Ecosystem Studies of Sub-arctic Seas:

Results of a Workshop held in Laguna Beach, California, 4-6 September 2002

Compiled by

George L. Hunt, Jr.[1], Convener

Introduction

The Bering Sea, the Barents Sea, and the Labrador shelf are among the sub-arctic regions that support the most important fisheries of the Northern Hemisphere. They are located at the southern extreme of seasonal sea ice cover, and thus are likely to be exceptionally sensitive to variations in climate that impact the extent and duration of sea ice. Sea ice is a forcing mechanism that affects the timing, amount and fate of primary production and the survival of larval fish (Hunt et al., 2002; Napp et al., 2001). Sea ice influences the temperature and salinity of the water column, its hydrographic structure, the availability of light for photosynthesis, and the spatial distribution of fish and their predators. Changes in the dynamics of sea ice will have profound influences on the ability of a region to support fish, and fisheries (Schumacher et al., 2002).

The fish biomass of the sub-arctic seas is dominated by a few species of gadid fish, particularly species of cod and pollock. These fish support immense fisheries, some of which are thriving (e.g., Bering Sea walleye pollock, *Theragra chalcogramma*), some of which cycle through periods of boom and bust (e.g., Barents Sea northern cod, *Gadus morhua*), and some of which have had their stocks collapse (e.g., Labrador Shelf and Grand Banks, northern cod) (Nakken, 1994; Hunt et al., 2002; Drinkwater, In Press). The importance of just a few species of gadoid fishes in each region suggests that there could be considerable value in developing studies that compare ecosystem function among the regions and provide mechanisms for sharing both basic science information and the means to incorporate this basic knowledge into the decision making of fisheries management.

To this end, a workshop was convened from 4 to 6 September 2002, in Laguna Beach California, to identify research priorities for a major research initiative in the Bering Sea, and to investigate the possibility of developing a series of comparative studies of the marine ecosystems of the sub-arctic seas. The Workshop Participants (Appendix 1) were enthusiastic about both possibilities.

[1] **Department of Ecology and Evolutionary Biology, University of California, Irvine 92697; e-mail: glhunt@uci.edu**

Why the Bering Sea?

The Bering Sea supports some of the world's most productive fisheries, contributing about 50% of all fisheries landings in the United States in 1998 (http://www.pmel.noaa.gov/foci/overview.html). The Bering Sea also modifies the heat and salt content of water as it flows from the North Pacific Ocean to the Arctic Ocean. In recent years, it has become evident that this seasonally ice-covered sub-arctic sea is subject to decadal-scale and secular changes in climate that have resulted in abrupt and unexpected changes in the ecosystem (Napp and Hunt, 2001). Thus, there is an urgent need to assess how global change may affect the marine ecosystem of the Bering Sea and its ability to support productive fisheries.

In the past 3 decades, major changes have occurred in the marine ecosystem of the southeastern Bering Sea (Vance et al., 1998; Hunt et al., 1999; Schumacher et al., In Press). Changes in the abundance of salmon, crab, and groundfish have caused significant economic impacts (NRC, 1996; Schumacher et al., In Press). Continuing declines in some populations of marine birds and pinnipeds have prompted protection measures such as trawling closures of critical feeding habitat of the endangered Steller sea lion (*Eumetopias jubatus*) (Hunt et al., 2002). This has disrupted fisheries and focused attention on the resilience of the ecosystem. In addition, there have been unexplained blooms of phytoplankton never before recorded in the Bering Sea (Vance et al., 1998), and since 1989, an exponential increase in the biomass of large gelatinous zooplankton (Brodeur et al., 2002). Although harvests of marine species have undoubtedly affected the population dynamics of exploited species, there is a clear need for an understanding of the causal relationships between climate, primary and secondary production, and the population dynamics of upper trophic-level organisms (e.g., Livingston and Tjelmeland, 2000). This information is vital for understanding the relative roles of climate variability and fishery harvests in structuring the Bering Sea ecosystem (Witherell et al., 2000).

