Summary of BEST Open Implementation Workshop
Victoria Conference Centre, Victoria, B.C., Canada
May 16, 2005

❖ The Workshop

The Bering Ecosystem Study (BEST) Open Implementation Workshop was convened from 08:00 to 18:30 on 16 May 2005, at the Victoria Conference Centre, in association with the Global Ocean Ecosystem Dynamics (GLOBEC) Symposium on Climate Variability and Sub-arctic Marine Ecosystems (see http://www.pml.ac.uk/globec/structure/regional/essas/symposium/annoucement.htm). Approximately 130 participants attended the workshop, underscoring the science community's interest in the proposed BEST program and the Bering Sea (see Appendix I for a list of participants). This Open Implementation Workshop was designed to inform the extensive stakeholder and scientific communities about the opportunities for climate-related research in the Bering Sea, particularly research opportunities in the BEST program, and to elicit comments on the draft BEST Implementation Plan. To ensure that the BEST Implementation Plan incorporated the concerns and interests from a broad constituency of researchers, resource managers, fishers, and Alaska Native communities, participants from a wide array of disciplines and backgrounds were invited to the workshop. The diverse workshop participation will ensure that the final BEST Implementation Plan is responsive to the needs and concerns of the multiple stakeholder communities and provides NSF with a broad-based sense of the interest and participation in climate-related ecosystem research in the eastern Bering Sea. The recommendations of the workshop participants also helped to refine the needs and objectives of a field program starting in March 2007 for the beginning of the International Polar Year 2007–2008 (IPY).

The workshop agenda (see Appendix 2) included introductory talks by George Hunt and Ben Fitzhugh who described, respectively, the natural science and human dimension aspects of the proposed BEST science program. These talks were followed by presentations from various stakeholders who will likely interact with the BEST program, including people who rely on the local marine resources or who are involved in research programs in the Bering Sea. In the afternoon, three breakout groups:

- remote/local physical processes,
- plankton dynamics, and
- upper-trophic levels, including people,

addressed the need for modification of the draft BEST Implementation Plan and made suggestions for the design of a field program. A final plenary session discussed the results of the breakout group discussions.

❖ Presentations

➢ Introduction of Draft BEST Implementation Plan - George Hunt, University of Washington

This presentation provided an overview of the BEST program objectives and time-line, and described the scientific priorities and collaborative research and funding opportunities outlined in the draft BEST Implementation Plan.

The BEST program has been developing since late 2002:
- Sept. 2002 Planning Workshop, Laguna Beach
- Mar. 2003 Planning Workshop, Seattle
- Oct. 2004 Science Plan published
- Mar. 2005 Scientific Steering Committee formed
- May 2005 Open Implementation Workshop

The tentative timeline includes the following:
- June 2005 Implementation Plan ready
- Nov. 2005 Possible time for an NSF Announcement of Opportunity (AO)
- Jan-Feb. 2006 Proposals due 90 days after AO
- Mar. 2007 Begin field program for the start of IPY

Future work will include planning efforts to catalyze outreach and implementation activities, the development of working groups as necessary to advance BEST implementation activities, and the establishment of close ties with other research (e.g., NOAA Fisheries) and funding (e.g., North Pacific Research Board) programs.

➢ Sustaining the Bering Sea Ecosystem: A Community-Driven Social Science Planning Process - Ben Fitzhugh, University of Washington

This presentation described the activities and objectives of the human dimensions aspects of the BEST program (H-BEST), which Ben has been developing with the assistance of Catherine Foster, Henry Huntington, Mary Pete, and Anna Kerttula, as well as inputs from many others. H-BEST seeks to seamlessly weave the social and natural science components of the BEST program together and is motivated by the need to better understand the ways environmental and climatological changes in the Bering Sea impact local communities and their responses to these challenges. These impacts are wide-ranging and include changes in resource extraction (commercial and subsistence) activities, shifts and predictability of weather, and potential changes and impacts associated with changes in shipping lanes in the face of retreating sea ice.

The H-BEST science plan addresses three main topics: (i) studying interrelated human-environment dynamics, (ii) assessing the resilience of local communities to this environmental change, and (iii) ensuring the engagement of local communities in the BEST program, both via their participation in research activities and through outreach efforts to make the scientific findings of the program widely available.

The development of the H-BEST science plan is founded on three principles: (i) making the needs and concerns of resident communities a top priority, (ii) learning what these communities want to know about the environmental changes currently underway in the Bering Sea, and (iii) establishing collaborations between natural and social scientists to address the interrelated human-environment dynamics at play in the Bering Sea.

