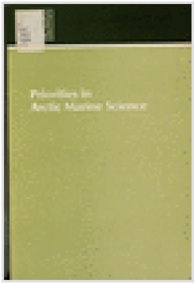

Priorities in Arctic Marine Science (1988)

Pages
83

Size
5 x 9

ISBN
0309319331

Committee on Arctic Marine Science; Polar Research Board; Commission on Physical Sciences, Mathematics, and Resources; National Research Council

Priorities in Arctic Marine Science

Committee on Arctic Marine Science
Polar Research Board
Commission on Physical Sciences,
Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1988

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Support for this project was provided by the Marine Mammal Commission, contracts MM2911056-0 and MM3309821-2. Project initiation funds were provided by the Andrew W. Mellon Foundation.

Illustration opposite contents page by G. B. Threlkeld.

Copies available in limited quantity from
POLAR RESEARCH BOARD
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

COMMITTEE ON ARCTIC MARINE SCIENCE

Vera Alexander, University of Alaska, Chairman
Knut Aagaard, Pacific Marine Environmental Laboratory, National Atmospheric and Oceanic Administration
H. Gote Ostlund, University of Miami
James P. Ray, Shell Oil Company
Constance Sancetta, Columbia University
Ian Stirling, Canadian Wildlife Service

Staff

Sherburne B. Abbott, Program Officer, 12/84 - 11/86
Bruce F. Molnia, Senior Program Officer, 12/86 - 12/87
Andrea L. Smith, Program Associate, starting 1/88

POLAR RESEARCH BOARD

Gunter E. Weller, University of Alaska-Fairbanks, Chairman
Knut Aagaard, National Oceanic and Atmospheric Administration
Roger Barry, University of Colorado
Rita Colwell, University of Maryland
Mim Harris Dixon, Chief Andrew Isaac Health Center
David Elliot, Ohio State University
Dennis Hayes, Columbia University
Arthur H. Lachenbruch, U.S. Geological Survey
Louis J. Lanzerotti, Bell Telephone Laboratories
Geoffrey F. Larminie, British Geological Survey
John Middaugh, Alaska Department of Health and Social Services
Ian Stirling, Canadian Wildlife Service
Kevin E. Trenberth, National Center for Atmospheric Research
Emmett F. Ward, Shell Oil Company
Patrick J. Webber, University of Colorado
Ray F. Weiss, University of California, San Diego

<u>Ex-Officio</u>

Charles R. Bentley, University of Wisconsin, Madison
Oscar J. Ferrians, Jr., U.S. Geological Survey
Charles F. Raymond, University of Washington
Robert H. Rutford, University of Texas at Dallas

<u>Staff</u>

W. Timothy Hushen, Staff Director
Andrea L. Smith, Program Associate
Mariann Platt, Administrative Secretary

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

FOREWORD

This document is one of a series ("Polar Research--A Strategy") issued by the Polar Research Board that identifies needs and develops strategies for polar research over the next two decades. Setting priorities is particularly important in times of financial stress. It is hoped that these studies will assist the decision makers in governmental and nongovernmental organizations concerned with the polar regions in establishing program priorities.

There are eight other reports in the series:

1. An Evaluation of Antarctic Marine Ecosystem Research.
2. Study of the Upper Atmosphere and Near-Earth Space in Polar Regions: Scientific Status and Recommendations for Future Directions.
3. Polar Biomedical Research: An Assessment, with an Appendix, Polar Medicine--A Literature Review.
4. Snow and Ice Research: An Assessment.
5. Permafrost Research: An Assessment of Future Needs.
6. Polar Regions and Climatic Change.
7. Antarctic Solid-Earth Sciences Research.
8. Physical Oceanography and Tracer Chemistry of the Southern Ocean.

Work continues on two other studies in the series: arctic solid-earth geosciences, and arctic social sciences. Further studies are to be initiated in the coming years.

The Polar Research Board greatly appreciates the work of Vera Alexander, chairman of the Committee on Arctic Marine Science; Sherburne Abbott, Bruce F. Molnia, and Andrea L. Smith, the program officers who guided the committee through all the difficult phases of report preparation; the members of the committee; and the researchers on whose work this study is based.

Gunter E. Weller, Chairman
Polar Research Board

1

Executive Summary

The integral importance of arctic regions to global oceans and climate and the importance of arctic living and nonliving resources to solutions to the diminishing global resource pool are ideas that have come of age. Recent events strongly indicate that the waters of the Arctic Ocean and connected adjacent seas play a significant role in influencing global climate and biogenic budgets of the major plant nutrients and carbon. The presence of multiyear or seasonal sea ice (see Figure 1) is an important factor in these processes and in the physical, chemical, geological, and biological regimes of marine systems of the Arctic. Large bird and mammal populations, including many migratory species, inhabit arctic waters, and prodigious fishing grounds are found on the shelf regions of the seas adjacent to the Arctic Ocean. Increased interest in the resource potential of the Arctic, particularly for the exploration for and development of hydrocarbons and fisheries, has focused attention on interactive elements in the arctic system that are anticipated to cause profound local, regional, and even global effects. Scientific understanding of the dynamics of the arctic marine ecosystem is necessary to isolate factors influencing global oceans and climate and to assess the impacts of resource development.

Increased human use of the northern seas reinforces the need for scientific knowledge. This need was a catalyst in the passage of the Arctic Research and Policy Act of 1984 (Public Law 98-373), which is providing increased momentum for arctic research. An assessment of overall research needs in the Arctic by the Polar Research Board established the rationale for additional studies in arctic marine science as they relate to national issues

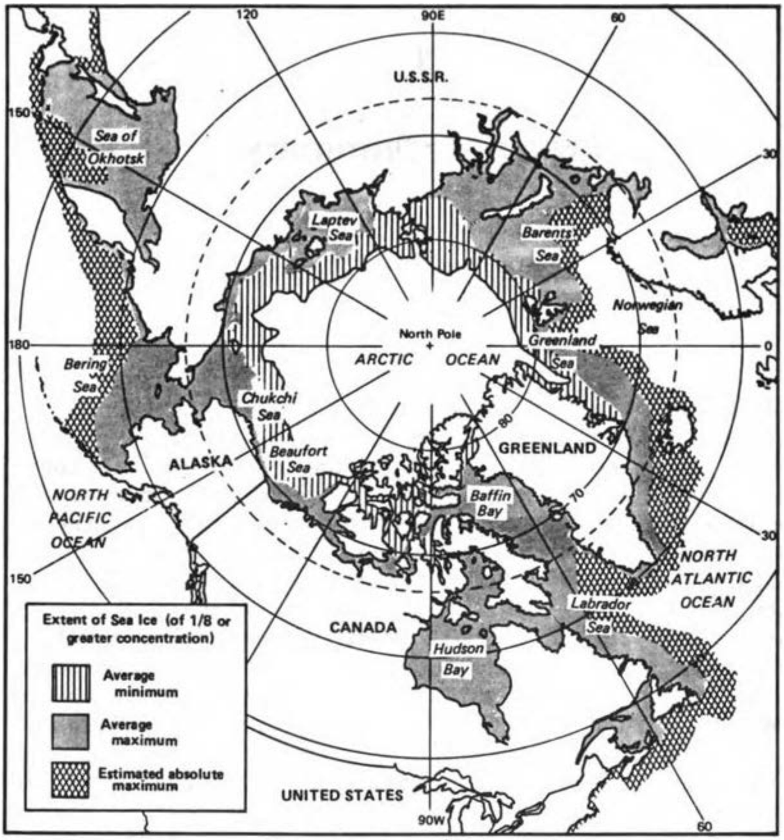

FIGURE 1 Map of the arctic regions showing the major marine areas and the maximum and minimum sea ice extent.

(National Research Council, 1985). In addition, the two organizations established by the act, the Interagency Arctic Research Policy Committee (IARPC) and the Arctic Research Commission (ARC), have identified aspects of marine research as priorities for the Arctic.

In 1984, the Polar Research Board formed the Committee on Arctic Marine Science to review long-term research directions in arctic marine science, identify gaps in current efforts, develop a program plan for addressing priorities, and identify the logistics and technology necessary to implement the proposed research.

This report addresses research needs beyond those necessary to evaluate environmental impacts of development. The report does not attempt to evaluate environmental impacts of development, nor does it look at specific fisheries problems (e.g., stock recruitment). Such targeted work is ongoing and should continue. Clearly, a need exists to repeatedly reexamine the United States' effort in these applied areas; there are existing mechanisms for doing this. For example, a major National Research Council study evaluating the Mineral Management Services' Outer Continental Shelf Environmental Assessment Program is under way.

This PRB report identifies two important and poorly understood arctic research areas requiring further emphasis:

1. Ecosystem dynamics of the arctic shelf and adjacent seas.
2. Circulation of the Arctic Ocean.

These topics were selected from a broad range of marine research questions in discussions at a 1983 workshop sponsored by the Polar Research Board and held at Woods Hole, Massachusetts, as timely opportunities for research that had not been adequately addressed in other documents. Both are of intrinsic importance themselves, but they also have global implications. The two topics are distinct, with different time scales and goals. Although presented as consecutive chapters in this PRB report, each is a stand-alone topic. The committee has made no attempt to tie them together.

A scientific framework for each topic is presented and recommendations are made with the aim of identifying discrete tractable projects that, when viewed together, would contribute to the whole effort, and that, in certain cases, could reasonably be added to existing or planned programs. To implement the proposed research programs, the report assesses logistical and support requirements and some guidelines for management. Attention is focused on the urgent need for an ice-capable research vessel since it is the single most important logistical requirement for the conduct of arctic marine research.

4

ECOSYSTEM DYNAMICS IN ARCTIC SHELF SEAS

The committee finds that there is a need for long-term basic research on marine ecology in the Arctic, with emphasis on continental shelves. This does not diminish the importance of the research already conducted by the Outer Continental Shelf Environment Assessment Program (OCSEAP). The research proposed by this report will provide the scientific framework for understanding not only arctic marine systems, but also any global consequences. Specifically,

- The arctic shelves are highly productive, in contrast to the Arctic Ocean.
- Seasonal variation in the light and ice regimes is a major controlling factor.
- Factors affecting biological distribution and abundance are inadequately understood.
- Such research will contribute to our understanding of the flux of carbon.
- The effects of human activities on the ecosystem are increasing, and have been shown to be deleterious for at least some species.

The committee finds a need for coordinated and interdisciplinary research to address the spatial and temporal extent of environmental variability and its biological consequences, the role of arctic shelf ecosystems in the global carbon dioxide budget, and the tolerance of these systems to man-caused perturbation. In addition to large-scale multicomponent studies, small focused research projects will be required.

The major priority is the establishment of long-term multidisciplinary ecological studies on the arctic continental shelves.

The committee recommends the establishment of programs to do the following:

- Address the role of ice in the biological productivity of arctic seas, starting with the Bering Sea and then moving to the Chukchi Sea.
- Determine the environmental control that mesoscale features (e.g., ice edge fronts and eddies) exert over primary production and food chain relationships.
- Determine production rates at, and transfer of energy between, trophic levels on arctic continental shelves.

- Estimate sinking and advection transport of particulate material in conjunction with studies of biological productivity, pelagic cycling, and vertical flux.
- Study pollutant-sediment interaction and develop basic information on sediment transport in arctic marine ecosystems.
- Initiate periodic monitoring programs to assess contaminant load for higher trophic level animals.
- Evaluate the environmental effects of fishing on adjacent seas.

The committee also recommends the continuation of work to establish baseline predevelopmental information.

The successful completion of many of these recommendations will require regional, interdisciplinary programs of sufficient duration to encompass at least the year-to-year variability time scale. Although not explicitly listed in this report, the successful completion of this work will involve chemical, physical, and geological/geochemical components.

CIRCULATION OF THE ARCTIC OCEAN

The committee finds a need for a concerted effort aimed at understanding the circulation of the Arctic Ocean.

- The Arctic Ocean contains a significant thermohaline circulation of importance far beyond its borders.
- Knowledge of Arctic Ocean circulation, dynamics, and chemistry is rudimentary.

Definition of Arctic Ocean circulation and its consequences provides a strong and useful framework for future research in the Arctic Ocean. Three priority areas exist:

1. Structure and maintenance of the interior Arctic Ocean.
2. Interaction of the interior with bordering shelf seas.
3. Consequences of exchange with the seas to the south.

The committee recommends the establishment of programs to do the following:

- Investigate the internal structure of the four major basins of the Arctic Ocean, and the means by which it is altered or maintained.
- Investigate shelf and shelf edge processes in the context of large-scale circulation in the Arctic Ocean.
- Investigate the effects on the Arctic Ocean of exchanges across its open boundaries: Fram and Bering straits, and the passages through the Canadian Archipelago and in the Barents Sea.

LOGISTICAL AND SUPPORT REQUIREMENTS FOR ARCTIC MARINE RESEARCH

Logistical needs to support research include aircraft, ice stations, satellites for remote sensing, and a polar research vessel. The continuity of our national research program in the Arctic will depend on a commitment to U.S. logistical facilities. However, the United States should also be prepared to support foreign logistical platforms in a mutually acceptable manner.

