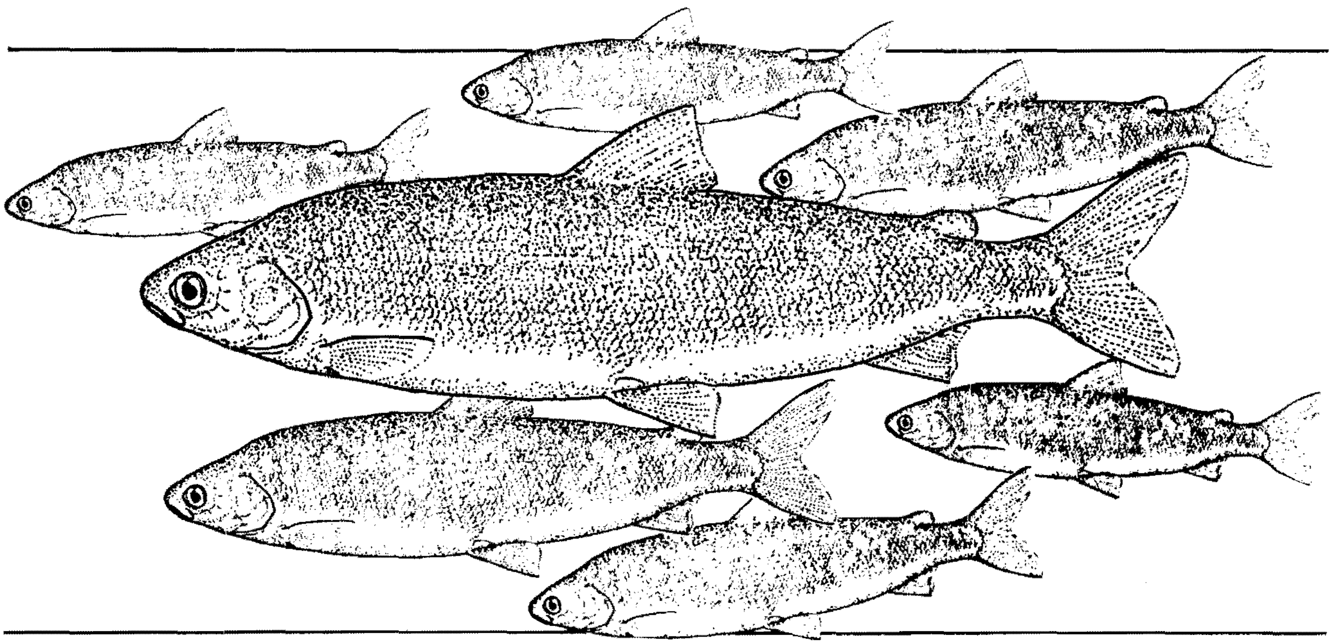
Outer Continental Shelf Environmental Assessment Program

Beaufort Sea Monitoring Program:

Proceedings of a Workshop and Sampling Design Recommendations



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Beaufort Sea Monitoring Program: Proceedings of a Workshop (September 1983) and Sampling Design Recommendations

Prepared for the
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NOTICES

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1. EXECUTIVE SUMMARY

1.1 BACKGROUND

The National Oceanic and Atmospheric Administration (NOAA) and the Minerals Management Service (MMS) have a regulatory mandate to assess potential areawide or cumulative effects of anticipated oil and gas development on the U.S. Beaufort Sea continental shelf. Accordingly, these agencies sponsored a workshop in September 1983 to begin the process of developing a long-term monitoring program for the area. Invited participants included regulators, managers, and scientists from cognizant agencies, as well as leading scientists with specialties in aspects of the Beaufort Sea ecosystem or in offshore monitoring programs elsewhere in North America.

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

- To detect and quantify change that might:
  - result from OCS oil and gas activities;
  - adversely affect, or suggest another adverse effect on, humans or those parts of their environment by which they judge quality; and
  - influence OCS regulatory management decisions.
- To determine the cause of such change.

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

- Summarize the workshop proceedings;
- Statistically analyze (using available data) monitoring approaches suggested by the workshop to optimize the statistical sampling design applied; and
- Detail optimum approaches to Beaufort Sea monitoring that meet the prescribed goals.

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 Beaufort Sea nearshore zones and potential monitoring approaches.
- Description of the biological environment of the Beaufort Sea nearshore zones and potential monitoring approaches.
- Description of geochemical, biochemical, microbial, and biological community indices and their potential applicability to the BSMP.

A panel of agency scientists then met to develop hypotheses about potentially significant development-related problems. The panel also suggested approaches to monitoring that were believed to be of greatest value in providing data regarding each hypothesis. Five of these hypotheses were considered relevant to the areawide monitoring program. These deal with OCS oil and gas development effects on the following components of the environment:

I Heavy metals accumulation in sediments and organisms
II Hydrocarbon accumulation in sediments and organisms
III Bowhead whale migration patterns
IV Anadromous fish numbers
V Waterfowl (oldsquaw) numbers.

Two other workshop-related hypotheses were considered more relevant to monitoring of localized impacts from specific activities. These dealt with:

VI Disturbance of common eider nesting
VII Effects on Boulder Patch community structure.

1.3 RECOMMENDED MONITORING PROGRAM

The consultant's team first restated each workshop-recommended hypothesis into a statistically testable format. This required splitting of each into at least two component null hypotheses—one stating that no change has (or will) occurred and the second (applicable only if the first is rejected) stating that any change observed is not related to OCS oil and gas development activity.

Testing of the second component of each null hypothesis (establishment of causality) was not addressed by the workshop or the consultant's analysis. In some cases rejection of the null hypothesis would constitute a strong inference of causality. For example, increases in organism body burdens of petroleum hydrocarbons could almost certainly stem only from oil and gas development activity although the specific source(s) of those hydrocarbons may remain in doubt. Once a change is detected, specific monitoring, research, or other investigations would be tailored to the change observed.

Existing Beaufort Sea data on relevant variables were sought to permit evaluation of components of variability that influence the optimization of sampling design. Where adequate data were available, power calculations were made to estimate the likelihood of detecting changes of various magnitudes, at several levels of replication of sampling. Material presented at the workshop and all available reports of sampling in the nearshore Beaufort 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 restated 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.

A considerable amount of sampling was conducted under Outer Continental Shelf Environmental Assessment program (OCSEAP) sponsorship in the late 1970s to provide data necessary to describe baseline sediment hydrocarbon and metals concentrations in the Beaufort Sea. However, the data were of limited value for designing a monitoring network because of the lack of replication in space and time. Components of variability due to measurement error and small-scale spatial patchiness cannot be separated from site-to-site variability or from temporal variability.

Thus, it was necessary to use statistical models instead of computed values for variances and covariances in many cases. The sampling design, D, was viewed as a set of labels (latitudes and longitudes) designating the sampling sites. These sites were chosen from a grid of all possible sites. Changes due to development might occur at any of the possible sites but can only be detected at the sampled sites. Assuming that, if a change occurs it has a certain assigned probability of occurring in each of 17 assumed blocks of area in the Beaufort Sea, the optimal fraction of sampling effort to expend in each block was derived. A two-way fixed effects analysis of variance was used to derive the number of stations and replicates required to detect changes of various magnitudes. Based on these analyses, it was recommended that four replicate sediment samples be taken at each of 36 stations. Most effort would be directed at geographic locations (blocks) judged to have highest potential exposure to OCS oil and gas development impacts. Since this analysis was based on data for only one metal, and since the other contaminants may exhibit greater variability an oversampling approach (additional replication at selected stations) is recommended in the first year to provide data that will permit optimum replication in subsequent years.

An alternative approach was considered, in which sampling stations were located and effort allocated without an *a priori* assumption regarding the probability of change in any block. This approach was considered less efficient than the first; greatest effort might well be directed at areas with little potential for impact.

Procedures for obtaining and handling samples as well as for performing chemical analyses (e.g., barium, chromium, vanadium, hierarchical analysis for hydrocarbons) are recommended. A 3-year baseline monitoring period is recommended, followed by sampling every 3 years to monitor for change.

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

The few existing data on contaminants in marine molluscs in Alaska suggest that both metals and hydrocarbon levels are very low. The workshop recommended that, if feasible, indigenous bivalves be used in caged animal experiments in the manner of the U.S. Mussel Watch Program to monitor body burdens of metals and hydrocarbons. Several factors cloud this approach, however:

Availability of sufficient numbers of large bivalves is uncertain and the biology and physiology of indigenous species is generally unknown. Species that rapidly metabolize hydrocarbons are of little value as indicators. Thus, a dual approach is recommended to evaluate the optimum design for a longer term program.

Dredging should be conducted to determine the availability of candidate indigenous indicator species. If sufficient numbers and sizes of one or more candidate species are located, they should be:

- analyzed for metals and hydrocarbons (as for sediments)
- used in caged animal exposure tests (below).

Because of the uncertainties surrounding feasibility of use of indigenous organisms and because of the proven physiological suitability of mussels, it is recommended that, in parallel with the above sampling and analysis, a pilot caged-organism study be conducted in the Beaufort Sea. This study should use bay mussels obtained from an unpolluted site elsewhere in Alaska. Mussels (and indigenous bivalves, if available) should be exposed during the open-water season at locations near and removed from sites of ongoing industrial activity in the Prudhoe Bay area. Analyses should be partitioned to explore the optimum statistical approach to pooling and analyzing tissues. Following the pilot study, the most successful approach/species should be instituted for 3 consecutive years at 5 locations (2 depths each) between Point Barrow and Barter Island. Sampling stations should coincide to the extent possible with sediment sampling stations. After the first 3 years, sampling frequency would be reduced to every third year.

III H_o: The axis of the fall migration of bowhead whales will not be altered during periods of increased OCS activity in the United States Beaufort Sea.

The substantial data base from aerial censusing of bowhead whales over the last several years was reviewed. It was determined that distinctly different fall migration situations occur in "light" and "heavy" ice years. Effects of OCS development on bowhead migration patterns (e.g., seismic exploration), if they occur, are most likely to be detectable during light ice years because these years are most conducive to seismic surveys and because the effects of ice on whale movements will not confound the analysis.

The median water depth at the location of bowhead sightings was chosen as a variable that can be readily used to assess shifts in migration patterns. It was concluded that continuation of purely random survey techniques such as were used in 1982 was appropriate and additional recommendations are made regarding aerial survey methodology. Analyses based on 1982 data indicate that such data should be adequate to detect a deflection of 5 to 10 nautical miles or more in axis of migration.

It was also recommended that ongoing efforts to assess behavioral reactions of bowheads to offshore activities be continued (separately from the random survey) along with documentation of concentrations of potential pollutants in bowhead tissues from samples of opportunity.

IV H_o: There will be no change in catch per unit of effort in the Colville River Arctic cisco fishery.

Catch per unit effort (CPUE) of Arctic cisco in the Colville River delta commercial fishery was selected as the best available indicator of potential OCS oil and gas activity effects on anadromous fish. This selection was based on the lengthy data base available (1967-present) at little cost to the government and the expectation that, due to their broad coastal movement patterns, Arctic cisco would be at least as good as any other anadromous species at reflecting the net effect of the myriad of coastal habitat alterations that may result from development.

The recommended approach is to continue to accumulate CPUE and life history data gathered by the commercial harvester and to plot CPUE vs. time for gross indication of trends.

An additional approach to detect change in CPUE is to employ an existing predictive model that uses existing population and harvest data to predict the next year's CPUE. If this model can be validated, it would appear to be sensitive to environmental changes that increase the difference between predicted and actual CPUE.

A second ongoing data collection effort that should be continued under the BSMP is the annual aerial index counts of spawning and overwintering Arctic char in several North Slope drainages. These surveys have been conducted since 1971 by the Alaska Department of Fish and Game.

V H_o: There will be no change in relative densities of molting male oldsquaw in four Beaufort Sea index areas.

Oldsquaw ducks have been identified as the most abundant and ubiquitous waterfowl along the western Beaufort coast. Although oldsquaw are not widely hunted, their distribution and abundance (as well as an existing data base in some areas) lend themselves to use as an indicator of regional trends in waterfowl.

The recommended approach is to use existing aerial survey methodology to index late summer densities and numbers of flightless (molting) male oldsquaw in four areas: Elson Lagoon/Plover Islands, Simpson Lagoon (using existing transects), Leffingwell Lagoon/Flaxman Island, and Beaufort Lagoon. Transect length and orientation should be patterned as closely as possible after established transects in Simpson Lagoon. Data (oldsquaw/km^2) should be tested for absolute abundance and for relative abundance between areas.

VI H_o: There will be no change in density or hatching success of common eiders on islands subjected to disturbance by OCS oil and gas development activity.

It is recommended that monitoring of common eider hatching success be instituted only in response to specific activities (such as the Thetis Island gravel stockpiling) that have the potential to have a direct impact. No data or detailed descriptions of such a program are yet available. However, it was suggested at the workshop that the monitoring done at Thetis Island in 1983 could serve as a model for future such programs, if and where needed.

VII H_o: There will be no change in productivity of *Laminaria solidungula* in areas of the Boulder Patch nearest OCS oil and gas development activity.

It is recommended that monitoring of kelp productivity in the Stefansson Sound (or other) Boulder Patch be instituted only in response to specific activities (such as nearby island construction) which have the potential for direct impact. Data analyzed show that the growth rate of *Laminaria solidungula* is a sensitive indicator of natural environmental variation with significantly lower growth under turbid ice canopy than under (less common) clean ice. A proprietary study has reportedly documented a further growth depression in kelp due to siltation/turbidity near a gravel island under construction. Future such activities should be monitored using similar techniques at up to 10 stations distributed throughout the Boulder Patch.

1.4 OTHER CONSIDERATIONS

A number of approaches or ecosystem components suggested by invited participants for inclusion in the monitoring program were rejected or side stepped.

Benthos was not included for several reasons. Epibenthos, although ecologically important, are too mobile and too variable in space and time to be measured with accuracy. Infauna, although sessile and sensitive to pollution effects, do not have well-known major links to higher trophic levels in the Beaufort Sea. Microbial indices and other biological indices were also omitted from the program on the premise that the sediment chemistry and "mussel watch" studies would provide more reliable and economical physical and biological indications of pollutant buildup in the environment.

No specific program was recommended for physical and chemical oceanography. Rather, the supportive data needed for each program were to 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 would presumably 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 techiques as used in this program in other programs where similar variables are to be measured in the Beaufort Sea. In this way, maximum utility and comparability will be achieved for all data gathered in the area.
- Institution, prior to initial monitoring activities, of a well-conceived and operated data management system that will incorporate all data from this and other Beaufort Sea monitoring activities.

2. INTRODUCTION

2.1 GENERAL

This document attempts to describe a long-term monitoring program for assessing potential effects of anticipated oil and gas development on the United States Beaufort Sea continental shelf. Various regulatory mandates requiring such an assessment be done are described in Section 2.2; the interrelationship 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 years these and several other agencies have funded a variety of studies which provide a basic understanding of physical and biological conditions and interrelationships in the Beaufort Sea (Section 2.4).

To assist in development of a longer term monitoring program for the Beaufort Sea, NOAA and MMS sponsored a workshop in September 1983 (Section 2.5). Invited participants included regulators, managers, and scientists from cognizant Federal agencies, as well as leading scientists with specialties in aspects of the Beaufort Sea ecosystem or in offshore monitoring programs elsewhere in North America. Objectives for this monitoring program are described in Section 2.7.

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

- Provide a summary and synthesis of the workshop proceedings (Chapter 3);
- Perform statistical analyses of monitoring approaches suggested by the workshop to optimize the statistical sampling design applied (Chapter 4); and
- Detail (based on 1 and 2 above) optimum approaches to Beaufort Sea monitoring that meet the prescribed goals (Chapter 5).

2.2 STATUTORY MANDATES

Both MMS and NOAA have extensive statutory and regulatory mandates to conduct environmental studies and monitoring in marine waters. This section discusses these mandates. The working relationship which has evolved between the two agencies to study effects of oil and gas development on the Alaska outer continental shelf (OCS) is explained in Section 2.3.

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 minimized.

The Outer Continental Shelf Lands Act Amendments of 1978 (92 Stat. 629) were passed September 18, 1978. Section 20 of these Amendments (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 decisionmaking 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 Outer Continental Shelf oil and gas development for leasing decisionmaking 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 decisionmaking 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 3301.7).

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 carry out such duties in full cooperation with affected States. To the extent that other Federal aqencies 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. The purpose of this act is to:

- Establish a comprehensive 5-year plan for federal ocean pollution research and development and monitoring programs in order to provide planning for, coordination of, and dissemination of information with respect to such programs within the federal government;
- Develop the necessary base of information to support, and to provide for, the rational, efficient, and equitable utilization, conservation, and development of ocean and coastal resources; and
- Designate the National Oceanic and Atmospheric Administration as the lead federal agency for preparing the plan to require NOAA to carry out a comprehensive program of ocean pollution research and development and monitoring under the plan.

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. The Administrator also is required to provide financial assistance for research, development, and monitoring projects or activities which are needed to meet priorities of the 5-year plan if these are not being adequately addressed by any federal agency. Funding for this financial assistance is authorized by Congress under Section 6 of the National Ocean Pollution Planning Act. In addition, the act directs the Administrator of NOAA to ensure that results, findings, and information regarding federal ocean pollution research, 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. The NOAA program must be comprehensive in scope and address problems:

- Over a broad geographic area including land and water from the inner boundary of the coastal zone to and including the land underlying and the waters of the high seas;
- Involving short- and long-term changes in the marine environment; and
- Involving the utilization, development, and conservation of ocean and coastal resources.

The program also must be coordinated both within NOAA and with other federal agency programs and be consistent with the federal marine pollution research, 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 carrying out such research, the Secretary of Commerce shall take into account such factors as existing and proposed international policies affecting oceanic problems, economic considerations involved in both the protection and the use of the oceans, possible alternatives to existing programs, and ways in which the health of the oceans may best be preserved for the benefit of succeeding generations of mankind."

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. These legislative authorities include the National Environmental Policy Act of 1969 (NEPA) (Pub.L. 91-190), the Marine Protection, Research, and Sanctuaries Act of 1972 (Pub.L. 92-532), the Coastal Zone Management Act of 1972 (Pub.L 2-538), the Marine Mammal Protection Act of 1972 (Pub.L. 92-522), the Federal Water Pollution Control Act Amendments of 1972 (Pub.L. 92-500), the Clean Water Act of 1977 (Pub.L. 95-217), the Fishery Conservation and Management Act (Pub.L. 94-265), the Sea Grant Improvement Act (Pub.L. 94-461), the Endangered Species Act (Pub.L. 93-205), and many others.

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 a substantial portion of program support by providing field logistics support. OCSEAP is managed by the Alaska Office of Ocean Assessments Division (OAD), Office of Oceanography and Marine Services, National Ocean Service, NOAA, located in Juneau, Alaska. The scope and scientific content of OCSEAP studies are determined annually by a set of Technical Development Plans (TDPs) which are approved by MMS. These TDPs, prepared by NOAA with funding guidance from MMS, and in coordination with the MMS Anchorage Office, describe the rationale, scope, and content of the individual research units (RUs) to be implemented by OCSEAP.

2.4 ONGOING RESEARCH AND MONITORING PROGRAMS IN THE BEAUFORT SEA

2.4.1 Outer Continental Shelf Environmental Assessment Program

Since 1975, OCSEAP has managed approximately 89 research units (RUs) which are wholly or in part related to the Beaufort Sea (U.S. MMS 1983). 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. Technical areas covered by the RUs have ranged broadly through many aspects of the physical, chemical, and biological enviromments of the area, including the atmosphere, land, and water. Many of these RUs included the kind of repetitive (in space and/or time) measurements of physical, chemical, or biological properties of the environment that are 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 United States Beaufort Sea (especially nearshore) which provide the basis for many of the thoughts expressed in the workshop (Section 3) and, to a lesser degree, 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, the focus of endangered species studies in the Beaufort Sea has been 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. Integrated into MMS study efforts has been 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.

A list of endangered species studies directly funded by MMS from 1978 projected through fiscal year 1985 is shown in Table 2-1. The scope of the study titled "Aerial Surveys of Endangered Whales in the Beaufort, Chukchi and Northern Bering Seas" was expanded in 1981 to incorporate a monitoring program to study potential effects of OCS oil and gas development activities on fall migrating bowhead whales. Through Endangered Species Act consultation, this monitoring program has served interagency decision needs as a major real-time information source relative to seasonal drilling and geophysical exploration issues.

Future directions of the 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 nonendangered species, continued study of potential effects on behavior of endangered species, and related synthesis requirements.

2.4.3 National Marine Fisheries Service

In the past, the National Marine Fisheries Service (NMFS) has funded or conducted several research programs in the Beaufort Sea. From 1976 to 1980, they developed the spring bowhead whale ice camp censusing techniques (Braham 1983). Since 1981, this program has been turned over to the North Slope Borough, although some equipment support is still provided by NMFS. NMFS also funded 1 year of a study of trophic interactions of marine mammals in the eastern Beaufort Sea. NMFS is currently working on a program to permit identification of specific bowhead whales so that repeated documented sightings will allow derivation of much needed life history and demographic information. NMFS continues to work closely with MMS-funded investigators on bowhead-related research in the Beaufort.

2.4.4 North Slope Borough

The North Slope Borough is the local governmental jurisdiction (comparable to a county) for the vast North Slope and Arctic Coastal Plain of Alaska. Although the Borough performs the usual functions of regional government, its legislative membership is primarily Inupiat and the Borough has a demonstrated commitment to maintaining traditional values.

In recent years there has been growing concern among the Inupiat and Inuit people of northern Alaska and Canada regarding the potential effects of offshore (and onshore) oil and gas development on species crucial to their historical subsistence life style. As a result, the North Slope Borough has funded a number of continuing studies to enhance understanding of population levels, biology, and sensitivity of important resources, primarily the bowhead whale.

2.4.5 State of Alaska

The Alaska Department of Fish and Game, has several long-term research programs in the Beaufort Sea and on the North Slope, some of which receive OCSEAP funding. Aerial surveys of ringed seal winter population densities (Burns and Harbo 1972; Burns et al. 1981; Burns and Kelly 1982) and studies of overwintering char populations (Bendock 1983) may be particularly relevant to the design of a long-term Beaufort Sea Monitoring Program.

TABLE 2-1
STUDIES OF ENDANGERED WHALES DIRECTLY FUNDED (OR PROPOSED*) BY MMS, 1978-1985

Fiscal Years(s)	Title
1978-1979	Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of the Beaufort Sea Lease Area
1979-1985*	Aerial Surveys of Endangered Whales in the Beaufort Sea, Chukchi Sea, and Northern Bering Sea
1979-1980	Development of Large Cetacean Tagging and Tracking Capabilities in OCS Lease Areas
1980	Tissue Structural Studies and Other Investigations on the Biology of Endangered Whales in the Beaufort Sea
1980	Effects of Whale Monitoring System Attachment Devices on Whale Tissues
1981-1984	Development of Satellite-Linked Methods of Large Cetacean Tagging and Tracking Capabilities in OCS Lease Area
1982-1983	Investigation of the Potential Effects of Acoustic Stimuli Associated with Oil and Gas Exploration/Development on the Behavior of Migratory Gray Whales
1983-1984	Computer Simulation of the Probability of Endangered Whale Interaction with Oil Spills in the Beaufort, Chukchi, and Bering Seas
1980-1984	Possible Effects of Acoustic and Other Stimuli Associated with Oil and Gas Exploration/ Development on the Behavior of the Bowhead Whale
1985*	Application of Satellite Linked Methods of Cetacean Tagging and Tracking Capability in OCS Lease Areas
1985*	Prediction of Site-Specific Interaction of Acoustic Stimuli and Endangered Whales as Related to Drilling Activities during Exploration and Development of the Diapir Lease Offering Area
1985*	Relationship of Distribution of Potential Food Organisms and Bowhead Whales in the Eastern Beaufort Sea
1985*	Ecology and Behavorial Responses of Feeding Gray Whales in the Coastal Waters of Alaska
1985*	Distribution, Abundance, and Habitat Relationships of Endangered Whales and Other Marine Mammals on OCS Lease Offerings of the Kodiak, Shumagin, and Southern Bering Areas

2.4.6 Other U.S. Monitoring Programs

A variety of developmental activities in the Beaufort Sea have resulted in requirements for a number of types and intensities of site-specific monitoring programs ("compliance monitoring"). In addition, numerous predevelopment "baseline" studies have been conducted by several oil companies in preparation for filing development permit applications. By far the largest monitoring program to date in the U.S. Beaufort Sea is that associated with the Prudhoe Bay Unit Owners Waterflood Project (U.S. Army, Corps of Engineers 1980; 1982; 1983). Benthos, bird, and fish studies within that program provide a substantial data base which has been considered in the present program design.

Monitoring of specific discharges (e.g., drilling muds) to the Beaufort Sea is required by the U.S. Environmental Protection Agency and the Alaska Department of Environmental Conservation under the National Pollutant Discharge Elimination System (NPDES). These programs are typically localized and directed at determining the extent of pollutant dispersal in relation to a prescribed mixing zone.

2.4.7 Canadian Beaufort Sea Monitoring

During the workshop, D. Stone (Canadian Department of Indian and Northern Affairs)* described the process by which Canada has been designing a long-range monitoring program for the Canadian portion of the Beaufort Sea. Oil development in the Canadian Beaufort Sea will soon be moving into the production phase. Stone reported that, during early efforts of environmental assessment, managers and decision makers had been deluged with research topics thought to be of importance by individual scientists, and had been forced to make decisions based on political, rather than biological needs.

To alleviate this situation, Canada embarked on a deliberate plan to analyze the utility of previous impact assessments (Beanlands and Duinker 1983) and to use this analysis and the best scientific expertise available in formulation of their long-range targets and approaches. Canada is currently using adaptive environmental assessment (AEA) techniques (Holling 1978) at a series of workshops (one or two per year). As an initial step, a crude ecosystem model was developed and probable development scenarios were examined. Two questions were then asked: "What environmental parameters are most likely to be affected by what activities?" and "Which of these environmental parameters do we care about?" In answer to the latter question, "valued ecosystem components" (VECs), were defined as those species that either:

- Are important to human populations,
- Have national or international importance, or
- Provide support for VECs under 1 or 2.

Using these criteria, the VECs are restricted to selected marine birds, mammals, and anadromous fish. The AEA "looking-outward" approach was used to identify the crucial information needed to answer impact questions about VECs. After an initial data gathering year in 1984, additional workshops will be held to evaluate the utility of the research data and to reorient future programs, if necessary.

2.5 WORKSHOP PURPOSE, OBJECTIVES, AND APPROACH

As stated by J. Imm (MMS), the purpose of the Beaufort Sea Monitoring Program (BSMP) Workshop was "to help design a realistic, effective research program to monitor long-term environmental effects of oil and gas development in the Beaufort Sea." To fulfill this purpose, the specific objectives of the workshop were to:

- Evaluate existing monitoring techniques for applicability to the Beaufort 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 Beaufort Sea environment and/or with systematic monitoring programs elsewhere in the U.S. and Canada were invited to the workshop, along with a number of scientists and managers from federal agencies, predominantly MMS and NOAA. A list of attendees and their affiliations is provided in Appendix A. The workshop was held at the Alyeska resort near Anchorage, Alaska, September 27-29, 1983. Proceedings of the workshop are summarized in Chapter 3.

MMS and NOAA managers opened the workshop by setting the framework, goals, and desired products from the session (Section 3.1). A potential oil and gas development scenario for the Beaufort Sea was presented (Section 3.2). Monitoring programs in the Beaufort Sea and elsewhere in the United States were described by a series of speakers (Section 3.3). The physical environment of the nearshore Beaufort Sea was discussed, along with techniques that have been used for monitoring various physical parameters (Section 3.4). Biological conditions in the Beaufort Sea and

*References to workshop attendees are followed by their affiliation only (first reference) or by name only (subsequent reference).

a wide variety of biological, physiological, and biochemical monitoring approaches were also presented (Sections 3.5 and 3.6).

After these presentations, a panel of NOAA and MMS scientists (D. Wolfe, J. Cimato, C. Manen, J. Geiselman, J. Nauman) met with the workshop convenor (J. Truett) to redefine the monitoring program objectives (Section 2.7) and develop a preliminary monitoring approach (Section 3.7). These panel recommendations were reported to and discussed by the entire workshop.

2.6 STUDY AREA

The area of interest for the BSMP could include the entire Diapir Field Planning area, including all United States waters from the United States/Canada Border to 162° West longitude and 73° North latitude. However, for practical reasons, based on the probable areas of development and possible areas of impact, the area under consideration includes the Alaska coastal waters between Point Barrow and the United States/Canada border (Figure 2-1) and out to the shelf break (about 50 meters).

Within this broad area, development in the near term (next decade) is likely within the shorefast ice zone and may extend into the "shear," or stamukhi, zone, which is located at approximately 25 meters depth. Present expectations are that offshore development will be further focused in three primary regions: Camden Bay, Stefansson Sound (including the Prudhoe Bay area), and Harrison Bay (J. Imm, MMS, this conference).

2.7 MONITORING PROGRAM OBJECTIVES

In keeping with the requirements of the OCS Lands Act (Section 20(b)) (see Section 2.2) and as a result of deliberations by the workshop panel a specific set of objectives for the BSMP was established as follows:

- To detect and quantify change that might:
  - result from OCS oil and gas activities,
  - adversely affect, or suggest another adverse effect on, humans or those parts of their environment by which they judge quality, and
  - influence OCS regulatory management decisions; and
- To determine the cause of such change.

2.8 CONSULTANT'S ROLE

J. Truett of LGL Ecological Research Associates, Inc. of Flagstaff, Arizona, was contracted to serve as Workshop Convenor. The convenor's role was to maintain the workshop schedule and focus. In addition, Truett formulated the initial version of the recommended monitoring program (the "strawman program") which was first considered by the panel and then by the entire workshop.

NOAA/OCSEAP contracted with Dames & Moore (Seattle and Anchorage offices) to document and report workshop proceedings and to perform statistical analyses on workshop-selected monitoring approaches. Specific responsibilities of Dames & Moore were to:

- Record and summarize the proceedings of all workshop sessions.
- Develop a sampling strategy including recommended sampling frequency, sample replication, and the overall number of samples to be collected in each location, all based on demonstrably valid, statistical procedures.

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

- SEAMOcean, Inc. (D. Segar) of Wheaton, Maryland.
- University of Washington, Department of Statistics (J. Zeh) of Seattle, Washington.

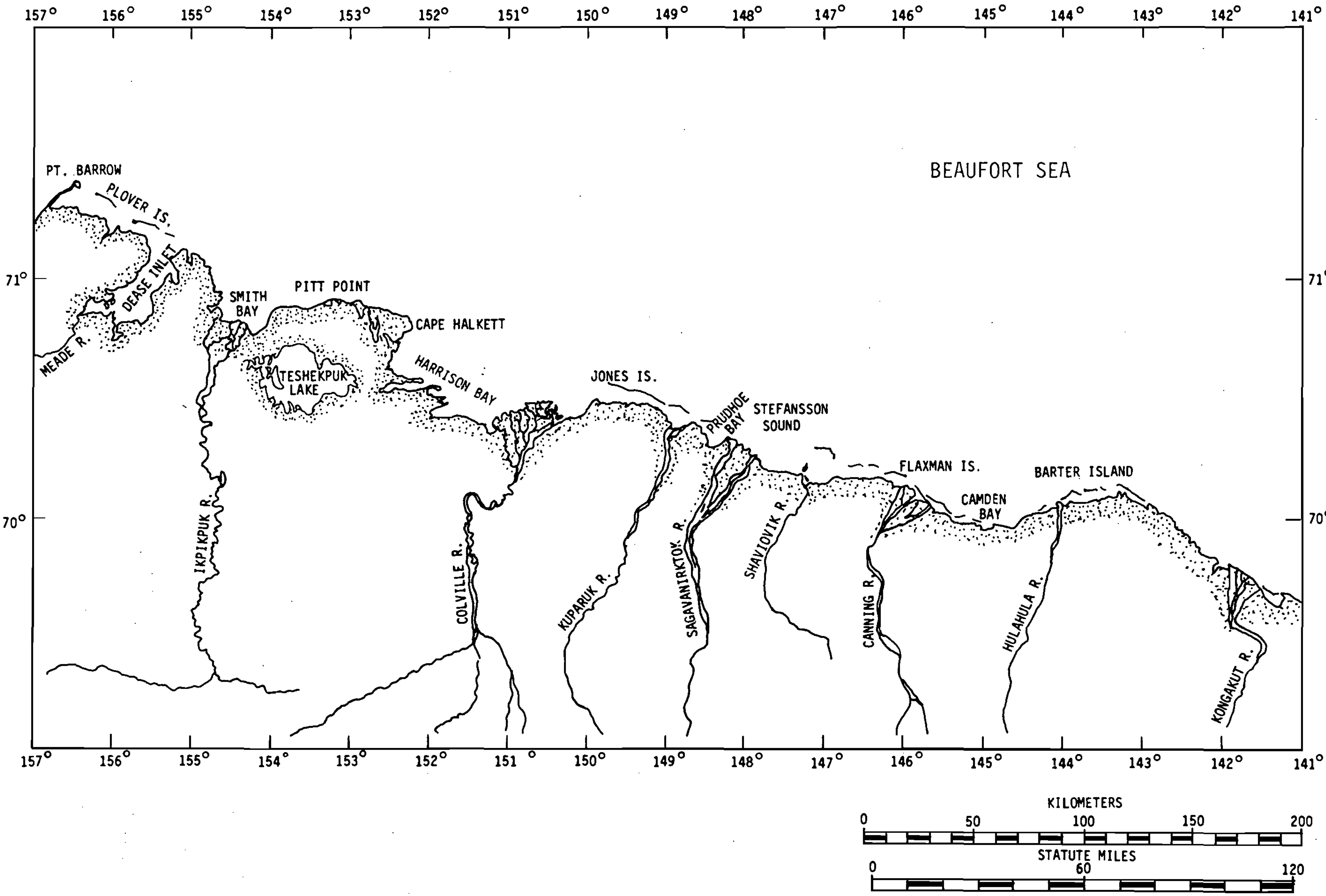


Figure 2-1

Beaufort Sea Study Area

3. WORKSHOP SUMMARY AND SYNTHESIS

This section contains brief summaries, by major topics, of presentations made during the course of the Beaufort 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 "strawman" 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 the workshop and its follow-on activities was to design a Beaufort Sea monitoring program. The framework within which this program was to be designed was elaborated in a series of presentations by representatives from NOAA, MMS, and the workshop convenor. This framework is summarized in this section.

The purpose of the proposed Beaufort Sea Monitoring Program (BSMP) is to identify the effects of oil and gas development activities on the Beaufort Sea environment and to establish the consequences that may occur as a result of many of these effects. The statutory basis for this program is twofold: As described by J. Imm (MMS), there is the specific Department of Interior mandate of the Outer Continental Shelf Lands Act (Pub. L. 92-372, Section 20(b) as amended) that the Secretary of the Interior, subsequent to leasing ". . . shall monitor the human, marine, and coastal environments. . . 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." W. Conner (NOAA/NMPO) noted the BSMP falls also within the broad mandate of the National Ocean Pollution Planning Act (Pub. L. 95-273) for NOAA to "establish within the Administration a comprehensive, coordinated and effective ocean pollution research, development, and monitoring program." To meet this need, NOAA, in cooperation with other agencies, has been working to develop an OCS long-term effects program with the goal of detecting and quantifying any subtle ecological effects that may result from OCS oil and gas activities conducted over long time spans or wide geographic areas.

Neither the OCS Lands Act or the National Ocean Pollution Planning Act defines or explains what is meant by monitoring; many 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, it was suggested at the workshop (J. Hameedi, NOAA/National Ocean Service [NOS]) that the monitoring program might consist of:

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

Subsequent discussions suggest that this definition should be interpreted to include the analysis of data gathered to (1) establish a measure of the environmental quality of the Beaufort Sea, and (2) relate changes in this quality to causal factors. It was suggested (J. Truett, LGL) that environmental quality should be measured by establishing the status of selected environmental variables in comparison to a desired status. 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.

Outer continental shelf oil and gas development activity in the Beaufort Sea is increasing steadily. Imm reported that, at present, approximately 2 million acres of federal offshore leases have been let, with estimates of the probability of finding oil as high as 99.3 percent. Additional activity is underway both within Alaskan state waters and the Canadian Beaufort Sea to the east. As of fall 1983, four exploratory wells had been drilled in the Joint Lease Sale area (Figure 2-1), and application for a development permit was expected for the Sagavanirktok (Sag) River delta. If this development occurs, it will be the first in ice-covered areas of the United States Arctic. The most likely areas where future development will be concentrated are Harrison Bay and Stefansson Sound, which includes Prudhoe Bay (Figure 2-1).

The BSMP must be consistent with and cognizant of the many different marine pollution monitoring activities performed by various federal agencies in response 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 included in Table 3-1 and a more complete listing and description of the activities involved can be found in U.S. NOAA (1982). While many of these activities do not currently include monitoring in the Beaufort 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 region.

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 Service (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.

Other Federal Agencies
Fish and Wildlife Service, Corps of Engineers, Department of Energy, Nuclear Regulatory Commission, National Marine Fisheries Service, Food and Drug Administration, etc.