Background:

The Bering Sea is a semi-enclosed, high latitude sea that is connected to the North Pacific Ocean via a series of passes through the Aleutian Arc (Stabeno et al., 1999) (Figure 1, top). Whereas the circulation in the Bering Sea basin is often described as a cyclonic gyre, it can also be described as a continuation of the subarctic gyre, with water from Alaskan Stream flowing through the central and western passes of the Aleutian Islands and exiting through Kamchatka Strait to form the Kamchatka Current. Flow through the eastern passes turns right as it enters the Bering Sea and forms the North Aleutian Current. This current continues northward along the eastern slope, with a portion of it flowing onto the shelf through several canyons and occasionally spinning off eddies that carry entrained nutrients and plankton onto the eastern shelf. The flow on the broad eastern shelf is weakly northwestward. Approximately 0.8×10^6 m^3 s^{-1} flows northward through Bering Strait. Bering Strait is the only connection between the Pacific and the Atlantic Oceans in the Northern Hemisphere, and while the total transport is not large, it provides a source of salt (from brine rejection during the winter), freshwater (during the summer from various rivers) and heat (during the summer) to the Arctic Ocean. Increases in the northward heat flux could play an important role in the melting of the Arctic ice cap.

The southeastern Bering Sea shelf is wide (> 500 km wide) and shallow (Figure I, bottom). During summer, shelf waters are differentiated into three domains (coastal, middle and outer) by hydrographic structure and currents associated with characteristic bottom depth ranges (Stabeno et al., 2001). Fronts or transition zones separate the domains. Increased production associated with the shelf-edge and structural fronts at the Pribilof Islands enhances feeding opportunities for higher trophic level organisms (Hunt et al., 1996a, Springer et al., 1996; Brodeur et al., 2000, Flint et al., in press).

In recent years, correlations between climate patterns and responses of marine ecosystems have been the focus of considerable attention (US GLOBEC,1996). In the North Atlantic, North Pacific and Southern Oceans, decadal-scale climate changes have impacted stocks of phytoplankton, zooplankton and fish (Murphy et al., 1995; Reid et al., 1998; Hare and Mantua, 2000; Pershing et al., 2001). In the North Atlantic, climate plays a significant role in the population dynamics of the economically important northern cod (e.g., Ottersen and Stenseth, 2001; Drinkwater, In Press).

The Bering Sea, as a marginal ice zone, should be particularly sensitive to climate change because small changes in wind velocities can make large differences in the extent, timing and duration of wintertime sea ice. Although such far-reaching effects as El Niño/Southern Oscillation (ENSO) on occasion may affect the climate of the Bering Sea (e.g., Overland et al., 2001), the climate of the Bering Sea is most strongly influenced by the Pacific North American pattern (PNA) (with which the Pacific Decadal Oscillation [PDO] is correlated), and by the Arctic Oscillation (AO) (Overland et al., 1999). Recent work has shown that ecosystem responses to decadal-scale changes in these and other indices of North Pacific Ocean and Bering Sea climate have been pervasive and of great economic importance (Francis et al., 1998; McFarlane et al., 2000; Hollowed et al., 2001).

Climate change can affect both the base of a marine food web and its productivity, and the distribution and abundance of upper trophic-level consumers (Reid et al., 1998; Hare and Mantua, 2000; Hunt et al., 2002; Hunt and Stabeno, 2002). Thus, there is the potential for climate change to cause shifts in the distribution and abundance of predators that in turn control the abundance of lower trophic level organisms such as small fish or zooplankton (top-down control). Alternatively, changes in the primary or secondary production may affect the abundance of higher trophic level organisms that can be supported (bottom-up control). Of particular concern is the possibility that the combined effects of climate change and fisheries removals may shift marine ecosystems into alternative stable states which may have a lower yield of species valuable to people (Parsons, 1996; Scheffer et al., 2001; Pauly et al., 1998).