The timeline of the H-BEST process is slightly behind the natural science dimension (initiated in September 2002). The H-BEST planning process was initiated at a workshop convened in March 2004, followed by presentations at the International Arctic Social Science Association (IASSA) in April 2004, and at the American Association for the Advancement of Science (AAAS) in September 2004. Following the March 2004 meeting, a set of guidelines were established to guide the developing H-BEST Science Plan: (i) the importance of facilitating the self-determination of local communities in face of environmental change, (ii) the need to incorporate guidance of local communities in terms of the program goals and research needs, and (iii) the commitment to pursuing applied research that provides tangible solutions and addresses the needs of local communities. To follow these guidelines, an interdisciplinary program with a broad spatial and temporal scope will be required. Such a program will address several space (e.g., households, villages, regions) and time (e.g., prehistory, history, contemporary) scales in a comparative fashion. Four priority H-BEST research themes have been identified: (i) traits promoting resilience and adaptability of local communities, (ii) end-to-end research of natural and social impacts of climatic variability, (iii) the role of humans in the Bering Sea ecosystem, and (iv) the social implications of environmental change.

The integration of the natural and social systems will follow the physical dynamics of the Bering Sea, as physical changes lead to ecological changes that permeate the marine food web, eventually impacting subsistence and commercial harvests and communities. To achieve a thorough understanding of these coupled physical-biological-social dynamics, H-BEST will rely on a variety of research approaches, including ethno-history, traditional ecological knowledge (TEK), archaeology, public health, economics, and anthropology. These approaches will yield information spanning back thousands of years into the past.

In addition to devising priority research themes and guidelines, it is critical to develop compelling outreach and educational projects to ensure the wide availability of the BEST science to the public and its application to answer tangible questions and problems. Effective "cultural translation" will be required to bridge the inherent differences between researchers in different disciplines (natural and social sciences), and between scientists and the public. In particular, effective research and outreach efforts will have to be sensitive to the cultures of the Bering Sea inhabitants. Planned visits to local communities throughout the region and "translated sessions" at the Alaska Federation of Natives meeting (fall 2005) will help forge culturally sensitive outreach and education programs involving local communities.

In spite of the slight delay in the start-up of the H-BEST program, the H-BEST and BEST implementation plans are developing in parallel, spurred by the desire to forge close collaborations early on. Next H-BEST steps include providing feedback to the BEST Implementation Plan, merging the social and natural science plans (summer–fall 2005), and developing the H-BEST Implementation Plan.

- **The Importance of Subsistence Harvests and the Concerns of Alaska Natives – Mary Pete, Alaska Department of Fish and Game**

Imarpik—the Bering Sea—is viewed by the Yup'ik people as a "big bowl", which provides resources to sustain local communities. Currently, over 70,000 people live on both sides of the Bering Sea, with over 55,000 Alaskans making use directly or indirectly of the marine resources of the Bering Sea. Annually, over 25 million pounds of dressed subsistence foods are produced, and the Alaska Department of Fish and Game (ADFG) has amassed a valuable 25-year time series to study the patterns of resource use by local communities. These data suggest that there are specialties in the patterns of resource extraction, and that very few individuals are subsistence-only users, since most people will supplement subsistence uses with commercial harvests or other economic activities.

This information also underscores the very specific information needs of Native communities, which relate to the ways the physical conditions and resources of the Bering Sea are changing. In particular, subsistence activities are impacted by the unpredictable nature of the weather and sea ice in recent years. Weather conditions affect Native communities by changing the distributions of marine resources and by impacting their ability to travel over the ice. Thus, local communities would like to be able to predict weather conditions over short and long time scales.

Effective research should be guided by a spirit of mutual understanding and appreciation. This requires acknowledging local contributions and perspectives and making the research mutually informative, relevant, regionally comparable, and collaborative.

- **What the Commercial Fishery Needs to Know – David Fraser, Commercial Fisherman, Port Angeles**

Commercial fishers are another major constituency with a stake in the BEST program.

As part of their "culture", fishers obtain information about the status of the Bering Sea through specific channels (e.g., Fishery Management Council stock assessment reports). Increasingly, these reports are including "ecosystem" chapters, which relate the status of fisheries to the ecology of other species and to the productivity of the entire Bering Sea ecosystem.