Although the Beaufort Sea marine environment is 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). These programs include the NOAA Northeast Monitoring Program; the National, State of California, and State of New Jersey Mussel Watch Programs; the NOAA and EPA Ocean Dumping Programs; the NOAA/OAD research and assessment efforts in the New York Bight; the Hudson-Raritan Estuary and Puget Sound; the EPA Chesapeake Bay Program; 301(h) waiver monitoring; the Southern California Coastal Research Project studies; the United Nations Environmental Program-Regional Seas Program; and other MMS programs, such as the outer continental shelf long-term effects studies and environmental assessment programs for areas other than the Beaufort Sea.

The participants in this workshop jointly 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 Beaufort Sea environment, would enable development of a monitoring plan composed of the best available techniques that would effectively assess the impact of oil and gas development on the Beaufort Sea environment.

Therefore, the workshop participants were charged by Hameedi to develop a monitoring program outline for the Beaufort Sea which incorporated those techniques and approaches most likely to be successful (1) in identifying changes in the Beaufort 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 participants were asked to remember the following important considerations:

- The program should be capable of detecting changes in the Beaufort Sea ecosystem that potentially could be caused by oil and gas development activities.
- The primary focus of the program should be to monitor the 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 gravel island and causeway construction, should also be examined.
- Potentially beneficial, as well as detrimental, changes should be considered.
- The program should provide data necessary to design experiments to identify the cause of any observed change (particularly change that results from natural events) or of identifying additional studies which could pinpoint the cause of the identified change.
- The techniques and sampling strategies recommended must 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 decisionmaking. In particular, if adverse changes are identified, sufficient information must be available, or easily obtained, 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.
- The monitoring program should address OCS oil- and gas-related effects on the marine environment of the Beaufort Sea from the shoreline out.
- The program should not address the noncontaminant stress that an increased human population would impose on the marine resources, such as increased hunting.
- The workshop participants should be aware that MMS and NOAA-NMFS studies of marine mammals, particularly bowhead whales, are currently active and will continue under the mandates of the Marine Mammal Act and the Endangered Species Act.
- Following the workshop, studies of appropriate data sets both from the Beaufort and elsewhere would be performed (Chapter 4) to aid in design of statistically valid sampling programs (including sampling design, minimum sample size, and field methodologies required to detect significant changes) for parameters and indices recommended by the workshop to be included in the monitoring program. Therefore, statistical considerations during the workshop should be of lower priority than identifying the parameters that should be measured.

3.2 FACTORS THAT MAY CAUSE EFFECTS

Many activities associated with oil and gas development in the Beaufort 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 (e.g., OCS lease sales, U.S. MMS 1982, 1983; Prudhoe Bay Waterflood Project, U.S. Army, COE 1980), 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. Construction and operation of facilities, including ship and aircraft movements, create noise (airborne and waterborne) and visual effects that may disrupt biota. 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 may accumulate in, organisms. 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.

Accidental spillage of large quantities of hydrocarbons or other oilfield chemicals could cause a significant short-term loss of vulnerable species (e.g., birds, benthos). 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 what are considered "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 the numerous and varied individual projects and activities anticipated 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 similar purposes elsewhere in the world and on the United States continental shelf, and for other purposes in the Alaska Beaufort Sea.

3.3.1 Mussel Watch

R. Flegal (Moss Landing Marine Laboratories) provided the following discussion of the National Mussel Watch Program.

Mussel watch programs have provided the first standardized baseline data on marine pollution within the past decade and are now considered to be a major component of marine pollution monitoring programs (UNESCO 1980). The United States national mussel watch evolved from a meeting convened in 1975 by the National Academy of Sciences (NAS) to formulate a national marine pollution monitoring program (Farrington 1983). The international mussel watch was then patterned after the United States program (NAS 1980) as were other national, state, and local mussel watch programs (e.g., Martin 1983). The rationale for a mussel watch program and the criteria for selecting sentinel organisms are delineated in Table 3-2.

TABLE 3-2

RATIONALE BEHIND MUSSEL WATCH APPROACH[a]

1. Bivalves are cosmopolitan (widely distributed geographically). This characteristic minimizes the problems inherent in comparing data for markedly different species with different life histories and relationships with their habitat.
2. They are sedentary and are thus better than mobile species as integrators of chemical pollution status for a given area.
3. They concentrate many chemicals by factors of 10^2 to 10^5 compared to seawater in their habitat. This makes measuring trace constituents in their tissues often easier to accomplish than analyzing seawater.
4. Inasmuch as the chemicals are measured in the bivalves, an assessment of biological availability of chemicals is obtained.
5. In comparison to fish and Crustacea, most bivalves exhibit low or undetectable activity of those enzyme systems which metabolize many xenobiotics such as aromatic hydrocarbons and polychlorinated biphenyls (PCBs). Thus, a more accurate assessment of the magnitude of xenobiotic contamination in the habitat of the bivalves can be made.
6. They have many relatively stable local populations extensive enough to be sampled repeatedly providing data on short- and long-term temporal changes in concentrations of pollutant chemicals.
7. They survive under conditions of pollution which often severely reduce or eliminate other species.
8. They can be successfully transplanted and maintained where normal populations do not grow—most often due to lack of suitable substrate—thereby allowing expansion of areas to be investigated.

(a) Adapted from Farrington et al. 1983.

The evolution of the mussel watch concept was based on the conclusion that measurements of pollutant concentrations in sentinel organisms (e.g., bivalves) would provide baseline data on pollutant concentrations and bioavailabilities in the marine environment. It was also concluded that those measurements could be made with relative ease and modest expense compared to measurements of pollutant concentrations in seawater (Goldberg and Martin 1983). This latter conclusion has since proven fortuitous because recent seawater measurements of some of the principal pollutants, including lead (Schaule and Patterson 1981) and silver (Martin et al. in press), have shown that many preceding seawater measurements of pollutants were erroneous (Quinby-Hunt and Turekian 1983).

The National Mussel Watch program, while considered to be an important component of a broader monitoring program, cannot, on its own, provide all of the information needed to evaluate the nature and effects of marine pollution in a given region. Rather, the program is viewed as a step in a research sequence. This research sequence has been delineated by UNESCO (UNESCO 1980) and summarized in the International Mussel Watch Report (NAS 1980) in the discussion on priorities for monitoring programs:

> "Analysis of a few samples of mussels or other bivalves for a small number of recognized pollutants will not, in itself, provide any assurance that scientists have determined the quality of local coastal waters. Nor would such analyses necessarily constitute a basis for a rational program for the long-term protection of the coastal zone. Thus, for example, if heavy metals are analyzed, associated research would be required to determine whether levels are elevated because of the activities of people, and whether higher levels might cause an alteration in local coastal food webs and ecosystems. . ."

Flegal illustrated the utilization of primary mussel watch data and complementary research to assess the relative magnitude of coastal marine pollution in a discussion of some of the principal results of the National Mussel Watch Program. Sentinel organisms exhibit elevated concentrations of some pollutants (lead, silver, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons) adjacent to local anthropogenic inputs of those pollutants. This has been illustrated by the lead data for the common mussel (*Mytilus californianus*) from the west coast of the conterminous United States. Relatively high (>2.5 ppm dry weight) lead concentrations in mussels from the more urban locations in southern California reflect an integrated bioaccumulation of the diverse sources of lead inputs within that region.

Sentinel organisms also exhibit elevated pollutant concentrations (mercury, cadmium, and plutonium) in some cases where the elevation is not directly correlated with anthropogenic inputs. The two mussel watch locations (Goldberg et al. 1978; Stephenson et al. 1979) along the west coast of the United States where *M.*

californianus have consistently elevated mercury concentrations (0.6 to 2.5 ppm) are relatively isolated from both anthropogenic inputs of industrial mercury and from natural deposits of mercury-rich minerals (Flegal et al. 1981). They are, however, the locations of major marine pinniped and sea bird colonies (U.S. BLM 1979), which apparently enrich the bivalve mercury concentrations by their locally concentrated discharge of mercury-rich waste products. Detailed discussion of these data has been reported elsewhere (Goldberg et al. 1978; 1983; Farrington et al. 1983), and there is now an extensive literature on other local, state, and international mussel watch studies.

Flegal recommended that a mussel watch program should be considered as a fundamental component for monitoring environmental pollution in the Beaufort Sea, based on its successful application in the conterminous United States and its now universal acceptance as part of the primary phase of any marine pollution monitoring program. He pointed out that adaptation of a mussel watch program for the Beaufort Sea will not be straightforward because the commonly used sentinel organisms are not common there, and there is a lack of intertidal habitat for bivalves (Bernard 1979). Additionally, comparisons of pollutant concentrations of temperate organisms with arctic species which are physiologically adapted to low temperatures and low levels of primary productivity would be of limited value. This problem has already been evidenced by the apparent twofold difference in the baseline silver concentration of *M. californianus* and *M. edulis*, even when they inhabit the same area (San Francisco Bay) of the conterminous United States (Goldberg and Martin 1983; Stephenson et al. 1979).

Flegal recommended that a Beaufort Sea mussel watch should be patterned after the United States National Mussel Watch Program, and should include the complementary research which has enabled the national mussel watch data to be properly interpreted. Flegal considered this latter consideration to be especially necessary, since comparisons with other mussel watch studies may be qualified by the utilization of arctic species and the differences in temperate and arctic habitats. However, it should be noted that inability to directly compare arctic species with temperate species would in no way compromise the capacity of an arctic species "mussel watch" to identify geographical and temporal variability in contamination within the Beaufort Sea itself.

3.3.2 EPA Ocean Discharges Monitoring

J. Hastings (EPA Region 10) provided an overview of EPA's monitoring requirements for discharges in the Beaufort 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 Adninistrator 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 determination 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. Therefore, immediate, specific effects and also long-term cumulative impacts are considered.

Hastings outlined a monitoring study conducted this year at Sohio's Mukluk Island site in Harrison Bay, approximately 17 miles north of the mouth of the Colville River. Sohio had plans to drill up to two exploratory wells in winter of 1983-84. They proposed to discharge drilling muds and cuttings from the first well just before or during ice formation. The first well site is located in approximately 14 m of water.

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.

(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 direct exposure to pollutants or 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.

EPA determined that there was insufficient information to make a reasonable judgment about certain potential environmental impacts of mud and cuttings discharges. Specifically, there was a lack of knowledge on the long-term sediment resuspension and transport of drilling muds discharged during unstable or broken-ice conditions, particularly in shallow waters in this area. This leads to uncertainty over the potential for bioaccumulation or persistence of heavy metals contained in the drilling muds and the compliance with marine water quality criteria during under-ice discharges.

EPA's approach was to design a monitoring program to first assess accumulation, resuspension, and transport of drilling muds on the bottom, in the near-field area (within 1,000 m). The program uses heavy metal concentrations (barium and chromium, in particular) and sediment grain size distribution as an indicator or tracer of drilling muds. The objectives of this program are: (1) to first collect baseline data (late in 1983 open water season); (2) then just after breakup, to look for any accumulation of drilling muds that were discharged below ice; and (3) at the end of the open-water period in 1984 (and possibly again in 1985), to measure any accumulation of drilling muds remaining in the survey area.

Using replicate sampling data from drill sites in the Canadian Beaufort Sea, the minimum detectable differences in mean sediment chromium concentrations were calculated (Table 3-4). Based on this, the study design called for a collection of two replicate samples at fixed points located at increasing distances away from the island. Sampling is concentrated along an east-west axis (aligned in the directions of the predominant currents) to enable a detailed assessment in the areas of maximum predicted solids deposition. However, there are also additional stations in between (toward the north and south) which allow for an assessment of the overall depositional pattern.

TABLE 3-4

MINIMUM DETECTABLE DIFFERENCES IN MEAN SEDIMENT CHROMIUM CONCENTRATIONS AT β = 0.20, α = 0.05[(a)]

Number Replicates	Minimum Detectable Difference, mg/dry kg (percent of mean)	
	10 Stations	36 Stations
2	21 (36)	25 (42)
3	15 (25)	18 (31)
4	12 (20)	15 (25)
5	10 (17)	13 (22)

(a) — Assumes overall mean concentration of 59 mg/dry kg.

In analyzing the data, EPA will make use of the record of mud discharges in conjunction with a continuous current meter record. This information will enable prediction of the most likely pattern of drilling mud deposition. Based on these records, the locations where samples should be analyzed will be determined. This sampling methodology requires the collection— but not necessarily the analysis—of samples from a large number of sites.

The data developed from this study will be useful in performing the ocean discharge evaluation. This information will also be essential in developing any future monitoring requirements for discharges from larger-scale, longer-term development operations which may include drilling up to 100 wells in a single area over a period of years.

3.3.3 Clean Water Act Section 301(h) Programs

T. Ginn (Tetra Tech Inc.) presented an approach to sample program design based on 4 year's experience monitoring sewage discharges under the 301(h) waiver program. The basic goal of each monitoring program is to ensure the maintenance of a "balanced indigenous population" (BIP). A BIP is defined as being similar to communities occurring in nearby unpolluted waters. Similarity is based on characteristics such as species composition, abundance, biomass, dominance, diversity, disease prevalence, indicator species, bioaccumulation, and mass mortalities.

The recommended approach to monitoring program design (which would be applicable to the BSMP) requires answers to the following questions:

- *What* are the monitoring program objectives? (Objectives should be stated as testable hypotheses.)
- *Which* biotic groups should be sampled?
- *Where* should samples be collected?
- *How many* samples should be collected?

Selection of biotic groups to focus on should be based on:

- Sensitivity or susceptibility to impacts.
- Recreational or commercial importance. (Subsistence use should be added for Beaufort Sea.)
- Trophic or habitat performance.
- Presence of distributional patterns enabling quantitative assessment.
- Impact potential of discharge (size, toxicants).

Examples of biotic groups in decreasing order of suitability to 301(h) monitoring programs are: benthic macroinvertebrates, demersal fishes, kelp beds, coral reefs, rocky intertidal, shellfish beds, and phytoplankton.

Variables to be measured should not be overly restricted *a priori* as those selected may prove disadvantageous. Variables can range from assemblage abundance, diversity, richness, etc. through the abundance or size of indicator species, levels of tissue contaminants, and incidence of disease or tissue abnormalities.

The number of stations required is dependent on the objectives of the program and the extent of the anticipated area of influence. The number of replicates per station is statistically determined based on the number needed to adequately describe the biotic assemblage or variable of concern, to describe within-area variability, and to conduct statistical comparisons with a predefined α and β error.

3.3.4 Prudhoe Bay Waterflood Benthic Monitoring Program Analysis

T. Ginn described the approach employed to evaluate the methodologies used in sampling benthic infauna near Prudhoe Bay and to formulate an optimum sampling design for future such studies (Tetra Tech 1983). In brief, their statistical analyses were aimed at minimizing both the uncertainty or statistical risk and cost associated with the sampling program. Using statistical power analysis, the effect of number of stations and sample replication on the ability to detect statistically significant differences among sampling stations was determined. Separate analyses were conducted to determine the effect of sample size on the precision of estimated mean values of selected variables. Rarefaction methods were also used to assess the effect of sample replication on the ability to characterize infaunal community relationships both within and among sampling locations (Tetra Tech 1983). Results of power calculations, and plots of minimum detectable differences (in number of individuals) versus number of replicates, as well as power versus minimum detectable difference, were used to demonstrate that some 10 or more replicates were desirable to permit a reasonable statistical strength. Data provided are shown in Figure 3-1. Additional detail is available in Tetra Tech (1983).

A general recommendation derived from this statistical evaluation potentially applicable to the BSMP is the use of stratification (e.g., by depth, substrate type) to minimize variability. It was also noted that:

- Low overall abundance of infauna in the nearshore area considered (depths to about 6 m) may have been a factor in lowering the statistical power to detect change.
- Increased taxonomic sophistication over the years created an artificial increasing trend in species richness and diversity.
- In general, use of assemblage variables allowed for a greater power to detect change than use of species variables.

3.3.5 Georges Bank Monitoring Program

J. Neff (Battelle New England) described the MMS-sponsored Georges Bank Biological Assessment Program. This program was instituted to monitor local and regional changes that might result from exploratory drilling on Georges Bank. Major potential impact-causing activities were the discharges of drilling fluids, cuttings, and associated materials.

The exclusive focus of the study was on the benthic environment, including benthos and hydrocarbons, as well as on heavy metals levels in sediments and benthos. The sampling design provided for a broad area,

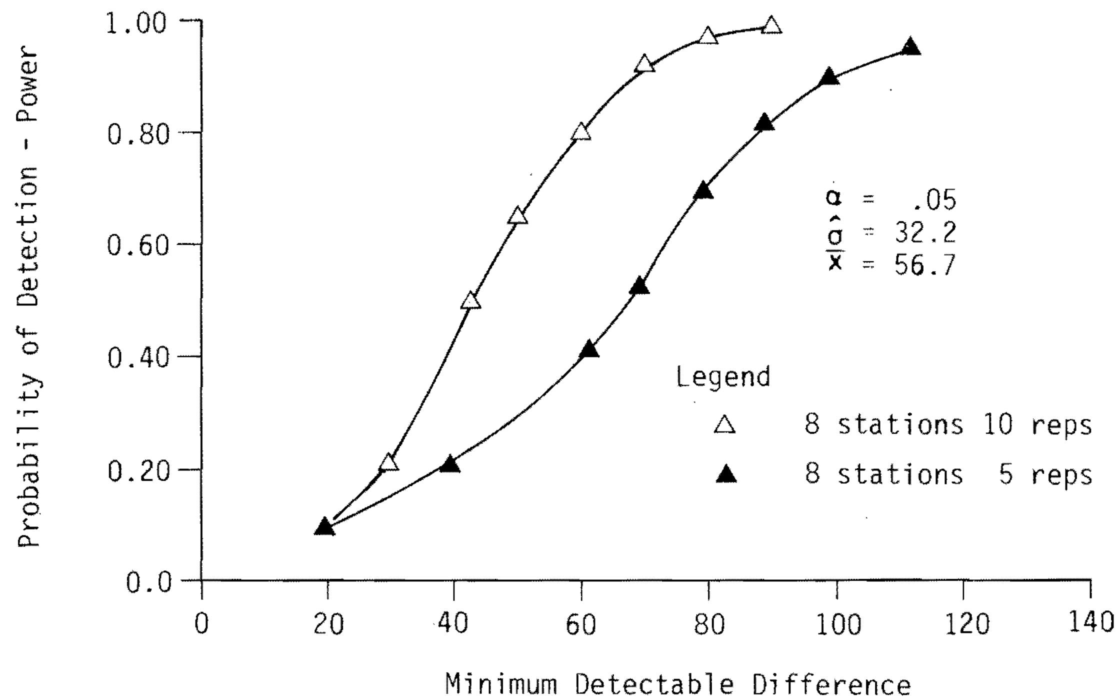


Figure 3-1

Probability of Detection Versus Detectable Difference in Number of Individuals

depth stratified coverage of the south side of the bank as well as a radial array around two active drill sites. An oversampling approach was used whereby samples from several stations were not immediately processed but were stored for possible future use. Eight replicates were taken at each station with four cruises per year over 3 years. The number of samples analyzed was reduced in the third year. Barium and chromium in the fine fraction of surficial sediments were used as indicators of the presence of drilling fluids. Elevated levels were detectable some 6 km downcurrent from the rigs. Additional details of this program and its results have been reported by Battelle/WHOI (1983), U.S. Geological Survey (1983), and Payne et al. (1982).

Points of particular relevance to the BSMP were:

- Use of fine fraction only for metals and hydrocarbon analyses.
- Use of an oversampling strategy so that additional station or replicate samples are available if deemed appropriate.
- Adjusting screen size for infauna to control variance (0.3 mm was used on Georges Bank).

3.3.6 California OCS Long-Term Effects Study

F. Piltz (MMS Pacific OCS Office) briefly described the approach being taken to document the long-term effects of upcoming oil and gas development on the southern California OCS in water depths to 1,000 m. The initial effort was to examine the historical data base and establish a statistically valid sampling design. Reconnaissance cruises are underway to better understand poorly studied geographic areas, to improve the state of knowledge of taxonomy of indigenous benthos, and to examine the somewhat unique hard bottom outcroppings in the area. Because of the water depths the effects of drilling fluids and cuttings are the primary concern. Benthic sediments and organisms will receive major attention because of the anticipated higher "signal to noise" ratio expected for drilling effluent effects on benthos compared to other aspects of the ecosystem. A 5-year monitoring program is anticipated using stations both near and removed from production platforms.

3.4 PHYSICAL ENVIRONMENT

3.4.1 Ice Conditions

As described by L. Hachmeister (Science Applications Inc.) and W. Sackinger (University of Alaska), the physical environment of the Beaufort Sea is characteristically very different from other areas of the United States Outer Continental Shelf because of its proximity to the arctic ice pack and the existence of fast-ice along the entire coastline during winter. From October through June, the entire Beaufort Sea is generally covered with ice. The permanent arctic pack ice zone is found in deep water and is usually in motion at variable rates up to 35 km per day. Shoreward of the permanent pack is a seasonal pack ice zone, which extends through most of the stamukhi zone (an offshore zone of grounded ice, sand, gravel, and rubble). In winter, grounded fast ice is found in this stamukhi zone; farther inshore is a region of seasonal floating shorefast ice; and a shallow coastal region is composed of seasonal bottom fast ice. A more detailed description of the ice regime in the Beaufort Sea can be found in Barnes and Reimnitz (1978).

Because water and sediment movement, and therefore contaminant movements, within the Beaufort Sea are profoundly influenced by the ice, they are subject to great seasonal variability. In winter, the presence of ice cover minimizes wind coupling with the water column and, therefore, water movements are dramatically reduced and water exchange rates in nearshore areas may be on the order of several months. In some coastal lagoons, the reduction in water movement, combined with the exclusion of salt from the forming ice, can lead to very high salinities (up to 180 ppt has been observed), which can persist until either breakup or the penetration of freshwater runoff during spring.

Where bottom fast ice is found near the shore, sediment distribution and reworking is influenced by ice movement. Ice movement takes place due to deformation and ridging in winter, and during formation and breakup periods. Sediments are also influenced by water scour due to drainage of river water which flows out over the ice in spring and drains through ice holes and cracks during this breakup period. Farther offshore, sediment distribution and reworking are influenced by grounding of ice and gouging by floating or moving ice, particularly in the stamukhi zone.

During the winter, contaminants introduced under the ice will tend to remain relatively undispersed until breakup begins. Contaminants introduced under the ice will tend to concentrate either directly under the ice, in the bottom layers of the ice, or in the underlying sediments, depending on a number of factors including: solubility of the contaminants, the matrix material, the particulate concentrations in the water column, the matrix material density, the time of year the material is introduced, and the level of microbial activity which might modify the contaminating material. In contrast, contaminant materials introduced on top of the ice will tend to remain in place or will be wind-dispersed until breakup, when they will be washed through the ice by fresh water overflowing the ice, or when they will be dispersed at a point where the melting ice releases them. While it is clear dispersal mechanisms that would affect contaminants introduced into the Beaufort Sea during winter are extremely complex, it is probable that in some cases the dispersion of the contaminant will be less than would be experienced in the open water season, or less than is encountered in other ice-free oil development areas. It also should be noted that current regulations require the disposal of drilling muds on the ice during fast-ice periods. However, spills or other accidental releases of oil or other materials could take place either on or below the ice.

During the ice-free period in the Beaufort Sea, contaminant distributions will be influenced by water, sediment, and suspended particulate movements which are considerably greater than during the winter. For example, summer currents typically average about 3 percent of the wind speed, but currents are typically only 0.3 percent of the wind speed during ice-covered periods. Therefore, transport of contaminants away from the immediate area of the discharge will take place predominantly during the ice-free and moving-ice periods.

3.4.2 Circulation

The major features of water circulation patterns in the Beaufort Sea during the open water season were described at the workshop by Hachmeister. The large-scale circulation within the Beaufort is dominated by the offshore Beaufort Sea gyre which moves water to the west at a mean rate of about 5 to 10 cm/sec. Inshore of the gyre is the Alaska coastal current system, a complex, reversing current regime which results in a mean movement of water to the east at about 15 to 25 cm/sec. In the nearshore zone on the shelf, currents are generally highly variable, mean westerly, wind-driven currents of 10 to 15 cm/sec. Most OCS development activity will take place within this nearshore area with its variable current regime.

Winds in the nearshore Beaufort typically come from the northeast. A generalized schematic of the nearshore flows resulting from such winds is presented in Figure 3-2. With northeast winds, upper-layer water is generally transported offshore with colder, more saline water flowing onshore in the lower layers, except within the lagoon system inside the barrier island chain. In these lagoons, the generally warmer and lower salinity water, resulting from the influence of freshwater runoff, is transported westward along the coast and replaced by colder, more saline water flowing into the lagoons through breaks in the barrier island chain. During periods of low tidal currents, the lagoon entrances often exhibit typical estuarine flow characteristics (strong vertical stratification, surface outflow, and inflow at depth). The influence of tidal fluctuations (particularly within Simpson Lagoon) is such that, under consistent northeast winds, pulses of colder, more saline water enter the lagoons at each tidal cycle and are transported to the west by the mean current. Under these circumstances, a series of cross-lagoon density fronts may be set up (Figure 3-2). In those parts of the coastline where the barrier island system is not well developed, the typical northeast winds tend to move surface water offshore.

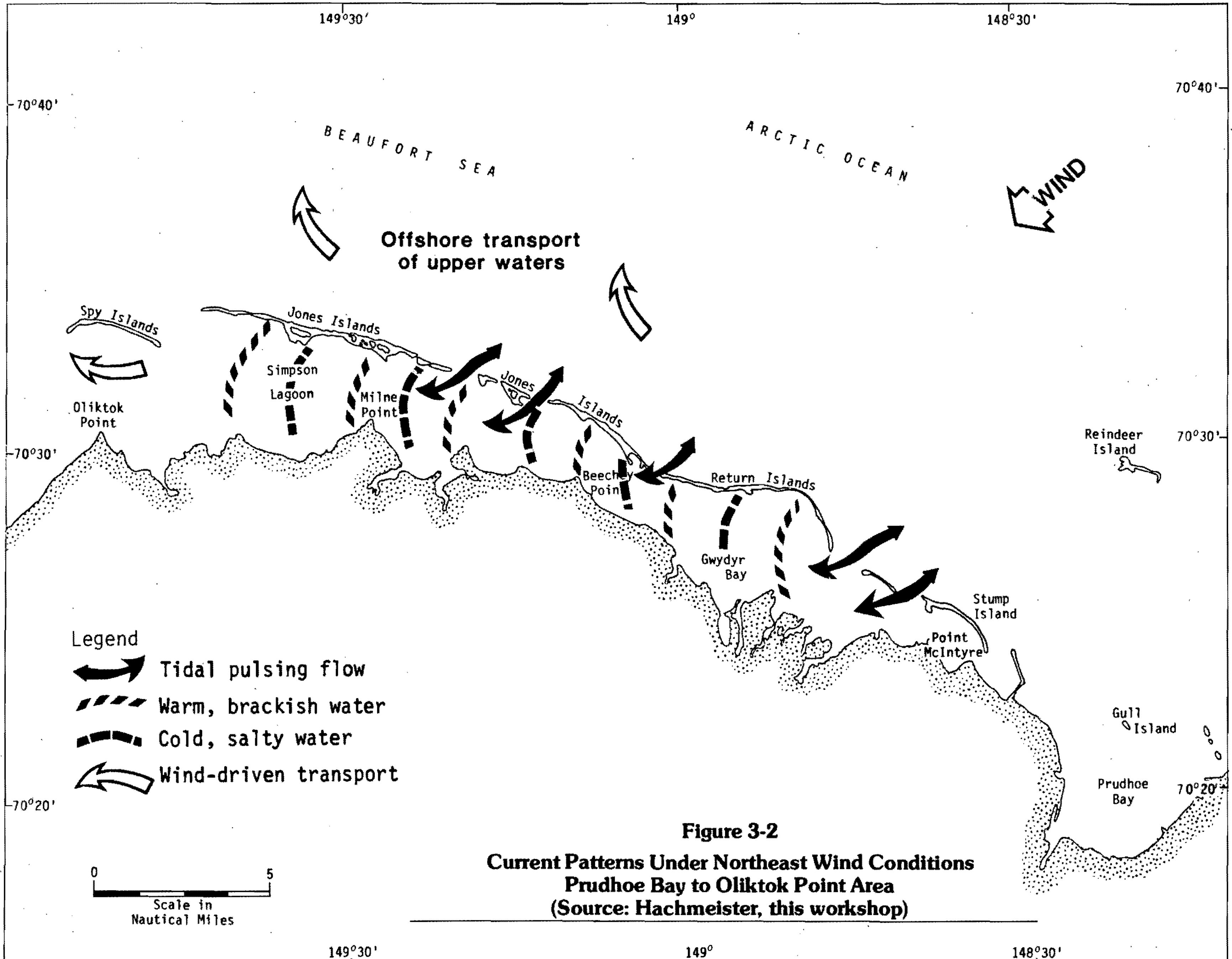


Figure 3-2

Current Patterns Under Northeast Wind Conditions Prudhoe Bay to Oliktok Point Area (Source: Hachmeister, this workshop)

Near river mouths, this offshore movement of surface waters enhances the natural estuarine type circulation and results in seaward spreading of the high suspended solids and warm, low-salinity surface water from the river outflow. Since surface water movement is generally offshore under normal northeast winds, coastal upwelling occurs during these periods.

Strong storm winds occur in the Beaufort quite frequently and are generally from the northwest or the west. The frequency of westerly wind occurrence is higher toward the eastern end of the United States Beaufort. Winds from the northwest or west cause onshore transport of upper-layer waters in the mid-shelf region and, because of the influence of the coastline, move coastal surface waters along the coast to the east (Figure 3-3). Under these conditions, mean water flow within the coastal lagoon system is to the east with warm, low salinity surface water being forced out of the lagoons through the barrier inlets. Therefore, downwelling of surface waters occurs on the inner shelf outside the lagoons where mid-shelf and lagoon surface waters converge. Westerly winds tend to constrain warm, low-salinity land or river runoff from mixing seaward and, therefore, river discharge plumes are oriented to the east of the river in a relatively narrow region adjacent to the coast.

Limited data on circulation patterns under ice and during breakup are reported by NORTEC (1981). More detailed descriptions of the circulation and current regime in the Beaufort Sea can be found in Aagaard (1979, 1980, 1981) and Mungall and Whitaker (1979).

The three major areas of concern for OCS development (Camden Bay, Harrison Bay, and the Stefansson Sound/Simpson Lagoon area) exhibit summer circulation patterns consistent with the descriptions above. Camden Bay, lying farthest to the east, experiences greater frequency of westerly winds and is primarily an open coastal system. The Stefansson Sound/Simpson Lagoon area is more complex with both well developed lagoon systems and the more open circulation areas, such as in the Prudhoe area. Harrison Bay is primarily an open coastline system, but the discharge from the Colville River during westerly winds is constrained to move eastward along the coast and may spread into the Simpson Lagoon system.

Although the physical characteristics which will influence the nature of biological communities in the Beaufort are diverse, the principal controlling factors can be identified. The structure of the primary production and benthic communities can be significantly affected by changes in nearshore circulation patterns and mixing rates, upwelling and nearshore/mid-shelf water exchange processes, and winter exchange processes under ice. Fish, bird, and mammal populations and distributions can be affected by water structure characteristics, exchange processes, and upwelling. In turn, each of these factors will be controlled primarily by the temperature regime, the extent and timing of ice cover, the wind patterns (particularly during the summer open season), and the amount and timing of freshwater runoff.

3.4.3 Monitoring Considerations

Hachmeister recommended that the Beaufort monitoring program should include the following provisions:

- Meteorological data should be processed to express climate changes in terms such as wind frequency and speed roses, and degree days. These data are now being routinely collected at stations between Barter Island and Point Barrow.
- Existing remote sensing data should be gathered and processed to provide a description of temporal trends in ice cover and water temperatures, at a minimum.
- Water and air temperature, salinity, and other physical data collected in biological studies should be evaluated and integrated into an areawide data base. These data will provide a description of air and water variations and permit confirmation of general circulation patterns inferred from meteorological and river runoff data.
- Continuous routine measurements of a limited number of physical parameters (such as water level, temperature, clarity, salinity, current and wind speed direction, and river runoff) should be made at a small number of stations along the Beaufort coastline to monitor the relationship between general transport, circulation, and exchange processes and meteorological driving forces.

Sackinger provided the workshop an overview of the remote sensing techniques available for making observations of the physical characteristics of the environment. Remote sensing of the marine environment can be performed by satellite and aircraft overflight techniques, or by fixed sensors placed in appropriate locations in/on the ocean. Parameters that can be measured remotely include air temperature and pressure, wind speed and direction, wave height and period, water level, water temperature, salinity, water current speed and direction, ice extent, ice pressure, and ice thickness. Basic information concerning the most probable sensor, the necessary location of the sensor, the sampling rate, and the mode of data reduction for each of these parameters is included in Table 3-5.

TABLE 3-5
APPLICATIONS OF REMOTE SENSING
TO ENVIRONMENTAL MONITORING IN THE BEAUFORT SEA

Physical Parameter	Sensor and System	Location	Sampling Rate	Reduction
Air temperature	Thermistor, etc.	On island or structure	Hourly	Digital
Air pressure	Barometer, etc.	On island or structure	Hourly	Digital
Wind speed and direction	Anemometer, etc.	On island or structure	Hourly	Digital
Wave height and period	Pressure or acoustic, etc.	Nearby seafloor	Approx. 2/sec.	Telemetry - needed much processing
Water level	Pressure or acoustic, etc.	Nearby seafloor	Hourly	Digital
Water temperature	Thermistor, etc.	Nearby seafloor	Hourly	Digital
Water salinity	Current meters, etc.	Nearby seafloor	Hourly	Digital
Water currents	Current meters, etc.	Nearby seafloor	Hourly	Digital
Ice presence	Satellite, or photography, or radar	Orbiting, or on-island	Daily	Human interpreter
Ice thickness	Over-ice radar	On-ice	Weekly	Human interpreter
Ice salinity	Sampling	On-ice	Weekly	Human interpreter
Ice temperature	Thermistor, etc.	On-ice	Daily	Digital
Ice transmissivity	Photocell, etc.	On-ice	Week/month	Human interpreter
Dissolved oxygen	Special sensors	Water column near island	Hourly/daily	Varies
Chemical contaminants	Special sensors	Water column near island	Hourly/daily	Varies
Sediment load	Photocell, etc.	Water column near island	Hourly/daily	Varies

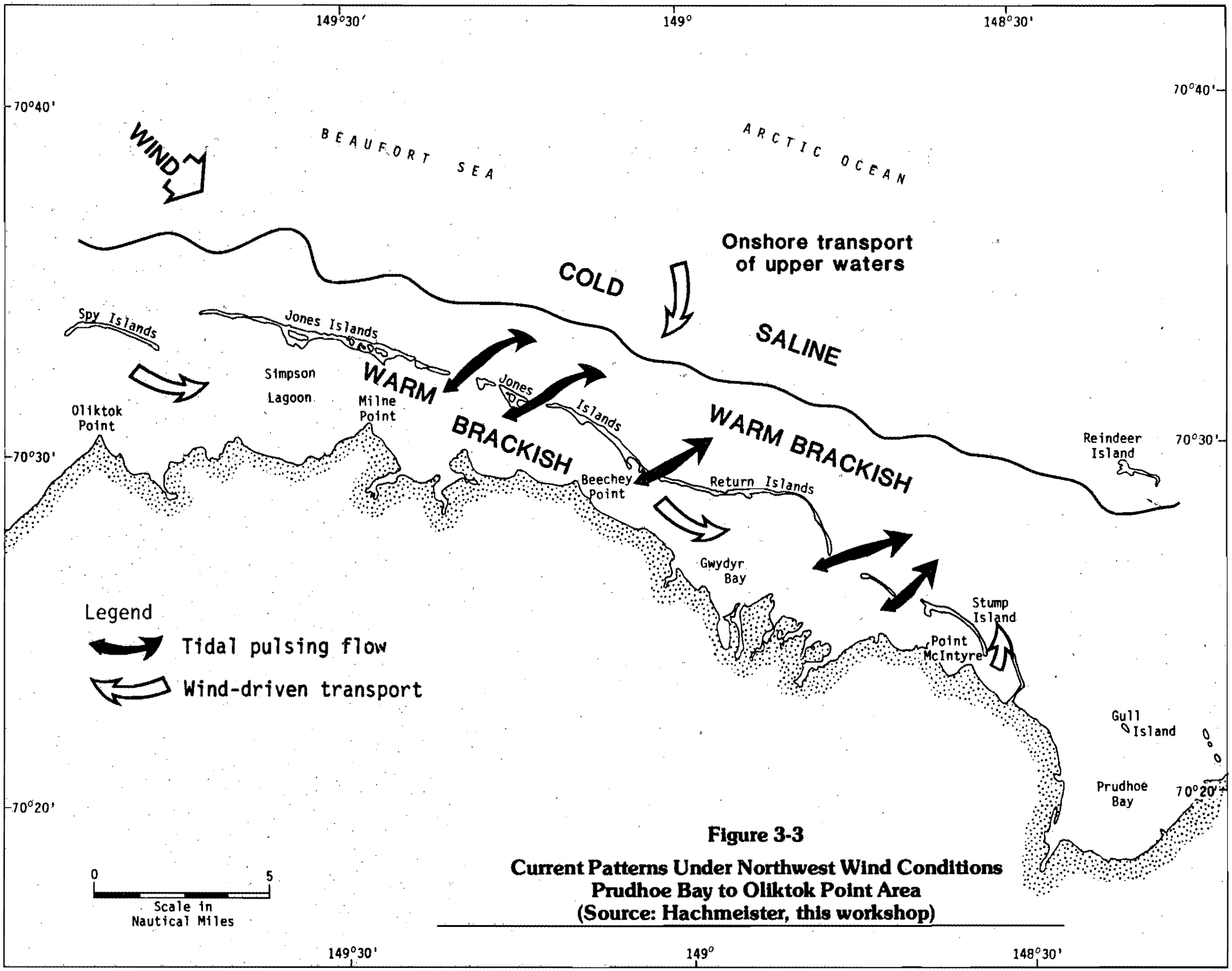


Figure 3-3

Current Patterns Under Northwest Wind Conditions
Prudhoe Bay to Oliktok Point Area
(Source: Hachmeister, this workshop)

3.5 BIOLOGICAL ENVIRONMENT

The biological environment of the nearshore Beaufort Sea was described by a series of researchers with experience studying various ecosystem components in the area. This section provides a brief summary of information presented describing this environment including discussion of the advantages and disadvantages of each ecosystem component for incluslon in an areawide BSMP.