Our capacity to learn more about the arctic regions is severely limited by the lack of any research ships sufficiently strengthened to operate in sea ice. The requirement for an ice-capable,* stable, surface research ship has been the finding of many governmental and nongovernmental, including academic, reports (see Appendix B for a historical background of such studies). There are enough research projects within the realm of all research agencies to justify employment of a surface polar research vessel* on a full-time basis. Nevertheless, the United States lacks a dedicated ice-capable vessel for arctic research. There are also a large number of prospective research projects that have never been proposed because the United States does not have such a vessel (see Appendix C).

The committee makes the following recommendation:

- The United States should proceed with the procurement of an ice-capable polar research vessel dedicated for supporting arctic marine research. This surface vessel should be operated as part of the UNOLS academic fleet or in a similar dedicated manner, and should be capable of station keeping in heavy weather under high-latitude conditions.

---

* See Appendix A for definitions of these terms.

2

Introduction

The objective of this report is to recommend long-term research priorities in arctic marine science. The report is part of the Polar Research Board's "Polar Research--A Strategy" series of studies to guide polar research over the next two decades. Setting research priorities is especially important in times of financial stress. In preparing this report, a series of meetings and workshops that addressed contemporary research needs in arctic marine science were conducted to establish priorities. This report should be viewed as a more detailed companion study to the marine portions of the board's identification of national issues and research priorities in the Arctic (National Research Council, 1985). Both reports provide focus to guide a national coordinated effort in the Arctic.

An increased emphasis on arctic marine research is consistent with the United States' current interest in global ocean science. The effects of environmental change can be readily detected through the responses of the arctic marine biota, because of the high seasonality and the narrow annual time slots for various activities and processes. Global temperature increases are likely to be exaggerated in the far northern latitudes and therefore can be detected sooner. In turn, the arctic regions themselves influence global change through several large-scale biogenic budgets and geochemical cycles.

The arctic marine regions have tremendous resource potential, for both living and nonliving resources. Interest in these resources has heightened awareness of the need for more complete understanding of arctic ecosystems. Traditional utilization for subsistence hunting and fishing, and modern commercial exploitation of natural resources (e.g., fishing and petroleum exploration and development) cause multiple pressures on the environment. We do not even understand the role of natural variability, either in climate or in biological stocks. In recent years, some subsistence hunting (e.g., the taking of endangered bowhead whales) has raised concern.

As another example, effective management of the large fishery in the southeast Bering Sea needs information not only on year class sizes and recruitment, but also on the ecological factors that regulate these parameters. The observed large fluctuations in some harvestable populations, such as the king crab, may be natural, due to overharvesting, or due to a number of complex factors acting in consort. We need to be able to separate these effects in order to adopt appropriate management strategies. In other words, management must be based on scientific knowledge. Comprehensive understanding of ecosystems will also help address the environmental questions raised by oil and gas exploration and development in the Arctic.

This approach has been used in the Barents Sea (Norwegian Barents Sea Ecosystem Study, PROMARE) and the Bering Sea (Processes and Resources of the Bering Sea Shelf, PROBES). The applied significance is not yet clear, because the link between the results of such marine ecological programs and fisheries has not yet been forged.

In 1983 the Polar Research Board saw the need for an action plan in arctic marine science to focus the federal effort. The board hosted a planning session in Woods Hole, Massachusetts, to identify major long-term research needs and to look at the logistics and technology required to address them. Three major points were revealed in that session. First, much of the recent U.S. effort has focused on climate-related research, which, although recognized as important, did not require detailed discussion here because it has been addressed adequately in other documents. Second, the committee acknowledged the extent of environmental impact work that has been undertaken, but concluded that a more comprehensive understanding of ecosystem structure and functioning is needed as a basis for all research and future management decisions. Finally, because of the large gap in knowledge about the interior Arctic Ocean, the region was identified as a "desert in hydrographic information." Because of its global interactions, this needs to be remedied.

Two gaps in ongoing or proposed studies were identified as requiring further investigation by the committee:

1. Ecosystem dynamics in arctic shelf seas.
2. Circulation of the Arctic Ocean.

It is these areas on which this report concentrates.

A framework for coordination of federal scientific effort in the Arctic has been provided by the Arctic Research and Policy Act of 1984. The two organizations established by the act, the Interagency Arctic Research Policy Committee (IARPC) and the Arctic Research Commission (ARC), have identified aspects of marine research as priorities for the Arctic.

The Interagency Arctic Research Policy Committee recommended that "in cooperation with other interested nations and the state of Alaska, the U.S. should commence a long-term, integrated, multi-disciplinary study of arctic marine ecosystems." (United States Arctic Research Plan, 1987)

The Arctic Research Commission identified as its top priority,

> research to understand the Arctic Ocean (including the Bering and marginal seas, sea ice and seabed), and how the ocean and the arctic atmosphere operate as coupled components within the arctic system.

Emphasis was given to

> prediction of ecosystem reactions to natural (e.g., climatic) and human-induced disturbances, including those affecting renewable resources of the arctic continental shelves, particularly Alaskan Bering Sea fisheries and the species on which the subsistence lifestyles of indigenous peoples depend. (Arctic Research Commission, 1986)

3

Ecosystem Dynamics of Arctic Shelf Seas

> . . . it seems probable that it is the total ecosystem, the food web, which has evolved to cope with particular circumstances. (Wyatt, 1980)

The integral importance of arctic regions to global ocean and climate dynamics, and of arctic marine resources to the diminishing global resource pool, is becoming evident. Scientific understanding of the dynamics of the arctic marine ecosystem is necessary to isolate factors influencing global oceans and climate and to assess impacts of resource development. As Wyatt (1980) suggested, from the biological point of view, the arctic marine system should be viewed as a unit, including its chemical, physical, and biological aspects. Ecological research thus provides a scientific framework for the confluence of oceanographic disciplines in addressing these complex interactions.

This discussion will embrace shelf systems of a major adjacent sea, the Bering Sea, as well as those around the periphery of the polar basin. It is important to recognize that, while these two areas are fundamentally different, for the purposes of this report, discussion of both must proceed together.

The shelf areas of the seas adjacent to the Arctic Ocean--the Bering, Greenland, and Barents seas--are biologically productive, and support some of the world's major fisheries. Overall, the productivity of the polar basin shelves is lower than that of the subarctic shelves. One indicator of the scale of the difference is the absence of commercial fisheries in the seas at the margin of the polar basin.

The coastal Beaufort and Chukchi seas support large populations of birds and mammals, including the bowhead whale during the summer. This large higher trophic level biomass can be produced and maintained in a system in which the energy input through sunlight is low and extremely seasonal. Scientific understanding of the cycle of solar energy and its propagation through the ecosystem, the physical transport and biological dynamics of the major inorganic plant nutrients (nitrogen, phosphorus, and silicon), and the effectiveness of their microbial regeneration at the low water temperatures requires closely coupled physical, chemical, and biological oceanographic research set in an ecosystem context.

The continuing interests of fishing, hydrocarbon production, and subsistence harvesting all have potential for disrupting shelf ecosystems. Some arctic shelves are already subject to oil and gas exploration and development, and various types of shelf-based commercial activities, associated with the U.S. Exclusive Economic Zone, are expected to increase. The resident coastal communities have legitimate concerns in view of the contrasting and at times conflicting priorities. Inuit concerns particularly emphasize marine mammals. Since knowledge of the ecological structure and function of these arctic ecosystems is important in long-term resource management, studies are needed to understand the ecological basis of the relative levels of productivity of these shelf systems, the food chain that supports migratory and resident marine mammals, and the dynamics and importance of physical features (such as ice) for biological processes.

The answers to many of these questions also will require biological research focused on specific organisms, including biochemical and physiological studies, and examination of the life history strategies that resident organisms have evolved to cope with the extreme and highly variable conditions typical of the Arctic. Thus, not all of the recommended research programs are large and interdisciplinary.

A SCIENTIFIC FRAMEWORK

Knowledge of ecosystem structure and function is key to understanding arctic marine systems and their local and global consequences. As for most ecosystems, the source of energy is solar radiation, which is fixed by primary producers, upon which higher trophic level organisms feed. Release of energy (and carbon dioxide) is accomplished by respiration, including bacterial breakdown of organic material. Where and how respiration occurs determines the fate of energy and important elements, most notably carbon. Transport of organic material into deep waters or its burial in sediments removes carbon from the biosphere and atmosphere, and in this way the oceans can be a sink for carbon. In areas of relatively high primary production, the proportion of the carbon returned to the atmosphere or removed from circulation can significantly affect atmospheric carbon dioxide concentrations.

High-latitude regions are characterized by intense seasonal changes in solar energy input. The difference in the duration of winter verses summer daylight is the greatest for any marine area in the world. This has a major effect in controlling pelagic primary production. Light and temperature, two critical variables for life, both vary as a function of solar radiation. Strong temperature changes lead to movement of the ice by wind, annual growth and decay of sea ice on the shelves, and the presence or retreat of ice, as well as solar elevation. These processes exaggerate even more the extreme variation in the light received at the sea surface. Given adequate light and nutrients, phytoplankton will "bloom," storing light energy in the form of chemical energy (fats and carbohydrates). Given the paucity of data, it is difficult to estimate the primary productivity of most arctic marine areas. However, we do know that the productivity in a portion of the northern Bering and southern Chukchi seas, about 400 $g/cm^2/yr$, is among the world's highest.

A wide range of primary production values has been reported from the Arctic; in general they are high in shelf regions such as bays and fjords and reach a minimum in the open waters of the Arctic Ocean (Rao and Platt, 1984). Much of the spatial variability is related to mesoscale features such as fronts, eddies, plumes, and the ice margins, which affect vertical and lateral mixing. Variability exists even in superficially similar areas. Although ice may diminish productivity by blocking light, ice also enhances productivity through several ice edge effects. A relatively shallow stable surface layer due to ice melt water in spring produces a strong bloom, whereby reduced vertical circulation allows phytoplankton to maintain their position in the well-lit surface region. Upwelling at the ice edge, especially in conjunction with stationary fronts at the Bering Sea ice edge, can enhance production by supplying nutrients from below (Niebauer and Alexander, 1986). Eddies serve a similar role at the ice edge in the deeper waters of Fram Strait (Smith et al., 1985). In the Southeast Bering Sea, the PROBES scientists found that the stationary fronts on the shelf play a very important role in controlling primary productivity and subsequent ecosystem dynamics during the open-water season (Iverson et al., 1979; Cooney and Coyle, 1982; Sambrotto et al., 1986). However, there is no information on how these processes translate into production at higher trophic levels.

The biochemical energy fixed by phytoplankton is distributed to higher trophic levels through several routes. A typical chain proceeds from phytoplankton to zooplankton grazer, and then on to the fishes and mammals. Because of mesoscale features, patchiness becomes a critical problem. The seasonally pulsed food supply through primary production and the low temperatures in the Arctic provide an opportunity to study the effects of these variables on growth, reproduction, and recruitment of zooplankton.

Higher trophic level forms must adapt to this boom-bust system. Most higher-level organisms migrate seasonally to avoid starvation. On the shallow subarctic shelves, a large proportion of the primary produced organic matter sinks to the bottom and is assimilated by benthic invertebrates such as clams, which can then serve as a year-round food source for large mammals such as walrus. Large polynyas are important wintering areas for marine mammals (Stirling and Cleator, 1981), and most arctic marine birds use ice-related biota as their primary food source (Brown, 1986). Further investigation of the flow of energy through these systems is necessary to elucidate functional relationships. Ice algae almost certainly play a role, but upwelling in polynyas may also be important (Dunbar, 1986).

A crucial and as yet little-understood link in the system is the role of bacteria in transforming energy and compounds. Bacterial populations are known to be significant and active in sea ice in the Southern Ocean (Sullivan and Palmisano, 1984) and at the Bering Sea ice edge (D. Button, University of Alaska-Fairbanks, personal communication, 1987). When and where the bacteria are active determine the allocation of nutrients, and, especially, the last steps in the transformation of carbon. If settling of particles into the sediment occurs at a greater rate than bacterial respiration, much organic carbon will be buried in the sediments and lost to the ocean-atmosphere system. If bacteria serve as a food source for higher organisms, the carbon remains in the ecosystem. If respiration occurs in the water column, the carbon may either be ventilated back into the atmosphere (i.e., no net change when integrated over a year) or flow off-shelf into the deep Arctic Ocean. These issues are expressed as a series of specific questions:

1. What factors cause the spatial and temporal variability in high-latitude seas?

The largest temporal variation in the Arctic is the transition between seasons and the annual solar radiation cycle. During the "growing" season, primary productivity is related directly to mesoscale features such as fronts, eddies, polynyas, and ice margins. The ecological consequences of such temporally and spatially discontinuous productivity should be addressed in light of interannual or year-to-year variability. Predictive capability remains poor. Responses of phytoplankton to variable conditions constitute an important area for investigation, since with the secondary producers, primarily the zooplankton, they respond directly to environmental cues and support the entire system.

One consequence of the annual cycle is an abrupt initiation of primary productivity in spring, as soon as the water column stratifies. In seasonal-sea-ice-covered portions of the "adjacent" seas, this stratification results from ice melt as the retreat begins. An important role in biological productivity and food chain dynamics has been attributed to ice edge phytoplankton bloom in the Barents Sea (Rey and Loeng, 1985) and in the Bering Sea (Alexander and Niebauer, 1981). However, it is unclear whether a single ecosystem follows the ice north, or whether there exists a spectrum of different integrating systems that remain stationary. Resident and migratory higher vertebrates concentrate along ice edges possibly, in part, as a result of enhanced food production.

