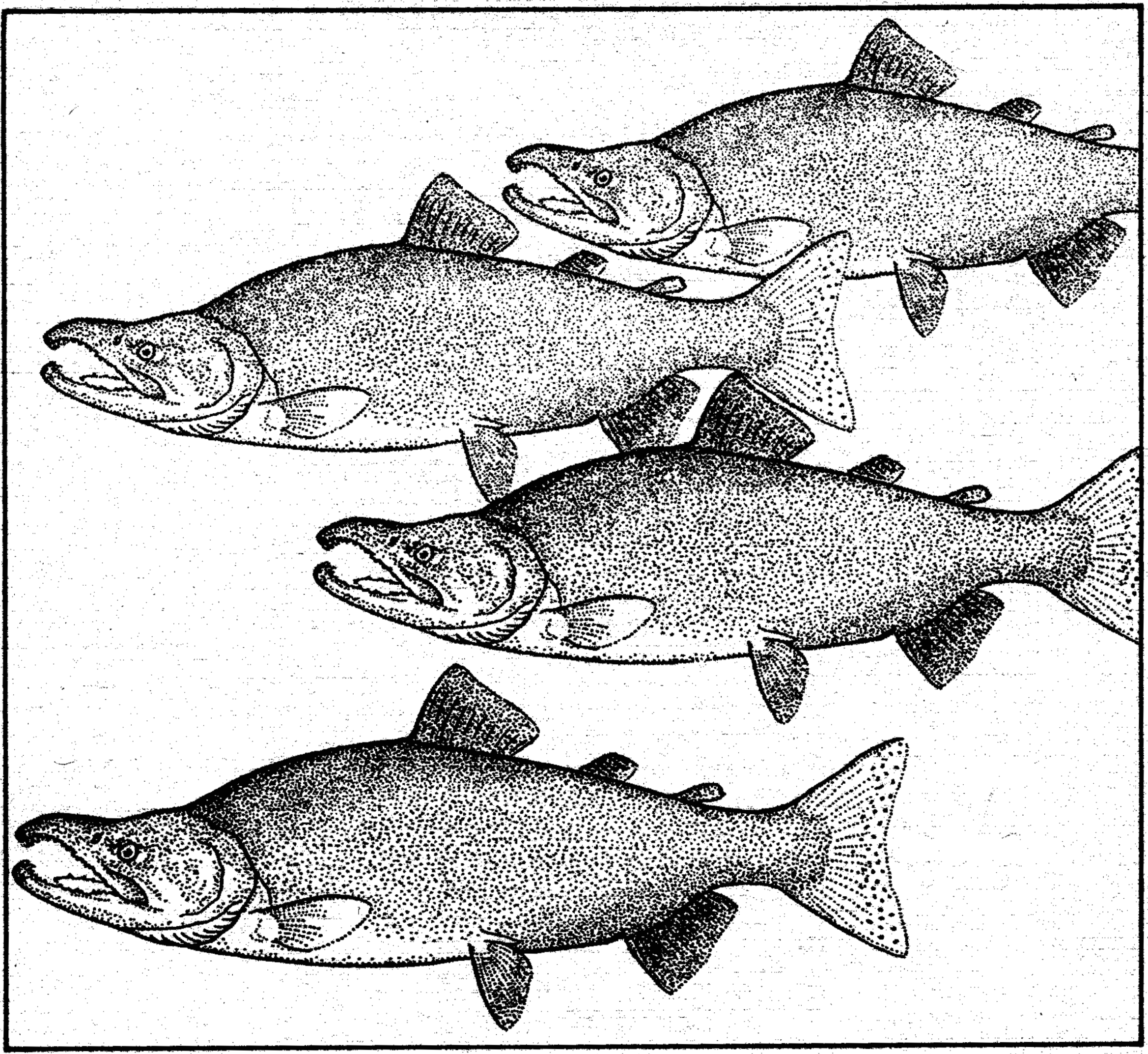
OCS Study
MMS 87-0048

Bering Sea Monitoring Program:

Proceedings of a Workshop
and
Sampling Design Recommendations



OCS STUDY
MMS 87-0048

BERING SEA MONITORING PROGRAM

PROCEEDINGS OF A WORKSHOP (JANUARY 1987) AND SAMPLING DESIGN RECOMMENDATIONS

Prepared for the
Minerals Management Service
Alaska OCS Region

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ABSTRACT

Future lease sales and subsequent oil and gas exploration and development activities on the U.S. Bering Sea continental shelf may produce potentially adverse effects on biological resources of concern. In January 1987 the Minerals Management Service sponsored a workshop in Anchorage, Alaska with the purpose of developing an environmental monitoring program for the Bering Sea. Based on a review of previous OCS monitoring programs as well as an analysis of Bering Sea physical and environmental data, there exists a very low probability of detecting any significant changes in monitored parameters at a distance greater than approximately 10 km from any oil and gas development in the Bering Sea. However, the biological resources of the Bering Sea are of sufficient value to warrant monitoring to ensure minimal risk of damage. The final recommendations include a design based on an area-wide monitoring program as well as a design for a site-specific, region by region program. Three specific components are recommended for inclusion in the monitoring program: concentrations of selected metals and hydrocarbons in sediments, concentrations of selected metals and hydrocarbons in bioindicator species, and population parameters of benthic invertebrate communities.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

The Minerals Management Service (MMS) and the National Oceanic and Atmospheric Administration (NOAA) have a mandate to assess potential areawide or cumulative effects of anticipated oil and gas development on the U.S. Bering Sea continental shelf. Accordingly, these agencies participated in the planning of a workshop to begin the process of developing a long-term monitoring program for the area. This workshop was in turn sponsored by MMS in January 1987. Invited participants included regulators, managers, and scientists from cognizant agencies, as well as leading scientists with specialties in aspects of the Bering Sea ecosystem or in offshore monitoring programs elsewhere in North America.

At the workshop, objectives for the Bering Sea Monitoring Program (BSMP) were established as follows:

- To detect and quantify changes that might:
  - result from OCS oil and gas activities;
  - adversely affect, or suggest another adverse effect on, important natural resources or those parts of the environment affecting resource quality; and
  - influence OCS regulatory management decisions.
- To determine the cause of such changes.

This document is the product of a MMS contract with Dames & Moore to:

- Organize and conduct the BSMP workshop and summarize its proceedings;
- Statistically analyze available data on monitoring approaches to optimize the statistical sampling design applied; and
- Detail optimum approaches to Bering Sea monitoring that meet the objectives described above.

1.2 WORKSHOP PROCEEDINGS

Invited participants made a series of background presentations on the broad areas of:

- Regulatory mandates and agency responsibilities for the BSMP.
- Approaches taken to OCS monitoring by other agencies or in other locales.
- Description of the physical environment of the Bering Sea and potential monitoring approaches.
- Description of the biological environment of the Bering Sea and potential monitoring approaches.
- Description of geochemical, biochemical, microbial, and biological community indices and their potential applicability to the BSMP.

Following these presentations, a number of hypotheses concerning potentially significant development-related problems were brought up for open discussion by the workshop participants. Advantages and limitations of each were discussed. A lengthly discussion of the appropriate geographic scale for monitoring concluded with the compromise recommendation that an area-wide framework should be provided which has the flexibility to be adapted to a variety of potential development scenarios. Approaches to monitoring that would be of greatest value in providing the necessary data to test the hypotheses were a main consideration. Three of these hypotheses were eventually determined to be relevant to an area-wide monitoring program. These concern OCS oil and gas development effects on the following components of the environment:

- Heavy metal and hydrocarbon accumulation in sediments,
- Heavy metal and hydrocarbon accumulation in indicator organisms,
- Sublethal effects of heavy metal and hydrocarbon accumulation in indicator organisms, and
- Changes in assemblage or population parameters for the benthic invertebrate community.

One other workshop-related hypothesis was considered more relevant to monitoring of localized impacts from specific activities:

- Impacts on the productivity of eelgrass beds.

1.3 RECOMMENDED MONITORING PROGRAM

There is a very low probability of being able to detect any significant changes in the far field (e.g., greater than 10 km) around any oil and gas development in the Bering Sea. None-the-less, it is our opinion that far field monitoring is required in the event that any OCS development occurs in the Bering Sea because of the magnitude of the renewable resources at risk. The economic and political sensitivity of these resources argue that any large scale activity in the Bering Sea might be perceived by the public as influencing resource health or abundance, and therefore, should be accompanied by a scientific program to demonstrate that no effect has occurred.

Existing Bering Sea data on relevant variables were sought for evaluation of components of variability that influence sample design optimization. Where adequate data were available, power calculations were made to estimate the likelihood of detecting changes of various magnitudes, at several levels of sample replication. Material presented at the workshop and available reports and data tapes from sampling in the Bering Sea were reviewed. We evaluated the applicability of methodologies, sampling stations, and data analysis techniques for adoption in the recommended program. A brief summary of the recommended sampling approach for each component hypothesis of no change follows:

I. H_o: There will be no change in concentrations of selected metals or hydrocarbons in surficial sediments beyond the zones of mixing or dispersion specified under relevant operating permits.

Considerable sampling was conducted between 1975 and 1980 under Outer Continental Shelf Environmental Assessment Program (OCSEAP) sponsorship to provide the data necessary to describe baseline sediment hydrocarbon and metal concentrations in the Bering Sea. However, the available data are of limited value because there was never more than one sample per station collected and analyzed using standardized methods. Thus it is impossible to assess and distinguish analytical, within-station, between-station, and year-to-year variability. Furthermore, for some important chemicals such as barium, samples are available from only a small number of stations covering a small part of the Bering Sea, and the chemical analysis methodology is so imprecise that even the mean concentration in the sampled area is in doubt.

Thus, it was necessary to use Beaufort Sea monitoring data to estimate the variances needed for even the simplest sampling design. These data, together with an assessment of risk of impact due to development in five zones of the Bering Sea, were used in an analysis of variance (ANOVA) -based approach. A two-way fixed effects ANOVA was used to estimate the magnitude of change that could be detected with different levels of replication (2 to 6 samples/station collected in 1 or 2 years before and 1 or 2 years after the commencement of development activities) under an optimal allocation of 36 stations to the different zones. It was concluded that changes in barium concentration in surficial sediments that might be expected under a plausible development scenario had a high probability of being detected under the assumptions of the five-zone model. However, it was emphasized that the definition of the zones, the assessment of risks, and the resulting design should be viewed as an example rather than as definitive given the present uncertainty concerning both the distribution of hydrocarbon and metal concentrations in the sediment and the likely course of development.

In addition to the ANOVA-based design, a subjective allocation of stations that gave more weight to expected sources and fates of pollutants and the importance of resources in different parts of the Bering Sea was presented. Finally, a different design approach using kriging was outlined. This approach could be implemented given data from a preliminary network of stations based on either the ANOVA-based or the subjective approach.

Procedures for obtaining and handling samples, as well as for performing chemical analyses (e.g., barium, chromium, vanadium, hierarchical analysis for hydrocarbons) are provided. A 2-year baseline monitoring period is recommended, followed by sampling every 3 years to monitor for change. Nevertheless, this proposed schedule should be reexamined after the 2 years of baseline data are available.

II. H_o: There will be no change in concentrations of selected metals or hydrocarbons in bioindicator species beyond the zones of mixing or dispersion specified in relevant operating permits.

III. H_o: There will be no change in the incidence of sublethal effects in bioindicator species beyond the zones of mixing or dispersion specified in relevant operating permits.

Existing data on contaminants in Bering Sea marine organisms generally suggest, with a few noteworthy exceptions, that both metals and hydrocarbon levels are very low. Taxonomic groups that were considered suitable for inclusion as BSMP indicator organisms include: marine mammals, bivalve mollusks, and demersal fish. Microbes may be a potential indicator group in the future if recent technological advances in analytical techniques become commercially available.

Marine mammal (walrus and seal) tissue samples are currently collected by the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) biologists during monitoring of native subsistence harvests. Incorporation of these existing data in conjunction with continued sampling for the BSMP would provide an indication of trace metal or hydrocarbon transfer to higher trophic levels. Demersal fish species (yellowfin sole and walleye pollock) have been, and will continue to be, collected in NMFS-sponsored trawl surveys. These species are recommended for sublethal effects measurements (e.g., incidence of tumors, fin erosion, and trends in biochemical indicators) that could indicate an increase in contaminant exposure. Benthic mollusks (the bivalve Macoma calcarea and the gastropod Neptunea spp.) live in close association with the sediments. Analyses of their soft body parts for trace metals and hydrocarbons is recommended to provide an early indication of contaminant transfer from the sediments to biological organisms.

Collection of marine mammal and fish samples should be coordinated with the ongoing studies and continued on an annual basis. Benthic invertebrate sampling should be conducted for 2 years to obtain baseline information, followed by sampling every 3 years to monitor change. Again, this proposed schedule should be reexamined following the baseline survey.

IV. H_o: There will be no change in values of selected benthic assemblage parameters or in population parameters of selected species beyond the zones of mixing or dispersion specified under relevant operating permits.

Monitoring benthic communities through measurement of assemblage and population parameters (e.g., species density, species biomass) can be a method of detecting changes at the community level that may be linked to contaminant exposure. However, since the benthic communities of the Bering Sea show considerable spatial variation, benthic community monitoring on an area-wide scale may not be practicable. We have recommended that benthic monitoring be considered for inclusion in the BSMP as part of individual sale-specific development programs. As activities begin to develop in a specific base area, benthic community monitoring should be carried out with at least 1 to 2 years of baseline data collection, then sampling at least every 3 years as development continues.

Design of a benthic sampling program should be tailored for the region of interest. Analysis of the extensive Bering Sea benthic data base (not possible for this workshop) would be required prior to such design.

1.4 OTHER CONSIDERATIONS

A number of approaches or ecosystem components suggested by invited participants for inclusion in the monitoring program were not developed further for reasons discussed below.

Monitoring of eelgrass beds was not included for several reasons. First, it was deemed that, although locally important ecologically, eelgrass production was not significant to the Bering Sea as a whole. Second, monitoring eelgrass productivity would be better suited to an analysis of local effects due to specific development activities rather than a Bering Sea-wide monitoring program. Microbial indices and other biological indices were also omitted from the program since the sediment chemistry and benthic studies would provide more reliable and economical physical and biological indicators of pollutant buildup in the environment.

No specific program was recommended for physical and chemical oceanography. Rather, the supportive data needed for each program would be specified by the detailed monitoring plans for each specific variable (e.g., measure water temperature and salinity when obtaining sediment samples). In addition, data may be available from ongoing programs sponsored by other agencies to document widespread physical phenomena (e.g., area meteorology, satellite imagery for ice distributions).

In our opinion, it will be essential to the overall success of the BSMP that specified physical and chemical environmental data are gathered and available to investigators on a timely basis.

Finally, a number of additional recommendations are made regarding activities and procedures that should be incorporated into the monitoring program. These include:

- Institution of detailed, formal procedures for quality assurance and quality control to ensure year-to-year consistency of data,
- Oversampling in the field and archiving of samples for potential future use,
- Imposition, where feasible, of standardized techniques for this program and other programs where similar variables are to be measured in the Bering Sea (e.g., compliance monitoring). In this way, maximum utility and comparability will be achieved for all data gathered in the area, and
- Institution, prior to initial monitoring activities, of a well-conceived and operated data management system that will incorporate all data from this and other Bering Sea monitoring activities.

2.0 INTRODUCTION

2.1 GENERAL

This document describes a long-term monitoring program for assessing potential effects of anticipated oil and gas development on the United States Bering Sea continental shelf. Various regulatory mandates requiring that such an assessment be made are described in Section 2.2; the interrelationships among the responsible agencies, primarily the U.S. Minerals Management Service (MMS) and the U.S. National Oceanic and Atmospheric Administration (NOAA), are detailed in Section 2.3. Over the last several decades, these and several other agencies have funded a variety of studies and gathered a large body of data that aid our understanding of physical and biological conditions and interrelationships in the Bering Sea (Section 2.4). However, this understanding is limited by the vastness, complexity, and variability of the area and its ecosystems.

To assist in development of a long-term monitoring program for the Bering Sea, MMS sponsored a workshop in January of 1987 (Section 2.6). Invited participants included regulators, managers, and scientists from cognizant state and federal agencies, as well as leading scientists with specialties in aspects of the Bering Sea ecosystem or in offshore monitoring techniques or programs elsewhere in the United States. Objectives for this monitoring program are described in Section 2.5.

MMS issued a contract to Dames & Moore to assist in organizing and conducting the workshop, to evaluate monitoring needs and approaches, and to formulate recommendations for a program to monitor the potential effects of oil and gas development in the Bering Sea outer continental shelf (OCS) lease sale areas. Dames & Moore also was to perform statistical analyses (Section 4) of monitoring approaches suggested by the workshop, and prepare a report summarizing workshop proceedings (Section 3) and detailing optimum approaches to Bering Sea monitoring studies that meet the prescribed goals and mandates of MMS (Section 5).

2.2 STATUTORY MANDATES

Both MMS and NOAA have extensive statutory mandates to conduct environmental studies and monitoring in marine waters. This section discusses these mandates.

The Outer Continental Shelf Lands Act (67 Stat. 462) was passed in 1953 and established federal jurisdiction over the submerged lands of the continental shelf seaward of states' boundaries. The Act charges the Secretary of the Interior with responsibility for administering mineral exploration and development of the outer continental shelf, as well as conserving natural resources on the shelf. It empowers the Secretary to formulate regulations so that the provisions of the Act might be met and conflicts are minimized.

Section 20 of the Outer Continental Shelf Lands Act Amendments of 1978 (92 Stat. 629; 43 USC 1346) gave impetus to establishment of an Environmental Studies Program within the Department of the Interior by mandating the Secretary to:

> "...conduct a study of any area or region included in any oil and gas lease sale in order to establish information needed for assessment and management of environmental impacts on the human, marine, and coastal environments of the outer Continental Shelf and the coastal areas which may be affected by oil and gas development in such area or region."

The Submerged Lands Act of 1953 (67 Stat. 29) set the inner limit of authority of the Federal Government by giving the coastal states jurisdiction over the mineral rights in the seabed and subsoil of submerged lands adjacent to their coastline out to a distance of 3 nautical miles with two exceptions. In Texas and the Gulf Coast of Florida, jurisdiction extends to "3 leagues" (7-8 nautical miles) based on colonial charter.

Subsequent to passage of the Outer Continental Shelf Lands Act, the Secretary of the Interior designated the U.S. Bureau of Land Management (BLM) as the administrative agency for leasing submerged federal lands, and the U.S. Geological Survey for supervising development and production. The Department of the Interior formulated three major goals for the comprehensive management program for marine minerals.

- To ensure orderly development of the marine mineral resources to meet the energy demands of the nation;
- To provide for protection of the environment concomitant with mineral resource development; and
- To provide for receipt of a fair market value for the leased mineral resources.

The second of these goals, protection of the marine and coastal environment, is a direct outgrowth of the National Environmental Policy Act (NEPA) of 1969. This act requires that all federal agencies shall utilize a systematic, interdisciplinary approach which will ensure the integrated use of the natural and social sciences in any planning and decision-making which may have an impact on man's environment. This goal of environmental protection was assigned to the BLM Environmental Studies Program which was initiated in 1973 with the following objective: "to establish information needed for prediction, assessment, and management of impacts on the human, marine, and coastal environments of the Outer Continental Shelf and the nearshore area which may be affected..." (43 CFR 3301.7).

Although this objective has not changed, the Environmental Studies Program is now located in the Minerals Management Service of the Department of the Interior, after departmental reorganization in 1982. Its task is to design and implement studies that:

- "Provide information on the status of the environment upon which the prediction of the impacts of the Outer Continental Shelf oil and gas development for leasing decision-making may be based;
- Provide information on the ways and extent that Outer Continental Shelf development can potentially impact the human, marine, biological, and coastal areas;
- Ensure that information already available or being collected under the program is in a form that can be used in the decision-making process associated with a specific leasing action or with the longer term Outer Continental Shelf minerals management responsibilities; and
- Provide a basis for future monitoring of Outer Continental Shelf operations" (43 CFR 3307.7).

The latter category of study, monitoring, has the statutory mandate found in 43 USC 1246 (Outer Continental Shelf Lands Act, Pub. L. 95-372; Section 20):

> "(b) Subsequent to the leasing and developing of any area or region, the Secretary shall conduct such additional studies to establish environmental information as he deems necessary and shall monitor the human, marine, and coastal environments of such area or region in a manner designed to provide time-series and data trend information which can be used for comparison with any previously collected data for the purpose of identifying any significant changes in the quality and productivity of such environments, for establishing trends in the areas studied and monitored, and for designing experiments to identify the causes of such changes.
>
> (c) The Secretary shall, by regulation, establish procedures for carrying out his duties under this section and shall plan and or carry out such duties in full cooperation with affected States. To the extent that other Federal agencies have prepared environmental impact statements, are conducting studies, or are monitoring the affected human, marine, or coastal environment, the Secretary may utilize the information derived therefrom in lieu of directly conducting such activities. The Secretary may also utilize information obtained from any State or local government, or from any person, for the purposes of this section. For the purpose of carrying out his responsibilities under this section, the Secretary may by agreement utilize, with or without reimbursement, the services, personnel, or facilities of any Federal, State, or local government agency."

An important part of NOAA's mission relates to marine pollution and the National Ocean Pollution Planning Act of 1978 (33 U.S.C. 1701 et seq.) which requires that NOAA take a lead role in the federal marine pollution effort.

This act directs the Administrator of NOAA, in consultation with appropriate federal officials, to prepare and update every 3 years a comprehensive 5-year plan for the overall federal effort in ocean pollution research and development, and monitoring. In addition, the act directs the Administrator of NOAA to ensure that results, findings, and information regarding federal ocean pollution research and development, and monitoring programs be disseminated in a timely manner and in a useful form to federal and nonfederal user groups having an interest in such information. Finally, the Administrator of NOAA must establish a comprehensive, coordinated, and effective marine pollution research, development, and monitoring program within NOAA.

This program also must be coordinated both within NOAA and with other federal agency programs and be consistent with the federal marine pollution research and development, and monitoring plan. Under the Marine Protection, Research, and Sanctuaries Act of 1972 (Pub. L. 92-532), Title II, Section 202, the Secretary of Commerce was mandated to:

> "initiate a comprehensive and continuing program of research with respect to the possible long-range effects of pollution, overfishing, and man-induced changes of ocean ecosystems. These responsibilities shall include the scientific assessment of damages to the natural resources from spills of petroleum or petroleum products."

In addition to these responsibilities, NOAA has numerous other statutory mandates to conduct, support, or coordinate programs and activities for marine pollution research and monitoring; ocean development; and living marine resource conservation and utilization. The programs mandated by these other laws complement NOAA's responsibilities under the National Ocean Pollution Planning Act.

2.3 MMS/NOAA COOPERATION IN OCS ENVIRONMENTAL STUDIES

In May 1974, the BLM requested that NOAA initiate a program of environmental assessment in the northeastern Gulf of Alaska in anticipation of a possible oil and gas lease sale in the region early in 1976. The Outer Continental Shelf Environmental Assessment Program (OCSEAP) was established in 1974 by NOAA to manage these studies and others proposed under the marine environmental portion of the Alaska OCS Environmental Studies Program. OCSEAP has continued to conduct a portion of the environmental studies for all Alaska OCS areas identified by the Department of the Interior for potential oil and gas development.

The BLM/NOAA working arrangement was further formalized in 1980 by a Basic Agreement between BLM and NOAA and the relationship has continued with the MMS. The Alaska OCS Office of MMS manages the Alaska portion of the MMS Environmental Studies Program and is responsible for identifying OCSEAP study needs and priorities. It provides NOAA with timely information concerning significant actions by the Department of the Interior affecting the scope and content of OCSEAP. The Alaska OCS office, with the assistance of OCSEAP staff, annually develops an Alaskan Regional Studies plan addressing information needs pertinent to the Department of the Interior's 5-year lease schedule. NOAA provides field research, planning, and coordination for OCSEAP studies in order to meet MMS's program policies, study needs, and priorities. NOAA also contributes program support by providing field logistics support.

2.4 ONGOING RESEARCH AND MONITORING PROGRAMS IN THE BERING SEA

2.4.1 Outer Continental Shelf Environnmental Assessment Program

Since 1975, OCSEAP has managed a number of research units (RUs) which are wholly or in part related to the Bering Sea. Some studies have been directed at summarizing and analyzing existing information, while others have involved extensive field investigations to document baseline conditions. Still others have consisted of laboratory (including computer) analyses to explore relationships and sensitivities of various environmental components. Technically, the RUs cover many aspects of the physical, chemical, and biological environments of the area, including the atmosphere, land, and water. Many of these RUs included repetitive (in space and/or time) measurements of physical, chemical, or biological properties traditionally performed to develop basic descriptions of the existing ecosystems and the physical and biological constraints that the area imposes on development. Considerable experience and data have been amassed for the eastern Bering Sea and provide the basis for many of the thoughts expressed in the workshop (Section 3) and in the final monitoring program recommendations (Section 5).

2.4.2 Minerals Management Service (MMS)

In addition to the OCSEAP portion of its Environmental Studies Program, the Department of the Interior has funded and directly contracted studies in Alaska since 1976. Under the Bureau of Land Management's Alaska OCS office, socioeconomic and endangered species studies were first directly funded in 1976 and 1978, respectively. Now administered by the Minerals Management Service, endangered species studies in the Bering Sea have focused on species of special concern related to leasing activities and associated interagency consultation under the Endangered Species Act. Aerial surveys of endangered whale distribution and abundance, as well as behavioral investigations on the effects of industrial noise, have been of particular relevance to recent MMS information needs and monitoring programs. MMS studies have integrated development of bowhead whale monitoring programs relative to seasonal drilling and geophysical exploration (see Reeves et al. 1983), with monitoring plans and procedures adopted and implemented by MMS since 1981.

Ongoing MMS-sponsored monitoring programs in the Bering Sea include:

- Monitoring of seabird colonies near offshore activity;
- Monitoring of ringed seal populations;
- Acquisition and curation of Alaska marine mammal tissues for determining levels of contaminants associated with offshore oil and gas development;
- Monitoring of the winter presence of bowhead whales in the Navarin Basin and association with sea ice; and
- Aerial surveys of endangered whales.

Future MMS Alaska OCS Region direct-funded studies are likely to include monitoring efforts for endangered whales and other biota/processes potentially affected by oil and gas development, simulation studies of oil spill movements and biotic interactions, study of effects on and biology of non-endangered species, continued study of potential effects on behavior of endangered species, and related synthesis requirements.

2.4.3 National Science Foundation Programs

The National Science Foundation, Division of Polar Programs funded the Processes of the Bering Sea Shelf (PROBES) study beginning in 1979. This program concentrated on the southeastern Bering Sea shelf and was aimed at understanding the southeastern shelf ecosystem focusing on the trophic web of the walleye pollock (*Theragra chalcogramma*). PROBES research has shown that the shelf ecosystem is organized by physical phenomena, e.g., the distribution of phytoplankton species mirrors the distribution of hydrographic regimes. An outgrowth of PROBES research, Inshore Transfer and Recycling (ISHTAR), is a currently funded NSF program in the Bering Straits area (Section 3.3.7).

2.5 MONITORING PROGRAM OBJECTIVES

In keeping with the requirements of the OCS Lands Act (Section 10(b), (see Section 2.2), and following the lead of the Beaufort Sea Monitoring Program (Houghton et al. 1984), a specific set of objectives for the Bering Sea Monitoring Program (BSMP) was established as follows:

- To detect and quantify changes that might:
  - result from OCS oil and gas activities,
  - adversely affect, or suggest another adverse effect on, important natural resources or those parts of the environment affecting resource abundance or quality, and
  - influence OCS regulatory management decisions; and
- To determine the cause of such changes.

2.6 WORKSHOP PURPOSE, OBJECTIVES, AND APPROACH

To aid in design of a realistic, effective research program to monitor long-term environmental effects of oil and gas development in the Bering Sea, a workshop was held at the Hilton Hotel in Anchorage, Alaska, January 14 and 15, 1987. The specific objectives of the workshop were to:

- Evaluate existing monitoring techniques for applicability to the Bering Sea,
- Introduce and consider any new monitoring concepts that might be relevant to this region, and
- Reach a consensus (or a majority opinion) on techniques, proven or promising, that should have high priority for inclusion in the BSMP.

About 20 scientists with expertise in the Bering Sea environment and/or with systematic monitoring programs elsewhere in the U.S. were invited to the workshop, along with a number of scientists and managers from federal agencies, industry, and interest groups. A list of attendees and their affiliations is provided in Appendix A.

The workshop opened with a discussion of the framework, goals, and desired products from the session (Section 3.1). A potential oil and gas development scenario for the Bering Sea was then presented (Section 3.2). Monitoring programs in the Bering Sea and elsewhere in the United States were described by a series of speakers (Section 3.3). The physical environment of the nearshore Bering Sea was discussed, along with techniques that have been used for monitoring various physical parameters (Section 3.4). Biological conditions in the Bering Sea (Section 3.5) and a wide variety of geochemical, biological, physiological, and biochemical monitoring approaches were also presented.

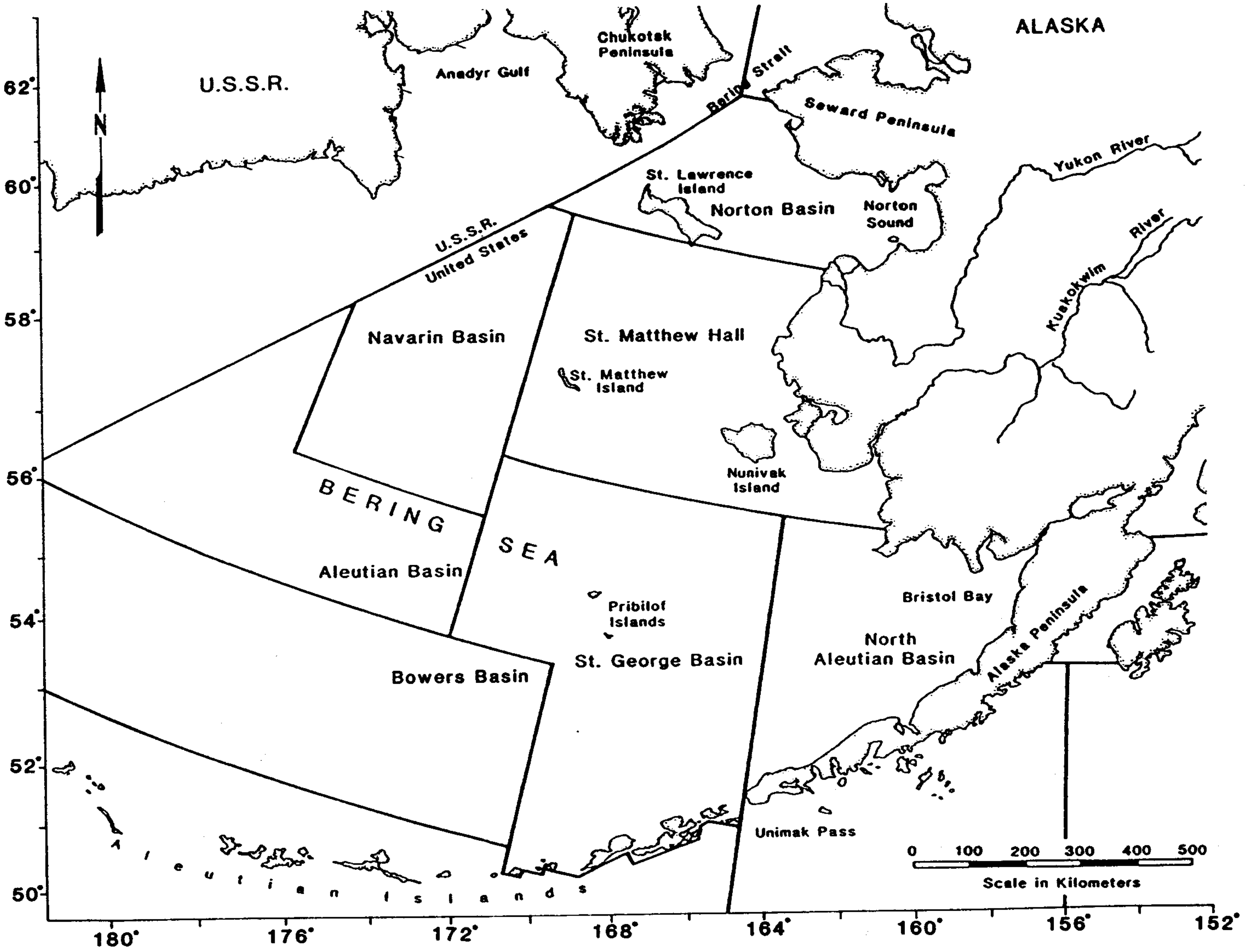
The second day of the workshop was devoted to consideration of various hypotheses, approaches to monitoring, and appropriate parameters for hypothesis testing (Section 3.7).

