboration with scientists at the University of Alaska Fairbanks are currently evaluating a new gear type to enable tag deployments for walleye pollock. In a parallel effort, AFSC and UAF scientists are developing a spatially explicit model for pollock that could be utilized if an appropriate tag deployment method is identified (see description in modeling section). Depending on the results of field trials with the new gear in 2006, scientist will seek funds in 2007 and 2008 to initiate tag deployment for walleye pollock.

Tanner crab - Scientists at the AFSC in collaboration with scientists at the University of Fairbanks have been working to identify techniques for deploying tags for Tanner crabs. In a parallel effort, scientists at the University of Washington have been developing techniques for modeling crab movements in the Bering Sea (see description in modeling section). Depending on the success of tag deployment experiments, scientists will seek funds in 2007 and 2008 to initiate tag deployments for snow crab and Tanner crabs in the eastern Bering Sea.

Ice-dependent seals – The distribution of ringed, bearded, and spotted seals may contract north as the Bering Sea climate changes. The summer distribution of harbor seals may also expand farther into the Bering Sea. In addition, the number of ribbon seals could drastically decline as they lose their essential breeding and molting platforms on sea ice within their critical foraging areas in the

Bering Sea. Satellite tagging of seal species ($150K/year) will help understand the extent of potential change.

Project 11 (Spring ice-edge study of ice-dependent seals and their prey: Process study).

LOSI investigators propose to augment NPCREP and BEST studies of ice edge processes with investigations of ice dependent seal diet and foraging behavior. LOSI will provide funds to tag seals, process movements, and assess foraging behavior. Prey fields will be assessed using acoustics as part of the NPCREP program.

Project 12 (Growth to critical size).

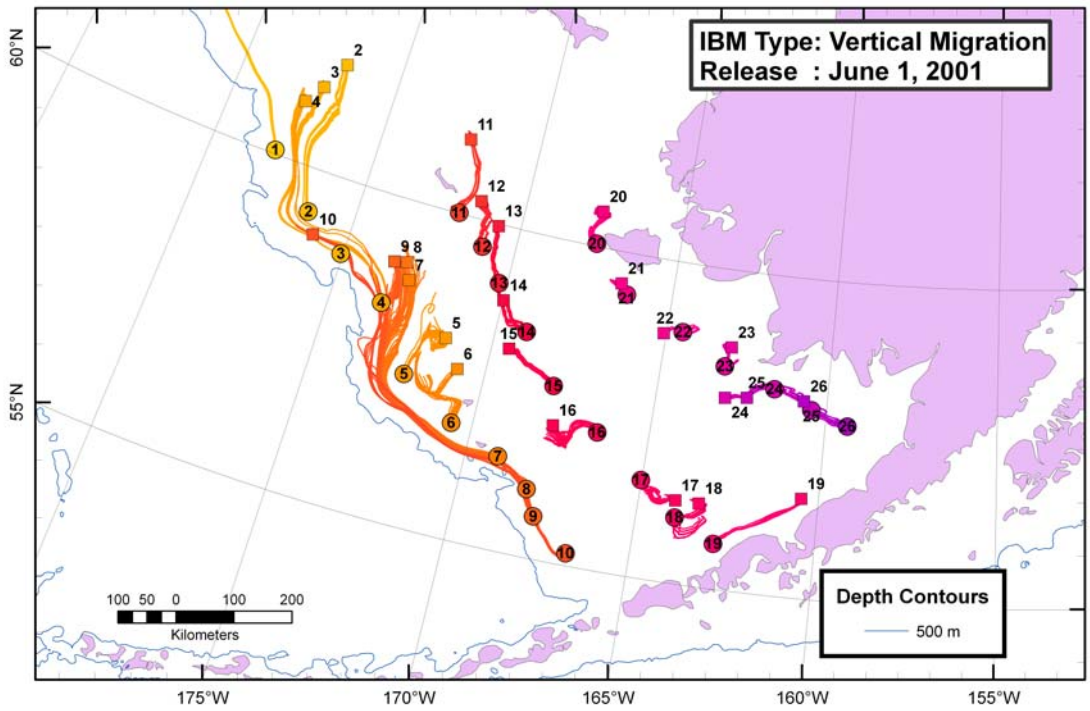
The sea ice retreat will create a later spring bloom, better coupling between primary and secondary production, and higher prey availability for juvenile fishes. These changes will extend the length of the growing season for marine fish. Extended growing seasons will favor species that rely on growth to a critical size during summer to survive the following winter (i.e., pollock, salmon) or accumulation of sufficient fat reserves to survive the following winter (i.e., herring, capelin).