Recently, Hunt et al. (2002) proposed the Oscillating Control Hypothesis (OCH) to explain climate-related variation in ecosystem control in the southeastern Bering Sea. According to this hypothesis, during periods when the spring bloom occurs in cold water, recruitment to populations of large predatory fish, such as walleye pollock should be limited by bottom-up processes because zooplankton prey will be in short supply for larval and juvenile fishes. However, during periods when the bloom coincides with warm water temperatures, the control of pollock populations would become top-down. This is because copepod growth and production will be high, as will be the survival of larval and juvenile fishes, including those of large piscivorous fish. As these fish mature, the incidence of cannibalism and predation on small fish will increase, eventually limiting the recruitment of pollock. This hypothesis remains to be tested.

Results of the Workshop

Bering Sea Research Requirements

Workshop Participants focused on the eastern Bering Sea as a first place to direct U. S. efforts, given the major fisheries there and the rapid, unexpected changes recorded in recent years. However, there was interest in the Bering Sea as a whole, and a hope that, if an international sub-arctic seas research program could be mounted, that research would be conducted in the basin and on the western shelves of the Bering Sea.

The overarching question of importance identified by the Workshop Participants was a very basic one: How do variations in physical forcing mechanisms impact the Bering Sea ecosystem as a whole? A number of related secondary questions provided amplification of this fundamental question: Are the impacts of changes in forcing factors most pronounced at lower or higher trophic levels (are the upper trophic level organisms more buffered from change than those at lower trophic levels?), or are the effects amplified as they cascade through the ecosystem (the ecosystem as a transistor model)? How does lifespan and fecundity relate to the temporal and spatial variability experienced by a species in its preferred habitats? What are the implications of these changes in forcing mechanisms for higher trophic level species including birds, mammals and fish? A continuing theme in the Workshop discussions was the need to strengthen the intellectual linkages between the study of ecosystem function and the application of this knowledge to fisheries management. It was recognized that there was a major need to develop quantitative indices that could be incorporated in management decisions.

From the above set of basic questions, Workshop Participants identified a number of hypotheses that could provide direction to a Bering Sea research program. The These included:

A. Changes in physical forcing mechanisms due to climatic changes will alter the patterns of community structure and energy flow (rates and pathways) between ecosystem components. Birds, mammals and fish (and fisheries) will integrate these changes and reflect them in the adjustments to their distribution, abundance and production.

   1. Change has a variety of frequencies and amplitude. How does the frequency and amplitude of change in physical forcing mechanisms affect their impact on biological components of the ecosystem?

   2. How do the magnitude, location, and variability of horizontal advection affect the structure and carrying capacity of the Bering Sea shelf ecosystem?

3. How does variability in key environmental factors (e.g., ice cover, seawater temperature, stratification) translate into changes in productivity at different trophic levels?

4. Does the size of the constituents of the plankton vary with water column structure or temperature? If so, why? How does this affect community succession and energy flow?

5. Did the atmospheric climate regime shift of 1998 affect the structure and function of the Bering Sea ecosystem?

B. There are critical nodal (often cryptic, non-charismatic) species that will react to change by switching the dominant pathways by which energy goes to the top predators. Thus, it is essential to examine the pelagic and benthic components of the ecosystem to identify those species or species groups that play important roles in the transfer of energy. We will call these "nodal species". The implication is that there exists some appropriate simplification of ecosystem complexity that would allow predictions of trends in the system without requiring an exhaustive list of physical variables and species for study. These nodal species should be investigated in a coupled biophysical model that will provide a quantitative understanding of the relations between different levels of the food web. Effort should be made to examine the consequences of various combinations of species composition at each trophic level.

1. The identity of the nodal species may change with changing regime.

2. Two potential nodal groups are copepods and euphausiids. There is a close relationship between the amount of copepod and euphausiid production and the survival of key fish species. What determines the efficiency of zooplankton as herbivores and as predators, and how does variation in their efficiencies affect their role in transferring energy to upper trophic levels?

3. Euphausiids are important consumers of copepods, and there may be an inverse relationship between copepod and euphausiid biomass. Does one type of regime favor copepods over euphausiids? If so, does this impact fish distribution, growth or survival?

4. What determines interannual variability in fish (e.g., walleye pollock) recruitment? Are density-dependent processes or density-independent factors more important?