2.7 STUDY AREA

The overall area of interest for the BSMP includes virtually the entire U.S. Bering Sea; however, for practical reasons, and because of the general lack of data from the southwestern Bering, the area of interest was narrowed somewhat to include the Norton Basin, St. Matthew Hall, Navarin Basin, St. George Basin, and North Aleutian Basin study regions (Figure 2-1). There was considerable discussion at the workshop regarding the desired geographic scale of the program in light of the disappointing results of exploratory drilling conducted to date and the vastness of the study area. The final consensus was that the program should be applicable to the Bering Sea overall, but should also include provisions for narrower implementation in whatever lease area(s) development appears likely. Development in the near term (next decade) is most likely within the St. George, North Aleutian, and Norton Basins.

2.8 CONSULTANT'S ROLE

MMS issued a contract to Dames & Moore, consultants in the environmental and applied earth sciences, to:



Source:
Alaska OCS Region Offshore Program July, 1985

Figure 2-1
Oil and Gas Planning Areas in the Southeastern Bering Sea

- Organize and conduct the workshop, schedule and fund speakers, establish and maintain the agenda and desired focus,
- Perform statistical analyses of monitoring approaches suggested by the workshop to produce a statistically optimum sampling design, and
- Prepare this report summarizing workshop proceedings and detailing optimum approaches to Bering Sea monitoring that meet the prescribed goals and mandates of MMS.

J. Houghton was the Project Manager of the Dames & Moore team which included the following subcontractors:

- University of Washington, Department of Statistics (J. Zeh), Seattle, Washington.
- Battelle New England Marine Research Laboratory (J. Neff, P. Boehm, T. Sauer), Duxbury, Massachusetts.
- Battelle Northwest Laboratory - (E. Crecelius, J. Word), Sequim, Washington.
- D. Segar - SEAM OCEAN, Inc., El Cerrito, California.

3.0 WORKSHOP SUMMARY AND SYNTHESIS

This section contains summaries, by major topics, of presentations and discussions during the course of the Bering Sea Monitoring Program Workshop. In these summaries, emphasis is placed on aspects of the presentations that were most relevant to workshop goals and to the final workshop recommendations regarding the monitoring program. Detailed presentations of information available elsewhere in report or published form are not repeated. However, references to published sources of such information are provided.

3.1 WORKSHOP FRAMEWORK

The purpose of this workshop and its follow-up activities was to provide a basis for design of a Bering Sea monitoring program. The framework within which this program was to be designed was presented by representatives from MMS and the workshop convenor, and is summarized below.

The purpose of the proposed Bering Sea Monitoring Program (BSMP) is to identify the effects of oil and gas development activities on the Bering Sea environment and the resulting consequences. The statutory basis for this program is described in Section 2.2.

Several different definitions of monitoring have been proposed. For the purposes of the National Ocean Pollution Planning Act, monitoring has been described as a program to gather marine pollution information to warn against unacceptable impacts of human activities on the marine environment, and to provide a long-term data base that can be used for evaluating and forecasting natural changes in marine ecosystems and the superimposed impacts of human activities (U.S. NOAA 1981). For the Beaufort Sea Monitoring Program, it was suggested (J. Hameedi, NOAA/ National Ocean Service, In: Houghton et al. 1984) that the monitoring program might simply consist of:

> "...a set of repetitive measurements of attributes and phenomena that can be used to document changes in the coastal and marine environments...resulting from OCS oil and gas development."

Subsequent discussions suggested that this definition should be interpreted to include the analysis of data gathered to (1) establish a measure of environmental quality, and (2) relate changes in this quality to causal factors. Discussions also highlighted the need for the end products of the monitoring program to provide continuing information about environmental quality such that policy and management decisions can be made about human actions that affect that quality.

The BSMP must be consistent with and cognizant of the many different marine pollution monitoring activities performed by various federal agencies responding to statutory responsibilities or agency mandates other than the Ocean Pollution Planning Act and the Outer Continental Shelf Lands Act. A partial list of federal agencies with such marine pollution monitoring activities is provided in Table 3-1. While many of these activities do not currently include monitoring in the Bering Sea, and others are of very limited scope in this region, the design of the proposed monitoring effort must take into account that such programs may be instituted, expanded, or reduced as federal and nonfederal development activities change in this area.

Although the Bering Sea marine environment is somewhat unique among United States coastal waters, numerous research and monitoring programs in other coastal areas have developed techniques that may be useful for monitoring environmental changes caused by oil and gas development and other similar activities (Section 3.3). The participants in this workshop (Appendix A) collectively represented a comprehensive body of knowledge regarding the effectiveness of techniques and approaches utilized by these and many other programs. It was intended that this knowledge, combined with many of the workshop participants' experience in the Bering Sea environment, would enable development of a monitoring plan composed of the best available techniques that would effectively assess impacts of oil and gas development on the Bering Sea environment.

Therefore, the workshop goal was to develop a monitoring program outline for the Bering Sea which incorporated those techniques and approaches most likely to be successful (1) in identifying changes in the Bering Sea environment that potentially could be caused by oil and gas development, and (2) in establishing the cause of any such changes. In developing the monitoring program, the following important considerations are pertinent:

- The primary focus of the program should be to monitor the fate and effects of contaminant releases to the environment, particularly chronic, long-term discharges of hydrocarbons, heavy metals, and other pollutants. However, the effects of development activities, such as drilling platform activities, noise, and port construction, should also be considered.
- The program should provide data necessary to design experiments or additional studies to identify the cause of any observed change (particularly change that results from natural events).
- The techniques and sampling strategies recommended should be capable of identifying, in a statistically valid manner, the degree of change in the measured parameter that might be caused by OCS oil and gas activities.
- The results of the monitoring program must facilitate management decision-making. In particular, if adverse changes are identified, sufficient information must be available, or obtainable, to permit mitigative measures or operational changes to be instituted in order to prevent further adverse change, and to minimize and redress any adverse impacts, where possible.
- Although the program should be economically feasible, cost of the monitoring program should not be a major concern at this stage of program design.

TABLE 3-1

FEDERAL AGENCIES RESPONSIBLE FOR MARINE POLLUTION AND ENVIRONMENTAL MONITORING

Environmental Protection Agency (EPA)
Monitors marine pollution compliance.

Food and Drug Administration (FDA)
Administers national shellfish sanitation program (also pesticides and metals in fish).

Minerals Management Services (MMS)
Subsequent to OCS leasing, monitors to provide time-series and data trend information for the purpose of identifying any significant changes in the quality and productivity of environments, for establishing trends in the areas, and for designing experiments to identify the causes of such changes.

U.S. Geological Survey (USGS)
Monitors water quality of the nation's rivers, streams, and estuaries.

National Oceanic and Atmospheric Administration (NOAA)
Monitors effects of ocean dumping and disposal of waste materials in the oceans (including contaminant levels in tissues of food fish). Responsible for comprehensive federal plan relating to ocean pollution. Monitors fish and shellfish stocks in the Bering Sea.

Other Federal Agencies
- Fish and Wildlife Service
- Corps of Engineers,
- Department of Energy
- Nuclear Regulatory Commission, etc.

The workshop participants were advised that MMS, NOAA-NMFS and USFWS studies of marine birds and mammals are currently active and will continue. Population level impacts on these groups are covered under these programs and were to be excluded from consideration in the BSMP. However, impacts and levels of contaminants in tissues of marine birds or mammals were considered suitable topics for inclusion in this program.

3.2 FACTORS THAT MAY CAUSE EFFECTS

No commercial finds of hydrocarbon have been reported from 20 exploration wells drilled in three Bering Sea lease areas to date. However, if oil is found in a lease sale area, oil production would likely span 20 years. To transport oil to southern markets, two hypothetical transportation scenarios have been proposed for the Bering Sea:

- Offshore loading to tankers, which is proposed for the Navarin Basin and the northern portion of St. George Basin.
- Pipeline transport to land-based terminals for loading on tankers. This scenario is proposed for the Norton and North Aleutian Basins, with terminals at Cape Nome and Balboa Bay.

Approximately 6.1 Bbbls of oil are projected to be produced and transported among the various Bering Sea subregions (Table 3-2). The current development scenario also projects an estimated volume of 4.4 Bbbls of oil to be transported through the Bering Sea from oil produced in the Chukchi and Canadian Beaufort Seas (Table 3-2). Therefore, an estimated 10.5 Bbbls of oil are projected to be produced or transported through the Bering Sea. Based upon past spill rates on the outer continental shelf, 26 spills of 1,000 bbls or greater and 1.57 spills of 100,000 bbls or greater are expected from the production and transportation of this 10.5 Bbbls of oil.

Federal oil and gas lease sales in the Bering Sea region include the St. George Basin (Sale 70), Norton Sound (Sale 57), Navarin Basin (Sale 83) and the North Aleutian Basin (Sale 92), as well as those scheduled in accordance with the Department of Interior's 5-year schedule. A summary of the estimated producible reserves and hypothetical exploration, development, and production-related oil spill probabilities in the Bering Sea is contained in Table 3-2.

- St. George Basin (Sale 70): The St. George Basin (Sale 70) was held April 12, 1983, with 96 blocks leased. Potential effects could result from tankering, oil spills, and the use of Unalaska as a support base.
- Norton Sound (Sale 57): The Norton Sound Lease (Sale 57) was held March 15, 1983, with 59 blocks leased of the 418 blocks offered. Potential effects could result from transportation of oil adjacent to the area and from any potential oil spills.

TABLE 3-2

RESOURCE ESTIMATES (BBBL) AND OIL-SPILL-PROBABILITY-ESTIMATES FOR SPILLS GREATER THAN 1,000 AND 100,000 BARRELS FOR THE BERING SEA REGION

Source	Volume (Bbbl)	Mean Number of Spills from Platforms		Mean Number of Spills from Transportation		Mean Number of Spills Total		Probability of One or More Spills-Platforms		Probability of One or More Spills-Transportation		Probability of One or More Spills - Total	
		≥1,000	≥100,000	≥1,000	≥100,000	≥1,000	≥100,000	≥1,000	≥100,000	≥1,000	≥100,000	≥1,000	≥100,000
Norton Basin (Sale 57)	0.470	0.47	0.02	0.96	0.08	1.43	0.10	0.37	0.02	0.62	0.08	0.76	0.10
St. George Basin (Sale 70)	0.570	0.57	0.02	1.04	0.06	1.61	0.08	0.43	0.02	0.65	0.06	0.80	0.08
Navarin Basin (Sale 83)	1.510	1.51	0.05	3.10	0.24	4.61	0.29	0.78	0.05	0.95	0.21	0.99	0.25
N. Aleutian Basin (Sale 92)	0.279	0.28	0.01	0.45	0.02	0.73	0.03	0.24	0.01	0.36	0.02	0.52	0.03
Navarin Basin (Sale 107)	3.280	3.28	0.12	6.72	0.52	10.00	0.64	0.96	0.11	**	0.41	**	0.47
Chukchi Sea (Sale 109)	2.680	2.68	0.10	4.29	0.17	6.97	0.27	0.93	0.10	0.99	0.16	**	0.24
Tankering of Canadian Oil	1.700	--	--	0.77	0.16	0.77	0.16	--	--	0.54	0.15	0.54	0.15
Total	10.489	8.79	0.32	17.33	1.25	26.12	1.57	**	0.27	**	0.71	**	0.79

Source: USDOI, MMS, 1985.

Note: ** = Greater than 99.5 percent.

- Navarin Basin (Sale 83): The Navarin Basin lease (Sale 83) was held on April 17, 1984. One hundred eighty-six (186) blocks were leased from a total of 5,036 offered. Based on the development scenario, effects could result if St. Paul and/or Unalaska were used as support-base sites, or from oil spills, and the tankering of oil.
- North Aleutian Basin (Sale 92): The North Aleutian Basin (Sale 92) FEIS was released in September 1985, but the sale has been delayed by Federal court order. Based on the development scenario, effects could result from oil spills, and the use of Unalaska as a support base.

Many activities associated with oil and gas development in the Bering Sea have the theoretical potential for directly or indirectly altering the natural range of physical, chemical, and biological variables that can be used to describe the existing environment. These activities and their potential consequences were briefly reviewed by several workshop participants. Since they have been thoroughly discussed in a number of environmental impact statements (EISs) dealing with individual federal permitting actions, and OCS lease sales, they will only be briefly outlined here.

Construction and/or placement of permanent shoreline or offshore structures directly destroys existing habitat and can cause changes in circulation that may affect water quality, nutrient transport, and movements of biota (e.g., U.S. Army Corps of Engineers 1984). However, the physical presence of structures also creates a reef effect that can greatly increase local biological diversity and productivity (Davis et al. 1982). Construction and operation of facilities, including ship and aircraft movements, create noise (airborne and waterborne) and visual effects that may disrupt biota. MMS has funded several recent and ongoing studies of the effects of waterborne noise on critical receptors, primarily marine mammals. Routine discharges (e.g., drilling fluids and cuttings, sewerage, wash water, brines, etc.) can alter local water and sediment quality and may contain compounds that are toxic to, or can accumulate in, organisms. Drilling fluids and produced waters (brines) are the major sources of metals released from drilling operations and are also potential sources of hydrocarbons (Houghton et al. 1981). In developed offshore fields such as the North Sea, the footprint of effluents from a single rig may be detectable as elevated sediment metals values for several kilometers from the rig (J. Ray, Shell Oil Company, this workshop).

Discharges of produced water to the Bering Sea, if permitted, will represent point source chronic inputs of petroleum hydrocarbons and heavy metals to this environment. In addition, accidents during field development may result in oil spills, or even blowouts, which will represent acute, possibly massive-scale inputs of petroleum to the Bering Sea. Suspended solids concentrations in some parts of the Bering Sea, especially Norton Sound, are seasonally very high. In these environments, it is likely that acute or chronic inputs of petroleum hydrocarbons and heavy metals will become adsorbed quickly to suspended particulate matter and be deposited in bottom sediments. Operation of high volume water intakes for treatment and waterflooding of oil bearing formations can cause entrapment and impingement or entrainment of large numbers of organisms. However, work by Dames & Moore (1986) has shown that, with a well designed intake system, entrapment rates can be very low.

Accidental spillage of large quantities of hydrocarbons or other oilfield chemicals could cause a significant short-term loss of vulnerable species (e.g., birds, neuston, benthos, littoral spawning fish). Repeated releases of smaller quantities could gradually degrade habitat quality, contribute to uptake of potentially toxic compounds by organisms, and ultimately influence the distribution, numbers, or health of some species.

Individual planned actions are subjected to permitting processes that typically result in restrictions limiting the extent of predictable impacts to "acceptable" levels. Often, monitoring to document compliance with imposed restrictions, and the extent of actual impacts, is also required. Such permitting "stipulations" and other mitigative actions in conjunction with extant laws and regulations are usually adequate to limit and/or document significant local (and often short-term) impacts. However, there remains concern for the potential that the cumulative effects of numerous and varied individual projects and activities that may occur in the coming decades could, in combination, cause larger scale (and longer term) changes in habitat quality and/or in the populations or health of "important" species or groups of species.

3.3 OTHER MONITORING PROGRAMS

Several invited participants described monitoring programs that have been instituted for purposes similar to those of the BSMP elsewhere on the United States continental shelf, and for other purposes in the Bering Sea.

3.3.1 EPA Ocean Discharges Monitoring

J. Hastings (EPA Region 10) provided an overview of EPA's monitoring requirements for discharges in the Bering Sea. The EPA regulates discharges associated with oil and gas operations in offshore areas in Alaska. Site-specific surveillance monitoring requirements are in some cases included as a condition of permits for such discharges. The main category of discharges dealt with to date has been drilling muds and cuttings, although there are a number of operational wastewaters also associated with proposed offshore facilities. Because these are discharges to ocean waters, Section 403(c) of the Clean Water Act requires that EPA's Regional Administrator determine whether they will result in unreasonable degradation of the marine environment. "Unreasonable degradation" has been interpreted to encompass the following: significant adverse ecosystem impacts, a threat to human health, or an unreasonable loss of scientific, recreational aesthetic, or economic values.

In making the determinations of whether a discharge will cause unreasonable degradation (and correspondingly in determining whether a permit can be issued) 10 factors known as the "Ocean Discharge Criteria" are considered (Table 3-3). These criteria address the following major issues: Are there areas of significant biological concern and will the discharge be transported to these areas of concern in sufficient concentrations or quantities to adversely affect them? Determination of whether unreasonable degradation will occur requires sufficient information on the proposed discharges and the affected environment to allow evaluation of the situation with respect to the Ocean Discharge Criteria. Where only limited site-specific field data are available, a discharge permit is issued only if it can be determined that the discharge will not result in irreparable--or irreversible--harm, given specific monitoring requirements and other conditions.

The primary objectives of permit-specified monitoring are thus twofold: first, to fill certain specific data gaps identified by the Ocean Discharge Criteria Evaluation and second, to ensure that the discharge does not cause unreasonable degradation of the marine environment. Both immediate, specific effects as well as long-term cumulative impacts are considered.

3.3.2 Beaufort Sea Monitoring Program

The objectives of the Beaufort Sea Monitoring Program include the detection and quantification of long term changes in hydrocarbon and trace metal distributions in the nearshore Beaufort Sea. The monitoring program is aimed at detecting far-field effects rather than near-field effects of specific production facilities. Data collected during 3 seasons of summer sampling (1984-1986) have established a baseline of information prior to forthcoming OCS activities (Boehm et al. 1986). Currently, there is not enough OCS activity in the region to have created measurable development-induced changes.

E. Crecelius (Battelle NW) spoke about the sampling results to date in the Beaufort Sea. Three years of sampling activities for surface sediments and bivalve mollusks have been carried out to date. The upper 1 cm of the sediment was collected with a grab sampler that was modified to produce minimal disturbance of the sediment during collection. Samples containing more or less than the upper 1 cm were rejected. Eight replicate sediment samples were collected; however, not all eight were analyzed depending on the parameters to be measured or the year of collection. Ten stations were sampled for bivalves. A grab sampler was used to collect sediment which was then passed through a sieve to recover the bivalves. All bivalves from a particular site were pooled in order to obtain enough biomass for chemical analyses of tissue contaminants. There was typically not enough biomass of bivalves collected at a station to allow replication within a station.

Sediment samples were analyzed for barium, copper, cadmium, chromium, lead, vanadium, and zinc. Resulting data were analyzed to determine the variability of metals concentrations within a station, local contamination, geographic trends, and the relationship between metals concentrations, sediment grain size, and total organic carbon.

TABLE 3-3

OCEAN DISCHARGE CRITERIA FOR DETERMINATION OF UNREASONABLE DEGRADATION OF THE MARINE ENVIRONMENT[a]
(40 CFR Part 125)

- Quantities, composition, and potential for bioaccumulation or persistence of the discharged pollutants.
- Potential transport of such pollutants.
- Composition and vulnerability of biological communities; e.g., presence of endangered species.
- Importance of receiving water area to surrounding biological community; e.g., presence of spawning sites.
- Existence of special aquatic sites; e.g., marine sanctuaries.
- Potential impacts on human health.
- Existing or potential recreational and commercial fisheries.
- Applicable requirements of approved Coastal Zone Management Plans.
- Marine water quality criteria.
- Other relevant factors.

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[a] "Unreasonable degradation of the marine environment" means: (1) significant adverse changes in ecosystem diversity, productivity, and stability of the biological community within the area of discharge and surrounding biological communities, (2) threat to human health through consumption of exposed aquatic organisms, or (3) loss of aesthetic, recreational, scientific, or economic values which is unreasonable in relation to the benefit derived from the discharge.

Sediment and tissue samples were analyzed for hydrocarbons using UV fluorescence techniques. Because high background fluorescence in sediment samples was observed, sediments were not analyzed by this method after the first year's sampling. Samples of interest (and after the first year, all sediment samples) were analyzed further using high resolution gas chromatography and gas chromatography/mass spectrophotometry.

Initial results have indicated several important considerations for future monitoring. Depending on the element, an approximate 50 percent change in sediment trace metal concentrations could be detected with acceptable statistical power with as few as four replicates per station. Since there is a large amount of variability in natural, background levels of organics, an increase in organics of less than approximately 200 percent could not be detected with adequate statistical power using four replicates per station. Finally, there was no systematic relationship observed between tissue body burdens of trace metals or hydrocarbons and concentrations in the sediments.

3.3.3 Santa Maria Basin Monitoring Program

The Santa Maria Monitoring Program is a long-term, MMS sponsored program in the western Santa Barbara Channel and portions of the Santa Maria Basin in southern California and is being developed in three phases. G. Brewer (MMS - Pacific OCS Region) summarized the objectives and methodology of this monitoring program.

Phase 1 began in 1983 and consisted of a baseline survey of benthos, hydrocarbon concentrations, and sediment grain sizes. The data acquired under this phase were used to identify stations for sampling during the next phase. Both soft bottom and hard bottom communities were surveyed in Phase 1.

Phase 2 began in the summer of 1986 and is a 5-year, multidisciplinary program aimed at monitoring potential environmental changes at regional stations in the Santa Maria Basin, as well as at site-specific stations around two operating production platforms. The specific objectives of Phase 2 are to detect and measure any short- or long-term changes in the marine environment adjacent to these platforms and determine whether the changes observed are caused by drilling related events or are the results of natural processes. These objectives are to be met by examining dose-response relationships developed through the measurement of changes in physical characteristics, sediment chemistry, and benthic biota at regular intervals away from the production platforms. Phase 2 sampling will be extensive during the first two years. After an evaluation of these data, further sampling in years 3 through 5 will be conducted on an annual basis at fewer overall stations.

The Phase 3 study is proposed for the future and will be developed after completion of Phase 2 and an evaluation of its results. Phase 3 will be directed at monitoring formation waters released during production.

3.3.4 NOAA Status and Trends Program

The NOAA Status and Trends Program is a national coastal and estuarine monitoring program begun in 1984. The overall program objective is to quantify the current status and long term trends of concentrations of toxic chemicals, heavy metals, polynuclear aromatic hydrocarbons, and chlorinated compounds in bivalve mollusks, bottom feeding fish, and sediments in coastal and estuarine areas of the United States. C. Manen (NOAA) presented an overview of this program. Three major questions that the program is attempting to answer include:

- What is the current status of the nation's estuaries,
- What compounds are being introduced; are more or less of these materials being introduced than in the past, and,
- Does the presence of these compounds make any difference?

The answers to these three questions will be used to determine whether the existing regulatory framework is sufficient for ensuring long-term health of the nation's coastal areas.

The program is ultimately intended to include routine measurement of a number of indicators of marine pollution at a nationwide network of coastal and estuarine sites. These indicators are planned to include the concentrations of toxic chemicals such as aromatic and chlorinated hydrocarbons and heavy metals in sediment and biota, incidence of bottom fish diseases such as liver neoplasm and fin erosion, altered structure of benthic communities, and lethal or sublethal effects on biota such as reduced condition index or reduced fertility.

Three projects are currently being undertaken within the overall program. The collection of historical data from around the country and creation of a nationwide data base is aimed at assessing the current status of the nation's coastal areas. Data are gathered from various sources, including federal and state government sponsored programs, university research, and industry monitoring studies. The benthic surveillance project is investigating the prevalence of diseases in bottom-feeding flatfish and the concentrations of contaminants in fish and sediments. The mussel watch project is attempting to measure the transient concentrations of contaminants in the water column through assays of the tissue from filter-feeding mollusks. These measurements are then correlated with sediment contaminant concentrations.

Quality assurance and specimen banking are two components of the overall program that were instituted to ensure validity of the data and future usefulness of the collected samples. The quality assurance component is intended to foster uniform analytical protocols, interlaboratory comparisons, calibration standards, and peer review of analytical results. The specimen banking component is an attempt to archive enough material from field samples to allow a future re-analysis of the material when and if it becomes necessary. This would be done in instances where additional toxic compounds of concern were identified that had not been previously covered, or if newly developed analytical techniques allowed a more detailed examination of the material.

The National Status and Trends Program is intended to be a long-term monitoring program. As such it was set up without a rigid sampling and analytical framework, the intent is for the program to evolve as time passes. New compounds will be analyzed and analytical schemes will change as the previous year's data become available. Geographic areas of known pollution may be looked at more closely to gain an understanding of how well a single reference station compares with the overall conditions in a particular area.

3.3.5 Bering Sea Oil Rig Monitoring

J. Ray (Shell Oil) spoke about industry-sponsored rig monitoring activities in the Bering Sea. Limited drilling activity to date in the Bering Sea has resulted in only two monitoring studies being carried out. The first involved a drilling mud dispersion study in the Norton Sound Basin during September 1982. The second was an acoustical study conducted in the St. George Basin during September 1982.

The Norton Sound study was conducted in response to compliance monitoring requirements of the operating permit for a jack-up drilling rig. It looked at the dispersion of approximately 1100 barrels of chrome lignosulfonate drilling fluid in 12 m water depth during a final dump situation that approximated maximum dumping rate at the end of a well. The mud plume was followed by a helicopter equipped with a rosette water sampler that was periodically lowered into the plume to collect water samples and to profile salinity and temperature with depth. Sediment traps, current meters, and a wave meter were installed at various points along the expected path of the plume. Major findings were that the mud plume was indistinguishable from background 800 to 900 m downstream from release given the high background suspended solids levels in the area. A drop in suspended solids of approximately 3 orders of magnitude was seen within the first 70 m of release. The conduct of this study and value of the results were negatively affected by poor weather conditions.

The St. George Basin acoustic study was conducted in 114 m water depth with the objective of quantifying the acoustical pressure and frequency of sounds from a semi-submersible drill rig. Rig activities during monitoring included rotary bit drilling and operation of two large mud pumps. Acoustic measurements were made at various intervals to 10 nautical miles and depths to 30 m along one major axis from the drill rig transect. Two other axes were sampled at less frequent intervals for comparison purposes. The study found that radiated noise levels were generally low and broad band sounds disappeared at approximately 0.5 nautical miles. Acoustic levels were generally lower at shallower depths, they tended to increase with increasing depth to 30 m.

3.3.6 USFWS Monitoring

The US Fish and Wildlife Service has been collecting tissue samples of marine mammals and seabirds from the Bering Sea and analyzing them for various contaminants and heavy metals. Few data are available to date on birds. D. Taylor (USFWS) spoke about the ongoing tissue analyses of several marine mammals in the northern Bering Sea. Most of the information that is available is for walrus, fur seal, and other pinnipeds. Based on preliminary analyses, walrus appear to be concentrating certain metals, particularly cadmium, in their kidneys and liver. Levels are particularly high in animals taken near Savoonga and Gamble on St. Lawrence Island. Some fur seal samples from the Pribilof Islands are also high in cadmium. The cadmium is thought to originate from natural environmental sources (although major mining activity was noted along the Siberian coast). The levels measured may be high enough to already pose a health risk to the animals (D. Taylor, this workshop). Industrial development in the Bering Sea may increase the levels of cadmium and other metals available to these animals. The effects of this are unknown at present but need to be considered.

USFWS is planning to continue this sampling in the summer of 1987 and expand sampling to include several walrus tissues, stomach contents, clams and sediments (H. Metzkar, USFWS personal communication).

3.3.7 Inner Shelf Transfer and Recycling

The Inner Shelf Transfer and Recycling (ISHTAR) program is a multidisciplinary study of organic matter production and recycling in shallow water areas of the northeastern Bering and southeastern Chukchi Seas. D. Shell (University of Alaska) covered the major objectives and preliminary findings of this program. The ISHTAR program was originally focused on the input of organic matter from the Yukon River into Norton Sound, however, this input was overwhelmed by the input of Anadyr Stream water moving north over the shelf. This eventually lead to an expansion of the program. This study is funded through the National Science Foundation, Division of Polar Programs with the University of Alaska playing the major technical role.

There are five component research projects in ISHTAR plus project management. The physical oceanography component is investigating the advection and mixing of coastal waters. It includes modeling and subsequent ground truthing of the flow through Anadyr and Shpanberg Straits, as well as modeling of the Anadyr Stream and Alaska coastal water for nutrient supply and transport north through the area west of the Seward Peninsula. The moored fluorometer component uses anchored fluorometers and transmissometers to measure actual particle fluxes over time in in coastal waters. This produces a time record of primary production and provides phytoplankton boundary conditions for use in the physical oceanography model. The organic matter production and degradation component looks at the distribution of organic matter to microbial, meiofaunal, and macrofaunal communities. The pelagic bacteria and protozoa component is aimed at quantifying the amount of secondary production in the water column as a result of non-photosynthetic processes. The tracer and stable isotope component is using labelled compounds to trace the movement of ammonia and nitrate through the food web and stable isotopes to trace the movement of carbon and nitrogen.

3.3.8 National Marine Fisheries Service Studies

Studies carried out by the Resource Assessment and Conservation Engineering (RACE) Division of the Northwest and Alaska Fisheries Center (NWAFC) of NMFS were divided by M. Hayes (NMFS, retired). The RACE program has looked at shellfish stocks in the eastern Bering Sea since 1955. Groundfish were included in 1971 and in 1975-1976 the study area and scope were further expanded. The current study plan provides for an annual trawl survey of a core area with triennial surveys of an expanded area.

Surveys are conducted using a bottom trawl, which limits the primary information to groundfish. Bottom trawls also capture some semipelagic species such as rockfish and pollock; additional hydroacoustic surveys have been added to target these species. Pelagic species such as salmon, herring, capelin, and smelt are not sampled quantitatively by this program. Due to their spawning preference for relatively limited habitats, e.g., specific beaches, these pelagic species may be particularly vulnerable to impacts from industrial development.

Results from RACE trawl studies have generally indicated wide variation in fish stocks over time. Indications are that overall standing stock biomass of commercially valuable species has not fluctuated greatly over the past ten years, but the species mix of the standing stock has changed greatly. Some shifts can be linked to increased fishing pressure, while others are as yet unexplained. These widescale, unexplained variations over time will make it difficult to detect any changes caused solely or partly by OCS oil and gas development.