Project 13 (Integrated field-laboratory studies of fish and shellfish temperature preferences and sensitivities: Process study).

Climate-change effects on growth and survival of Bering Sea Pacific cod - Determine the effect of climate related changes in sea ice and lower trophic level productivity on the growth and survival of early life stages of Pacific cod in the Bering Sea. Climate-related changes in sea ice conditions in the Bering Sea affect the timing of spring plankton blooms and likely drives the vital rates and distributions of important commercial fish populations during early life stages. Late ice retreat is coupled with an early bloom (Mar.-Apr.) in cold water (0-2° C) whereas no ice or and early retreat of ice results in an open-water bloom in May-June in warmer water (2-4° C). Pacific cod may be particularly vulnerable to such changes because of their relatively discrete spawning period during the spring and the resulting potential for mismatches with prey production. We will develop models to test two hypotheses which predict differing responses of marine larvae/juveniles to the magnitude and timing of prey production in the Bering Sea. The first, Oscillation Control Hypothesis (OCH), states that late blooms in warm water result in high food production and consequently favor marine larval survival (Hunt et al. 2002). The alternate scenario, based on the match-mismatch hypothesis (MMH), states that early blooms provide better conditions for fish because of the closer temporal ‘match’ in prey and larval cod production (Cushing 1990). Both mechanisms have been suggested for Bering Sea fish populations, but neither has been examined explicitly. Hypothesis testing will be accomplished through an integration of laboratory experiments and population models for Pacific cod. Laboratory experiments will focus on the growth and survival responses of larval and juvenile stages of cod exposed to varying temperature and food regimes. Then, the two hypothesis will be tested by developing models for the Bering Sea using a combination of the laboratory results and available field data on body size (monthly averaged), spatio-temporal temperature data (remotely sensed SST) and data on spatio-temporal productivity from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project. The result will be spatially explicit projections of survival probabilities at monthly and annual scales for the Bering Sea suitable for distinguishing the primary mechanisms that affect climate-related variability in productivity of Pacific cod.

Project 14 (Coupled bio-physical model: Modeling).

A core team of ocean modelers capable of developing and maintaining ocean circulation and coupled biophysical models will be created. In the near term, observed summer currents derived from drifter trajectories will be compared with modeled currents generated by the North Pacific circulation model (NEP), which has been implemented at 10-km resolution. AFSC and PMEL scientists will work together to provide annual maps of fronts and current features during summer, based on this model (Appendix Fig. 2-1). The NEP model is based on the Regional Ocean Circulation Model (ROMS; Haidvogel et al. 2000; Moore et al. 2004, Shchepetkin and McWilliams 2005). ROMS is a terrain-following, free-surface primitive equation model with sophisticated data assimilation capabilities. It is capable of simultaneously computing both tidal and sub-tidal currents, and the resulting mixing and density fields; PMEL scientists are currently using ROMS for this purpose in the Coastal Gulf of Alaska under GLOBEC support. A spatially nested set of models based on ROMS are currently in use for multiple studies of the Northeast Pacific (NEP); model coupling is described in Curchitser et al. (2005). Boundary conditions are derived from the global Community Climate System Model (CCSM); this will ultimately provide both hindcast and forecast (climate change scenario) global conditions. Preliminary NEP runs with ice dynamics (but no tides) are now available for simulation years 1958-2000. Previous modeling studies (Hermann et al. 2002) underscored the importance of tidal dynamics in setting the location of frontal features in the Bering Sea; presently our NEP hindcasts are being modified to include such tidal dynamics. AFSC scientists will utilize the model output (3D flow trajectories and maps of convergence) to identify regions of larval or prey retention. These maps will be provided on the world-wide-web and investigators will develop tools to display this information in ArcMAP.



Appendix Figure 2-1. -- Map of individual based model (IBM) tracks for particles that vertically migrate diurnally between depths of 5-20 m at night and 80-100 m during the day. Particles were released on 1 June 2001 and tracked for 70 days. Circles denote release locations, squares indicate final location of 1 track per release location. At each release location, 25 particles are simultaneously released over a small 5 × 5 grid centered on the release site.