5. What is the ecological significance of the coccolithophore and other unusual phytoplankton blooms? How does the production of these organisms affect the transfer of energy to upper trophic levels?

C. There are significant differences in the forcing factors and biology of the northeastern Bering Sea and the southeastern Bering Sea such that they are likely to respond to changes in physical variables in different ways. These include differences in the amount and timing of cross-shelf advection, differences in the amount, duration and timing of retreat of sea ice, and water temperature.

1. How will changes in climate, including temperature, cloud cover, wind stress and the magnitude and frequency of storms differ in their effects on the northern and southern portions of the eastern Bering Sea shelf?

2. How is it that the southeastern Bering Sea apparently supports a several-fold increase in biomass of pelagic fish and benthic fish and invertebrates than it did three decades ago (Hunt et al., In Press; E. Conners, NMFS/Alaska Fisheries Science Center, Pers. Com) while in the northeastern Bering Sea other evidence suggests a three-fold decrease in the rates of primary production (e.g. Schell 2000; Hirons et al., 2001)?

D. The longevity of a species reflects the frequency of the occurrence of environmental conditions favorable for reproduction and the likelihood of events that inflict severe mortality. The implication is that long-lived species have a lower probability of success in any one breeding event and thus maximize the number of breeding attempts over a lifetime. Thus, there is a relationship between a species' longevity and the periodicities of environmental variability in their preferred habitat. The length of time between regime shifts and strength of interannual variability are critical to this relationship.

Comparative Studies of Sub-arctic Sea Ecosystems

The Workshop Participants were enthusiastic about the development of a set of studies of the sub-arctic seas that would compare physical forcing mechanisms in the various systems and the responses of the biological components, including commercially exploited fish stocks, to variation in these physical forcing mechanisms. There was recognition that the populations of gadids in each ecosystem have been impacted both by natural variability and also by fisheries extractions of the gadids as well as other species in the ecosystems that interact directly and indirectly with the gadids. The Workshop Participants recognized that comparative studies of these systems could be extremely valuable to fisheries managers as they try to avoid repetitions of the population crash that has devastated the cod fishery in the northwest Atlantic Ocean.

Workshop Participants suggested a number of questions that might form the nucleus of a program addressing comparison of sub-arctic sea ecosystems. These included:

1. What are the ecosystem implications of the differences in advection, wind mixing, and the amount, duration and timing of retreat of sea ice cover in the various sub-arctic seas?

2. How does latitudinal variation in light availability affect the timing and amount of primary production (and the foraging of visual predators)? Comparisons can be made both within ocean systems and between them.

3. How do the carbon budgets of the sub-arctic seas differ, and what are the implications of these differences? What are the relative rates of primary production, zooplankton production and fish production? Does the rate of export to the benthos differ between regions, and if so, why?

4. What determines the temporal variation in the biomass of copepods? What triggers the release of calanid copepods from diapause , and what are the relative contributions of advection and *in situ* production to the abundance of copepods in the upper water column? How does the timing of release from diapause affect their transport to fish nursery areas and their role in the transfer of carbon from low to high trophic levels?

5. What are the implications for energy flow and upper trophic-level consumers of the species composition and age-class distribution of the small forage fish that are important re-packagers of energy consumed by large fish, seabirds and marine mammals? For example, capelin, which are important in this role in the Barents Sea and over the Labrador shelf are largely absent from the southeastern Bering Sea at present, and age-1 pollock are the primary forage fish there.

6. How does the role of cannibalism by the dominant gadid vary among the sub-arctic seas, and what are the implications for the regulation and stability of these dominant gadid species? How does food-web complexity and geography impact the likelihood of cannibalism being a dominant aspect of population regulation?

7. To what extent are the various size-classes of fish spatially segregated? Is this segregation the result of differential swimming speeds, preferences for different temperatures or different habitats defined by some other criterion?

The Workshop Participants expressed willingness to engage in the development of an international program to investigate these and other questions relevant to the understanding and wise stewardship of these important ocean regions.

References Cited

Brodeur, R. D., Sugisaki, H., and Hunt, G. L., Jr. (2002). Increases in jellyfish biomass in the Bering Sea: implications for the ecosystem. *Marine Ecology Progress Series, 233*, 89-103.