Fishers are very interested in climatic variability, especially as it pertains to unpredictable oceanographic regime shifts and stock recruitment and trends. These large-scale environmental changes impact fisheries at many levels, by introducing ecological uncertainty with grave economic implications. Because environment change operates at many temporal scales, the information needs of fishers are also scale-dependent:

- Short-term (~ months) information needs relate to the distribution and maturity of target species (e.g., pollock) in response to the changing extent and location of the cold pools. An example of these short-term applications is the forecast of the roe maturity in pollock, which is depends on water temperature and influences the price received for the roe. Other potential future ecosystem-level implications of water temperature forecasting include minimizing salmon bycatch.

- Intermediate-term (~ years) information needs include predicting the dispersion and trends in the biomass of target species. For instance, the spatial distributions and abundance of cod are correlated with the location of the cold pools (water temperature $< 2^{o}C$). Another potential intermediate-term implication entails the northward range shifts in epibenthic fish species (e.g., yellowfin sole) north of $59^{o}N$, which have been reported by fishers.

- Long-term (~ decades) information needs relate to the abundance of different target stocks during different oceanographic regimes. For instance, fishers need to anticipate shifts between rockfish/crab/pollock regimes to shift their effort and investment. Other important long-term management implications include the "spiky" nature of recruitment in long-lived species (e.g., rockfishes), and the improved understanding of the links between fish stocks from different fishery management areas (e.g., Bering Sea/Aleutians).

In summary, fishers are aware of the complicated temporal variability of the Bering Sea ecosystem and want information at the relevant temporal scales, which will allow them to make informed decisions about how to invest and exploit these marine resources. Moreover, because fishers depend on the marine environment and document its changes, their input will be essential to the study and management of the Bering Sea. In essence, a strong partnership between fishers and researchers will be critical to ensure effective research and resource management. A prime example of this collaboration is the use of fishing vessels as platforms of opportunity to monitor—in a relatively inexpensive fashion—the Bering Sea over broad scales of space and time.

- **NOAA's North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) and the Loss of Sea Ice (LOSC) Programs – Jeff Napp, Alaska Fisheries Science Center, Seattle**

NOAA Fisheries has documented pervasive physical and ecological changes in the Bering Sea (1950–2004). To better quantify and understand these ecosystem-wide changes, NOAA has developed two research programs that address environmental change in the Bering Sea: the North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) and the Loss of Sea Ice (LOSC). An overarching goal of NOAA is to coordinate research efforts in the Bering Sea with other activities derived from NSF, NPRB, USGS, USFWS funding. In particular, the recently created LOSC program will provide opportunities for collaborative studies of biological responses to climate change, including species range shifts, changing larval transport patterns, shifts in the availability of prey resources in the vicinity of pinniped rookeries, and the establishment of new biological interactions (e.g., host-parasite).

The establishment of a multi-agency Climate Change and the Bering Sea Ecosystem working group in April 2005 will help coordinate future research and funding activities in the Bering Sea. In addition to coordinated research, it will be critical to develop integrated outreach activities, including symposia, publication of special volumes in research journals, and educational products.

- **National Marine Fisheries Service (NMFS) Field Activities – Anne Hollowed, Alaska Fisheries Science Center, Seattle**

NOAA Fisheries conducts a vast array of stock assessment surveys in the Bering Sea, including acoustic transects, longline surveys, and trawl surveys. Some of the most comprehensive surveys are the pollock echo-integration/trawl surveys targeted for the Bering Sea in 2006. The bottom-trawl surveys sample the eastern Bering Sea annually and the Gulf of Alaska/Aleutians every other year during May–July and August–September and quantify fish habitat associations. Longline surveys by the Auke Bay laboratory focus on the shelf-break of the Gulf of Alaska and the Bering Sea from June through late August. In addition to these fish stock assessment cruises, marine mammal aerial/ship/shore-based surveys target pinniped rookeries and at-sea distributions of cetaceans. NOAA also conducts focused process-oriented studies looking at the foraging ecology of Steller sea lions, including interactions with forage fish and cod trawling/abundance in the vicinity of haul-out sites. These surveys vary in the types of physical data collected. For instance, while NOAA vessels routinely gather a vast suite of physical and biological data (e.g., CTD and underway data), the charter vessels used for trawling surveys collect a narrower subset of measurements (e.g., temperature profiles from net casts). Increasingly, NOAA is using these physical and biological data to develop biological indicators to assess the status of the marine ecosystem. For instance, the "trawling impact index" uses habitat-specific information on fishing effort, proportional reductions in extent, and inherent recovery rates after disturbances to evaluate the susceptibility of different benthic habitat classes to trawling.