NMFS has also conducted many years of research on the biology and harvest of northern fur seals on the Pribilof Islands.

3.4 PHYSICAL ENVIRONMENT

Information on the physical environment of the Bering Sea described in this section is derived from workshop presentations by J. Niebauer and G. Sharma (both University of Alaska) and from Sharma (1979).

3.4.1 Bathymetry and Shorelines

The Bering Sea is unique in the breadth (500 km) of its shallow shelf between the adjacent Alaska mainland and the Aleutian Basin. The shelf edge dividing these major bathymetric features lies at around 170m to 200m depth, and is a steep continental margin cut by several submarine canyons. The shelf has three large and a few small islands, which are important features in affecting local circulation, sea ice and sedimentation. Otherwise, the Bering Sea shelf topography is notable for its smoothness.

The origin of the configuration of the Bering Sea shelf lies in the last glaciation when most of the northern part of the shelf was covered by ice (Niebauer, this workshop). The shelf was above sea level then, about 18,000 years ago, with the sea at about 120 meters below present level. The current sea level was reached about 6,000 years ago with the melting of the glaciers. There was an intermediate sea level stand at about the present 80 meter isobath around 13,000 years ago, during which time Norton Sound was a fresh water lake. These historic conditions contributed to the observed bathymetry and shoreline of the Bering Sea, and to the nature of the sedimentary deposits over the shelf.

The shoreline boundary of the Bering Sea shelf includes the Aleutian Island chain in the south, the Alaska Peninsula and mainland on the east, three major embayments (Bristol Bay, Norton Sound, and Anadyr Bay in the USSR), and two major delta shorelines (the Kuskokwim and Yukon). The Aleutian boundary is "permeable" in a physical oceanographic sense, and there is also the major "leak" of the Bering Strait in the north.

The four primary OCS lease areas are spread amongst and influenced by these physical settings as follows:

- St.George Basin - shelf edge with submarine canyons, Aleutian Island Chain, Pribilof Islands;
- North Aleutian Shelf - Bristol Bay, Aleutian Islands and Alaska Peninsula;
- Navarin Basin - outer shelf edge with submarine canyons, St.Matthew and Pribilof Islands; and
- Norton Basin - Norton Sound, Bering Straits.

The diversity of physical settings and relative lack of close interconnection between lease areas complicates development of Bering Sea-wide monitoring programs.

3.4.2 Meteorology

The key characteristic of the Bering Sea that results from its meteorological environment is its winter ice cover (Niebauer, this workshop). The atmospheric processes that influence ice formation and circulation of Bering Sea waters are both regional and global in extent.

The Aleutian Low is a strong and deep barometric feature that dominates the Bering Sea area. The low is a statistical low feature with a high variability and is a key part of the Pacific North American Pattern (strong Aleutian Low with an Alaska High), which causes warm Pacific Ocean air to flow northward over the Bering Sea area.

From a global perspective, recent work has suggested correlations between Bering Sea oceanography (e.g., sea ice, circulation, and temperatures) and the Southern Oscillation Index (Niebauer, this workshop). This suggestion of multi-year aperiodic variability has important implications to regional monitoring plan design.

3.4.3 Oceanography

Bering Sea circulation is influenced strongly by the geologic/geographic boundaries discussed above, by regional circulation of the northern Pacific Ocean, and by air-sea interactions. The "porous" geographic boundaries of the Aleutian Islands and of the Bering Straits allow the regional circulation to provide watermass movement into and out of the Bering Sea (Niebauer, this workshop).

The north Pacific net flow is westward through the Aleutian Islands (Unimak Pass) and into the Bering Sea. This circulation then splits into flows northward (1 to 5 cm/sec) along the shelf and eastward (2 to 5 cm/sec) along the Alaska Peninsula. Occasionally the speed of the northerly flow segment at the shelf break is up to 1 knot. The middle shelf zone in between these flow segments has a very sluggish net flow.

The circulation forms three regimes: coastal, middle (50 to 100 m depth) and outer (deeper than 100 m). The shallow coastal domain has complete water column mixing due to the winds at the surface and tidal mixing below. Tidal influences are most prominent in the southern Bering Sea shelf.

The middle shelf has very low mean flow. It is generally stratified, with low-salinity water near the surface. The presence of this distinct zone creates two fronts in contact with the well-mixed inner shelf (coastal) waters at about the 50 m isobath, and the outer (and locally oceanic) waters near the 100 m isobath. The more saline oceanic waters flow at 5 to 15 cm/sec northwestward along the shelf edge. Dispersion occurs over much of the shallow Bering Sea shelf. This shelf area appears too shallow to support significant eddying; however, eddies are seen in satellite images along the shelf break.

3.4.4 Ice Conditions

The seasonal sea ice reaches its maximum extent in March-April and recedes north of the Bering Straits during summer (Niebauer, this workshop). The northern Bering Sea is ice-free from about July through September. The southern Bering Sea has a longer ice-free season. The interannual variability in the extent of ice cover over the Bering Sea shelf is great, as indicated by the 400 km difference between the maximum extent of sea ice measured for 1976 versus 1979. The majority of the sea ice forms and melts in place, with only minor changes due to advection of ice. However, there is a lot of ice motion in Norton Sound, the Bering Strait, and near polynyas. Both the spatial and temporal variability are important to biological processes in the Bering Sea.

3.4.5 Sedimentary Regimes

The sediments represent an important sink for much of the contamination introduced into the shelf environment. Since higher trace metals and hydrocarbons concentrations generally are associated with finer sediments, it is reasonable to place greater emphasis on these sediments in monitoring.

The predominant source of sediments entering the Bering Sea is the Yukon River (80 to 100 million tons per year). The other major source is the Kuskokwim River. The high rates of spring and summer runoff leave deposits of finer sediments in the nearshore region. These deposits remain there until re-suspended by storm waves, when extensive plumes of fine sediments have been observed to move offshore. Thus, there is a temporary nearshore storage of fines.

The sediment cover over the nearshore Bering Sea shelf is primarily sandy, and even gravelly in the inshore zone of the mainland and larger islands. The outer shelf sediments are primarily silts.

There is a great deal of re-suspension of sediments in the shallower shelf, less than 50 meters depth, especially during fall storms (before sea ice cover; Sharma, this workshop). The effect of wave energy decreases with depth. Singular storm events have been shown to cause significant redistribution of sediments over the shelf.

3.4.6 Geochemistry

Organic carbon in sediments decreases nearer to shore, except near the major deltas, where organics are deposited faster than they can be dispersed (Sharma, this workshop). The coastal zone is a key source of the organic materials, and the other main natural carbon source is the water column. The greater amount of organic carbon deposition in deeper waters reflects the lower energy and finer grain sizes of the outer shelf environment.

Sharma (1979) presented plots of the distribution of several chemical parameters, including trace metals. The latter include metals of potential interest in monitoring, such as barium, which is a key component in drilling muds. In these data, barium exhibits complex patterns and the greatest variation over the shelf, but no trend, such as a difference with distance from shore.

3.4.7 Monitoring Considerations

The sediments represent a key monitoring parameter in view of their function as a major sink for many contaminants. They are also influenced directly (physically) by seafloor construction, such as pipelines, and strongly affected by trawling in some areas. Changes due to man's activities in the Bering Sea may be detectable earlier by monitoring the sediments than by monitoring biological parameters.

Sharma (this workshop) noted that monitoring of sediments should take into account the seasonal characteristics of sediment transport in the Bering Sea. The temporary deposition of fines in shallow water and their subsequent resuspension and deposition is an important process and a mechanism for re-introduction of contaminants into the water column. The temporary "storage" of possible contaminants must be considered in the monitoring plan to avoid misinterpretation of sediment measurements. Timing as well as location of sediment sampling will be important in the Bering Sea.

The distribution of the final depositional sites for fine sediments also is an important monitoring consideration. Since OCS development may take place on the outer shelf (Navarin and St. George Basins), and, since this is also a zone of intense fishing activity, greater emphasis should be given to the outer shelf zone. This is also an oceanographic region with significant current transport, so there may be northward displacement and "smearing" of any contaminant effects over this vast region.

The recent potential linkage of Bering Sea oceanography with El Nino phenomena poses both a means for greater overall understanding of the processes impacting monitoring, and a challenge to monitoring program design. The documentation of episodic changes of environmental conditions over the Bering Sea region makes it essential that any such cycles be accounted for in the long-term monitoring. Such fluctuations in characteristics that occur over periods of years of a magnitude greater than seasonal changes, could easily lead to misinterpretation of the timing and causes of any real impacts due to man's activities.

3.5 BIOLOGICAL ENVIRONMENT

3.5.1 Primary Producers

D. Schell (University of Alaska) spoke on primary productivity in the Bering Sea. He noted that primary productivity estimates have ranged from 125 to 250 g of carbon/m^2 in the Bering Sea. The oceanographic domain within which the primary production occurs plays a major role in determining whether or not the produced carbon falls to the bottom and enters a benthic food web or is consumed by a pelagic food web in the water column. Carbon produced by phytoplankton has been traced through all levels of most food webs in the Bering Sea, pointing out its major role in production. In contrast, carbon produced by eelgrass does not appear to enter significantly into food chains outside the immediate area of occurrence of even major eelgrass beds.

3.5.2 Benthos

The infaunal and epifaunal benthos of the Bering Sea are comprised of a diverse array of organisms, most of which are Boreal-Pacific forms (Sparks and Pereyra 1966). Habitat types and potential food supplies play a major role in determining what assemblages are present in any given region of the Bering Sea. In general, sediment grain size can be used to predict the benthic assemblages present in any given region (Stoker 1981). H. Feder (University of Alaska) noted this predictive ability of sediment grain size in discussing the general distribution of benthic organisms throughout the Bering Sea. For instance, nearshore high energy environments, such as around the Pribilof Islands, support large populations of sand dollars while the offshore central regions of the Bering Sea, which have predominately muddy bottoms, are characterized by deposit feeding bivalve mollusks.

The success of benthic organisms is also partly determined by carbon flux. In the middle shelf domain of the Bering Sea (the area between 50-100 m depth), the early spring primary productivity bloom is only partially grazed by zooplankton. Much of the resulting carbon production sinks to the bottom where it supports large populations of benthic mollusks and polychaete worms; these are in turn preyed upon by such species as king crabs and bottom feeding demersal fish. Within the outer shelf domain (100 m depth to the shelf break) where incomplete mixing occurs, copepod populations overwinter at depth. The initial primary productivity blooms that occur in this domain are grazed upon by early developmental stages of these copepods that have migrated to the surface waters. As a result, little carbon production passes to the bottom and this domain is one of diverse zooplankton assemblages and pelagic feeding fish.

Several types of dominant benthic invertebrate groups are found within the Bering Sea that, due to their major role in trophic interactions or commercial importance, might serve as useful indicator organisms for long-term monitoring of the benthos (Table 3-4). Tanner crabs and king crabs are somewhat widely distributed and are an important commercial fishery resource. Ampeliscid amphipods are abundant, tube-dwelling organisms in the northeast Bering Sea and are also an important prey item for gray whales. A number of clam species are widely distributed throughout the Bering Sea and are important prey items for bottom feeding fish and walrus. There are a number of species of large snails that are relatively easily collected. Sea stars and brittle stars are very abundant in the northern Bering Sea. Sea stars are an important predator in the absence of bottom feeding fish and brittle stars are in turn an important prey item for many bottom feeding fish.

3.5.3 Fish

Approximately 235 to 240 fish species are commonly identified from collections in the eastern Bering Sea. The majority, approximately 185 species, is typically taken by bottom trawl. Twenty species comprise 98 percent of the total bottom-trawl biomass with walleye pollock and yellowfin sole (Limanda aspera) accounting for approximately 40 and 22 percent of the total, respectively. Thus, the fish fauna of the Bering Sea, though diverse, is actually concentrated in relatively few species.

M. Hayes (NMFS, retired) described the commercial fisheries monitoring work that is conducted by NMFS in the eastern Bering Sea. Surveys conducted by RACE Division (see Section 3.3.8) have shown that the relative importance of major species changes with depth. In relatively shallow shelf waters, flatfish species predominate. Pollock occur through several depth zones, while deepwater areas are characterized by species such as grenadiers. Multi-year comparisons of RACE data from 1979, 1982, and 1985 showed that the total biomass estimate for the eastern Bering Sea remained relatively close to 16 million metric tons. However, the species mix varied considerably.

TABLE 3-4

BENTHIC INVERTEBRATE SPECIES OF POTENTIAL INTEREST FOR MONITORING IN THE BERING SEA

Taxon/Species	Depth Range of Primary Abundance	Region of Primary Abundance
Mollusks		
Macoma calcarea[a]	50 - 100 m	SE, NE Bering Sea
Nucula tenuis	50 - 100 m	SE, NE Bering Sea
Nuculana fossa[a]	75 - 125 m	SE, NE Bering Sea
Spisula polynyma[a]	50 - 100 m	SE, NE Bering Sea
Neptunea spp.[b]	50 - 200 m	Entire upper slope and shelf
Crustaceans		
Paralithodes camtschatica	>40 m	SE Bering Sea Shelf
Chionoecetes opilio[c]	>40 m	SE Bering Sea Shelf
Ampelisca spp.[d]	>100 m	Norton Basin, St. Matthew Hall
Echinodermata		
Asterias amurensis[c]	0 - 40 m	NE Bering Sea
Evasterias echinosoma[c]	0 - 40 m	NE Bering Sea
Leptasterias polaris acervata[c]	0 - 40 m	NE Bering Sea
Lethasterias nanimensis[c]	0 - 40 m	NE Bering Sea
Gorgonocephalus caryi[c]	>40 - 100 m	SE, NE Bering Sea
Strongylocentrotus droebachiensis	>40 - 100 m	NE Bering Sea

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[a] McDonald et al. (1981).

[b] MacIntosh and Somerton (1981).

[c] Jewett and Feder (1981).

[d] Feder (this workshop).

Variation within a species over time is apparent from RACE data. Yellowfin sole biomass estimated from 1964 through the early 1980s showed that biomass increased dramatically in the 1970s with a peak occurring in the early 1980s. Pacific cod (Gadus macrocephalus) showed a ten-fold increase in biomass over the last 10 years which was primarily the result of a very successful 1977 year class. Substantial declines in total biomass for species such as Pacific herring (Clupea harengus pallasi) and Pacific Ocean perch (Sebastes alutus) were observed since 1964. These declines may have been due to factors such as overfishing (Pacific Ocean perch) or subtle environmental changes (herring).

This type of variation over time presents a problem that must be seriously considered in the design of any monitoring program for the Bering Sea. Detailed knowledge of the past fluctuations of a particular fish resource is required prior to making assumptions for a monitoring program; otherwise any changes observed may be difficult to link with a specific environmental perturbation. Currently, variations in the year classes of fish stocks in relation to environmental changes in the Bering Sea are not clearly understood. It is likely that impacts from oil development, with the exception of a major environmental accident, would be difficult to separate from natural enviromental variability and that resulting from changes in commercial fishing effort.

3.5.4 Birds and Mammals

Although bird and mammal population level studies were outside the scope of this workshop, the following brief descriptions from the literature are provided to place these important organisms in the broader ecological context of the Bering Sea.

The bird fauna of the eastern Bering Sea has four components: marine species, shorebirds, gulls, and waterfowl. Approximately 45 species of seabirds occur throughout the Bering Sea with the most abundant species including short-tailed shearwater (Puffinus tenuirostris), least auklet (Aethia pusilla), thick-billed murre (Uria lomvia), common murre (U. aalge), fork-tailed storm petrel (Oceanodroma furcata), and Leach's storm petrel (O. leucorhoa) (Hunt et al. 1981). Their distribution and abundance is controlled to a large extent by interrelationships between available food, location of adequate nesting sites, and physical oceanographic conditions.

Some 52 species of shorebirds occur in nearshore habitats along the Bering Sea coastline (Gill and Handel 1981). Of these species, 30 occur regularly in the eastern Bering Sea region and approximately ten inhabit the nearshore Bering Sea. During the summer and fall migratory periods the numbers of shorebirds present increases dramatically as numerous species move to or from their nesting grounds in the Arctic. Critical feeding habitats for shorebirds include the littoral zone (both vegetated and unvegetated) and the supralittoral area, which receives the influence of storm tides. Approximately eight species remain in the region for nesting, including semipalmated plover (Charadrius semipalmatus), black turnstone (Arenaria melanocephala), long-billed dowitcher

(*Limnodromus scolopaceus*), short-billed dowitcher (*L. griseus*), red phalarope (*Phalaropus fulicarius*), northern phalarope (*Lobipes lobatus*), semipalmated sandpiper (*Calidris pusilla*), and dunlin (*C. alpina*). The Yukon River delta represents the main shorebird nesting habitat within the Bering Sea region.

Several species of gulls (Laridae) frequent the coastal and island areas of the Bering Sea. Major breeding colonies of black- and red-legged kittiwakes occur on many of the islands of the Bering Sea.

Approximately 30 waterfowl species (swans, geese, and ducks) regularly occur in the region and 19 of these have significant percentages of their world population that depend on the region for nesting, feeding, or resting habitat (King and Dau 1981). Waterfowl begin to congregate in early April at the southern end of the Alaska Peninsula, especially within Izembek Lagoon. As ice recedes from lagoons farther north, these waterfowl move north along the coastline crossing the Bristol Bay region and eventually arriving in the area of the Yukon Delta. A large number remains in the Yukon Delta for nesting which typically begins in late May. North and south of this area, nesting activity by waterfowl declines.

Twenty-five marine mammal species are known to inhabit the Bering Sea and 19 of these regularly inhabit the shelf (Fay 1981). Species occurrence is seasonal. The majority of the western Arctic populations of bowhead (*Balaena mysticetus*) and beluga whales (*Delphinapterus leucas*), walrus (*Odobenus rosmarus*), and bearded (*Erignathus barbatus*), spotted (*Phoca largha*), and ribbon (*Phoca fasciata*) seals winter near the southern extent of the pack ice. Some polar bear (*Ursus maritimus*) and Arctic ringed seals (*Phoca hispida*) can also be found at this time. In summer, most of the populations of gray whales (*Eschrichtius robustus*) and northern fur seals (*Callorhinus ursinus*) frequent the shelf area. In addition, fin (*Balaenoptera physalus*), minke (*Balaenoptera acutorostrata*), humpback (*Megaptera novaeangliae*), and killer (*Orcinus orca*) whales and Dall (*Phocoenoides dalli*) and harbor (*Phocoena vomerina*) porpoises are distributed throughout the shelf during the summer. Sea otters (*Enhydra lutris*), sea lions (*Eumetopias jubata*), and harbor seals (*Phoca vitulina*) are year-round residents of the southern part of the shelf. All these species are predatory carnivores, consuming a large amount of the standing stocks of vertebrates and invertebrates. Their responses to environmental perturbations is largely unknown but it can be assumed that they are food limited. Any major damage to their food supply would undoubtedly have a negative effect on their numbers.

3.6 MONITORING INDICES AND APPROACHES

A series of scientists discussed state-of-the-art techniques for monitoring potential effects of oil and gas development in the marine environment.

3.6.1 Geochemical Indices

Oil and gas exploration activities may result in the introduction of hydrocarbon and trace metal contaminants into the Bering Sea ecosystem. In order to assess whether such inputs might affect the ecosystem, it will be necessary first to determine whether inputs of such contaminants occur in quantities sufficient to be detectable above natural background levels (see Section 3.7.2). Since natural variation may be large, only dramatic concentration increases can be reasonably interpreted as demonstrating a significant contaminant input. However, the elemental metal and hydrocarbon composition of contaminant inputs is generally significantly different than the characteristic composition of environmental samples that reflect natural hydrocarbon and trace metal sources. Therefore, the use of geochemical indices (ratios of elements and compounds, or indices dependent upon such ratios) can often permit detection of contaminant inputs at much lower levels than would measurements of a single element and single or total hydrocarbons. In addition, these indices can often be used to identify the sources of such contamination.

A recent report on the Beaufort Sea Monitoring Workshop (Houghton et al. 1984) listed geochemical indices that can be used to enhance detectability of petroleum hydrocarbons in the marine environment and summarized some of the factors that must be considered in sampling for such analyses. Since these indices and sampling considerations are also applicable to the Bering Sea, the appropriate material from Houghton et al. (1984) is reproduced here and updated with information gained in the first two years of the Beaufort Sea Monitoring Program (Boehm et al. 1985, 1986) and in presentations by T. Sauer (Battelle Ocean Sciences Center, this workshop).

The objectives of a hydrocarbon monitoring program should be (1) to determine if statistically significant increases in ecosystem concentrations of hydrocarbons occur in the environment, (2) to identify the sources of such increases, and (3) to delineate the geographical extent of the affected area (i.e., the extent of contaminant transport from its input location). This information would be utilized to decide whether more detailed biological monitoring studies should be instituted to determine impact on biota from the increased contaminant level.

Sampling sites for hydrocarbon monitoring should be located in areas where the biota may be exposed to waterborne hydrocarbons and where hydrocarbon residues may ultimately be transported. Extensive studies of the transport of spilled oil and hydrocarbon-contaminated effluents indicate that hydrocarbons introduced into the marine environment are primarily partitioned into the sediments within a short period of time, particularly where concentrations of suspended sediment are high (NAS 1975). Because the resulting water column hydrocarbon concentrations are very low and variable, monitoring of instantaneous hydrocarbon concentration in the water column is of little value except in the area of a major spill (NAS 1975). However, since hydrocarbons in the water column may be efficiently bioaccumulated, cumulative exposure to hydrocarbons in the water column can be monitored through analysis of indigenous demersal fishes (e.g., yellowfin sole), benthic organisms (e.g., caged mussels or other filter or suspension feeders), or via in-situ time-integrated samplers (e.g., hydrocarbon absorption tubes or filters through which large volumes of water are filtered over large time intervals).

Monitoring of hydrocarbons in sediments should be concentrated in offshore, low-energy areas where fine grained sediments are found and where hydrocarbons will tend to accumulate. Nearshore sediments will generally only be affected by hydrocarbon contaminants when spilled oil is allowed to reach the shore or when great quantities of oil are spilled and "tar mats" are formed. Analysis should be performed only on the upper layer of sediments and, if possible, on a layer no thicker than necessary to contain all of the inputs since the last sampling period. However, this is often impossible since the thickness of this layer is seldom known and will vary from sampling site to sampling site. Since the character of the sediments and factors such as bioturbation affect the availability of sedimented hydrocarbons, the exposure of demersal fishes and marine benthos to hydrocarbons should be assessed through analysis of hydrocarbon levels in organism tissues. Krahn et al. (1984) and Krahn et al. (1987) have identified a number of individual metabolites of aromatic compounds in the hydrolyzed bile of English sole (*Parophrys vetulus* from polluted sites in Puget Sound. Yellowfin sole *Limanda aspera*) and surface deposit feeders such as *Macoma* spp. may be good indicator species because of their wide distribution and relatively high abundance in the Bering Sea (Section 3.6.3).

A number of features of the behavior of oil and hydrocarbon compounds in marine environments must be borne in mind when monitoring the Bering Sea. First, the microbial degradation of oil will be slow in the Bering Sea and oil spilled under or trapped within annual ice will not weather significantly. Second, evaporation of oil released to the sea surface will be slow in the Bering Sea compared to temperate regions. This reduced rate of evaporation may prevent the loss of the more toxic volatile fraction from the oil before it is incorporated in the sediments. Therefore, sedimented oil may be more toxic in northern latitudes than in temperate areas. Finally, marine bivalves depurate oil very slowly, requiring one year to "near totally" depurate after an acute exposure and even longer after chronic oil exposure.

The stations selected for hydrocarbon monitoring in the Bering Sea should be established hierarchically. Regional or area-wide stations should be relatively few in number and should include those for which baseline data already exist and which are located in likely spill and depositional impact zones. Site-specific stations should be established and sampled as part of permit-compliance monitoring programs. They should be established radially around specific activity sites, such as rigs or gravel island construction sites, and should be monitored at least annually during the lifetime of the activity and any "recovery" period. In order to obtain the maximum information from the proposed sediment analysis program, sampling for chemical analysis should be coordinated both in time and in space with any samples taken to assess biological population structure and health. Baseline sediment hydrocarbon sampling should be conducted for 2 to 3 years prior to large-scale development activity. This would allow the development of a data base of sufficient size to perform statistical evaluations of parameter variability and determine necessary sampling frequency and replication levels in order to detect a change in conditions (Section 5.4.1.2). Depending on the baseline sampling results and the schedule of development activity, long-term sediment monitoring could be conducted every third year. This schedule would present a compromise between the costs of monitoring and the need for useful information.

Compositional analysis is expensive and time consuming, thus limiting the number of samples that can reasonably be analyzed in the BSMP. UV fluorescence can be used in certain circumstances as a low cost screening measure in place of gas chromatography/mass spectrometry. UV fluorescence will be most useful in site-specific monitoring or in studies of spills where petroleum concentrations may substantially exceed background values. In the Beaufort Sea Monitoring Program, it was found that sediments had a high background UV fluorescence that limited the sensitivity of the method such that contamination of sediments by low levels of petroleum hydrocarbons could not be detected (Boehm et al. 1985). However, biota in the Beaufort Sea did not exhibit high background fluorescence. While UV fluorescence measurements can provide an inexpensive assessment of hydrocarbon concentrations and petroleum contamination, they do not provide significant information concerning the nature or possible source of the hydrocarbons.

Compositional data can be used to investigate changes in hydrocarbon levels and to determine the origin of the hydrocarbons through a number of indicator compounds and parameters and several geochemical indices. Those indicators that are most useful for monitoring changes in hydrocarbon concentration are listed in Tables 3-5 and 3-6, and those that are most useful in identifying the source of the hydrocarbons are listed in Tables 3-7 and 3-8.

In addition to hydrocarbon compositional analyses, the BSMP should also consider analyses of lignin concentrations and composition in sediments (T. Sauer, Battelle Ocean Sciences Center, this workshop). Lignosulfonate is a major additive to the water-based drilling muds used exclusively in the U.S. exploratory operations. For a single exploratory well, between 100 and 200 metric tons of drilling mud might be used, and 50 to 80 percent of this amount may be discharged to the ocean during or after drilling (Neff 1984). Lignosulfonates are polymers derived from the lignin of wood and are detected in marine sediments by oxidation followed by gas chromatographic determination of the component phenolic monomers. Naturally-occurring lignins in marine sediments are oxidized in this process and phenolic monomers from this oxidation are identical to those from the lignosulfonates. However, the ratio of different phenolic monomer components (p-hydroxyl phenols, vanillyl phenols, syringyl phenols, and cinnamyl phenols) may be used to isolate the contribution of lignosulfonate to the total lignin-derived phenols since lignosulfonate has a substantially different composition than natural lignins in marine sediments (Requejo and Boehm 1985).

TABLE 3-5

SATURATED HYDROCARBON QUANTITATIVE PARAMETERS (GC/FID) USED TO TEST NULL HYPOTHESES RELATED TO HYDROCARBON CONCENTRATION CHANGES (From Boehm et al., 1986)

Parameter	Significance
1. Total n-alkanes (TALK)	Quantifies n-alkanes from n-C_{10} to n-C_{34}. This total is directly related to the fineness of the sediment and, hence, to the total organic carbon content.
2. n-alkanes C_{10}-C_{20} (LALK)	Crude petroleum contains abundant amounts of n-alkanes in this boiling range; unpolluted samples are very low in many of these alkanes.
3. Phytane	This isoprenoid alkane is low in abundance in unpolluted sediment; crude oil contains significant quantities of phytane.

TABLE 3-6

PAH QUANTITATIVE PARAMETERS (GC/MS) USED TO TEST NULL HYPOTHESES RELATED TO HYDROCARBON CONCENTRATION CHANGES (From Boehm et al., 1986)

Parameter	Significance
1. Total Polycyclic Aromatic Hydrocarbons (PAH)	The sum of 2-5 ringed aromatics is a good quantitative indicator of petrogenic addition if statistical limits are determined. The sum of 2-3 ringed PAH is a better indicator since these components are more prevalent in oil.
2. Individual PAH and PAH homologous series (i.e., naphthalenes, phenanthrenes and dibenzothiophenes)	Individual PAH compounds may be quantitatively less variable than the total PAH parameter. Also, several individual marker compounds (e.g., the alkylated dibenzothiophenes) may be extremely sensitive monitoring parameters.

TABLE 3-7

SATURATED HYDROCARBON PARAMETER SOURCE RATIOS (GC/FID) USED TO TEST NULL HYPOTHESES RELATED TO SOURCES OF HYDROCARBONS

(From Boehm et al., 1986)

Parameter	Significance
1. LALK/TALK	This ratio has been applied to monitoring studies to indicate the relative abundance of C_{10}-C_{20} alkanes characteristic of light crude and refined oils, over the total alkanes which are diluted by terrigenous plant waxes.
2. Isoprenoid Alkane/Straight Chain Alkane Ratio	This parameter ratio measures the relative abundance of branched, isoprenoid alkanes to straight chain alkanes in the same boiling range. This ratio is a useful indicator of the extent of biodegradation and a source indicator as well.
3. Pristane/Phytane Ratio	The source of phytane is mainly petroleum, while pristane is derived from both biological matter and oil. In "clean" samples, this ratio is very high and decreases as oil is added.
4. TOT/Total Organic Carbon (TOC)	The ratio of total saturated hydrocarbons (TOT) to TOC, or n-alkanes (a subset of the saturated hydrocarbons) to TOC has been used to monitor oil inputs. In sediments receiving "normal" pollutant inputs within a given region, a specific TOT/TOC or n-alkanes/TOC ratio is characteristic of the "geochemical province". TOC, n-alkanes, and other pollutants are associated with finer particles (i.e., high silt/clay content). Small (tens of ppm) additions of petroleum to the sediment cause the ratio to increase dramatically, since n-alkanes (ug/g) increase and TOC (mg/g) does not.
5. OEPI (odd-even carbon preference index)	Oil lowers the OEPI value. OEPI values in areas of low hydrocarbon content have been used as an effective monitor of oil additions.

TABLE 3-8

PAH SOURCE PARAMETERS (GC/MS) USED TO TEST NULL HYPOTHESES RELATED TO SOURCES OF HYDROCARBONS

(From Boehm et al., 1986)

Parameter	Significance
1. Fossil Fuel Pollution Index (FFPI)[a]	Pyrogenic or combustion-derived assemblages are relatively more enriched in 3-5 ringed PAH compounds; fossil fuels are highly enriched in 2-3 ringed PAH and polynuclear organosulfur compounds (e.g., dibenzothiophene and its alkyl homologues). This ratio is designed to determine the approximate percentage of fossil fuel to total PAH.
2. Alkyl Homologue Distribution	Used to assess the importance of fossil fuel and combustion PAH sources.
3. Specific PAH Ratios	For example, the ratio of phenanthrenes to dibenzothiophenes appears to be related to specific sources of PAH (and others).
4. PAH/TOC	Analogous to total hydrocarbon/TOC ratio.