Sea ice appears to have major ecological (and fisheries) implications. Year-to-year variations in sea ice extent are probably extremely important in determining the survival of larval forms of some species, since the ice edge controls the first major phytoplankton bloom in spring (Niebauer and Alexander, 1985). This relationship has tentatively been established for at least one species of crab (Chionocetes opilio). The early life stages are often the critical times for survival, and therefore sea ice extent probably influences recruitment in several species. These relationships can be worked out through a research program that embraces physical oceanographic, meteorological, nutrient dynamics, biological oceanographic (including benthic), and fisheries research; extends over a significant north-south area on the continental shelf; and includes a strong modeling phase. An intensive program investigating the ice ecology in the Bering and Chukchi seas would be appropriate. These areas support a fishery (Bering Sea) and substantial populations of mammals and birds (Bering and Chukchi seas). While the program should emphasize fundamental relationships, a number of species should receive early attention, including crabs and salmon, as well as other commercially important species. Such a program offers an ideal focus for collaborative research between academic, state, and federal participants, and would be an effective approach to early implementation of the intent of the Arctic Research and Policy Act of 1984.

Recommended:

Initiation of a research program to address the role of ice in the biological productivity of arctic seas, with early attention on the Bering Sea, followed by the Chukchi Sea.

Along the northern coast of North America, many of the upper trophic level organisms are migratory, and their summer feeding probably is controlled by local physical processes that affect the spatial distribution of production and/or food organism concentration. In this way, "patchiness" in primary and secondary production influences higher organisms in controlling their distribution and in producing adaptations for locating patches (e.g., search patterns, cooperative interspecific and intraspecific behavior). Polynyas and leads are recognized as important habitats for birds and mammals. Assessing the consequences of shipping and offshore petroleum development on these populations will require understanding the environmental controls that mesoscale features exert over primary productivity. Current information suggests that these features are very important (Iverson et al., 1979; Alexander, 1980; Stirling and Cleator, 1981).

Recommended:

Studies to determine the environmental control that mesoscale physical features (e.g., ice edge, fronts, and eddies) exert over primary production and food chain relationships.

On a totally different temporal scale, studies of modern ecosystems must be set in the context of long-term climate oscillations (e.g., Vibe, 1967). Furthermore, to understand the stability of the ecosystem, the effects of variations over greater-than-annual time scales must be monitored. Several greater-than-annual times scales exist. Interannual to decadal variations include quasi-periodic events such as El Nino. Recent work by Karl et al. (1984) has shown that the period between 1950 and 1970 was unusually stable, as reflected in the average winter temperatures of the contiguous United States. Prior to that time, for at least 60 years, winter temperatures were more variable, and frequently lower. Since most knowledge of the Arctic was accumulated during the past 30 years, consideration must be given to the possibility that the climate of that time may not be representative of what will happen in the future. The earth's climate, in fact, has varied on scales ranging from decades to millennia (see Vibe, 1967; Lamb, 1972; Imbrie and Imbrie, 1979). The modern ecosystem has been influenced by such previous events as the Little Ice Age (1450-1850 AD), the climatic optimum (6000-5000 BC), and the Pleistocene Ice Ages. During each major glacial advance on land, sea level dropped by more than 100 m, so that most of the arctic shelves were exposed as land, and sea ice may have been present throughout the year. In the context of geological time scales and species lifetimes, the present locations are ephemeral and were only established in their present locations within the last 10,000 years. The implications of this fact must be explored further to assess the vulnerability of arctic ecosystems to climate changes such as global warming due to an atmospheric "greenhouse" or another Little Ice Age.

An excellent opportunity exists to examine interactions between physical and climatic cues and biological processes in hydrographically different regimes around the Arctic. For example, hydrographic conditions in the Fram Strait to the east of Greenland (Smith et al. 1985) are very different from those on the Bering Sea shelf (Niebauer and Alexander, 1985), which in turn differ from those on the far northern and Beaufort Sea shelf (Barnes et al., 1984). Such comparative studies could be used to define climatic-ecological-oceanographic linkages. The Antarctic provides a further contrast, as a vast polar continent surrounded by deep and extensive ocean, which is subject to seasonal sea ice.

Recommended:

Comparative interdisciplinary programs, among different circumpolar regions, of sufficient duration to encompass at least the year-to-year-variability time scale.

For the Arctic Ocean itself, very limited process-oriented biological data exist. Information is lacking for such basics as production rates at, and transfer of energy between, the various trophic levels. This is the least-understood part of the Arctic, and over the years it was assumed that the permanent ice cover and low nutrient concentrations in the surface water severely constrain primary productivity (less than 5 g $C/m^2/yr^1$). However, recent satellite imagery has shown that the central Arctic Ocean basin has at least 10 percent open water in summertime, so that light penetration may be better than previously thought. There have been insufficient measurements of primary productivity in the Arctic Ocean to determine the regional productivity.

Recommended:

Process-oriented studies in the Arctic Ocean to determine production rates at and transfer of energy between trophic levels.

2. What are the effects of anthropogenic perturbations on arctic marine ecosystems?

Anthropogenic perturbations range from disturbance due to human activities to the input of pollutants. A variety of present and potential problems exist, and in part, their nature differs from the Bering Sea to the higher latitude areas of the Beaufort and Chukchi seas and the Arctic Ocean because of differences in ice cover and productivity. In the Bering Sea, commercial fishing activities dominate the environmental perturbations, whereas oil and gas activities represent the main influences in the Beaufort.

In the Bering Sea, the effects of bottom trawling on benthic communities and their habitat represent major disturbances. The removal of large amounts of biomass at the higher trophic levels also can have significant effects on the overall ecosystem balance. Derelict (lost) fishing gear (nets and traps) has become an increasing problem because of the incidental catching of birds, fish, crabs, and mammals (Day et al., 1985; Fowler, 1985).

The petroleum industry's development of the Arctic, although temporarily slowed due to depressed world oil prices, will most probably continue for the next several decades. A variety of biological impacts are possible (Geraci and St. Aubin, 1980; Stirling and Calvert, 1983). Some of the applicable questions are very specific, such as the effects of hydrocarbons on larval stages of fish. However, a variety of pollutants may be released during offshore development. With the exception of accidental releases, all pollutant discharges are regulated via either the Environmental Protection Agency or State of Alaska permits. These include drilling fluids, produced water, treatment chemicals, and domestic/sanitary wastes. Additionally, a variety of industrial activities can affect localized areas of sea bottom. Mud and cuttings discharge, gravel island building, dredging, and pipeline construction are examples. A knowledge of the undisturbed sediments and primary transport processes is necessary for evaluating the effects of such activities. Noise may affect whale migration, seals, walruses, polar bear, and migrating waterfowl, and some of these are in shared populations covered by international agreement.

Historically, the most detrimental effects on arctic wildlife populations have resulted from overharvesting (e.g., bowhead whales and polar bears). Studies are needed to assess the long-term effects of harvesting by humans on individual species and the resultant changes to their ecosystems.

Additional information is needed on the long-term effects of oil pollution on trophic relationships, which may have impacts on food supplies of higher trophic level organisms, such as marine mammals. This work must include attention to the distribution of oil with respect to sediment, ice, and water. The Canadian Beaufort Environmental Monitoring Program is a useful model.

Recommended:

Assessment of the nature of pollutant-sediment interaction and development of basic information on sediment transport systems in arctic marine ecosystems; regional ecological studies prior to active development; initiation of periodical monitoring program for higher trophic level animals to assess contaminant load; and research to evaluate the environmental effects of fishing on adjacent seas.

PROGRAM DESIGN AND MANAGEMENT

In many multidisciplinary research programs, biology has been added as an afterthought and therefore the effort never becomes truly interdisciplinary. The programs should be designed as ecological research from the start. A well-defined management structure should be formulated at the outset to control direction and ensure flexibility. A strong steering committee can keep the project focused and on track, but it must provide the flexibility to change the research plan in the field. Flexibility in the program can be built into the field program. For example, a "pulsed" field approach is useful, in which two- or three-year programs are interrupted by two-year data work-ups, including publication, synthesis, and reassessment. In this way, a program can be extended for a sufficient time period to address year-to-year and multiyear variability. However, a rigorous annual reporting system should be designed, including a critical review procedure.

Flexibility in execution of research programs is also required of government contracting officers. For example, while funding for a research program should be adequate to cover all essential components and include multiyear support, it is essential to plan and establish priorities to ensure availability of adequate funds, as contingencies develop.

In recognizing increased international interest in arctic research, the committee believes that a conference along the North Atlantic Treaty Organizations (NATO) conference format would be useful in bringing together the participants in ongoing and proposed programs to encourage national and international liaisons between programs.

4

Circulation of the Arctic Ocean

INTRODUCTION

The Arctic Ocean is the largest of the world's geographically contained seas, but it has been so poorly sampled that its 10 million square kilometers constitute one of the least known components of the entire world ocean. For a number of reasons, it is important to begin remedying this situation:

1. Global climate models suggest that climate change induced by increasing atmospheric concentrations of carbon dioxide and other radiatively important gases will be largest at high latitude (e.g., cf. MacCracken and Luther, 1985, and Semtner, 1987). However, without knowledge of the processes that control the structure and circulation of the high-latitude ocean, our predictive capability is very limited.
2. The extremely large stratification in the upper Arctic Ocean, which effectively shields the ice and atmosphere from the interior ocean, is underlain by a relatively warm interior ocean. A weakening in this stratification would probably result in a very different arctic climate and ice cover. The means by which this thermally unstable layering is maintained, and what it would take to change it, constitutes a significant ocean climate problem (cf. Killworth and Smith (1984) and Semtner (1984) for recent attempts to model aspects of the problem).
3. There is increasing evidence that processes within the Arctic Ocean contribute significantly to the deep structure of the Norwegian Sea, and thereby at least indirectly to the thermohaline circulation of the North Atlantic and its role in ventilating the World Ocean

(Aagaard et al., 1985). The mechanisms by which the Arctic Ocean participates in this circulation need to be determined.

4. The dominant feature of the circulation on the northern Alaskan shelf (the Beaufort Undercurrent (Aagaard, 1984)), and possibly on at least the outer portions of other arctic shelves as well, appears to be the local manifestation of a basin-scale system of boundary currents. It will therefore be difficult to understand events and processes on the shelf without an appreciation of the large-scale circulation and its dynamics.

5. The interior Arctic Ocean is an anomalously low energy environment (Levine et al., 1987), and therefore provides an especially favorable setting for studies of such phenomena of general oceanic interest as double-diffusive mixing and staircase structures (Padman and Dillon, 1987) and long-lived sub-mesoscale coherent vortices (D'Asaro, in press).

Except for studies aimed primarily at geophysics and at the kinematics and dynamics of the sea ice, the attention of arctic marine scientists in the area of physical studies has almost exclusively been centered on the adjacent and marginal seas, rather than on the Arctic Ocean itself. For example, Outer Continental Shelf Environmental Assessment Program (OCSEAP) work was directed at Alaskan shelf problems, as was PROBES in the Bering Sea; the ISHTAR program continues this emphasis near Bering Strait. Likewise, the Greenland Sea has received considerable attention, for example, through the Marginal Ice Zone Experiment (MIZEX) and currently through planning for the Greenland Sea Project.

On the other hand, the Arctic Ocean, which contains 75 percent of the water in the arctic seas (excluding the Bering Sea), has seen no dedicated U.S. oceanographic programs except near Fram Strait and north of Prudhoe Bay (AIWEX). The chemical and physical oceanography that has been done in the Arctic Ocean has principally been ancillary to programs in geophysics or sea ice study. A result is that there is only a small number of modern deep hydrographic and tracer profiles and then only from a severely limited area. The same can be said of basic chemical and physical measurements of other kinds. Therefore, except for information about ice cover, little is known of the circulation of the Arctic Ocean, its dynamics, and its property distributions.

In considering remedies for this situation, it is particularly important to provide a conceptual framework for long-term scientific planning and programmatic development. Work over the past decade suggests a valid scientific framework to be the large-scale circulation and ventilation of the Arctic Ocean, including the special role of the shelf seas, major boundary currents, and exchanges with the adjoining seas.

A SCIENTIFIC FRAMEWORK

Knowledge of the circulation of the water of the polar basin, together with its dissolved and suspended matter, has been based primarily on extrapolation of the drift patterns of sea ice, together with inferences from an extremely coarse description (in space and time) of the distributions of temperature, salinity, and a few other parameters. Summaries of the older data can be found, for example, in Coachman and Aagaard (1974), while more sharply focused recent syntheses of different data sets have been provided by Thorndike and Colony (1982), Ostlund and Hut (1982), and Aagaard et al. (1985).

While the driving force for the circulation must, in part, be the wind field (which is probably better known than over any part of the world ocean, thanks to an extensive drifting buoy program maintained since 1979 (Colony and Thorndike, 1984)), attention has recently been called to the thermohaline forcing and response, particularly with respect to the ventilation of the Arctic Ocean and its relationship to that of the adjacent seas.