3.5.1 Primary Producers

D. Schell (University of Alaska) noted that peat from eroding coastlines and from riverine sources provides a major input of carbon to the nearshore waters of the Beaufort Sea. However, his research using carbon isotope ratios has shown that direct carbon uptake by higher marine organisms is primarily from recent marine primary productivity (see Schell 1982). A few benthic organisms appear capable of directly utilizing peat, but its primary contribution is in the form of nutrients released during microbial breakdown. Much of this nutrient release occurs under ice and is transported downslope by density currents created by brine drainage from freezing ice.

Ice algae contribute only a small fraction of the annual energy budget of the nearshore Beaufort Sea, especially near shore where large expanses of turbid ice may be formed during fall storms. Phytoplankton productivity during the limited growing season is the major source of organic carbon for most of the upper trophic levels of the Beaufort Sea. Highest phytoplankton productivity occurs in areas off Point Barrow and just west of the Canadian border. Benthic microalgae is thought to contribute little to the overall energy budget of the Beaufort shelf (Schell et al. 1982; Dunton 1983b), primarily because of the lack of hard bottom areas suitable for attachment and because of ice disturbance of the bottom.

However, in limited areas, most notably the Boulder Patch in Stefansson Sound, areas of gravel and cobble substrate support a relatively rich epibiota dominated (in terms of biomass) by laminarian kelps (Dunton et al. 1982; Dunton 1983b). In these areas kelp productivity provides the major primary productivity input to the system (Dunton 1983b). Because of the limited geographic area and the resulting uniqueness of the biota of the boulder patch, the area has attained a high political sensitivity. Schell described proprietary research in 1983 showing that waterborne silt from nearby island construction depressed the growth of boulder patch kelp.

Primary grazers in the shallow Beaufort Sea are epibenthic and pelagic zooplankton (primarily crustaceans —copepods, mysids, euphausiids) and benthic filter feeders (including bivalves). In the boulder patch, a chiton (*Amicula*) is the dominant macroherbivore. Phytoplankton settling to the bottom are consumed by a variety of infaunal and epifaunal detritivores.

Other than the Boulder Patch kelp, Schell did not believe that primary producers were suitable for the BSMP because of their high variability in space and time and their expected resiliency to local effects.

3.5.2 Benthos

Infaunal communities in the nearshore areas are stratified by depth. Densities are generally low in the bottomfast ice zone inside the 2-m isobath. In deeper waters, infauna becomes more diverse with polychaetes and bivalves as numerical dominants (Carey et al. 1981; Feder and Jewett 1982). In terms of numbers of individuals, a majority of polychaetes are tentaculate filter feeders with increasing numbers of deposit feeders and predators below 15 m (Carey et al. 1981). Bivalves are primarily filter feeders, although surface deposit feeders (e.g. *Macoma*) are also present. G. Robilliard (Woodward-Clyde Consultants) described studies to evaluate changes in benthic community composition induced by the Prudhoe Bay causeway. Of physical factors tested, infaunal structure was most strongly influenced by sediment grain size and depth. Robilliard pointed out that benthos is an excellent "red flag" indicator group for the kinds of impacts anticipated from OCS development because pollutants of concern (metals, hydrocarbons) are ultimately deposited in the sediments and because benthic infauna is easy to monitor, faithful to location, and provides a time and space scale of change. There has been little demonstrated linkage between benthic infauna and higher trophic levels, although B. Griffiths (LGL Limited) noted that bivalves may comprise about 10 percent of the diet of oldsquaw ducks in Simpson Lagoon.

In contrast, Griffiths pointed out that epibenthic crustaceans, most notably mysids and amphipods, are the primary prey of a variety of important fish and birds in the nearshore zones of the Beaufort Sea. Carbon in these organisms is in turn derived largely from marine primary production (Schell et al. 1982). There is a massive influx of mysids and some amphipods as the bottomfast ice melts from the shorelines and lifts and breaks up in the lagoons (see Griffiths and Dillinger 1981). This onshore movement of epibenthos continues intermittently through much of the open-water season, contributing to a very high temporal and spatial variability. Because of this variability and their overall abundance, Griffiths concluded that epibenthos was not well suited for inclusion in a quantitative monitoring program, despite their obvious importance to higher trophic levels.

3.5.3 Fish

Fish populations in the nearshore Beaufort Sea can be divided into two major groups: truly marine fish and anadromous fish—those species spending a majority of the time (spawning, juvenile rearing, and usually over-wintering) in fresh or, in some cases, brackish, water. Principal marine fish (e.g., Arctic cod, four-horned sculpin) are sufficiently abundant, ubiquitous, and variable in space and time that they were not considered vulnerable to major impacts from oil and gas activity, except perhaps from major seawater intake structures that were not properly screened. Marine fish are not harvested commercially in the Beaufort Sea, although they are of limited subsistence value and are important in marine food webs. Marine fish were not addressed in detail by the workshop.

A number of anadromous species, primarily salmonids (ciscoes, whitefish, and char), are seasonally abundant in the nearshore zone of the Beaufort Sea. As described by B. Gallaway (LGL Ecological Research Associates Inc.), the behavior of several of these species puts them in close contact with existing and planned oil development activities (e.g., causeways, islands, intakes, and possibly spills). "Typical" Beaufort Sea anadromous fish spawn and rear for one to several years in fresh water. Subsequently, they leave to feed in salt water for a number of summers, outmigrating with spring breakup and returning to overwinter in fresh water or delta areas from August or September through the following spring. Indications from the Beaufort (Gallaway) and the Chukchi (Houghton and Hilgert 1983) are that overwintering does not necessarily occur in the same system as does spawning.

In the Alaska Beaufort, the most important anadromous species is likely the Arctic cisco, which is the subject of commercial and subsistence fisheries in the Colville River as well as a subsistence harvest near Kaktovik. Large numbers of this species (200,000 to 1,000,000) overwinter in the Colville from which they emigrate each spring to feed along the coastline. Because no mature fish have been found in the Colville or in other Alaska rivers, Gallaway's current theory is that these fish, upon maturing, return to the Mackenzie River to spawn. Least cisco also range widely along the Beaufort coastline with runs reported in the low-gradient coastal streams from the Sagavanirktok and Colville westward. Broad and humpback whitefishes generally stay closer to their home streams than the ciscoes and, as such, would be more vulnerable to localized rather than regionalized impacts. Arctic char, like Arctic cisco, range widely in the coastal waters. Major populations occur from the Colville eastward in streams with headwaters in the Brooks Range. In contrast to the situation in the Chukchi Sea, char are not subject to intense commercial or subsistence fishing in the United States Beaufort Sea. Overwintering and spawning char in upper Colville and Sagavanirktok tributaries have been indexed by aerial survey for several years (Bendock (1983).

Gallaway reported on recent field and laboratory studies (see Griffiths and Gallaway 1982) demonstrating a preference of anadromous fish for higher temperature and lower salinity waters typical of those found in the lagoons and nearshore waters during the open-water season. Gallaway described density driven and random walk models that have been used to predict the movement of anadromous fish around the Prudhoe Bay causeway. These unverified models support the theory that anadromous fish movements are governed in part by water quality conditions encountered. In another modeling effort, Gallaway has used population parameters gathered in the Colville Delta commercial fishery to model catch per unit effort in the fishery over the years 1967 through 1981. Fit has been generally good. The predicted values tracked well during a major population decline in 1978-1980 that resulted from the unexplained loss of an entire year class from the population.

3.5.4 Birds

Bird use of the Alaska Beaufort coast was presented by S. Johnson (LGL Limited). Except for a half dozen species, birds are present in the Alaska Beaufort Sea area for only about half the year, from May through October. For the other half year they are scattered south as far as the Antarctic. In spring, as many as 5 to 10 million birds migrate through the Beaufort Sea to nesting locations in Canada and Alaska. The most abundant of these are waterfowl and shorebirds. When birds first arrive during late May and early June, most of the Beaufort Sea is still ice covered, and migrant birds tend to concentrate in the limited areas of open water—in the offshore leads and along the coast at river deltas.

By mid-June, most birds have completed their migration through the Beaufort Sea and many have dispersed to tundra nesting habitats away from the coast. However, a large number do nest on the barrier islands and in the river deltas. The most important of these locations have been identified through earlier work. They are:

- Plover Island
- Colville Delta and Thetis Island
- Sagavanirktok River Delta and Howe/Duck Island
- Cross Island
- Canning River Delta (see Figure 2-1)

Birds occupy these habitats through the breeding season from June to mid-August.

By mid-July, most tundra-nesting birds, mainly waterfowl and shorebirds, are rearing their newly-hatched young. Many adults (mostly males) move to the coast to feed and/or molt prior to southward migration. From mid-July to mid-August, several species of shorebirds and waterfowl (especially oldsquaw) aggregate in very large numbers (thousands to tens of thousands) along the barrier islands and in the adjacent lagoons. Tens of thousands of molting waterfowl are flightless during a portion of this period. The most important locations for these molting and staging birds are:

- Barrow Spit/Plover Island
- Jones Island/Simpson Lagoon
- Flaxman Island/Leffingwell Lagoon area

In addition, thousands of molting ducks and geese congregate in the Teshekpuk Lake area, southeast of Barrow.

During late August through September, most birds migrate out of the Beaufort Sea area. Notable exceptions are the hundreds of thousands of geese that move westward from nesting areas in Canada to feed along the coastal plain of northern Yukon and Alaska. Also, hundreds of thousands of females and young-of-the-year oldsquaws move from tundra lakes and ponds to coastal lagoons to feed for 2 to 3 weeks before southward migration. By mid-October, most nearshore areas are frozen and most birds have left the Alaska Beaufort Sea.

Only a very small number of birds recorded on the Alaska north slope have been identified by society as "important"; that is, identified as key species or valued ecosystem components (VECs). These include those species listed by regulatory agencies as "rare and endangered," such as the peregrine falcon or Eskimo curlew. They also include species of economic or cultural importance, such as waterfowl which are hunted by sportsmen and native people. Very abundant and widely distributed species that are easy to count and may serve as an indicator of change are also considered VECs.

Birds can be affected by hydrocarbon development either directly, through contact with oil/fuel, or indirectly, through changes in their habitat and/or food. The direct effects have been dramatically documented in several instances where major spills have caused heavy mortality of waterbirds. Other than through massive contamination or alterations in habitat or food supply, Johnson thinks it highly unlikely that a key species population would be radically affected through indirect means. An exception might be the displacement of birds from key habitats through chronic disturbance, such as noise and/or movement associated with aircraft, ships, and other vehicles.

3.5.5 Marine Mammals

T. Albert (North Slope Borough) described in depth the importance of marine mammals to the Inuit people of the North Slope Borough. From the viewpoint of the local residents, there is little doubt that the most important species (mammal or otherwise) is the bowhead whale. This endangered species makes its spring migration from the Bering Sea in open leads near Barrow, then heads east to Canadian waters through an extensive lead system well offshore. Its return to the west in the fall follows the coastline more closely. Feeding has been documented in Alaska waters at least between the border and Camden Bay. Albert suggested this area may be a critical habitat for the bowhead, providing the whales their last abundant food resource prior to the winter.

The hunting and harvesting of bowhead whales is a central aspect of the Eskimo culture. Although hunting methods have been modernized somewhat in recent years (especially in the fall hunt), the social and cultural aspects of the harvest remain much as they were in prehistoric days. The food provided by the whales is highly prized by Eskimos with entire villages sharing in the bounty of each kill.

Because of the importance and low numbers of this species, the bowhead is always the primary concern of the local Eskimos in considering any development in the Beaufort (or northeast Chukchi) Sea. In addition to major oil spills (not the focus of this workshop), the major pollutant of concern with respect to whales is noise. There is some evidence that levels of noise from normal at sea drilling and construction activities do not unduly impact movements of gray whales in California (Gales 1982) and bowhead whales in the Beaufort Sea (Fraker et al. 1982) although in the latter study some behavioral changes were noted where whales were approached by boats and aircraft. By far the greatest source of waterborne noise pollution associated with oil and gas activities is from seismic exploration. Albert related that Eskimos at Barrow have developed a growing conviction that seismic activity during the fall migration has displaced the animals offshore from their usual patterns, increasing overwater distances that must be traveled in the hunt. Concern is also growing that this same displacement may interfere with the Kaktovik hunt.

Public (primarily native) and government concerns related to the bowhead's endangered status have resulted in a number of recent and ongoing research projects on the bowhead whale (Sections 2.4.2 and 2.4.4). The status of bowhead research has been most recently summarized in the proceedings of the Second Conference on the Biology of the Bowhead Whale *Balaena mysticetus* sponsored by the North Slope Borough (Albert et al. 1983).

Albert reported that next to the bowhead whale, the most important marine mammal from the North Slope Borough's perspective is the ringed seal, followed by the bearded seal. Both are ice-associated species with ringed seals widely distributed across the landfast ice zone in winter. Aerial censusing has been conducted by Alaska Department of Fish and Game for OCSEAP for several years in various areas of the Beaufort shelf (e.g., Burns et al. 1981; Burns and Kelley 1982). In addition, the effects of on-ice seismic exploration surveys on ringed seal behavior are being studied by Burns et al. (1983) and Halliday et al. (1984). These data provide a reliable baseline index of ringed seal numbers in the area. S. Johnson (LGL Limited) described use of this aerial censusing of ringed seal holes to assess the effects of ice road construction and operation in the Seal Island area off Prudhoe Bay. The technique was sufficiently robust to detect a statistically significant positive correlation of hole density with distance from the ice road and gravel island.

Other marine mammals in the Beaufort Sea such as polar bear, walrus, and beluga whale, were not discussed in any detail at the workshop.

3.6 MONITORING INDICES AND APPROACHES

3.6.1 Geochemical Indices

Oil and gas exploration and development activities may result in the introduction of hydrocarbon and trace metal contaminants into the Beaufort 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 significantly raise the environmental concentrations of these contaminants. Because both trace metals and hydrocarbons are found naturally in marine ecosystems, it is usually difficult to interpret data showing changes in the environmental concentration of a particular metal or of hydrocarbons. Since natural variation may be large, such data can be reasonably interpreted as demonstrating a significant contaminant input only if dramatic concentration increases are found. However, the elemental 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.

P. Boehm (Battelle New England) presented detailed information to the workshop participants concerning the potential use of hydrocarbon indices in the Beaufort Sea. His presentation was supported by a paper giving detailed descriptions of the use of various hydrocarbon indices and proposing a sampling and analysis scheme to utilize these indices in monitoring oil and gas development inputs to the Beaufort Sea ecosystem. The remainder of this section summarizes the major points of Boehm's presentation and paper.

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 biomonitoring studies should be instituted to determine the biotic impact from the increased contaminant level.

Hydrocarbon monitoring strategies should focus on sampling 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 partitioned within a short period of time primarily into the sediments, particularly where suspended sediment concentrations 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 and should be monitored through analysis of indigenous benthic organisms, such as caged mussels or other similar filter 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. Sediment analysis should be performed only on the upper layer of sediments and, if possible, on a layer with the smallest thickness that contains all of the inputs since the last sampling period. Since the character of the sediments and factors such as bioturbation affect the availability of sedimented hydrocarbons, the exposure of marine benthos to hydrocarbons should be assessed through analysis of hydrocarbon levels in organism tissues, particularly levels in surface deposit feeders (such as *Macoma* spp.) which feed on the recently deposited surficial material.

A number of features of the behavior of oil and hydrocarbon compounds in arctic marine environments must be borne in mind when monitoring the Beaufort Sea. First, the microbial degradation of oil will be very slow in the Beaufort and oil spilled under ice or trapped within annual ice will not weather significantly. Second, evaporation of oil released to the sea surface will be slow compared to temperate conditions, and this reduced rate of evaporation may prevent the loss of the more toxic volatile fraction from the oil before it is sedimented. Therefore, sedimented oil may be more toxic in the arctic than in temperate conditions. Finally, marine bivalves in the Arctic depurate oil very slowly, requiring 1 year to "near totally" depurate after an acute exposure and even longer after chronic oil exposure.

The sampling plan for hydrocarbon monitoring in the Beaufort should include sediment and biotic measurements, and caged biota experiments at the same sites. The stations sampled should be established hierarchically. Regional or areawide stations should include those for which baseline data already exist and which are located in probable spill and depositional impact zones. These stations should be sampled at 2- to 5-year intervals, with the probable impact zone stations being monitored annually when activities are such that impacts may be more likely (e.g., after spills). Site-specific stations 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. These site-specific stations might reasonably be established and sampled as part of permit compliance monitoring programs.

Since sample replication is important, a minimum of five sediment samples and a similar number of biotic samples should be collected concurrently at each site. In the site-specific sampling program, or if there is a spill, hydrocarbon analysis should be performed on all samples initially by UV fluorescence, which is a good low-cost screening measure, and by a more detailed compositional analysis (gas chromatography and mass spectrometry) on a subset of samples, including those samples showing elevated oil concentrations via the UV fluorescence measurements. For the regional sampling, compositional analysis should be performed on all samples analyzed, although the number of samples taken should be higher than the number analyzed to reduce costs, and all samples should be stored for future possible analysis.

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. These are listed in Table 3-6.

In order to obtain the maximum information from the proposed hydrocarbon 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. The monitoring program should be aware of the existence of numerous natural seeps in the Beaufort region, including those in Simpson Lagoon, near Umiat, and near the Colville River delta which empties into Harrison Bay.

Although not extensively addressed by the workshop, metals analysis and analysis of organics, such as lignosulfonates, should be emphasized during monitoring of exploration activities, while hydrocarbon analysis should be emphasized during monitoring of production activities and spill situations. Metals, such as barium or chromium, may be good indicators of drilling mud fate and distribution during the exploration phase when very little hydrocarbon release would be expected. Other metals, such as vanadium, may also be useful indicators of oil releases to the sedimentary environment. Neither Boehm nor other presenters at the workshop discussed trace metal geochemical indices in detail. More detailed discussion of trace metal indices is incorporated in Sections 3.7.2 and 5.2.1 of this report, since the use of such indices was supported by the workshop for incorporation in the proposed monitoring program.

3.6.2 Microbial Indices

Contaminant inputs to the marine environment can affect the microbial communities either through the introduction of nonindigenous microorganisms (usually sewage-related) or through alteration of the chemical environment in such a manner as to cause changes in the composition of the natural microbial populations.

R. Atlas (University of Louisville) described the potential application of microbial analysis to monitoring of the Beaufort Sea with respect to oil and gas activities. Four generic approaches are possible: indicator organisms, indicator species, indicator activities, and community analyses. One or more of these approaches may be used to identify effects caused by two possible types of contaminant inputs related to oil and gas activities in the Beaufort. These inputs are hydrocarbons and sewage. Because both sewage and hydrocarbon inputs will always, at least partially, reach the sediments, microbial monitoring can be limited to the sediments. Moreover, the microbial community is much larger in sediments than in other parts of the marine ecosystem and, therefore, is easier to study.

Sewage inputs to the Beaufort caused by the increased human populations that would be associated with oil and gas development could conceivably lead to pathogen contamination of edible marine organisms. Because of the low temperatures in the Beaufort, the survival times of any introduced pathogens could be very long and the standard-indicator organism analyses (e.g., for *E. coli*

TABLE 3-6
HYDROCARBON INDICATOR COMPOUNDS OR GROUPS

1. Total n-alkanes:	**Quantifies n-alkanes from n-C_{15}** to n-C_{34}; baseline data are available at areawide stations in the Beaufort. 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}):	Crude petroleum contains abundant amounts of n-alkanes in this boiling range; unpolluted samples are very low in these alkanes.
3. Phytane:	This isoprenoid alkane is low in abundance in unpolluted sediment: crude oil contains significant quantities of phytane.
4. Total polyaromatic hydrocarbon (PAH):	The sum of 2-5 ringed aromatics is a good quantitative indicator of petrogenic addition if statistical limits are determined. The sum of 2-5 ringed PAH is a better indicator since these components are more prevalent in oil.
5. Saturated Hydrocarbon Weathering Ratio (SHWR):	This diagnostic petroleum weathering ratio has been applied to spill situations to determine the degree of weathering. Weathering models may be based on this parameter in conjunction with the next (AWR).
6. Aromatic Weathering Ration (AWR):	This parameter, similar in concept to SHWR, indicates degree of loss of the more volatile and soluble aromatics from oil.
7. Isoprenoid Alkane/ Straight Chain Alkane Ration (ISO/ALK); Rhytane/n-C_{18} Ratio:	These parameters are measures of the relative abundant of branched, isoprenoid alkanes (slower to be biodegraded) to straight chain alkanes in the same boiling range. Those parameters are useful indicators of the extent of biodegradation.
8. Phytane/Pristane 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 low and increases as oil is added.
9. n-alkanes/Total Organic Carbon (TOC):	The ratio of total saturated hydrocarbons (TSH) 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 TSH/TOC or n-alkane/TOC ratio is characteristics 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 (ng/g) increase and TOC (mg/g) does not.
10. CPI (carbon preference index):	The range of CPI values for Beaufort Sea sediments has been established. Oil lowers the CPI value. CPI values in areas of low hydrocarbon content have been used as an effective monitor of oil additions.
11. Unresolved Complex Mixture (UCM):	The UCM is generally a feature of weathered petroleum although microbial activitiy can result in formation of these GC/FID-unresolved components.
12. Fossil Fuel Pollution Index (FFPI):	Pyrogenic or combustion-derived PAH assemblages are relatively higher enriched in 3-5 ringed PAD compounds; fossil fuels are highly enriched in 2-3 ringed PAH and polynuclear organo-sulfur compounds (e.g., dibenzothiophene and its alkyl homologues). This ratio is designed to determine the approximate percentage of fossil fuel to total PAH.
13. Alkyl Homologue Distribution (AHD) Curves (relative abundance plots of homologous series, number of alkyl carbons present on side chains or polycyclic aromatic hydrocarbons):	Used to look at the relative importance of fossil fuel and combustion PAD sources.
14. Biomarkers:	The pentacyclic triterpane distributions in sediments from the Beaufort Sea are primarily derived from biogenic sources. If petroleum is added, the ratio of triterpane stereoisomers changes and oil is detected at low levels.

and other coliforms) could be misleading since certain pathogens may survive longer than the indicator species. Therefore, any monitoring for pathogens in Beaufort marine organisms may require analysis for concentrations of the pathogens themselves. However, unless enormous human population increases occur in the region, sewage pollution will not conceivably become significant in the Beaufort, and the simple precautions of compliance monitoring and limiting seafood harvesting immediately adjacent to known sewage inputs will provide totally adequate protection. No regionwide monitoring for pathogens is justifiable for the foreseeable future.

Although the indicator organism method is the standard approach for assessing sewage contamination in the marine environment, this approach is not applicable to hydrocarbon contamination since no suitable indicator microbe is known. However, an indicator population approach can be used based on measurements of the number of hydrocarbon-degrading bacteria present in the sample. All natural sediments contain hydrocarbon degraders at low levels (0.01 to 0.001 percent of the microbial community). When hydrocarbons are added to the sediments by spills, this population size increases rapidly, often by several orders of magnitude. In oil-polluted ecosystems, hydrocarbon degraders can constitute up to 100 percent of the total viable heterotrophic bacteria (Atlas 1981). Populations of hydrocarbon-degraders also increase in response to chronic low-level inputs. However, the rate of increase is slow in the low temperatures of the Beaufort Sea environment, as demonstrated by the observed response to a deliberate input to the sediments of several parts per million of oil (Table 3-7).

TABLE 3-7

RESPONSE OF BEAUFORT SEA SEDIMENT MICROBES TO HYDROCARBON EXPOSURE[a]

Exposure Time	Direct Count (Number x 108/g)	MPN[b] Hydrocarbon Utilizers (Number/g)	Percent of Hydrocarbon Utilizers in Total Pop.
0	4.9	30	$6.1x10^{-6}$
0.5	4.7	40	$8.5x10^{-6}$
72 hours	4.5	40	$8.9x10^{-6}$
1 month	5.0	210	$4.2x10^{-5}$
4 months	6.2	420	$6.8x10^{-5}$
8 months	4.8	2,100	$4.4x10^{-4}$
1 year	5.3	2,100	$4.0x10^{-4}$
1½ years	5.1	2,800	$5.5x10^{-4}$
2 years	5.9	24,000	$4.1x10^{-3}$

(a) Source: Atlas, this workshop.
(b) MNP - most probable number.

Monitoring of hydrocarbon degraders is an option for detecting increased input of hydrocarbons into the marine environment and has the advantage that the measurement identifies a biological response to the hydrocarbons and not just the microbial presence. This approach also has several disadvantages, including the tedious and moderately expensive analytical methodology required and the inherent imprecision of microbial population assays. However, the major disadvantage is that the method does not distinguish between biogenic and petrogenic sources of hydrocarbons and, therefore, cannot distinguish between oil and gas development related inputs and natural seeps, changes in land runoff (peat hrdrocarbons), or enhanced production of marine biogenic hydrocarbons. In addition, it is not certain whether the methodology is as sensitive as chemical analysis for the detection of low-level inputs of hydrocarbons.

Microbial communities can be altered by contamination in much the same way as benthic infaunal communities. Therefore, it is possible to perform microbial community structure analysis in a manner similar to benthic infaunal community structure analysis and to develop indices of contamination comparable to the benthic infaunal index (Horowitz et al. 1983). However, studies of microbial community structure and its response to contamination are not extensive and, consequently, there are only limited data on which to base interpretation of any observed community structure changes. Further, very extensive and expensive analysis and data acquisition are required for microbial community structure analysis.

A second type of microbial community analysis which could be applied to monitoring for hydrocarbon or heavy metal contamination of the Beaufort Sea is the analysis of change in the abundance of plasmids in the population which code for resistance to these contaminants (Burton et al. 1982, Devanos et al. 1981). Although the methodology for this analysis is simple and less expensive than microbial community structure analysis, a number of limitations are inherent in the use of this technique. These limitations include the lack of knowledge concerning the natural abundance and variability of the appropriate plasmids in the Beaufort Sea, and the fact that an increase in the number of appropriate plasmids does not demonstrate a cause-and-effect relationship with the source of pollution. This causal relationship is not identifiable since plasmid levels will vary with any change in natural or anthropogenic inputs of hydrocarbons or heavy metals and these responses are still poorly understood.

The final basic approach to monitoring contamination of the marine environment through microbial studies is measurement of the indicator activities of the organisms (Barnhart and Vestal 1983). Microbial productivity, which can be measured by determining the rates of carbon dioxide fixation, nitrogen fixation, or heterotrophic activity, responds to pollution by oil, and changes in these rates can give an indication of the impact of the contaminants on secondary production. However, the natural fluctuations in these activities are large, while the response to pollution is often small and highly variable. These factors suggest that the monitoring of changes in these microbial activities is not presently useful in defining pollutant effects. In addition, methodologies for such analyses are tedious and expensive.

3.6.3 Biological Community Studies, Sublethal Effects Studies

Since suspended solids concentrations in most of the Beaufort Sea are normally very high, it is likely that chronic or acute contaminant inputs of hydrocarbons, other organics, and heavy metals will become absorbed quickly to suspended particulate matter and will be deposited in bottom sediments. Thus, any adverse effects from oil and gas development activities will most likely occur first, and persist longest, in the benthic environment. particularly in depositional environments downstream of the activities. Impacts may include elimination of some sensitive species; changes in abundance, diversity, or community structure; 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 Beaufort Sea might include study of any changes in benthic faunal communities (including demersal fish) that might be caused by contaminant inputs to the sediments.

J. Neff (Battelle New England) described several approaches to the monitoring of biological populations for contaminant-induced effects. 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 the microbes, plankton, nekton, 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, multivariate techniques (e.g., numerical, classification, ordination, discriminant analysis, multiple regression, and canonical correlation), and the benthic infaunal trophic index (Section 3.6.4).

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 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 Beaufort unless a major spill event occurred. This drawback to population structure monitoring may be particularly severe in the Beaufort where the abundance, species composition, and distribution of the benthic fauna are mediated by such highly variable factors as ice scour, wave action, salinity fluctuations, and sediment type and distribution.

Any population structure monitoring program for the Beaufort should be designed to minimize the problems associated with environmental variability. Such a program would (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 new 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 system (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 determine one or more morphological, physiological, biochemical, or behavioral 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. However, many such responses are of no utility in assessing pollutant damage to the Beaufort Sea marine ecosystem, since there is insufficient basic biological information available about the Beaufort species and/or about the relevant physiological/biochemical processes. Thus, any measured response would 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 3-8.

TABLE 3-8

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, descriminant 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

(a) Source: Neff, this workshop

A number of biochemical changes have been evaluated for diagnosing pollutant stress in teleost fish. These are summarized in Tables 3-9 and 3-10. 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 have generally met with little success.

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 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. In the Beaufort Sea, the Arctic cod (*Boreogadus saida*), the fourhorn sculpin (*Myoxocephalus quadricornis*), and possibly the Arctic flounder (*Liopsetta glacialis*) may be suitable monitoring species because of their abundance and generally demersal life style.

TABLE 3-9

POTENTIAL BIOCHEMICAL INDICATORS OF FISH EXPOSURE TO POLLUTION[(a)]

Parameter	Expected Response	Environmental Interpretation
Metallothioneins	Induction	Exposure to Cd, Cu, Hg, Zn
Mixed Function	Induction	Exposure to petroleum, PCB, dioxin, PAH
Blood Enzymes	Increased activity	Liver damage
Erythrocyte ALADase	Decreased activity	Lead poisoning
Tissue Enzymes	Change in activiy	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

(a) Source: Neff, this workshop.

TABLE 3-10
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 lipid 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 or	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 depletion
Catecholamines	Brain	Decrease	Acute or chronic stress

(a) Source: Neff, this workshop.

Another group of organisms that could be monitored for sublethal stress is the benthic amphipods, since they have been shown to be sensitive to oil contamination. Arctic amphipods have been shown to be moderately sensitive to acute or chronic exposure to oil, but relatively insensitive to drilling fluids. Amphipods are abundant in Beaufort Sea coastal and nearshore waters (Section 3.5) 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 (Section 3.3.1), may be highly beneficial to a monitoring program, particularly when the sentinel organisms are caged and possess the same gene pool and life history. Several biological parameters show promise for measuring stress in mussels including: measures of bioenergetic balance 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 Beaufort 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)
  - Reciprocal transplants of bivalve molluscs, such as *Astarte*, with studies on contaminant bioaccumulation, scope for growth, O/N ratio, condition index, and biochemical composition
  - Indicator organisms, such as benthic/demersal amphipods, with studies on seasonal abundance patterns, distribution, reproduction, size/age structure of populations, length/weight regression, O/N ratio, and digestive enzyme activity.

3.6.4 Infaunal Trophic Index

J. Word (University of Washington) discussed the history of use of the Infaunal Trophic Index (ITI) as a tool to define the area of influence of municipal waste discharges, primarily off southern California. The ITI is formed for an infaunal sample based on the categorization of organisms by feeding types. Values can range from 0 (100 percent subsurface deposit feeders) to 100 (100 percent suspension [filter] feeders). The typical response off a domestic waste outfall is a depression of the ITI in areas of deposition even though numbers of organisms, diversity, and/or biomass may remain constant or increase. For the ITI to be useful in a monitoring program there must be a plausible hypothesis linking some aspect of the event being monitored (e.g., Beaufort Sea oil and gas development) to changes in sediment organic carbon. Sediment BOD provides such a measure and typically parallels changes in ITI. Since in the Beaufort Sea petroleum hydrocarbons will be the major potential source of increased organic material in the sediments, the ITI might not be an effective monitoring tool. Also, the significance of the ITI is much reduced where there is little "chaining" of impacts from the infauna to VECs. Since in the nearshore Beaufort Sea such chaining is poorly documented, Word believed that the ITI might be of less value than elsewhere as a component of an area wide monitoring program.

Word also emphasized that the recovery potential of an ecological component is highly important in evaluating the significance of impacts. A major change (e.g., in plankton population) may be of little import to higher trophic levels if recovery occurs in a matter of days or weeks. Research is needed on transport pathways and depositional areas (if any) on the Beaufort shelf as well as on the assimilative and recovery potential of Beaufort Sea benthos before an optimum monitoring strategy can be defined.

3.7 WORKSHOP SYNTHESIS SESSION

3.7.1 Monitoring Program Management Goals

On the last day of the session, D. Wolfe (NOAA) discussed the concept of ocean monitoring in the context of its significance for valued ecosystem components (VECs) and implications for the management of OCS lands. His premise was that monitoring is, in essence, a management tool or a part of a system for management of OCS oil and gas development activity and the affected environment. The objective of monitoring should not be to determine what changes can be measured and then to ask which of these detected changes are important and finally which are oil and gas related. Rather, the manager should ask in turn.

- 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., marine mammals, birds, fish, 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 Beaufort Sea include such things as contaminant exposure (hydrocarbons, metals), disturbance effects (noise, activities), circulation changes (currents, water quality), 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 emphasized that:

- Criteria for variable selection should include:
  - Value placed on the resource
  - Credibility of a hypothesized impact mechanism (perceived risk to the resource)
  - 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).
- Monitorinq 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?"

As described in Section 2.7, a workshop panel of NOAA and MMS scientists (D. Wolfe, J. Cimato, C. Manen, J. Geiselman, J. Nauman) met with the workshop convenor (J. Truett) to redefine the monitoring program objectives and develop a preliminary monitoring approach (Section 3.7.2). This panel developed a specific set of objectives for the BSMP as follows:

- To detect and quantify change that might:
  - result from OCS oil and gas activities;
  - adversely affect, or suggest another adverse effect on, humans or those parts of their environment by which they judge quality; and
  - influence OCS regulatory management decision.
- To determine the cause of such change.

3.7.2 Proposed Hypotheses and Approaches to Regionwide Monitoring

The workshop panel developed seven "strawman" hypotheses and methods to test each. The hypotheses and the methods for testing them would comprise the BSMP. These hypotheses and a summary of panel discussions surrounding each were presented to the full workshop for discussion in the final plenary session. This section provides a statement of each of the first five hypotheses and the rationale behind each as presented at the workshop. This section also includes an analysis of how each hypothesis fits the stated objectives for the BSMP (Section 3.6.1). Related aspects considered by the panel and workshop important for inclusion into the program in a form other than as testable hypotheses are discussed in Section 3.7.3. Two of the hypotheses adopted by the workshop but considered more applicable in site-specific monitoring programs, as well as monitoring approaches considered by the panel/workshop but not included in the "strawman" program, are treated in Section 3.7.4.

3.7.2.1 Trace Metals

Hypothesis: Certain trace metals may accumulate in the environment such that hazards result to human health or to ecosystem components valued by humans.

The suggested monitoring strategy was to first identify those sites or areas where it would be expected that metal accumulation would occur. This would be based on information concerning the location of OCS activities and their anticipated discharges. Metals accumulation at these sites would be monitored by measuring the concentrations of metals of concern in indicator species and in sediments at both test and control sites. No discussion took place as to which metals were of concern. However, earlier in the workshop, barium and chromium had been identified as the only two heavy metals that were likely to have their environmental concentrations significantly altered by development activities. Vanadium was identified as the metal most likely to have its environmental concentration altered by releases of oil.

There was substantial discussion concerning the utility of monitoring the sediments since benthic/pelagic coupling appears to be limited in the Beaufort Sea. Some participants believed it would be more appropriate to measure contaminants in the water column, since they would be more directly available to the VECs which are predominantly pelagic species. However, it was acknowledged that variability in water column concentrations, both temporally and spatially, is so large that monitoring dissolved contaminant concentrations would require an impractically large number of samples be taken in order to arrive at a realistic value. Therefore, it was acknowledged that concentration changes due to inputs from OCS activities would probably be more easily observed in the sediments than in the water column. In addition, it was believed that changes in contaminant concentrations in the sediments would be good indicators of contaminant changes in the water column and/or in biotic concentrations. Consequently, changes in sediment concentrations would be indicators of the potential for adverse effects on VECs or man. The concept of measuring metal (and hydrocarbon) concentrations in certain indicator or sentinel species (comparable to the mussel watch program) was uniformly supported by the workshop participants. Since species used in mussel watch programs in other locations do not appear to be abundant in the Beaufort Sea, discussions centered around the choice of an appropriate species, or possibly two species from different feeding niches, to monitor. Most participants believed it was important to utilize species indigenous to the Beaufort Sea, but the possibility was discussed of monitoring transplanted or laboratory-reared populations of suitable indigenous species that are not naturally abundant in all parts of the Beaufort. The question of whether transplanted populations should be caged or introduced into the environment at appropriate sites without such enclosures was not addressed. Also not discussed was the related question of whether the indicator species would be monitored at sampling sites throughout the Beaufort (i.e., at all sediment sampling locations) or whether monitoring would be restricted to intertidal and shallow water sites in the manner of the National Mussel Watch Program.