- **The Alaska Ocean Observing System (AOOS) – Tom Weingartner, University of Alaska, Fairbanks, (on behalf of Molly McCammon, AOOS Executive Director)**

AOOS (www.aoos.org) covers a vast geographic area subdivided into three regions: Bering Sea/Aleutians, Gulf of Alaska, Arctic. Each region is characterized by specific needs and perspectives within the realm of AOOS activities and the broader national ocean observing strategy. The U.S. OOS includes responsibilities for weather prediction, national security and navigational safety, effective resource management, and public education.

The top four AOOS information needs involve: (i) improved bathymetry for all the study areas, (ii) effective coordination of field and modeling activities and funding, (iii) acquisition and use of real-time data, (iv) particularly for sea-ice forecasting. Due to the importance of sea ice, it is essential to consider the need for expensive radar imagery. Additionally, the long-term maintenance of biophysical moorings will require the coordination of funding.

- **Bering Sea/Aleutian Salmon International Survey (BASIS) – Jack Helle, International Pacific Anadromous Fish Commission**

BASIS is an international research program (Japan/Russia/U.S.), initiated in 2001, to address the concurrent declines in salmon stocks in Asia and North America. BASIS focuses on retrospective and contemporary studies to determine the carrying capacity of the Bering Sea for salmon populations. BASIS started an ecosystem study of the epipelagic (upper 10 m of water column) realm in 2002, focusing on the ecology of juvenile salmon and forage fish in summer–fall (August–October). Plankton (including gelatinous species) distribution data have been collected as part of this project and are available for other ecosystem-level studies. To ensure data standardization across sampling gears, calibration experiments involving side-by-side sampling by the three national vessels were conducted in 2002.

Some of the current BASIS products include spatially-explicit models of growth potential for young-of-the-year (YOY) pollock and sockeye salmon, forced with information on forage fish energy density and at-sea distributions. While these models and carrying capacity calculations have thus far focused on juveniles, BASIS wants to tackle immature and adult fish in the future.

Even though BASIS was envisioned as a 5-year program (2002–2006), it will be expanded into the future. For instance, Japan is undertaking a 2006 winter-time cruise

(January–March). The critical issue of increasing salmon bycatch as water temperature in the Bering Sea rises will likely become the focus for future long-term studies.

- **North Pacific Research Board (NPRB) Activities – Clarence Pautzke, North Pacific Research Board**

To date, NPRB's awards have totaled $17 million funding 94 projects. Since funding started in 2002, NPRB has released four requests for proposals. NPRB expects to distribute $6 million per year in the next four years, following an annual timeline of a fall (October) RFP, a winter (December) proposal deadline, followed by a January science symposium. NPRB's draft science plan for the next 7–10 years outlines the development of an integrated plan, with regional components.

To fulfill this timeline, NPRB will need to have a set of clear research needs from the community by late August. NPRB plans to organize three workshops (June–August) to refine and incorporate these guidelines into the 2005 RFP. NPRB will consider both the social and natural science dimensions of BEST and has already set aside funds ($250,000) for "local traditional knowledge" (LTK) proposals

- **PICES/GLOBEC Climate Change and Carrying Capacity (CCCC) program – Hal Batchelder, Oregon State University**

The goal of the CCCC program is to provide a strategy to determine the carrying capacity of the higher upper-trophic predators (salmon, pollock, birds, mammals) in the subarctic North Pacific. As part of this program, a cooperative plan has been developed to study how climate affects fish productivity following the regional GLOBEC model of integrating modeling, process-oriented observations, retrospective analyses, and synthesis activities. This program started in 1993, under the auspices of PICES and will likely continue until 2009. A major synthesis meeting is planned for 2006.

These CCCC activities were organized into four task teams: Model, Basin-Scale (BAS)—focusing on oceanic processes, Regional Experiments (REX)—focusing on coastal processes, and Monitor. These task teams were fluid, and eventually REX and BAS merged into the Climate Forcing and Marine Ecosystem Response task group (CFAME), which met recently for the first time.

This approach to synthesis in CCCC is based on three main building blocks: modeling, process-oriented studies, and retrospective analyses. In addition, to facilitate synthesis and integration, two modeling approaches were adopted: (i) broad-based ecosim/ecopath models, and (ii) seasonal models of the lower trophic-level constituents. It became apparent early on that there was no single approach for achieving synthesis and no single synthesis goal. Thus, the lack of a prescribed end goal required a flexible approach with different routes and extrapolations. CCCC will assemble a variety of synthesis products, including broad-based ecosystem reports (3-year cycle), comparative regional summaries, and scientific meetings and symposia.