The context is as follows (Figure 2): A significant portion of the ventilation of the deep waters of the world ocean originates in the North Atlantic and its extensions. The seas lying north of the Greenland-Scotland ridge system are particularly important in supplying cold and well-oxygenated water to the global abyss. Of these northern seas, the Arctic Ocean is by far the largest. However, until very recently it was thought that because of the strong and shallow stratification of the Arctic Ocean proper, little if any ventilation could occur locally. Instead, such renewal as there was presumably resulted from inflow (of unknown quantity) from the Greenland and Norwegian seas, south of Fram Strait. Were this in fact the case, then the Arctic Ocean could only play an indirect and passive role in buffering the atmospheric carbon dioxide increase.

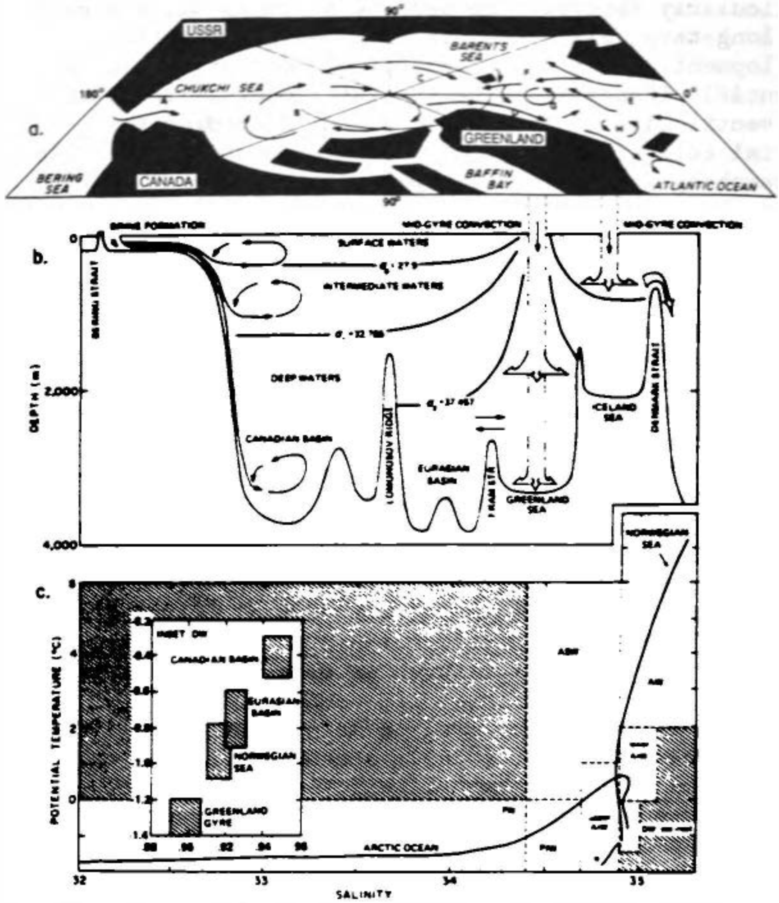

FIGURE 2 Schematic circulation and water mass structure in the Arctic Mediterranean and θ/S curve for the major regions and water masses.

Furthermore, the oceanic contribution to the surface heat budget would primarily be limited to fluxes and storage in the upper mixed layer, generally shallower than 50 m.

New lines of evidence in the last few years suggest that these concepts are in fact erroneous and that significant and deep-reaching ventilation does occur within the Arctic Ocean itself. While the new oceanographic data within the deep Arctic Ocean are very sparse, when taken together with the results of recent work in adjoining shelf seas they point toward the importance of shelf processes in deep water renewal, and in particular to the importance of brine rejection (Aagaard et al., 1985). In addition, recent studies on chemical tracers have provided new information (Ostlund, 1982; Moore et al., 1983). This evidence suggests that very dense water is produced over the vast continental shelves of the Arctic Ocean, but that this water is modified considerably by entrainment on its way to the deeper strata.

There is also clear evidence from the rapidly increasing hydrographic, current, and tracer data base in Fram Strait that in the eastern part of the strait water may move into the Arctic Ocean from the south at all depths (Hanzlick, 1983; Swift, 1983; Aagaard et al., 1987). Such water seems to spread into the interior remarkably quickly, pointing toward a separate effective ventilating mechanism, viz. exchange through Fram Strait. For example, tracer-tagged water near 1500 m appears to have reached the North Pole from Fram Strait within about three years (Livingston et al., 1984). On the other hand, what is known of the circulation in the deep interior suggests only very slow transports, except near the major topographic features (Aagaard, 1981). It is therefore likely that currents along major topography and the basin margins, such as have been observed along the Lomonosov Ridge (Aagaard, 1981) and north of Alaska (Aagaard, 1984), are an important part of the large-scale circulation. Work during the AIDJEX program suggests that in the interior of the Arctic Ocean, away from the basin margins, mesoscale baroclinic eddies may dominate the circulation (Manley and Hunkins, 1985), although far too little of the ocean has been sampled to extrapolate the results to the entire basin.

A recent study by Aagaard et al. (1985) shows that the Arctic Ocean also exports southward-moving dense waters formed within the polar basin, and that these probably contribute significantly to the deep ventilation of the seas to the south, including the Norwegian Sea.

In summary, the Arctic Ocean appears to contain a significant thermohaline circulation of importance far beyond its borders. The definition of this circulation and its consequences provides a useful scientific framework for future research, as addressed in three questions.

1. <u>What is the structure of the interior Arctic Ocean and how is it maintained</u>?

The immediate and pressing need is to improve knowledge of the hydrography and the velocity field in the deep basins of the Arctic Ocean to a point where there can be significant input to and comparison with the expanding modeling efforts. This would require a series of complete hydrographic profiles of high quality, representative of each of the four primary basins of the Arctic Ocean (separated by the Alpha-Mendeleyev, Lomonosov, and Mid-ocean Ridges). These profiles should include those measurements of demonstrated usefulness in inferring the large-scale circulation and its time scales: temperature, salinity, oxygen, nutrients, chlorofluoromethanes, tritium, helium-3, radiocarbon, strontium-90, and radium and cesium isotopes. Several of these parameters are particularly well suited for tracing the influences of shelf processes on the interior ocean, while others provide specific information on exchange with the adjacent seas.

It is also important to begin mapping the subsurface velocity field in the interior, with a view toward determining the principal flow patterns, energy levels, and advective time scales. The near-surface flow may become adequately determined from the surface buoy drift corrected for wind effects (Thorndike and Colony, 1982), though this remains to be verified. Other techniques will be required to track movement deeper in the water column. Both moored instrumentation and SOFAR floats appear to be feasible and appropriate for such an effort, as do suspended or downward-looking sensors in connection with the data buoy programs, along with dynamic topography mapping. The widest geographical coverage would probably come through SOFAR floats deployed in connection with hydrophones linked to the drifting data buoys; feasibility studies for such work have begun.

The physical and chemical structure near the basin margins, where the evidence points to important deep boundary currents, constitutes a special problem set. Required data include a selected set of detailed hydrographic sections (including tracers) across major topographic features, together with direct current measurements using moored arrays and supplemented by Lagrangian drifters.

Recommended:

<u>Investigation of the internal structure of the four major basins of the Arctic Ocean, and the means by which it is altered or maintained.</u>

2. How does the interior Arctic Ocean interact with its extensive bordering shelf seas?

The main halocline of the Arctic Ocean (50 to 200 m) is ventilated from shelf sources around its periphery (e.g., Aagaard et al., 1981; Melling and Lewis, 1982 Moore et al., 1983). Increasingly, the evidence also points to these sources driving a deep circulation as well (Aagaard et al., 1985). Furthermore, it appears that this circulation is primarily driven by the production of dense water through brine rejection during freezing, but in some areas (notably the Barents Sea) this is augmented through cooling of warmer saline water derived from the North Atlantic (Swift et al., 1983; Midttun, 1985). Upwelling may be a contributing factor in some instances (Aagaard, 1981), bringing relatively saline water onto the shelves, where cooling will increase its density. Such upwelling would also contribute nutrients to the shelves.

At this point the principal questions appear to involve the rate at which the spectrum of dense waters is produced, the means by which these waters leave the shelves, and the manner and rate at which they are mixed or stirred into the interior of the Arctic Ocean. In addition to the density modification that occurs on the shelves, there appears to be a number of modifications of the chemical composition of the water. These involve exchange with the atmosphere, consequences of the freezing process, biochemical effects, and exchange with the sediments. These chemical modifications on the shelves are likely to provide unique information about the origin and subsequent history of the water.

Recommended:

Investigation of shelf and shelf-edge processes in the context of large-scale circulation in the Arctic Ocean.

Important formation areas for dense shelf water include the Chukchi and northern Bering seas, adjacent to Alaska, which provide a logical early focus for investigations. Such work may include the chemical description of the shelf waters during the annual cycle, with an emphasis on tracer fluxes from the sediments into the overlying waters and on the effect of freezing. A second likely research component is the formation, outflow, and interleaving of brine plumes from the shelves. This is in large part an issue of plume dynamics, but directed toward more realistic representations than the steady, homogeneous plumes used in modeling to date. The Barents Sea appears to contribute to the thermohaline circulation in a somewhat different manner, probably in large part through the cooling of saline water from the Norwegian Sea (Swift et al., 1983; Anderson and Jones, 1986). Enough is now known about all these shelf seas, however, that well-formulated and directed research efforts are possible in several of the key areas.

The contribution to the circulation and water masses of the Arctic Ocean of the shelf seas bordering the U.S.S.R. (the Kara, Laptev, and East Siberian seas) has not been investigated in recent years by western researchers. This constitutes a major gap in oceanographic efforts, and any successful move to reduce this gap through cooperative investigations with Soviet scientists is likely to provide new results of major significance.

3. <u>What are the dynamic and thermodynamic consequences of exchange between the Arctic Ocean and the seas to the south</u>?

There are four open boundaries across which water is exchanged with the Arctic Ocean, each with a distinctive role and unique characteristics: Fram Strait, the Canadian Archipelago, Bering Strait, and the Barents Sea.

The importance of the open (advection) boundaries to the circulation and ventilation of the Arctic Ocean is that they are sources and sinks for water and its various dissolved substances, and that these sources and sinks are specific and selective. For example, the outflow of water from the Arctic Ocean through the relatively shallow passages of the Canadian Archipelago is limited to the upper few hundred meters. Furthermore, to the extent that the circulations of the Eurasian and Canadian basins are separate and distinct (e.g., through the effects of the Lomonosov Ridge), this outflow will affect primarily the Canadian Basin. Such a withdrawal is not necessarily only a boundary effect, however, for the outflow can induce compensating vertical motion in the interior, with consequences for the interior stratification.

In contrast, the outflow of water through Fram Strait may occur at all levels down to about 2600 m, as may inflow, so that the Eurasian Basin can at least in principle be ventilated laterally, without recourse to vertical motion, although this does not of course prevent vertical motion from being driven by other forcing mechanisms, e.g., by shelf plumes. The role of Fram Strait as a source is important, both because of the source strength (it probably dominates most of the advective exchanges) and because of the distinctive signals. In the upper ocean, warm, salty, nutrient-poor water carries a variety of anthropogenic tracers, and at depth water in the Greenland Sea is colder and fresher than the deep waters produced within the Arctic Ocean.

Important exchanges also occur across the other two open boundaries. Bering Strait is a major source of low-salinity water for the Arctic Ocean, and probably also of nutrients; while the Barents Sea is probably principally an inlet to the Arctic Ocean of water from the Norwegian Sea, but substantially modified over this large shelf.

Three fundamentally different kinds of questions can be asked about the exchanges across these boundaries. The first is a kinematic one about the properties and rates of exchange, e.g., What is the total mass flux across a particular boundary? More useful refinements would be directed at these fluxes as a function of time, location (depth and horizontal position in a cross-section), and density. The second kind of question is a dynamic one, relating to the mechanisms that control the exchange. This may in part be an issue of local dynamics, but it is also one of driving on larger scales. The most fundamental question of this kind is probably the extent to which the various mean flows and their variabilities are wind driven and to what extent density driven. The third kind of question relates specifically to the role of the particular exchange in the circulation of the Arctic Ocean. This is essentially the interpretive context that joins a particular problem to the central issue of ventilation and large-scale circulation; it is therefore the crucial question for justifying a particular study and relating it to other investigations.

Several of these advective boundaries are currently either under investigation or being considered for such. From the perspective of Arctic Ocean investigations, a major need is to relate this work at the boundaries to the central conceptual framework, so that the effects of these exchanges on the Arctic Ocean can be accounted for. In this context, the goal of the advection boundary studies is to quantify the sources and sinks, including their time dependence; and to give sufficient insight

into the mechanisms that control their strength, so that prediction is possible.

Recommended:

Investigation of the effects on the Arctic Ocean of exchanges across its open boundaries: Fram and Bering straits, and the passages through the Canadian Archipelago, and in the Barents Sea.