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[a] $$\text{FFPI} = \frac{N + P + F + DBT}{\text{Total PAH}} \times 100$$

$= 100$ for fossil PAH (oil, coal)

$= 0$ for combustion PAH

where:

$N = C_oN + C_1N + C_2N + C_3N + C_4N$ (naphthalenes)

$P = C_oP + C_1P + C_2P + C_3P + C_4P$ (phenanthrenes)

$F = C_oF + C_1F + C_2F + C_3F$ (fluorenes)

$D = C_oD + C_1D + C_2D + C_3D$ (dibenzothiophenes)

Total PAH = N + P + F + D + Fluoranthene + Pyrene + Benzo(a) anthracene + Chrysene + Benzofluoranthene + Benzo(a)pyrene + Benzo(e)pyrene + Perylene

Lignosulfonates are not known to be toxic in the environment, but they may be used as tracers for the environmental fate of drilling muds. Since the lignosulfonates are contained in the less dense fraction of the drilling mud solids, they may be more suitable than barium for tracing the transportable fraction of these muds. Barium is associated with the dense fraction of the muds and is useful as a tracer of this less-readily transported fraction. After any unplanned release, petroleum hydrocarbons sorbed on suspended sediments would be predominantly transported in a less dense fraction. Therefore, lignosulfonate accumulation in sediments would be a better predictor of potential petroleum hydrocarbon contamination than barium accumulation.

The sensitivity of the method for detecting lignosulfonate input to marine sediments depends on a variety of factors, including the composition and variability of natural lignins in different regions of the ocean. However, Requejo and Boehm (1985) estimated that the technique should be able to detect 1 percent or less of lignosulfonate in the sediments. Since this conclusion was reached by these authors based on the relatively high background lignin composition of sediments in both the Beaufort Sea and Norton Sound, the method may achieve this sensitivity or better in the Bering Sea. This indicates that lignosulfonates should be approximately as sensitive as (and, possibly, better than) barium in tracing drilling mud interactions. A more precise estimate of the sensitivity of the lignosulfonate technique for tracing drilling muds in the Bering Sea would require better background lignosulfonate data for the study area. Therefore, lignosulfonate measurements were recommended for sediments collected in site-specific studies in exploratory areas, and may also be useful at regional stations in the Bering Sea, particularly if the sensitivity of the technique in continental slope sediments of the central Bering is substantially better than 1 percent. Sauer recommended that lignin analysis should be performed at all regional sediment sampling stations during the first year's sampling, and additional sampling should be contingent on these results.

3.6.2 Microbial Indices

Monitoring of microbial indices can be useful due to the important role that microbes play in nutrient cycling, their responsiveness to inputs of hydrocarbons, and their predictive ability for determining hydrocarbon persistence. There is some background information on microbial populations in areas of potential lease sale activity in the Bering Sea. Conclusions that can be drawn from this information are that both the rate of hydrocarbon degradation and the numbers of hydrocarbon degrading bacteria are very low. These findings are typical for a pristine area.

R. Atlas (University of Louisville, this workshop; see also Houghton et al. 1984) briefly described the existing techniques and indices for microbial monitoring and also touched on state-of-the-art developments. Potential microbial indices that have been or are currently in use include measurements of microbial biomass, population characteristics of hydrocarbon degrading microbes, measurements of microbial activity, and microbial community diversity analyses.

Measurements of microbial biomass indicate the biomass available for detrital food webs through secondary production of carbon. Microbes stressed with low molecular weight hydrocarbons have been shown to produce increased amounts of CO_2 at the expense of secondary production. Microbial biomass is easily measured using several available methods. Its major limitation as a monitoring index is that it responds only to major disturbances and not to specific small stresses. It is also impossible to distinguish between changes due to natural or petroleum related events from measurements of microbial biomass.

Hydrocarbon degrading microbes are sensitive to biologically detectable levels of hydrocarbons and are easily measured with several existing techniques. These microbes can be used as indicator populations that increase or decrease in numbers in response to specific hydrocarbon inputs. These populations will return to background levels fairly rapidly after a specific input of hydrocarbons. Major limitations include the need for live organisms (i.e., samples cannot be preserved) and the fact that this index could not be used to pinpoint the source of hydrocarbon.

Microbial activity measurements look at the rate of secondary productivity. Extensive background information has been developed in this area through OCSEAP-related studies. By measuring the rate of hydrocarbon degradation, an estimate of environmental persistence can be developed.

Microbial community diversity analyses can be carried out using the same types of parameters established for benthic invertebrate communities. Previous studies have shown that such parameters of microbial populations are strong indicators of environmental stresses. Biochemical analyses that determine the lipids present in a sample can precisely determine microbial community composition. Disadvantages include the fact that these analyses are very costly and time consuming, they require live organisms, there is no background information for the Bering Sea, and the results do not indicate a source of any observed changes.

Two very recently developed, state-of-the-art approaches to microbial monitoring allow an analysis of population and community parameters at the genetic level and are sensitive indicators of the presence of hydrocarbon degrading bacteria. The two methods, genetic diversity measurements and gene probes, involve the extraction of DNA from a water sample, the subsequent breakdown of the DNA into smaller units, and finally, an analysis of patterns of reannealing or resuming the double strand configuration. With the genetic diversity method, the length of time required to reanneal is directly related to sample diversity. A sample from a stressed community with relatively few species would reanneal more rapidly than a sample from a diverse, unstressed community. With the gene probe method, the sample is spiked with a labeled gene prior to the reannealing point. The amount of binding with the labeled probe indicates the abundance of a specific type of microbe in the natural population.

The potentially greatest advantage of these two approaches is that they will probably be fully automated in the near future and thus allow relatively inexpensive monitoring from any stable platform in the Bering Sea. However, these methods have not yet been adequately tested in the marine environment. Their continuing development and applicability to the Bering Sea should be periodically evaluated for potential future inclusion in the BSMP.

3.6.3 Biological Indices

3.6.3.1 Biological Community Studies, Sublethal Effects Studies

As discussed in Section 3.2, adverse impacts of OCS oil and gas development activities are most likely to occur first and persist longest in the benthic environment near and downcurrent from development platforms. Impacts to community structure include elimination of sensitive species and changes in species abundance, diversity, composition, and dominance. Sublethal effects may include impaired health and vitality of surviving resident fauna and bioaccumulation of contaminants. Monitoring for environmental effects caused by oil and gas development activity in the Bering Sea might include study of any changes in benthic faunal communities (including demersal fish) caused by inputs to the sediments.

J. Neff (Battelle Ocean Sciences Center) described several approaches to the monitoring of biological populations for contaminant-induced effects (Table 3-9). These methods may be considered in three categories: population structure studies, sublethal effect studies, and sublethal effect studies on sentinel organisms. Population structure studies generally try to identify changes in species composition that may be caused by the combination of a variety of lethal or sublethal effects on one or more sensitive species and/or by changes in the physical or chemical environment that may favor the growth of one or more opportunistic species. In contrast, sublethal effect studies generally aim to identify morphological, physiological, biochemical, or behavioral changes in individual organisms or species.

Population structure studies are performed through field studies on biotic communities. Usually the benthic infauna are sampled, but other communities such as plankton and epibenthos, can be used. Members of the community are counted and identified; changes are assessed by comparison with reference communities or with samples taken at the station at an earlier time. Because simple comparison of species lists and abundances from sample to sample is usually not informative and always difficult to interpret, population structure data must be reduced into some form of population index. Many such indices have been used including diversity, rarefaction methods, dominance-diversity curves, log-normal distribution, changes in size class distribution, and multivariate techniques (e.g., numerical classification, ordination, discriminant analysis, multiple regression, and canonical correlation).

While one or more of these methods may be promising for application in the BSMP, they all suffer from the same major problem. That problem

TABLE 3-9

BIOLOGICAL MEASUREMENTS TO ASSESS DAMAGE TO OR RECOVERY OF MARINE ECOSYSTEMS[a]

Measurement Type	Description
Ecosystem effects	Diversity indices Rarefaction method Dominance-diversity curves Log-normal distribution of individuals among species Changes in size class distribution of populations Multivariate techniques; e.g., numerical classification, ordination, discriminate analysis, multiple regression and canonical correlation
Morphological effects	Skeletal deformities Diseases, including cancer Histopathology
Physiological effects	Respiration, osmoregulation Scope for growth O:N ratio Hematology Reproduction and growth
Biochemical effects	Activity of toxification/detoxification systems Blood enzymes Tissue biochemicals

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[a] Source: Neff, this workshop.

is that natural marine communities, particularly those in coastal waters, exhibit a high degree of small-scale spatial and/or temporal variability, the causes of which are poorly understood. As a result, population structure investigations often produce ambiguous or uninterpretable results. It is seldom possible to separate changes due to natural causes from those due to chronic, or even acute, pollutant inputs. This is particularly true when the pollutant-induced changes are subtle, as would be expected in the Bering Sea beyond the nearfield surrounding a specific development, unless a major spill event occurred. This drawback to population structure monitoring may be particularly severe in the Bering where the abundance, species composition, and distribution of the benthic fauna are mediated by such highly variable factors as ice scour (littoral only), storm wave action (less than 60 meters), salinity fluctuations, and sediment type and distribution.

Any population structure monitoring program for the Bering Sea should be designed to minimize the problems associated with environmental variability. Such a program should: (1) concentrate on the benthic infauna, (2) take a sufficient number of replicate samples, (3) perform careful matching of sediment physical type to community data, and (4) sample along pollution gradients near the point source discharges. This last requirement suggests that benthic infaunal population structure monitoring may be more appropriate for compliance monitoring than for the proposed regional program.

Neff introduced two approaches to benthic infaunal monitoring that may be useful. First, if sufficiently fine screens are used to separate the biota from the sediments, early life stages of the infauna may be sampled. Such sampling would facilitate size/age structural analysis which might be useful if, as reported, the early life stages are more sensitive to pollution impacts. Second, an innovative sediment profile imaging systems (Rhoads and Germano 1982, Germano 1983) may offer substantial cost savings and the ability to obtain distributional data on a greater number of samples, which would thus improve the detectability of statistical differences between stations. This system provides an image of the sediment column (which may include depths below the redox potential discontinuity) and permits documentation of in-situ community relationships, although many species (particularly smaller organisms) may not be identifiable.

Because of the severe limitations of population structure studies, recent efforts have been directed more toward the development of techniques for measuring the sublethal effects of pollutants on individual organisms or species. These techniques attempt to quantify one or more morphological, physiological, biochemical, or behavior measures of an organism and to relate changes in these indicator characteristics to pollutant inputs. Many biochemical and physiological processes in marine animals are known to be sensitive to pollutant-mediated alterations. Nevertheless, many such responses are of no utility in assessing pollutant damage to the Bering Sea marine ecosystem, since there is insufficient basic biological information available about the Bering Sea species and/or about the relevant physiological/biochemical processes. Thus, any measured response, could in many cases, just as likely be due to nonpollutant stress. Even when a biochemical or physiological response is clearly linked to the presence of pollutants, the significance of the response to the long-term health of the affected community is usually obscure. The types of sublethal response that can be monitored are briefly summarized in Table 3-9.

A number of biochemical changes have been evaluated for diagnosing pollutant stress in teleost fish. These are summarized in Tables 3-10 and 3-11. Because fish regulate their internal biochemical composition and metabolism much more precisely than most invertebrates, attempts to apply these same biochemical parameters to benthic invertebrates are generally unsuccessful.

Generally, monitoring of fish populations for pollutant stress is most effectively performed by studying a number of different morphological, biochemical, and physiological changes simultaneously. Fish exposed to pollutants, including petroleum, may respond with a variety of simultaneous changes, including increased disease incidence, and a variety of histopathological and biochemical changes. Unfortunately, many species of fish are migratory and, therefore, are not suitable to use in determining the effects of pollution, since it cannot be determined where the organism became exposed. However, several species of demersal fish appear to make only limited migrations and have been shown to be good indicators of pollutant effects at a given site. For example, Krahn et al. (1986) found a significant correlation between the occurrence of hepatic lesions and the concentration of metabolites of aromatic compounds in English sole (Parophrys vetulus) from Puget Sound. In the Bering Sea, pollock and yellowfin sole were suggested as suitable bioindicator species because of their abundance and generally demersal life style.

Another group of organisms that could be monitored for sublethal stress is the benthic ampeliscid amphipods. These amphipods have been shown to be moderately sensitive to acute or chronic exposure to oil, but relatively insensitive to drilling fluids. Ampeliscid amphipods are abundant in Bering Sea coastal and nearshore waters in the vicinity of the Bering Strait (Section 3.5.2), and may be appropriate to monitor for seasonal patterns of abundance and distribution, size/age structure of the population, reproductive cycles and fecundity, and sublethal stress through length/weight regression, bioenergetics, and digestive enzyme activity depression. However, the natural variations in the life history, distribution, and biological condition of these animals would need to be better understood before monitoring data could be interpreted to establish causal links between any observed changes and oil and gas activities.

Neff reaffirmed that the use of sublethal effect studies with sentinel organism programs, such as the National Mussel Watch Program, may be highly beneficial to a monitoring program, particularly when the sentinel organisms are caged and possess a known and controlled gene pool and life history. Several biological parameters show promise for measuring stress in mussels including: measures of bioenergetic balance

TABLE 3-10

POTENTIAL BIOCHEMICAL INDICATORS OF FISH EXPOSURE TO POLLUTION[a]

Parameter	Expected Response	Environmental Interpretation
Metallothioneins	Induction	Exposure to Cd, Cu, Hg, Zn
Mixed function oxydases	Induction	Exposure to petroleum, PCB, dioxin, PAH
Blood enzymes erythrocyte	Increased activity	Liver damage
ALADase	Decreased activity	Lead poisoning
Tissue enzymes	Change in activity	Unknown for most enzymes
Gill ATPases	Change in activity	Impaired osmoregulation
ACHEase	Decreased activity	Exposure to organophosphate or organochlorine pesticides or some industrial chemicals
Blood biochemicals	Change in concentration	Acute pollutant stress
Tissue biochemicals	Change in concentration or tissue distribution	Chronic pollutant stress

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[a] Source: Neff, this workshop.

TABLE 3-11

USE OF FISH TISSUE BIOCHEMICALS TO DIAGNOSE POLLUTANT STRESS[a]

Biochemical	Tissue	Response	Clinical Significance
Glycogen	Liver, muscle, brain, kidney	Increase or Decrease	Acute stress, liver damage, chronic stress, starvation
Protein	Liver	Decrease	Depressed protein synthesis liver, liver hypertrophy
Total lipids, and specific classes	Liver	Increase Decrease	Fatty infiltration of liver, Altered lipid metabolism
Lactic acid	Liver, muscle	Increase	Acute stress, tissue hypoxi, muscle exhaustion
Sialic acid	Gill	Decrease	Mucus hypersecretion, irritation
Glutathione	Liver, kidney	Increase	Pollutant detoxification
Ascorbic acid	Liver, kidney, gill, brain	Increase or Decrease	Mobilization and redistribution for tissue repair and detoxification, chronic stress
Collagen	Bones, connective tissue	Decrease	Ascorbate
Catecholamines	Brain	Decrease	Acute or chronic stress

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[a] Source: Neff, this workshop.

and energy partitioning, such as scope for growth, ratio of oxygen consumed to nitrogen excreted, growth efficiency, growth rate, condition index, biochemical composition; and histological and cytochemical changes, including mutation. One major advantage of caged sentinel organism experiments is that these biological tests can be used in conjunction with measurements of body burdens of specific contaminants to provide information concerning the pollutant load/biological response relationship.

Neff suggested an appropriate Bering Sea monitoring program might include:

- Ecological analysis of benthic community characteristics along pollution gradients (age/size structure and reproduction/ recruitment of dominant benthic species, sediment profile imaging).
- Chronic sublethal effects studies:
  - Biochemical and histopathologic condition of demersal fish (liver/muscle glycogen; liver/skin ascorbate; liver glutathione; brain catecholamines; histopathology of gill, liver, gastrointestinal tract, skin; fin erosion; parasitic diseases; condition indices), and
  - Indicator organisms, such as benthic epibenthic amphipods, with studies on seasonal abundance patterns, distribution, reproduction, size/age structure of populations, length/ weight regression, O/N ratio, and digestive enzyme activity.

3.6.3.2 Recent Trends In Community Analyses

J. Word (Battelle NW) discussed recent trends in benthic community analyses. In the conduct of environmental damage assessments, there are four categories that need to be considered: the strength of the effect, the effect's areal coverage, passage of effects from one trophic level to the next ("chaining of effects") and recovery rates.

The strength of the effect has been investigated recently using behavioral reactions of organisms, bioassay testing, and screening level concentration determinations. Examples of behavioral studies include the effects on salmon chemoreception from the presence of different concentrations of petroleum hydrocarbons in water and the effect on commercial rockfish catch per unit effort from seismic exploration activities.

Recent observations of sediment bioassays have shown that if sediments are disturbed, a toxic effect is often present which may be absent if the sediments are allowed to settle prior to exposing the animal. The concentration of a toxicant, such as DDT, that is present in the pore water in equilibrium with the organic carbon is what determines the acute toxicity of sediments to the test organism. Thus, the practice of combining several replicates of sediment, mixing and agitating the sediments with additional water of physicochemical conditions different from that in the pore water, then conducting bioassay tests often leads to a toxic effect being observed which may not be present with undisturbed sediment. In-situ sediment assays may prove to be a much more accurate method of determining sediment toxicity.

The areal extent of the effect is important in determining whether the effect is occurring at the level of individual organisms or on populations of organisms. For example, the distribution of pelagic fish eggs is variable and poorly known in areas such as the Bering Sea. If a toxicant on the water surface comes into contact with pelagic eggs, the results could be devastating to the population of fish that produced these eggs if the eggs are concentrated within the area of impact. Alternatively, if the eggs are widely dispersed, little impact on the population may occur due to the effect of a slick of limited area.

Chaining of effects from one trophic level to the next may occur and the study of such effects can provide insight into the pathway of contaminant movement from the sediments or water column into higher order consumers. For example, an analysis of the feeding habits of important commercial organisms, such as tanner and king crabs, may reveal a link between sediment contaminants, crab prey items, and observed contaminant levels in the crabs. Bioaccumulation studies are being pursued by a great number of investigators. However, many questions still remain concerning causal links that may exist between observed sediment contaminant concentrations, observed concentrations in animal tissue, and tissue, organ, or organism abnormalities.

Estimation of recovery rates is difficult because the experimental studies needed to determine these rates are often difficult to carry out. Word reported that Battelle Northwest has recently conducted an investigation of the recovery of oiled sediments at a protected sand and mud shoreline in western Washington that was the site of an oil spill. The hydrocarbon concentrations that remained in the sediments after cleanup activities were similar to the concentrations present in earlier experimental studies of in-situ rates of oil depuration and infaunal recolonization. As a result, fairly detailed predictions of recovery times for these characteristics were made from the experimental results. The rate of other recovery processes, such as the redevelopment of sediment armoring, remain poorly known. The amount of time required for the gluing together of particles into a shield or mat that resists resuspension is difficult to determine and is poorly understood.

3.7 WORKSHOP SYNTHESIS SESSION

The second day of the workshop was devoted to a discussion of the need to monitor when no statistically significant changes are expected. The geographic scales appropriate for monitoring in the Bering Sea and the optimum monitoring approaches to test several hypotheses of impact were also considered.

3.7.1 Monitoring Program Management Goals

A discussion of the management goals of ocean monitoring programs by D. Wolfe (NOAA) in relation to the Beaufort Sea was reported in Houghton et al. (1984). This discussion is equally applicable to the Bering Sea and is largely repeated here to help summarize aspects that were also discussed in the Bering Sea workshop. Wolfe discussed the concept of ocean monitoring in the context of its significance for valued ecosytem components (VECs) and implications for the management of OCS lands. His premise was that monitoring is, in essence, a management tool or part of a management system for OCS oil and gas development activity and the affected environment. The following questions should guide the manager in developing a framework for monitoring.

- What important OCS oil and gas development related effects do we wish to avoid?
- How can we avoid them?
- What monitoring, measurement, or research program is required or useful to determine if we have successfully avoided these effects?

To respond to these questions it is necessary first to establish which components of the ecosystem are important in our perception of quality of the environment. Components of concern are typically human health and VECs (e.g., fish, marine mammals, birds, commercial or subsistence species). Second, the manner in which the ecosystem functions to support and sustain the VECs must be understood; then causal mechanisms through which OCS activities may affect VECs must be postulated. The question of how well the potential causal mechanisms are understood and the likelihood of their acting in such a fashion as to measurably affect the VECs must also be addressed. Potential causal mechanisms in the Bering Sea include such things as contaminant exposure (hydrocarbons, metals), disturbance effects (noise, activities), and oil spills (Section 3.2).

The manager then must go back to the question, If the system works as we think it does, how can we avoid the postulated effects of concern? Management of activities is typically based on two hypotheses:

- Regulatory stipulations, discharge and receiving water criteria, etc. will prevent significant near-field effects (i.e., outside of a mixing zone or direct impact zone).
- If effects cannot be detected in the near field, they probably won't be detectable in the far field.

These management hypotheses lead to two kinds of monitoring:

- Compliance monitoring - for example, inspection or measurement of construction or drilling activities and discharges - to ensure that the activity is conducted as prescribed.
- Near-field surveillance monitoring - for example, measurement of water, sediment, or benthos contamination outside the mixing zone - to verify that effects of concern do not occur if stipulations and/or discharge criteria are met.

In practice, near-field surveillance monitoring has a reasonably high probability of detecting effects. If effects are detected, then diagnostic studies may be warranted to establish the specific pollutant or activity causing the effect in question. If the effects are of sufficient concern, then management may opt to alter stipulations/criteria for future similar activities.

A third type of monitoring program (that which was the primary focus of this workshop) is required where there are concerns for broad-scale changes in the health or numbers of important populations. A major problem with such far-field monitoring programs is that cause-effect relationships may be very hard to establish; thus, it may be very hard to use the knowledge that an impact has occurred to make management decisions alleviating the cause. Nonetheless, some potential effects may be so important that managers would want to know about them even if they cannot pinpoint the cause.

In designing and funding any monitoring program, it is important to identify potential effects that require further study. Ecological processes must be explored to refine our ability to assess changes, their significance, and their causes.

In summary, Wolfe (In Houghton et al. 1984) emphasized that:

- Criteria for variable selection should include:
  - Value placed on the resource,
  - Credibility of a hypothesized impact mechanism (perceived risk to the resource), and
  - Testability of the hypothesis of impact in terms of statistical strength and expected cost of measurements required.
- Far-field surveillance monitoring might consist mainly of a closely coordinated suite of near-field monitoring programs tied to specific development activities (would require a consistent approach to sample design, methodology, analysis, and reporting).
- Monitoring must be adaptable to react to changes in OCS development direction and to changes indicated by previous results obtained.
- Managers and scientists must ask "Do we understand the system well enough to suggest that OCS activity is likely to cause a major change in that variable in a way that can be ascribed to oil and gas development?"

This management perspective of monitoring was widely discussed and generally adopted by the Bering Sea Monitoring Program Workshop. Specific discussions are chronicled in the following sections.

3.7.2 General Workshop Discussions

The philosophical question of the need to monitor where conventional logic suggests that there will be no detectable far-field impacts from OCS oil & gas development was discussed at length. C. Cowles (MMS) noted that MMS is not obligated to monitor if conclusive evidence is available to show that planned OCS activities, based on existing scenarios (Section 3.2) and given the known natural variability in the environment and in sampling and analysis techniques, couldn't possibly cause detectable changes in parameters in the "far field"; i.e., in areas beyond the detectable influence of single activities. Supporting the premise that detection of far-field changes is unlikely, J. Ray (Shell Oil Company) reiterated that, in the North Sea development area, the footprint of drilling activity from a given rig is detectable for no more than about 4 km. Davies et al. (1984) conducted chemical analyses of sediments around North Sea platforms and showed that hydrocarbon concentrations decreased rapidly with increasing distance from the platform, approaching background concentrations around 3 km. J. Hastings (EPA) said that EPA attempts to define the maximum acceptable zone of impact in activity-specific discharge permits, implying that, even if effects are detectable beyond these limits, they are not of significance.

To place in perspective the potential detectability of one of the major discharges from offshore petroleum development, several authors (e.g., Houghton et al. 1981; E. Crecelius, reported in this workshop) have analysed potential "worst case" dispersion and deposition models for metals in drilling fluids. To examine the case of the North Aleutian Basin development scenario, the following approach was taken:

The amount of drilling fluids expected to be discharged from each well was multiplied by the projected number of wells and the fraction of drilling fluid weight comprised of barium and chromium, generally accepted as the best indicators of presence of drilling fluid deposition (Table 3-12). These total amounts of released metals were then assumed to be transported to, and deposited in, various sized depositional areas. If all of the barium were deposited in an area 100 by 100 km (10,000 square km) and evenly mixed into the top 5 cm of sediment, the resulting concentration increment would be 153 mg/kg, compared to a presumed background concentration of about 500 mg/kg (see Chapter 4.2 for reservations about this number). Given the state of the existing baseline data (Chapter 4.2), this increment would likely not be measurable. However, with a carefully controlled baseline, such as this document recommends for the Bering Sea (Section 5), this increment may be detectable. If the size of the hypothetical depositional area were 100,000 square km (which may be more realistic, given the scale and dispersive characteristics of the Bering Sea), the increment would be only 15 mg/kg and would be undetectable.

In the case of chromium, the increment for even a 10,000 square km deposition area is about 0.5 mg/kg which would be completely undetectable against a background of some 64 +/- 21 mg/kg (Table 3-12).

Given the conservatism of the above approach and despite the additional potential for metals additions from discharges of produced waters, it seems unlikely, but not completely out of the question, that a well-placed far-field station would detect changes in barium concentration. If similar transport and deposition mechanisms are (somewhat implausibly) postulated for hydrocarbons from chronic low level discharges of produced water and from other sources, there should be a somewhat greater potential to detect a change. This is due to the much lower background levels of hydrocarbons in Bering Sea sediments and the resulting greater signal-to-noise-ratio (D. Segar, SEAMOcean, this workshop).

TABLE 3-12

BERING SEA MONITORING PROGRAM
WORST CASE SCENARIO FOR METALS ACCUMULATION FROM DRILLING FLUIDS

Assumptions		Area of Deposition(KM^2)	
		10,000	100,000
Maximum area development (wells)	250		
Average drilling fluid weight per well (metric tons)	1000[a]		
Total drilling fluid release (metric tons)	250000		
Average composition of barium (% by weight)	49.00%[b]		
Average composition of chromium (% by weight)	0.16%[b]		
Total quantity released - Ba (metric tons)	122500		
Total quantity released - Cr (metric tons)	387.93		
Barium background in surficial sediments (mg/kg/ dry)	500[c]		
Chromium background in surficial sediments (mg/kg/ dry)	64 ±/1 21[d]		
Assumed weight of sediment (top 5cm) (kg/m^2)	80		
Incremental addition of Ba (mg/kg) (assumes complete mixing in the top 5cm)		153.13	15.31
Incremental addition of Cr (mg/kg) (assumes complete mixing in the top 5cm)		0.49	0.05

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[a] E. Crecelius, Battelle, this workshop.
[b] Houghton, et al. 1981.
[c] See Section 4.2.
[d] Burrell et al. 1981.

The next question is: what is the significance of these changes, should they occur? In the case of barium, increases of 30 percent in the natural background levels would certainly have no significant biological effect. Increased sediment hydrocarbon levels are potentially of greater significance because of the potential for bioaccumulation of known or suspected carcinogenic compounds (e.g., Malins et al. 1980, 1982) and the immense resource value of Bering Sea benthic and demersal fish and shellfish stocks (M. Hayes, this workshop).

It was pointed out by D. Schell (University of Alaska, this workshop) and others that these resources are so economically and politically important that no other justification is needed for some sort of monitoring of OCS development activities even if the likelihood of detecting any change is vanishingly small. This sort of monitoring would still be required (given that significant development occurs), if only to demonstrate that there is, in fact, no detectable impact traceable to the development. J. Houghton (Dames & Moore) observed (based on the earlier presentation of M. Hayes) that many fish stocks in the Bering Sea are highly variable with numerous examples of major declines in stocks over the last several decades, some with and some without corresponding increases in fishing pressure. Houghton reasoned that some form of broad scale monitoring program might be a valuable "insurance policy" to protect MMS and the oil industry against false assumptions or claims of responsibility for future declines which could well coincide with, but be unrelated to, oil and gas development.

Discussion then moved on to the question of what was an appropriate geographic scale for the BSMP, given the present low level of industry interest in lease areas where exploration has occurred. The dilemma is that scientifically, there are several good reasons to have region-wide baseline data, while realistically, there is little potential for region-wide impacts if development occurs only in one of the lease areas. A compromise suggested by C. Cowles (MMS) was to set up a region-wide monitoring network to be sampled in the event that development becomes more likely (than at present) in more than one lease area. In addition, a more localized, "sale-specific" monitoring network should be established with the flexibility to be modified for each lease area when activity in that lease area is imminent.

In establishing either scale of program, D. Wolfe (NOAA) cautioned that the location of stations in the vastness of the Bering Sea should take account of the likely location of contaminant sources and the physical transport and depositional processes that will govern the fate of these releases. It was also pointed out (J. Houghton, Dames & Moore) that there might be a dichotomy in priorities for station selection: some stations may be selected primarily because of their potential as an ultimate sink for sediment-associated contaminants while others are selected because of an abundance of potential biological receptors. General considerations describing desired station criteria are shown in Table 3-13.

TABLE 3-13

BSMP STATION SELECTION CONSIDERATIONS

DEPOSITIONAL AREAS FOR ANTICIPATED SOURCES

- Eddies/canyons
- Outer shelf/shelf edge
- Middle shelf

HIGH RESOURCE VALUES

- Bristol Bay
- Island vicinities (Pribilofs, St. Lawrence, St. Matthew, Nunivak)
- Port Moller
- Unimak Pass

EXISTING DATA OR SAMPLING PROGRAMS

3.7.3 Proposed Hypotheses and Approaches

Prior to the workshop, Dames & Moore and MMS established a list of four sets of testable hypotheses related to potential impacts of OCS oil and gas development. The form and wording of the hypotheses were patterned after those adopted for the Beaufort Sea Monitoring Program (Houghton et al. 1984). The rationale behind and methods for testing of each of these was examined by the workshop in some detail. For each set of hypotheses, the following questions were asked:

WHY? - Why monitor this aspect of the environment; how does it fit in with management priorities?
WHAT?- What are the appropriate parameters to be measured to test the hypothesis?
HOW?- How should these parameters be measured?
WHERE?- Where should sampling occur?
WHEN? - What is the optimum time and frequency for monitoring?

Of the components (sets of hypotheses) discussed, three were accepted by the workshop as appropriate for inclusion in the BSMP; discussions concerning these are presented in the following sections. The fourth was rejected as inappropriate for this program (Section 3.7.4). Several other essential features of a successful ocean monitoring program were covered or alluded to in the course of the workshop and are included in Section 3.7.5. More detailed descriptions of the Consultant's recommended monitoring program are provided in Chapter 5.

3.7.3.1 Trace Metals and Hydrocarbons

H_o 1: There will be no change in concentrations of selected metals or hydrocarbons in surficial sediments beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o 2: Changes in concentrations of selected metals or hydrocarbons in surficial sediments are not related to OCS oil and gas development activity.

The sediments represent the ultimate sink for a majority of the potential contaminants from OCS activity and high levels of metals and/or hydrocarbons in the sediments are known to affect the nature and health of benthic invertebrates and demersal fish. Because of this proven chaining of pollutants to VECs, it was generally agreed that sediment chemistry should be included in the BSMP.