To ensure that the CCCC synthesis products were broadly applicable, it was critical to determine the program's constituency early on and to envision ways to communicate the results to those people who would use this information to implement actions. The certainty that the gained knowledge would eventually lead to societal benefits was a critical motivator for the research and the program as a whole.

❖ Open Discussion of BEST Implementation Plan

Jackie Grebmeier, University of Tennessee:

Highlighted the need to study benthic species and processes in the Bering Sea shelf and requested a more detailed explanation of the way this habitat and its associated taxa will be studied as part of BEST. In particular, four issues require more in-depth attention:

1. Study of the extent and location of the cold pool: Need to determine whether there will be declines in the size and extent of this physical feature, particularly in the northern Bering Sea shelf.

2. Demersal/pelagic coupling: While the BEST Implementation Plan addresses this topic, a more detailed explanation of the approaches/methods/measurements used to study the benthic communities is required.

3. Ecosystem-level responses: The BEST Implementation Plan describes changes in the productivity and structure of the Bering Sea ecosystem, but this discussion is dominated by a focus on the pelagic realm. To fully understand the response of the Bering Sea ecosystem, it is critical to include species that feed on the benthos (e.g., eiders, walrus).

4. The BEST Implementation Plan also needs to consider mid-shelf benthic organisms (e.g., crabs, sole), which may serve as useful indicator/sentinel species.

Allan Devol, University of Washington:

Stressed the importance of denitrification (the conversion of nitrate and nitrite back into N_2 due to reduction in sediments) in shelf systems. Rowe and Phoel (1992) suggest that up to 51% of nitrogen in sediments may be lost via denitrification in the Bering Sea shelf. An implication of this increased denitrification is a shift in the Redfield ratio of N:P from 16:1 to 12:1.

Rowe GT and Phoel WC. 1992. Nutrient regeneration and oxygen-demand in Bering Sea continental-shelf sediments. Continental Shelf Research 12 (4): 439-449.

Potentially, a higher proportion of nitrate/nitrite may be lost during periods of low oxygen concentration, particularly when the spring phytoplankton bloom is diverted to the benthos. Additional biological implications influencing the magnitude of sediment denitrification include changes in productivity and changing bioturbation patterns due to shifts in the composition of benthic communities. Enhanced productivity stimulates denitrification, drawing down nitrate/nitrite. Declines in the abundance of burrowing species—known to influence the sediment permeability via the building of tunnels—will also affect denitrification. In the subsequent group discussion, the influence of water temperature on carbon remineralization rates and the potential influence of changing N:P ratios for the formation of coccolithophore blooms were raised as additional topics of interest. Concerning the influence of bioturbation, the role of walruses and grey whales should also be considered, since these species disturb the seafloor when they feed benthically. The disappearance of these large disturbances may cause changes in benthic communities and influence local denitrification rates.

Integrating benthic studies into BEST poses several logistical complications. While benthic species and processes are important, there is little opportunity to contrast contemporary observations with historical measurements. For instance, benthic measurements of denitrification were performed along the PROBES* line, but only during a single cruise. Moreover, for logistical reasons related to the sample processing time and disturbance, it is inherently difficult to conduct benthic and pelagic sampling during the same research cruise. Thus, the benthic and pelagic surveys may not take place concurrently and from the same research vessels.

*PROBES is the Processes and Resources of the Bering Sea program, funded by NSF from 1974–82.

Carleton Ray, University of Virginia:

Stressed the ecological significance of walruses and grey whales for the benthos, by virtue of their benthic feeding and their dense aggregations. Walruses, in particular, inhabit shallow waters with broken pack ice, where they aggregate into vast herds (> 10,000 individuals). Walruses resuspend sediment, influence the chemistry of the sediment pore water, and alter benthic species assemblages by disturbing the bottom. A critical question that is currently unknown is whether walruses have changed their distributions as the broken pack ice has shifted/retreated. Because this species requires ice for hauling out and shallow water for foraging, a spatial mismatch between these two resources may prove critical.

Jim Overland, Pacific Marine Environmental Lab, NOAA:

Showcased NOAA's Bering Sea Climate and Ecosystem Web-site (www.beringclimate.noaa.gov), a repository of physical and biological datasets which provides online graphing and subsetting tools to view and plot these time series. Raised the question of whether the Bering Sea may be entering a new state where local conditions are becoming uncoupled from basin-wide patterns and stressed the need to "firm-up" the benthic component of the BEST Implementation Plan.

Rebecca Woodgate, University of Washington:
Stressed the need for a more detailed description of the physical oceanographic work required as part of the BEST Implementation Plan.