Brodeur, R. D., Wilson, M. T., & Ciannelli, L. (2000). Spatial and temporal variability in feeding and condition of age-0 walleye pollock (*Theragra chalcogramma*) in frontal regions of the Bering Sea. *ICES Journal of Marine Science, 57,* 256-264.

Drinkwater, K. (In Press). A review of the role of climate variability in the decline of northern cod. *Transactions of the American Fisheries Society*.

Flint, M.V., Sukhanova, I. N., Kopylov, A. I., Poyarkov, S. G., Whitledge, T. E., and Napp, J. (2002). Plankton mesoscale distributions and dynamics related to frontal regions in the Pribilof ecosystem, *Deep-Sea Research II*, In Press.

Francis, R. C., Hare, S. R., Hollowed, A. B., and Wooster, W. S. (1998). Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. *Fisheries Oceanography, 7,* 1-21.

Hare, S. R., & Mantua, N. J. (2000). Empirical evidence for North Pacific regime shifts in 1977 and 1989*. Progress in Oceanography, 47,* 103-146.

Hirons, A. C., Schell, D. M., and Finney, B. P. (2001). Temporal records of $\delta^{13}C$ and $\delta^{15}N$ in North Pacific pinnipeds: inferences regarding change and diet. *Oecologia, 129*, 591-601.

Hollowed, A. B., Hare, S. R., and Wooster, W. S. (2001). Pacific-Basin climate variability and patterns of northeast Pacific marine fish production. *Progress in Oceanography, 49*, 257-282.

Hunt, G.L. and Stabeno, P. J. (2002). Climate Change and the Control of Energy Flow in the Southeastern Bering Sea. *Progress in Oceanography,* In press*.*

Hunt, G.L., Jr., Baduini, C.L., Brodeur, R.D., Coyle, K.O., Kachel, N.B., Napp, J.M., Salo, S.A., Schumacher, J.D., Stabeno, P.J., Stockwell, D.A., Whitledge, T.E., Zeeman, S.I. (1999). The Bering Sea in 1998: A second consecutive year of extreme weather-forced anomalies. *EOS, Transactions of the American Geophysical Union, 80*, 561, 565-566.

Hunt, G. L., Jr., Coyle, K. O., Hoffman, S., Decker, M. B., & Flint, E. N. (1996a). Foraging ecology of short-tailed shearwaters near the Pribilof Islands, Bering Sea. *Marine Ecology Progress Series, 141,* 1-11.

Hunt, G. L., Jr., Stabeno, P., Walters, G., Sinclair, E., Brodeur, R. D., Napp, J. M., & Bond, N. A. (2002). The Eastern Bering Sea: Evidence for Change and a New Hypothesis Linking Ecosystem Control and Climate. *Deep-Sea Research II*. In press.

Livingston, P. A., Tjelmeland, S. (2000). Fisheries in boreal ecosystems. *ICES Journal of Marine Science,. 57*, 619-627.

McFarlane, G. A., King, J. R., & Beamish, R. J. (2000). Have there been recent changes in climate? Ask the fish. *Progress in Oceanography, 47,* 147-169.

Murphy, E. J., Clarke, A., Symon, C. & Priddle, J. (1995). Temporal variation in Antarctic sea-ice: analysis of a long term fast-ice record from the South Orkney Islands. *Deep-Sea Research I*, 42, 1045-1062.

Nakken, O. (1994). Causes of trends and fluctuations in the Arcto-Nowegian cod stock. *ICES Marine Science Symposium, 198*, 212-228.

Napp, J.M. and G.L. Hunt, Jr. (2001). Anomalous conditions in the southeastern Bering Sea, 1997: Linkages among climate, weather, ocean, and biology. *Fish. Oceanogr*. *10*, 61-68.

Napp, J.M., A.W. Kendall, Jr., and J.D. Schumacher (2000). A synthesis of biological and physical processes affecting the feeding environment of larval walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea. *Fish. Oceanogr*., *9*, 147-162.