In a dissenting opinion, D. Schell (University of Alaska) and others argued that, in the Beaufort Sea, the sediment chemistry sampling to date has shown no relation to oil and gas development activities. He observed that the only potential impact associated with sediments was related to possible growth suppression in algae, and that the only other things of real concern in the Beaufort are effects of physical environmental changes (causeways) on fish and disturbance on whales. With so little effect demonstrated in the relatively low energy environment and smaller geographic area of the Beaufort, he reasoned, how can we possibly expect to detect sediment chemistry effects in the Bering Sea? Furthermore, he stressed that changes in sediment chemistry are of little interest per se so why not simply monitor bioindicators?

Rebutting this argument, it was pointed out that offshore production in the Beaufort Sea is very limited to date. Moreover, the elevated levels of sediment contaminants are expected to precede any detectable biological effects (e.g., increased incidence of fin erosion in fish) by many years and the management need for monitoring is to detect environmental degradation before VECs are impacted. Finally, the hoped-for outcome of monitoring is acceptance of the null hypothesis of no change, precisely the outcome that has occurred to date in the Beaufort Sea.

Chemicals monitored in the sediments should include those heavy metals associated with drilling fluids and produced waters (e.g., barium, chromium, and vanadium), as well as hydrocarbons. It was agreed that the same set of metals and hydrocarbons measured in the Beaufort Sea Monitoring Program (Boehm et al. 1985, 1986) should be considered for measurement in this program. In addition, lignosulfates may be suitable tracers of drilling muds.

Field sampling procedures used in the Beaufort Sea Monitoring Program (Boehm et al. 1986) also were endorsed for this program. Replication and compositing strategy should be based on a statistical analysis of the data from the Beaufort Sea Monitoring Program and other similar data sets. A sampling device with combined characteristics of ease of operation, reliability, and the ability to collect undisturbed surficial sediment samples should be used (e.g., a modified van Veen grab).

The modified Van Veen sampler appears to offer several advantages over other grab-sampling devices (e.g., a box core) for use in the BSMP. First, it has been widely used throughout the Bering Sea by previous investigators (e.g., Feder et al. 1982). Thus, data comparability between previous baseline studies and future BSMP sampling would be enhanced. Comparability of results with other geographic areas would also be enhanced. For example, the modified Van Veen grab has been used for benthic sampling in the Beaufort Sea (Boehm et al. 1985, 1986), in Cook Inlet (Lees and Houghton 1980), and in Puget Sound (Word et al. 1984, METRO 1986). Further, it has been recommended as the standard benthic sampling device for all future Puget Sound studies (Tetra Tech, Inc. 1986).

Since the Van Veen takes a semicircular bite out of the bottom, the depth of penetration is not uniform as it is for the box core. Thus it may not sample deep-dwelling organisms as efficiently as the box core. Both sampling devices show decreased penetration with increasing grain-size. The box core will however, penetrate deeper into the sediment than will a Van Veen regardless of grain size (Hessler and Jumars 1974). However, other operating characteristics of the Van Veen are as good, or better, than other benthic samplers. During deployment, the modified Van Veen creates a minimal bow wake while descending, forms a leakproof seal after the sample is taken, and prevents excessive sample disturbance while ascending (Tetra Tech, Inc. 1986).

Although the top 2 cm of sediment have been analysed in many similar monitoring efforts (for consistency with historic data), it was recommended that only the top 1 cm of sediment be analysed, as is the case in the Beaufort Sea program, to maximize the signal-to-background ratio. Analysis of different depth horizons from cores was also suggested (E. Crecelius, Battelle NW) as a means of assessing historic levels of contaminant input.

As noted above (Section 3.7.2), two different approaches to the location of sampling stations were discussed. First, a region-wide scale of sampling was discussed in case development in the Bering Sea occurs in more than one lease area simultaneously. In this event, sampling would be conducted in areas with significant biological resources in depositional zones adjacent to, and removed from, areas of activity. Sampling locations for a sale-specific monitoring approach should be chosen in a similar manner. However, the number and location of sampling stations should be flexible and dependent on sources, transport mechanisms, and deposition areas. Station placement along gradients away from sources, both industrial and natural was also suggested.

There was considerable discussion of the time at which sampling should start relative to the expected timing of exploration, discovery, and development. Given the uncertainty or even improbability of development in the Bering Sea OCS, there was a group of workshop participants that felt no sampling could be justified until the timing and location of development is known. At that time, the principles developed by the workshop could be used to tailor a sample design for that development. It was also noted that there are sufficient oceanographic differences between the various portions of the Bering Sea (e.g., Norton Sound vs. the Navarin Basin) that no specific criteria for design of a program can be applied uniformly to all of the various subareas.

An alternate philosophy held that the goal of the BSMP should be to begin data collection soon on a region-wide basis in order to develop the long-term data base necessary to assess annual variability in parameters measured. Once specific areas to be developed are confirmed, lease-specific monitoring would be designed to complement the region-wide data already gathered. Once it became certain that some lease areas are unlikely to ever be developed, portions of the region-wide program specific to those lease areas would be dropped.

The time of year at which sampling should occur was briefly discussed. It was noted that the spring bloom typically occurs in late April/early May and follows the retreating ice edge north. By the end of June, stratification has set up and the seafloor is isolated from the upper water column, perhaps creating optimum conditions for sediment sampling. On the other hand, June is the time of peak flood in the Yukon and there may still be some ice present creating a significant logistic problem; also, spring is a time of high year-to-year variability because of year-to-year climatic differences (Zeh et al. 1981). There may be a need to sample sediment coincident with other parameters. Late summer would be the time of maximum deposition of contaminants in shallow zones where there is seasonal resuspension of finer sediment and would be the time of maximum potential uptake (if any) by potential indicator organisms.

3.7.3.2 Biological Monitors/Sentinel Organisms

H_o 1: There will be no change in concentrations of selected metals or hydrocarbons in the selected organism(s) beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o 2: There will be no tainting of edible flesh of harvested resources due to increases in concentrations of metals or hydrocarbons in the selected organism(s) beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o 3: Changes in concentrations of selected metals or hydrocarbons in sentinel organisms are not related to OCS oil and gas development activity.

As stated by many workshop participants, reasons for monitoring contaminants in biological organisms are many:

- Indicator organisms can show chronic exposure to contaminants in a variety of circumstances;
- Monitoring organisms in conjunction with sediment chemistry can be useful in establishing significance of trends (only biologically available fractions are measured in tissue); and
- Bioindicators can, in some instances, forewarn of the potential for impacts to biological resources of importance to humans.

In the Bering Sea, perhaps the most compelling reason to monitor (given the extremely low likelihood of a measureable far-field impact from oil and gas activities) is the immense economic value and concommitant political importance of the renewable resources present. If there is any significant oil and gas development anywhere in the Bering Sea, there must be data developed to demonstrate that contaminants are, or are not, influencing biological resources, even if experts can present convincing data (e.g., Table 3-12) that such an influence is virtually impossible. Lay persons whose livelihoods depend on the biological resources will want field data to verify that the resources in question are not adversely affected.

Two aspects of the question of what to monitor include the target organisms of interest and the parameters to measure. Four groups of target organisms were suggested as suitable for inclusion in the BSMP: invertebrates, marine mammals, seabirds, and fish. Microbes could potentially be included as target organisms if recently developed analytical procedures become practical to apply in an environment like the Bering Sea. A listing of desirable attributes of bioindicator species from the Beaufort Sea workshop (Houghton et al. 1984) was presented and remains relevant (Table 3-14).

Among the invertebrates, taxa considered were bivalves, predatory gastropods, tanner crabs (Chionoecetes spp.), red king crab (Paralithodes camtschatica), and ampeliscid amphipods. Bivalves have the advantages of being sedentary bottom dwellers and a major food resource of commercially important species. Several species have wide distributions and adequate size and abundance, although collection can be a problem (see below). In addition, there is considerable pollutant metabolism information in the literature for congenors of some Bering Sea species. H. Feder (University of Alaska) discussed, and provided a listing of, the known characteristics of many bivalve candidates for the BSMP (Table 3-4). Macoma calcarea was suggested as the most ubiquitous bivalve of sufficient size. Nucula and Nuculana spp. were also suggested as abundant in depositional areas. Predaceous gastropods have the advantages of being at the top of the benthic food web and of direct commercial importance; they also reach a convenient size and are widely distributed. A disadvantage is that little is known of their pollutant metabolism.

Commercially important crab species meet several, but not all, of the criteria for bioindicator species (Table 3-14). For instance, tanner crabs are reasonably abundant throughout much of the Bering Sea and they ingest sediments directly. However, it is thought that due to

TABLE 3-14

DESIRABLE ATTRIBUTES OF POTENTIAL BIOINDICATOR SPECIES[a]

- A simple correlation should exist between the pollutant content of the organism and the average pollutant concentration in the surrounding water.
- The organism should accumulate the pollutant without being killed by the levels encountered in the environment.
- The organism should be abundant throughout the study area.
- The organism should be sufficiently long lived to allow the sampling of more than a 1-year class, if desired.
- The organism should be of reasonable size, giving adequate tissue for analysis.
- The organism should be easy to sample and hardy enough to survive in the laboratory, allowing depuration before analysis (if desired) and laboratory studies of pullutant intake.
- The organism should tolerate brackish water.
- Kinetics of the contaminant in the organism should be understood.

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[a] Source: Segar (1983), _In_ Houghton et al. (1984).

rapid metabolism (Rice et al. 1976) they do not tend to accumulate hydrocarbons to any significant degree. This attribute makes tanner crabs less desirable as potential bioindicator species. Much is known concerning the uptake of hydrocarbons by king crabs. For example, Rice et al. (1985) reported the effects of exposure to water soluble hydrocarbon fractions and oiled sediment on juvenile king crab. Exposure to water soluble fractions was lethal at elevated concentrations (4 day LC50=1.5 ppm). Exposure to all sediment concentrations up to the maximum (2 percent oil) produced sublethal effects. Uptake of hydrocarbons by king crab was noted in both muscle tissue and in the hepatopancreas; however, uptake varied by mode of exposure. Elevated levels of hydrocarbons in muscle tissue were seen for crabs exposed to oil-laden sediment; exposure to water soluble fractions of hydrocarbons did not result in elevated muscle tissue hydrocarbon levels. Conversely, hepatopancreas hydrocarbon levels were elevated in crabs exposed to water soluble fractions. Exposure to oil-laden sediment did not result in elevated hydrocarbon levels in the hepatopancreas. Although oil-laden sediments produced no lethal effects over the length of exposure (3 months), it was concluded that long term uptake from oil-laden sediments (1 year or more) may produce adverse, chronic effects. However, no single species of king crab is as common throughout the Bering Sea subregions as is tanner crab (C. opilio); therefore king crab would not be as suitable for a region-wide monitoring program but could be used in specific areas.

Ampeliscid amphipods were noted by J. Neff (Battelle Ocean Sciences Center) to be highly sensitive to spilled oil and a major benthic group in much of the Bering Sea. They are also a major food resource for the endangered gray whale in the northern Bering Sea.

Among the marine mammals, the walrus tissue analysis described by D. Taylor (Section 3.3.6) was endorsed as an excellent approach. Walrus are benthic feeding mammals which have a stronger potential for concentrating pollutants that might accumulate in the sediments than do many other bioindicators. Northern fur seal, a pelagic feeder, was suggested as another candidate mammal which has an existing harvest (on St. Paul Island) with attendant biologists who could obtain and process samples.

Seabirds breeding on the Bering Sea islands were also suggested as an important ecosystem component that might be sampled. It was noted that the USFWS is apparently collecting seabird tissues for possible later tissue analysis. While there is a considerable amount known about the pollutant metabolism of seabirds (e.g., Hunt 1985), interpretation of the data could be difficult because of the wide-ranging feeding habits of most species.

It was generally agreed that fish tissue analysis should be included in the BSMP for a variety of reasons (C. Manen, NOAA):

- Extensive knowledge of pollutant metabolism;
- High sensitivity to hydrocarbons with uptake (in bottom dwelling fish) through a variety of mechanisms;

- Known correlations between sediment chemistry and incidence of abnormalities; and
- Extreme economic value.

On the negative side, depuration (e.g., of liver bile metabolites) may be relatively rapid once the sources are removed.

Candidate fish species are many, but it was agreed that yellowfin sole, a demersal fish of commercial importance, might be the first choice. Yellowfin are both ubiquitous over the study area and are dominant in virtually every trawl program conducted in the Bering Sea. It was suggested (M. Hayes, NMFS retired) that the semi-pelagic species like walleye pollock and Pacific cod might be less suitable because of their lesser association with the sediments.

Parameters to be measured in appropriate organs should include, at a minimum, the chemical parameters measured in the sediments. Additional parameters of interest, although not covered explicitly in the hypotheses stated above, might include (on demersal fish) incidence of liver tumors, concentration of bile metabolites, incidence of visible external abnormalities such as fin erosion, and activity of the hepatic mixed function oxidase system (see Table 3-10).

The method of collection of the target species must vary with the group of organisms sampled. Because of the cost of field operations in the Bering Sea, many of the approaches suggested rely on sampling programs already in place. Walrus and fur seal could be sampled in conjunction with current FWS tissue sampling programs and NMFS biological programs coordinated with the native subsistence harvests. Fish samples should logically be obtained through the ongoing NMFS/RACE trawl sampling program. Bivalves should be sampled using a dredge apparatus following established protocols.

Sampling locations should coincide with sediment chemistry stations to the extent possible. These locations could be identical for organisms such as bivalves, but would be taken from a broader area with organisms such as marine mammals or demersal fish. Bivalve samples should be collected during concurrent sediment sampling activities in order to maximize logistics efficiency.

Time of year to sample will be dependent in many cases on the timing of activities relied upon to provide the samples. For benthos, there would be valid reasons to sample early in the summer before spawning occurs. However, in the inner shelf, maximum pollutant accumulations in tissues might be expected in late summer following the period of maximum growth and before the onset of fall storms that resuspend and redistribute finer sediments and associated pollutants.

The second part of this topic, related to tainting, was discussed as a subcategory of the issue of chemical contamination. It was noted (J. Ray, Shell Oil Company) that some tainting of flatfish has been found in fish in the vicinity of North Sea drill rigs that routinely discharge hydrocarbons in concentrations that are orders of magnitude higher than is allowable in U.S. waters. However, J. Neff pointed out that usually (e.g., the Amoco Cadiz work) chemicals are readily detectable analytically before humans will notice a deterioration in taste. These comments are supported by the recent experimental work of McGill et al. (1987) which assessed chemical tainting of flatfish (Limanda limanda) collected in the vicinity of a North Sea oil platform. Fish caught in a zone between 550 to 860 m from the platform showed detectable tissue concentrations of petrogenic hydrocarbons, whereas fish caught between 1,000 to 1,870 m from the platform did not. However, no evidence of oil tainting was detected by a panel of tasters who sampled fillets of fish from both zones.

3.7.3.3 Benthos

H_0 1: There will be no change in values of selected benthic assemblage[1] parameters or in population[2] parameters of selected organism(s) beyond the zones of mixing or dispersion specified under relevant operating permits.

H_0 2: Changes in values of selected benthic parameters are not related to OCS oil and gas development activity.

Benthic community monitoring has been included in many large scale monitoring programs where the objective was to detect changes in ecosystems related to pollution. Because there is little chance of detecting changes in sediment chemistry in the far field, the question remains whether there is any possibility of measuring any change in benthic parameters. The variability of benthic populations in response to factors unrelated to oil and gas activity complicates this even further (J. Houghton, Dames & Moore). J. Word (Battelle NW) pointed out that benthos could be an asset to the BSMP in several ways:

- As an indicator of depositional areas and the persistence of depositional areas with time;
- As the first component of the food chain that comes into contact with sediment contaminants; and
- As a link in the chaining between the benthic contaminants and higher trophic levels.

Benthic populations in the Bering Sea not only include several important commercial fishery resources but also represent significant prey items for fish, marine mammals, and birds. It was recognized, however, that little change is likely to occur in the far-field and that the probability of detecting such a pollution-induced change, given high natural variability, is remote.

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[1] Assemblage parameters are those such as total benthic biomass, species diversity or richness that include information on all species present.

[2] Population parameters reflect the nature of individual species populations, e.g., species density, biomass.

An important problem with benthic monitoring is that there is a very high probability of rejecting the first part of the null hypothesis; i.e., there is very likely to be a significant change from baseline conditions or between stations once OCS development begins (D. Segar, SEAMOcean). The problem is that it will be very difficult to establish the linkage or mechanism of causality (difficult to test the second part of the hypothesis).

A large volume of baseline data exists from previous OCSEAP-sponsored studies in the Bering Sea. It was agreed that this data base, primarily collected by H. Feder and S. Jewett of the University of Alaska, forms an appropriate baseline of data on benthic community structure and abundance and should form the basis for the BSMP. Benthic assemblage and population parameters that should be measured and are available for the baseline years include: total density and biomass of organisms, a species richness indicator, diversity, density and biomass of dominant species, and age structure. To take advantage of this data base, the BSMP sampling approach should closely follow the procedures developed for the OCSEAP studies, including sampler type and degree of taxonomic resolution. The number of replicate samples required to detect development induced changes still needs to be determined (see Section 4.2.3).

Sampling locations should correspond to sediment chemistry sampling stations and also take advantage of as many OCSEAP baseline stations as possible given the needs of the BSMP.

3.7.4 Hypotheses and Approaches Considered but not Included in the Recommended Program

The workshop considered in some detail the potential use of measurements that directly assess populations, population distribution, and the health of populations other than the benthos. However, there was no strong support for the inclusion of these techniques in the monitoring program. One set of hypotheses (concerning eelgrass beds in Izembek Lagoon) discussed in the workshop was represented as a site-specific concern and thus not adopted for the regional monitoring program.

3.7.4.1 Eelgrass Productivity

H_o 1: There will be no change in the productivity of eelgrass beds in areas beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o 2: Changes in productivity of eelgrass beds are not related to OCS oil and gas development activity.

Workshop discussions concerning the need to monitor the productivity of the substantial areas of eelgrass occurring along the northwestern Alaska Peninsula, particularly in Izembek Lagoon, eventually concluded (data from Schell, this workshop) that production from eelgrass, while important locally, was not a major source of carbon for the Bering Sea as a whole. Since eelgrass habitats occur in relatively limited areas, their inclusion as part of a Bering Sea-wide monitoring plan would not be appropriate.

It was the general consensus of the workshop participants that eelgrass habitats would most likely be impacted as a result of specific OCS oil and gas development scenarios, such as transportation related events or site specific drilling. As such, eelgrass monitoring might better be instituted as part of compliance monitoring requirements, or tied into specific regional development activities.

3.7.4.2 Other Potential Topics for Formulation of Hypotheses

Other topics discussed in the workshop as to their utility in monitoring and usefulness of the data obtained included:

- Water column chemistry,
- Environmental noise,
- Caged organism studies, and
- Incident or spill-related hypotheses.

No formal hypotheses were developed concerning these topics. The general feeling of the workshop was that, even though the information developed through monitoring related to one or more of these topics would be useful, considerations such as logistics and analytical costs, uncertainty over causal links, and application to the Bering Sea as a whole limited their effectiveness.

Monitoring of water-column hydrocarbon concentrations is desirable from the standpoint of acquiring the earliest possible detection of potential impacts from OCS oil and gas activities. Also, the potential for adverse impacts to pelagic eggs and larval life history stages of numerous important fish and invertebrate resources suggests that this type of monitoring be considered. However, several factors combined to decrease its practicability. First, very little baseline information is available for assessing natural variability of water column hydrocarbon concentrations in the Bering Sea (except for low molecular weight hydrocarbons such as methane). Second, the dispersion and dilution of dissolved hydrocarbons is likely to be so great that far-field effects would be virtually impossible to detect. Finally, the detailed life history information necessary for evaluation of impacts is generally lacking and would probably require a great deal of effort and expense to develop. Based on these considerations, monitoring of water-column hydrocarbon concentration was not recommended for inclusion in the BSMP.

Monitoring the environmental noise produced as a result of OCS oil and gas development activities was considered for inclusion in the BSMP because of its potential for adverse impacts on marine mammal behavior. This issue could be of some importance in certain regions of the Bering Sea such as the ice edge or bowhead whale wintering areas. This subject was not a specific mandate of the BSMP workshop, however, it is a legitimate concern. Studies of this nature are ongoing in several areas and those results would certainly be applied to situations in the Bering Sea. The expense required for the establishment of an acoustic monitoring network on an area-wide basis is probably not justifiable. For these reasons, monitoring of environmental noise was not recommended for inclusion in the BSMP.

Use of caged organisms in the water column as an integrator of the types of compounds present received some interest as an adjunct to water-column hydrocarbon concentration monitoring. Although problems exist with interpretation of any data collected in terms of what it means to pelagic populations, the caged organism approach offers advantages of experimental design and control that sampling natural populations lack. The expense and difficulty of locating and maintaining such a network of caged organisms in the Bering Sea may also be prohibitive.

Incident or spill-related hypotheses were discussed briefly but were considered to be outside the purview of this workshop.

4.0 STATISTICAL EVALUATIONS

4.1 GENERAL CONSIDERATIONS

Optimal statistical design of a monitoring program would ideally involve the examination of data on all likely monitoring variables. Pilot studies with adequate replication for estimating variances and covariances required for determining the best sampling plan would be conducted if existing data proved inadequate. Clearly, such a design effort would be demanding in terms of time and money.

Our statistical evaluations were restricted to examination of available data on the variables suggested by the hypotheses and monitoring strategies developed prior to the workshop. In most cases, the available Bering Sea data were inadequate for solution of the design problem. Thus, we have attempted to achieve a robust and flexible design which will fill the data gaps. After the recommended period of baseline monitoring, the data obtained should be evaluated to see if modifications to the initial sampling design are warranted.

Much of the previous Bering Sea research relevant to monitoring program design was conducted as part of the Alaska NOAA-OCSEAP program. Data collected under OCSEAP research programs is submitted to the National Oceanographic Data Center (NODC), for archival. NODC was used as the source for data analyzed in designing the BSMP.

A request was made for all relevant Bering Sea data collected since 1971 in NODC master data files. The files requested were Benthic Organisms (Files 032 and 132) and Marine Toxic Substances and Pollutants (File 144). Files 032 and 132 contain all benthic trawl and point samples and File 144 all data on concentrations of metals and hydrocarbons in bottom and suspended sediment, biota, and the water column.

The data received from NODC included 150 benthic stations sampled in 1979, 1980, or 1982, and 1,232 metal or hydrocarbon stations sampled between 1975 and 1981. However, on examining these data, we ascertained that replicate samples collected at a given time and place or from the same station in different years were rarely available. Thus, the data provided little help in assessing natural variability in the Bering Sea. This natural variability determines what level of change attributable to development activity may be detectable. Analyses conducted on the NODC data are summarized in Section 4.2.

The following types of data were not requested although the Catalog of OCSEAP Data (NODC 1980) indicated that some of them were available for the Bering Sea.

- Fish/shellfish surveys were not requested because it was believed that the NMFS RACE surveys (Section 3.3.8), were a better source for such data.

- Herring spawning data were not requested. Herring spawning areas are inshore of the lease areas. In addition, although herring are important commercially and in the Bering Sea food web, it was felt that they were not suitable for monitoring because fishing pressures greatly affect the herring populations and environmental factors such as temperature affect the time of spawning (Wespestad and Barton 1981).
- Intertidal data were not requested because very few stations were available in areas of interest.
- Marine invertebrate pathology data collected in Norton Sound and fish pathology data from the southeastern Bering Sea were not examined because we did not expect them to be a major focus of our monitoring program.

4.2 SPECIFIC EVALUATIONS OF BERING SEA DATA

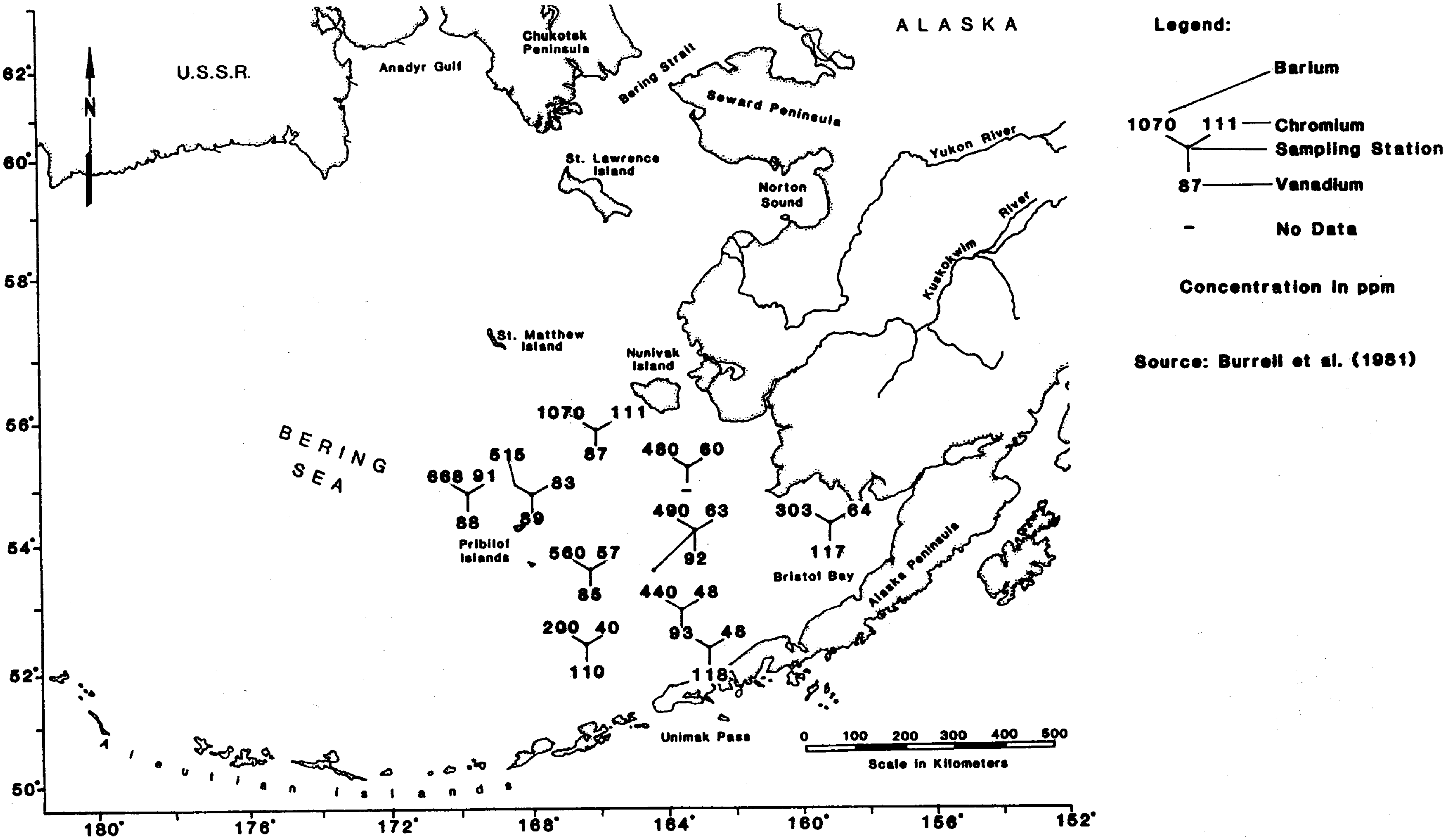
4.2.1 Sediment Chemistry

The Marine Toxic Substances and Pollutants (File 144) data we received included concentrations of metals and hydrocarbons in the water column and suspended sediment as well as bottom surficial sediments and biota. As discussed by Houghton et al. (1984), the only metals likely to have their environmental concentrations significantly altered by development activities or releases of oil are barium, chromium, and vanadium. We therefore focused our analyses on these three metals. We do not discuss analyses of water column and suspended sediment data since it was decided at the BSMP workshop that the focus of the monitoring program should be on bottom sediments and biota.

4.2.1.1 Trace Metals in Bottom Sediments

The two data sets we received are discussed in Burrell et al. (1981). The first was collected in June 1975 on the southeastern Bering Sea shelf and the second in September 1976 in Norton Sound. The sample collection method is not specified in the NODC data sets, but Burrell et al. (1981) report that a stainless steel corer and Van Veen grab were used. As far as we can determine from the data sets and the report, there was never more than one sample collected and chemically analyzed at a given station. Concentrations of barium, vanadium, and chromium were included in the southeastern Bering Sea data but not the Norton Sound data. The chemical analysis method recorded in the data set for these metals was neutron activation analysis, although Burrell et al. (1981) say that "rabbit" irradiation was used for vanadium. Between one and six values for these metals were given for each sample in which the chemical analyses were done. We assumed that these represented replicate analyses and computed "station means" from them (although they may well only represent laboratory analytical variability).

We then computed means and standard deviations of these station means (Table 4-1 "From NODC Data Set"). The station means for these three metals are mapped on Figure 4-1. The means and standard deviations reported by Burrell et al. (1981) for chromium and vanadium, but



Source: Burrell et al. (1981)

Figure 4-1
Concentrations (ppm) of Barium, Chromium, and Vanadium in Bering Sea Sediments

not barium, along with the corresponding quantities we computed from the data set and the numbers of samples and stations on which they were based, were also tabulated (Table 4-1). Our barium mean is likely to be an overestimate since 8 of the 27 barium analyses we found in the data set were coded as below the limit of detection limit. At least some of these represented lower concentrations than those included in our means. Thus, it appears that there are some discrepancies between the NODC data and the published data, but these discrepancies are not too great. However, the within-station variability in barium and vanadium was so high that no between-station differences were detectable by analysis of variance.

TABLE 4-1

AVERAGE CONCENTRATION (ppm) OF BARIUM, CHROMIUM, AND VANADIUM IN BERING SEA SEDIMENTS

	From Burrell et al. (1981)			From NODC Data Set		
Metal	Mean (ppm)	Standard Deviation	No. of Samples	Mean (ppm)	Standard Deviation	No. of Samples
Barium	--	--	19	538	235	10
Chromium	64	21	27	64	23	11
Vanadium	93	17	23	98	13	9

--, data not reported

In summary, the data available from NODC on trace metals in Bering Sea surficial sediments did not provide an adequate baseline for monitoring program design for the following reasons:

- There is never more than one sample per station so it is impossible to assess within-station variability properly either within or between years,
- Data on sediment characteristics, which make a significant contribution to variability in trace metal concentrations, are not available in the NODC data sets,
- Barium values are available for only 10 stations in the southeastern Bering Sea,

- Sampling and chemical analysis methods are uncertain, so future sampling cannot duplicate the methodology, and
- In the case of vanadium and barium, it would not be desirable to duplicate the chemical analysis methodology since more precise and accurate methods are now available.

4.2.1.2 Hydrocarbons in Bottom Sediments

A number of data sets on hydrocarbons in surficial bottom sediments were obtained from NODC. All but the 1980 samples from the Navarin Basin and St. Matthew Hall (Figure 4-2) are documented by Venkatesan et al. (1981), who found that almost all their samples were typical of other unpolluted, relatively coarse marine sediments.