3.7.2.2 Petroleum Hydrocarbons

Hypothesis: Petroleum hydrocarbons may accumulate in the environment such that damage could result to ecosystem components valued by humans.

This hypothesis is essentially parallel to the hypothesis regarding trace metal accumulation. Therefore, the suggested strategy for testing this hypothesis is identical to that discussed for metals in the previous section. Deliberation by workshop participants of such questions as the use of sediment versus water samples, the choice of a sentinel organism, and the potential use of caged versus natural populations were included with the trace metal discussions and are previously described. However, several additional considerations received workshop attention and are relevant to the hydrocarbon hypothesis.

Since hydrocarbons and metals are accumulated by different physiological and biochemical processes, the most appropriate species to be used as sentinel organisms may differ for these two groups of contaminants. However, for the monitoring program to be most practicable, the same species should be used for both metals and hydrocarbons. Since hydrocarbons are considered to be of greater potential importance as environmental contaminants in the Beaufort, the best sentinel species for hydrocarbon monitoring should be selected.

Section 5.2.2 of this report details the factors that should be considered in selecting a sentinel organism species. One of the important considerations in selecting a sentinel species is the degree of mobility of the organism. A sedentary species sampled from a given site will have a body burden of contaminants (that it does not readily metabolize) that generally reflects the degree of contamination at that site. In addition, a sedentary organism is more suitable for caged transplant experiments. In contrast, migratory species contamination of environments far removed from the sampling site. Therefore, sedentary species are preferred as sentinel organisms since they can provide more information as to the extent and possible source of any contamination. Nonetheless, the most important of the VECs were judged by workshop participants to be those that are highly migratory, including whales and seals. Because these higher order animals have a generally higher lipid content than do lower order animals and because they are at the top of marine food chains, they likely to accumulate greater concentrations of hydrophophobic petroleum hydrocarbons through bioaccumulation and/or biomagnification. For these reasons, workshop participants believed that hydrocarbon concentrations in selected higher order animals, particularly bowhead whales, should be monitored. Because several of these mammals are protected by law, participants suggested that sampling of these higher order animals for hydrocarbon analysis be focused on whales and be restricted to samples of opportunity, especially annual hunt captures. In the context of this opportunistic sampling, some participants believed that it would be appropriate to include some biochemical and/or histopathological measurements of the "health" of the harvested animals.

3.7.2.3 Bowhead Whales

Hypothesis: OCS operations may alter the migration patterns of bowhead whales.

Because of an earlier decision by MMS, it was not intended that this workshop focus on research necessary to document the potential influence of OCS oil and gas development activities on bowhead whales or other marine mammals. It was the position of MMS that there are other forums, bringing together a broad range of expertise on these animals (and issues relating to their preservation), that are more appropriate for consideration of needed research on monitoring programs. However, this position, first stated by J. Imm (MMS) in his opening remarks, triggered a disagreement that surfaced a number of times during the workshop as to whether marine mammals should be included as part of this workshop. Some participants supported the view that, because the bowhead is an endangered species, necessary bowhead research is appropriately and adequately covered under existing MMS programs. Others argued that the mandate of this workshop was to develop an overall monitoring program for the Beaufort Sea; therefore, marine mammals should certainly be included. However, since few workshop participants were experts in the area of marine mammal research, even those who believed the monitoring program should include marine mammals were hesitant to make specific recommendations for monitoring them.

No monitoring strategy for testing the stated hypothesis was included in the convenor's presentation of the panel's recommendations, largely because of lack of time during the panel's meeting. Two important points were made in the discussion subsequent to the presentation of the hypotheses and monitoring strategies. The first was that, particularly in the context of Wolfe's emphasis on "Valued Ecosystem Components" (Section 3.7.1), bowhead whales, walruses, and ringed and bearded seals should certainly be considered.

Second, it was suggested by C. Cowles (MMS) that approaches to testing the hypothesis regarding bowhead whales should be examined as part of the post-workshop study design. In particular, existing aerial survey data should be carefully evaluated to determine what level of displacement in the fall migration path could be detected using aerial survey techniques. Aerial surveys to determine the routes of bowheads during the fall migration through the Beaufort Sea have been conducted since 1979 (see Section 4.2.3).

In consideration of the obvious importance of the bowhead whale, it was the workshop concensus that this document should reflect the general degree of concern for this species and should attempt to carry out the recommendations of Cowles.

3.7.2.4 Anadromous Fish

Hypothesis: OCS oil and gas development (discharges containing oil or metals, changes in water quality, addition of structures) may affect abundance/recruitment of anadromous fishes.

Several species of anadromous fish (Arctic and least cisco, broad and humpback whitefish, Arctic char) qualify as VECs based on commercial and subsistence use or potential use. As a result of their life history (Section 3.5.3) these species are vulnerable to OCS oil and gas activities only during the open-water season and only during feeding and migration. The whitefish and, to a lesser degree, least cisco migrate relatively short distances from their natal streams while char and Arctic cisco range widely along the coast. Thus, the latter two species were considered more sensitive to regionwide impacts and hence better suited for inclusion in this monitoring program. Two existing data bases appear suitable for continuation in the program; each is being sustained through independent funding.

The primary data record recommended for inclusion in the program is the catch per unit of effort (CPUE) of Arctic cisco in the Colville River commercial fishery. Mr. J. Helmericks, a resident guide and commercial fisherman, has maintained meticulous records of catch, effort, and size of various species captured in his gill net fishery in the lower Colville. Gallaway has compiled these data (1967-1981) and used them along with recaptures of marked fish to calculate a population estimate for Arctic cisco overwintering in the Colville.

The workshop recommended that, as a test of this hypothesis, this compilation of data be continued and analyzed for changes in catch rates or size distribution. The assumption was made that Helmericks would continue the fishery and that he would continue to provide good data for analysis. Should any anomalies occur (e.g., 1978-1980, Figure 3-4), programs would be initiated to investigate the cause(s).

The workshop also recommended investigation of other potential data bases for suitability for inclusion in the program. It was pointed out (J. Houghton, Dames & Moore) that Alaska Department of Fish and Game has a second multiyear data base in the form of several years of aerial index counts of char spawning or overwintering in several North Slope rivers (see next section, Figure 4-3).

3.7.2.5 Oldsquaw

Hypothesis: OCS oil and gas development (discharges containing oil or metals, changes in water quality, addition of structures) may affect abundance or distribution of oldsquaw in nearshore habitats.

As described in Section 3.5.4, male oldsquaw gather to molt during the summer in very large numbers in several lagoons along the Beaufort coastline. S. Johnson (LGL Ltd.) has 5 to 7 years' of data from systematic aerial counts of flightless molting male oldsquaws in areas of Simpson Lagoon and has established survey tracks elsewhere on the U.S. Beaufort coast. Johnson noted that, while absolute numbers of oldsquaw may vary due to unrelated factors acting during their winter absence from the Beaufort Sea, the relative abundance from place to place in the Beaufort was fairly constant.

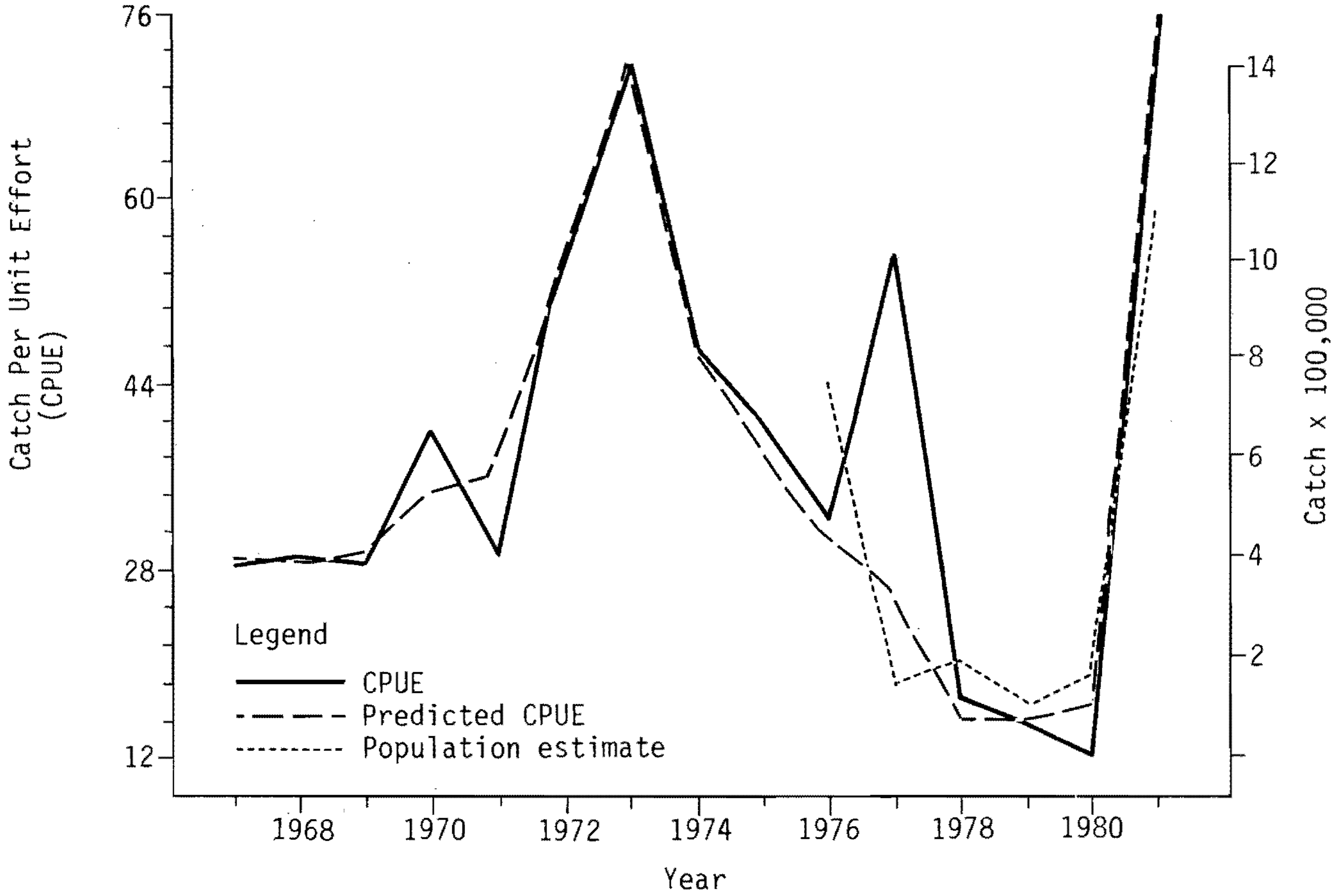


Figure 3-4

Population Trends of Arctic Cisco Based Upon CPUE, Model, and Mark-Recapture Data from the Helmericks' Commercial Fishery, 1967-1981 (Source: Gallaway, this workshop)

The recommended approach for testing of this hypothesis was to continue, with expanded geographic coverage, the summer aerial surveys of molting male oldsquaw described by Johnson. Data on density (birds per square kilometer) would be compared from year to year on each index transect and the ratio of one area to another could likewise be monitored over the years. If changes in their distribution patterns were detected, additional research would be instituted to attempt to identify cause(s). It was pointed out that, in addition to spending half the year away from the study area, sea birds are fairly tolerant of many of the kinds of impacts that might result from OCS activities. It was believed that only a major oil spill (which would elicit another type of monitoring program) would be likely to significantly change regional numbers of oldsquaw. In addition, Johnson noted that oldsquaw were not widely sought as a subsistence resource (cf. other waterfowl) and thus are not the most valued avian ecosystem component.

Nonetheless the workshop consensus was that, given the regionwide abundance of oldsquaw and the existing data base, this monitoring approach would be the best indicator of OCS development effects on waterfowl.

3.7.3 Related Considerations

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

3.7.3.1 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 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 descriptions of physical parameters, such as salinity, temperature. and currents throughout the entire Beaufort 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 Beaufort Sea, the principal such anomalies include early or late ice formation or breakup, and spring river discharge. 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 and wind data, by 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 Beaufort Sea, such as discharge compliance 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 fron any monitoring program should clearly be incorporated in a single data management system for maximum utility (see Section 3.7.3.3).

3.7.3.2 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 enviromnental 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 Beaufort 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.

3.7.3.3 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 (see Section 5.4). Although conceptually the data and information management system can be added to an existing program, this rarely occurs and, when it does, it is usually found to be neither possible nor affordable to incorporate data already gathered into a new management system. 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 to 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;
- Ensure that appropriate trend analyses and special studies of the monitoring data are performed in a timely manner.

3.7.3.4 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, it is likely that this technique will be adequate for most future sample uses.

3.7.3.5 Coordination of Biological and Chemical Sampling

It was believed to be important that, to the extent possible, all biological and sediment sampling should be coordinated in time and space. This will provide the maximum ability to interpret changes in the various parameters monitored.

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

The workshop considered in some detail the potential use of measurement techniques that directly assess populations, population distribution, and the health of biological populations. However, there was no strong support for the use of these techniques in the proposed monitoring program. Two hypotheses adopted by the workshop were clearly represented as site- or activity-specific concerns and as such were not included with the regionwide monitoring approaches covered in Section 3.7.2.

3.7.4.1 Common Eider Nesting

Hypothesis VI: OCS operations on or near islands may cause changes in nesting populations of common eiders.

Since at least the late 1970s, concern has been expressed that activities on or near barrier islands might disrupt breeding activities of waterfowl. Stipulations attached to recent state and federal lease sales have restricted proximity of certain operations (e.g., aerial overflights) to sensitive wildlife habitats. Despite such stipulations, some concern remains that specific activities, which by their nature require closer approaches to sensitive areas (e.g., nesting habitats), may be permitted on a case-by-case basis and that these activities could disrupt breeding success. Of particular concern are colonies of common eider that breed on certain sand islands as well as the lone United States breeding population of snow geese that use an island in the Sagavanirktok Delta (U.S. Army, COE 1980).

A case in point was the Sohio Mukluk Island construction plan which called for winter stockpiling of gravel on Thetis Island, a known breeding area for common eiders. Permission was granted provided that Sohio operate primarily on the side of the island away from the colony, institute strict control of ground and air approaches to the colony, and conduct a study of the effects of the activity on the nesting success of the eiders.

At the workshop, Johnson briefly described the nature of study conducted. The study included mapping of nesting sites within the colony and making observations through the brooding period of nesting behavior and hatching success. A higher than usual success rate was reported despite the nearby activities, perhaps because direct close-range disturbance of the colony was prohibited. Fraker (1983) indicated that details of the study would be available early in 1984.

This study was cited by the workshop as a prototype for future monitoring of the effects of nearby activities on other island nesting colonies. However, it was considered appropriate in the context of site-specific rather than regionwide impact monitoring. As such, no action is required for the BSMP until activities approach important islands. At that time a program similar to that employed at Thetis Island would be designed to monitor the specific effects of the project in question.

3.7.4.2 Boulder Patch Kelp

Hypothesis VII: OCS operations may cause changes in the structure of the Boulder Patch kelp community in Stefansson Sound.

As described in Section 3.5.1, the Boulder Patch in Stefansson Sound has become a biopolitically sensitive area because of its unique epilithic flora and fauna. The boulder patch has been studied since 1976 and good data exist on community structure, biomass, kelp productivity and growth, and carbon energy budget (Dunton et al. 1982; Dunton 1983[b]). The community as a whole changes little from year to year (Dunton 1983[b]) with geographic limits set by the substrate and absence of heavy ice scour, and with long-lived sessile community dominants. Because of this stability, various kelp bed measurements have reasonably low variability and it has been possible to detect statistically significant changes due to both man-caused and natural environmental alterations. The variable selected for measurement by the workshop is growth rate of *Laminaria solidungula* because of the ease in making nondestructive measurements and because of its importance in boulder patch energy budgets (Dunton 1983[b]).

Schell reported at the workshop on proprietary studies for Exxon that demonstrated a reduction in *Laminaria* productivity attributed to nearby gravel island construction. Dunton (1983) showed a significantly greater mean annual blade elongation for this species at a study site under clear ice compared with normal growth under turbid ice cover (see Section 4.2.7). Proprietary study reports of the Exxon monitoring, expanding the available data base by 2 years, may be available in early 1984 (Dunton 1983[a]).

The workshop recognized that this hypothesis and monitoring approach is most appropriate for site-specific activities such as that described by Schell rather than as part of a regionwide monitoring program. In the event that development activities encroach on the boulder patch such that a reasonable impact mechanism can be postulated, a program using the techniques of Dunton et al. (1982) would be designed to monitor changes in kelp growth rates.

3.7.4.3 Indicators of Organism Health

There are several reasons for not including measurement of indicators of organism health in the Beaufort monitoring program:

- Biological effects measurements have generally not been extensively used in monitoring programs because the resulting data are difficult to interpret in a manner that can aid management. Biological health measurement techniques have generally led to data that show changes, or lack of changes, in the monitored parameters, but which are not directly relatable to contaminant loadings or to significant adverse effects on species survival or abundance.
- Biological effects techniques are not readily applicable to the fish, bird, and mammal species of major importance in the Beaufort.
- Biological health measurements may be more appropriate for near-field effects study or monitoring since it would be easier to relate cause and effect.
- The monitoring program should detect contaminant inputs before the concentrations reach levels at which significant biological effects occur. Chemical analyses should provide this capability in the nearly pristine Beaufort.

3.7.4.4 Physical Environment

A separate physical environment monitoring program was not endorsed by the panel for inclusion in the Beaufort monitoring program. However, a physical environment assessment component of the program was endorsed and is discussed in Section 3.7.3. The major reasons for not endorsing a specific physical environment field monitoring effort included:

- Significant broad-scale changes in the physical regime of the Beaufort caused by OCS activities are highly improbable. Changes in the physical regime at, or close to, the site of a specific activity can be monitored more effectively through specific activity study or compliance monitoring (if properly designed and executed).
- Significant broad-scale natural changes in the physical environment of the Beaufort can be observed or inferred from information regarding the meteorological forcing functions and certain simple response parameters, such as sea surface temperature, ice cover, and river flow rates. Knowledge of such changes is needed to assess whether any observed biological population changes can be explained by natural climatic variability. Many of the necessary data needed for assessment of these parameters are already being gathered in monitoring programs performed for other purposes and can be accessed, analyzed, and interpreted, as proposed in Section 3.7.3. However, certain improvements in these other monitoring programs may be needed, for example, improving gauging of major rivers.
- Specific OCS activity studies and compliance monitoring programs will include physical environment measurements. These data, which will address near-field physical environment effects of OCS activities, can be combined with the more general, broadscale data to identify near-field physical environment changes or anomalies that may affect the biota. In this manner, an assessment can be made as to whether these near-field physical environment changes are caused by broad-scale natural variations or the OCS activity.

3.7.4.5 Benthos

While there was general agreement that the epibenthos offers little opportunity for detection of statistically significant changes due to OCS development in the Beaufort Sea, there was no such agreement regarding benthic infauna. As was noted by several participants, infauna has been the primary or exclusive biological group targeted in a long list of monitoring programs and studies of offshore drilling effects. By their very nature, infauna and sessile epifauna offer the following advantages to monitoring programs designed to assess impacts that may occur in the course of OCS oil and gas development in the Beaufort Sea:

- Major pollutants of concern (drilling fluids, hydrocarbons) will ultimately reside in the sediments where exposure to organisms will be maximized.
- Infauna and sessile epifauna have limited mobility and are often long lived so that organisms present at a given location and time will have been exposed to conditions at that location over an extended period.
- They are relatively easy to monitor reliably and have species or assemblage variables (e.g., species counts, assemblage counts, diversity, richness) that have manageable levels of variance (cf. more motile organisms).

As a result of the above, benthic infauna are widely considered the best ecosystem component to monitor for assessment of pollutant-caused changes in aquatic and marine environments—the combination of pollutant behavior, organism immobility, and ease of sampling often means that any pollutant-caused changes can be detected in benthic communities first. The benthos then acts as a "red flag," warning that perturbations are sufficient to affect a natural assemblage and providing managers time to alleviate the situation before effects extend to VECs.

The major disadvantage of benthic infauna monitoring that led to its exclusion from the workshop recommended monitoring program is that, in the Beaufort

Sea nearshore ecosystem, there is little proven linkage between infauna and higher trophic levels or VECs. It was pointed out by several participants that this apparent lack of linkages to higher trophic levels in the near shore may reflect a current lack of understanding of nearshore systems, and that the situation may be different farther offshore or under ice where there is much less data on trophic relationships. For example, flatfish (e.g., Arctic flounder) are likely predators on infauna and are increasingly abundant offshore. It was also noted that bearded seal and walrus (which are becoming increasingly abundant in the western Beaufort) are heavily dependent on benthos (Albert, this workshop) and that mysids and amphipods, which are a major food source for VECs, in most nearshore ecosystems are at least partially dependent on benthos (e.g., Simenstad and Cordell 1983).

A second factor leading to the rejection of benthos by the workshop was the apparent level of sampling effort required to detect change, based on Ginn's presentation of his statistical evaluation of the Prudhoe Bay area infaunal data base (Tetra Tech 1983). He showed, for example, that with 10 replicates per station there would be an 80 percent chance of detecting a 100 percent change in the mean number of individuals (Figure 3-1). Ginn also noted that, due to the nature of individual species counts, it is usually far easier to detect significant increases in abundance than it is to detect significant decreases. However, it was also noted that assemblage variables (diversity, richness, etc.) generally have greater power to detect change and that variability (spatial and temporal) in benthic communities is likely less extreme in deeper water. Finally, it was noted that perhaps the reason the power to detect change in benthos appeared low is that no similar power calculations for other parameters were presented at the workshop.

4. STATISTICAL EVALUATIONS

4.1 GENERAL CONSIDERATIONS

Our statistical evaluations were restricted by the requirement to examine only available data on those variables mandated by the hypotheses and monitoring strategies developed in the workshop synthesis session. Optimal statistical design of a monitoring program without such a constraint would involve considering available 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.

The strategy of having scientists and managers reach a consensus of what to monitor before the statisticians conduct their examinations of variables makes sense. The scientists and managers have more relevant background information on the ecosystem being monitored than could be gathered by the statisticians, even with a great deal of effort, so their choices are likely to be reasonable ones. Similarly, the restriction of statistical analyses to available data is sensible when there is a need to obtain answers quickly.

The price that must be paid for imposing these restrictions is a statistical design which cannot claim to be optimal and cannot be inflexible. In some cases, our statistical evaluations indicate that there is little hope of detecting a departure from the chosen null hypotheses using the chosen variables. In those cases, the scientists and managers must re-evaluate their choices. In other cases, the available data are inadequate for the solution of the design problem. In those cases, we have attempted to achieve a robust and flexible design which will fill the data gaps. After a year or so of monitoring, the data obtained should be evaluated to see if modifications to the initial sampling scheme are warranted.

Data sources for our evaluations have been computerized files provided by the Laboratory for the Study of Information Science at the University of Rhode Island (URI) as well as published reports and papers. In the latter category, final reports of principal investigators in the Alaska environmental studies program managed by OCSEAP, the Prudhoe Bay Waterflood Project Environmental Monitoring Program, and various marine mammal research programs have been particularly helpful.

In order to perform statistical analyses, each of the hypotheses adopted by the workshop has been restated as a testable null hypothesis (H_o) (Table 4-1). Each of the workshop-generated hypotheses has at least two distinct components requiring separate hypotheses and proofs. The first hypothesis deals with proof that a change has occurred; the second with proof that the observed change was caused by oil and gas activities. Only the first of these has been dealt with in our statistical analyses since the second part of the hypothesis need not be tested (in fact, is untestable) until the first part is disproven by the monitoring program, i.e. some change has occurred.

4.2 SPECIFIC EVALUATIONS

4.2.1 Sediment Chemistry Network

Aspects of Hypotheses I and II from the workshop relevant to sediment chemistry were restated as follows to allow statistical analyses:

H_o1 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_o3 Changes in concentrations of selected metals or hydrocarbons in sediments . . . are not related to OCS oil and gas development activity.

A considerable amount of sampling was conducted in the 1970s to determine baseline concentrations of hydrocarbons and heavy metals in Beaufort Sea sediments. Results for hydrocarbons at nearshore stations are discussed by Shaw (1977, 1978, 1981), while Kaplan and Venkatesan (1981) deal with distribution and concentration of hydrocarbons farther offshore. Data on heavy metal concentrations were obtained and summarized by Burrell (1977, 1978) and Naidu et al. (1981b).

Subsets of these investigators' data were provided to us on tape by the Laboratory for the Study of Information Science at URI. The hydrocarbon data base included results of one analysis performed on one sample from each of the 20 sites sampled by Shaw in 1977 and from the 11 sites sampled by Kaplan and Venkatesan in 1976. These stations are shown in Figure 4-1. The heavy metals data included selenium and chromium determinations for a few Burrell samples collected in 1976 as well as iron, vanadium, zinc, copper, nickel, chromium, cobalt, and manganese in 1970, 1971, 1972, and 1977 samples discussed by Naidu et al. (1981b).

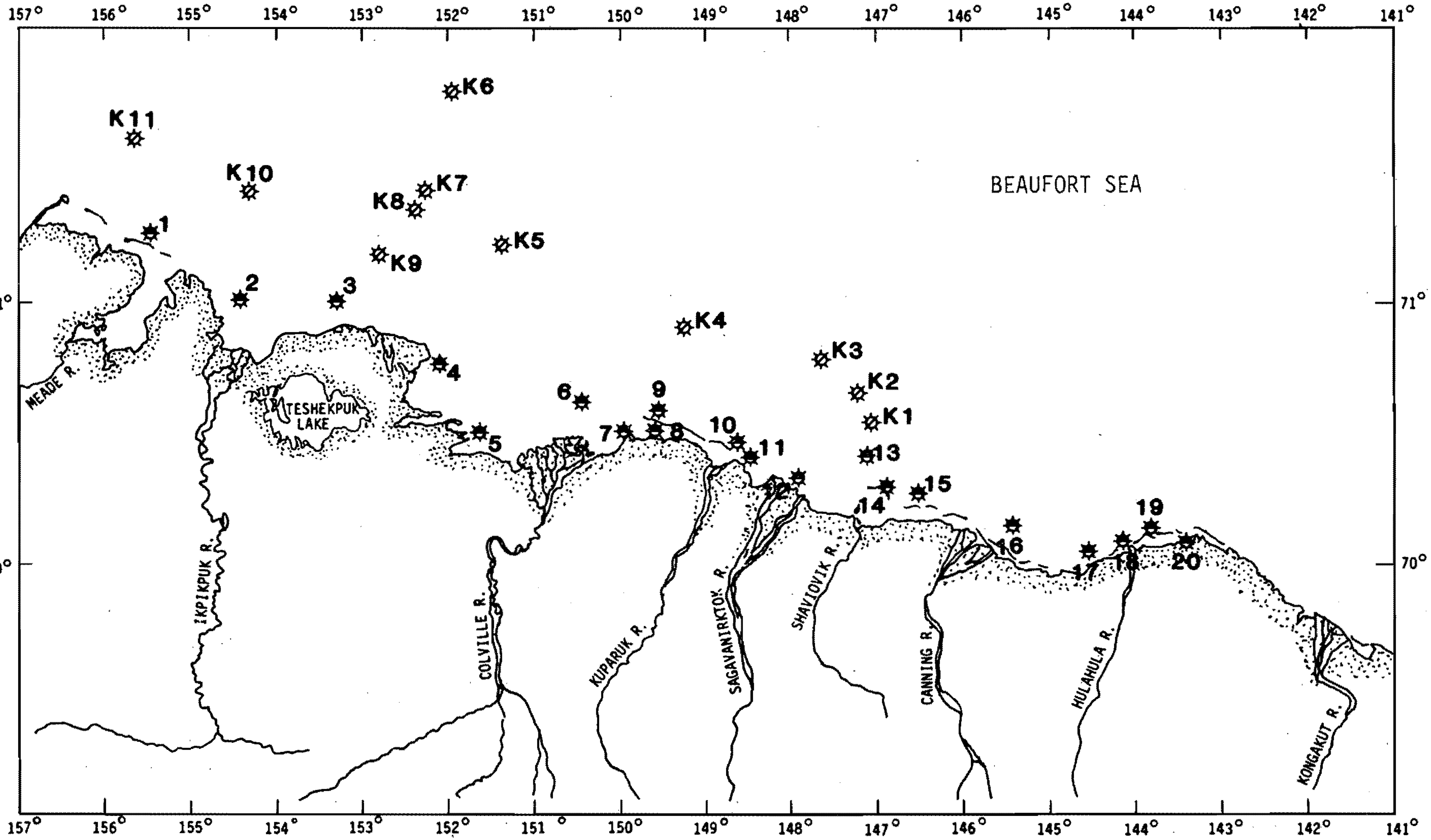
These data provide a description of baseline conditions. In general, they indicate an unpolluted environment, although some polycyclic aromatic hydrocarbons (PAH) were found in higher than expected concentrations by both Shaw (1981) and Kaplan and Venkatesan (1981), perhaps due to natural oil seeps and/or input from rivers that flow over outcrops, tar sands, etc.

TABLE 4-1

RESTATEMENT OF HYPOTHESES FOR STATISTICAL TESTING

Working Hypotheses(a)		Restatement
I & II	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 the relevant operating permits.
	H_o 2	There will be no change in concentrations of selected metals or hydrocarbons in the selected sentinel organisms beyond the zones of mixing or dispersion specified under the relevant operating permits.
	H_o 3	Changes in concentrations of selected metals or hydrocarbons in surficial sediments or sentinel organisms are not related to OCS oil and gas development activity.
	H_o 4	Changes in selected metals or hydrocarbon levels in sediments or organisms will not affect human health or VECs.
III	H_o 1	The axis of the fall migration of bowhead whales will not be altered during periods of increased OCS activity in the United States Beaufort Sea.
	H_o 2	Changes in bowhead migration patterns are not related to OCS oil and gas development activity.
IV	H_o 1	There will be no change in catch per unit of effort (CPUE) in the Colville River Arctic cisco fishery.
	H_o 2	Changes in Arctic cisco CPUE are not related to OCS oil and gas development activity.
V	H_o 1	There will be no change in relative densities of molting male oldsquaw in four Beaufort Sea index areas.
	H_o 2	Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.
VI	H_o 1	There will be no change in density or hatching success of common eiders on islands subjected to disturbance by OCS oil and gas development activity.
	H_o 2	Changes in density or hatching success of eiders on gravel islands are not related to OCS oil and gas development activity.
VII	H_o 1	There will be no change in productivity of *Laminaria solidungula* in areas of the Boulder Patch nearest OCS oil and gas development activity.
	H_o 2	Changes in *Laminaria solidungula* productivity in the Boulder Patch are not related to OCS oil and gas activity.

(a) See Sections 3.7.2 and 3.7.4 for original statement.



Legend

1 ✱ Shaw (1977)

K1 ☼ Kaplan and Venkatesan (1981)

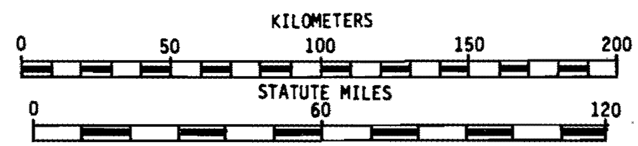


Figure 4-1

Area-Wide Sediment Chemistry Sampling Stations

However, the data are of limited value for designing a monitoring network. The lack of replication in the hydrocarbon data means that components of variability due to measurement error and small-scale spatial patchiness cannot be separated from site-to-site variability. Temporal variability cannot be assessed since each site was sampled only one time. The validity of comparisons between the offshore and nearshore stations is also questionable since they were analyzed by different investigators. The interlaboratory comparisons of trace hydrocarbon analyses reported by Hilpert et al. (1977) and Chesler et al. (1978) indicate that while intralaboratory precision in determination of, say, hydrocarbons in the gas chromatograph (GC) range in sediment samples, is of the order of ± 25 percent, determinations of this and other parameters of interest by different laboratories may differ by factors of 10 or more. Since analytical methodology for the determination of hydrocarbons in sediments is evolving at a rapid rate, it seems unwise to incorporate into the design of the monitoring network assumptions about variability in hydrocarbon concentrations that are based on measurements made several years ago.

However, there were also problems in using the trace metal data. First, we were unable to obtain data on concentrations of barium, one of the metals of primary interest for monitoring impacts of OCS development activities since it is an important constituent of drilling muds. Second, there were many discrepancies between data received on tape and data tabulated in reports. For example, copper and zinc determinations on the tape matched those in Naidu et al. (1981a) but different values were given for the other metals. Third, while there appeared to be some replicate samples and analyses, they were not unambiguously identified. There were no good time series at particular sites which could be used for estimating variances and covariances required to solve the design problem.

Thus, it was necessary to use statistical models instead of computed values for variances and covariances in many cases. The details concerning the development of these models are given in Appendix B. We summarize only the main ideas here.

The sampling design, D, was viewed as a set of labels (latitudes and longitudes) designating the sampling sites. These sites were chosen from a grid of all possible sites. Changes due to development might occur at any of the possible sites but can only be detected at the sampled sites.

Clearly, a pervasive areawide change could be detected with any design D while a large point impact affecting only a single site could only be detected if that site belonged to D. Since the former assumption about the nature of the change leads to an overly optimistic view of its detectability and the latter to an overly pessimistic one, we adopted an intermediate assumption concerning the nature of the change.

We supposed that the Beaufort Sea from the Canadian border to Point Barrow can be partitioned into a relatively small number, k, of subregions or blocks. We assumed further that an impact caused by development activities would be confined to one of these blocks and that it would affect each site in the block equally. The blocks are labeled using an index i, $i = 1, 2, \ldots, k$. Finally, we assumed that we can assign probabilities p_i (with $p_1 + p_2 + \ldots + p_k$; $\Sigma p_i = 1$) that if a change occurs then it will occur in block i.

In Section 2 of Appendix B we derived the optimal fraction, f_i, of the total number of sites to be sampled which should be in block i under these assumptions and others specified in Appendix B. The total number of sites, I, and the number of replicate samples, K, to collect at each site in order to detect changes of various magnitudes are also given in that section. The detectable changes depend on the probabilities, p_i, and the sampling (replicate or error) variance, which is assumed to be the same in all blocks. A two-way fixed effects analysis of variance (ANOVA) model was used in the derivation, and it was assumed for simplicity that a test for change would be based on one predevelopment and one postdevelopment set of measurements.

In Section 3 of Appendix B we used a second, more general, approach to choosing D. The simplifying assumption that we wish to test for change using one pre- and one postdevelopment sampling was not used in this approach. Instead, the approach was to choose sampling sites which would maximize the amount of information provided about both sampled and unsampled sites. The additional assumptions needed for this approach were:

- The information can be written as a simple function of the canonical correlation coefficients between sampled and unsampled sites using multivariate normal distribution theory.
- We can consider a single metal, say chromium, instead of all metals and hydrocarbons simultaneously without seriously affecting the design.
- We can use a components of variance model for changes with a random overall component, a block component which is the same for all sites in a given block, a site-specific component, and a component due to sampling error at the sampled sites.

From these assumptions we derived a theoretical covariance matrix among sites and the canonical correlations and information corresponding to each choice of D. To make the problem mathematically feasible, we selected a stepwise procedure which chooses, first, the "best" block for the first sampling site and then, at each step, the "best" block for the next site, given that the sites determined at the previous step are to be sampled.

The baseline data of Naidu et al. (1981b) were used as described in Section 4 of Appendix B for assigning block, site, and error components of variance. The 17 blocks used in both of our design approaches are shown in Figure 4-2. They were synthesized from maps and comments provided by Hameedi, Houghton, Manen, Zimmerman, and other workshop participants.

We recognize that many of the assumptions used in our statistical analyses probably do not hold. For example, we cannot consider only chromium and expect to specify a monitoring network and level of replication optimal for all metals and hydrocarbons. We view the proposed sampling design resulting from our analyses as an initial one, adequate for obtaining the data on variability required to produce a more refined design after a year or two of sampling.

4.2.2 Biological Monitors/Sentinel Organisms

Aspects of Workshop Hypotheses I and II related to bioaccumulation and pollutant effects at the organism level have been restated as follows:

H_o2 There will be no change in concentration of selected metals or hydrocarbons in the selected sentinel organism(s) beyond the zones of mixing or dispersion specified under relevant operating permits.

H_o3 Changes in concentrations of selected metals or hydrocarbons in . . . sentinel organisms are not related to OCS oil and gas development activity.

We were able to obtain few data on tissue concentrations of hydrocarbons and none on heavy metals in Beaufort Sea bivalves. Shaw (1981) reports hydrocarbon concentrations in tissues of clams (*Astarte* sp. and *Liocyma* sp.) collected from the nearshore Beaufort Sea in the summer of 1978. Shaw (1977) analyzed concentrations in *Macoma balthica, Mya arenaria,* and *Mytilus edulis.*

A few measurements of heavy metals (Burrell 1977, 1978) and hydrocarbons (Chesler et al. 1977; Wise et al. 1979; Shaw et al. 1983) in *Mytilus* tissue are available from other Alaska locations. Our statistical evaluations also relied on the experiences of mussel watch programs in other areas, summarized for the most part in R. Flegal's workshop presentation and in The International Mussel Watch (1980).