NRC (National Research Council) (1996). *The Bering Sea Ecosystem*. National Academy Press, Washington, D.C.

Ottersen, G., and Stenseth, N. C. (2001). Atlantic climate oceanographic and ecological variability in the Barents Sea. *Limnology and Oceanography*, *46*, 1774-1780.

Overland, J. E., Adams, J. M., and Bond, N. A. (1999). Decadal variability of the Aleutian low and its relation to high-latitude circulation. *Journal of Climate, 12,* 1542-1548.

Overland, J. E, Bond, N. A. and Miletta, J. (2001). North Pacific atmospheric and SST anomalies in 1997: links to ENSO? *Fisheries-Oceanography, 10,* 69-80.

Parsons, T. R. (1996). The impact of industrial fisheries on the trophic structure of marine ecosystems. In: G.A. Polis, & K.O. Winemiller *Food webs: Integration of patterns and dynamics* (pp. 352-357). New York, N.Y.: Chapman and Hall.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F., Jr. (1998). Fishing down marine food webs. *Science 279*, 860-863.

Pershing, A. J., Greene, C. H., Hannah, C., Sameoto, D., Head, E., Mountain, D. G., Jossi, J. W., Benfield, M. C., Reid, P. C., & Durbin, T. G. (2001). Oceanographic responses to climate in the northwest Atlantic. *Oceanography, 14*, 76-82.

Reid, P. C., Edwards, M., Hunt, H. G., and Warner, A. J. (1998). Phytoplankton change in the North Atlantic. *Nature, 391*, 546-546.

Scheffer, M., Carpenter, S., Foley, J. A., Folks, C., and Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature, 413,* 591-596.

Schell, D.M. (2000). Declining carrying capacity in the Bering Sea: Isotopic evidence from whale baleen. *Limnology and Oceanography, 45*, 459-462.

Schumacher, J. D., Bond, N. A., Brodeur, R. D., Livingston, P. A., Napp, J. M., and Stabeno, P.J. (In Press). Climate Change in the Southeastern Bering Sea and Some Consequences for Biota. In: *Large Marine Ecosystems of the World: Trends in Exploitation, Protection, and Research*. Hempel, G. and Sherman, K., editors. Amsterdam: Elsevier Science.

Springer, A. M., McRoy, C. P., Flint, M. V. (1996). The Bering Sea green belt: shelf-edge processes and ecosystem production. *Fisheries Oceanography 5*, 205-223.

Stabeno, P. J., Bond, N. A., Kachel, N. B., Salo, S. A., and Schumacher, J. D. (2001). On the temporal variability of the physical environment over the southeastern Bering Sea. *Fisheries Oceanography, 10,* 81-98.

Stabeno, P.J., Schumacher, J.D., Ohtani, K. (1999). The physical oceanography of the Bering Sea. In: Loughlin, T.R., Ohtani, K. (Eds.), *Dynamics of the Bering Sea: A Summary of Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea*, T.R. Loughlin and K. Ohtani (eds.), North Pacific Marine Science Organization (PICES), University of Alaska Sea Grant, AK-SG-99-03, Fairbanks, Alaska, USA, pp. 1–28.

U.S. GLOBEC. (1996). *Report on Climate Change and Carrying Capacity of the North Pacific Ecosystem*. Berkeley, California: University of California: U.S. GLOBEC Report 15, 95p

Vance, T. C., Baier, C. T., Brodeur, R. D., Coyle, K. O., Decker, M. B., Hunt , G. L., Jr., Napp, J. M., Schumacher, J. D., Stabeno, P. J., Stockwell, D., Tenant, C. T., Whitledge, T. E., Wyllie-Echeverria, T., and Zeeman, S. (1998). Anomalies in the Ecosystem of the Eastern Bering Sea: Including Blooms, Birds and Other Biota*. EOS, Transactions of the American Geophysical Union, 79 (10),* 121/126.

Witherell, D., Pautzke, C., and Fluharty, D., (2000). An ecosystem-based approach for Alaska groundfish fisheries. *ICES Journal of Marine Science. 57*, 771-777.