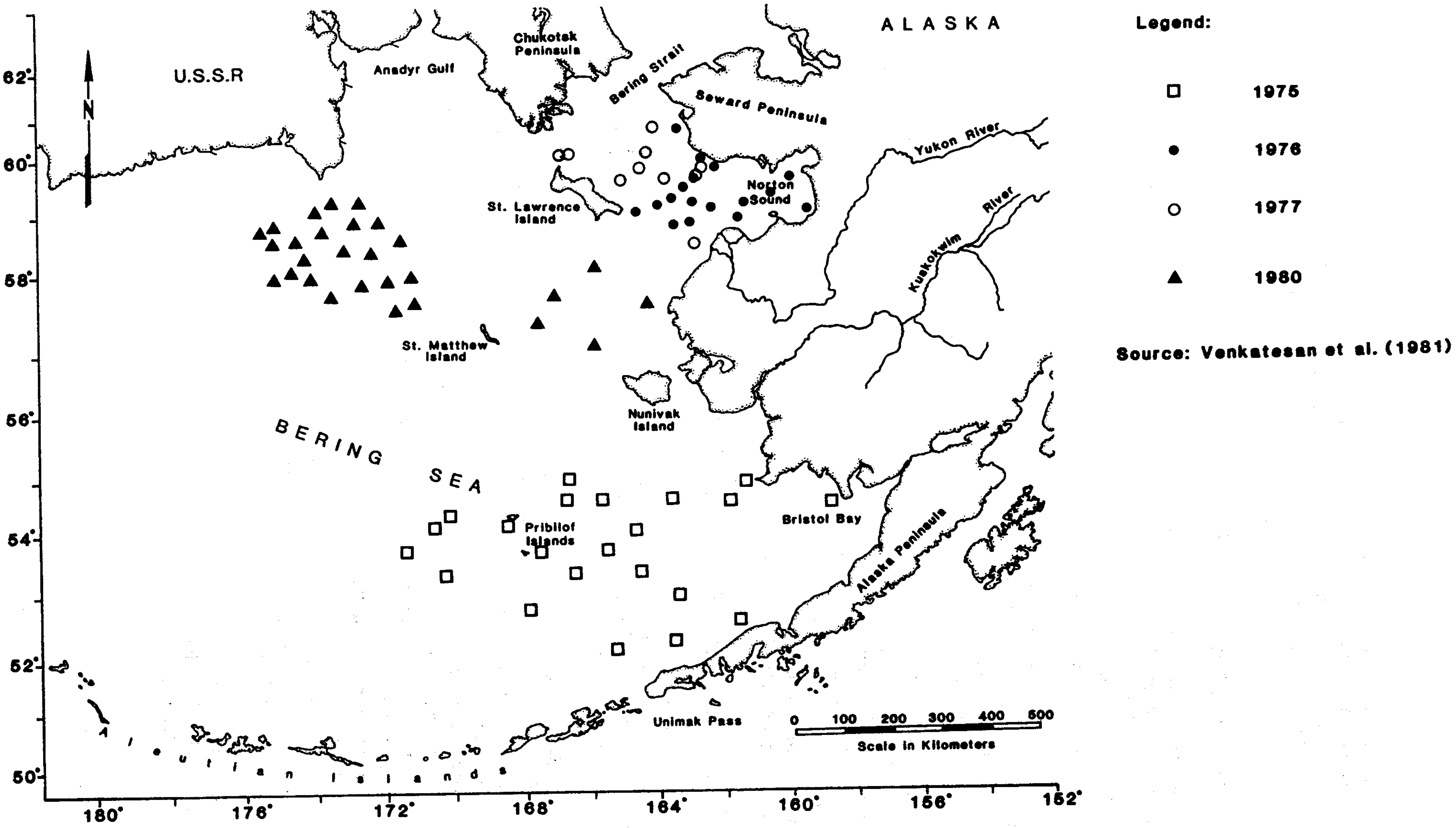
Slightly different sampling and laboratory techniques were used for the 1975 southeastern Bering Sea samples compared to the 1976-1977 Norton Sound samples. Our analyses focused on Norton Sound data since they included samples collected at the same time and place and in different years at nearly the same places. The objective was to assess within-station and year-to-year variability, as well as variability within subregions of Norton Sound. Enough discrepancies were found between reported results and the NODC tapes that we did not pursue these analyses. We concluded that within-station, year-to-year, and subregional variances computed from the NODC data would not be valid indicators of variances which would be obtained in a well-designed monitoring program using standardized sampling and analysis methods.

4.2.2 Biological Monitors/Sentinel Organisms

Five NODC data sets included concentrations of trace metals in plant and animal tissue. The metals reported included cadmium, copper, and zinc but not barium, chromium, or vanadium. The five data sets received from NODC were as follows:

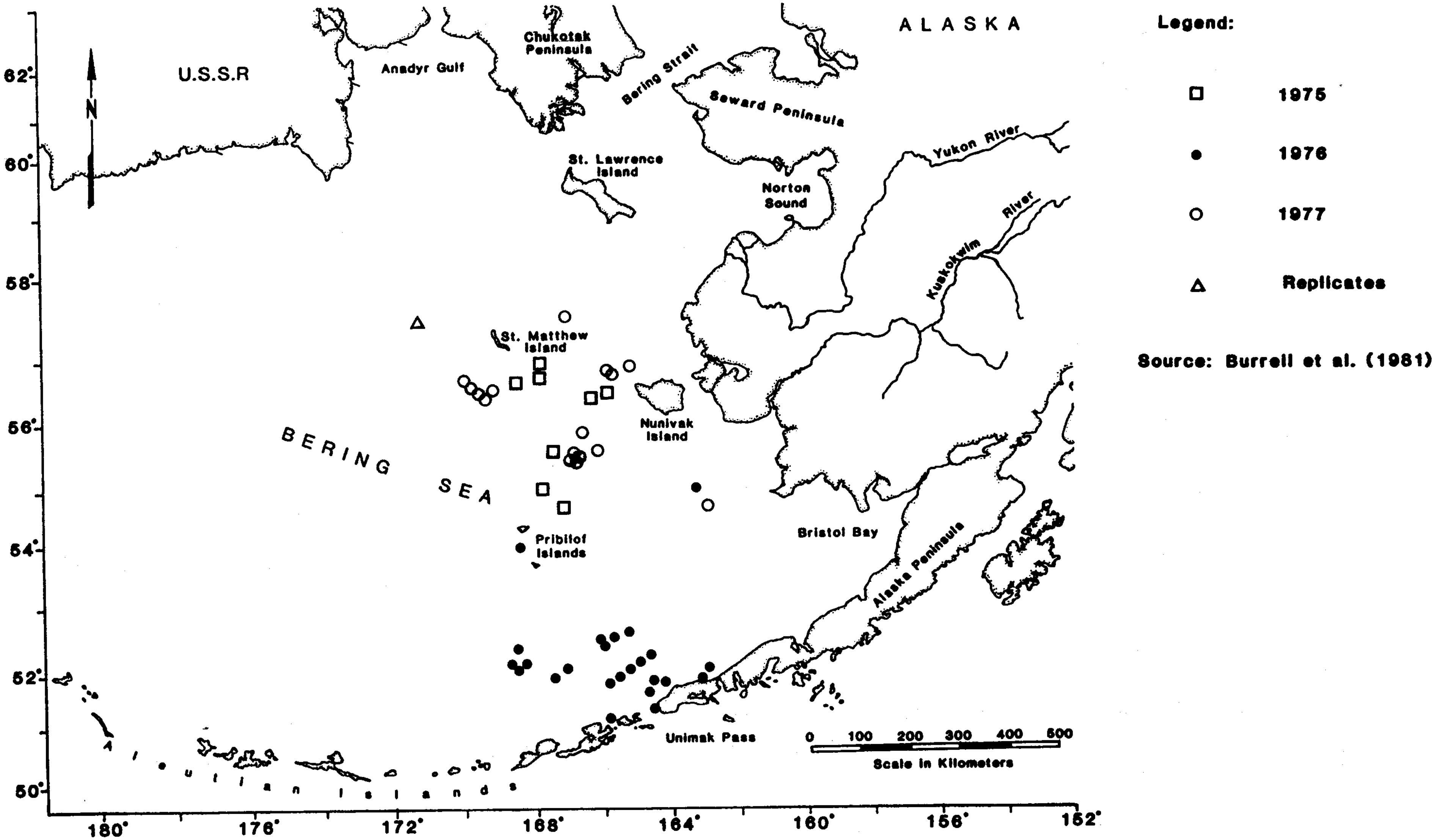
- A data set collected in August 1975 in the general vicinity of St. Matthew Island, Nunivak Island, and the Pribilof Islands giving selenium concentrations in several fishes and sea plants;
- One data set collected in April 1976 giving concentrations of cadmium, copper, and zinc in Neptunea, plaice, pollock, and Tanner crab from the southeastern Bering Sea;
- One data set collected in summer 1976 giving concentrations of these metals in Mytilus and Fucus, mostly from the Unimak Pass area; and
- Two data sets collected in spring and summer 1977 in the Navarin Basin giving concentrations of these metals in tissues of several species of seals (24 animals) and a walrus.

These data are given in Tables 21-3 and 21-4 of Burrell (1981). Locations at which all the samples from these five data sets were collected are shown in Figure 4-3.



Source: Venkatesan et al. (1981)

Figure 4-2
Sediment Hydrocarbon Sampling Stations
Within the Southeastern Bering Sea



Source: Burrell et al. (1981)

Figure 4-3
Sampling Locations in the Southeastern Bering Sea for Hydrocarbon Concentrations in Biota

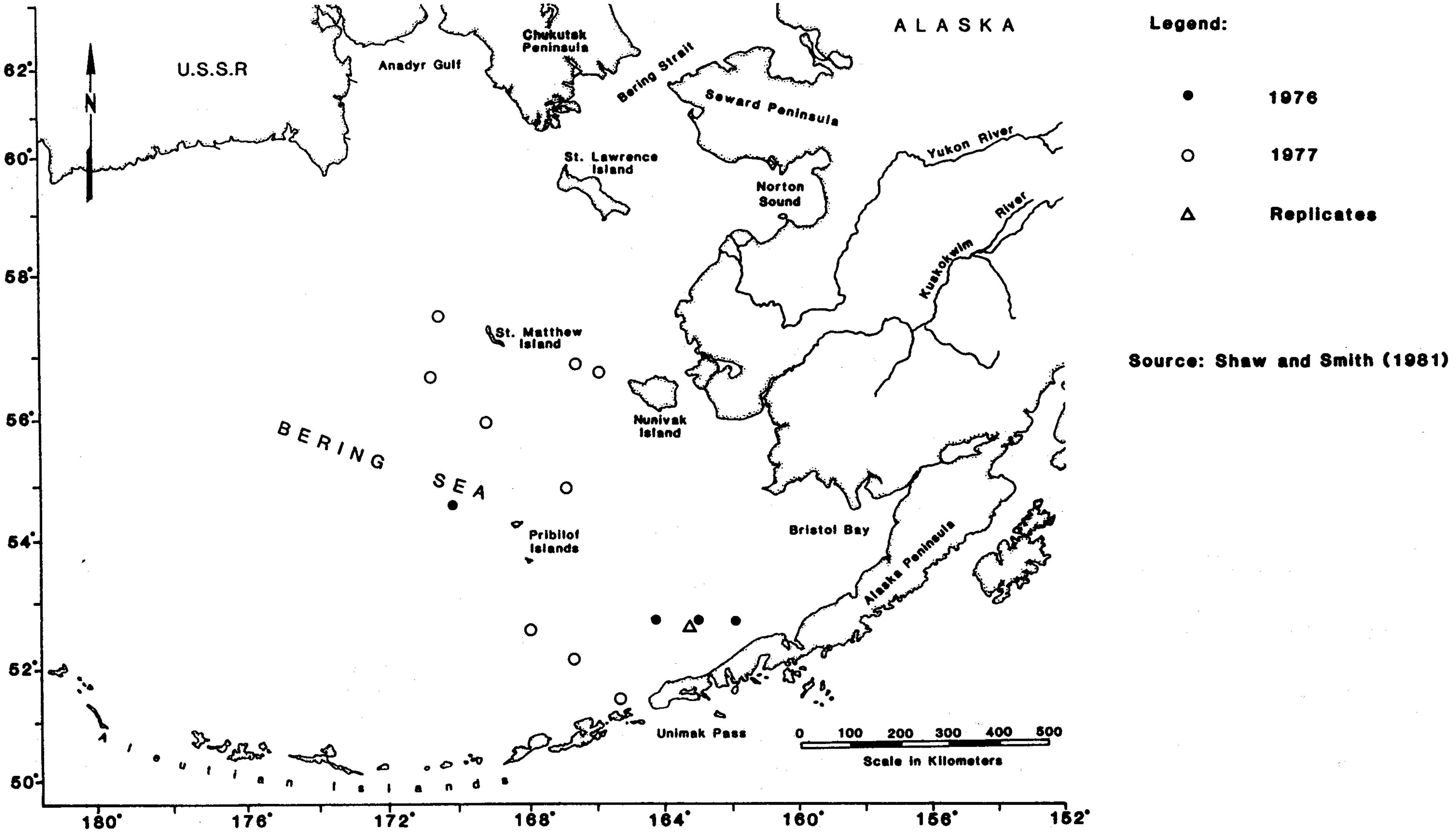
The replicates shown in Figure 4-3 are from the 1977 data. They represent samples from three different spotted seals collected on the same date at the same latitude and longitude in the Navarin Basin and thus provide some indication of variability within this species in the Navarin lease sale area. However, age, sex, and weight of these animals, although presented by Burrell (1981), are not included in the NODC data set. Furthermore, means of duplicate determinations of liver concentrations rather than the individual determinations are given in the NODC data set. In summary, although the data on trace metals in biota have serious limitations, they provide some background information which could be used in monitoring program design and for comparison with future observations if these species were to be monitored. No data permitting an assessment of year-to-year variability are available. Data on metals levels in walrus which were reported at the workshop by D. Taylor (USFWS) were requested but are in a preliminary form and not yet released.

The NODC data sets we received included only one containing data on hydrocarbons in biota. These data are also given in Tables 24-1 and 24-2 of Shaw and Smith (1981). Locations at which samples were collected are shown in Figure 4-4. The 1976 samples, including the replicates shown (duplicate determinations for hydrocarbon concentrations in livers of two spotted seals collected on the same date at the same location) are all from seals. In 1977 various other organisms, including Chaetognatha, Euphausiacea, and some birds, were sampled. Several samples were taken at some stations, so within-station variability can be estimated for these although the number of samples is too small to yield reliable estimates. As with metals in biota, no data are available for assessing year-to-year variability. Figure 4-4 also makes clear that the total number of locations sampled is too small to permit a realistic assessment of spatial patterns. Shaw and Smith (1981) point out additional (methodological) limitations of these data. Primarily for these reasons, the data were not considered further.

4.2.3 Benthos

Locations and dates of the benthic tow (trawl) and point (grab) samples included in the data sets received from NODC are shown in Figure 4-5. At some of the stations shown, taxonomic data records were included for only one of the two types of samples, so it was unclear whether or not both types of sampling were actually done. There were few replicate samples in the NODC data sets. Only three stations, all sampled in August 1982, had replicate trawl samples.

A larger subset of the 1982 stations had replicate grab samples. It should be noted that replicate samples were collected in the 1979 and 1980 sampling programs although only summary data for each station were included in the data sets. It should also be noted that data from major benthic sampling programs carried out in the Bering Sea in 1975 and 1976 by Feder and others were not included in the data sets we received, and



Source: Shaw and Smith (1981)

Figure 4-4
Sampling Locations in the Southeastern Bering Sea for Trace Metal Concentrations in Biota

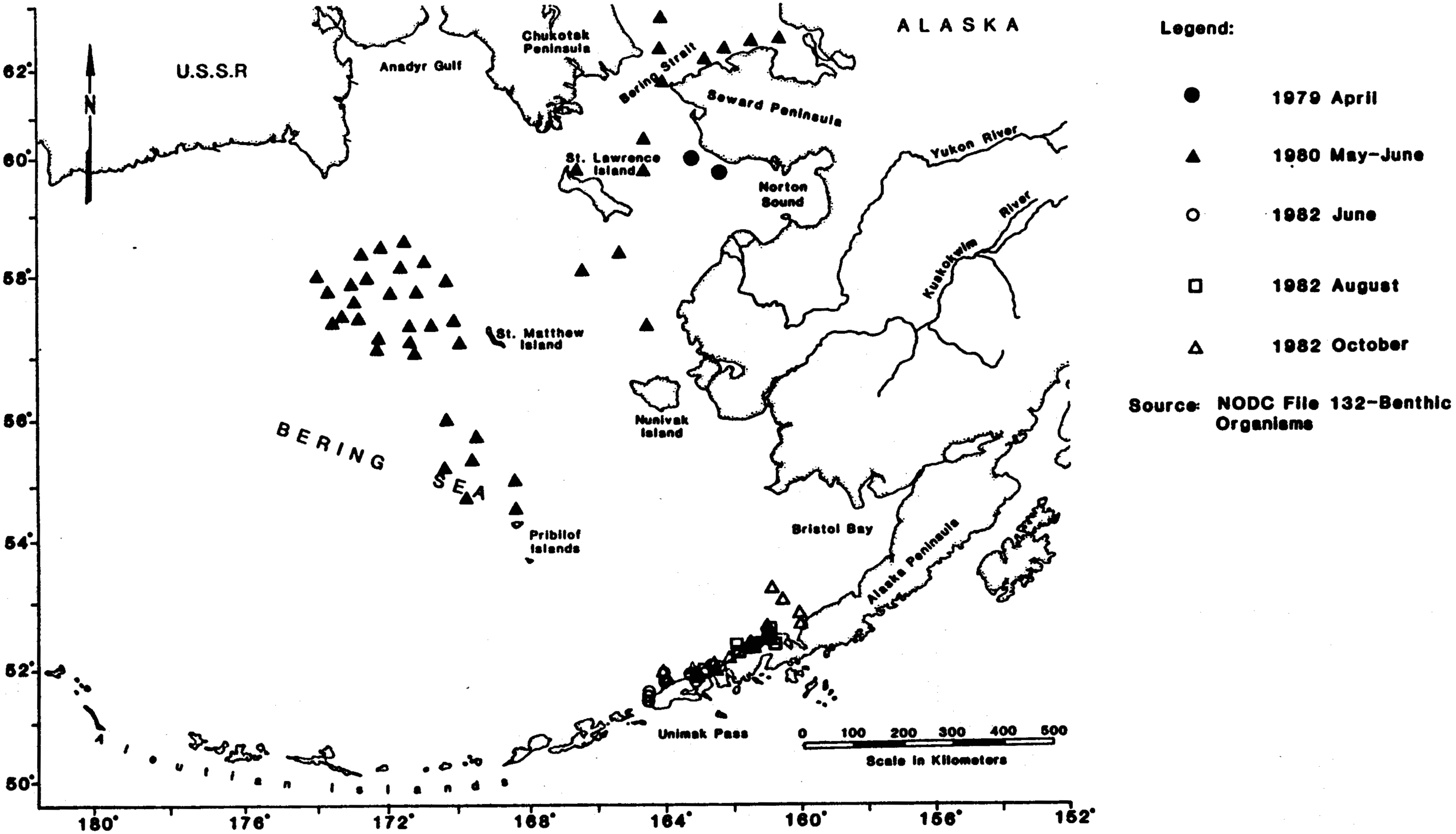


Figure 4-5
Benthic Tow and Point Station Sampling Locations
in the Southeastern Bering Sea

were not available in a usable format from the investigations. These data sets represent the most comprehensive benthic invertebrate baseline information for the Bering Sea. Lack of these data sets effectively precluded meaningful analyses of the benthic data.

Some simple calculations of year-to-year changes detectable at a group of stations were carried out using the replicate data available in Cimberg et al. (1986). These estimates (Table 4-2) give some idea of the relative sensitivity of such community and population parameters as species richness or counts. They also indicate that somewhat smaller changes are detectable in grab sampling data than in trawl data. However they should be interpreted with caution. Omitted and incorrectly coded taxa were a problem with the data; also, these samples represent only a very small part of the Bering Sea.

4.2.4 Designs for Hypothesis Testing

The first design for hypothesis testing is based on the statistical model and design by Zidek (Appendix B in Houghton et al. 1984). Assumptions implicit in this design are that the Bering Sea is partitioned into five zones of potential OCS development (see Section 5.3.3) and that OCS oil and gas development activities will have a potential effect in only one of the zones. Further, it is assumed that a probability of effect can be assigned for each zone. To obtain Table 4-2, we assumed that these probabilities are 0.1, 0.1, 0.1, 0.3, and 0.4. Given such zones, we further assume that we have a total of 36 stations and that we collect 4 replicates at each of these stations before development activities begin. The optimal sampling fractions given by Zidek (in Example 2.1, Appendix B of Houghton et al. 1984) imply that there should be 3 stations in each of the zones to which we have assigned a 0.1 probability of effect. These zones can be viewed as relatively "low risk" zones. There should be 13 stations in the "medium risk" zone to which we assigned effect probability 0.3 and the remaining 14 in the highest risk, probability 0.4, zone. We assume the effect adds a constant value to the parameter being measured at each station in the zone where it occurs. Then, if we have an estimate "s" of the sampling (replicate) standard deviation at a site, we can calculate detectable levels of these constant effect values using Zidek's method in Houghton et al. 1984, Appendix B. Detectable effect values are defined as values which we have an 80 percent chance of detecting if we are testing at the 5 percent level.

The test on which Zidek's power calculations are based is an F-test in a two-way (stations x time), fixed effects analysis of variance. We therefore assumed this model in calculating s from the Cimberg data. The species richness (number of animal taxa) data were used without transformation. A log transformation (the base 10 logarithm of count + 1) was used for counts of particular taxa to help normalize the data and stabilize variances. Bartlett's test for homogeneity of variances did not reject the hypothesis of equal variances, needed in the analysis of variance model, for the parameters of Table 4-2. A pooled within-station variance estimate was computed for each of the parameters shown in our

TABLE 4-2

DETECTABLE CHANGES FROM BERING SEA BENTHIC DATA[a]

Type of Sample	Parameter	Detectable Percent Change	No. Samples From Which s Computed	Increase or Decrease
Tow	Number of Animal Taxa	21%	6	Either
	Number of Pleuronectidae	56%	6	Decrease
	Number of Rock Sole	57%	6	Decrease
Grab	Number of Animal Taxa	18%	44	Either
	Number of *Scoloplos armiger*	36%	44	Decrease

---

[a] Percent change detectable with 4 replicates at each of 36 stations assuming the change occurs at each station within some block of stations as in Example 2.1 of Zidek (*In* Houghton et al. 1984). A detectable change is defined as a change which has an 80 percent chance of being detected by an F-test at the 5 percent significance level in a two-way, fixed effects analysis of variance.

table from all stations with replicate samples; s was computed as the square root of this pooled variance estimate. Detectable effect values were then computed by multiplying s by the product of the value 0.42 read from Zidek's table and the square root of two. These values were converted to detectable percent changes in order to make them easier to interpret.

We emphasize that Table 4-2 is merely an example of the type of calculations needed to determine detectable levels of change. Given a more correct and complete benthic data set and a more realistic model for regions and risks of potential effects in the Bering Sea, more meaningful estimates of detectable change could be computed.

4.3 ANALYSIS OF BEAUFORT SEA MONITORING DATA

Because the available Bering Sea sediment chemistry data were inadequate guides to monitoring program design, we examined data from Boehm et al. (1985, 1986) summarizing results from the first two years of the Beaufort Sea Monitoring Program. The Beaufort Sea Monitoring Program has the same objectives and some of the same methods as the proposed BSMP. Sediment samples were collected using a modified Van Veen grab sampler, and chemical analyses were conducted on the top 1 cm of surface sediment; 26 stations were sampled in both years. Replicate samples were analyzed for hydrocarbons by GC and GC/MS for only a small subset of these stations in the first year but for all in the second year. Replicate samples from all stations were analyzed for metals in both years, so we focused our analyses on metals data. In particular, we examined barium data from stations sampled in both years because barium is the metal most likely to be added to the environment in substantial quantity by drilling operations.

Boehm et al. (1986) found a positive correlation between metal concentrations and percent mud. Most stations with large year-to-year changes in metal concentrations showed correspondingly large changes in percent mud. There are at least two possible approaches to controlling this source of variability.

One is to do chemical analyses on only the mud fraction of the sediment rather than the bulk sediment. In the second year of Beaufort Sea monitoring, analyses were performed on both the bulk and mud fractions. Analyses currently being conducted will compare metal concentrations in the mud fraction in the second and third year Beaufort monitoring data to see if use of the mud fraction reduces year-to-year variability.

A second approach considered for the Bering Sea Monitoring Program is to sample only areas with fairly high percent mud since these are depositional areas where any sediment contaminants would be expected to collect. Each general area to be sampled would be oversampled in each year of sampling. Samples with percent mud varying significantly from the target percent mud value for the area would be rejected to eliminate variability caused by year-to-year changes in current patterns, river runoff, and other environmental variables.

Using this latter approach, we examined data from seven Beaufort Sea stations which had 30 percent mud or more in both years of sampling. Means and standard deviations among all these samples and among stations are summarized and compared with Bering Sea values (Table 4-3).

TABLE 4-3

BEAUFORT SEA BARIUM (mg/kg) STATISTICS

Data	Mean	Standard Deviation
All Beaufort Sea samples examined	511	150
Seven 1st-year Beaufort station means	530	165
Seven 2nd-year Beaufort station means	478	136
Bering Sea samples above detection limit	542	236
Ten Bering Sea station means	538	235

Source:

Beaufort Sea values recalculated from data of Boehm et al. 1986
Bering Sea data from Table 4-1.

The major results of our analyses are the following:

- Barium concentrations from individual samples at these seven stations during both years ranged from 289 to 788 ppm.
- Differences among stations were highly significant and contributed more to overall variability than differences between the two years. Stations in different regions (Harrison Bay vs Mikkelsen Bay) usually differed more than stations which were near neighbors.
- Some stations changed more from one year to the next than others, with the biggest year-to-year change occurring at a station just offshore of the Colville River delta.
- The detectable change in barium concentration at stations affected by OCS development using the model of Zidek's Example 2.1 (p. 99 in Houghton et al. 1984) is 30 ppm under relatively optimistic assumptions regarding variability and 64 ppm under somewhat more pessimistic assumptions if 36 stations are sampled. Even with only 10 stations, changes of 101 ppm or less are detectable. These values are below the 153 ppm change which we calculated might be caused by one OCS development scenario (Section 3.7.2). The assumption that we have sampled stations in the affected area is, of course, crucial.

Boehm et al. (1986) reported means and standard deviations of barium for each year of sampling at each station sampled in the Beaufort Sea Monitoring Program. They kindly provided us with the barium values for the individual replicate samples as well. In the first year of sampling, a replicate sample was taken from each side of each of three grabs unless one or more of the grabs was too small to yield two samples. In that case, the pair of replicates came from different grabs instead of from the two sides of one grab. Thus, each reported first-year mean is a mean of 6 replicates. In the second year of sampling, the sediment from both sides of a grab (or of two grabs if one was too small) was composited in the field and the composites returned to the laboratory for analysis. Thus, each second-year mean is a mean of three composited samples.

Boehm et al. (1986) reported that grab-to-grab variability was not found to be significantly higher than within-grab variability for barium in the first year samples, so we can probably treat the first-year and second-year means as means of six and three replicates, respectively. However, we note that such discrepancies in the definition of replicates should be avoided in the BSMP.

The estimated within station standard deviations of the second-year samples given by Boehm et al. (1986) tended to be higher but more homogeneous than those of the first-year samples. Cochran's test for equality of within-station variances was significant ($p < 0.01$) for the first-year but not the second-year samples. Homogeneity of variances is desirable if an analysis of variance model is to be used to detect year-to-year changes as envisioned by Zidek (Houghton et al. 1984) in the Beaufort Sea monitoring design. Thus, it seems most reasonable in the BSMP to analyze one sample per grab, using a well-mixed composite of the surface sediment available in that grab.

The resulting replicate variance will incorporate both analytic variability and small-scale spatial patchiness. Quality control methods such as those described by Boehm et al. (1986, p. 45), which are endorsed as part of the BSMP, should be adequate to indicate the contribution of analytic variability to the replicate variance. If the quality control program suggests the possibility of batch effects in laboratory analyses, different samples from a station should be analyzed in different batches to avoid introducing any biases due to such effects.

As noted above, there was significant heterogeneity of variance among the seven stations we examined for the first-year but not the second-year samples. There was no evidence of a relationship between the station means and standard deviations which would point to the possibility of stabilizing variances by, for example, a log transformation. Thus we used an analysis of variance in spite of the heterogeneity of the replicate variances to get a rough idea of whether there was evidence of year-to-year change in barium concentration at some or all stations and to assess the relative contributions of year and station differences to the overall variability.

The analysis indicated a highly significant interaction between station and year; in other words, there was a greater year-to-year change at some stations than at others. The biggest change among the stations we considered occurred at station 6B just north of the Colville River delta. Differences in riverine inputs and current patterns between the two years might explain such changes. We would expect similar year-to-year variability in some parts of the Bering Sea; for example, in Norton Sound under the influence of the Yukon River.

There was a significant ($p < 0.01$) component of variance due to station location. The greatest differences were between two Mikkelsen Bay stations and a western Harrison Bay station. The Mikkelsen Bay stations had the lowest barium concentrations (around 350 ppm) and the Harrison Bay station the highest (around 700). A Foggy Island Bay station not far west of the Mikkelsen Bay stations also had relatively low barium concentrations. The other stations, in the Harrison Bay area, had intermediate values.

In order to calculate the level of change in barium concentration in surficial sediment which could be detected by a monitoring program, we must have an estimate of sampling variability for this concentration. As noted elsewhere in this report, adequate barium data for the Bering Sea are unavailable, so the Beaufort Sea data discussed above must serve. In light of the recommendation to analyze one composited sample per grab, the within-station standard deviation from the second year of Beaufort Sea Monitoring Program sampling is a reasonable estimate to use. This estimate, calculated from the pooled within-station variance of the second-year samples, is 51 ppm. Under this model a replicate sample is defined as in the second year of the Beaufort program. Thus K in Zidek's Table 1 (Houghton et al. 1984), which will be used for computing detectable change, is the number of grabs per station.

The year-to-year variability at some stations discussed above suggests a slightly more conservative model. It can be argued that change caused by OCS development activities must be detected against a background of natural year-to-year changes. Then instead of assuming, as in Section 4.2.4, that sampling is done on just one occasion before and one occasion after development commences, we would make the more realistic assumption that each station would be sampled in several years before and several years after the start of development. Year would be viewed as a random factor, treating the years in which sampling was done as a small sample of all possible years before and after the start of development. Because we had only two years of Beaufort Sea data to examine and because the definition of replicates varied somewhat between years, the Beaufort Sea results provide only very rough guidelines for design of the BSMP under this model. We computed a residual standard error of 66 ppm from a two-way analysis of variance (year x station) in which the mean at each station in each year was treated as a single observation. This value gives some idea of the appropriate standard deviation to use in calculating detectable change from Table 1 and Example 2.1 of Zidek (Houghton et al. 1984) under this model, with K in

Zidek's table now being the number of years before and after development. We assume K=2, and we assume that the amount of replication at each station in each year in the BSMP will be comparable to that in the Beaufort.