5

Logistical and Support Requirements for Arctic Marine Research

The research priorities addressed in this document will require logistical support in the form of aircraft, ice stations, remote sensing techniques, icebreakers,* and ice-capable* surface research vessels. The possible role of submarines and submersibles was not considered in this report. Since the scientific issues in this report are inherently international in scope, the United States should be prepared to support research on foreign logistical platforms in a mutually acceptable manner. However, the continuity of our national arctic scientific research program will depend on a U.S. commitment to provide logistical support. The use of aircraft and ice stations for oceanographic application is well proven, but has not been broadly or fully exploited, and this must be done in the future. Remote sensing is of central importance to arctic marine research. It has been addressed in detail in other documents, and will only be examined briefly here. The major emphasis in this discussion, therefore, is on the requirement for a dedicated ice-capable polar research vessel, since there is little documentation of the scientific need for a ship for arctic research in other academic reports. To date, the United States has no dedicated ice-capable research vessel to serve as a platform for arctic marine research.

REMOTE SENSING

Satellite observations are particularly important in support of arctic oceanographic research; visible and

*These terms are defined in Appendix A.

infrared imagery has been used for more than a decade to determine ice cover, motion, and characteristics. Recently, satellite-borne scanning multispectral microwave radiometers have used the passive microwave properties of ice to establish ice characteristics. Active microwave (such as synthetic aperture radar (SAR)) is capable of providing detailed information on ice cover (such as individual ice floes) even in the presence of cloud cover. The data are useful for studying polynyas, ocean eddies, ice velocities, and other processes in the marginal ice zone.

A primary need for ecological research is synoptic information on phytoplankton distribution and abundance, which is only obtainable through color imaging. The Coastal Zone Color Scanner (CZCS) and the proposed Ocean Color Imager (OCI) are imaging radiometers that estimate concentration of phytoplankton pigments near the surface. Estimates of productivity are also useful in understanding carbon and nitrogen fluxes and the role of arctic waters in climate.

Ocean color data have applications for the Arctic in addition to quantification of phytoplankton. Flow visualization of water mass transport of features such as fronts and eddies enables investigation of dynamic oceanic features. Guiding research ships to important oceanographic features for study or commercial vessels to highly productive areas for fishing could be facilitated by color imaging data. In view of the large geographical area and difficult access to the Arctic, an improved color imaging capability would be valuable for the arctic marine science community.

Polar orbiting satellites incorporating these instruments, as well as communication packages for data transmission, are also important in assuring that data are utilized to their fullest extent. However, aircraft remote sensing utilizes many of the same instruments, and the lower altitudes can afford a far better spatial resolution. Aircraft-based color scanning could be a very powerful tool for marine ecological and fisheries research. Moored instruments and buoys will also continue to play a very important role in arctic marine research. Tools such as the new Arctic Remote Autonomous Measurement Platform (ARAMP) will greatly facilitate data acquisition.

DEDICATED ARCTIC RESEARCH VESSEL

Our capacity to learn more about the arctic regions is severely limited by the lack of any research ships sufficiently strengthened to operate in sea ice. That deficiency is especially noteworthy when compared with the capabilities of our neighbors around the Arctic Basin, especially the Soviet Union. At present, the only U.S. research vessel with even minimal ice-worthiness operating in the Arctic is the R/V Alpha Helix, which has only very limited ice strengthening. For a number of years the U.S. national oceanographic community, and specifically those investigators and institutions having direct interest in the polar marine environment, have recognized the need for a vessel to support research in sea-ice-dominated waters (see Appendix B for historical summary). There are enough research projects within the realm of all research agencies (see section on "scientific justification" below) to justify employment of a polar research vessel on a full-time basis. Nevertheless, the United States lacks a dedicated ice-capable research vessel for arctic research. There are also a large number of prospective research projects that have never been proposed because the United States does not have such a vessel (see Appendix C).

Recommended:

The United States should proceed with the procurement of a surface ice-capable research vessel dedicated for supporting arctic marine research.

This vessel should be capable of independent operation in seasonal sea ice and station keeping in high-latitude open seas. The scientific community would be best served if the vessel were operated as part of the UNOLS academic fleet, or in a similar dedicated manner.

A U.S. Coast Guard report on U.S. polar icebreaker requirements (Interagency Report, 1984; see Appendix A) defines a polar research vessel as:

> An ice-capable vessel dedicated primarily to research, designed to operate independently in the marginal ice zone and in unconsolidated pack ice during the summer melt season. It would be designed to ABS Class 1A or 1AA ice strengthening, capable of breaking 2.5 feet of first year thin, level ice continuously, have 60-day

endurance, capacity for two helicopters, and accommodations for 50 passengers plus crew. A good example of a modern PRV is the Norwegian vessel Polarbjorn. It is 162 feet in length with 2,500 SHP.

SCIENTIFIC JUSTIFICATION

The U.S. research fleet is notably deficient with respect to ice capability, especially when compared with fleets of many other countries. For many years, research by U.S. scientists in arctic waters has been hampered by the lack of ice-capable research ships. Even though modern solutions to polar marine logistical problems include technology such as satellite imagery, long-range aircraft, submarines, drifting ice stations, and remote sensing, much of the important research can be accomplished most effectively and economically from an ice-capable, stable, research ship. The requirement for such a vessel has been the finding of many academic, governmental, and nongovernmental (e.g., National Research Council) documents.

A polar research vessel questionnaire was circulated among the oceanographic community in 1977. The responses revealed that most prospective users desired ship capability in seasonal sea ice (Elsner et al., 1977). In 1984 the Federal Fleet Coordination Council (FFCC) undertook a study of the need for a polar research vessel. Its findings showed shiptime requirements of 573 days per year about evenly divided between icebreakers and ice-capable ships. It recommended that an ice-capable vessel in the 250- to 275-foot range be acquired and operated by the National Science Foundation as a national facility. More recently, the UNOLS Fleet Replacement Committee has conducted a planning study, and in a recent report addressed the future trends in ocean sciences. The committee report emphasized the need for ice capability in the fleet, mentioning that twice in recent years the R/V Alpha Helix (ABS Ice Class C) sustained ice damage, and that numerous other instances exist where relatively light ice has constrained UNOLS and other research ships from intended areas of investigations. The report concludes that polar research can, and should, be accomplished from ice breakers and from lesser ice-worthy, but ice-capable, vessels dedicated to polar research. Consequently, an ice-capable vessel was included in the recommended ship replacement plan (University-National Oceanographic Laboratory System, 1986).

In preparing this discussion, the Committee on Arctic Marine Science surveyed approximately 100 arctic ocean scientists for present and future needs for an ice-capable research vessel. Their comments support the immediate need for a U.S. surface research ship capable of operating in sea ice (see Appendix C). Even a casual overview of ongoing needs (a partial summary is provided as Appendix D) identified such projects as ISHTAR (Inner Shelf Transport and Recycling; National Science Foundation Division of Polar Programs), which has had to delay initiation of field work in spring due to ice in the northern Bering Sea, and Amphipod Energetics and Production in the Northern Bering Sea (also National Science Foundation Division of Polar Programs), which misses the biologically critical spring period due to the inability to work in the presence of sea ice. Studies of the ice edge region in the Bering Sea are severely constrained by the inability to penetrate within the pack; and access to polynyas, identified in many studies as both physically and biologically important, is generally impossible at present. As another example, the National Oceanic and Atmospheric Administration currently supports research in the Kotzebue Sound and the southeastern Chukchi Sea, looking at water circulation, carbon flow, and sediment parameters, while another study examines the community structure of the northeastern Chukchi Sea in relation to such physical parameters as sea ice distribution. For these studies, the spring break-up period is critical, but no ice-capable vessel is available to provide access.

A dramatic illustration of the effects of limited capability to carry on research in ice is our inability to support marine mammal research. Most of the marine mammals that inhabit Alaskan waters, and are of greatest interest to the scientific community and greatest practical value to the State of Alaska, reside in the ice-covered seas to the west and north. Up to now, the marine mammal studies in the ice have been conducted mainly from Soviet vessels, and, occasionally, by "piggybacking" on multipurpose cruises of U.S. Coast Guard icebreakers. The work from U.S. research vessels has been limited to areas of loose ice at the ice edge and to open water. Each of these options offers a very limited scope for conducting the research, which greatly retards the research. The required access to animals and their primary habitat is impossible without the help of an ice-capable ship that is dedicated to support research. Furthermore, proposals for marine mammal scientific research, which requires penetration of sea ice, have not been encouraged due to the lack of any suitable support ship. The mandate of the Marine Mammal Protection Act requires that sufficient research into the ecosystem relationships of marine mammals be performed to support the application of the best available information relating to their conservation and development. This is difficult to accomplish at present.

A large marine mammal project, supported by the Minerals Management Service, provides yet another good example of the impact of the U.S. deficiency in arctic logistical support. This project seeks to determine the importance of the Alaskan Beaufort Sea in bowhead whale energetics. The project is currently hampered in its scientific operations in the Beaufort Sea by the limited and expensive icebreaker support, with limited laboratory space and the inherent difficulties in conducting varied scientific research aboard a nondedicated vessel. The coastal residents of northern Alaska are particularly concerned about research on the bowhead whale. An ice-capable research vessel would have access to the Beaufort Sea during the critical summer months.

Some nations have chosen to provide full icebreaking capability for their polar research vessels. The Japanese Shirase is one such vessel, but its mission includes breaking into the antarctic base, and the ship is dedicated almost exclusively to antarctic research. The West German vessel Polarstern transits between the Antarctic and Arctic, a feat made possible because both programs are undertaken by the same research institution, the Alfred Wegener Institute for Polar and Marine Research. U.S. scientists have had the opportunity to participate in programs on board Shirase and Polarstern; and, while such opportunities should be seized upon, they should not be the substitute for independent U.S. capability. For example, the MIZEX project in the Greenland Sea required an icebreaker, as does winter work on the Alaskan shelves. The MIZEX project has used the German vessel Polarstern and chartered vessels. Although the vessels have been suitable, problems are inevitable, and use of foreign vessels cannot substitute for a U.S. capability.

Industrial needs must also be taken into account, and industrial use must be anticipated and accommodated. One immediate need is the ability to carry out research on ice. Both observation, which would eliminate the need for some expensive overflights, and the ability to make measurements, are immediate concerns.

The lack of an ice-worthy research vessel has already severely hampered the progress of scientific investigations in the Arctic. The Department of Energy lists the magnitude of FY 1985 U.S. federal agency oceanographic research programs in the Arctic as:

Oceanography	$13.3 M
Marine ecology	18.0 M
Est. marine geology, sea ice, etc.	1.0 M
TOTAL	$32.3 M

Logistics support necessary for the above research is currently poorly provided by foreign ships, NOAA vessels, USCG icebreakers, and small boats. With an anticipated increase in focused arctic research activity, pursuant to the Arctic Research and Policy Act of 1984, this deficiency will become an increasing liability. Furthermore, the availability of a dedicated ice-worthy surface research vessel will remove a major constraint inhibiting generation of proposals for arctic marine research. Past experience and future projections confirm that an ice-capable vessel (ABS Class 1A or 1AA, Arctic Class 2 or 3) should be given highest priority for the U.S. research vessel fleet.

6

Conclusions and Recommendations

ECOSYSTEM DYNAMICS OF ARCTIC SHELF SEAS

Conclusions

The committee finds that there is an urgent need for marine ecological programs in the Arctic, because of the regional importance of the arctic shelves, and their role in global fluxes:

- emphasis should be on the shelf systems of seas adjacent to the Arctic Ocean, which are highly productive in contrast to those of the high Arctic;
- seasonal variation in the light and ice regime is a major controlling factor;
- factors affecting biological recruitment, distribution, and abundance are not understood;
- the flux of carbon is important; and
- the effects of human activities on the ecosystem are unclear.

Recommendations

1. Studies are needed to determine the environmental control that mesoscale physical features (e.g., ice edge, fronts, and eddies) exert over primary production and food chain relationships.
2. In addition to large-scale, multidisciplinary process-oriented studies, a need still exists for small, focused research programs.
3. Regional, interdisciplinary programs are needed of sufficient duration to encompass at least year-to-year variability in order to encompass normal climatic variability and long-term global trends.

4. Studies to address the partitioning of carbon in arctic ecosystems are needed.

5. Assessments of the nature of pollutant-sediment interaction and development of basic information on sediment transport systems in arctic ecosystems are needed.

6. A long-term baseline data set for arctic marine ecosystems (e.g., Chukchi Sea) needs to be established.

7. A periodical monitoring program is needed for higher trophic level animals for assessing contaminant load (e.g., oil, mercury, pesticides).

8. Research is needed to evaluate the environmental effects of commercial fishing on adjacent seas.

Some Strategic and Management Suggestions

The committee also suggests that in the design and conduct of arctic marine research, the following steps be taken:

- Biological research should be designed into multidisciplinary research programs from the outset so that biologists can take advantage of other data and so that programs can be designed with biological needs in mind.
- A well-defined management structure should be formed in the case of large interdisciplinary projects, to control direction and ensure program flexibility. A strong steering committee can keep the project focused and on track, but must provide the flexibility to change the research plan in the field.
- A "pulsed" field approach is useful, in which two- or three-year field programs are interrupted by two-year data work-ups, including publication, synthesis, and reassessment. In this way, a program can be extended for a sufficient time period to address year-to-year and multiyear variability.
- National liaisons between arctic programs and projects as well as international liaisons should be developed and maintained.
- The logistic and instrumentation needs of arctic marine research should receive continued attention.