Victor Smetacek, Alfred Wegener Institute:
Highlighted the need to understand how the dynamics (extent, location, temperature) of the cold pools influence the formation and retreat of the sea ice in the Bering Sea shelf.

Lyn McNutt, University of Alaska, Fairbanks:
Reiterated the significance of sea ice for the ecology of the Bering Sea shelf. Sea ice plays a pivotal role because it is an integrator of climate, physics, and biology.

Anne Hollowed, National Marine Fisheries Service, NOAA:
The need for year-round measurements to understand year class strength of fish populations and other upper-trophic predators is very compelling. Due to the funding constraints, BEST will have to make choices in terms of the spatial and temporal scope of field activities.

Sandra Moller, Aleut Enterprise Corp., Adak:
Stressed the importance of balancing environmental protections for the Aleutians with the need to maintain economic activities and development of this region.

Randall Peterman, Simon Fraser University:
Highlighted the need to describe the functional relationships underlying ecological interactions. In particular, raised the example of the curvilinear relationship between feeding efficiency of fish larvae and wind mixing (quantified using the cube of wind speed). A similar model was described for anchovy larvae by Reuben Lasker in the California Current System. However, there is no evidence for such a relationship for pollock in the Bering Sea. Jeff Napp stated that there seems to be an interaction between light intensity and wind speed, such that with enhanced turbulence, fish larvae move deeper in the water column. In doing so, they occupy waters of lower light intensity, which can interfere with their visual feeding. This group discussion underscores the need to address the interactions between different environmental factors.

Randall Peterman, Simon Fraser University:
Questioned the use of models to guide the BEST field sampling and to test hypotheses in the field. If the models are used to link the various physical and biological observations (e.g., turbulence/zooplankton abundance/fish larvae abundance), it is critical to understand the functional responses underlying the mechanisms at play.

Jim Lovvorn, University of Wyoming:
Highlighted the importance of advection and transport for some of the upper-trophic predators (e.g., eiders), and suggested that the physical oceanography component of

BEST needs to provide the basis to understand these physical-biological interactions.

❖ Break-out Groups

The workshop participants broke up into three topic groups devoted to remote/local physical forcing, zooplankton-larval fish dynamics, and upper-trophic predators (including humans and social dimensions). Each group was charged with reviewing the BEST Implementation Plan with the goals of: (i) identifying knowledge gaps, missing topics, and unclear concepts, and (ii) suggesting revisions to the background, priority research questions, and research plan. The discussions of each break-out group were led by a moderator and recorded by a rapporteur not associated with the BEST Science Steering Committee. Below, we summarize the reports of the break-out groups.

I. Physics: Compiled by Albert Hermann, Pacific Marine Environmental Lab, NOAA

The physics break-out group provided three main suggestions: (i) the value of integrating the modeling and the field program from the very onset of the BEST program, (ii) the critical importance of acknowledging the "non-linearities" in the physical world, and (iii) the need to address the influence of freshwater inputs into the system, which can expand to within 50–200 km from shore.

This break-out group advocated the use of modeling to address how and where the field program will be instituted, to explore the sensitivity of the models to various parameters, to evaluate the spatial and temporal resolution of the field data required, and to assess potentially important regions to be targeted by field activities. Moreover, the modeling and field activities should also focus on quantifying the non-linear behavior of these coupled physical-biological systems (e.g., the timing and magnitude of specific events), in addition to quantifying the average conditions (e.g., monthly means of properties).

In addition to these general issues, this break-out group made the following logistical recommendations for the design of a field program: (i) the area between St. Paul and St. Matthew can provide important long-term comparisons with the PROBES dataset, (ii) it will be critical to perform sensitivity analyses of the three existing physical models of the Bering Sea using remote sensing data, to assess potentially key regions before the field program is initiated, and (iii) because many of the boundaries between different water masses are poorly understood (e.g., extent of freshwater plumes), the field activities may have to be adaptive in order to sample phenomena and habitats of changing location, dimensions, and timing.

II. Zooplankton: Compiled by Jim R. Lovvorn, University of Wyoming

The three main suggestions of the zooplankton break-out group were: (i) that more emphasis be placed on benthic systems and especially pelagic-benthic coupling, (ii) that the high-priority Module 1 be extended in geographic scope to include the northern Bering Sea, and (iii) the need to quantify the magnitude and role of advection.