We explained the assumptions of our detectable change calculations in detail in Section 4.2.4. As noted there, these calculations are merely an example, but one which might be applicable given appropriate definitions of zones in the Bering Sea which we will discuss later. Detectable impact values for barium under both the models for sampling variability discussed in this section are summarized in Table 4-4.

TABLE 4-4

DETECTABLE IMPACT VALUES FOR BARIUM

Number of Years of Sampling		Number of Stations	Number of Samples per Station	Assumed Standard Deviation	Detectable Change (mg/kg)
Before Impact	After Impact				
1	1	36	4	51	30
1	1	36	3	51	39
1	1	36	2	51	50
1	1	10	4	51	48
1	1	10	3	51	57
1	1	10	2	51	78
2	2	36	3 to 6	66	64
2	2	10	3 to 6	66	101

It is notable that the area covered by the seven Beaufort Sea stations included in our analysis is roughly 10,000 square kilometers, the depositional area assumed to be impacted by development in the calculations (Section 3.7.2) which led to the possible areawide change of 153 ppm. The area represented by the actual and potential lease areas in the Bering Sea is perhaps 10 times as great. Thus, unless the areas of possible impact can be narrowed down, we might well need more stations than our power calculations suggest just to be sure that some were located in whatever area ended up experiencing an impact. With only 10 stations total, the low risk zones of the example would have only 1 station each. Even with 36 stations total they would have only three each.

5.0 RECOMMENDED SAMPLING DESIGN

5.1 GENERAL

This chapter contains the specific recommendations of the study team regarding testable hypotheses, statistical design, field and analytical methods, and spatial and temporal scale for components to be included in the BSMP. These recommendations are based on our analysis of information presented and directives received at the workshop, related information reviewed in the course of this project, our experience in similar projects, and the statistical analyses presented in Chapter 4.

Each of the BSMP components adopted by the workshop include two hypotheses requiring separate proofs. The first hypothesis deals with proof that a change has occurred in a parameter that could be influenced by oil and gas activity, the second with proof that the observed change actually was caused by oil and gas activities. In most cases, the programs described lack the capability of testing the causal relationship required by the second hypotheses. Nevertheless, priority should be placed on monitoring to detect changes in parameters we know or suspect could be altered by oil and gas development activity and which we believe could lead to, or indicate the potential for, adverse impacts on resources of importance to man. Studies to determine causality (where it cannot be positively established on the basis of circumstantial logic) should be initiated once a change has been detected. In this way, studies of causality can be directed to specific questions, maximizing the utility and cost-effectiveness of information gained.

Proving direct causality in marine pollution monitoring studies is rare. More frequently, circumstantial evidence is gathered linking statistically significant changes in physical or chemical aspects of the environment (known or suspected to cause impacts) with statistically proven changes in the target variable (Houghton et al. 1984). To establish direct causality usually requires field manipulation or laboratory studies rather than field monitoring data.

One of the mandates from MMS (C. Cowles, this workshop and the Statement of Work) for the ultimate product of our design was that it be flexible enough to be useful to MMS regardless of the ultimate pattern and extent of development in the Bering Sea. This flexibility is thus primarily geographical and relates to the ultimate placement of sample stations in relation to development activities that may occur (see Section 5.3).

In describing field sampling that is recommended at whatever stations are to be monitored, we have been as specific as possible using the best information available to us and our best scientific judgement. We recognize that the specific approach recommended may not be the only technically sound method and that many alternatives are available (especially with respect to bioindicator species and parameters). Nonetheless, as in the Beaufort Sea Monitoring Program (Houghton et al. 1984), we urge that other approaches be incorporated at the start of the program only if they have been demonstrated to be superior to those suggested. Once incorporated into the program, procedures should be rigorously followed unless alternative approaches are proven superior. Even then, it is desirable to continue the old method along with the new for a sufficient period to establish the relationship between the two.

In addition to the recommended approaches described in this chapter, we feel strongly that the BSMP cannot succeed without the full implementation of recommendations regarding physical environmental data, quality control and quality assurance, data management, and coordination as described in Section 5.5.

5.2 MONITORING RATIONALE

Convincing logical arguments were made at the workshop against the need for a long-term, area-wide monitoring program. First, the disappointing results of exploratory drilling to date, coupled with lower oil prices, have greatly reduced industry interest in most of the Bering Sea. This likely will mean a much lower level of activity and/or more localized development in the Bering Sea than had been foreseen a few years ago. Second, as noted in the Beaufort Sea Monitoring Program (Houghton et al. 1984), the first and most sensitive "line of defense" against environmental degradation that could cause an unacceptable impact on VECs (valued ecosytem components) is compliance monitoring of individual activities. If, through construction and operational stipulations (including discharge limitations), degradation below acceptable levels is prevented beyond a definable distance from each activity, then it is very unlikely that area-wide or far-field degradation sufficient to impact VECs would be possible in the Bering Sea. Third, the size and diversity of the Bering Sea makes any area-wide program unwieldly and expensive. Logistics would be particularly expensive if a dedicated vessel is required and achieving the goals of the BSMP could be compromised by reliance on vessels of opportunity.

Finally, there is the problem of establishing the linkage of impacts among parameters measured, resources of concern, and oil and gas activity as is mandated by the BSMP objectives (Section 2.5). Changes in certain sediment chemistry parameters may be circumstantially linked to discharges from oil and gas activity but could also be caused by discharges from the fishing fleet and large-scale mining activity. Linking a change in the community structure of benthos or the incidence of fin rot in flatfish to oil and gas activity would be very difficult unless these changes were correlated with changes in sediment chemistry that were in turn traceable to oil and gas activity. However, field studies around areas of intensive development to date have shown little evidence of measureable change beyond a distance of several kilometers (e.g., Davies et al. 1984). Moreover, sediment levels of metals or petroleum hydrocarbons that have been circumstantially linked to carcinogenesis (e.g., Malins et al. 1980, 1982) are very high and have resulted from multiple, poorly-regulated inputs over many decades.

On the positive side, there are several strong factors (in addition to the regulatory mandates) supporting a need for a region-wide monitoring program in the Bering Sea.

- While exploratory drilling results have been discouraging to date, there is still a chance that future drilling may discover recoverable reserves. The North Aleutian Basin has yet to be explored.
- If any major offshore exploration/development is to occur in the Bering Sea, there is a strong political need to document that adverse changes do not result. This will hold regardless of how strong a case can be made, using existing knowledge, that adverse effects could not occur. The possibility exists that pollutant behavior, organism physiology, or population controlling factors may be sufficiently different or poorly understood in the Bering Sea that conclusions based on extrapolations from other OCS areas may not hold. Field documentation that changes have or have not occurred would be required.
- As noted in Chapter 3.7, there may be some changes that are so important that resource administrators will want to know about them even if scientists cannot foresee a reasonable mechanism that would cause them to occur in response to oil and gas development activities. If they do occur, it is essential that we know about them and initiate further studies as appropriate to identify their causes.
- At this point, we cannot predict the pattern that development may take, if it occurs at all, in the Bering Sea. Because there are compelling scientific reasons for obtaining repeatable multi-year measurements before development begins, it is desirable to have at least some index data over the entire area that could ultimately be influenced by any realistic development scenario.

While the three primary components recommended for inclusion in the BSMP and detailed in the following sections do not fully meet the stated objectives for the program (Section 2.5), this may be the result of setting overly idealistic objectives. In effect, the designed program will monitor two components of the environment (sediment chemistry and bioindicators) believed to have the greatest potential for detecting increased contaminant levels should they occur. While causality of changes that may be seen in these parameters may be difficult to establish, any changes detected would be useful as an early warning of the potential for significant effects on VECs. The program also calls for monitoring of benthic infaunal populations as a lower priority; changes in benthos attributable to oil and gas development activity would provide a more direct indication of effects on resources of direct importance to man.

Thus, while none of the individual approaches recommended meets all of the stated objectives for the BSMP, each addresses at least one objective. As in the Beaufort Sea Monitoring Program (Houghton et al. 1984), it is unlikely that any single monitoring focus could be devised that would meet all of the stated objectives. Within the limitations of the existing knowledge of the Bering Sea and our technological ability to monitor the environmental effects of OCS activities, we have tried to define approaches that collectively address the stated program objectives in an optimum manner.

5.3 GEOGRAPHIC SAMPLE DESIGN CONSIDERATIONS

As noted in Section 3.7.2, there was much discussion and disagreement regarding the appropriate geographic scale of the BSMP; this discussion was closely tied to the issue of when monitoring should begin (area-wide, begin immediately; or sale-specific, wait for discovery). As requested at the workshop, we provide in this section a flexible menu of approaches. We offer two alternatives for initially selecting stations within either the area-wide or sale-specific scales resulting in four different programs. These alternatives are:

- Use of the ANOVA-based approach developed by Zidek (In Houghton et al. 1984), and
- Subjective location by informed scientists, based on the criteria listed in Table 3-13.

Once reliable estimates of spatial and temporal variance are available, an additional statistically based approach is offered.

As envisioned, the actual sampling to be done at each station under the various components of the program (Section 5.4) would vary little with the geographic sampling design selected. We view the design considerations below and in Section 5.4 as adequate for initial stages of the BSMP and expect that the data on variability obtained would be used to produce a more refined design after initial baseline sampling.

5.3.1 Area-Wide Geographic Design

The rationale for an area-wide monitoring program is discussed in detail in a number of places in this report (e.g., Sections 3.7.2, 4.2.4, 5.2). If there is to be OCS oil and gas development in the Bering Sea, we recommend that an area-wide program be implemented, based on one of the approaches described below, and subsequently modified as appropriate to reflect the data generated and the ultimate development plan.

5.3.1.1 ANOVA-Based Approach

The ANOVA-based approach to station selection has the advantage of being a region-wide program that can be tailored subjectively, and modified over time to reflect best available information on likely patterns of development and higher risk environments. Because the future of development in the Bering Sea is uncertain, it is more difficult to stratify into various risk areas than was the Beaufort Sea (Houghton et al. 1984). Therefore the design we propose must be viewed more as a simplified example of a design that might prove to be appropriate, depending on the course of development; not as one that is rigidly recommended. As noted above, it would nonetheless provide a reasonable area-wide initial assignment of station locations. As data are analysed and information becomes available, effort can be reallocated to improve the sensitivity of the program.

For purposes of the area-wide example, we partitioned the Bering Sea into a number of blocks (about 30) each of which was assumed to have an assignable risk of effects that is equal over the entire block. This risk factor (1 - highest through 5 - lowest) was used to group the blocks into five zones (Figure 5-1). A sixth zone accounts for the rest of the area and was assumed to have negligible risk of effect.

In general, areas of lease sales where additional exploration is possible were assigned 1's except for the Navarin where industry interest appears to be least. Adjacent blocks have declining risk dependent on expected direction of net transport, distances from likely sources, and presence of depositional areas. The Port Moller, Nome and St. Paul areas were assigned higher risk factors because of the potential use as support bases or transshipment points. Areas north of St. Matthew and St. Lawrence Islands and south of Nunivak Island were given higher readings where presence of finer sediments indicates depositional environments.

The configuration of blocks and assignment of risk categories shown in Figure 5-1 is based on a relatively limited consideration of factors thought to be important. Adjustment of block boundaries and reassignment of risk can be readily accommodated in the approach, depending on expectations concerning OCS development. Assignment of zone designations allows assignment of the number of stations in a given zone by the use of the ANOVA approach of Zidek. To make the model of a uniform change throughout the impacted block reasonable, some of the blocks may need to be reduced in area by eliminating or changing the assigned risk of those portions of each which are less, or not at all, likely to be affected by OCS development.

Suggested allocation of stations for sediment chemistry sampling is described in Section 5.4.1 below. Specific location of stations within zones ideally should be accomplished using a randomization technique; however, because of the size of the zones and other considerations regarding station location (Table 3-13), Zidek's method allows for some subjectivity. For example, if a given zone was allocated six stations, the investigator could arbitrarily place one in a known depositional area, randomly select three stations from the suite of previously sampled stations, and randomly place the remaining two.

5.3.1.2 Subjective Approach

This approach is based on many of the same underlying assumptions that went into the definition of blocks and assignment of risk categories in the ANOVA-based approach. In essence, available effort (number of stations) is assigned based on consideration of factors listed in Table 3-13 with appropriate "controls." The major drawback to this program is that there is no guidance to the optimum allocation of stations to areas with varying degrees of risk other than professional judgement. A suggested subjective allocation of 36 stations throughout the Bering Sea is provided in Figure 5-2. These stations were placed with consideration of sources, transport, depositional areas, resources,

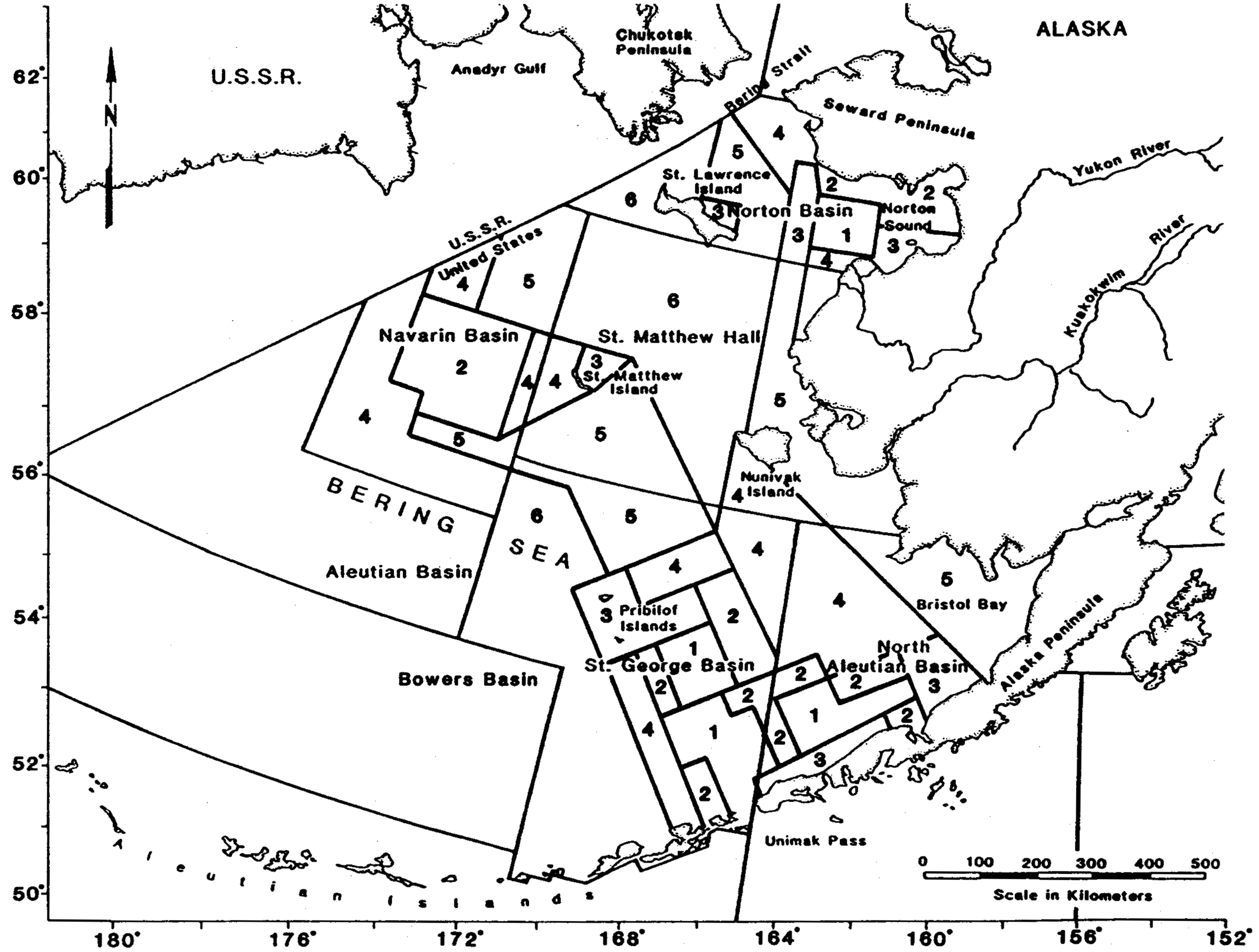
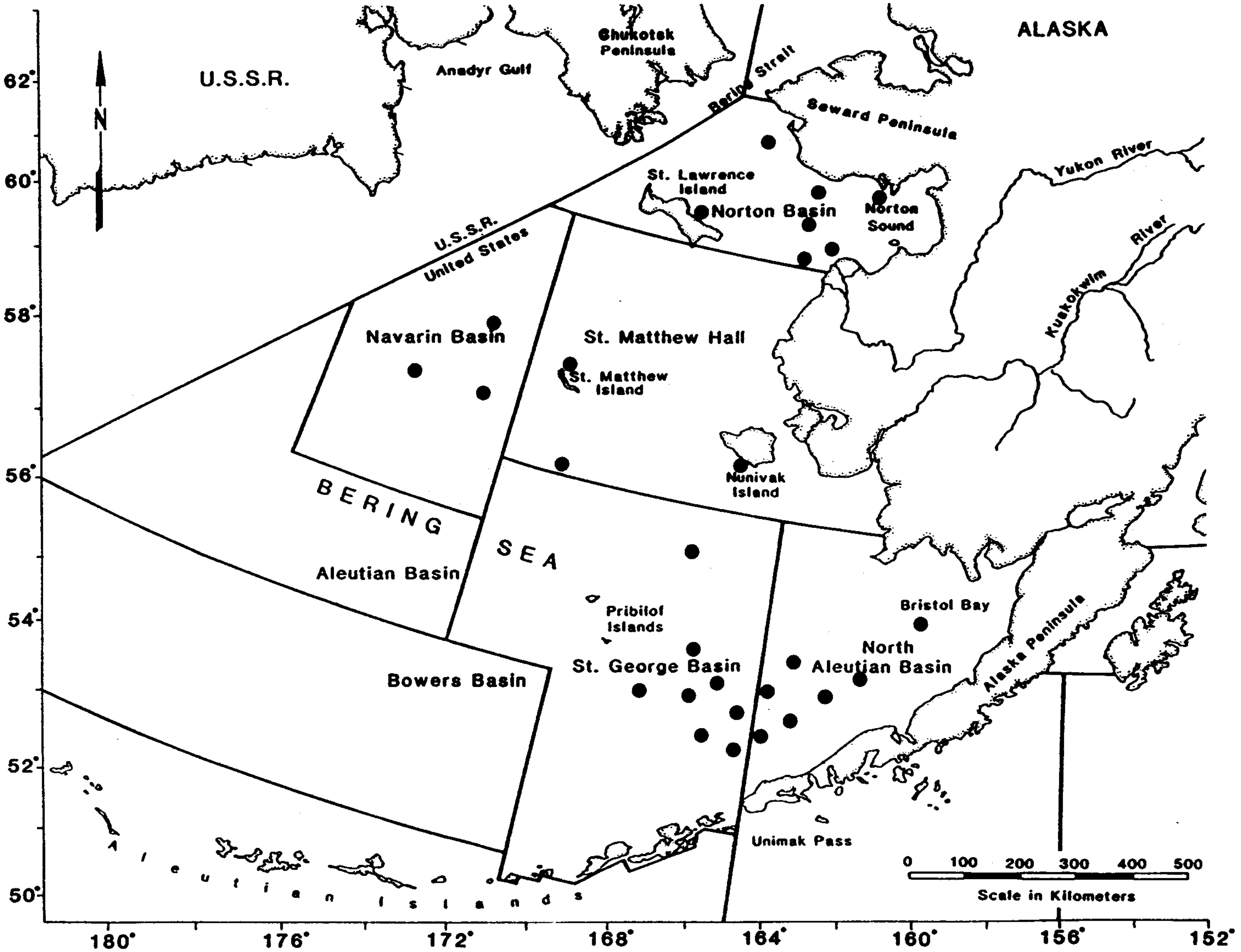


Figure 5-1
Suggested Assignment of Blocks and Risks.
ANOVA-based, Area Wide Approach

Source:
Alaska OCS Region Offshore
Program July, 1985



Source:
Alaska OCS Region Offshore Program July, 1985

Figure 5-2
Suggested Subjective Allocation of Stations, Area-Wide Approach

and previously sampled stations. In most cases, we would recommend additional minor adjustments of station locations to coincide more closely with nearby stations previously sampled in OCSEAP benthic and sediment chemistry programs, or in RACE trawl surveys (in that order of priority).

5.3.1.3 Kriging

The ANOVA-based approach of Section 5.3.1.1 allows us to compute an optimal allocation of stations for detecting impacts of OCS oil and gas development given a fixed total number of stations and/or samples and a number of underlying assumptions. Most importantly, we must assume that an impact occurs in only one zone among several being monitored, that it has the same effect on all stations within that zone, and that we know the probability of the impact occurring in each of the zones which make up the region being monitored. All three of these assumptions are unrealistic for the Bering Sea. Given the present uncertainity about when and where development may occur, the last is particularly questionable.

In this section we describe an approach of network design that does not require these unrealistic assumptions. However, it does require estimates of spatial and temporal variability of the chemical concentrations or biological parameters of interest which could not be determined at this time from the Bering Sea data available to us. Thus, we outline this approach only briefly, as a guide to investigators who might want to implement it after initial baseline sampling (using one of the other approaches) have provided the necessary data.

Given data (barium concentrations, for example) from a preliminary network of stations, the method known as "kriging" (Huijbregts 1975, Journel and Huijbregts 1978, Ripley 1981) provides estimates of concentration with standard errors not only at the monitored sites, but also at any point in the monitored region. In other words, it provides a spatial map of concentrations. Given such a preliminary map, we can determine where the standard errors of estimation are unacceptably large and locate new sampling sites in areas which will reduce these standard errors. For example, if development appeared likely in a particular part of the Bering Sea, and the preliminary map indicated that baseline barium concentration was imprecisely known in that part, we would locate additional stations there to collect additional baseline data.

The most important assumption underlying the kriging approach is that there are spatial correlations among the concentrations; values at neighboring stations are more likely to be similar than values at stations which are far apart. This assumption is plausible in light of our knowledge that chemical inputs to a marine ecosystem, whether natural, or the consequence of development, are propagated spatially according to the physical processes which govern the movement of water and sediment. The results of our examination of barium data collected in the Beaufort Sea Monitoring Program (Section 4.3) also support this assumption.

The kriging approach requires estimates of the assumed spatial correlations and takes them into account explicitly in computing estimates of concentration and their standard errors. Kriging is the analogue for spatial processes, e.g., time series. Wiener-Kolmogorov theory says that the minimum mean square error predictor of the value of a realization of a random process at a particular time is the conditional expected value given the values up to that time. This conditional expected value and the error associated with it depend on the correlation structure of the process. The process is generally assumed to be weakly stationary, i.e., the process mean, variance, and covariance do not change through time. If there is evidence of a time trend in the level of the process, it is assumed to be independent of the random component of the process and fitted as a function of time.

Ripley (1981) gives the clearest discussion of the spatial generalization of interest to us in this framework. Kriging estimates of concentrations are derived from estimates of an assumed slowly varying spatial trend in concentrations and on the variance and spatial covariance of an assumed mean-zero random deviation from this trend. They are the best linear unbiased estimates under this "trend + random fluctuation" model.

Any monitoring network designed for optimal detection, as discussed above, will provide necessary information for estimation of these quantities, although the specific geometry of the network and the nature of the spatial covariance will determine how accurate these estimates are. Given our extremely limited present knowledge concerning temporal and spatial variability of, say, barium concentrations in the Bering Sea, any estimates of the magnitude of standard errors of prediction of such concentrations made without further sampling would be speculative at best, based on guesses as to the nature of the spatial covariance.

The kriging approach of network design based on the aim of providing good spatial maps of concentration is quite different from the ANOVA-based approach. It does not provide a design which is optimal for testing the significance of effects of future development. On the other hand, it can provide baseline estimates of concentration, with standard errors, not only for stations at which sampling is conducted, but for any location in those parts of the Bering Sea which are monitored. Effects of development can be assessed against this baseline without making the unrealistic assumptions required by the ANOVA-based approach.

When the trend and spatial covariance are assumed known, the standard errors of the kriging estimates are independent of the monitored values themselves. They depend only on the spatial covariance function and the geometry of the monitoring network. For this reason, kriging can be very useful for monitoring network design when the focus is providing sufficiently small standard errors of estimation (Hughes and Lettenmaier 1981, Chami and Gonzalez 1984, and Olea 1984). Estimation errors increase as we move farther away from monitored sites. The estimation error at a monitored site is determined simply by sampling and temporal variability at that site. Thus, if we can estimate and/or model trend, local variability, and spatial covariance of a parameter such as barium concentration using data from a preliminary network of stations and knowledge of the physical processes governing water and sediment characteristics, we can estimate standard errors of future estimates of this parameter which would be obtained from the same or from a modified monitoring network.

5.3.2 Sale-specific Geographic Design

In the event that development only occurs in one or two lease areas of the Bering Sea, any one of the above approaches to sample design could be employed on a smaller scale to provide adequate coverage.

5.3.2.1 ANOVA-Based Approach

The application of the ANOVA-based approach to a one or two lease area specific program can be accomplished by simply downgrading the assigned risk in the blocks in the vicinity of lease areas where development is not expected to occur and reallocating the effort. For example, if no development is expected in the Norton Basin, the entire Basin would drop to a zone 6 classification. Similar logical adjustments would be possible for any combination of developing lease sales except that as fewer areas are included in the program the fine detail of assignment of blocks can be improved and, of course, the sample density for a given level of effort can be increased.

5.3.2.2 Subjective Approach

Under the subjective approach to station selection, the procedure for scaling the geographic scope down to reflect less than full area-wide development would proceed much as described for the ANOVA-based approach. Again, most if not all stations would be dropped from areas with no anticipated development. Development in either the Navarin or Norton Basins alone would not require sampling in any other basin. However, because of their proximity to each other, the same cannot be said of the St. George and North Aleutian Basins.

Additional sampling stations could be carefully placed in relation to specific sources and site-specific studies, if conducted, in a pattern reflecting expected gradients in the direction of prevailing transport. Additional sampling density could be added in particularly sensitive resource areas or nearby depositional areas.

5.4 SPECIFIC COMPONENTS AND APPROACHES

5.4.1 Sediment Chemistry Network

The initial hypotheses considered for the sediment chemistry component of the BSMP are recommended for the basis of the final program design:

H_o 1: There will be no change in concentrations of selected metals or hydrocarbons in surficial sediments beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o 2: Changes in concentrations of selected metals or hydrocarbons in surficial sediments are not related to OCS oil and gas development activity.

5.4.1.1 Statistical Design

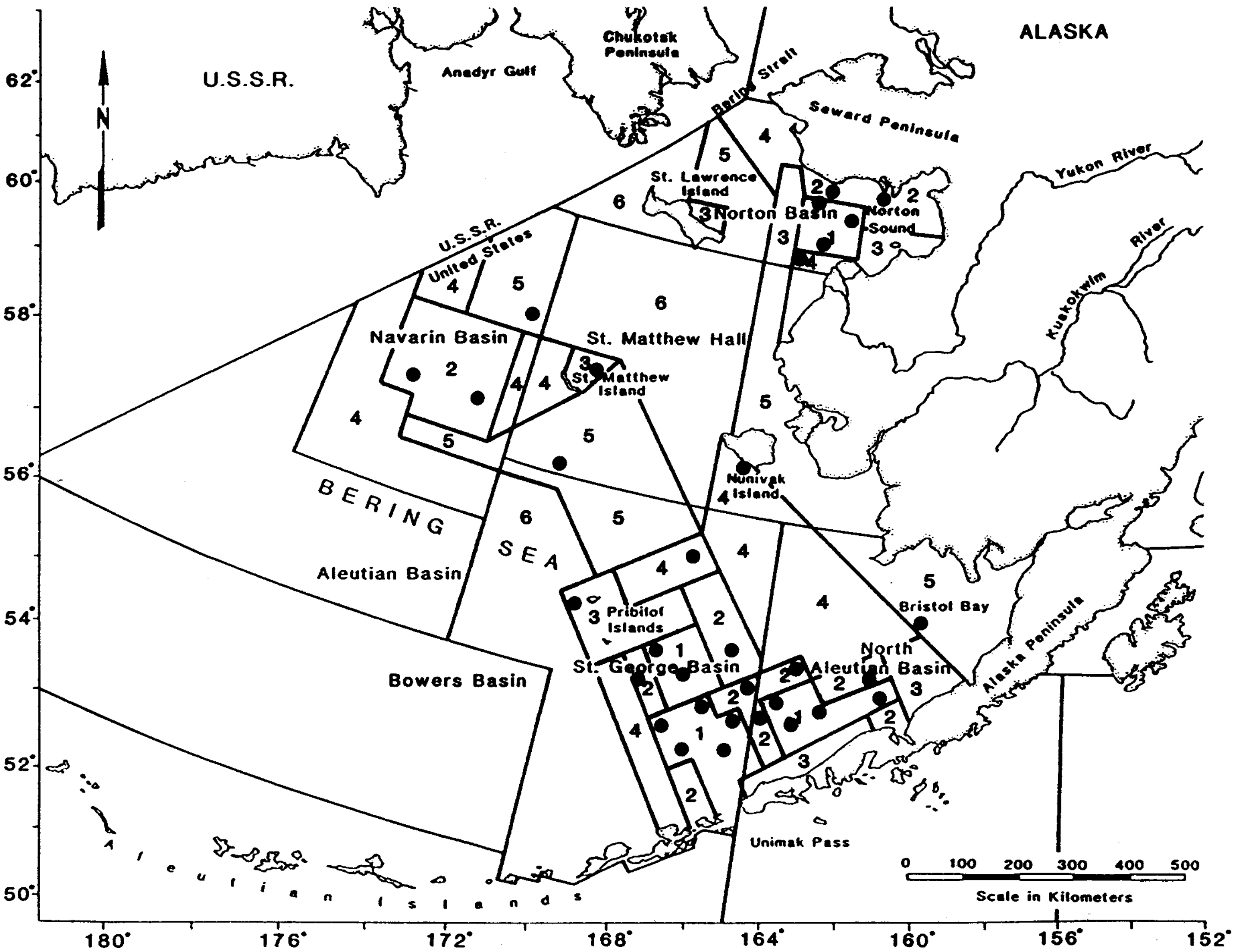
The recommended statistical design for sediment chemistry monitoring assumes that the Bering sea has been partioned into the six zones discussed in Section 5.3.1. Following the approach to sediment chemistry monitoring detailed by Zidek (in Houghton et al. 1984), as we have in earlier discussions in this report, we assume that development activities will have an impact (or be detected first) in one, and only one, of the first five zones and not elsewhere in the Bering. We assume that the probability of impact is 0.4 in Zone 1, 0.3 in Zone 2, 0.1 in zones 3 to 5, and 0.0 in zone 6.

If we have 36 stations (a relatively small number) for the entire Bering Sea, the optimal allocation of them to different parts of the Bering, from Zidek's example, is 14 to Zone 1, 13 to Zone 2, and 3 to each of zones 3 through 5. We have shown a scheme of potential station locations on Figure 5-3. Of the stations shown, approximately one-half were chosen to coincide with stations previously sampled in OCSEAP studies, one-quarter were placed near and downcurrent of potential sources, and the remaining one-quarter were "randomly" placed to fill each zone's allocated number. Criteria which would be used to choose station locations more precisely are shown in Table 3-13. In addition, percent mud should be high (silt plus clay fraction > 30 percent), indicating that the station is in a depositional area. Within these constraints, station locations should be randomly chosen.