Using gas chromatography, Shaw (1981) analyzed six samples of approximately 10 g wet weight of clams collected in Elson Lagoon (just east of Barrow) and Tigvaviak Island (70°16.1′N, 147°38.0′W). He found strikingly low concentrations of hydrocarbons, many below detectable levels. For example, the mean concentration of total unsaturated hydrocarbons in the four *Astarte* samples from Elson Lagoon was 0.43 mg/kg and the standard deviation was 0.19 mg/kg on a wet weight basis. Aromatic hydrocarbon concentrations were low as well. The values in Shaw (1977) are not precisely comparable to his 1981 values because they incorporate a rough division into Fraction 1 and Fraction 2 hydrocarbons, but they are also low. Shaw (1981) suggests that the absence of significant accumulations in bivalve tissue of hydrocarbons clearly present in the sediment may imply rapid assimilation and metabolizing of these compounds by the organisms.

Burrell (1978) compared concentrations of cadmium and several other heavy metals in *Mytilus* from the Gulf of Alaska with similar measurements from other parts of the world and finds the Alaska values to be among the lowest. He does not report standard deviations for these measurements, but the determinations on standard reference materials (e.g., orchard leaves, bovine livers) in Burrell (1977) indicate that his accuracy and precision meet National Bureau of Standards criteria.

Year-to-year change in metal concentrations appears to be fairly small; cadmium determined from a summer 1975 sample was 4.5 mg/kg while the summer 1976 value was 6.3 mg/kg (dry), giving a concentration mean of 5.4 mg/kg and a sample standard deviation of 1.3 mg/kg. These values are comparable to mussel watch values obtained for mussels of the United States west coast presented by Flegal (this workshop) and would presumably be similar to Beaufort Sea data.

Neither Burrell nor Shaw reported the number of bivalves pooled to form their samples. The International Mussel Watch (1980) recommends that a minumum of 25 mussels be used to represent a population for chemical assay. For broad based monitoring where the emphasis is on studying as many sites as possible, it was suggested that a single analysis of a composite of all 25 individuals from a site is appropriate. However, such an analysis eliminates the possibility of determining separate components of variability due to analytical error, within-site differences, and between-site differences. This sort of analysis of variance is needed if the power to detect changes of various magnitudes under a given sampling scheme is to be computed and an optimal monitoring plan determined. Thus, multiple pools of individuals from each site and multiple analyses of each pooled sample are needed at least at the beginning of the monitoring program (see Section 5.2.2).

The International Mussel Watch (1980) stresses the importance of intercalibration of analytical results. For metal concentrations, ± 20 percent of the certified value is cited as a reasonable standard of accuracy on a reference material. According to this report, standard reference materials for tracelevel hydrocarbons in mussel tissue cannot be issued until problems associated with sample homogeneity, storage stability, and matrix effects are resolved. Results by Dunn (1976) on the precision of analyses of mussel homogenates for benzo(a)-

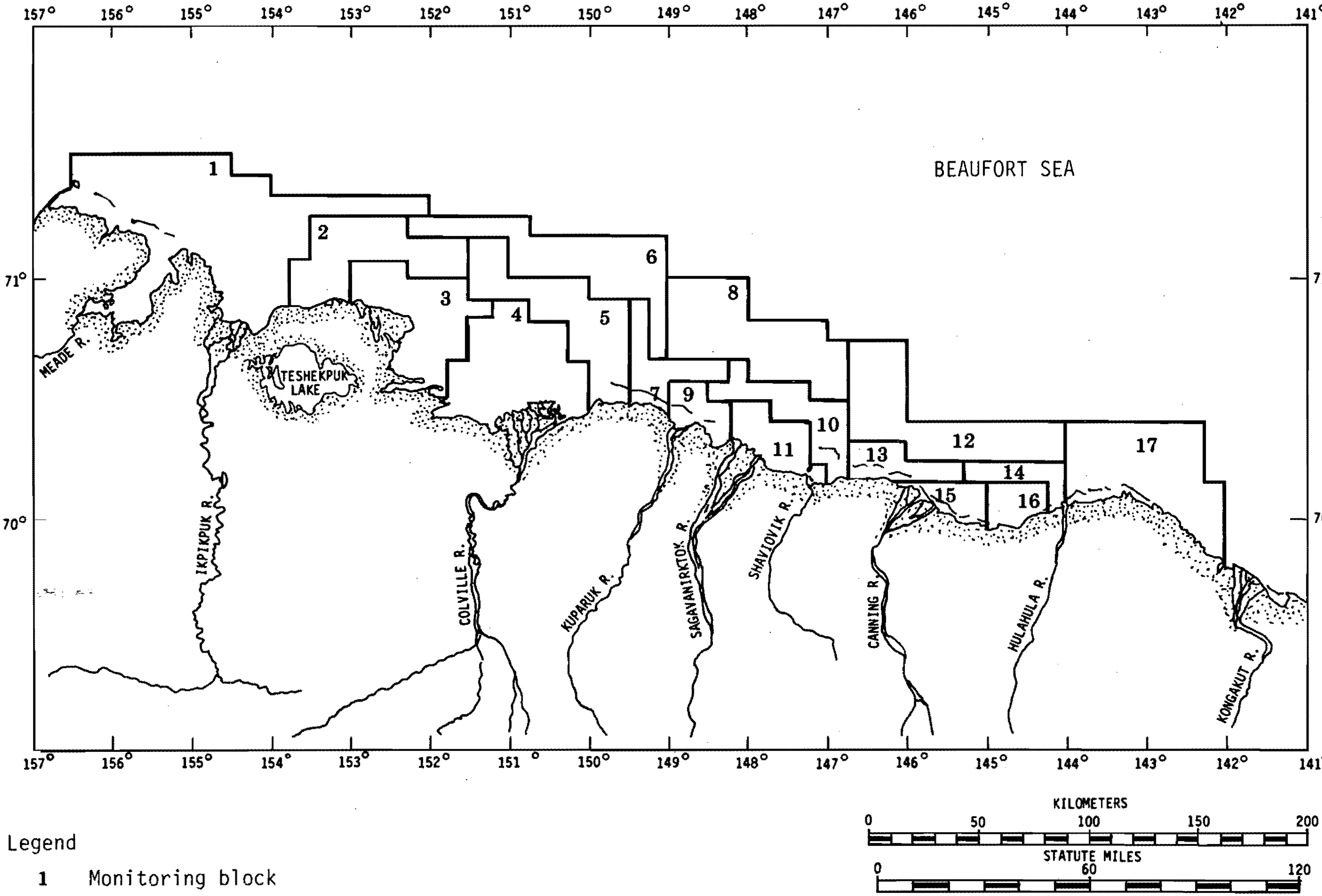


Figure 4-2

Sediment Monitoring Network Block Configurations

pyrene using subsamples of 20 to 30 g of tissue found standard deviations of analytical results ranging from 3.2 to 8.1 percent of the mean. Wise et al. (1979) compared laboratories' determinations of total extractable hydrocarbons, total hydrocarbons in the GC elution range, pristane/phytane ratio, and concentrations of the most abundant aliphatic and aromatic hydrocarbons for mussel samples. Good agreement among laboratories was shown in some cases. In other cases, measurements among laboratories differed by a factor of 2 or even by an order of magnitude or more. These discrepancies accentuate the need for standardization of analysis techniques and intra- and interlaboratory calibrations, especially in the early stages of the Beaufort Sea mussel watch.

4.2.3 Bowhead Whale

Restated Hypotheses:

H_o1 The axis of the fall migration of bowhead whales will not be altered during periods of increased OCS activities in the United States Beaufort Sea.

H_o2 Changes in bowhead migration patterns are not related to OCS oil and gas development activity.

Our analyses of data on the fall bowhead migration focused on the workshop mandate to assess the degree of precision with which shifts in migration can be detected using present data and methods of data collection and on possible ways to improve the sampling strategies in use.

According to Ljungblad et al. (1983), the fall bowhead whale migration appears to have an "offshore" component through deep waters north of the shelf break in August and a "nearshore" component which usually passes through the region between mid-September and mid-October. It is the nearshore component which is of interest since it is this component which is most vulnerable to disturbance by OCS oil and gas development activity and is also most important to humans on the North Slope, especially subsistence hunters from Kaktovik, Nuiksut, and Barrow. We have therefore concentrated on September and October data in our analyses of H_o1.

Ljungblad (1983) notes that routes of the fall bowhead migration in the years of heavy ice cover, 1980 and 1983, are more difficult either to observe or to predict than in lighter ice years. Sighting rates characteristically have declined in heavy ice years. It is likely that in severe ice years, any effects of OCS oil and gas development on the whales' migration path would be small relative to effects of the ice conditions. It would likely be impossible to separate ice-caused from man-caused effects. We have therefore restricted our analyses to data from the light ice years 1979, 1981, and 1982. However, as noted in Section 5.3.3.1, it may be desirable in the future to incorporate data on ice conditions so that analyses could include both light and heavy ice years.

Objectives of the fall aerial surveys have differed from year to year with consequent shifts in areas surveyed and methods used (Ljungblad et al. 1983). In 1979 nearly all effort was concentrated near the proposed state/federal oil lease areas, with random north-south transects flown in a block between 146°W and 149°W longitude and bounded on the north by the 70°40'N latitude line. There were a few flights north of this block to 71°20'N, west to 151°W, and east to 143°W but almost no effort in the rest of the United States Beaufort Sea. In 1981 there was again almost no effort offshore, i.e., north of the 200-meter (m) isobath, and almost none west of 153°W. In addition, an attempt was made to conduct both behavioral studies and surveys of relative abundance and migration routes using the same airplane. As a result, relatively few random transect survey data were obtained. In 1982, two aircraft were provided for fall bowhead studies. Thus, a fairly complete survey of the entire area from 141°W to 157°W and north to 72°N could be conducted. In addition, monitoring of seismic operations, whale behavior (including responses to geophysical vessels), and migration timing was possible.

A natural approach to describing the fall nearshore migration route is in terms of relative abundances or densities of whales in subregions of the region surveyed. Ljungblad et al. (1983) divided the study area into four regions in the E-W direction. Each of these regions was subdivided in the N-S direction along depth contours. The first stratum extended from the shoreline to 10 m, the second from 10 to 20 m, the third from 20 to 50 m, and the remaining three represented progressively greater depths. The first four depth strata in the two eastern sections were adequately surveyed in all three of the years we are considering.

Peak bowhead densities during September and October in 1979, 1981, and 1982 occurred in the 20- to 50-m stratum. Of the 499 whales observed between these longitudes during September and October of 1979, 1981, and 1982, 450 were in the 20- to 50-m stratum. The second highest densities were usually in the 10- to 20-m stratum but occasionally in the 50-to 200-m stratum. No whales were seen in the 0-m to 10-m stratum. Absolute density values varied considerably from year to year. For example, confidence ranges given in Table B-13 of Ljungblad et al. (1983) indicate that sighting densities in the 20- to 50-m stratum between 146°W and 150°W were significantly different in 1981 and 1982.

These analyses indicate strongly that during light ice years, the vast majority of bowheads in the nearshore fall migration travel between the 20- and 50-m depth contours. The distance between these contour lines is roughly 20 nautical miles (nm) in the eastern half of the United States Beaufort, narrowing in much of the western half, particularly north of Harrison Bay and near Point Barrow. Thus, the hypothesis of a seaward displacement of the fall migration path, particularly in the region between the Canadian border and Camden Bay, can be formulated as a shift to following deeper depth contours, with a 3-m depth change corresponding roughly to 2-nm displacement.

It was not possible to refine Ljungblad's analyses to determine relative densities within the 20- to 50-m depth range, for example at 10-m increments, because the 40-m depth contour was not included in the data base used for the density calculations. The computations of densities within subregions from aerial survey data are too complex to perform without a computer.

However, even if the computations could have been performed, we suspect that they might not have suggested a simple test for displacement of the fall migration path. The reason is that observed densities and their variances are highly dependent on when and where survey effort is concentrated, as well as on such external factors as visibility conditions. Therefore, we would expect to see statistically significant between-year density differences like those of Table B-13 within any set of subregions considered. Differences that might be attributable to OCS development would be hard to distinguish from those due to a combination of these other factors.

What is needed is a simple statistic which adequately defines an axis of migration. The one we chose for our analyses is the median water depth for bowhead sightings on random N-S transect surveys conducted during September and October. In other words, we define the observed axis of migration as the depth contour such that half the sightings during these surveys were at shallower (or equal) depths and half at deeper (or equal) depths. This sample median can be computed for the whole Beaufort coastline or for a subregion defined by longitude.

Median depths are particularly easy to compute for 1982 from data in Appendix A of Ljungblad et al. (1983) since that appendix contains the number of whales seen, latitude, longitude, and water depth (m) for each bowhead sighting. Water depths were read off charts during the surveys, so they may not be precise. However, the median depth is a particularly robust statistic for defining the center of the migration path as it is insensitive to unusually large or small depth values which appear in the data, either legitimately or erroneously.

We computed both the overall sample median for 1982 and the median east of 146°W longitude as 37 m. Each entry in Appendix A of Ljungblad et al. (1983) was treated as a single sighting regardless of the number of whales seen. We omitted sightings obtained during E-W search surveys, which were usually conducted by following the 20- or 30-m depth contour.

We used the median depth of *sightings* rather than of *individual whales* seen for several reasons. The first is that the depths used in computing the median need to represent independent random observations if we wish to derive confidence intervals for the population median. The water depths corresponding to the individual whales in a group when a group is sighted are clearly not independent; in fact, they are all the same. Secondly, although Ljungblad (1983) is not aware of any differences in sightability of bowheads as a function of water depth, counting sightings rather than individuals would help remove biases due to such differences if any did exist. For example, if individuals spent more time at the surface at one depth than at another and were thus more likely to be seen, and if groups which were actually the same size were sighted at each depth, more individuals might be counted in the first group than in the second.

We omitted E-W search transects because water depths of sightings along such transects are clearly not a random sample of depths of all possible sightings; depths for a search along the 30-m contour will all be close to 30 m. In order for the sample median of sighting depths to accurately represent the axis of migration, all depths which the migrating population uses must be adequately sampled. The N-S line transect surveys in September and October of 1982 appeared to represent thorough coverage of the depth range of interest.

Tests for a displacement in the axis of migration assume that there is a "true" axis of migration, the median depth for all possible bowhead sightings that might have been made during the nearshore fall migration. A 99 percent confidence interval for this true median depth, discussed in Appendix C (this volume), is (31 m, 38 m) for the whole area surveyed. This interval is based on 103 sightings from the 1982 September-October survey. The corresponding interval for the area east of 146°W longitude, based on 41 sightings, is (37 m, 42 m).

A standard test for a shift in median (Breiman 1973) is the two-sample Wilcoxon, or Mann-Whitney, test. The 1982 data provide a baseline sample with which other years' data can be compared. Chi-square tests for homogeneity of other years' depth distributions and the 1982 distribution could also be performed if a more complicated change in the migration path than a simple shift in the median depth is suspected. This test is discussed in more detail in Appendix C.

We were unable to perform any of these tests on the 1979 and 1981 data because water depths were not given in Ljungblad et al. (1980) or Ljungblad et al. (1982). However, a rough comparison between these years and 1982 was performed by assigning 1979 and 1981 sightings to categories of less than or equal to

30-m depth and greater than 30-m depth using the latitude and longitude of the sighting and the 30-m depth contour shown on the maps in these reports. We could not use the 40-m depth contour, which would also have been a reasonable choice for comparison with 1982, because it was not shown on the maps. Some sightings near the 30-m contour may have been incorrectly assigned in this analysis due to inadequate resolution of the maps. However, the results, shown in Table 4-2, appear to be consistent with the 1982 data.

In both 1979 and 1981 there were more sightings in water depths exceeding 30 m than at shallower depths, so the sample median is greater than 30. Plots of the sightings indicate that confidence intervals would almost certainly overlap the 1982 confidence intervals. In all 3 years considered, the data suggest that the median depth may be slightly greater between the Canadian border and Camden Bay than farther west.

TABLE 4-2

NUMBERS OF BOWHEAD SIGHTINGS BY WATER DEPTH AND LONGITUDE DURING SEPTEMBER-OCTOBER TRANSECT SURVEYS IN 1979 AND 1981 [a,b]

	1979			1981		
Depth	W of 146 W	E of 146 W	Total	W of 146 W	E of 146 W	Total
≤30 m	47	4	51	7	2	9
>30 m	48	5	53	13	8	21
Total	95	9	104	20	10	30

(a) Behavioral, search, and E-W line transect surveys omitted.
(b) Source: Ljungblad et al. 1980, 1982.

The Mann-Whitney test should be used to compare both the 1979 and 1981 sighting depths, if available, with those for 1982. We recommend testing at the 1 percent rather than the 5 percent level both for the 1979 and 1981 data and in future light ice years. Seismic exploration, proposed by Albert (this workshop) as the most probable cause of displacement of the migration path, will continue for several years. Thus, if we use the 1982 survey as a baseline, we will probably have to test against it 3 to 5 times. As discussed in Appendix C, if we test at the 5 percent level, the probability of incorrectly asserting that a change occurred based on at least 1 of 5 tests is approximately 23 percent. If we test at the 1 percent level, this probability is only 5 percent.

If comparisons of the earlier years with 1982 on other concerns suggest that 1982 does not provide adequate baseline data, sample medians from future years could be compared with some absolute depth value, say 40-m. The hypothesis that the median depth was ≤ 40-m would be rejected if the 99% confidence interval for the median had its lower limit > 40-m. More complicated hypotheses about the absolute distribution of depths of sightings could also be devised and tested.

Power calculations for nonparametric tests such as the Mann-Whitney test are difficult, but the Mann-Whitney test is generally highly efficient. We can use a simple heuristic argument to get some idea concerning the magnitude of displacement in the axis of migration that should be detectable.

Suppose the 1982 confidence intervals include the true median depths, and suppose these true medians happen to fall at the lower limits of the intervals. Suppose sampling in a future year produces confidence intervals for that year's axis of migration of the same length as the 1982 intervals. Suppose that these intervals also include the true median depths for the year, but this time at the upper ends of the intervals. A test which rejected the hypothesis of no difference between the 2 years if the corresponding 99 percent confidence intervals did not overlap would be testing at approximately the 1 percent level. Under our assumptions, we would reject the hypothesis of no difference in the overall median if the new interval were (39 m, 46 ml, compared to the 1982 interval (31 m, 38 m). For sightings east of 146° W longitude, the corresponding intervals are (43 m, 48 m) and (37 m, 42 m).

Under our assumptions concerning the true medians, these results would represent detection of differences of 46 - 31 = 15 m, or roughly 10 nm, and 48 - 37 = 11 m, or roughly 7½ nm, respectively. Since these assumptions represent a "worst case" situation among intervals which cover the true medians, it seems likely that the power of this test to detect a displacement of 5 nm to 10 nm in the axis of migration is fairly high.

However, these rough calculations depend on a number of assumptions about past and future surveys. These are addressed in Section 5.3.3 on recommended sampling design, and additional studies and analyses.

A possible objection to using the number of sightings rather than the number of whales in defining the migration path is that changes in group size patterns as a function of depth might not be detected by an analysis of median sighting depth. We performed a simple test (Table 4-3) for independence of water depth and group size which showed no dependence in the 1979, 1981, and 1982 data. A chi-square test for independence of row and column classifications in this table gave a chi-square value of 1.77, which is not significant ($p > 0.5$). Tests on data for each year separately also indicated no significant relationship between water depth and number of whales per sighting. Similar tests could be performed on data from future surveys to verify that no relationship between group size and depth had appeared.

TABLE 4-3

NUMBERS OF BOWHEAD SIGHTINGS BY WATER DEPTH AND NUMBER OF WHALES PER SIGHTING DURING SEPTEMBER-OCTOBER TRANSECT SURVEYS IN 1979, 1981, AND 1982[(a,b)]

	Number of Whales				
Depth	1	2	3	>3	Total
≤30-m	67	19	3	7	96
>30-m	90	29	9	13	141
Total	157	48	12	20	237

(a) Behavioral, search, and E-W line transect surveys omitted.
(b) Source: Ljungblad et al. 1981, 1982, 1983.

4.2.4 Anadromous Fish

Restated Hypotheses:

H_o1 There will be no change in catch per unit of effort (CPUE) in the Colville River Arctic cisco fishery.

H_o2 Changes in Arctic cisco CPUE are not related to OCS oil and gas development activity.

We were able to obtain data on anadromous fish from two sources. Annual catch and effort data for Arctic cisco from Helmericks' Colville Delta commercial fishery were obtained from graphs in Gallaway et al. (1983) for the years 1967 through 1981. Aerial survey index counts of Arctic char between 1971 and 1983 in two tributaries of the Sagavanirktok River, the Ivishak, and the Echooka, were provided by Bendock (1983). Bendock also provided aerial survey estimates for the Anaktuvik, a Colville tributary, starting in 1979.

These data are plotted in Figure 4-3. Catch per unit effort (CPUE) is plotted for the Arctic cisco data. Both the cisco CPUE and the char counts exhibit extreme year-to-year variability. Bendock hypothesizes that some of the variability in the char data may be due to weak year classes in 1965-1967 which influenced numbers through 1976. However, there was also a change in survey methodology in 1979. Helicopters were used before that time and fixed-wing aircraft after. Bendock notes that this change might also contribute to differences in the counts.

While there are a number of missing years (due to weather) in the char data series, the time series from Helmerick's fishery is complete. Moreover, the methodology of Helmerick's fishery has been consistent during the 1967-1981 period. Thus, we concentrated on the cisco data in our analyses.

Gallaway et al. (1983) used a population dynamics model of Deriso (1980) to explain the variability in the Arctic cisco data. The model was quite successful in following trends in CPUE. The largest difference between modeled and observed CPUE was around 28, and most differences were less than 10. The model parameters suggested a strongly density-dependent stock-recruitment function and an exceptionally high uncatchable proportion of spawners. The estimated age ($k = 5$ years) of recruitment of individuals to the fishery was consistent with the age composition data obtained by Craig and Haldorson (1980) from samples of Helmericks' catch analyzed in 1976, 1977, and 1978. Gallaway et al. suggested that the large proportion of uncatchable spawners, along with other evidence, indicates that this arctic cisco population may spawn in the Mackenzie rather than the Colville River.

We were unable to reproduce the results of Gallaway et al. (1983) because their computer programs were not available to us. However, as they point out, the inclusion of the $k = 5$ lag between spawning and recruitment in the model means that they had only 10 data points available to fit five model parameters. Thus, the strongly density-dependent stock-recruitment function obtained could be the result of a few environmentally extreme years which affected transport or survival of juvenile fish rather than of actual recruitment phenomena.

Some additional years of data are needed before we can arrive at a decision concerning the validity of the model and its usefulness for impact assessment. If the stock-recruitment relationship for this population turns out to be adequately represented by the model parameters obtained by Gallaway et al., this relationship would lead to oscillations in population level which would likely far exceed any caused by OCS oil and gas development activity. On the other hand, if the observed fluctuations are caused by such environmental factors as ice conditions, these would have to be appropriately included in the model to differentiate their impacts from any due to OCS development.

If we consider Helmericks' CPUE data outside the context of a population dynamics model, as was the apparent intent of the workshop, the prognosis for change detection via statistical analysis seems quite poor unless additional environmental data, such as data on ice conditions, can be used to eliminate some of the year-to-year variability. The mean of the 15 years of data is 38.5 and the standard deviation 19.5; no significant amount of the variability about the mean could be explained by simple statistical models such as autoregression (Jenkins and Watts 1968) or a linear trend over time.

A test for white noise (Jenkins and Watts 1968, p. 187) uncovered no significant time correlations in the CPUE data. Thus, it is reasonable to treat the time series as purely random. If we assume that the $n_1 = 15$ CPUE values plotted in Figure 4-3 are a random sample under

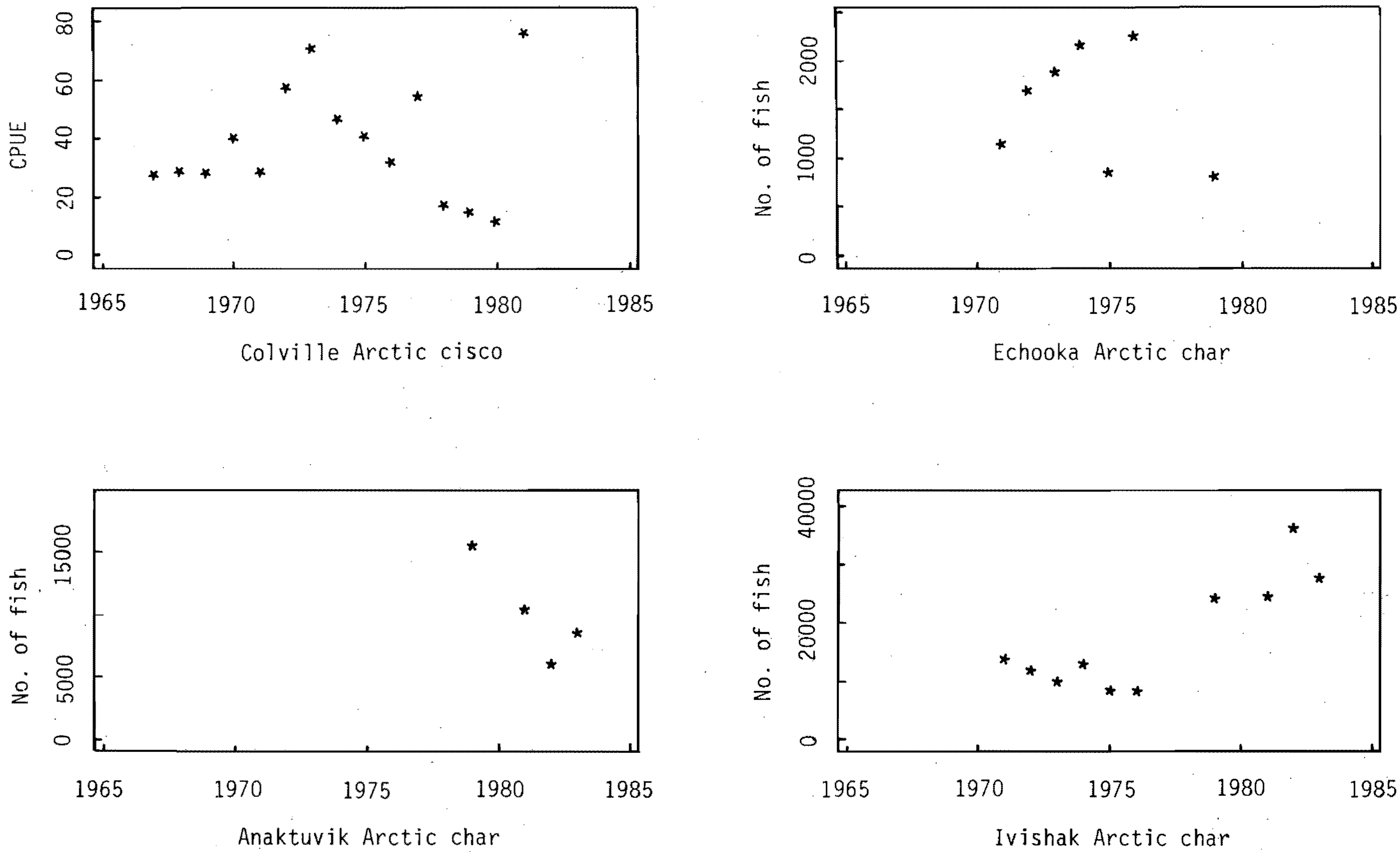


Figure 4-3

Colville Delta CPUE for Arctic Cisco and Arctic Char Aerial Index Counts from Three North Slope Rivers

baseline conditions, we can determine the level of change in mean CPUE which we have a reasonable probability of detecting.

We assume for the purpose of this power calculation that both the baseline sample and a postdevelopment sample of n_2 years of Arctic cisco CPUE data from Helmericks' fishery are normally distributed with the same standard deviation: approximately 19.5. We would perform a one-sided, two-sample t-test if we wished to detect a decrease in mean CPUE which might be due to development. Then Table A-12b of Dixon and Massey (1969) allows us to determine the power to detect various magnitudes of change in mean CPUE values with tests of various levels (see Appendix C). The detectable changes are given in the following table for the 5-percent level:

	Power				
n_2	0.5	0.7	0.8	0.9	0.95
3	21.2	27.9	32.0	37.6	—
15	12.0	15.8	18.2	21.4	24.1

In other words, with only 3 years of postdevelopment data, we have only a fifty-fifty chance of detecting a reduction in mean CPUE from approximately 38.5 to approximately 17.3. We have a 90 percent probability of detecting a reduction of the CPUE nearly to zero. Even with 15 years of postdevelopment data, a decrease in CPUE must be quite large to be detectable with high probability.

In spite of these odds, changes may well be detected among years. For example, if the data from 1967 through 1977 had been treated as a baseline sample and compared with the data from 1978 through 1980, a two-sample t-test would have detected a highly significant decrease in mean CPUE ($p < 0.01$). Yet the CPUE in 1981 was higher than in any of the previous years, so the statistically significant decrease in 1978-1980 was due either to random error or, more likely, to population dynamics and/or environmental conditions ignored by this simplistic statistical analysis. Thus, if H_o1 above were rejected in the future monitoring of the fishery, the assignment of cause would require a considerable amount of additional data concerning the population's age structure, reproductive success, and environmental changes (natural and man-caused) across several hundred miles of the United States and Canadian Beaufort Sea coastline.

4.2.5 Oldsquaw

Restated Hypotheses:

H_o1 There will be no change in relative densities of molting male oldsquaw in four Beaufort Sea index areas.

H_o2 Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.

The workshop proposal for testing for change in the distribution patterns of birds incorporated the approach suggested by Johnson in his presentation. Oldsquaw ducks were selected over other species for monitoring because they are the most ubiquitous local waterfowl in the summer and fall. Aerial surveys of males in the lagoon systems during the summer molting period (mid-July to mid-August) were recommended. Since the birds are flightless for about a month after molting, they are particularly vulnerable to oil spills or other disturbances. They are also easier to monitor then, since they stay in one place long enough to be counted. Although absolute numbers of birds per square kilometer vary greatly from year to year, it was maintained that relative concentrations in particular areas stay the same over the years. High use areas such as Simpson Lagoon would always be expected to have higher concentrations than other areas in the absence of environmental changes.

A great deal of background data on oldsquaw distributions is available (see, for example, Johnson and Richardson [1981] and the references cited therein). Johnson and Richardson report on intensive aerial surveys of the Jones Islands-Simpson Lagoon system conducted in 1977, 1978, and 1979. Areas east and west of Simpson Lagoon were also surveyed. The transects flown are described in Table 4-4. Survey procedures were standardized as much as possible. However, three different types of aircraft (both helicopter and fixed-wing) were used. In addition, bird counts were recorded at different time increments in different years.

Peak oldsquaw densities in Simpson Lagoon occurred on August 15, 1977; July 15, 1978; and July 28/29, 1979 (Table 17 of Johnson and Richardson 1981). Higher densities were recorded on the transect along the south shoreline of the Jones Islands than on mid-lagoon and mainland shoreline transects. Figures 18 and 19 of Johnson and Richardson (1981), comparing mean oldsquaw densities in the Simpson Lagoon area with areas to the east and west, do not appear to support the contention that relative concentrations in different areas are constant from year to year or even within the molting period in a given year. If we extract the relevant data from these figures, we obtain Table 4-5. Johnson and Richardson argue that the low densities east of Simpson Lagoon in 1978 may be due to in-

TABLE 4-4
AERIAL WATERFOWL SURVEY TRANSECT DESCRIPTIONS, BEAUFORT SEA, ALASKA 1977-1979[a,b]

Transect Number	Transect Length (km)	Habitat TYPE	Location
1	35.4	Offshore marine	1.6 km seaward of the Jines Islands, E to W.
2	37.0	Lagoon-south shoreline of barrier islands	From W end Spy Is., E to E end Cottle Is.
3	30.6	Mid-lagoon	From Beechey Pt., W to Oliktok Pt.
4	32.2	Lagoon-mainland shoreline	From Oliktok Pt., E to Beechey Pt.
5	33.8	Mainland tundra	4 km inland from Simpson Lagoon, E to W.
6	13.8	Mid-lagoon	Harrison Bay from 6 km S of Oliktok Pt., NW to Thetis Is.
7	16.1	Mid-lagoon	Harrison Bay, from Thetis Is., SW to Anachlik Is.
8	56.3	Unprotected bay	Harrison Bay, from Thetis Is., W to Atigaru Pt.
9	30.3	Unprotected bay	Harrison Bay, from Atigaru Pt., SE to E side of Colville R. delta.
10	35.1	River delta	From E side of Colville R. delta to W side of mouth of Kupigruak channel.
11	12.1	Mid-lagoon	From W side of mouth of Kupigruak channel, NE to Thetis Is.
12	34.8	Lagoon-south shoreline of barrier islands and protected bay	From E end Cottle Is. to E end Stump Is., E across Prudhoe Bay to Heald Pt.
13.1	16.4	Semi-protected sound	From Heald Pt., NW across Stefansson Sound to Reindeer Is.
13.2	123.9	Lagoon-South shoreline of barrier islands	From W end Reindeer Is., ESE to Brownlow Pt.
14	87.7	Lagoon-south shoreline of barrier islands	From Brownlow Pt. ENE to W end Arey Is.
15	152.1	Lagoon-south shoreline of barrier islands	From W end Arey Is., ESE to E end Demarcation Bay or to US-Canada Border.
16	144.7	Mid-lagoon	from US-Canada Border or E end Demarcation Bay, WNW to W end Arey Is.
17	86.1	Mid-lagoon	From W end Arey Is., WNW to Brownlow Pt.
18	81.3	Mid-lagoon	From Brownlow Pt., W to Pt. Brower.
19	17.4	River delta	From Pt. Brower, W to Heald Pt.
20	6.4	Mainland shoreline	From Heald Pt., S to East Dock Prudhoe Bay.
21	37.0	Mid-lagoon	From East Dock Prudhoe Bay, W to Beechey Pt.

(a) Transects 1-5 lie within the Jones Islands-Simpson Lagoon intensive study area. These transects were surveyed during 1977, 1978, and 1979. The remaining transects lie to the east and west of the intensive study area and were surveyed only during 1978 and 1979.

(b) Source: Johnson and Richardson 1981.

TABLE 4-5
UNWEIGHTED MEAN DENSITIES OF OLDSQUAWS DURING THE MOLTING PERIOD 1978 AND 1979, IN SIMPSON LAGOON AND AREAS TO THE EAST AND WEST

Area	Date				
	7/15/78	7/25/78	8/5-6/78	8/15/78	7/28-29/79
W. of Simpson Lagoon	670.0	50.8	27.8	370.5	45.1
Simpson Lagoon	536.8	135.0	142.5	373.3	243.8
E. of Simpson Lagoon	334.5	28.0	103.8	87.3	219.2

adequate survey effort, but they do not offer an explanation of the changes in relative importance of the area west of Simpson Lagoon both within 1978 and between the 2 years.

Monitoring of molting oldsquaws through aerial surveys continued in 1980, 1981, and 1982. A comparison of oldsquaw distributions in Simpson and Stump Island lagoons is included in Troy et al. (1983). Four standard transects in Stump Island Lagoon were established in addition to those used in the earlier studies to facilitate this comparison.

Densities of molting oldsquaws were significantly higher in Simpson Lagoon than in Stump Island Lagoon. Estimates obtained by combining data from barrier island and mid-lagoon transects during the molt period for all years in which both lagoons were surveyed are shown on Figure 8-4 of Troy et al. (1983), reproduced here as Figure 4-4. This figure supports the claim that relative concentrations in these two areas show considerable year-to-year consistency; however, the accompanying plot of density in Simpson Lagoon versus density in Stump Island Lagoon (Figure 4-5) shows that the relationship is not perfect. Troy et al. (1983) cite census data from Bartels and Zellhoefer (1982) which also support the claim that relative densities are consistent. Surveys of 10 lagoons in the Arctic National Wildlife Refuge in 1981 and 1982 yielded densities which showed a high year-to-year correlation ($r = 0.92$, $P < 0.001$).

We requested all available aerial survey data on oldsquaw during the July 15-August 15 molting period from URI in order to conduct our own analyses of year-to-year patterns in the use of different areas. The only data they were able to provide were collected in 1976, 1977, and 1978. Area surveyed and number of oldsquaws seen were included in the records, along with identifying information (latitude, longitude, station or transect number, date, time).

Since the standard transects discussed by Johnson and Richardson (1981) were not established until 1977 for Simpson Lagoon and 1978 for the remaining areas, most of our comparisons had to be based on matching latitudes and longitudes of starting points as closely as possible. This approach permitted only very rough comparisons since areas with very different densities may have almost the same latitude and longitude. For example, the starting point for the the transect seaward of the Jones Islands, where oldsquaw densities are very low during the molting period, is very close to the mid-lagoon transect, which has very high densities.

A further problem in analyzing the limited data set obtained from URI was that it appeared to contain many errors. For example, in the 1976 data, there were several pairs of transects labeled with exactly the same latitude, longitude, date, time, and transect length but with counts of birds differing by as much as a factor of four. In the 1977 and 1978 data, there were observations with latitudes and longitudes corresponding to one of the transects of Table 4-4 but with a station number indicating a different one. There appeared to be other errors in dates, latitudes, and longitudes as well.

In Figure 4-6, we plot densities for six areas in which transects were flown during each of the 3 years included in our data set. An observation was assigned to one of the areas if its latitude and longitude were within the ranges given in Table 4-6 and/or if the locations on Table 4-4 indicated that it fell mostly in the corresponding area. Data from transects flown on the same day in the same area were combined to obtain the plotted densities.