CIRCULATION OF THE ARCTIC OCEAN

Conclusions

The Arctic Ocean contains a significant thermohaline circulation of importance far beyond its borders. It is the definition of this circulation and its consequences that provides a strong and useful framework for future research in the Arctic Ocean. Three priority areas exist:

- Research on the structure and maintenance of the interior Arctic Ocean.
- Research on the interaction of the interior with bordering shelf seas.
- Research on the consequences of exchange with the seas to the south.

Recommendations

1. Investigation of the internal structure of the four major basins of the Arctic Ocean, and the means by which it is altered or maintained, is needed.
2. Investigation of shelf and shelf edge processes in the context of the large-scale circulation is needed.
3. Investigation is needed of the effects on the Arctic Ocean of exchanges across its open boundaries: Fram and Bering straits, and the passages through the Canadian Archipelago and in the Barents Sea.

References

Aagaard, K. 1981. On the deep circulation in the Arctic Ocean. Deep-Sea Research 28:251-268.

Aagaard, K. 1984. The Beaufort undercurrent. In: The Alaskan Beaufort Sea: Ecosystems and Environments, D.M. Schell, P.W. Barnes, and E. Reimnitz, editors, pp. 47-71.

Aagaard, K., L.K. Coachman, and E.C. Carmack. 1981. On the halocline of the Arctic Ocean. Deep-Sea Research 28:529-545.

Aagaard, K., J.H. Swift, and E. Carmack. 1985. Thermohaline circulation in the Arctic and Mediterranean Seas. Journal of Geophysical Research 90:4833-4846.

Aagaard, K., A. Foldvik, and S.R. Hillman. 1987. The West Spitsbergen Current: disposition and water mass transformation. Journal of Geophysical Research 92:3778-3784.

Alexander, V. 1980. Interrelationships between the seasonal sea ice and biological regimes. Cold Regions Science and Technology 2:157-158.

Alexander, V., and H.J. Niebauer. 1981. Oceanography of the eastern Bering Sea ice-edge zone in spring. Limnology and Oceanography 26:111-125.

Anderson, L.B., and E.P. Jones. 1986. Water masses and their chemical constituents in the western Nansen Basin of the Arctic Ocean. Oceanologica Acta.

Barnes, P.W., D.M. Schell, and E. Reimnitz. 1984. The Alaskan Beaufort Sea. Ecosystems, and Environments. New York: Academic Press.

Broecker, W. 1987. Unpleasant surprises in the greenhouse? Nature 328:123-126.

Brown, R.G.B. 1986. Seabirds and the arctic marine environment. In: Marine Living Systems of the Far North. V. Alexander and L. Rey, editors. Leiden, Netherlands: E.J. Brill.

Cline, J.D., R.A. Freely, and G.J. Massoth. 1979. Identification of natural and anthropogenic petroleum sources in the Alaskan shelf areas utilizing low molecular weight hydrocarbons. In: Environmental Assessment of the Alaskan Continental Shelf 8:73-198, National Oceanic and Atmospheric Administration.

Coachman, L.K., and K. Aagaard. 1974. Physical oceanography of arctic and subarctic seas. In: Marine Geology and Oceanography of the Arctic Seas; Y. Herman, editor. Pp. 1-72.

Colony, R., and A.S. Thorndike. 1984. An estimate of the mean field of arctic sea ice motion. Journal of Geophysical Research 89:10623-10629.

Cooney, R.T., and K. Coyle. 1982. Trophic implications of cross-shelf copepod distributions in the southeastern Bering Sea. Marine Biology 70:187-196.

D'Asaro, E.A. In press. Observations of small eddies in the Beaufort Sea. Journal of Geophysical Research.

Day, R.H., D.H.S. Wehle, and F.C. Coleman. 1985. Ingestion of plastic pollutants by marine birds. In: R.S. Shamura and H.D. Yoshia, editors, Proceedings of a Workshop on the Fate and Impact of Marine Bevrism, November 26-29, 1984, Honolulu, Hawaii. NOAA Technical Memorandum 54. National Marine Fisheries Service. Pp. 344-386.

Department of Energy. 1985. Federal Arctic Research, Detailed Listing of Existing Programs, Initial Compilation. DOE/ER-0251, prepared by the Interagency Arctic Research Policy Committee.

Dunbar, M.J. 1986. The Arctic Ocean as a biological environment. In: Marine Living Systems of the Far North. V. Alexander and L. Rey, editors. Leiden, Netherlands: E.J. Brill.

Elsner, R., J. Dermody, and J. Leiby. 1977. Polar Research Vessel. A Conceptual Design for the National Science Foundation. Columbia, Maryland: Artec, Inc.

Fowler, C.W. 1985. An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands. In: Proceedings of the Workshop on the Fate and Impact of Marine Debris. November 26-29, 1984, Honolulu, Hawaii, NOAA Technical Memorandum 54. National Marine Fisheries Service. Pp. 291-306.

Geraci, J.R., and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Marine Fisheries Review 42:1-12.

Hanzlick, D.J. 1983. The West Spitsbergen Current: transport, forcing, and variability. Ph.D. thesis.

Hood, D.W. 1986. Processes and resources of the Bering Sea Shelf (PROBES). Continental Shelf Research 5(1/2):288 pp.

Imbrie, J., and K.P. Imbrie. 1979. Ice Ages, Solving the Mystery. Hillside, N.J.: Enslow.

Interagency Report 1984. United States Polar Icebreaker Requirements Study. U.S. Department of Transportation, U.S. Coast Guard, 396 pp.

Iverson, R.L., L.K. Coachman, R.T. Cooney, T.S. English, J.J. Goering, G.L. Hunt, Jr., M.C. Macauley, C.P. McRoy, W.S. Reeburgh, and T.E. Whitledge. 1979. Ecological significance of fronts in the southeastern Bering Sea. In: Ecological Processes in Coastal and Marine Systems, R.J. Livingstone, editor. New York: Plenum Publishing, pp. 437-466.

Karl, T.R., R.E. Livezy, and E.S. Epstein. 1984. Recent unusual mean winter temperatures across the contiguous United States. American Meteorological Society Bulletin. 65:1302-1309.

Kelley, J.J., L.L. Longerich, and D.W. Hood. 1979. Effect of upwelling, mixing and high primary productivity on carbon dioxide concentrations in surface waters of the Bering Sea. Journal of Geophysical Research 76:3687-3693.

Killworth, P.D., and J.M. Smith. 1984. A one-and-one-half dimensional model for the arctic halocline. Deep-Sea Research 31:271-293.

Lamb, H.H. 1972. Climate: Present, Past and Future. London: Methuen. P. 30.

Levine, M.D., C.A. Paulson, and J.H. Morison. 1987. Observations of internal gravity waves under the arctic pack ice. Journal of Geophysical Research 92:779-782.

Livingston, H.D., S.L. Kupferman, V.T. Bowen, and R.M. Moore. 1984. Vertical profile of artificial radionuclide concentrations in the central Arctic Ocean. Geochimica et Cosmochimica Acta 48:2195-2203.

MacCracken, M.C., and F.M. Luther, editors. 1985. Projecting the Climatic Effects of Increasing Carbon Dioxide. Report DOE/ER-0237, Department of Energy, Washington, D.C., 381 pp.

Manley, T.O., and K. Hunkins. 1985. Mesoscale eddies of the Arctic Ocean. Journal Geophysical Research 90:4911-4930.

Melling, H., and E.L. Lewis. 1986. Shelf drainage flows in the Beaufort Sea and their effect on the Arctic Ocean pycnocline. Deep-Sea Research 29:967-985.

Midttun, L. 1985. Formation of dense bottom water in the Barents Sea. Deep-Sea Research 32:1233-1241.

Moore, R.M., M.G. Lowings, and F.C. Tan. 1983. Geochemical profiles in the central Arctic Ocean: their relation to freezing and shallow circulation. Journal of Geophysical Research 88:2667-2674.

National Research Council. 1985. National Issues and Research Priorities in the Arctic, prepared by the Polar Research Board. Washington, D.C.: National Academy Press. 124 pp.

Ostlund, H.G. 1982. The residence time of the freshwater component in the Arctic Ocean. Journal of Geophysical Research 87:2035-2043.

Ostlund, H.G., and G. Hut. 1982. Arctic Ocean water mass balance from isotope data. Journal of Geophysical Research 87:6373-6381.

Padman, L., and T.M. Dillon. 1987. Vertical heat flux through the Beaufort Sea thermohaline staircase. Journal of Geophysical Research 92:10799-10806.

Petersen, G.H., and M.A. Curtis. 1980. Differences in energy flow through major components of subarctic, temperate and tropical marine shelf ecosystems. Dana 1:53-64.

Rey, F., and H. Loeng. 1985. The influence of ice and hydrographic conditions on the development of phytoplankton in the Barents Sea. In: Marine Biology of Polar Regions and Effects of Stress on Marine Organisms, J.S. Gray and M.E. Christiansen, editors. Pp. 49-63.

Sambrotto, R.N., H.J. Niebauer, J.J. Goering, and R.L. Iverson. 1986. The relationship among vertical mixing, nitrate uptake, and growth during the spring bloom on the southeast Bering Sea middle shelf. Continental Shelf Research 5:161-198.

Semnter, A.J., Jr. 1984. The climatic response of the Arctic Ocean to Soviet river diversions. Climatic Change 6:109-130.

Semnter, A.J., Jr. 1987. A numerical study of sea ice and ocean circulation in the Arctic. Journal of Physical Oceanography 17:1077-1099.

Smith, S.L., W.O. Smith, L.A. Codispoti, and D.L. Wilson. 1985. Biological observations in the marginal ice zone of the east Greenland Sea. Journal of Marine Research 43:693-717.

Stirling, I., and W. Calvert. 1983. Environmental threats to marine mammals in the Canadian Arctic. Polar Record 21:433-449.

Stirling, I., and H. Cleator, editors. 1981. Polynyas in the Canadian Arctic. Canadian Wildlife Service Occasional Paper No. 46, 70 pp.

Sullivan, C.W., and A.C. Palmisano. 1984. Sea ice microbial communities: distribution, abundance, and diversity of ice bacteria in McMurdo Sound, Antarctica, in 1980. Applications of Environmental Microbiology 47:788-795.

Swift, J.H., T. Takahashi, and H.D. Livingston. 1983. The contribution of the Greenland and Barents seas to the deep water of the Arctic Ocean. Journal of Geophysical Research 88:5845-5852.

Thorndike, A.S., and R. Colony. 1982. Sea ice motion in response to geostrophic winds. Journal of Geophysical Research 87(CB):5845-5852.

University-National Oceanographic Laboratory System. 1986. Science Mission Requirements for New Oceanographic Ships, UNOLS Fleet Replacement Committee.

Vibe, C. 1967. Arctic animals in relation to climatic fluctuations, Meddelelser om Groenland Ed. 170(5):227.

Walsh, J.J., G.T. Rowe, R.L. Iverson, and C.P. McRoy. 1981. Biological export of shelf carbon is a neglected sink of the global CO_2 cycle. Nature 29:196-201.

Wyatt, T. 1980. The growth season in the sea. Journal of Plankton Research 2(1):81-97.

Appendixes

Appendix A
DEFINITIONS OF SHIPS THAT OPERATE IN ICE

Figure A-1 and all terms except E are from *United States Polar Icebreaker Requirements Study*, U.S. Department of Transportation, U.S. Coast Guard, July 1984, chapter 5, pages 24-25. These are definitions used by the Federal Oceanographic Fleet Coordinating Council.

A. *Ice strengthened*--A vessel able to operate in very open pack (<3/10 concentration), first-year thin ice (or earlier stage of development), which is less than 1.5 feet thick. The vessel is structurally strengthened around the waterline and has a conventional bow form. Safe navigation through sea ice is possible only under ice escort. The strengthening around the waterline is designed to minimize damage from the hull hitting sea ice at slow speed. An example of this vessel type is the USNS *Maumee*.

B. *Ice-capable*--A vessel able to operate in open pack (4/10 to 6/10 concentration), first-year thin/medium level ice, which is 1.5-4.0 feet thick. The vessel is structurally strengthened around the waterline, has an ice-breaking bow form, and has more horsepower than required for transit through ice-free waters. Safe navigation can be accomplished independently in very open pack; however, in open pack (or greater concentration) it is prudent to navigate with an ice escort. For independent operations, the vessel must navigate at slow speed using available leads in the pack ice and/or by pushing the ice out of its path. An example of this vessel type is the South African vessel *Agulhas*.

C. *Polar Research Vessel* (PRV)--An ice-capable vessel dedicated primarily to research, designed to operate

Vessel Type	Ice Stage of Development (Hardness Increases with Age)	Ice Thickness (feet)	Ice Concentration (tenths)	Operational Scenario
Ice Strengthened	Young Ice	< 1.0	0-3	Ice Escort Required
	Thin 1st Yr (1st stage)	1.0-1.5		
Ice Capable	Thin 1st Yr (2nd stage)	1.5-2.5	0-3	Limited Independent
	Med 1st Yr	2.5-4.0	4-6	Ice Escort Required
Icebreaker	Thick 1st Yr	> 4.0	*	Unlimited Independent
	2nd Yr	4.0-8.0		
	Multi-year	variable (approx. 9.5)	0-10	
Polar Research Vessel	Young Ice	> 1.0	0-9	Within 50nm of ice edge, unlimited independent
	Thin 1st Yr (1st stage)	1.0-1.5		
	Thin 1st Yr (2nd stage)	1.5-2.5	*	
	Med 1st Yr	2.5-4.0		

* Range of designed, continuous ice-breaking capability

FIGURE A.1 Ice navigation capabilities.