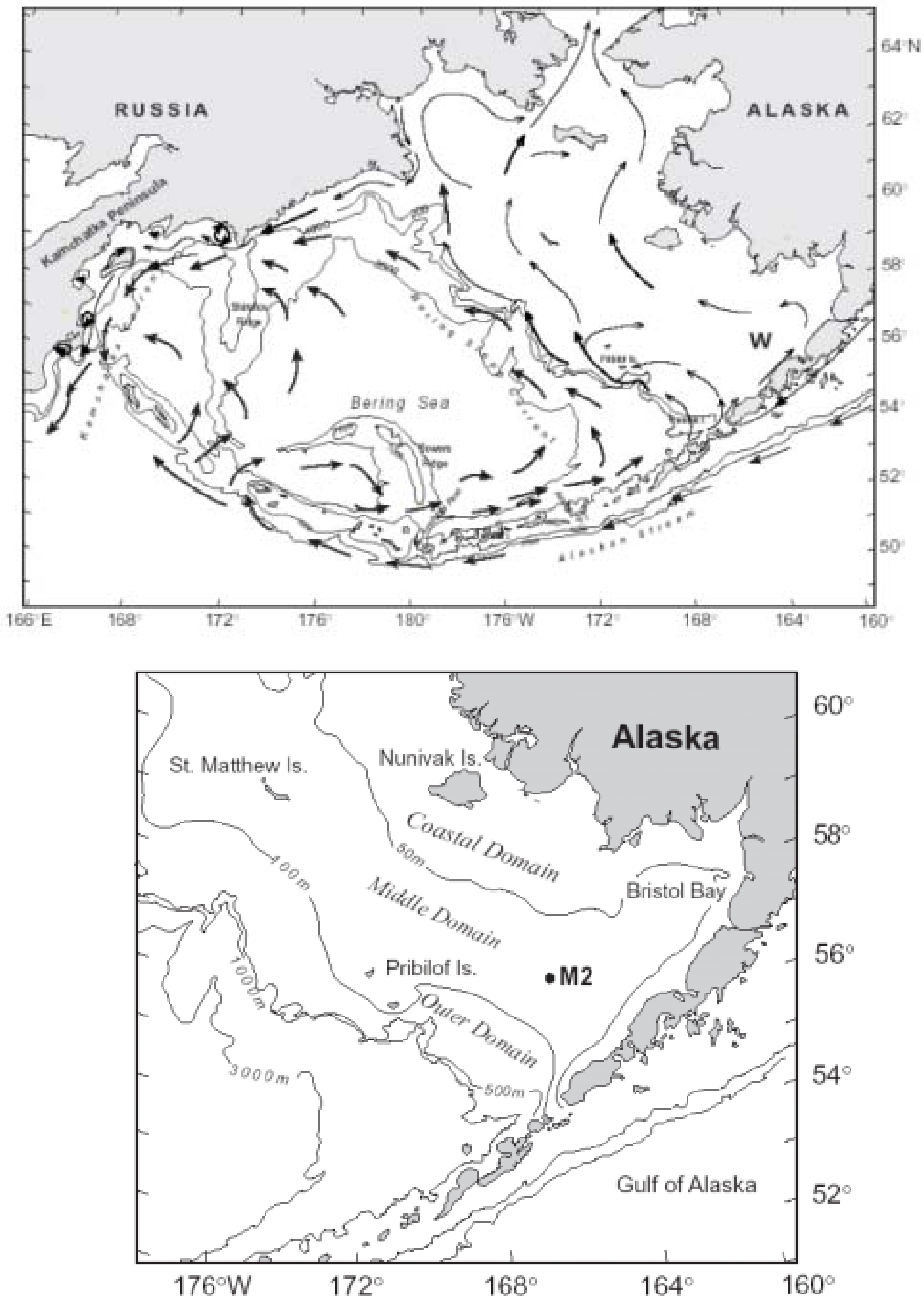

Figure 1. Top: Bering Sea Currents; Bottom: Southeastern Bering Sea, Alaska, with 50, 100, 200 and 1000-m isobaths. M2 marks the location of the NOAA biophysical mooring which contributes measurements to important biophysical time series. .