In Figure 4-7, we plot 1978 densities in two areas in which the same transects were flown several times during the molt period.

In both Figures 4-6 and 4-7, it was necessary to use a log scale for oldsquaw densities because of the tremendous variability, not only among years and areas, but also at different times in the same season and area. Within-season densities even on the same transect sometimes varied by factors of 10 or 100.

We did not attempt more quantitative analyses of these survey results because of the data problems discussed above. However, Figures 4-6 and 4-7 lend some support to the notion that relative densities in different areas show consistent year-to-year patterns, particularly if geometric means over each season for each area are considered.

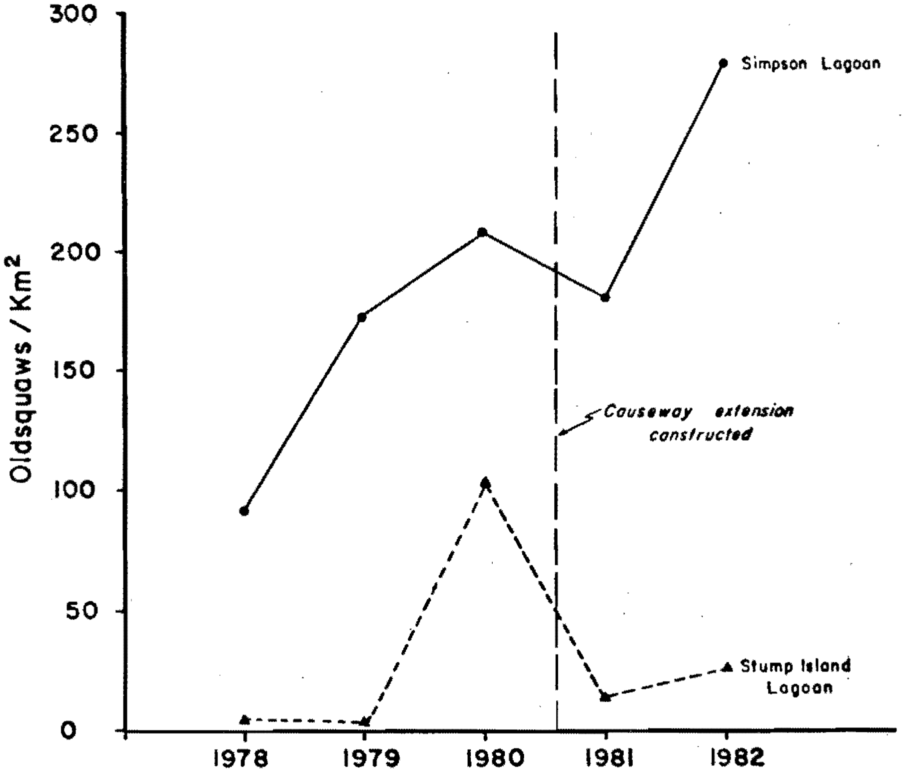


Figure 4-4

Estimated Densities of Molting Oldsquaws Using Simpson and Stump Island Lagoons (Source: Troy et al. 1983)

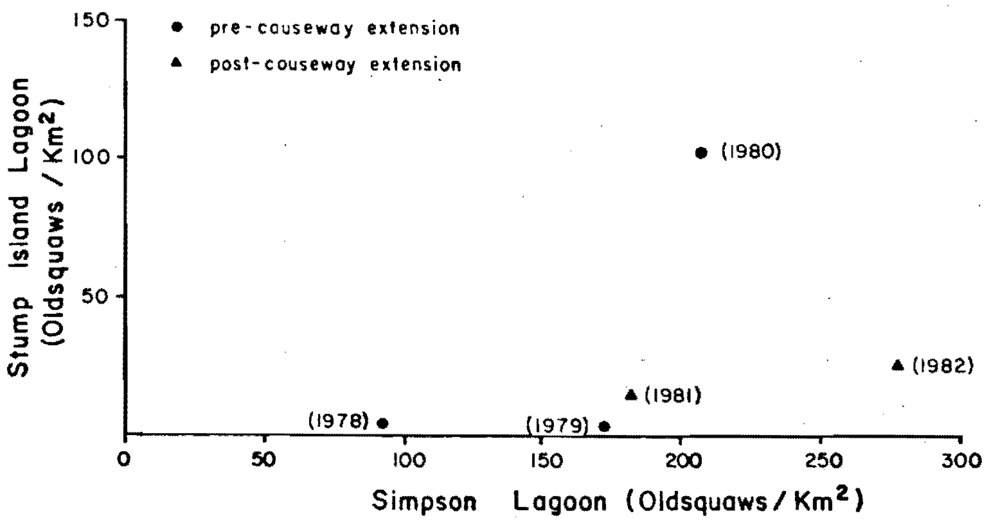


Figure 4-5
Densities of Molting Oldsquaws in Stump Island Lagoon in Relation to Densities in Simpson Lagoon (Source: Troy et al. 1983)

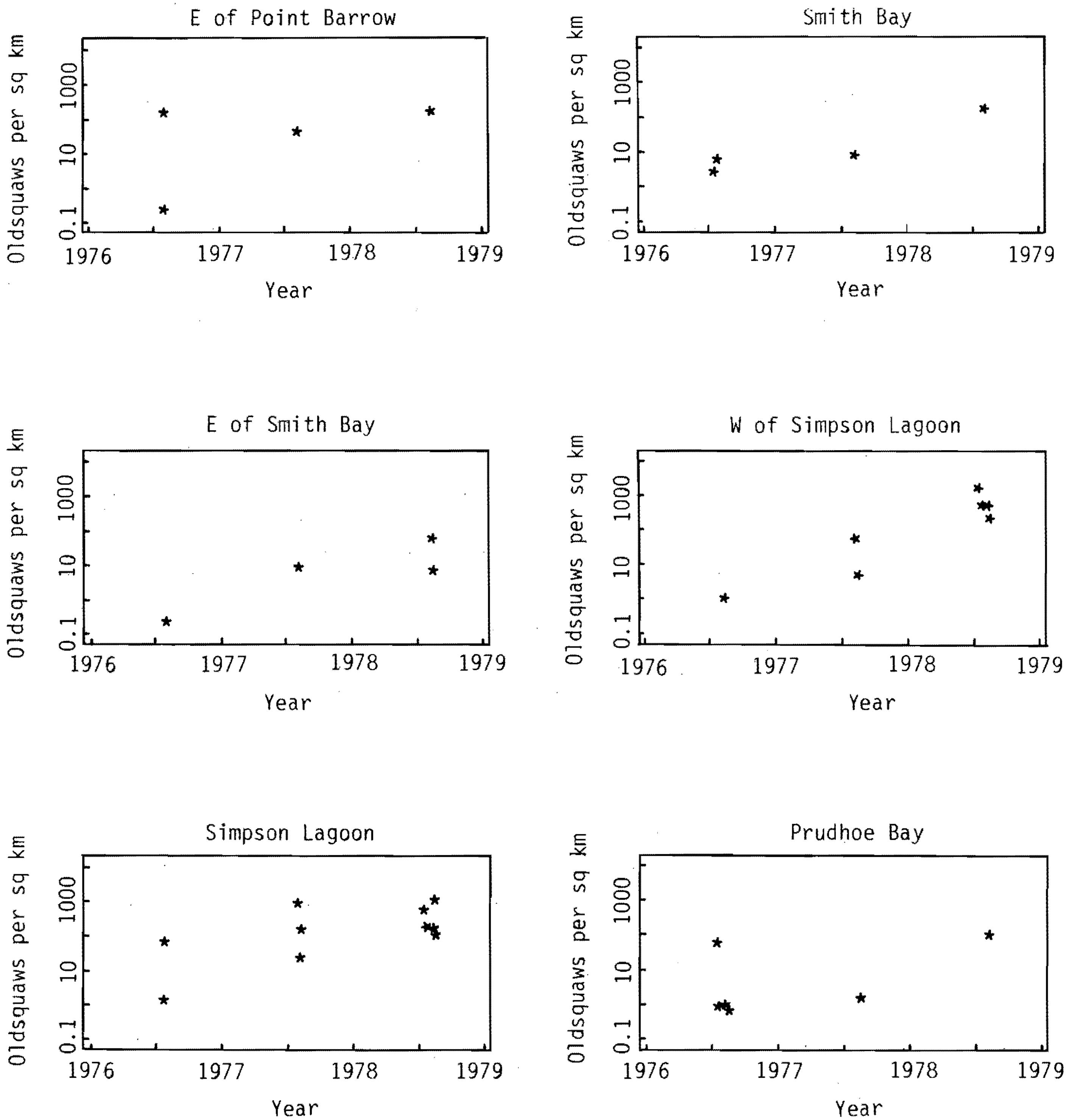
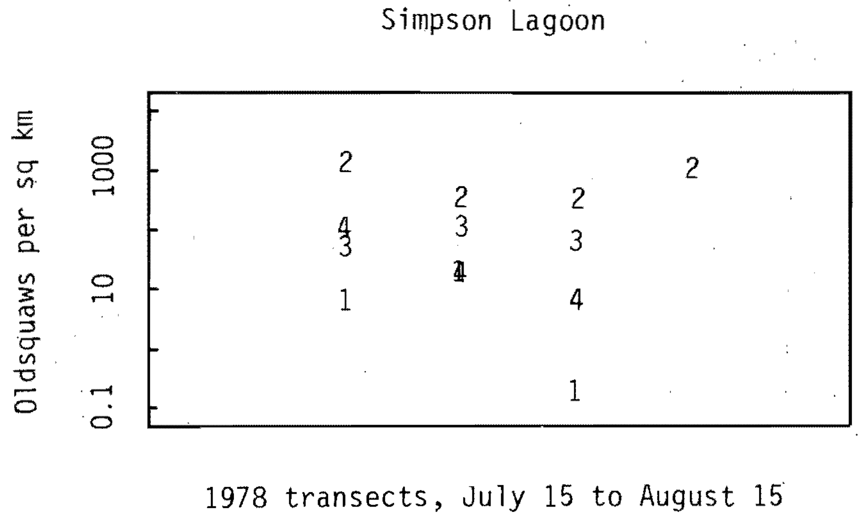


Figure 4-6

Oldsquaw Densities in Six Beaufort Sea Survey Areas 1976-1978



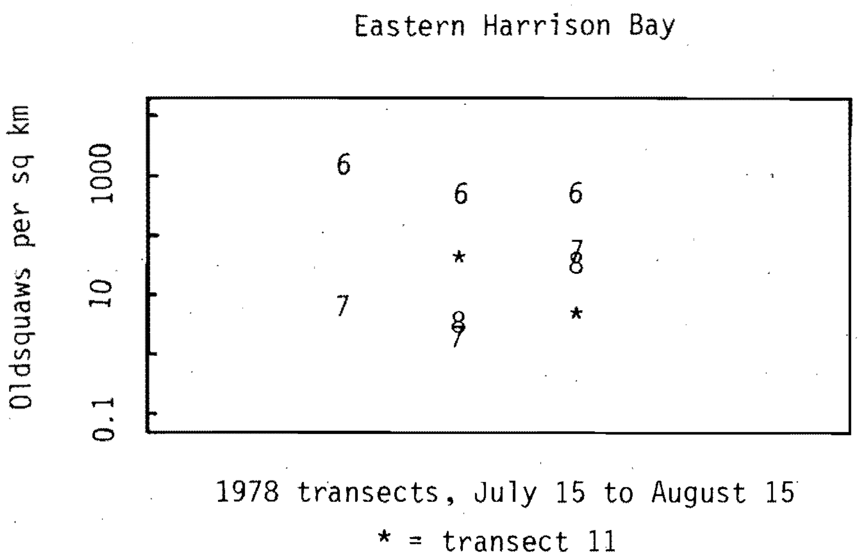


Figure 4-7

Oldsquaw Densities in Eastern Harrison Bay and Simpson Lagoon, July-August 1978 (Numbers are Transect Numbers from Table 4-4)

TABLE 4-6
LATITUDES AND LONGITUDES DEFINING AREAS SHOWN IN FIGURE 4-6

Area	Latitude		Longitude	
	Minimum	Maximum	Minimum	Maximum
E. of Point Barrow	71°14'	71°15'N	155°29'W	156°01'W
Smith Bay	70°50'	71°3'N	154°31'W	154°39'W
E. of Smith Bay	70°54'	70°56'N	152°30'W	153°20'W
W. of Simpson Lagoon	70°28'	70°32'N	149°56'W	150°11'W
Simpson Lagoon	70°29'	70°33'N	149°6'W	149°55'W
Prudhoe Bay	70°21'	70°25'N	148°11'W	148°36'W

4.2.6 Common Eider Nesting

Restated Hypotheses:

H_o1 There will be no change in density or hatching success in common eiders on islands subjected to disturbance by OCS oil and gas development activity.

H_o2 Changes in density or hatching success of eiders on islands are not related to OCS oil and gas development activity.

No statistical evaluations of the study of nesting common eiders on Thetis Island were possible because we were unable to obtain data from the study. Fraker (1983) indicated that reports may be available early in 1984. However, the impression given at the workshop by Johnson was that statistics for nesting density and hatching success are reasonably robust.

4.2.7 Boulder Patch Kelp Community Structure

Restated Hypotheses:

H_o1 There will be no change in productivity of *Laminaria solidungula* in areas of the Boulder Patch nearest OCS oil and gas development activity.

H_o2 Changes in *Laminaria solidungula* productivity in the Boulder Patch are not related to OCS oil and gas development activity.

Only partial information on annual productivity of kelp (*Laminaria solidungula*) in the Boulder Patch was available. Dunton et al. (1982) provided a graph (their Figure 13) of linear blade growth during different seasons over a 2-year period, fall 1978 to fall 1980. They also gave a 95 percent confidence interval of 0.95 ± 0.14 for average annual production-to-biomass (P:B) ratio based on a single year's measurement of 17 plants.

Of these measurements, linear blade growth appeared to be the simplest to monitor. Blades of *Laminaria solidungula* are divided by constrictions into ovate segments of different sizes. The constrictions form in November, a new ovate segment appears by the following February, and the most rapid growth occurs in late winter and early spring. Linear growth is slowest in late summer and fall. Thus, a single measurement of segment length in late summer or fall provides a good indication of a year's growth. These measurements can be made with little disturbance of the plant.

To measure the P:B ratio, on the other hand, it is necessary to detach and weigh individual plants at the beginning of the year (in November) and remove and weigh the new segments at the end of the year. Furthermore, Dunton (1983b) shows that there is a strong correlation between blade lenqth and biomass, so the P:B ratio can be estimated from linear growth data.

We read values of blade elongation in mm/day and days from Figure 13 of Dunton et al. (1982). We were then able to compute rough annual linear growth values of 24 cm for November 1978 to November 1979 and 27 cm for November 1979 to November 1980. The mean of these two measurements is 25.5 cm and the approximate sample standard deviation of the annual measurements about this mean is 2 cm.

According to Dunton et al. (1982), almost all of the linear growth of these plants takes place in darkness. A turbid ice canopy prevents penetration of light in some areas between October and early June. During the open water period, inorganic nitrogen, depleted by the spring bloom of microalgae, is insufficient for the synthesis of new tissue in the kelp. Instead, products of photosynthesis are stored and used during the winter when enough inorganic-N is available for blade production.

Low productivity of the kelp in the Boulder Patch community compared to Canadian high arctic communities is attributed in part to the absence of winter photosynthesis.

Dunton (1983b) gives annual linear blade growth values (cm) from fall 1976 through fall 1979 at two Boulder Patch dive sites (DS-11 and DS-11A) roughly 200 m apart in his Figure 2. A Student-Newman-Keuls test comparing the means for each site and year showed no significant differences except that the mean growth of 37.7 cm in the third year at DS-11A significantly exceeded any of the others, which ranged from about 22 to 25 cm. There was a clean rather than a turbid ice canopy over DS-11A during the winter of 1978-79.

The year-to-year standard deviation at DS-11, where turbid ice was presumably present all 3 years, was about 1.3 cm. However, the approximately 55 percent increase in linear growth during the year with clear ice at DS-11A led to a year-to-year standard deviation of around 8.2 cm. Thus, unless transparency is measured and included in a model for kelp growth, variations in growth caused by natural variations in the turbidity of the ice will likely far exceed effects of OCS development activity, and the latter will not be detectable.

If we assume that annual linear growth values can be adjusted for turbidity, for example by analysis of covariance, then we can get some idea of detectable change by looking at the 3 years of data at DS-11 given by Dunton (1983b) as three groups in an analysis of variance. Suppose a fourth group consists of data from a year with a change in growth caused by OCS development activity. Then we can use standard charts such as Table A-13 in Dixon and Massey (1969) to determine what level of change could be detected with a given power (see Appendix C for details). We find, for example, that testing at the 5 percent level has a 90 percent probability of detecting a 7-cm change in annual linear growth under these assumptions if we obtain 20 growth measurements in the fourth year.

5. 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 programs included in the BSMP. These recommendations are based on our analysis of information presented at the workshop, related information reviewed in the course of our effort on this project, our experience in similar projects, and especially the statistical analyses presented in Chapter 4.

As noted in Chapter 4, each of the hypotheses adopted by the workshop has been restated as null hypotheses (H_o) against which monitoring program results can be tested (Table 4-1). Each of the workshop-generated hypotheses has at least two distinct components requiring separate null hypotheses and proofs: The first hypothesis deals with proof that a change has occurred; the second with proof that the observed change was caused by oil and gas activities. In most cases, the programs described lack the capability of testing this second aspect. We concur with the workshop recommendations that first priority should be placed on monitoring to detect change with the expectation that studies to determine causality would be initiated once a change has been detected. In this way, studies for causality can be directed to specific questions maximizing the utility and cost effectiveness of information gained.

Establishment of direct causality is rare in marine pollution monitoring studies. More frequently, circumstantial evidence is gathered linking statistically significant changes in physical or chemical aspects of the environment (known or suspected of causing impacts) with statistically proven changes in the target variable. To establish direct causality usually requires much more laboratory study or field manipulation than strict field monitoring. Stone (Canadian Department of Indian and Northern Affairs) reported that Canada was allocating some 30 percent of their program resources to actual monitoring with the remaining 70 percent going toward studies to aid in understanding of key relationships (based on the outcome of their adaptive environmental assessment) and sensitivites of VECs. While we have not attempted to detail the studies that might be necessary to establish causality, we have tried to identify avenues of research that might achieve this goal.

In describing field studies recommended for inclusion in the Beaufort monitoring program, we have been as specific as possible using the best information available to us and our best scientific judgment. We recognize that each of our detailed recommendations may not be the only technically sound approach. Nonetheless, 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 monitoring program, procedures should be rigidly adhered to (see Section 3.7.3.2) unless alternate approaches are proven superior. Even then, it may be 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 section, we feel strongly that the monitoring program cannot succeed without full implementation of recommendations of the workshop regarding physical environmental data, quality assurance, data management, oversampling and archiving, and coordination of physical, chemical, and biological sampling, as described in Section 3.7.3.

5.2 MONITORING RATIONALE

Regulatory mandates aside, convincing logical arguments can be made against the need for a long-term, areawide monitoring program such as that proposed below. Firstly, the recent disappointing results of test drilling in the Mukluk Formation may portend a much lower or more localized level of offshore development than had been previously forecast. Secondly, as noted by Wolfe (Section 3.7.1), the first and most sensitive "line of defense" against environmental degradation that could ultimately impact VECs is compliance and site-specific monitoring of individual activities. If, through construction and operational stipulations (including discharge limitations), degradation below acceptable levels is prevented beyond a defined distance from each activity, then it is very unlikely that areawide degradation sufficient to impact VECs would occur.

Finally, it does not appear that all five aspects (hypotheses) of the workshop-recommended BSMP approach meet the objectives of the monitoring program set forth in Chapter 3. The first two of these hypotheses deal with aspects of the environment (sediment and sessile benthos) difficult to link with VECs, while the remaining hypotheses relate to VECs that spend only a fraction of their life history in the area of concern. With our present state of knowledge it is very difficult to hypothesize a realistic development scenario that would result in a significant regionwide effect on waterfowl or anadromous fish that could not be linked to a specific obvious event or action (e.g., major mortalities due to an oil spill; losses to impingement or entrainment at a large seawater intake). Once seismic exploration is complete this may apply to bowhead whales as well. Increasing levels of petroleum hydrocarbons or certain metals (e.g., barium or chromium) in sediments, if detected, could reliably be attributed to OCS oil and gas development activities (oil spills, drilling fluid, and formation water discharges). However, field and laboratory analyses to date have produced no evidence that such accumulations are measurable beyond a few kilometers from a site (e.g., Houghton et al. 1981; Menzie 1982). Moreover, sediment levels of petroleum hydrocarbons and metals that have been circumstantially linked to carcinogenesis (e.g., in flatfish) are high (Malins et al. 1980, 1982) and have resulted from multiple, poorly-regulated inputs over many decades.

Increases in sediment metals and petroleum hydrocarbons will be significant in the terms of the workshop objectives only if they can be linked to changes in VECs or otherwise suggest that changes in VECs may occur if conditions worsen. Because of the difficulty in establishing this linkage, the mussel watch approach (Section 5.2.2) might be considered the closest to meeting the BSMP objectives. Even though the selected organisms may or may not be indigenous, relatively small increases in their body burden should be a reliable early warning that environmental contaminant levels have increased in the area and could extend to VECs. At present, oil and gas development activities are the only likely sources of such increased levels in the Beaufort Sea.

On the positive side, there are several overriding factors (in addition to the regulatory mandates) that reinforce the need for a regionwide monitoring program in the Beaufort Sea.

1. While Mukluk results were discouraging, there are other areas of the Beaufort where offshore production will occur and other offshore formations which are yet to be drilled.
2. Given that additional major exploration and some offshore development will occur in the Beaufort, there is a strong political need to document that changes do not occur. This holds regardless of how strong a case can be made, using existing knowledge, that adverse effects would not occur. There is a possibility that pollutant behavior, organism physiology, and population controlling factors are sufficiently different and imperfectly understood in the Arctic that conclusions based on extrapolation of experience from other OCS areas may not hold. Concerned citizens of the North Slope Borough, the environmental community, and some regulatory agencies can be expected to demand field documentation that changes have or have not occurred.
3. As stressed by Wolfe (Section 3.7.1) there may be some effects that are so important that we want to know about them even if we cannot foresee a reasonable mechanism that would cause them to occur. If they do occur, we wish to know about them and initiate further studies as appropriate to identify their causes.

Finally, while the five workshop hypotheses selected for inclusion in the BSMP do not each fully meet the stated objectives for the program, this may be the result of setting overly idealistic objectives. In reality, the program as designed will monitor two aspects of the environment believed to have the greatest chance of detecting increased contaminant levels (sediment chemistry and sentinel organism body burden). While causality of increases observed could not be readily established, they would be significant as an early warning of the potential for effects that might eventually reach VECs. The program will also monitor populations and/or distributions of three species thought to be representative of three major groups about which we indeed care very much (marine mammals, waterfowl, and anadromous fish) but for which we may have difficulty in establishing causality for any changes observed.

Thus, while none of the individual approaches selected meets all of the objectives established for the BSMP, each addresses at least one objective. Moreover, it is likely that there is no practical single monitoring effort that would meet all of the stated objectives.

Within the limitations of our technological ability to monitor the environmental effects of OCS activities, recommended monitoring approaches collectively address the objectives for the program in an optimum manner.

5.3 SPECIFIC HYPOTHESES AND APPROACHES

5.3.1 Sediment Chemistry Network

5.3.1.1 Statistical Design

Aspects of Hypotheses I and II from the workshop relevant to sediment chemistry were restated as follows to allow statistical analyses:

H_o1 There will be no change in concentrations of selected metals or hydrocarbons in surficial sediments beyond the zones of mixing or dispersion specified under the relevant operating permits.

H_o3 Changes in concentrations of selected metals or hydrocarbons in surficial sediments. . . are not related to OCS oil and gas development activity.

The theory outlined in Section 4.2.1 and detailed in Section 2 of Appendix B was applied to specify a sediment monitoring network relative to the 17 subregions shown in Figure 4-2. The 17 blocks of that figure could be combined in various ways to represent different kinds or probabilities of subregional impacts. It is desirable to reduce the number of blocks to simplify both the assignment of the probabilities p_i (described in Section 4.2.1) and the subsequent calculations.

The subregions where the probability of an oil spill, say, was particularly high might not be the same as the areas at highest risk of increased barium in the sediments from drilling muds, so a monitoring network optimal under all scenarios is probably unattainable. We illustrate in Figure 5-1 the specification of a network based on one reasonable reduction which treats regions 12 and 17, 6 and 8, and 1 as low-risk blocks with probabilities (p) of a specified impact $p_1 = p_2 = p_3 = 0.01$. Regions 10, 13, and 14; 5 and 7; and 2 are medium-risk blocks with $p_4 = p_5 = p_6 = 0.04$. Regions 4, 11, and 16 form a high-risk block with $p_7 = 0.38$, and regions 3, 9, and 15 form the block with highest risk, $p_8 = 0.47$. See Section 4 of Appendix B for details.

The calculations lead to the following conclusions:

- Collect 4 replicate samples at each of 36 stations.
- Choose 17 stations from among the potential locations available in regions 3, 9, and 15.
- Similarly, choose 16 stations in regions 4, 11, and 16.
- Choose 1 station in region 2, 1 in region 5 or 7, and 1 in region 10, 13, or 14.

If the risk probabilities assigned above are correct and the assumptions of Section 1 of Appendix B hold, the minimum change in sediment concentration of any particular metal or hydrocarbon being monitored which we have an 80 percent chance of detecting can be derived from Table 1 of Appendix B. This minimum detectable change is approximately 0.64 times the replicate standard deviation for that metal or hydrocarbon. Clearly, the minimum detectable change in, say, a hydrocarbon for which the analytical and sampling variability is high will be larger than the minimum detectable change in a metal with lower analytical and sampling variability since these components of variance determine the replicate standard deviation.

We have suggested collection of four replicates because we feel that this number will be adequate to permit the estimation of replicate standard deviations after the first year of monitoring. However, the analysis of the first year's data may reveal that more or fewer replicates are needed to achieve the desired power to detect absolute changes in particular contaminants considered significant. Therefore, the strategy of oversampling discussed in Section 3.7.3.4 should be employed during the first year of sampling (e.g., at selected stations) to ensure that archived samples are available to provide additional replicates for those contaminants for which more than four samples are found to be needed.

A sampling network can also be defined using the information transmission approach outlined in Section 4.2.1 and detailed in Sections 3 and 4 of Appendix B. Recall that in this approach we do not assign risk probabilities to the blocks of Figure 5-1 but rather assume that sites within a block will be more "similar" (in terms of concentration of the metal or hydrocarbon on which the design is based) than sites in different blocks. We sample those sites in the grid of potential sites which maximize the amount of information provided about both sampled and unsampled sites. The change to be detected is assumed to be a global change (affecting all sites) to which individual block and site effects are added.

Not surprisingly, the differences in the assumptions of the two approaches lead to differences in the resulting sampling networks. The information transmission approach as applied in Section 4 of Appendix B recommends that at least one station be placed in each block. Stations after the first 17 are assigned to the larger blocks.

In our view, the approach which considers risk probabilities in different blocks provides the network most likely to be successful in detecting changes most likely to occur. However, if our assessments of risk prove wrong and an important change occurs within Blocks 1, 6, 8, 12, and/or 17, this change cannot possibly be detected by the network concentrated in the "high risk" blocks since these "low risk" blocks contain no stations. The information transmission approach puts 3 stations in each of these blocks and 1 to 3 stations in each of the other blocks; thus there is at least a possibility that change will be detected regardless of the subregion in which it is most evident.

The extent to which a compromise between the two designs appears desirable depends on one's perceptions concerning which set of assumptions seems most appropriate, the confidence with which extremely low risk probabilities can be assigned to some subregions, etc. We wish to reiterate that what we have tried to provide in Appendix B is a general methodology for network design. Our proposed network is an example of the application of this methodology rather than a final definition of a sediment monitoring network for the BSMP. The contractor chosen by NOAA and/or MMS to monitor sediment chemistry for the BSMP will need to resolve the questions concerning kinds of impacts with which the sampling strategy is to be concerned global vs. local) and technical details (how much westerly or easterly transport of pollutants to expect) and possibly redraw the blocks and recompute the allocation of stations.

Comments from reviewers of the draft report suggest several possible redefinitions. For example, it might be decided that Blocks 3, 9, and 15 and 4, 11, and 16 have equally high risk of impact. Block 14, a medium-risk block, might well be extended east to Barter Island to cover potential activity in that area. After the first year of monitoring, analysis of the data and a more realistic development scenario may suggest other possibilities.

If it is felt that 4 replicates at 36 stations are too many (i.e., too expensive to sample and analyze), the number of stations can be reduced. The minimum change in concentrations detectable with high probability would

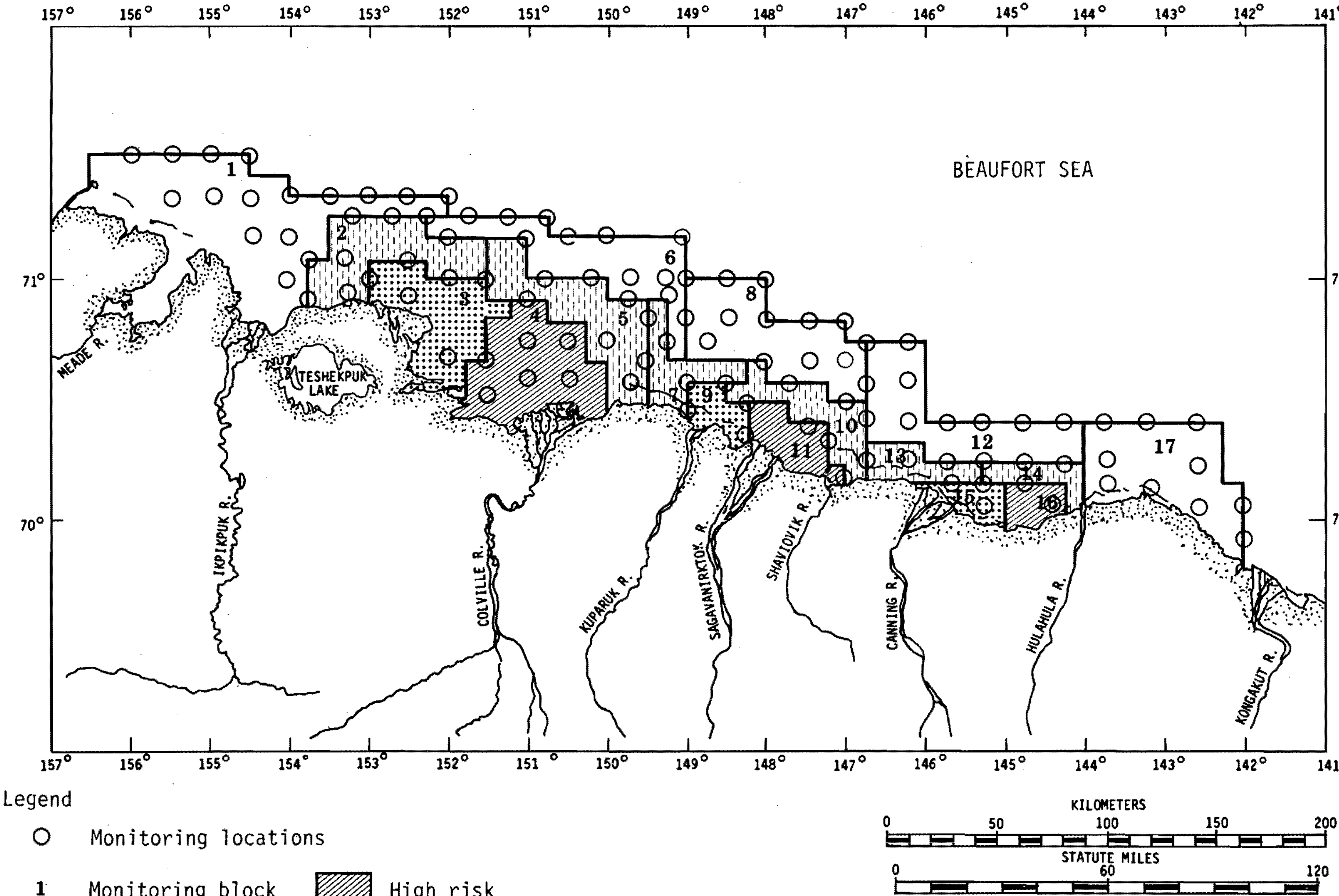


Figure 5-1

Sediment Monitoring Network Blocks Showing Assumed Risk Levels and Locations of Potential Sampling Sites

be correspondingly increased, as indicated in Table 1 of Appendix B.

Once blocks and the number of stations per block have been defined, particular station locations should be chosen randomly within each block. If the stations of Shaw (1981) and Kaplan and Venkatesan (1981) were so chosen, and if it is felt that the existing baseline data at these stations is valuable, some or all of them may be used. If this resulted in more stations than needed in some blocks, a subset could be randomly selected. Stations could also be randomly chosen from among the potential stations shown as open circles in Figure 1 of Appendix B if the blocks we have defined are used. Sediment characteristics may eliminate some potential stations since it is desirable to sample fine rather than coarse sediments for chemical analysis; i.e., stations with less than a certain predetermined percentage of fines would be rejected.

The alternative of nonrandom selection of stations within blocks (e.g,. stratification of station locations around specific development activities) is considered as activity-specific compliance monitoring rather than areawide monitoring which is the subject of the BSMP.

5.3.1.2 Sampling Considerations

In addition to the locations at which sediment samples should be taken (Section 5.2.1.2), several other parameters of the sampling program need to be defined. These include the frequency of sampling, the means of collecting the sample, and the sample handling and storage needs during transportation to the laboratory and to sample archives.

The frequency of sampling should, to some extent, be determined by the rate of growth of OCS activities at any given time. However, unless these activities become much more extensive than currently foreseen, it is suggested that a complete set of sediment samples be obtained from the 36 selected station locations during each of the years 1984, 1985, and 1986 and thereafter every 3 years. Based on experience elsewhere, it is reasonable to believe that OCS oil and gas activity would not lead to major increases in concentrations of the contaminants of interest within less than a 3-year period, except within close proximity of a development site (within the compliance monitoring area) or in the event of a major accidental spill. Therefore, unless an increase is observed during the first 3 years of the monitoring program, a sampling interval of once a year for 3 years and every 3 years thereafter represents a reasonable frequency. Sampling in each of the first 3 years will serve to demonstrate whether changes are likely to occur that are more rapid than would be observed by sampling every 3 years. In addition, if no contaminant concentration changes are observed, as anticipated by the working hypothesis $H_0 1$ of this program, the first 3 years of data will provide a statistically stronger baseline from which to measure any future changes.

The objective of the sediment chemistry monitoring program is to assess changes in the rate of input of selected contaminants to the sediments. The rate that is being assessed is averaged over the 1- to 3-year period between samplings. Therefore, ideally the sediment samples collected should represent only the last 1 to 3 years of accumulation. In an undisturbed offshore coastal sediment, even one subject to relatively high accumulation rates, the thickness of a 1-to 7-year sediment layer would be very small, several millimeters at most. However, most sediments are not undisturbed and materials representing recent inputs to the sediment surface are mixed with previously deposited materials through physical resuspension, bioturbation, and, in the Beaufort Sea, ice scour. The depth of this reworking is highly variable and dependent upon many different physical and biological factors. Therefore, the choice of an appropriate depth of sediment sample to take is a difficult one. It is generally made through a compromise between a desire to take the narrowest possible surface layer, in order to best represent recent inputs, and practical considerations which limit the thickness of the sample. Usual practice is to obtain an undisturbed core or grab of sediment 10 cm or more in depth and to remove for analysis the top 1 cm of sediments.

Several types of sampler are potentially useful for obtaining the sediment samples in the field. These include hydraulically damped corers, box corers, and grab samplers. Many different samplers are routinely used for sediment monitoring and several different devices might be suitable for use in the Beaufort. The primary characteristics of the sampling device needed for the BSMP include reliability, simplicity, ease of shipboard operation, ability to provide a large enough sample, and, most important, ability to obtain an undisturbed sample so that the upper 1 cm sampled properly represents the upper 1 cm of sediments *in situ*.

Since the program requires trace metal and hydrocarbon analysis subsamples, as well as subsamples for archiving, a substantial quantity of sediment is required and the sampler must provide a large enough sample. The minimum quantity of each sample required will probably be on the order of several hundreds of grams and the sample will, therefore, have to be obtained from a sediment surface area of close to 0.1 m^2. For example, a 0.1-m^2 Van Veen grab sampler was utilized in the Georges Bank monitoring program (Payne et al. 1982).

Although the Van Veen grab is a suitable sampler and generally fulfills the requirements listed above, several other types of sampler, including various box corers and multiple-barrel, hydraulically damped corers, may better fulfill the requirements, especially the requirement for an undisturbed surface sample. An ongoing contract study currently being performed for NOAA includes an evaluation of the various sediment sampling devices available. Since the results of this evaluation are expected to be available before initiation of the BSMP, selection of an appropriate sampler should be made when this information is available.