The benthic component of BEST should relate back to how physical and biological processes in the water column affect the quantity and quality of organic matter settling to the bottom. These processes, in turn, provide food for walruses and bearded seals—important resources exploited by Native communities in the northern Bering Sea. The integration of the benthic research component into the BEST program will require some reorganization of the text, such as including references to benthic species (e.g., flounder, crabs) and benthically feeding upper-trophic predators (e.g., walrus, grey whales) throughout the text. For instance, replace "plankton community" with "planktonic and benthic communities", and refer to both "zooplankton" and "benthos".

The expansion of Module 1 activities into the north Bering Sea is critical, and will require adding some background material to highlight the peculiar physical-biological dynamics in this part of the shelf. On the northern shelf, Yup'ik people depend economically and culturally on the harvest of marine mammals, supported by food webs of both the water column (e.g., bowhead whale) and benthos (e.g., walrus, bearded seal). These food webs, in turn, are influenced by interactions between ice cover and the strength of the Anadyr Current. In the northern shelf, ice patterns affect not only the nature and productivity of food webs, but also the accessibility to foods by marine mammals, and accessibility to marine mammals by human hunters. In order to characterize the relative effects of ice cover vs. advection on the food webs on the northern Bering shelf, a field season will likely have to be expanded into July.

This break-out group also highlighted the need to address ecosystem responses to cross-shelf advection. Spatial patterns of primary productivity on the eastern Bering Sea shelf are affected by upwelling at the shelf break and advection of those nutrients onto and across the shelf. In contrast to much of the central and southern shelf, where cross-shelf flows are relatively weak, the physics and biology of the northern portion (e.g., Chirikov Basin) are strongly influenced by cross-shelf advection by the Anadyr Current. Consequently, interactions of wind, sea ice, algal blooms, and carbon flows to pelagic and benthic food webs may differ appreciably between the sluggish southern and central shelf vs. the highly advective northern shelf. The physics and biology of the Chukchi Sea and western Arctic Ocean are, to a great extent, defined by processes in the advective portion of the northern Bering Sea. Thus, regional studies in these regions are key to understanding patterns at much larger regional and hemispheric scales.

Break-out group participants voiced three main concerns relating to the research approach: (i) the need to address upper-trophic predator climatic responses in terms of functional and numerical responses, (ii) the importance of these functional responses to understand and model the distributions of predators relative to the distributions of prey,

(iii) the value of understanding what factors cause variation in advection of slope species onto and across the southern/central/northern shelf of the Bering Sea.

Finally, the plankton break-out group also made some logistical recommendations: (i) real-time access to imagery during cruises will help identify and prioritize adaptive sampling opportunities, (ii) the critical need to ensure access to satellite data well in advance of any field activities to minimize the associated costs, (iii) the importance of coordination efforts to exploit collaborative funding and ship-time opportunities with other agencies (e.g., NOAA, NPRB) well in advance of the field program, and (iv) the need to expand the field season from June to July to maintain compatibility with long-term monitoring data on the north-central Bering Sea shelf.

III) Upper-trophic Predators: Compiled by Anne Hollowed, NOAA

The upper-trophic predator break-out group, which included the role of and impacts on humans and social systems, stressed the need for clear scientific objectives and key research questions. The candidate key questions provided by this group included: Why are populations of upper-trophic predators in the Bering Sea changing? What can scientists and resource managers do in response to these changes? How will Native communities survive in the face of these changes? How will the social systems in these communities respond? What are the traits that make certain biological and social systems more or less resilient to these environmental changes? Are there diagnostic spatial scales associated with the observed climatic changes in the productivity of the Bering Sea? How will these changes affect the management of marine resources (e.g., stock-assessment relationships, species ranges, the location of fishing grounds, the interactions of protected species with fisheries, and the design of Marine Protected Areas)? In summary, this break-out group felt that because the Bering Sea is undergoing dramatic changes, the BEST research questions need to clearly reflect the magnitude of these physical and biological shifts and their ecological and social implications.

This break-out group also raised three questions concerning the scope of the BEST Implementation Plan: (i) the focus on the physical-biological interactions seems to stop at the level of the zooplankton and does not address the functional responses of the upper-trophic predators (e.g., fishes, birds, marine mammals, humans), (ii) there is a critical need to acknowledge the human implications that go beyond climatic effects by addressing changing cultural and social systems, and (iii) the program needs to take advantage of opportunities for establishing broad-based partnerships with Bering Sea stakeholders, including local communities and commercial fishers.