Source: Table 5.4 from U.S. Polar Icebreaker Requirements Study, U.S. Department of Transportation, U.S. Coast Guard, 1984, p. 5-26.)

independently in the marginal ice zone and in unconsolidated pack ice during the summer melt season. It would be designed to ABS Class 1A or 1AA ice strengthening, capable of breaking 2.5 feet of first-year thin, level ice continuously, have 60-day endurance, capacity for two helicopters, and accommodations for 50 passengers plus crew. An example of a modern PRV is the Norwegian vessel Polarbjorn. It is 162 feet in length with 2,500 SHP.

D. Icebreaker--A vessel able to operate independently in close pack (or greater), first-year thick to multiyear ice, which is greater than 4.0 feet in thickness. The vessel is structurally strengthened around the waterline, has an ice-breaking bow form, and has added horsepower and displacement to continuously break level first-year medium to second-year ice, which ranges from 2.5 to 8.0 feet in thickness. The vessel can operate in first-year pack ice without risk of hull damage. Vessel endurance, facilities, and berthing are dependent upon the design mission needs. Examples of this vessel type are USCGC Westwind (3.1 feet of level ice at 3 knots), and the Leonid Breshnev (7.5 feet of level ice at 3 knots).

E. Ice-worthy--A nonquantitative term used to describe the ability of a ship to operate in icy waters.

Appendix B
ARCTIC RESEARCH VESSEL REQUIREMENT: HISTORICAL BACKGROUND

Numerous recommendations in support of the need for a national research capability in ice-covered seas have been made by deliberative bodies composed of representatives of academic and agency marine science communities. As early as 1963, a National Academy of Sciences report, which addressed research in the Arctic Ocean Basin, included the following recommendation: "That initially, at least one suitable and adequately supplied vessel be provided as a floating laboratory to transport and to house scientists engaged in approved investigations in the Arctic Basin" (National Academy of Sciences, 1963). On December 12, 1979, the Polar Research Board chairman A.L. Washburn and the Ocean Sciences Board chairman Warren Wooster wrote a letter to National Academy of Sciences president, Dr. Philip Handler, expressing the concerns of the two boards about the lack of U.S. logistical capability in ice. In this letter, several strong statements refer to the impact on research of the lack of a vessel, such as: "Accordingly, the concerned U.S. scientific community is handicapped from submitting proposals for such research" and "While the ability of the United States to conduct research in the polar oceans is reaching its lowest level in almost two decades, other nations have significantly increased their capacity to conduct such work." The letter states that for the United States to maintain vigorous participation in scientific investigations in the polar oceans it will be necessary to acquire an ice-strengthened vessel for research in the Arctic. A summary of polar oceans needs and opportunities was attached, along with a listing of ice-worthy ships of the world, compiled by Dr. Robert Elsner. Dr. Handler transmitted these concerns by letter (February 6, 1980) to the director of the National Science Foundation, the administrator of the National Oceanic and Atmospheric Administration, the assistant secretary of the Navy, the assistant secretary of the Maritime Administration, and the commandant of the U.S. Coast Guard.

A review and design study, sponsored by UNOLS and supported by NSF and the Alaska Council on Science and Technology, was undertaken from 1977 through 1982 by the Institute of Marine Science, University of Alaska. Conceptual and preliminary designs, engineering, and model testing were developed with participation of U.S. and foreign experts. The purpose was to respond to the national requirement for an independently operating research vessel.

In January 1981, the National Advisory Committee on Oceans and Atmosphere, in a report on national ocean goals and objectives for the 1980s, stated that over the next 15 years we have to move into the Arctic and Antarctic for research and resource motivations. In support of this, the report identified the need for greater polar capability of the U.S. oceanographic fleet (National Advisory Committee on Oceans and Atmosphere, 1981).

The following excerpts are from a recently published U.S. Coast Guard study (Interagency Report, 1984):

a. A 1979 Coast Guard study envisioned "ice strengthened polar research ships" which could complement polar icebreakers by handling "a significant portion of the research currently performed by icebreakers" in loose pack.

b. In 1982, a National Research Council (Ocean Sciences Board) study sought to record the status of the nation's academic research fleet and project the future need for and probable nature of that fleet. One conclusion was the need for an ice strengthened vessel in each polar ocean, in order to provide 1000-2000 scientist-days at sea per year. The study went on to recommend immediate construction of such a vessel (National Research Council, 1982).

c. A 1983 National Research Council (Polar Research Board) study responded to a National Science Foundation (NSF) request to recommend priorities among "a small set of major scientific questions of outstanding importance in antarctic research." This study identified a need for an icebreaking research vessel in order to conduct various antarctic oceanographic projects (National Research Council, 1983).

d. In the introduction to a 1980 PRV Design Study, prepared for NSF by the University of Alaska Institute of Marine Science, it was stated that "much of the important research which will be required can be accomplished most effectively and economically from an ice strengthened, stable research ship" (Elsner and Leiby, 1980).

New developments in arctic research are on the horizon, with arctic components planned for such major global ocean programs as the Global Ocean Flux initiative. In the eastern Arctic, a coordinated international research effort, the Greenland Sea Project, will follow MIZEX. The Arctic Research Commission has identified as its number one research priority research to understand the Arctic Ocean (including the Bering and marginal seas) and how the ocean and the arctic atmosphere operate as coupled components within the arctic system. Commission chairman James H. Zumberge, in a letter dated October 9, 1986, to Erich Bloch, director of the National Science Foundation, stated: "Important aspects of arctic marine research have long been neglected because of the lack of a suitable and dedicated research vessel. With the passage of the Arctic Research and Policy Act, the time has come to face this problem. I look forward to working with you to resolve it."

The lack of an ice-worthy research vessel has already severely hampered the progress of scientific investigations in the Arctic. With an anticipated increase in focused arctic research activity, pursuant to the Arctic Research and Policy Act of 1984, this deficiency will become an increasing liability. Past experience and future projections confirm that an ice-capable vessel (ANS Class A) should be given high priority for the U.S. research vessel fleet.

The above-mentioned U.S. Coast Guard study defines an appropriate ship as follows:

Polar Research Vessel--An ice-capable vessel dedicated primarily to research, designed to

> operate independently in the marginal ice zone and in unconsolidated pack ice during the summer season. It would be designed to ABS Class 1A or 1AA ice strengthening, capable of breaking 2.5 feet of first year level ice continuously, have 60 day endurance, capacity for two helicopters and accommodations for 50 passengers and crew . . .

Further,

> The research community has not been satisfied with the research support as it has been available from USCG icebreakers, because other missions often took priority in the past. Today, the current full reimbursement system is financially prohibitive for many occasional users. In addition, there has been user dissatisfaction with the quality of the science support equipment and space allocation for laboratories and passenger berthing on board the icebreakers.

This emphasizes the distinction between a multimission icebreaker and a polar research vessel designed solely for science. Clearly the research-oriented users would like a dedicated polar research vessel that could serve several different agencies. In all likelihood, there are enough fundable research projects spread throughout the research community to fully employ a polar research vessel.

REFERENCES

Elsner, R. 1983. Arctic Research Ship. Report to the Alaska Council on Science and Technology, 9 pp.

Elsner, R., and J. Leiby, editors. 1980. Polar Research Vessel. A Preliminary Design for the National Science Foundation. 483 pp.

Interagency Report. 1984. United States Polar Icebreaker Requirements Study. U.S. Department of Transportation, United States Coast Guard. 396 pp.

National Academy of Sciences. 1963. Science in the Arctic Ocean Basin. A Report by the Committee on Polar Research. Publication 1086. Washington, D.C.

National Advisory Committee on Oceans and Atmosphere. 1981. Ocean Sciences for the Nation. National Ocean Goals and Objectives for the 1980s.

National Research Council. 1982. Academic Research Vessels 1985-1990. Steering Committee for Academic Research Fleet Study, Ocean Sciences Board. Washington, D.C.: National Academy Press.

National Research Council. 1983. Research Emphases for the U.S. Antarctic Program. Polar Research Board. Washington, D.C.: National Academy Press. 126 pp.

Appendix C
RESULTS OF A SURVEY OF THE ARCTIC MARINE SCIENCE COMMUNITY ON RESEARCH VESSEL REQUIREMENTS

A questionnaire was circulated to approximately 100 arctic ocean scientists to determine present and future needs for an ice-capable research vessel. The results indicate that the oceanographic community is eager to work in ice-covered seas. Table C.1 shows by geographical regions work that is anticipated (requirements for the period from 1988 to 1990) or that will be proposed if appropriate U.S. ice-capable research vessels are available to the scientific community (requirements for the period from 1990 to 2000).

Much of the shipboard equipment and facilities required by those who responded to the survey is standard on oceanographic vessels. This includes conductivity-temperature-depth (CTD) equipment and associated winches, an A-frame/crane, and a deep-sea winch. Vessels should have the ability to core in deep water and also to handle drifting buoys and moored instrumentation. An Acoustic Doppler Current Profiler was also identified.

Some projects require towed instruments, including side scan sonar. Others need a high-frequency echo sounder and integrator. Good laboratory facilities (with refrigerator/freezer, cold room, and fume hood) are essential to many projects, and the capability to handle refrigerated vans was recommended by one respondent.

Vessels should have the ability to handle helicopters and remotely operated vehicles (ROVs). Good positioning ability is essential and Global Positioning System (GPS) is recommended. The ability to receive real-time satellite data is important.

TABLE C.1a Results of a Survey of the Marine Science Community on Research Vessel Requirements for the Period 1988 to 1990

Location Study	Period	Number of Days Per Year	Ship Requirements Vessel	 Facilities
BERING SEA				
a) seabirds	ongoing	30	IS	CTD; high-frequency echo sounder
b) hydrography	1988	30	IC, IB	large scale; CTD; helicopter
	1989	45	IC, IB	large scale; CTD; helicopter
c) ecological role of ice edge		40	IC	CTD; GPS
d) biological oceanography at ice edge and in high Arctic	1988	30	IS	ice-edge work
	1989	30	IB	high arctic work

CHUKCHI SEA

a) seabirds (expansion of work in Bering Sea "a")			IC	
b) industry program addressing ice features, sea-bed gouging, summer ice retreat, forecasting season length, and storms	1988-1989	40	IS, IB	helicopter support; towed instruments; buoy and ROV deployment
c) industry program addressing ice environment (ice movement, type, geometry ofice features)			IB	aircraft or remote observation and helicopter-supported, on-the-ice work
d) nutrient dynamics, marine mammal biology, stable isotope distributions	1988	10-60	IB, IS	standard hydro-winches
e) geological processes, stratigraphy, and benthic ecosystem	1988	60	IS, IC,	vibrocorer for sediment
			IB	coring
f) nutrient dynamics, marine mammal biology, stable isotope distributions	1988	10-60	IB	standard hydro-winches

TABLE C.1a (continued)

Location Study	Period	Number of Days Per Year	Ship Requirements Vessel	 Facilities
BEAUFORT SEA				
a) hydrography	1988	30	?	large scale; CTD; helicopter
	1989	45	?	large scale; CTD; helicopter
b) seabirds	ongoing	30	IS	CTD; high-frequency echo sounder
c) seabirds (expansion of above)			IC	
d) radio-tracer studies of water and particle transport	1988-1989	2-3	IB	good winches and wire
e) geological work on sedimentary processes	1988	14	IC	capable of handling heavy corers over side or through well; survey at slow speeds with coring ability
f) industry program addressing ice features, sea-bed gouging, summer ice retreat, forecasting season length storms (to 2000-m depth)	1988-1989	40	IS, IB	helicopter support, towed instruments; buoy and ROV deployment and capability
g) industry program addressing ice environment (ice movement, type and geometry of ice features)			IB	aircraft or remote observation and helicopter

BEAUFORT SEA (continued)				
h) nutrient dynamics, marine mammal biology, stable isotope distribution	1988	10	IB, IS	standard hydro-winches
ARCTIC OCEAN				
a) physical oceanography	1988	90	IC, IB, IS	moored instrument capability
	1988	60	IC, IB IS	moored instrument capability
b) marine geology, paleoocean-ography and paleoclimatology of Alpha-Lomonosov Ridge	ongoing	?	IS	
S. CANADA BASIN				
a) geology and geophysics of Northwind Ridge	1988–1989	30	IB	coring/dredging winch; A-frame; GPS
GREENLAND SEA				
a) hydrography	1988	30	IC, IB	large scale; CTD; helicopter
	1989	45	IC, IB	large scale; CTD; helicopter
b) physical oceanography	1989	45	IC, IB	large scale; CTD; helicopter

TABLE C.1a (continued)