Appendix 1 LIST OF ATTENDEES

Richard Beamish
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Street
Nanaimo, British Columbia V9T 6N7
Canada
Tel: 250-756-7029
Fax: 250-756-7141
e-mail: BeamishR@pac.dfo-mpo.gc.ca

Ken Drinkwater
Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006,
Dartmouth, N.S. B2Y 4A2
Canada
Tel: 902-426-2650
Fax: 902-426-6927
e-mail: DrinkwaterK@mar.dfo-mpo.gc.ca

Mikhail Vladimirovich Flint
P.P.Shirshov Institute of Oceanology
Russian Academy of Sceinces,
Nakhimovskiy prospekt 36,
Moscow 17851
Russia
m_flint@orc.ru

Jackie Grebmeier
Department of Ecology and Evolutionary Biology
University of Tennessee
Knoxville, TN 37996, USA
e-mail: jgrebmei@utk.edu

Roger Harris
Plymouth Marine Laboratory
Prospect Place
Plymouth PL1 3DH,
United Kingdom
Direct Phone: +44 - (0)1752-633400
Switchboard: +44 - (0)1752-633100
FAX: +44 - (0)1752-633101
e-mail: rph@pml.ac.uk

George L. Hunt, Jr.
Dept. of Ecology & Evolutionary Biology
University of California, Irvine
Irvine, CA 92697, USA
Tel: 949- 824-6322
Fax: 949-824-2181
e-mail: glhunt@uci.edu

Nina Karnovsky
Dept. of Ecology & Evolutionary Biology
University of California, Irvine
Irvine, CA 92697, USA
Tel: 949-824-4747
Fax: 949-824-2181
e-mail: nkarnovs@uci.edu

Harald Loeng
Havforskningsinstituttet / Institute of Marine Research
Postboks 1870 Nordnes 5817 Bergen
Norway
Tel: +47 5523 8466
Fax: +47 5523 8584
email: harald.loeng@imr.no

James Morison
Polar Science Center
Applied Physics Lab,
University of Washington
1013 NE 40th St.
Seattle, WA 98105, USA
Tel: 206 543 1394
Fax: 206 616 3142
morison@apl.washington.edu

Jeff Napp
Alaska Fisheries Science Center
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE
Seattle, WA 98115, USA
Tel: 206-526-4148
Fax: 206-526-6723
E-mail: Jeff.Napp@noaa.gov

Brenda L Norcross
Institute of Marine Science
University of Alaska, Fairbanks
P.O. Box 757720
Fairbanks, Alaska 99775-7220, USA
Tel: 1-907-474-7990
Fax: 1-907-474-1943
email: norcross@ims.uaf.edu

Geir Ottersen
Department of Biology
Division of Zoology
P.O Box 1050 Blindern
N-0316 Oslo
Norway
Tel: (47) 22 85 72 88
Fax : (47) 22 85 46 05
email: geir.ottersen@bio.uio.no

Clarence Pautzke
North Pacific Research Board
441 West 5th Ave, Suite 500
Anchorage, AK 99501-2340
USA
Tel: (907) 278-6772
Fax: (907) 276-7178
Email: cpautzke@nprb.org

Naonobu SHIGA
Marine Biodiversity Laboratory
Graduate School of Fisheries Sciences
Hokkaido University
3-1-1 Minato, Hakodate 041-8611
JAPAN
Fax: +81-138-40-5542
Naonobu Shiga nao@fish.hokudai.ac.jp

Phyllis Stabeno
Pacific marine Environmental Laboratory
National Oceanic and Atmospheric
Administration
7600 Sand Point Way NE
Seattle WA 98115, USA
Tel: 206-526-6453
Fax: 206-526-6485
e-mail: Stabeno@pmel.noaa.gov

Neil Swanberg
Arctic Natural Sciences Program
Office of Polar Programs
National Science Foundation
4201 Wilson Blvd.
Arlington, VA 22230 USA
Tel: (+1-703) 292 8029
Fax: (+1-703) 292 9081
e-mail: nswanber@nsf.gov