A portion of the NEP modeling work is supported under separate programs (e.g., GLOBEC, NPCREP). Support from the Bering Sea Ecosystem (BEST) program is being sought to develop a 3-km version of ROMS for the Bering Sea and to drive these circulation and related biological models with a subset of the IPCC climate projection scenarios. Support requested here will be used to 1) refine the ice dynamics and mixing algorithms of these models, which, in conjunction with tides, are key to setting the correct location of frontal features; 2) compare circulation hindcasts with drifter data collected under this and other programs; 3) incorporate field data collected under this and other NPRB-funded work into an adjoint-based data assimilation scheme. Data for assimilation include the XBT data resulting from this project, and the current, temperature and salinity time series from PMEL's long-term moorings M2, M4, M5, and M8, which span the Eastern Bering Sea shelf domain.

The model above will be utilized to assess the distribution and dispersion of larval pollock, rock sole, and snow crab. It is likely that investigators striving to couple oceanographic models to NPZ models as part of the BEST and NPCREP programs will collaborate with LOSI fisheries oceanographers to link oceanography and prey fields to LOSI larval survival models.

Project 15 (Development of a bioeconomic spatially explicit mode: modeling).

LOSI funds will fund development of spatially explicit bio-economic models for marine fish and for maintaining these models once they have been developed. Funds will be utilized by AFSC's modeling core team to accelerate projects. These investigators will collaborate with LOSI field programs to ensure that the data collected can be readily utilized in these models.

Project 16 (Enhancing ecosystem models: modeling).

LOSI funds will fund exploration of techniques for modeling ecosystem level responses to climate change. Funds will be utilized by AFSC's modeling core team to accelerate projects. This funding will also include staff to assess new species if fisheries develop in the Arctic. These investigators will collaborate with LOSI field programs to ensure that the data collected can be readily utilized in these models. Models of climate, oceanography and biota will be nested and include economic and sociological outcomes.

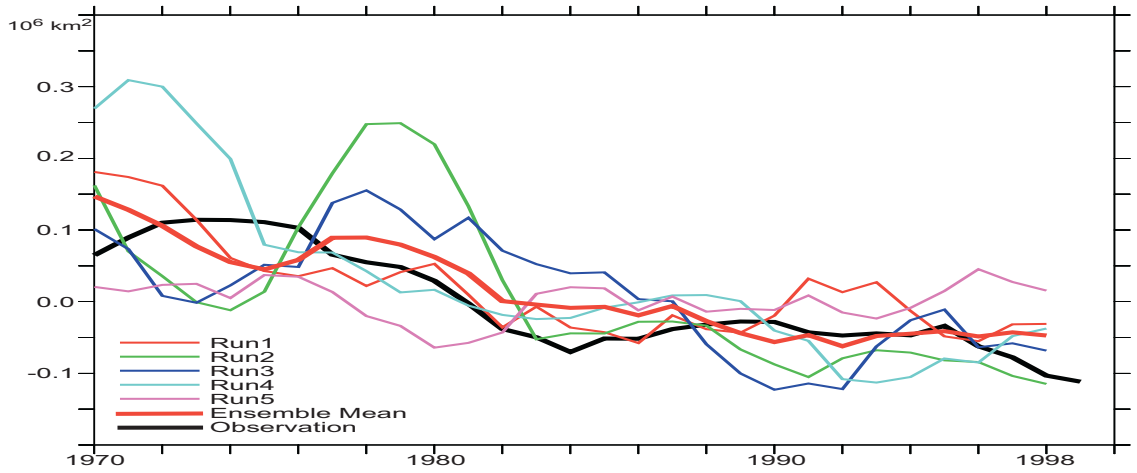
Project 17 (Core climate modeling team: modeling).

There is a clear need to provide future climate scenarios for the LOSI program. While the climate has shown long-term trends in sea ice and temperature since the 1970s, there is also large variability on decadal scales in the Bering Sea that are typical of high latitude conditions.