5.4.1.2 Sampling Considerations

BSMP sediment sampling protocols should generally follow those employed by Boehm et al. (1985, 1986) in the Beaufort Sea. A Kynar-coated, stainless steel 0.1-m^2 van Veen grab is recommended for sampling. A suction system should be employed to remove surface water from the grab sample, and a coated aluminum scoop used to collect replicate, 1-cm deep surface sediment samples from each side of the grab for compositing in the field (see Section 4.3). The sampler and scoop should be cleaned between grab samples. Samples should be placed in teflon jars and stored over dry ice prior to shipment to the laboratory.

Sampling should be conducted for at least two years and preferably three prior to initiation of large-scale development activities to establish "baseline" contaminant levels. If two to three years of sampling are carried out prior to substantial development activity in zones 1 through 5, the resultant data base will allow a better assessment of detectable change and a more optimal allocation of sampling effort



Source:
Alaska OCS Region Offshore
Program July, 1985

Figure 5-3
Suggested Station Placement
Under ANOVA-based Approach

than is possible at present. Depending on the results of baseline sampling, sampling during development and production should be conducted every third year (a compromise between science and economics) to document any long-term trends. Additional sampling should be implemented following any anomolous pollution event such as a large spill or major pulse of drilling activity or following indication of development of an adverse trend.

All sampling should be conducted (as a matter of practicality) in July or August.

5.4.1.3 Analytical Considerations

The analytical strategy for the sediment chemistry monitoring component of the BSMP should adhere to the procedures followed by Boehm et al. (1986) for the second year of Beaufort Sea background sediment chemistry analyses. Based on the first year analytical results, modifications to the analytical strategy may be recommended to optimize future sampling and analytical efforts (e.g., Boehm et al. 1986).

A percentage (e.g., 10 percent) of samples should be split in the laboratory so that "paired" analyses of the various chemicals can be performed for analysis of analytical variability. The sediment parameters of interest include trace metals, hydrocarbons, sediment grain size, and total organic carbon.

Trace metal analyses should be conducted for barium, chromium, and vanadium. Additional metals of interest include cadmium, copper, lead, and zinc. Cadmium, lead, and zinc can be present at elevated concentrations in drilling muds depending on the source of the barite portion of the mud (Houghton et al. 1981). Copper may be present in elevated concentrations in produced waters. Lead has also been reported at high concentrations in certain fluids associated with the drilling process (Houghton et al. 1981). Analytical techniques for these metals include a combination of flame or graphite furnace atomic absorption (FAA or ZGFAA), inductively coupled plasma emission spectrophotometry (ICAP), and energy dispersive x-ray fluorescence (XRF) (Boehm et al. 1985).

Hydrocarbon analyses should follow the hierarchical strategy outlined in Boehm et al. (1985). Hydrocarbon parameters to be measured are listed in Table 5-1. A few samples should be screened using ultra-violet/fluorescence spectroscopy (UV/F) to determine if Bering Sea background levels are lower than seen in the Beaufort Sea. This should be followed by a more detailed, component-specific analysis by gas chromatography flame ionization detection (GC-FID) and gas chromatography/mass spectrometry (GC/MS). All sample replicates should be analyzed using GC-FID and GC/MS. Results of these analyses techniques can be used to identify hydrocarbon sources (e.g., petrogenic, marine, terrestrial, see Tables 3-5 through 3-8).

TABLE 5-1

AROMATIC HYDROCARBONS AND HETEROCYCLICS TO BE QUANTIFIED USING HIGH RESOLUTION CAPILLARY GAS CHROMATOGRAPHY/MASS SPECTROMETRY(a)

m/e Ion Search	Compound Identification
128	Naphthalene
142	Methyl naphthalenes
156	C-2 napththalenes
170	C-3 naphthalenes
184	C_4 naphthalenes
152	Acenaphthene
154	Biphenyl
166	Fluorene
180	Methyl fluorenes
194	C-2 fluorenes
178	Phenanthrene, anthroacene
192	Methyl phenanthrenes (anthracene)
206	C-2 phenanthrenes (anthracene)
220	C_3 phenanthrenes
234	C_4 phenanthrenes
202	Flouranthene, pyrene
216	Methyl fluoranthene or methyl pyrene
228	Chrysene, triphenylene
242	Methyl chrysene
256	C-2 chrysenes
252	Benzopyrene, perylene
184	Dibenzothiophene
198	Methyl dibenzothiophenes
212	C_2 dibenzothiophenes
226	C_3 dibenzothiophenes

(a) Source: Boehm, in Houghton et al. (1984)

Lignin analysis described in Section 3.6.1 are not recommended for far-field monitoring at this time. The demonstrated sensitivity of detecting 1 percent or less of lignosulfonate in sediments does not appear adequate as an indicator of a compound that seldom comprises more than 4 percent of drilling mud solids; i.e., if drilling muds discharged are diluted by only 1:4 prior to deposition, they would not be detectable using this technique at these sensitivities.

5.4.2 Biological Monitors/Sentinel Organisms

5.4.2.1 General

Two BSMP workshop hypotheses that are related to bioaccumulation and pollutant effects at the organism level were adopted.

H_o 1: There will be no change in concentrations of selected metals or hydrocarbons, or other sublethal effects, in bioindicator species beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o 2: Changes in concentrations of selected metals or hydrocarbons, or sublethal effects, in sentinel organisms are not related to OCS oil and gas development activity.

It was recommended in the workshop that indigeneous species be used as the bioindicator/sentinel organism(s) if at all possible. In the following sections candidate indigeneous species are discussed, followed by discussions of sampling and analytical considerations.

5.4.2.2 Candidate Bioindicator Species

Several species of Bering Sea organisms were suggested as candidate bioindicator species (Table 5-2). These species include walrus and possibly northern fur seal, yellowfin sole and possibly walleye pollock, *Macoma calcarea*, and *Neptunea* spp.

TABLE 5-2

CANDIDATE INDIGENOUS SPECIES

Species	Analyses
Walrus (*Odobenus rosmarus*) Northern fur seal (*Callorhinus ursinus*)	Trace metal concentrations in tissue/organ samples
Yellowfin sole (*Limanda aspera*) Walleye pollock (*Theragra chalcogramma*)	Sublethal effects, trace metal and hydrocarbon concentrations in liver.
Macoma calcarea *Neptunea* spp.	Trace metals and hydrocarbon concentrations in soft body parts

Specific characteristics considered desirable for inclusion as a candidate bioindicator species were a wide distribution in the Bering Sea, population density of a magnitude that would facilitate collection of sufficient numbers, size characteristics amenable to biomass requirements for chemical analyses, and ongoing research programs that can be used as a source of measurements or collections for the sentinel organism (see also Table 3-13).

Walrus tissue and organ samples have been routinely collected by the USFWS in conjunction with native subsistence harvests (Section 3.3.6). The archival of marine mammal tissue for subsequent chemical analysis was initiated in 1987 through MMS/OCSEAP. Continued sampling and analysis of the samples for petroleum hydrocarbons, barium, chromium, and vanadium would provide an indication of whether bioaccumulation was potentially important in higher trophic level organisms. If concentrations of these contaminants show increases over baseline levels, it may be possible to trace the source of the contamination based on a knowledge of walrus feeding habits and movement patterns. Coordination of BSMP requirements and analytical protocols (Section 5.4.2.3) with USFWS sampling schedules and procedures would be required.

A second potential candidate marine mammal is the northern fur seal. If sampling of seal tissue and organs could be conducted by NMFS biologists monitoring the native subsistence harvest on the Pribilof Islands, this would be an efficient means of monitoring another higher level consumer for exposure to potential contaminants due to OCS oil and gas development.

Demersal fish are an extremely important commercial resource in the Bering Sea. Two species, yellowfin sole and walleye pollock, occur in large numbers over a wide area and thus are suitable candidate species. Yellowfin sole appears to be the more suitable of the two candidate demersal fish species for monitoring since it is demersal and has a much closer association with the sediments than does walleye pollock, a semi-demersal species. There are also ongoing studies (RACE trawl surveys, NOAA Status and Trends Program) that provide for regular sampling of the populations of these two species and obtaining samples for the BSMP may be possible through cooperative efforts (Section 3.3.8).

Macoma calcarea is a surface-feeding detritivore occurring in greatest abundance on the southern portion of the southeastern shelf (McDonald et al. 1981). Beyond this area, its distribution extends north and west into the outer shelf and the central shelf. Most (97 percent) of the population occurs between 50 and 100 m water depth in substrates composed of medium silt. Thus, this species would be likely to occur in the depositional zones that are key locations for the sediment sampling network. Where insufficient *M. calcarea* are available, other tellinid clams could be substituted. *M. calcarea* is also of sufficient size to satisfy the tissue volume needs for analytical chemistry without expending excessive collection effort; it is capable of reaching over 20 mm shell length in approximately 8 years (McDonald et al. 1981). *M. calcarea* is also known to be an important prey item for commercially important fish and shellfish species. Thus, monitoring of trace metals and hydrocarbon concentrations in the soft body parts of this species would provide some indication of potential biotransfer ("chaining") of contaminants to higher trophic levels.

Neptunea spp. is a large, predatory gastropod with a wide distribution throughout the continental shelf area and upper slope of the eastern Bering Sea (MacIntosh and Somerton 1981). Five species of Neptunea comprise over 87 percent of the snail biomass taken in NMFS-sponsored RACE trawl surveys. A wide variety of benthic organisms are consumed by Neptunea, including polychaetes, bivalves, barnacles, fishes, and crustaceans. Thus, monitoring of trace metals and hydrocarbons concentrations in the soft body parts of this species would provide some indication of contaminant transfer within the benthos. These features all serve to make Neptunea a top benthic carnivore candidate for monitoring.

5.4.2.3 Sampling Considerations

Sampling of marine mammal tissue and organs must be coordinated with USFWS so that adequate replication is achieved for BSMP purposes. If possible, a minimum of five replicate samples for each tissue or organ type is desirable for purposes of estimating within sample variation and/or possible archiving. Replicates in this case would ideally come from animals harvested in one particular area, rather than from animals collected over a broad geographic expanse. Adjustment of the number of replicates required would be made after analysis of several year's worth of data (including those data already gathered by USFWS). Tissue and organ samples should be collected in a manner that prevents contamination with any of the metals or hydrocarbons of concern and kept frozen prior to laboratory analyses.

Obtaining ample replicates of demersal fish and Neptunea spp. should not be the problem it is for marine mammals. Rather, the limiting factor for these species may be the time available to collect samples and process them apart from other shipboard duties. Since the RACE trawl studies obtain data from a wide area of the Bering Sea, it is recommended that samples be obtained over a broad geographic sampling grid (e.g., Figures 5-2, 5-3) to optimize the chances of detecting increases in sublethal effects that are specific to only a portion of the Bering Sea.

Neptunea samples should only be analyzed for whole body (soft parts) metals and hydrocarbons. A subsample of 50 yellowfin sole from each station should be examined for signs of external morphological anomalies. A subsample of ten of these should be necropsied for visual examination of liver condition. Liver and bile from at least six fish should be frozen onboard for later analyses.

Bivalve samples should be collected by the most efficient gear available (large grab or dredge), as near as possible to sediment sampling locations. In practice, only a limited amount of ship time can be allocated to the bivalve collection effort. All the dominant species taken should be processed and saved. Selection of samples to analyze will be done later to maximize the information obtained. Soft body parts of each species should be pooled to form 30 g "replicates" (an optimal weight of sample) to provide adequate tissue volume for chemical analyses.

For each biological tissue sample, enough material should be collected to provide at least six replicates for initial determination of appropriate sample size. Dissection techniques should be carefully carried out to avoid hydrocarbon or metals contamination of the samples. This same approach was recommended by Houghton et al. (1984) and followed by Boehm et al. (1986) in the Beaufort Sea.

Sampling for bivalves should occur coincident with sediment chemistry sampling. Fish sampling will follow the standard RACE sampling schedule (usually June-July) and walrus would come from the subsistence harvest. Sampling of sediment and bivalves in late summer will allow maximum organism exposure in shallow areas to contaminants deposited over the previous winter-spring-summer before they are dispersed by fall storms. A minimum of two and preferably three or more years of predevelopment sampling is needed to provide baseline data and to allow refinement of replication and design needs. Depending on the degree of natural variation determined by the baseline sampling results and advanced sampling design, sampling every three years during development and following any major pollutant incident should be adequate to identify long-term trends.

5.4.2.4 Analytical Considerations

Analytical considerations for sentinel organisms can generally be divided into three categories: analysis for trace metals, analysis for hydrocarbons, and sublethal effects analyses.

Analysis of tissue samples for the trace metals barium, vanadium, and chromium should be carried out following protocols recommended in the Beaufort Sea Monitoring Program Workshop (Houghton et al. 1984) and subsequently refined by Boehm et al. (1986). These metals are the ones most likely to have their sediment concentrations influenced by discharges of drilling muds and produced waters. Additional metals of interest include cadmium, copper, lead, and zinc. Biota samples should be frozen and stored at -20 degrees C until analysis. Prior to analysis the tissues, organs, or organisms to be analyzed should be thawed, cleaned of foreign material, and rinsed in double deionized water. Samples should be placed in an acid-cleaned, pre-weighed plastic jar, the wet-weight recorded, and the sample freeze-dried to a constant weight. After weighing, the sample should be ground to a fine powder in a plastic ball mill. Acid digestion using nitric acid should then be carried out. Concentrations of barium, copper, vanadium, and zinc should be determined by inductively-coupled flame emission spectrophotometry (ICAP). Concentrations of cadmium, chromium, and lead should be determined using graphite furnace atomic absorption (ZGFAA) (Boehm et al. 1986).

Tissue/organ sample preparation for hydrocarbon concentration determinations should follow the protocols outlined by Boehm et al. (1986). Total extracts of the tissues should be analyzed with high-resolution gas chromatography using flame ionization detection (GC-FID) and gas chromatography/mass spectrometry (GC/MS) for saturated and unsaturated/ aromatic hydrocarbons, respectively.

Sublethal effects monitoring of demersal fish species is aimed at detecting a number of biochemical/physiological conditions that have been linked to exposure to various contaminants (Section 3.6.3.1). Sublethal effects applicable to the BSMP include incidence of internal and external tumors, fin erosion, bile extract screening for PAH metabolites (using protocols developed by NMFS at NWAFC, Seattle, Washington), and activity of the mixed function oxygenase system. Analytical methods for necropsies should be carried out following the methods developed by Malins et al. (1980, 1982). Weight, length, and age (from otolith collections) measurements should also be recorded for demersal fish. Analytical methods for bile extract screening and induction of the mixed function oxygenase system are currently evolving. We recommend that at initiation of the BSMP, the most current/accepted techniques for these analyses be instituted.

5.4.3 Benthos Sampling Network

5.4.3.1 General

BSMP Workshop hypotheses related to benthic monitoring are as follows:

H_o 1: There will be no change in values of selected benthic assemblage parameters or in population parameters of selected species beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o 2: Changes in values of selected benthic parameters are not related to OCS oil and gas development activity.

Benthic populations in the Bering Sea are widely variable in both time and space. Previous studies have shown that each of the major basins of the Bering Sea where OCS activities may occur have a characteristic group or groups of species that are somewhat unique (Feder et al. 1982). For example, assemblages identified in the Navarin Basin lease area were primarily deposit-feeders characteristic of the muddy bottom in the area. In contrast, tube-dwelling ampeliscid amphipods dominated the suspension-feeding assemblage present in the western Norton Basin lease area north of St. Lawrence Island (Feder et al. 1982). Since an area-wide benthic monitoring program would, by definition, deal with highly divergent benthic communities in a variety of habitats, we recommend that benthic monitoring for the BSMP be carried out on a region by region basis as development proceeds.

5.4.3.2 Statistical Design

Sampling locations should correspond as closely as possible with previously defined locations for the sediment chemistry monitoring network in lease areas of interest. Without access to the 1975-1976 Bering Sea data set of Feder and individual sample data of Cimberg et al. (1980; discussed in Section 4.2.3), a detailed statistical design is not possible. A review of this data set will be necessary prior to making final recommendations regarding replication.

5.4.3.3 Sampling Considerations

In addition to the locations at which benthic samples should be taken, several other aspects of the sampling program need to be defined, including: sampling frequency, means of collection, sample handling and storage, and sample archiving.

The frequency of sampling should be determined by the rate of growth of OCS activities. Given the current low level of industry interest in the area, background benthic sampling should not be attempted until a more concrete schedule for development exists. Once a development schedule has been put forward, 2 to 3 years of background benthic sampling should be carried out in the area. Once development has begun, continued sampling on a schedule of every third year is probably appropriate, unless the baseline sampling indicates excessively high year-to-year variability.

Methodological conventions for sample collection developed and utilized by Feder and his co-workers for numerous OCSEAP-related infaunal surveys throughout the Bering Sea should be adhered to for benthic sampling carried out as part of the BSMP (McDonald et al. 1981). Samples collected by a 0.1-m^2 van Veen grab and pipe dredge have received the most detailed quantitative analyses. Since the recommended sediment sampling device is a similar-sized van Veen grab, we recommend the use of this device for benthos in the BSMP. Until a detailed analysis of parameter variability from historic data or, failing this, analysis of a pilot study to determine replication levels for various parameters, recommendations concerning replication cannot be made.

Benthic samples should be washed over 1-mm^2 wire mesh screens after collection and preserved aboard ship. A 10-percent buffered formalin solution should be used for field preservation of samples. Care should be taken to properly label all samples. Samples should be stored in airtight containers prior to laboratory processing. Any samples intended for archival should receive double labels (on the inside and outside of the sample) and should be placed in a sealed container to prevent evaporation of preservative. Prior to sealing, the amount and concentration of preservative in the container should be checked and adjusted, if necessary.

As for other components of the sampling program, the timing of benthic sampling is recommended to occur in late summer for two to three baseline years prior to the initiation of major development and potentially every third year thereafter. In addition, benthos should also be sampled in the year following any major pollution incident or major increase in the overall rate of development activity.

5.4.3.4 Analytical Considerations

Taxonomic identifications of benthic organisms should be to the species level and should be carried out by individuals with experience with Bering Sea fauna. Independent verifications of identifications should be carried out by recognized taxonomic authorities. Such measures will help ensure that the the assemblage and population parameters calculated from the species identifications are accurate.

Recommended parameters to record for each replicate sample include: density (number of organisms/m^2) and wet weight biomass (g/m^2) of both total organisms and dominant species, number of individuals, number of species, and age structure of dominant species.

Cluster analysis techniques have been used to delineate species assemblages characteristic of sampling stations in order to characterize broad areas of benthic habitat. Carried out routinely for all baseline and post-development benthic sampling, a detailed picture of the benthic assemblages would emerge. If, for whatever reasons, changes in benthic populations were to occur, subsequent analyses would be expected to detect this change. Cluster analysis is therefore recommended for BSMP benthic sampling as a tool for delineating benthic assemblages. This method would not, however, allow a determination of the cause of any observed change.

5.5 OTHER MONITORING CONSIDERATIONS

5.5.1 Solutions to Problems with the Existing Bering Sea Data Base

NOAA contracts which involve data collection generally require timely submission of data in a specified National Oceanographic Data Center (NODC) format. Our experiences with NODC formats in designing the Beaufort Sea Monitoring Program (Houghton et al. 1984) have been positive for the most part. We suggest that these data formats are good ones for use in a Bering Sea Monitoring Data Base. This is a first step in providing an accessible data base; however, there are several problems with this approach.

Submitted data often contain serious errors that are never corrected (see Zeh et al. 1981). Specific problems identified within the NODC data sets we reviewed included lack of identifying information for surveys, discrepancies between NODC data and reported results, incorrect taxonomic codes, incorrect coding of replicate samples, missing data sets, and ambiguous records. To eliminate errors and misunderstandings resulting from use of different versions of NODC codes (e.g., taxonomic codes) in different studies, the BSMP data base should be updated whenever NODC codes are changed so that codes in the data sets are compatible with the most recent NODC versions. Most of the serious errors and omissions can be eliminated by better funding and planning for data submission. Investigators contracted to carry out sampling for the BSMP should meet with the BSMP data manager before beginning their sampling to decide on the formats in which the data are to be submitted and to resolve questions and problems. It should be made clear to investigators that they must use NODC taxonomic, chemical substance, and other codes in submitting their data, and they should be strongly encouraged if not required to use these codes at the outset instead of using coding systems devised for other purposes. When replicates are collected, the contracting agency should require them to be included individually in the data base instead of accepting summary data.

NODC formats that are used for identifying general sample information (station, latitude, longitude, date and time, etc.) appear on one or more types of record while variable measurements (concentration of hydrocarbons or metals, taxon counts, etc.) appear on other record types. As a result, it is often difficult, if not impossible, to determine where or when specific data were collected. Unless a copy of the report text is available, or referenced on the NODC tape, the data may be unusable. The lack of identifying information accompanying data sets can be eliminated by making sure that survey header records are complete and adding text records immediately following the survey header which list references (e.g., the reports in which the data set is discussed). These text records can be added after the initial submission of the data if the data are submitted before the reports, as they should be. If simple procedures for supplementing and amending data sets after submission to NODC do not presently exist, they should be developed.

Even when separate samples and replicates are coded completely and correctly, text records at the start of a file would be helpful to more fully explain the methodology and to clarify definitions of samples and replicates. For example, such a record could note whether each sample is a separatek Van Veen grab or the result of pooling subsamples from one or more grabs or the result of subsampling a composite of several grabs. If there is more than one replicate per sample, another record could explain whether each replicate is the result of reanalysis of the whole sample or of analysis of subsamples. If subsampling is involved, the method should be explained. Needed improvements in NODC formats should be implemented. For example, the lack of data on bottom characteristics in File 144 can be eliminated by adding fields to currently unused columns of the existing environment record for File 144 or creating an additional bottom characteristics record. Of course, such additions should be coordinated with NODC and documented in their User's Guide.

In general, we encourage the inclusion of the BSMP data base in NODC archives. However, adequate quality control and data accessibility require that this data base be under the control of a BSMP data manager as well.

5.5.2 Data Management

Many marine monitoring programs have failed because budgetary constraints have led to implementation of a field and analytical data gathering program without having the necessary data and information management system in place. For the BSMP to be successful, a comprehensive data and information management system should be established at the outset of the program. This system will be particularly important to the program, since much of the physical and environmental data critically needed to interpret any changes observed in the parameters of primary interest (i.e., contaminant concentrations; bird, mammal, and fish populations) will be obtained from other program sources and may need to be reformatted or reprocessed to be useful in the monitoring program.

At a minimum, the data and information management program should:

- Ensure that all data gathered by monitoring program components are properly formatted and stored so as to be readily accessible;
- Ensure that the necessary ancillary data from other programs are obtained, analyzed, and stored in appropriate formats;
- Ensure that all reports and publications relevant to monitoring programs are available in a central location; and
- Ensure that appropriate trend analyses and special studies of the monitoring data are performed in a timely manner.

To improve data accessibility in the BSMP, we recommend that funding be provided to establish and maintain a computerized Bering Sea Monitoring Data Base supervised by a single data manager and staff. To the greatest extent possible, this data base should physically contain all data collected by all agencies and institutions involved in various Bering Sea research and monitoring efforts. The data manager should be responsible for maintaining an index of all Bering Sea monitoring data, whether or not it is physically contained in the data base. This would expedite the flow of information to researchers working in the area.

In addition to keeping track of all Bering Sea monitoring data sources, responsibilities of the data manager should include:

- Coordination with NODC for incorporation of existing Bering Sea data into the data base and compatibility of formats.
- Obtaining data from investigators in a timely manner.
- Developing data checking programs or using existing ones to ensure that data submitted are free of such errors as illegal or inappropriate codes; unreasonable sampling dates, latitudes, and longitudes; impossible values for measurements. This data checking requires the data manager and staff to have greater familiarity with the type of sampling being done by each investigator than has generally been the case in previous NODC data verification projects.
- Developing programs which allow easy selection and reformatting of data into files appropriate for statistical analysis.

- Providing data on magnetic tape in industry-standard formats or by direct transmission between computers in response to authorized requests for data. Providing cost estimates for fulfilling particular requests if costs are associated with this service.

5.5.3 Related Considerations

The workshop briefly discussed and endorsed several concepts that should be incorporated into the overall program to optimize the monitoring program outlined in the preceding section and to enable optimum interpretation of the data generated.

5.5.3.1 Physical Environmental Data

To interpret changes in biological populations and in environmental concentrations of chemical contaminants observed from year to year, it is necessary to identify whether such changes may have been caused by natural events or natural variability in the environment. With the possible exception of some disease epidemics, all such natural change or variability would be mediated ultimately by changes in the physical environment associated with climatic variations. Therefore, the BSMP should make provisions for routine gathering and assessment of physical environmental data which can be used to identify variations in the "climate" or physical regime. The physical environmental data and data assessment needed for this purpose do not necessarily include detailed field description of physical parameters, such as salinity, temperature, and currents throughout the entire Bering Sea coastline. The information gathered should be sufficient to allow identification of anomalies in climate-controlled factors that could account for anomalous biological or sedimentological events. In the Bering Sea, the principal such anomalies include early or late ice formation or breakup, spring river discharge, and on a broader scale, El Nino-related changes in ocean circulation and weather. These factors might alter migration and reproduction patterns of certain species, primary production, and the availability of food for certain species. In addition, abnormally severe or quiescent weather, particularly during ice formation and breakup, and during the open water period, could modify primary production, ice scour, and wind-induced wave and current redistribution of bottom sediments.

The need for "climate" information can be illustrated by three examples of rapid biological population structure changes that might have been misinterpreted as being caused by pollution impacts if the scientific community had not been aware of causative anomalous climate events. First, a crash in bird populations and the elimination of several bird species from Christmas Island during 1982-1983 might have been incorrectly attributed to possible pollution effects without the knowledge that a strong El Nino event was in progress. This knowledge led to the subsequent deduction that this natural event had reduced the Christmas Island birds' food supply. Second, major changes in biota observed in the northern Chesapeake Bay during 1972 and 1973 were similar to some pollutant-induced changes and might have been ascribed to increased contamination of the bay. However, it was known that the very large rainfall and runoff associated with hurricane Agnes caused dramatic changes in sediment distributions in the affected area, and therefore, these physical changes resulted in the Chesapeake Bay effects. Third, the catastrophic kill of shellfish in the New York Bight during the summer of 1976 was initially ascribed to pollution until existing data were examined that revealed that anomalous physical conditions caused this event. Unusual weather in the winter and spring combined with a prolonged quiescent period to reduce the flushing rate of shelf bottom waters and to cause onshore movement and concentration of a natural midshelf phytoplankton bloom. The bloom resulted in anomalously high natural oxygen demand, and the anomalously low oxygen resupply resulted in the anoxia and the shellfish kill.

It is important to note in each of these three events that unjustified policy decisions concerning contamination of the marine environment could have been made on the basis of biological monitoring data. These data showed an effect that reasonably could have been caused by pollution, if "climate" information had not been available. However, in each instance, very limited information concerning the anomalous climatic forcing functions operating during the period when the biological changes took place, combined with a sound basic knowledge of the relevant ecosystem, allowed correct interpretations to be made concerning these events.

The BSMP should incorporate an assessment approach to the physical regime which is designed to cost-effectively permit identification of anomalous regional-scale physical events. In general, some of this type of information can be obtained from existing observations, such as flow records of some rivers, weather records, and satellite images. These existing information bases should be routinely accessed for the BSMP and processed to provide an annual description of, at least, the following: monthly (except in the winter) patterns of ice cover and, where possible, estimated thickness; weekly, or more frequent, discharge rates for some major rivers; frequency and intensity of strong storms and normal winds, preferably at two or three shore stations and, if available, at one or more offshore stations throughout the region; weekly or monthly air temperature averages for these same locations; and, if possible, up to weekly remote sensing images during the spring showing the extent of turbidity plumes caused by river inflow.

If some parts of this information are not available, it will not necessarily compromise the monitoring program and it probably will not be necessary to develop extensive long-term monitoring programs to fill the gaps. For example, if remote sensing images of river plume extent are not routinely available, this information could be inferred with sufficient certainty from river discharge rates, wind data, and several limited surveys of the plumes conducted over one or more spring periods, or by inference on the basis of existing knowledge of plume distribution for some rivers. However, to meet this basic need, some improvements may be required in the existing physical measurements programs such as more complete gauging of river discharge.

In addition to the BSMP, there will continue to be many other ongoing and periodic monitoring programs in the Bering Sea, such as discharge compliance monitoring programs for which physical data, including water column structure and current data, are obtained. Where appropriate, these data should be acquired on a routine basis by the BSMP and subjected to analysis and interpretation to supplement the more general regional data discussed previously. Such analyses become particularly important when it is suspected that anomalous climatic conditions may have contributed to any observed biological or chemical contaminant distribution change. Physical data from any monitoring program should clearly be incorporated in a single data management system for maximum utility.

5.5.3.2 Quality Assurance

The proposed BSMP will incorporate a number of chemical and, perhaps, biochemical measurement techniques, some of which will be highly complex, requiring evolving techniques. For example, hydrocarbon and trace metal analyses will be performed at very low environmental concentrations. Since the monitoring program will be aimed at detecting small changes and trends in these environmental concentrations, it is imperative that the analyses produce consistent, accurate, and reproducible results, both within a given set of samples and over the years of program operation. These results can only be achieved if the measurement program is performed under rigorous quality control and quality assurance procedures. These procedures would require strict adherence to written field and laboratory procedures and full traceability of samples. They would also require the use of reference samples, when possible, and intercalibration studies among laboratories participating both in the Bering Sea monitoring program and in similar programs in other regions. Sufficient budgetary resources must be set aside to develop and maintain this quality assurance throughout the duration of the monitoring program. Quality assurance should be afforded the highest possible priority throughout the field, analytical, and data handling parts of the proposed monitoring program. Quality assurance must also be extended to all other data obtained and used in the BSMP. The quality of monitoring efforts and reporting results should be assured through peer review procedures throughout the program.

5.5.3.3 Oversampling and Storing

Since many of the analytical techniques to be used in the monitoring program are sophisticated, expensive, and evolving, it is recommended that the monitoring program utilize a strategy of oversampling and storing samples for chemical analysis. Although the cost of obtaining samples and storing them is not trivial, this approach can be cost-effective in the long run since it will allow for retroactive analyses to more efficiently address questions that may arise later in the monitoring program. For example, if additional stations are sampled but not analyzed, these samples can be used to confirm findings and improve geographical coverage if contamination of part of the region is discovered at the small number of primary stations. In addition, oversampling of each station can allow sequential analysis of replicate samples until a desired level of statistical power in the results is achieved. Finally, properly stored samples will allow retroactive analyses for currently unidentified contaminants or by new and improved techniques. Generally, it is believed that small quantities of all samples should be archived in their original wet state, frozen to below -20°C. Although it is certain that this storage technique will not protect the sample against concentration change in all chemicals, is it likely that this technique will be adequate for most future sample uses.

5.5.3.4 Coordination of Biological and Chemical Sampling

To the greatest extent possible, all biological and sediment sampling should be coordinated in time and space. Since the expected probability of detection of effects is small, sampling of biological and sediment prameters must occur concurrently in order to maximize the probability of detection of relationships between biota and sediments.

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APPENDIX A

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