Sample handling and storage requirements for this program are fairly simple and straightforward. Since ultratrace concentration metal analysis is not envisaged, rigid clean room techniques on board ship are not necessary. However, since hydrocarbon concentrations will be low, reasonable precautions must be taken to avoid contamination by shipboard air. Samples should be deep frozen (-20°C or lower) during storage and transport to the laboratory and archives. Samples should be homogenized in the laboratory before subsamples are taken for analysis and storage. Although the primary archived sample should be deep frozen, a small (10-20 g) subsample should be freeze dried, vacuum sealed in plastic, and stored at room temperature for possible future analyses of metals other than those recommended (see below) for the initial program. Materials coming in contact with the sample during sampling and sample processing should be carefully selected to prevent possible contamination, especially by hydrocarbons or other organics that might interfere in sample analysis, and vanadium and chromium which are present in many steels. Careful and complete documentation of materials used must be made in order that potential contamination may be assessed when future analyses of archived samples are conducted for parameters other than those currently anticipated.

5.3.1.3 Analytical Considerations:

Sediment samples collected in the Beaufort will be subjected to analysis for hydrocarbon concentrations and concentrations of selected trace metals. The recommended analyses for each sample period are as follows:

- Each sample (4 replicates at each of 36 stations = 144 samples) should be analyzed for total barium (Ba), chromium (Cr), and vanadium (V) concentrations.
- Each sample should be analyzed for the presence of oil through UV fluorescence and 1 replicate from each of 26 stations and all 4 replicates from 10 selected stations should be analyzed for individual hydrocarbons and groups of hydrocarbons through gas chromatography (GC) with a flame ionization detector (FID) and gas chromatography/mass spectrometry (GC/MS).
- Statistical analysis of data obtained at the end of the first sampling period should be used to adjust numbers of replicates analyzed as described in Section 5.3.1.1. Results would also be used to evaluate how much the detectable level of change in petroleum hydrocarbon contamination could be improved by using GC/FID and GC/MS for each replicate sample rather than UV flourescence. On the basis of this evaluation, in subsequent years either the routine UV fluorescence analysis should be eliminated or the GC/MS analysis should be reduced to analysis of homogenates of all replicates from 10 selected stations. In the latter case, additional GC/MS analysis would only be performed after an indication of change has been obtained from the UV fluorescence or GC/FID data.

The metals chosen for analysis, Ba, Cr, and V, are chosen because Ba and Cr are the two metals whose sediment concentrations are most likely to be affected by discharged drilling muds (National Academy of Sciences 1983), and V is likely to be the best inorganic indicator of oil contamination. Other metals may be appropriate for inclusion in the monitoring program if their concentrations in drilling muds or oil discharged from OCS activities in the Beaufort are found to be abnormally high. Trace metal analysis will most likely be performed through strong acid digestion of the sediments followed by atomic absorption spectrometry. However, several other analytical techniques may be appropriate. The technique adopted should be periodically tested for accuracy and reproducibility through analyses of appropriate standard reference materials.

Hydrocarbon analysis should be performed through a hierarchical scheme because of the high cost of gas chromatography/mass spectrometry. However, it should be understood that gas chromatography/mass spectrometry can provide the most information concerning possible sources of hydrocarbons in the sediments. The general hierarchical scheme is shown in Figure 5-2. UV/fluoresence analysis provides information on the presence of oil in the samples but is relatively insensitive. Gas chromatography with a flame ionization detector provides greater sensitivity and substantial information concerning diagnostic parameters needed to identify the sources of hydrocarbons present (see Table 5-1). Gas chromatography/mass spectrometry provides additional detailed information about a number of important specific hydrocarbon compounds or groups (Table 5-2) and permits examination of a number of additional key source diagnostic parameters (Table 5-1).

Both the trace metal and hydrocarbon analyses should be performed with the utmost of care. Appropriate quality control and assurance programs must be an integral part of the analytical program and the considerations regarding quality assurance outlined in Sections 3.7.3.2 and 3.7.3.3 should be applied.

TABLE 5-1
KEY DIAGNOSTIC QUANTITATIVE AND SOURCE PARAMETERS[(a)]

Parameter	Analytical Source	Use
Quantitative		
Total n-alkanes	GC/FID	Compare with baseline data and between monitoring sets
n-alkanes (C_{10}-C_{20})	GC/FID	Key subset of alkanes-low value in baseline samples; increases with additives of petroleum
Phytane	GC/FID	Key petrogenic isoprenoid alkane of very low abundance in pristine sediments and animals
Total PAH	GC/MS	Compare with baseline data and between monitoring sets
Source		
Saturated hydrocarbon weathering ratio (SHWR)	GC/FID	Rate and extent of weathering of petroleum residues in samples
ISO/ALK (and/or: Pytane/n-C_{18})	GC/FID	Ratio of isoprenoid to normal alkanes in C_{13}-C_{18} range; diagnostic of microbial degradation of oil
Total n-alkanes/TOC	GC/FID; CHN analyzer	Ratio is reasonably constant within a given region of normal deposition in sediments. Increases markedly with petroleum additions
CPI (carbon preference incex)	GC/FID	Diagnostic for petroleum addition; ranges from 5-10 for petroleum-free sample to 1 for petroleum
Unresolved complex mixture (UCM)	GC/FID	Presence may indicate weathered petroleum
Fossil fuel pollution index (FFPI)	GC/MS	Ratio of fossil fuel-derived PAH (2-3 rings) to total (fossil + pyrogenic + diagenetic) PAH
Alkyl homolog distributions (AHD) of PAH	GC/MS	Relative quantities of alkylated to unsubstituted compounds within each homologous family indicates source of hydrocarbons
Aromatic weathering ratio (AWR)	GC/MS	Rate and extent of weathering of petroleum residues in samples
Molecular biomarkers (triterpanes, steranes)	GC/MS	Presence of certain stereoisomers of these cyclic alkanes is a powerful indicator of petroleum additions

(a) Source: Boehm, this workshop.

TABLE 5-2

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 naphthalenes
170	C-3 naphthalenes
184	C_4 naphthalenes
152	Acenaphthene
154	Biphenyl
166	Fluorene
180	Methyl fluorenes
194	C-2 fluorenes
178	Phenanthrene, anthracene
192	Methyl phenanthrenes (anthracene)
206	C-2 phenanthrenes (anthracenel
220	C_3 phenanthrenes
234	C_4 phenanthrenes
202	Fluoranthene, 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, this workshop.

5.3.2 Biological Monitors/Sentinel Organisms

5.3.2.1 General

Aspects of Workshop Hypotheses I and II related to bioaccumulation and pollutant effects at the organism level have been restated as follows (from Table 4-1):

H_o2 There will be no change in concentration of selected metals or hydrocarbons in the selected sentinal organism(s) beyond the zones of mixing or dispersion specified in relevant operating permits.

H_o3 Changes in concentrations of selected metals or hydrocarbons in . . . sentinal organisms are not related to OCS oil and gas development activity.

As noted in Section 3.7.2, the workshop recommended use of indigenous species as bioindicators if at all possible. Ideally, both a suspension feeder and a surficial deposit feeder would be included. It was noted, however, that distribution and size of organisms present on the Beaufort Sea shelf might dictate substitution of species from elsewhere. In the following discussion we first describe the desirable attributes of indicator organisms used in a mussel watch program; we then discuss potential candidate species indigenous to the Beaufort Sea; finally, we describe a suggested approach to a pilot study aimed at the data necessary to set a reasonable direction for a Beaufort Sea mussel watch program.

5.3.2.2 Desirable Attributes of Candidate Species

Each biological species has its own unique biochemical composition and functions, and its own unique feeding and other ecological characteristics. Therefore, it is essential that substantial information be available concerning the characteristics of any species chosen as a sentinel organism in order that it may be used effectively. The attributes that are required of an organism to be used as an effective sentinel organism have been listed and amended by several authors (Butler et al. 1971; Haug et al. 1974; Phillips 1980). The most recent listing of these attributes based on Phillips (1980) was made by participants at the Mussel Watch II meeting held in Honolulu in November 1983 and is as follows (Segar 1983):

- 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 sedentary in order to be representative of the study area.
- 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.

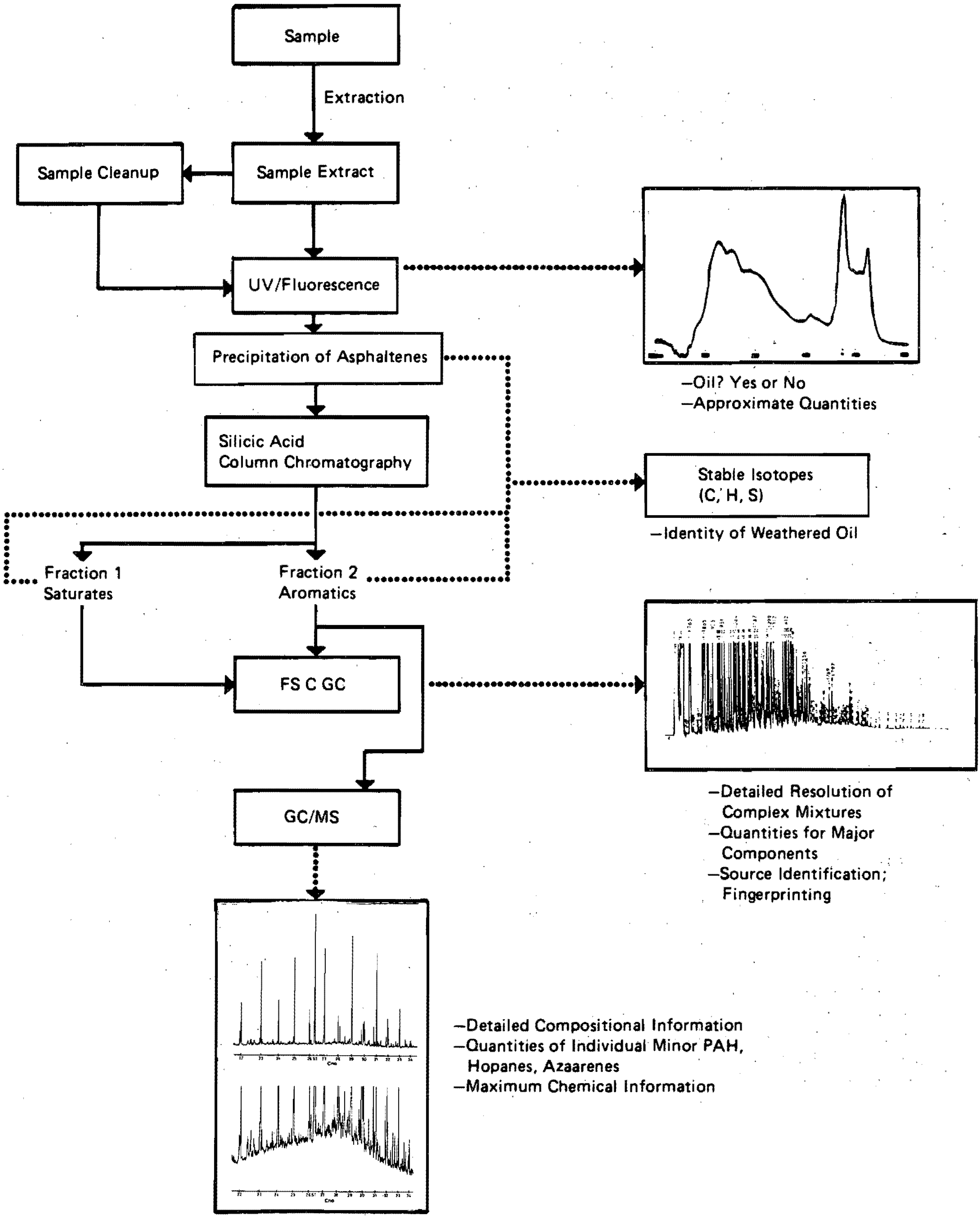


Figure 5-2

Schematic of Hierarchical Analytical Strategy for Hydrocarbons

TABLE 5-3
SUMMARY OF CHARACTERISTICS OF POTENTIAL BEAUFORT SEA INDICATOR SPECIES

Species (feeding type)	Maximum Length (mm)[a]	Abundance (no/m^2) Prudhoe Bay [b]	Pitt Point (depth)[c]	Boulder Patch[d]	Notes
Portlandia arctica (deposit)[a]	30	44	142 (10 m) 182 (20 m) 196 (25 m)	0.4	Usually no more than 15 mm.[a] 15-20 mm common in Beaufort Sea[e]
Musculus discors (suspension)	40	—	—	69.2	Average biomass in Boulder Patch was 2.1 g/m^2 plus 0.19 g/m^2 for smaller unidentified *Musculus*
Musculus niger (suspension)	45	—	—	—	Reported in 27 to 101 m of water. [a]
Astarte borealis (deposit?); may filter interstitial water)	55	—	—	1.6 (as *Astarte* sp.)	To 40 mm; shells common in Beaufort Sea.[e]
Macoma calcarea (surficial deposit)	54	—	232 (5 m) 22 (10 m)	0.4	Good size but patchy; live deep in sediments.[e]
Lyocyma fluctuosa (suspension)	33	32	644 (5 m) 182 (10 m)	—	Usually less than 15 mm.[a]
Cyrtodaria kurriana (suspension?)[a]	40	25	304 (5 m)	—	Usually less than 30 mm.[a] Less than 20 mm in the Beaufort Sea.[e]

(a) Source: Bernard 1979.
(b) Source: Feder and Jewett 1982.
(c) Source: Carey (1981) highest densities only.
(d) Source: Dunton et al. 1982.
(e) Source: Scott 1983.

- 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 pollutant uptake.
- The organism should tolerate brackish water.
- Kinetics of the contaminant in the organism should be understood.

Very few species are known well enough to conclude whether or not they fulfill all of these requirements and, therefore, additional research will generally be needed before a candidate species can be proven acceptable for use in a sentinel organism program. Certain mytilid species have been extensively studied and are widely used as sentinel organisms; thus, substantial data bases exist for them. Therefore, any new species used as a sentinel organism in the Beaufort Sea ideally should be carefully compared with appropriate mytilid species *(M. edulis or californianus)* with regard to its behavior when subjected to contamination of its environment. Only in this way will it be possible to relate the magnitude and importance of any change in contaminant concentrations in the Beaufort sentinel organisms to what is known about marine pollution impacts in other areas.

5.3.2.3 Candidate Indigenous Species

Ignoring for a moment the problem described above (that little is known of their response to changes in environmental concentration of metals or hydrocarbons), several species of Beaufort Sea bivalves were suggested at the workshop and by subsequent research as candidates for a Beaufort Sea mussel watch. Relevant known size and distribution characteristics of these species are summarized in Table 5-3. Of the seven species listed, *Astarte, Musculus* (2 sp.), and *Macoma* have the largest reported upper size limit but little data on size distribution in the Beaufort Sea could be found. Scott (1983), who has done much of the work on collections of Carey et al. (1981), noted that shell sizes of *Astarte borealis* and *Macoma calcarea* were among the largest in Carey's collections. *M. calcarea* was relatively abundant in shallow water (5 m) on the Pitt Point transect; however, the depth in the sediments favored by this species would make it difficult to collect. *M. calcarea* is nonetheless the best candidate for a surficial deposit feeder. *M. calcarea* has the added benefit that its congener *M. balthica* has been widely used in marine pollution studies; thus, there is a good body of information on sensitivites, uptake and depuration of pollutants by the genus that may be applicable to *M. calcarea* as well.

Of the suspension feeders, *Cyrtodaria* and *Liocyma*, which are very abundant in shallow water (5 m), are generally small in the Beaufort — usually less than 20 mm. Of the mytilids (mussels), *Musculus discors* is locally very abundant where a substrate is present for attachment (e.g., in the Boulder Patch). Average size is small, however, with an average weight of 0.03 grams per individual in Boulder Patch samples (Dunton et al. 1982). *Musculus niger* is larger but is found in deeper water and is less common. Based on this information, *Cyrtodaria* appears to be the best indigenous suspension feeder available. However, there appears to be little information on its pollutant metabolism. Shaw (1981) obtained sufficient samples of *Astarte* spp. and *Liocyma* spp. for hydrocarbon analyses but did not specify the collection means or the number of individuals comprising a sample.

The alternative to collection and use of an indigenous suspension feeder is the importation of a suitable species from elsewhere, preferably from as close to the Beaufort Sea as possible. The logical candidate for such use is *Mytilus edulis* because of its widespread use in other mussel watch programs, its well-studied physiology, and its availability. While not reported from the Beaufort Sea by Bernard (1979), scattered live individuals have been taken from near Prudhoe Bay, perhaps transported to the area by ships or barges (Feder and Jewett 1981). *Mytilus* shells are among the most abundant bivalve shells on beaches in the southeast Chukchi Sea (J. Houghton, Dames & Moore personal observation) and are reportedly abundant on hard bottom areas in the northeast Chukchi as well (Dunton 1983a). Thus, there would appear to be no physiological barrier to adult *Mytilus* living in the Beaufort Sea although there may be a barrier to reproduction or simply a geographic barrier formed by the extensive distances lacking undisturbed (by ice) hard substrates.

5.3.2.4 Recommended Approach to Establishing a Beaufort Sea Mussel Watch

Based on anticipated problems with securing adequate numbers of indigenous bivalves in the Beaufort Sea, and the uncertain physiological nature of the organisms that might be obtained, we recommend two pilot approaches be evaluated to establish the optimum direction for a long-term Beaufort Sea mussel watch:

- Collection and analysis of indigenous species.
- Transplantation and analysis of *M. edulis*.

Indigenous Species. An effort should be made early in the open water season to collect necessary numbers of adequate-sized indigenous bivalves for use in subsequent analyses. Because of the size (minimum 15 to 20+ mm) and number (several hundred) of animals needed, we recommend using a scallop-dredge type of gear that can plough through a large volume of sediments retaining only objects larger than a given mesh size (e.g., 15 mm). Because this gear will require a large vessel equipped with a fairly strong winch,

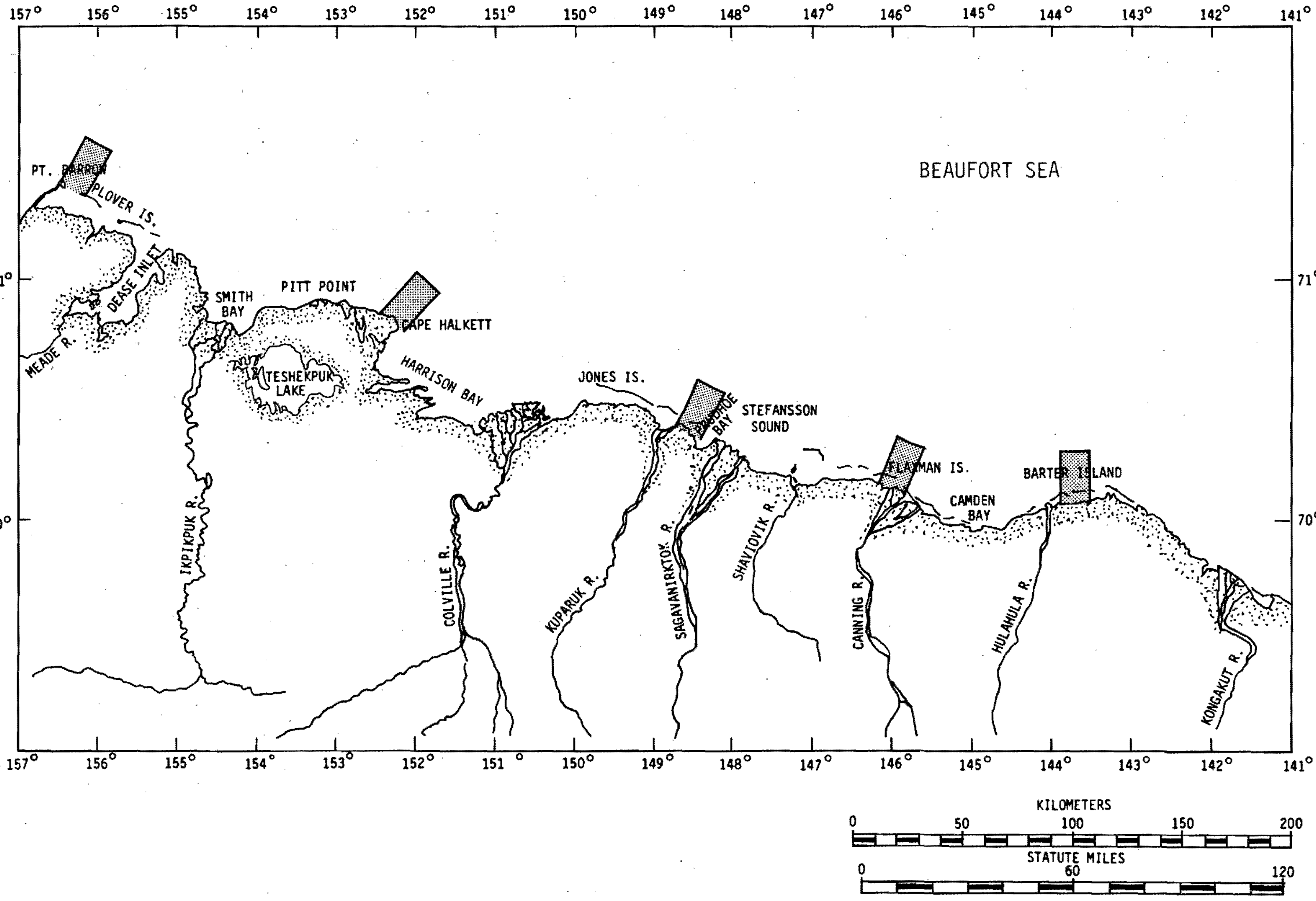


Figure 5-3

Suggested Locations for Mussel Watch Stations

the operation can probably best be run out of Prudhoe Bay. An initial series of depth-stratified drags would be run on one or more transects out to 20 to 25 m to attempt to locate promising areas. Any large clams would be identified and held on board live. After four to six transects (out and back) if no suitable populations have been found, a decision would be required whether to keep searching or terminate this approach.

Very likely this amount of effort would provide a sufficient number of one or more species to at least obtain tissue samples for determination of "baseline" body burden of selected metals and hydrocarbons. This sampling and analysis could be repeated next year and then at reduced frequency (e.g., 3-year intervals) to constitute a Beaufort Sea Mussel Watch program. If logistics can be arranged, similar sampling efforts should be carried out at five locations in the areas shown on Figure 5-3. If at all possible, these clams should be taken from as close as possible to stations sampled under the sediment monitoring network (Section 5.3.1). These five areas are in blocks rated as having both the highest and lowest risk of exposure to oil and gas development impacts (see Figure 5-1). Timing of sampling should be moved back to mid- to late August in subsequent years to maximize accessibility to all areas and to provide more exposure time during the open water season.

If several hundred or more of a given species are recovered from any location, a portion should be included in the caged experiments described below to examine them for changes in body burden during the open water season and for uptake in areas of high exposure. If this approach proves feasible, then collection of clams from other geographic locations would not be required.

Caged Organism Studies: *Mytilus edulis* obtained from an unpolluted environment elsewhere in Alaska and, if available, indigenous bivalves gathered as described above should be transported to one or two of the locations shown on Figure 5-3 for a pilot study of caged animals. Prudhoe Bay and either Barrow or Kaktovik would be the locations of choice to provide developed and relatively undisturbed sites. However, it might be possible to conduct the entire pilot study out of Prudhoe Bay.

Organisms would be exposed in cages anchored at a minimum of three locations including at least two "control" locations at different depths and one or more in a potential impact zone—exposed to shipping activity (e.g., near Dockhead 3 on the causeway) or to active or recent drilling mud discharges. If at all possible, stations in this pilot program should be coincident with sediment sampling stations described in Section 5.2.1. Cages should be constructed of inert materials, preseasoned in clean seawater, and should be large enough to hold the requisite number of organisms without crowding. At least two cages, each separately anchored (preferably with a subsurface acoustic release buoy), should be placed at each location as early as possible in the open water season.

A random subsample of each species should be taken at the time of capture for initial analysis of body burden. At present the national mussel watch protocol does not call for depuration of the gut contents of test organisms (Flegal, the workshop) although there is an ongoing controversy on the subject. For suspension feeders held in cages suspended in the water column, it is likely that the gut at the time of sampling will contain much lower concentrations of target materials that bioaccumulate than will the remaining soft body tissue. Hence, depuration will gain little and may result in significant loss of body burden of rapidly metabolized chemicals. In contrast, deposit feeders may contain significant quantities of inorganic material in their gut that would lead to erroneous body burden levels of metals at least. On the other hand, this "error" may be considered desirable since undepurated deposit feeders contain samples of recently deposited sediment in their gut and analysis data may be used to represent the most recent contaminant inputs.

For the BSMP pilot program we suggest the following approach. If sufficient numbers of indigenous bivalves (suspension and/or deposit feeders) are found in the test dredging described above, they should be split into at least two lots on board. One lot (sufficient to provide three to five replicate (pooled) 30-g samples should be quick frozen for subsequent dissection and analysis. A second similar lot should be held on board in clean, filtered (0.45 micron) sea water, flowing or frequently replaced at ambient water temperature, to depurate for 24 hours prior to freezing. If available, a third lot could be held for 48 hours. Mussels when initially procured (from elsewhere in Alaska) should be similarly treated to provide the "pre-exposure" body burden.

At present, we recommend that organisms be pooled as necessary to exceed the minimum sample size required for analysis by about 20 percent (5 g for metals + 20 g for hydrocarbons) x 1.2 = 30 g. A sufficient number of animals should be placed in each cage to supply at least six of the minimum tissue samples. Dissection techniques used should be sufficiently clean to avoid all chance of contamination with hydrocarbons. Considerations for sample handling, freezing, storage, documentation, and analysis described in Sections 5.3.1.2 and 5.3.1.3 should be applied. At least five replicate pooled samples should be analyzed for metals and hierarchical analysis of hydrocarbons as described in Section 5.3.1.3. Analyses during the first year should be as follows:

- All replicates from each station should be analyzed by UV fluorescence.
- One pooling of all replicates for each station and species should be analyzed by GC/MS.

- All replicates from two stations should be analyzed individually by GC/FID and GC/MS.

Second and subsequent year analyses should either

- use UV fluorescence for all replicates with selected minimal number of GC/FID and GC/MS analyses.

or

- eliminate UV fluorescence and depend totally on GC based analyses.

Selection of the approach to be used should be based on statistical examination of the pilot year data as suggested for sediments in Section 5.3.1.3.

The present mussel watch protocol calls for homogenization of a fairly large number (15) of individual organisms and replicate analyses of samples drawn from the pooled homogenate (Flegal, this workshop). This approach provides no definition of variability within groups of similarly exposed organisms. Our suggested approach (analysis of fine replicate [pooled] samples) will provide some local data on the former (organisms within sample) variability. Within-laboratory analytical variability should be estimated by providing the laboratory sufficient similarly exposed (or unexposed) tissue for homogenization and replicate analysis of the homogenate.

At one control and one potentially "polluted" station twice the above determined number of each species should be set out in cages to allow a mid-period sampling and analysis for a few selected contaminants (including those most likely from known nearby activities). Near the end of the reliable open water season all cages and animals should be recovered for sampling.

Following this initial year's pilot study, sufficient data will be on hand to design the most efficient possible study for future years. It is expected that caged organism sampling should occur in the same five areas (coincident with sediment sampling stations) shown on Figure 5-3 for sampling natural bivalve populations. At each area, stations should be occupied at two different depths. As in the National Mussel Watch Program and the sediment chemistry monitoring (Section 5.3.1), 3 years should be sufficient to establish baseline conditions (assuming this sampling is completed before major changes in contaminant input rates occur). Subsequent sampling every 3 years should be adequate to detect long-term trends. However, more frequent sampling could be instituted if increasing contaminant inputs occur or if increased levels are measured during sediment monitoring.

If H_o3 is rejected and significant increases in organism concentrations of metals or PAHs are detected during increased OCS activity, then there would be a strong circumstantial proof of H_o2 that these increases are due to oil and gas development activity.

An increase in contaminants in sediments or in indicator species (rejection of Hypotheses I and II, H_o1 or H_o3) would be cause to greatly increase monitoring of contaminant levels in hiqher organisms including VECs (marine mammals, waterfowl, anadromous fish). This would provide data to investigate H_o4 and answer the question of transmitability of effects to higher trophic levels.

5.3.3 Marine Mammals

5.3.3.1 Continuation of Aerial Transect Surveys

Restatements of the workshop hypothesis related to bowhead whales are as follows:

H_o1 The axis of the fall migration of bowhead whales will not be altered during periods of increased OCS activity in the United States Beaufort Sea.

H_o2 Changes in bowhead migration patterns are not related to OCS oil and gas development activity.

Acoustic monitoring techniques for determining displacements in the fall migration path were considered at the Second Conference on the Biology of the Bowhead Whale (Albert et al. 1983). Conference participants concluded that acoustical techniques were not practical at this time, primarily because the distances over which monitoring must be done for this purpose are too great to be covered by nearshore systems. Aerial survey techniques were recommended over acoustic techniques for studying the fall migration path.

Based on the conclusions in Albert et al. and our analyses of the existing aerial survey data (Section 4.2.3), we recommend aerial surveys during the fall nearshore migration period (September-October) as the best method for obtaining data to test Hypothesis H_o1. Surveys should be conducted annually, with the possible exception of years with heavy ice cover; this consideration is discussed in more detail below.

Line transect surveys with randomly determined starting and ending points should be flown. The area which should be surveyed and details of survey methodology can be found in Ljungblad et al. (1983). We recommend that data continue to be reported as in Appendix A and Appendix B of Ljungblad et al. (1983), along with the additional analyses that we have discussed in Section 4.2.3. The ensuing paragraphs highlight important considerations regarding survey and data analysis methodology.

Lines should be flown in approximately a N-S rather than E-W direction so that all possible sighting depths in a block are covered by each transect line. Search surveys along a depth contour or latitude line must be clearly distinguished from the random N-S line transects and omitted from calculations of median sighting depths. Sighting depths on the line transects should, of course, be recorded as accurately as possible.

If the 1982 survey is to be used as a baseline, survey effort in the different bathymetric zones in the future surveys must be comparable to the 1982 effort. Table B-5 of Ljungblad et al. (1983) indicates that in 1982 survey time was roughly proportional to the area to be surveyed across the entire United States Beaufort from the Canadian border to Point Barrow and north to 72°N latitude with the following exceptions:

- Areas with water depth exceeding 2,000 m received little attention.
- Areas with depths from 200 m to 2,000 m were less thoroughly surveyed in the eastern half of the region.
- The most intensive effort was in the depth range from 10 m to 50 m believed to cover the near-shore migration path.

This general distribution of survey effort seems appropriate for detecting subtle shifts in migration path. It is important to continue to expend enough effort at depths exceeding 50 m to detect any future displacement of the migration into this deeper water.

From a statistical standpoint, we recommend using the 1982 survey as a baseline rather than combining the 1979, 1981, and 1982 data because the earlier surveys had very little coverage of offshore areas; thus, they may be biased toward shallower depths. However, 1982 may represent an "altered baseline" condition since considerable seismic activity was underway in the survey area at that time (Reeves et al. 1983). For this reason, it may be appropriate to give further thought to statistical approaches which would incorporate data from other years in the definition of the baseline. Differences in the amount of seismic activity and in survey effort at various depths in different years might be incorporated in the statistical model. As mentioned in Section 4.2.3, another alternative is to compare sighting depths in future years with some fixed depth contour, say 40 m.

If there were to be a dramatic displacement of a portion of the migrating population into waters beyond the shelf break (beyond majority of aerial survey effort), surveys comparable to the 1982 effort might fail to detect it using our median depth analysis. That is, the median depth of the few whales sighted in the surveyed area could remain the same while the majority of whales were passing unseen through deeper waters not being surveyed. However, it seems unlikely that OCS development activities would cause a sudden shift of this magnitude.

Ljungblad et al. (1983; Table B-5) reflects time spent in search as well as random transect surveys. Changes in the proportion of line transect flights suitable for use in median depth analyses in particular bathymetric zones in future years could lead to significant test results in the absence of changes in the behavior of the migrating bowheads. For example, we omitted from our analyses a large number of sightings near Demarcation Bay because they were made on E-W transect lines which did not provide a random sample of possible sighting depths. If a future survey covered this area more thoroughly with random N-S line transects and if, in fact, the whales congregate at the relatively shallow depths where they were seen during the nonrandom transects in 1982, the future data might indicate a shift in the axis of migration toward shore although the whales had made no changes in their migration and feeding patterns. These sorts of problems should be kept in mind in the design of future surveys and analysis of data obtained from them.

If there is a desire to focus on particular subregions of the Beaufort, survey effort can be increased in these subregions to obtain more sightings from which to compute the median depth. Increasing the number of sightings will increase the power to detect a displacement in the axis of migration for these subregions. For example, areas of particular interest to citizens of the North Slope Borough are between the Canadian border and Camden Bay and between Smith Bay and Point Barrow; thus, extra survey effort may be warranted in these areas.

We have already mentioned that bowhead migration routes are likely to be determined by ice conditions in heavy ice years. We have suggested that tests for displacement of the fall migration path be based on data from light ice years. However, the heavy/light ice year dichotomy is undoubtedly an oversimplification. Ice coverage should continue to be recorded during the aerial surveys. It might be possible to develop models for the axis of migration which incorporate data on ice conditions if surveys are conducted in heavy as well as light ice years.

In summary, further examination and discussion of available data should take place before a final decision about how to test for a shift in the axis of the fall bowhead migration is incorporated in the BSMP. The proposed aerial surveys provide appropriate data for whichever statistical test is chosen.

5.3.3.2 Continued Collection of Behavior Data

If a statistically significant shift in the axis of migration from the 1982 value is detected in some future year (rejection of H_o1), the question of whether it was caused by OCS oil and gas development, ice conditions, or other factors will remain unanswered. Rejection of H_o1, as restated, would strongly imply that the shift was due to OCS oil and gas activity although causality would be only circumstantial (the shift occurred during periods of increased activity). It is therefore important to continue the types of studies reported by Reeves et al. (1983) that look for correlations between whale behavior and such OCS activities as seismic vessel operations. These behavioral studies need to be conducted separately from the transect surveys discussed in Section 5.3.3.1 since they require a different survey methodology.

Conflicting results have been obtained from behavioral studies conducted to date. For example, Fraker et al. (1982) found a significant reduction in surface times in the presence of seismic sounds, while Reeves et al. (1983) found a statistically significant increase in mean surface time in the presence of such sounds. "Huddling" behavior was observed by Reeves et al. at the onset of seismic noise in some cases but in the absence of any known disturbance in other cases. The lack of conclusive results is not surprising, considering the small number of independent behavioral observations that are available. The unavoidable problems encountered in conducting these studies are well summarized by Reeves et al. (1983).

Our main recommendations for future behavioral studies are as follows: :

- Methods of assessing and recording bowhead behavior and the attendant environmental conditions (e.g., sonobuoy recordings of noise) should be standardized between different years and/or different investigators to the greatest extent possible.
- Workshops such as the Second Conference on the Biology of the Bowhead Whale (Albert et al. 1983) and annual interagency coordination meetings sponsored by NMFS/National Marine Mammal Laboratory should be held to facilitate the required communication and cooperation among investigators.
- Standardized formats for behavioral data in a computerized data base should be established. Such a data base containing data from different years and investigators should be assembled, and observations from future studies should be added to it. The problem of inadequate sample sizes for statistical analyses would be mitigated to some extent by combining data in this way.

The issue of computerizing the data base is discussed in more detail in Section 5.4.

5.3.3.3 Additional Marine Mammal Studies

Although the Second Conference on the Biology of the Bowhead Whale (Albert et al. 1983) did not recommend acoustic techniques for studying the distribution of bowheads during the fall migration, passive acoustic monitoring was suggested to document the use by bowheads of certain nearshore feeding areas in the late summer and fall. Albert included this proposal in his presentation at the Beaufort Sea Monitoring Program Workshop, recommending nearshore hydrophone array placement at two or three sites between the Canadian border and Camden Bay from August to October. Such an array would be able to detect and approximately locate bowhead vocalizations within a 10- to 20-kilometer radius.

This approach may well be preferable to aerial survey for monitoring bowhead use of feeding areas near Barter Island and Demarcation Bay, for example. Hydrophones could monitor these areas continuously if desired, while aerial survey coverage is limited by weather conditions, the need to monitor broader areas, etc. In addition, acoustic monitoring involves less potential disturbance of the feeding whales than do overflights.

Passive acoustical monitoring will be used at Point Barrow during the spring 1984 ice-based census to detect bowheads which pass beyond visible range of the ice camps. We suggest that if this spring effort proves successful, the equipment used should be adapted for the fall monitoring described, probably at Kaktovik. The fall effort could be expanded to additional sites if this pilot study produces useful data.

Since the analyses we have proposed for detecting displacement of the fall migration path involve median depths of sightings rather than bowhead numbers or densities, they would not flag increases or decreases in bowhead population size. The Second Conference on the Biology of the Bowhead Whale concluded that the spring ice-based census was the most reliable and cost-effective method for obtaining population size estimates. This census and other studies aimed at determining health and fecundity of the population should clearly continue to be funded. As noted by Reeves et al. (1983), a reduction in bowhead population size or physical condition would be of greater concern than the displacement in migration path which the effort described in Section 5.3.3.1 is designed to monitor.

We have mentioned in previous sections the need for additional statistical analyses of available bowhead aerial survey data to verify the year-to-year stability of the axis of migration as defined by median sighting depth, to attempt to model the effect of ice conditions on the migration path, etc. Further analyses might also be useful to improve our understanding of the offshore component of the fall migration. These analyses and analyses of future years' data may require the development of statistical techniques to adjust for biases caused by year-to-year differences in survey effort in different bathymetric zones.