The current generation of climate models now under development that are included in the fourth Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) are a major advance over previous climate projection studies in terms of resolution, physical processes, and careful validation by a large number of international researchers. Results from about one-third of the 20 available climate models show similarity to 20th century Arctic climate, in terms of representing ice processes and capturing the large natural climate variability in the western Arctic. LOSI will make use of the projections from a subset of IPCC models to provide a quantitative range of future conditions. This project shifts the understanding of future sea ice from the current more speculative approach to providing quantitative outlooks to drive the process-oriented ecosystem models.

Climate scenarios will be developed making full use of recently available results from 15 state-of-the-art coupled atmosphere-ocean climate models which are part of the IPCC's AR4. A subset of these models, found to represent the Bering Sea reasonably well based on *in situ* data for the late 20th century, will be used to forecast ocean climate scenarios and assess attendant uncertainty. We consider both forced climate change from increased greenhouse gases and natural climate variability, such as seen in 20th century regime shifts. Preliminary analysis shows that some models provide reasonable simulations of sea ice for 1970-1999 (Compare the model (red line) with observations (black line) for the NCAR Community Climate Model in). It is also important to assess the range of natural variability in climate; this is accomplished by running the model several times with slight variations in initial conditions (see thin lines in Appendix Fig. 2-2). Such plots provide initial confidence for providing climate scenarios over the next 25 years.

LOSI funds will fund model development and a modest core research team within NOAA to support the long-term modeling needs necessary to forecast impacts of climate change on sub-arctic and arctic ecosystems.



Appendix Figure 2-2. -- Time series of sea ice area anomalies for the Bering Sea based on the CCCMA-CGCM3-T47 model simulations for March 1970-1999. There are five realizations provided by this model, and the thick-solid red line indicates the ensemble mean (average of the five runs). The thick black line is the time series of observed values.

Project 18 (Species identification and abundance estimation for benthic infauna and benthic epifauna: monitoring).

Grebmeier et al. (2006) hypothesize that climate change will influence the standing stock of benthic species. Our understanding of the species-specific responses of different members of the benthos is limited and comprehensive surveys of this aspect of the ecosystem have never been conducted. This project seeks funds to augment proposed extensions of AFSC's groundfish /crab trawl surveys to allow time to collect benthic grab samples. Funds are also needed to hire benthic ecologists capable of identifying species during the survey. Species that are too small to identify at sea will be preserved and brought back to the laboratory for identification. Expected outcomes of this project include: abundance estimates for selected species of benthic infauna and benthic

epifauna; new data to ground-truth biomass estimates derived from food habits estimates; new data to derive species-specific responses to shifts in ocean conditions at or near the bottom.

Project 19 (Biophysical mooring: monitoring)

Funds will be provided annually by LOSI for partial support of the primary biophysical moorings on the Bering Sea shelf. This includes support for additional "cutting edge" instruments to monitor zooplankton, hydroacoustics for sampling fish populations, acoustically monitor mammals and the thickness of ice, and the addition of real-time moorings in the northern Bering and Chukchi Sea. Moorings measure temperature, salinity, currents (ADCP), nitrate levels, and fluorescence at hourly, or shorter, intervals. Moorings are deployed and recovered in May (when possible) and again in September each year.

APPENDIX 3

ORGANIZATION OF LOSI RESEARCH BY TYPE OF ACTIVITY

Physical Monitoring
Project 1 - Near surface underway sampling
Project 2 - Water column properties sampling
Project 19 – Biophysical moorings

Biological Monitoring
Project 3 - Expand Bering Sea surveys to encompass northward movement of managed species
Project 4 - Summer zooplankton sampling.
Project 5 -Acoustic sampling from ships of opportunity
Project 6 - Sustain standard cetacean sighting and passive acoustic detection surveys
Project 7 - Is it Food?
Project 18 - (Species identification and abundance estimation for benthic infauna and benthic epifauna: monitoring).

Process Studies
Project 7- Is it Food?
Project 10 - Movement studies of fish, shellfish and marine mammal species
Project 11 - Spring ice-edge study of ice-dependent seals and their prey
Project 12 - Growth to critical size
Project 13 - Integrated field-laboratory studies of fish and shellfish temperature preferences and sensitivities

Retrospective Studies
Project 8 - Comparative study of seasonal oceanography
Project 9 - Development of a conceptual model

Modeling
Project 14 – Coupled biophysical models
Project 15 - Development of a spatially explicit model
Project 16 - Enhancing ecosystem models
Project 17 - Core climate modeling team

APPENDIX 4

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