Location Study	Period	Number of Days Per Year	Ship Requirements Vessel	 Facilities
GREENLAND SEA (continued)				
c) physical oceanography	1988	30	IC, IB, IS	moored instrument capability
	1988-1989	60	IC, IB IS	moored instrument capability
BAFFIN BAY				
a) biology	1988	10	IB	crane; A-frame; deep-sea winch; refrigerated van
	1989	10	IB	crane; A-frame; deep-sea winch; refrigerated van
NANSEN BASIN				
a) radio-tracer studies of water and particle transport	1988-1989	2-3	IB	good winches and wire
FRAM STRAIT				
a) hydrography	1988	30	?	large scale; CTD; helicopter
	1989	45	?	(same)
b) radio-tracer studies of water and particle transport	1988-1989	2-3	IB	good winches and wire

BARENTS SEA				
a) radio-tracer studies of water and particle transport	1988-1989	2-3	IB	good winches and wire
NORWEGIAN SEA				
a) biology	1988	10	IB	crane; A-frame; deep-sea winch; refrigerated van
	1989	10	IB	crane; A-frame; deep-sea winch; refrigerated van
ALASKAN SHELF				
a) physical oceanography and sea ice processes	1988	60	?	none
	1989	30	?	none
b) physical oceanography	1988	30	IC, IB IS	moored instrument capability
	1988	60	IC, IB IS	moored instrument capability
	1989	60	IC, IB IS	moored instrument capability
CANADIAN ARCTIC AND GREENLAND SHELVES AND FJORDS				
a) coring and single-channel seismic	1988	30	IS	
	1989	30	IS	

TABLE C.1a (continued)

Location Study	Period	Number of Days Per Year	Ship Requirements Vessel	Ship Requirements Facilities
OTHER				
a) Navy development	1988	75	IB	special equipment provided by Navy
	1988	45	IB	special equipment provided by Navy
	1989	60	IB	special equipment provided by Navy
b) Federal marine weather observations	1988-1989	many	IC, IB IS	only existing communications equipment are required

Note: The abbreviations are as follows (definitions can be found in Appendix A):

IB - icebreaker
IC - ice-capable
IS - ice-strengthened
CTD - conductivity/temperature/density instrument
GPS - global positioning satellite
ROV - remotely operated vehicle

TABLE C.1b Results of a Survey of the Marine Science Community on Research Vessel Requirements for the Period 1990 to 2000

Location Study	Period	Number of Days Per Year	Ship Requirements Vessel	Ship Requirements Facilities
S.E. CHUKCHI AND NORTH BEAUFORT SEA, ARCTIC ALASKA				
a) litho- and biostratigraphy of Arctic Basin leading to understanding of arctic paleogeography and paleoclimate, and sedimentary processes	1990-2000	30-45	IB	deep-sea drilling in ice-stressed waters
	2000+	30-45	IB	deep-sea drilling in ice-stressed waters
ARCTIC OCEAN, GREENLAND SEA, ALASKAN SHELVES				
a) physical oceanography	1990-2000	30-60	IB, IC IS	
NORTH AMERICAN ARCTIC				
a) Navy development (submarine warfare related)	1990-2000	60-90	IB	heavy lift cranes; access to ice; hold space
	2000+	60-90	IB	heavy lift cranes; access to ice; hold space
GREENLAND SEA (IN WINTER)				
a) physical oceanography	1990-2000	45	IC, IB	

TABLE C.1b (continued)

Location Study	Period	Number of Days Per Year	Ship Requirements Vessel	 Facilities
NORWEGIAN SEA				
a) box coring	1990-2000	10-14	IB	deep-sea winch; crane; A-frame; refrigerated van
	2000+	10-14	IB	deep-sea winch; crane; A-frame; refrigerated van
ARCTIC SHELVES				
a) sea ice, meteorology, physical oceanography	1990-2000	60	IS, IB	CTD winches
	2000+	60	IS, IB	CTD winches
b) comprehensive coverage of Arctic for marine weather observations	1990+	many	IC, IB IS	communication equipment
NANSEN BASIN, FRAM STRAIT, BARENTS SEA, BEAUFORT SEA				
a) radio-tracer studies	1990-2000	7	IB	
WESTERN BEAUFORT				
a) relationship of bird and mammal distribution to prey availability and ice edge/ice type and cover	1990-2000	20	IB	CTD; high-frequency echo sounder and integrator

GREENLAND SEA, BARENTS SEA, BERING SEA				
a) ecosystem responses to physical forcing and ice dynamics. Global Ocean flux-related measurements of vertical standard transport of biogenic material	1990–2000	60–90	IB	real-time, interactive satellite links; good positioning information; oceanographic capabilities
	2000+	60–90	IB	real-time, interactive satellite links; good positioning information; oceanographic capabilities
CHUKCHI AND BEAUFORT SEAS				
a) sea ice ecosystem: ice algal and phytoplankton production, ecology and taxonomy	1990–2000	30	IB	helicopter, ice coring equipment; diving capability
b) coastal environmental data gathering	1990–2000	60	IB	
	2000+	60	IB	
BAFFIN BAY REGION				
a) marine geology and geophysics equipment	1990–2000	30	IB	reflection seismology and coring
ARCTIC OCEAN				
a) paleo-oceanography, marine geology of the Lomonosov-Alpha area but including uncored parts of Fram and Canadian basins	1990–2000	360	IB	coring and bottom photography equipment; winch
b) marine geology, sedimentology and tracer research in central Arctic Ocean	1990–2000	30–75	IB	good aircraft support
	2000+	30	IB	good aircraft support

TABLE C.1b (continued)

Location Study	Period	Number of Days Per Year	Ship Requirements Vessel	 Facilities
FRAM STRAIT, EAST GREENLAND COAST, NORTH OF ALSAKA IN BEAUFORT SEA REGION				
a) mesoscale and larger oceanography eddy generation and tracking within large field	1990-2000	20	IB	real-time satellite imagery equipment shipboard
	2000+	20	IB	real-time satellite imagery equipment shipboard
BEAUFORT, EAST SIBERIAN, AND LAPTEV SEAS				
a) marine geology and sedimentology related to sea and glacial ice	1990-2000	15	IB	coring and drilling capabilities at shelf depths (500 m); core winch; heli-copter; core lab; deck hoses and mud sinks
	2000+	15	IB	coring and drilling capabilities at shelf depths (500 m); core winch; heli-copter; core lab; deck hoses and mud sinks
BARENTS, GREENLAND, AND CHURCHI SEAS				
a) multidisciplinary	1990-2000	45	IB	
	2000+	45	IB	
BARENTS AND GREENLAND SEAS AND ARCTIC BASIN				
a) biological, optical, oceanographic research	1990-2000	30	IS, IB	good lab facilities and at least two conducting cable-winches

CHUKCHI BORDERLAND				
a) marine geology and geophysics	1990-2000	30	IB	dredging/coring-winch; helicopter, A-frame for winch wire
BEAUFORT AND CHUKCHI SEAS				
a) biological, chemical work in Amundsen Gulf to West of dateline	1990-2000	30	IB	
FJORDS, SHELF, DEEP SEA (Transects from Alaska around Arctic to Svalbard)				
a) marine geology; coring and profiling	1990-2000	30	IB, IS IC	

Note: The abbreviations are as follows (definitions can be found in Appendix A):

IB - icebreaker
IC - ice-capable
IS - ice-strengthened

CTD - conductivity/temperature/density instrument
GPS - global positioning satellite
ROV - remotely operated vehicle

Appendix D
SOME CURRENT AND PROPOSED RESEARCH IN ICE-COVERED WATERS

A detailed listing of existing U.S. government programs was compiled recently by the Interagency Arctic Research Policy Committee (September 1985). Several programs in oceanography and marine ecology were identified, and the discussion here will identify a few of those that would utilize an ice-worthy research vessel were it available. It should be pointed out that proposed large-scale research activities that emphasize satellite remote sensing will also require access by surface vessel for ground truth (e.g., Program for International Polar Oceans Research (PIPOR) and World Ocean Circulation Experiment (WOCE)).

Arctic Sea Ice Program. This work involves remote sensing by satellite, but also simultaneous observations by satellite, aircraft, and surface vessel. Surface-truth experiments use drift stations, ships, and ice sheets. (Department of Interior, United States Geological Survey)

Bowhead Whale Feeding. This project is currently under way in the Beaufort Sea supported by the Minerals Management Service through LGL Ecological Research Associates. The project uses stable isotope techniques to compare zooplankton composition with that of the whales over their migratory range in order to determine the amount of feeding at each locale. This work will lead into a number of new proposals that will also require logistical support for sampling in ice-covered waters. Many of these are high priority, and concerned with marine mammals, especially bowhead whales. Current projects are hampered in their scientific operations in the Beaufort Sea by the limited and very expensive icebreaker operations. Laboratory space is limited on the polar class icebreakers, and there are obvious inherent difficulties in conducting varied scientific tasks aboard a military vessel. (Minerals Management Service, LGL Ecological Research Associates)

Bowhead Whale Research Program. The National Marine Mammal Laboratory is conducting research on bowhead whales, aimed at assessing the species and the impact of Eskimo take on the species. The work focuses on collecting data on recruitment rates as well as on more accurately determining life history. (National Marine Mammal Laboratory, National Oceanic and Atmospheric Administration)

Kotzebue Sound/Southeast Hope Basin Habitat Utilization and Ecological Characterization. This study aims to describe the water circulation, carbon flow, and sediment parameters of Kotzebue Sound and adjacent southeast Chukchi Sea, in relation to the biological system of the sound and adjacent waters. It is supported by the National Oceanic and Atmospheric Administration, Ocean Assessment Division, and conducted with the University of Alaska-Fairbanks. At present, all the work must be conducted during the ice-free season, and therefore a substantial portion of the year is missed, and in particular work cannot begin before late June or early July. (National Oceanic and Atmospheric Administration)

APEX (Arctic Polynya Experiment). This project addresses the mesoscale oceanographic, sea ice, and meteorological processes associated with a polynya. It is centered in the St. Lawrence Island Polynya on the northern Bering Sea shelf. (Department of Defense, Office of Naval Research)

The Chukchi Sea Continental Shelf Benthos-Environmental Interactions. This project focuses on the community structure of the northeastern Chukchi Sea benthic ecosystem and the relationship between the benthic productivity and ocean circulation, sediment and sea-ice distribution, and food availability. It is supported by the National Oceanic and Atmospheric Administration, Ocean Assessment Division. A number of processes, critical to the understanding of biological production, occur at spring break-up in the marginal ice zone.

Availability of an ice-capable ship would allow collection of data critical to estimating carbon fluxes to the sediment and establishing the significance of this flux in the overall carbon flow in the study area. (National Oceanic and Atmospheric Administration)

Population Dynamics of the Pacific Walrus. This work is supported by the National Science Foundation, Division of Polar Programs. This work uses radio-telemetry for study of the basic group structure at sea, on ice, and on shore, on at least three levels of organization. The shipboard surveys will continue to be dependent on Soviet cooperation, since they have the only ice-capable research vessels in the area. A much more effective alternative would be a U.S. arctic vessel, which would greatly facilitate and improve the quality of the work. (National Science Foundation/Division of Polar Programs)

This study would contribute also to the technological means for attaching satellite-trackable transmitters to walruses, which will be needed by a complementary project supported by the U.S. Fish and Wildlife Service. That project is just getting under way to develop a satellite-tracking program for walruses. It will not only require the attachment technology, but will also need the support of an arctic research vessel for deployment of the transmitters. Satellite tracking of walruses is desirable for studying their migration routes, individual activity rhythms, social behaviors, and feeding schedules, some aspects of which cannot be elucidated in any other way.

Breeding Behavior of Walruses. The social behavior of walruses during the breeding season appears to be unique, possibly showing closer resemblance to the "lek" system of some African ungulates than to that known for other pinnipeds. Many basic questions remain unanswered, however, and cannot be determined without logistical support via an icebreaking research vessel, since walruses breed in mid-winter, deep within the pack ice. A proposal submitted to the National Science Foundation was rated as excellent, but was not encouraged because there was then and still is no possibility for providing the logistical support.

Amphipod Energetics and Production in the Northern Bering Sea. This project investigates a dominant component of the benthic fauna of the Chirikof Basin north of St. Lawrence Island in the Bering Sea. Preliminary evidence suggests that the benthic gammaridean amphipods serve as a unique trophic link between the high phytoplankton production, which apparently settles ungrazed to the bottom, and gray whales. This project is examining the amphipod population dynamics, habitat features, feeding behavior, food resources, growth, reproduction, respiration, excretion, and life span. These data are used to estimate secondary production rates and resource partitioning in a portion of the gray whale feeding grounds north of St. Lawrence Island. This area is subject to ice cover for a period of up to eight months of the year. During the spring pre-breakup and breakup season, the area is, at present, inaccessible. (National Science Foundation/Division of Polar Programs)

ISHTAR (Inner Shelf Transfer and Recycling in the Bering/Chukchi Seas) is looking at the production, transport, and recycling of organic matter in the northern Bering Sea and southern Chukchi Sea. This region has a relatively high primary production even after the spring bloom, apparently due to nutrient-rich water that moves north into the area through the Gulf of Anadyr. There is confluence with nutrient-poor water flowing north along the east side of the Bering Sea. The differing regimes within these two water masses present a natural experiment in ecosystem contrast. (National Science Foundation)