Finally, this break-out group discussed the need for integrating the lower-trophic level investigations (physics-productivity-plankton) currently described in the BEST Implementation Plan with similar studies of upper-trophic predators. Whether these two components will be undertaken using different field programs funded by separate sources is unclear. Nevertheless, the effective end-to-end integration of the top-down and bottom-up perspectives will require an understanding of the mid-level ecosystem constituents (e.g., larval fish, forage fish, squid).

Some of the logistical recommendations of this break-out group included: (i) the value of developing functional ecosystem indicators in conjunction with other funded initiatives (e.g., NPRB seabirds as indicators workshop, funded for 2006), (ii) the need to quantify both temporal and spatial variation in physical (e.g., sea-ice characteristics) and upper-trophic predator responses (e.g., diet) to compare regional physical and ecosystem responses, and (iii) the critical importance of taxonomic information—in addition to biomass—to better assess changes in plankton populations and ecosystem-level responses.

❖ Synthesis Discussion of BEST Implementation Plan

The workshop participants reconvened in plenary to review the reports of the three break-out groups. An open discussion followed the presentations of the group recommendations by the three rapporteurs (see previous summaries).

- Important to highlight the potential contribution of commercial fishers as platform of opportunity vessels to sample the oceanography and the biology of the Bering Sea ecosystem.

- The understanding of the ecology of upper-trophic predators (including human consumption and the associated social systems) will require a system-wide understanding. This approach will require developing social and natural science research questions in parallel. One of the key concepts shared by the natural and social science dimensions is the notion of adaptability of ecological and social systems to environmental change. This nexus provides a strong interdisciplinary focus.

- A critical way to bring together the lower- and upper-trophic level constituents will be to establish functional relationships (e.g., feeding success, recruitment dynamics, secondary and tertiary productivity) by the mid-level food-web constituents (e.g., larval and juvenile fish).

- The role of moorings for sampling the physics and the biology of the Bering Sea shelf is critical because these platforms will provide continuous (year-round) records and a way to relate conditions during field observations to past time series (1996–present). It seems critical to acknowledge that biophysical moorings capable of sampling biological indicators (e.g., oxygen concentration, optical properties like PAR [Photosynthetically Active Radiation], plankton backscatter) are vital for the ability to model physical-biological coupling. The use of moorings should consider appropriate use of profiling instruments, the potential for telemetering data back to shore, and the sampling constraints imposed by seasonal ice cover.

- Moorings may also be equipped with sensors to characterize size class information for plankton populations. Moreover, even though sediment trap records are subject to resuspension, they may provide useful information. Note recent sediment trap research at mooring site M-2.

- Species and size class composition of the plankton community is critical to understand ecological changes in the Bering Sea shelf. The importance of obtaining taxonomic information for the plankton cannot be understated. Critical implications include shifts from large-sized to small-sized copepods, shifts in diatom community structure, and the onset of toxic phytoplankton blooms. For the plankton, taxonomic analyses should consider other groups in addition to copepods and euphausiids (e.g., chaetognaths, appendicularians).

- Plankton analyses should also consider previously under-studied groups, such as micro-zooplankton and gelatinous plankton—including the small-sized jellies.

- Field studies may require developing the ability to sample the environment adaptively. Adaptive sampling will require developing methods to telemeter mooring data back to shore, operational oceanographic models to assimilate field data, and remote sensing products to guide the field sampling of specific oceanographic features.

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Appendix 2: Agenda

08:00	Registration for Workshop and Symposium - closes at 09:30
08:30	George Hunt - Introduction of BEST Draft Implementation Plan
09:00	Ben Fitzhugh – Human Dimensions of BEST
09:30	Mary Pete - Subsistence Harvest and Alaska Natives
09:45	David Fraser - What the Commercial Fishery Needs to Know
10.00	*Break*
10.15	Jeff Napp - NOAA's North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) and the Loss of Sea Ice (LOSC) Programs
10.30	Anne Hollowed – National Marine Fisheries Service (NMFS)
10.45	Tom Weingartner – Alaska Ocean Observing System (AOOS)
11.00	Jack Helle - Bering Sea/Aleutian Salmon International Survey (BASIS)
11.15	Clarence Pautzke – North Pacific Research Board (NPRB)
11:30	Hal Batchelder - PICES/GLOBEC Climate Change and Carrying Capacity (CCCC) program
11:45	Discussion
12:30	*Lunch*
14:00	Open discussion
14:45	*Break*
15:00	Break-out groups: remote/local physical processes, plankton dynamics, and upper-trophic levels, including people
16:30	Plenary to assess results of breakout groups
18:00	Adjourn
19:00	Official reception at Royal British Columbia Museum