Other marine mammals, most notably ringed seals, are also VECs in the Beaufort Sea. Albert noted that surveys of ringed seal density in the Beaufort have been conducted for the past 5 to 7 years by J. Burns of the Alaska Department of Fish and Game (Burns et al. 1980; 1981) who suggests that such surveys should be repeated every 2 to 3 years to monitor long-term trends in distribution and abundance. Site-specific monitoring of seals in relation to development activities believed likely to affect them would also clearly be appropriate.

Finally, tissue samples from bowheads' ringed seals, and other marine mammals obtained on an opportunistic basis (e.g., Albert 1981) should be monitored for levels of hydrocarbons and trace metals. The program described by Albert (1981) is continuing under North Slope Borough funding. This will provide a growing data base against which to test the most important of our monitoring program hypotheses regarding effects on human health.

5.3.4 Anadromous Fish

Restated Hypotheses:

H_o1 There will be no change in catch per unit of effort (CPUE) in the Colville River Arctic cisco fishery.

H_o2 Changes in Arctic cisco CPUE are not related to OCS oil and gas development activity.

The workshop recommended approach of continued monitoring of catch data from the Colville River Arctic cisco commercial fishery is an obvious requisite for testing of this hypotheses. However, our statistical analysis (Section 4.2.4) shows a high probability that factors unrelated to oil and gas development (i.e., natural population cycles, variability) may lead to rejection of H_o1. To ensure correct interpretation of such a rejection, it is necessary to gather and analyze associated data on population size, age and growth, and changes in freshwater and marine environments. Any changes in nets used, locations fished, duration of fishing, etc. must also be documented and analyzed to ensure a constant unit of effort is expended.

The modeling approach described by Gallaway (Section 4.2.3 and Gallaway et al. 1983) may offer a greater sensitivity to detect real development-related effects on anadromous fish populations than merely testing each year's CPUE against the baseline of earlier values. For the years 1976 through 1981, the CPUE predicted by the Deriso model appears to fall relatively close to the actual value (e.g., ± 20 percent) except in 1977 when the predicted value was about half the actual (Gallaway et al. 1983). With verification and calibration of the model and its input parameters, it would be a useful adjunct to the BSMP. Once the model is verified and calibrated, a statistically significant increase in the discrepancy between predicted and actual CPUE values should be easier to establish than it would be to establish that a given year's CPUE has changed from its "baseline condition." If this increased discrepancy between predicted and actual CPUE occurred (statistically significant or not), it would be cause to examine available population data and data on recent natural or man-caused environmental changes in the Beaufort Sea for an explanation. In all likelihood, it will not be possible to firmly establish causality for changes observed without an extensive data base on possibly related factors. At present, it is not even certain where these fish spawn (Gallaway et al. 1983); hence, interpretation of observed changes can only be extremely tentative and based only on what we know of a brief portion of their life history.

Although we did not perform statistical analyses on Arctic char aerial index counts in North Slope rivers (Figure 4-3), it is possible that these estimates may be as good as Arctic cisco CPUE for monitoring anadromous fish numbers in the Beaufort Sea. In the Ivishak River, for instance, the 1971 to 1976 data all fall within a very narrow range (8,570 to 13,958 fish). Data from 1979 to 1983 likewise fall within a reasonably narrow, albeit very different, range (24,403 to 36,432 fish). While the reason for this shift is uncertain (Section 4.2.4) it would appear that these counts, if continued using the same observer, aircraft, and pilot as in previous surveys, would provide a useful indicator of population trend. As in the case of the Colville fishery data, however, much additional research and tracking of events in the Beaufort Sea would be required to assign the cause of changes that may be observed.

Finally, catch data from the Colville River subsistence harvest should be incorporated into the long-term data base as they become available.

5.3.5 Oldsquaw

Restated Hypotheses:

H_o1 There will be no change in relative densities of molting male oldsquaw in selected Beaufort Sea index areas.

H_o2 Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.

Inadequacies in the data available to us prevented us from carrying out definitive analyses to develop an optimal sampling design. However, some conclusions can be drawn from the evaluations discussed in Section 4.2.5.

First, there do appear to be some relatively consistent patterns in oldsquaw distributions during the summer molting period. However, between-year variability in the timing of the molt and within-season variability in densities estimated by aerial survey are so high that multiple surveys within each area and season are mandatory. Four surveys approximately every 10 days between July 15 and August 15 should catch the peak of the molt and also help to average out differences in counts caused by time-of-day effects and unavoidable differences in survey aircraft used, visibility, etc. Of course, any such differences that can be avoided by stratification should be.

Second, transects should be very precisely defined and faithfully repeated. The available data indicate that transects on the lagoon-side shores of barrier islands and mid-lagoon transects should be used. Transects should be of similar lengths so that densities computed from them will represent comparable survey effort in areas of similar size. Monitoring should include, from west to east, transects in Elson Lagoon/Plover Islands, Simpson Lagoon (transects 2 and 3), Leffingwell Lagoon/Flaxman Island, and Beaufort Lagoon (Johnson 1983). Transects from Table 4-4 for which there are existing baseline data should be included where possible. It may be necessary to establish completely new transects (Elson Lagoon for example) where important oldsquaw molting areas are not covered by the existing transects.

The data collected from 1976 to the present should be installed in a data base in a consistent format, carefully checked for errors, and corrected. Along with the sort of identifying data we received, data on the type of aircraft and on visibility conditions should be included since the density estimation procedure may need to adjust for these factors. Field survey techniques (number of observers, flight lines, data recording techniques, etc.) should duplicate those used on previous lagoon surveys (Troy et al. 1983).

Statistical analyses will likely need to be based on log densities or ranks (where the lowest of n densities has rank 1 and the highest, rank n, with the others in between) because of the nature of the variability in the survey results. Correlation analysis, analysis of variance, and related techniques should be used to determine which transects show the most consistent year-to-year patterns in the absence of environmental disturbance. The approaches discussed in previous sections may be helpful in determining the best transects to use for monitoring and what levels of change could be detected.

If H_o1 as restated above is rejected, this would imply that the relative densities of molting male oldsquaw have changed. However, unless a specific significant oil- and gas-related activity were known or could be determined to be affecting areas with reduced oldsquaw density, there would be no reason to implicate OCS activity as the cause of the decline. Even if some OCS activity occurred during times and places of reduced relative densities, the cause and effect relationship would only be circumstantial (except in the instance where known mortality resulted from a major oil spill).

5.3.6 Common Eider Nesting

Restated Hypotheses:

H_o1 There will be no change in density or hatching success of common eiders on islands subjected to disturbance by OCS oil and gas development activity.

H_o2 Changes in density or hatching success of eiders on islands are not related to OCS oil and gas development activity.

Detailed descriptions of the Thetis Island study of effects of disturbance on nesting common eiders were not available. When available, techniques used in that study should be reviewed for general applicability to other such studies elsewhere in the Beaufort Sea. As indicated in Section 3.7.4, we do not believe that this approach is appropriate for the regionwide monitoring program, primarily because of the limited number and distribution of important breeding islands and the apparently limited sphere of disturbance of OCS activities. As in the Thetis Island case, monitoring should be imposed when specific development activities encroach upon breeding sites if there is reason to suspect that stipulations and restrictions on the permitted activities may not fully protect the nesting colony.

If H_o1 as stated above is rejected, this would imply that density or hatching success of eiders on the island subjected to disturbance by oil and gas activity has changed (declined) relative to success on control islands not subjected to disturbance. In this case, the oil and gas activity is strongly (although circumstantially) implicated as the cause of the decline. Testing of H_o2 would probably not be necessary to elicit a management decision to protect eider nesting in the future.

5.3.7 Kelp Community Structure in the Boulder Patch

Related Hypotheses:

H_o1 There will be no change in productivity of *Laminaria solidungula* in areas of the Boulder Patch nearest nearest OCS oil and gas development activity.

H_o2 Changes in *Laminaria solidungula* productivity in the Boulder Patch are not related to OCS oil and gas development activity.

As a simple measure of change in the Boulder Patch, the recommendation in the concluding session of the workshop was to monitor annual productivity of *Laminaria* whenever OCS development activities that might affect it were going on in the vicinity of the Boulder Patch. We concur with this approach for this hypothesis. However, as indicated in Section 3.7.4, we do not believe that this hypothesis is appropriate for the region-wide monitoring program, primarily because of the apparently limited distribution of boulder patches in the Beaufort Sea.

The analysis of kelp growth data in Section 4.2.7, although based on too little data to be conclusive, is encouraging. Our recommendation is to measure linear blade growth using the techniques of Dunton et al. (1982) once a year, preferably in late fall, on 20 or more *Laminaria solidungula*.

Since measurements should be made only in response to some site-specific activity, it would be advisable to measure plants at various "distances" from the activity site, where "distance" may be a measure that takes into account such factors as current direction as well as actual physical distance. "Distance" should be recorded for each measurement, since appropriate statistical analyses (which will probably not be the simple analysis of variance discussed in Section 4.2.7) will likely involve this "distance." Eight to 10 stations distributed amongst the four major subareas of the Boulder Patch (see Dunton et al. 1982, Figure 3) should be sufficient to document established within-patch variability and to monitor the health of the entire patch as well as detect changes in discrete locations within the patch. Similar effort should be directed at any other boulder patches subsequently discovered that support comparable biota and which are subjected to site specific OCS activities.

Physical measurements will be needed to support the analyses of the kelp data including measurements of ice transparency at each station and currents.

If H_o1 as stated above is rejected, this would strongly imply that kelp productivity in areas of the Boulder Patch nearest oil and gas development activity is reduced, in comparison with productivity in areas removed from such activity. In this case the oil and gas activity is strongly (although circumstantially) implicated as the cause of the reduced productivity. Testing of H_o2 would probably not be necessary to elicit a management decision to protect the Boulder Patch from future activities of the nature implicated.

5.4 NEED FOR A BEAUFORT SEA MONITORING DATA BASE

Our statistical evaluations of variables, described in Chapter 4, were handicapped in many cases by inaccessibility of existing data, including, in some cases, data sets collected under contract to NOAA. This sort of data inaccessibility, if allowed to continue under the BSMP, could clearly hamper attempts to determine and quantify changes which the program is designed to monitor.

NOAA contracts which involve data collection generally require timely submission of data in a specified National Oceanographic Data Center (NODC) format. This is a first step in providing an accessible data base, but it is not enough. There are several problems with this approach:

- Submitted data often contain serious errors (see Zeh et al. 1981, for examples) that are never corrected.
- NODC formats generally specify that identifying information for samples (station, latitude and longitude, date and time, etc.) appear on one or more types of record while measurements on the variables of interest (concentration of hydrocarbons or metals, counts of taxa, etc.) appear on one or more other record types. Most statistical analysis programs accept data on a sample-by-sample basis, with identifying information as well as measurements in the same record.
- The NODC scheme was no doubt designed to save storage space on disks and tapes by avoiding redundancy. However, in practice, this lack of redundancy leads to errors (misidentified measurements) and even greater redundancy than was originally contemplated since new files arranged on a sample-by-sample basis must be created by investigators each time they wish to conduct statistical analyses.
- Investigators often do not know how to obtain subsets of previously collected data relevant to their interests from NODC.
- Data often are not available in a timely manner from NODC data bases. For example, we were able to obtain oldsquaw data collected between 1976 and 1978 for the analyses of Section 4, but none of the more recent data.

To improve data accessibility in the BSMP, we recommend that funding be provided to establish and maintain a computerized Beaufort 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 (NOAA, MMS, EPA, etc.) in the various Beaufort Sea research and monitoring efforts. Industry could also be urged to provide their extensive monitoring results in compatible formats for inclusion in the data base. The data manager should be responsible for maintaining an index of all Beaufort Sea monitoring data, whether or not it is physically contained in the data base. Thus, investigators needing Beaufort Sea monitoring data need only contact a single person to obtain data directly or at least to find out what data are available and where they might be obtained. As discussed in Section 3.7.3.3 it is imperative that the data management program be fully functional before field data collection efforts begin.

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

- In consultation with funding agencies and investigators, determining formats for submitting data sets to the data base. NODC formats may be appropriate in many cases.
- Obtaining data from investigators in a timely manner.
- Developing data checking programs or using existing ones to ensure that data submitted are free of illegal or inappropriate codes (for example, taxonomic codes or codes indicating sampling gear); unreasonable sampling dates, latitudes, and longitudes; impossible values for measurements, etc. 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 NODC data verification projects.
- Developing programs which allow easy selection and reformatting of data into files appropriate for statistical analysis. This would be necessary if the formats used for submitting the data, such as NODC formats, required accessing several types of records to obtain identifying information and measurements associated with a single sample. In some cases, this may require considerable processing of the raw data, for example to determine area surveyed from aerial survey transect data.
- Providing data on magnetic tape in industry-standard formats or by direct transmission over phone lines between computers in response to authorized requests for data. If costs are associated with this service, being prepared to give cost estimates for fulfilling particular requests.

The last two functions of the data manager on the above list were well fulfilled in response to our requests for some of the data needed for the statistical evaluations in this report by Johnson and his coworkers at the Laboratory for the Study of Information Science at URI. However, because their mandate did not cover all Beaufort Sea monitoring data and did not in general include the first three responsibilities mentioned above, they were not able to fill all our data needs or resolve inconsistencies that we discovered in data received from them.

The BSMP can build on the work of the URI group to establish a comprehensive and well managed data base useful to both scientists and decision makers.

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APPENDIX B
DETAILED STATISTICAL APPROACH TO SEDIMENT CHEMISTRY MONITORING

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1.0 GENERAL CONSIDERATIONS

Detecting changes in key sediment chemical parameters due to OCS oil and gas development in the Beaufort Sea is the specified purpose of the proposed network. This suggests testing the hypothesis of no change against some natural alternative. A general approach to the design of such a network is provided in Section 2 of this appendix. A key feature is the incorporation of the uncertainty about where such an impact might occur.

This objective seems unduly restrictive. The data provided by this network will be used for many purposes both seen and unforeseen by environmental managers, biologists, and so on. For instance, certain impacts of future concern may not yet have been identified, or other inferences about average change over the region, total change, or maximum change may be called for. Contour maps may well be drawn. The network might informally be regarded as an information gathering device.

Each of the many conceivable objectives of the network would ideally require a different design. The problem of simultaneously accommodating them in a single design is a familiar one. A solution to this problem is given by Caselton and Zidek (1983) and it is implemented in Section 3 of this appendix.

Beyond the question of an objective is that of a criterion by which to measure the efficacy of any proposed design. For testing, the conventional criterion is the power of the test, i.e. the probability with which an impact of specified size would be detected. This criterion is adopted in Section 2.

In the absence of a uniquely defined objective, Caselton and Zidek (1983) adopt an information transmission criterion. A particular set of "gauged" sites is "good" if it provides, in a sense made precise in Section 3, a lot of information about the ungauged sites.

The paucity of data about spatial covariation (between sites) and temporal covariation (between times) for most parameters to be monitored requires the use of an approach which relies heavily upon intuition, qualitative experience, and accumulated knowledge. This information is incorporated in the design of applicable models in Sections 2 and 3. These models are the simplest of those with descriptive value. More complicated models would be hard to fit and mathematically intractable; in short, unable to shed much light on the design problem.

The resulting design will be somewhat sensitive to the choice of model so that common sense is called for in implementing the design, and the design will change in time with the increasing data base, level of understanding, objectives, adopted criteria and so on. We suppose initially that only two measurements, before and after the commencement of development, are taken. And at any future stage of development the network in place has the minimal purpose of providing the data on which it might be amended.

2.0 DESIGNS FOR TESTING

A design, D, is a set of labels designating the sampling sites. The region of interest is overlain with an imaginary grid of sites from which D is to be chosen. The fineness of this grid is its degree of resolution. This is determined by practical and economic considerations such as the accuracy of navigational equipment. Each site is identified by latitude and longitude coordinates.

"Impact" may be thought of, *a priori*, as a random field, Z, overlaying the whole area. At site i, Z_i is the size of the change due to development and other, uncontrolled effects. Only Z_i's with i in D will, in fact, be measured (with error) once D is specified.

The likely success of the design will depend on what is assumed about Z. If Z_i is large for all i, any D will detect this change. At the other extreme a large point impact with $Z_i \cong 0$ for all but a few i's will be hard to detect. For if P_D is the probability that D includes the sites where $Z_i > 0$, the power of the test is about $P_D + (1-P_D)(0.05)$ for a test at level 5 percent. To insure an overall power of, say, 0.80 would require that $P_D = 0.79$. That is, something like 79 percent of all possible sites would have to be gauged to guarantee satisfactory performance.

We address a case between these extremes. Suppose K replicate measurements of Z_i are taken at each gauged site i in D. Their variability is assumed constant over i and indicates the precision of the process of measurement. Changes will be measured against this variance. Measurements taken on successive occasions will also include a component of temporal variability. The lack of data makes time series modeling impossible. Two strategies are adopted to reduce the impact of time effects which, if ignored, would obscure changes due to development alone. These are suggested by Green (1979). First, measurements at each site in D are made on just two occasions which closely bracket the start of development (drilling, for example, at a particular site). Second, sites outside areas of likely impact are admitted as possible quasi-controls. These do increase the power of the test even though they are not controls, strictly speaking.

Again, following Green (1979), we take as the null hypothesis, the assumption of no time × space interactions. Since there are only two times this is, equivalently, the hypothesis that the difference in before and after site means is constant over sites.

Let us suppose the measurement data, transformed if necessary, admit the usual assumptions underlying the two-way, fixed effects ANOVA. The power of the F-test has the noncentrality parameter $\delta^2 = K \sum_{i \text{ in } D} (Z_i - \overline{Z}_D)^2 / (2\sigma^2)$ where $\overline{Z}_D = \sum_{i \text{ in } D} Z_i / I$ with I the number of elements in D and σ^2 the sampling variance. To maximize the power of this test we will seek the D which maximizes δ^2 and confine ourselves to a special case which admits an explicit solution.

Suppose the region may be partitioned into k blocks or zones and that the impact is confined to one of these blocks, say i, with probability $p_i \geqq 0$, $\sum_{i=1}^{k} p_i = 1$. Furthermore, the impact is uniform over the block in which it occurs, adding a constant amount, say Δ, to each of the sites in this block. The random impact field so obtained would seem to describe to a first approximation both impacts due to catastrophes and those subregional, pervasive changes due to site development even when the locations of these sites remain to be fixed and hence uncertain. For convenience relabel the zones, if necessary, so that $p_1 \leqq \cdots \leqq p_k$.

Let $S = S_D = \sum_{i \text{ in } D} (Z_i - \overline{Z}_D)^2$ so that $\delta^2 = KS/(2\sigma^2)$. Suppose D gauges n_j sites in block j. If the impact were to occur in zone j, $\overline{Z}_D = [(I - n_j)0 + n_j \Delta]/I = f_j \Delta$ where $f_j = n_j / I$, the sampling fraction in block j. And

$$S_D = (I-n_j)(0-\overline{Z}_D)^2+n_j(\Delta-\overline{Z}_D)^2 = I\Delta^2 f_j(1-f_j).$$

So the expected value of S_D is $I\Delta^2\sum p_j f_j(1-f_j) = \tau$, say, and this must be maximized to obtain the optimal sampling fractions, subject to $0 \leqq f_j \leqq 1$, $\sum f_j = 1$.

By an involved argument which is omitted for the sake of brevity it can be shown that the optimal sampling fractions, f_j^0 say, $j=1,...,k$ are:

$$f_j^0 = 0, \; j=1,...,m$$
$$= (1-\lambda/p_j)/2, \; j=m+1,...,k$$

where $\lambda=\lambda_m = (k-m-2)/\sum_{j=m+1} p_j^{-1}$ and m is either 0 or the solution of $p_m \leqq \lambda_m < p_{m+1}$ if it exists. If the solution exists, it is unique.

For these optimal sampling fractions $\tau = I\Delta^2\zeta^2$ where $\zeta^2 = \sum_{j=m+1}^{k} p_j - \lambda^2 \sum_{j=m+1}^{k} p_j^{-1}$. The expected value of the noncentrality parameter under this scheme is $KI\Delta^2\zeta^2/(2\sigma^2)$. The effect of adding replicates is, under this scheme, the same as adding stations, and this depends on the size of $\zeta > 0$.

The limiting factor in the choice of I and K, the number of monitoring stations and replicates, respectively, is likely to be economic. It is of some interest then to see what sort of impacts the testing procedure will detect for given values of I and K. These are given in the following table as amended impact effect to sampling error ratios, $\zeta|\Delta|/(\sqrt{2}\sigma)$, when the size and power of the test are 0.05 and 0.80, respectively.

TABLE 1. The values of $\zeta|\Delta|/(\sqrt{2}\sigma)$ which yield $\alpha = 0.05$ and $1-\beta = 0.80$ for various I and K.

$K \backslash I$	10	36	50	100	200	500
2	1.08	0.69	0.63	0.50	0.42	0.36
3	0.79	0.52	0.47	0.37	0.35	0.28
4	0.67	0.42	0.37	0.33	0.30	0.24
5	0.59	0.37	0.33	0.28	0.26	0.22

Finding the optimal number, m, of null sampling fractions is easily shown to be equivalent to finding the largest m for which $L_{m+1} < 0 \leqq L_m$ where $L_m = (k-m-2)p_m^{-1} - p_{m+1}^{-1} - \cdots - p_k^{-1}$, if such an m exists. Otherwise, $m = 0$. Observe that, of necessity, $m \leqq k-3$ if $k \geqq 3$ and $m = 0$ if $k < 3$.

Example 2.1. Here $k=5$ and the p_j's are .1, .1, .1, .3, and .4. Since $L_5<0$, $L_4<0$, and $L_3<0$ in any case with $k=5$, our search for m can begin with $m=2$ when we consider $L_m = L_2 = p_2^{-1} - p_3^{-1} - \cdots - p_5^{-1} = -5.83$. Since $L_1 = L_2 < 0$ also, we must take $m=0$, and $\lambda = (5-0-2)/(p_1^{-1} + \cdots + p_5^{-1}) = 0.0836$. The optimal sampling fractions are $f_1^0 = f_2^0 = f_3^0 = (1-\lambda/.1)/2 = 0.08$, $f_4^0 = 0.36$ and $f_5^0 = 0.40$. For this design $\zeta^2 = 1-(0.0836)^2\sum p_i^{-1} = 0.996$. The detectable impacts Δ would in this case be obtained by multiplying the values of Table 1 by approximately $\sqrt{2}\sigma$ where σ is the sampling (replicate) standard deviation at a site.

Example 2.2. Let $k=9$ and the p_i's be 0.05, 0.05, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.3. Here $L_3<0$ but $L_2>0$ so $m=2$, $\lambda=0.07895$, $\zeta^2=0.605$, and the optimal sampling fractions are $f_1^0 = f_2^0 = 0$, $f_3^0 = f_4^0 = f_5^0 = f_6^0 = f_7^0 = f_8^0 = 0.105$, and $f_9^0 = 0.37$. Thus the impact values are obtained from Table 1 by multiplying by $\sqrt{2}\sigma/\zeta$ where $\zeta=0.778$.

3.0 INFORMATION NETWORKS

The future benefits that may be derived from a network cannot all be specified in advance. Even the specifiable objectives will be various and call for somewhat different designs from case-to-case. Caselton and Zidek (1983) circumvent these difficulties by an approach which may be suboptimal in specific cases but which would seem, overall, to be quite sensible. Their design maximizes, in a sense which will now be made precise, the amount of information which can be generated.

Let Z denote that random field of measurable quantities indexed by site labels, i. In general, Z_i would be a multidimensional array. For example, it might be a matrix whose columns correspond to times and rows correspond to measurable attributes, such as chromium, all of which would be measured on each sampling occasion. A third dimension might correspond to replication.

As in Section 2, the design D consists of a subset of site-labels, the "gauged" sites. The remainder are ungauged sites. Decompose Z as $Z(U,G)$ where G stands for gauged, U for ungauged.

There is *a priori* uncertainty about Z which we assume is expressible in terms of probabilities. Uncertainty about G is resolved by the process of sampling. And uncertainty about U is reduced by the same process. The degree of this reduction depends on the degree to which U and G are related. An optimal choice of G will maximize the amount of "information" in G about U.

To formalize this let $Inf = I(U,G) = [-E \log p_0(U)] - [-E \log p(U \mid G)]$, the reduction in the entropy of U resulting from observing G, averaged over G. Equivalently, $Inf = E \log[p(U \mid G)/p_0(U)]$, Shannon's index of information transmission. This can be rescaled as $Inf \to A\, Inf$ where A is the utility per unit of information or monetary value per unit of information, for example. The dependence of Inf on D can be made explicit by writing $U = U(D)$ and $G = G(D)$. The optimal D maximizes $I(U(D),G(D))$.

To achieve a usable version of this result, suppose the data are transformed, if necessary, to a form given by a multivariate normal distribution. Then $I(U,G) = -\frac{1}{2}\log |I-R|$ where $R = Diag\{\rho_1^2, \ldots, \rho_f^2\}$ and $\rho_1 \geqq \cdots \geqq \rho_m$ are the canonical correlation coefficients between U and G.

This leads to the very natural conclusion that the optimal design maximizes the canonical correlations between gauged and ungauged sites. Unfortunately, to implement this result would require a great deal of preliminary data from which to estimate the multivariate normal's covariance matrix. This forces us to look for an even simpler, but plausible model.

First, let us restrict our analysis to the univariate case to bypass the problem of determining the complete attribute-by-space covariance structure. This restriction will be justified if the optimal designs are insensitive to the choice of attribute.

Next, adopt a components of variance model. All sites include a random overall component W. Then all sites in block j share a second random component B^j, $j=1,\ldots,k$. At the next level is a site-specific component; S^i, $i=1,\ldots,m$. Finally, at the gauged sites there is a component for sampling error which would be negligible under replicated sampling. Assume all of these components are independent.

The covariance matrix for the resulting model would have a block structure. Off-diagonal blocks would all be $\sigma_W^2 J_r$, where J_r is a square matrix of 1's and r is an appropriate dimension. The diagonal block corresponding to block j would have off-diagonal elements $\sigma_W^2 + \sigma_j^2$, where $\sigma_j^2 = Var(B_j)$, $j=1,\ldots,k$; its diagonal elements for site i would be $\sigma_W^2 + \sigma_j^2 + \sigma_i^2$ if it is ungauged where $\sigma_i^2 = Var(S^i)$, $i=1,\ldots,m$. If the site were gauged an additional term, σ^2, corresponding to sampling error would have to be added.

It is easy to think of intuitively more realistic components of variance models, but only at the expense of adding to the supply of parameters to be fitted. It's not clear that any gain in the realism of the model would not be offset by losses incurred from choosing with error the additional parameters.

The optimal design would in principle be found by computing Inf for every choice of D, with the size of D fixed. In practice such a computation would be impossible. Even when $I=40$ and $m=200$ potential sites, there are 2.05×10^{42} possible choices for D.

Once D has been specified for each I, the information transmission curve, Inf as a function of I can be explored. If the per-unit value of information can be quantified, for example, in dollars, and sampling costs are known, this curve will yield an optimal I. Even in the absence of such a scaling the curve is nevertheless quite useful. When I is small it will be seen that the addition of an additional station contributes a large percentage gain in the amount of information transmitted. However, long before the total number of stations is reached the percentage gained by adding a station becomes negligible. Thus a practical upper limit to the size of D is perceived.

To gain some insight into the operation of this methodology, assume the block effects are zero. Then $U^i = W + S^i$ and $G^i = W + S^i + E^i$. Here E^i represents sampling error. The S's are the random site effects. These encompass variation due to varying depths, surface sediment textures, and so on. The last component W is the global change component due to development. All these variables are assumed to be independent of one another.

The within ungauged sites covariance matrix, $\sum_U$, is easily shown to be $\sum_U = \sigma_W^2 j_{m-n} j_{m-n}^T + d_0$ where $d_0 = Diag\{\sigma_1^2, \ldots, \sigma_{m-I}^2\}$ and m is the total number of sites, j_r in general denotes the column r-vector all of whose elements are 1, σ_W^2 and σ_i^2 are respectively the variances of W and S^i. A similar calculation gives $\sum_G = \sigma_W^2 j_n j_n^T + d$ where $d = Diag\{\sigma^2 + \sigma_{m-n+1}^2, \ldots, \sigma^2 + \sigma_m^2\}$ where σ^2 is the common variance of the E^i. Finally, the covariance between gauged and ungauged sites is given by $\sum_{UG} = \sigma_W^2 j_{m-n} j_n^T$.

To compute the canonical correlations we need $\sum_G^{-1}$ and $\sum_U^{-1}$. These cannot be explicitly evaluated in general. However, they are easily approximated in the case where the "signal to noise" ratios, $\sigma_W^2/(\sigma_i^2 + \sigma^2)$, σ_W^2/σ_i^2 are small for all i, a conservative assumption. Then $\sum_G^{-1} \approx d^{-1} - \sigma_W^2 d^{-1} j_n j_n^T d^{-1}$ so that

$$\sum_{UG} \sum_G^{-1} \sum_{GU} \approx \sigma_W^4 tr(d^{-1})[1 - \sigma_W^2 tr(d^{-1})] j_{m-n} j_{m-n}^T$$

Also $\sum_U^{-1} \approx d_0^{-1} - \sigma_W^2 d_0^{-1} j_{m-n} j_{m-n}^T d_0^{-1}$. The canonical correlations are the positive eigenvalues of

$$\sum_U^{-1} \sum_{UG} \sum_G^{-1} \sum_{GU} \approx K d_0^{-1} j_{m-n} j_{m-n}^T$$

where $K = \sigma_W^4[1 - \sigma_W^2 tr(d^{-1})] tr(d^{-1})[1 - \sigma_W^2 tr(d_0^{-1})]$. There is only one such eigenvalue, $f_U(1-f_U) \cdot f_G(1-f_G) = \lambda$, say, where $f_U = \sigma_W^2 tr(d_0^{-1})$ and $f_G = \sigma_W^2 tr(d^{-1})$.

To interpret this result, let s_i denote the "signal to noise ratio" at site i so $s_i = \sigma_W^2/\sigma_i^2$ and $\sigma_W^2/(\sigma_i^2 + \sigma^2)$, respectively, at ungauged and gauged sites. Then $f_U = \sum_{i \text{ not in } D} s_i$ and $f_G = \sum_{i \text{ in } D} s_i$. Consequently,

$$\lambda = \Big(\sum_{i \text{ not in } D} s_i\Big)\Big(1 - \sum_{i \text{ not in } D} s_i\Big)\Big(\sum_{i \text{ in } D} s_i\Big)\Big(1 - \sum_{i \text{ in } D} s_i\Big).$$

This is approximately, if the s_i's are small, $\lambda \approx \Big(\sum_{i \text{ not in } D} s_i\Big)\Big(\sum_{i \text{ in } D} s_i\Big)$. It follows since $I = \log(1-\lambda)^{-\frac{1}{2}}$ in this case, that D should be chosen to maximize λ.

This suggests that σ^2, the component of variance due to measurement error, should be reduced by averaging sufficiently many replicate samples at each site.

Otherwise, $\sum_{i \text{ in } D} s_i$ will be small for all D.

Next, sites judged *a priori* to have small σ_i^2's, i.e. components of site-variance, should be identified and these should be allocated to D and its complement in a balanced way. This poses the following programming problem: Given numbers $a_1 \leq \cdots \leq a_R$, how should these be partitioned into sets E and F in order to maximize the product $(\sum_E a_j)(\sum_F a_j)$. One algorithm for doing this is suggested by the following argument. Suppose at some stage $\sum_E a_j = (x+A)$ and $\sum_F a_j = (y+B)$. It is worthwhile interchanging x and y if and only if $(x+A)(y+B) - (y+a)(x+B) = (x-y)(B-A) < 0$, i.e. if and only if $x<y$, $A<B$ or $x>y$, $A>B$. This observation can be applied sequentially to reach an optimum. Consider, for example, the sequence 1, 2, 3, 4, 5, which is to be partitioned optimally into sets of size 2 and 3. The sequence of steps is as follows, with "NC" denoting "no change":

(1) Initial partition: (1, 2, 3) (4, 5)
(2) ($1<4$, $2+3=5$): NC
(3) ($1<5$, $2+3>4$): NC
(4) ($2<5$, $2+3<5$): change to (1, 4, 3) (2, 5)

The process has converged at step (4) although six steps like (2) and (3) are required to establish this.

Given I, the number of sites in D, a rough preliminary design can be found by assigning on intuitive or empirical grounds values to the signal to noise ratios, $\{s_i\}$, and then partitioning the sites according to the algorithm given above, if these s_i's are assumed small.

The effect of varying I is seen by considering the homogeneous case where $\sigma_i^2 = \sigma_S^2$ for all i. Then $\sum_U = \sigma_W^2 j_{m-n} j_{m-n}^T + \sigma_S^2 I_{m-n}$ and $\sum_G = \sigma_W^2 j_n j_n^T + (\sigma_S^2 + \sigma^2) I_n$. It follows that $\sum_U^{-1} \sum_{UG} \sum_G^{-1} \sum_{GU} = I \mu\nu j_{m-n} j_{m-n}^T$ where $\mu = \sigma_W^2(\sigma_S^2 + \sigma^2 + I\sigma_W^2)^{-1}$ and $\nu = \sigma_W^2(\sigma_S^2 + (m-I)\sigma_W^2)^{-1}$. The only non-zero eigenvalue of this matrix is $\lambda = I(m-I)\mu\nu$, and so $Inf = -\frac{1}{2}\log|1-\lambda|$.

A few values of Inf are give in Table 2 below. In every case s_U, the signal-to-noise ratio for ungauged sites is 0.05.

An examination of Table 2 shows how this information-based methodology works. When a station is added to D, uncertainty about S^i (ignoring sampling error) is removed from that of the uncertain field. Beyond this it becomes a transmitter of information about the remaining ungauged sites. So there is a considerable total gain from adding a new station to D when D is small. As D increases the amount of uncertainty decreases. In all cases the gain in transmission by increasing D is eventually offset by the reduction in the number of receiving stations and on balance Inf begins to decline.

Well before this stage is reached, a point will be found where the reduction in uncertainty is negligible. This yields a practical limit for I, the size of D. Suppose, for example, m=500. Then if $s_U = 0.05$ and $s_G = 0.04$, going from $I = 15$ to 16 produces only a one percent improvement. On the other hand, if $s_U = 1$ and $s_G = 0.6$, I reaches 25 before information increments as small as one percent are reached.

TABLE 2. Information transmitted about ungauged sites in gauged sites for varying numbers of sites (m), design sizes (I), and the signal-to-noise ratio s_G for gauged sites.

m	s_G	I	Inf
50	0.025	5	0.0543
		10	0.1068
		25	0.2379
		30	0.2749
	0.05	5	0.0543
		10	0.1068
		25	0.2379
		30	0.2749
100	0.025	10	0.1091
		20	0.2003
		50	0.4030
		60	0.4557
	0.05	10	0.1979
		20	0.3416
		50	0.6214
		60	0.6882
500	0.025	50	0.4050
		100	0.6259
		250	0.9900
		300	1.0695
	0.050	50	1.6192
		100	1.9560
		250	2.4002
		300	2.4987

4.0 APPLICATIONS

In consultation with others involved in the Beaufort monitoring program, the block map given in Fig. B-1 was constructed. It is based on NOAA's nautical chart 16003. The blocks (subregions) are thought to be homogeneous with respect to risk and other factors relevant to the monitoring program. All horizontal boundaries lie along lines of latitude which are five minutes (of a degree of latitude) apart. The vertical boundaries lie along lines which are separated by the same distance.

4.1 A Design for Testing

To apply the theory of Section 2 these 17 primary blocks may be combined in various ways to represent different kinds of subregional but pervasive impacts. Blocks 3, 9 and 15, say, B3, B9 and B15 are very high risk areas because of expected locations of high development activity and the prevalent east to west currents. B4, B11 and B16 are next in order of riskiness, say "high" for short. Then come B2, B5, B7, B10, B13, B14, say "medium" while B1, B6, B8, B12 and B17 are "low".

One fairly natural recombination and reordering from highest to lowest risk would make subregions 3, 9, and 15 into a new block, b8. Then (B4, B11, B16) → b7, B2 → b6, (B5, B7) → b5, (B10, B13, B14) → b4, B1 → b3, (B6, B8) → b2 and finally (B12, B17) → b1. Other combinations are obviously possible. We have not systematically explored all these possibilities.

To assign riskiness probabilities, observe that b8 is the very high risk zone, b7 is high, b4, b5 and b6 are medium and b1, b2, b3 are low. Recall that we are assuming for the purpose of design a conservative, but by no means worst case, scenario where development impacts on one only of these blocks.

Choosing b8 as a reference, reasonable relative odds for b7, (b6, b5, b4), and (b3, b2, b1) are 4:5, 2:5 and 1:20. This translates readily into probability 20/41 for b8, 16/41 for b7, 4/41 for (b6, b5, b4) combined and 1/41 for (b3, b2, b1) combined. If we assume equality of probability for b4, b5, and b6 and also for b1, b2, and b3 we obtain (with rounding) the following probabilities expressed as percentages:

Combined block:	b1	b2	b3	b4	b5	b6	b7	b8
Impact probability:	1	1	1	4	4	4	38	47

According to the theory of Section 2 of this appendix, $\lambda = 0.028$, $m=3$, the optimal sampling fractions are $0 = f_1^0 = f_2^0 = f_3^0$ while $f_4^0 = f_5^0 = f_6^0 = 0.03$, $f_7^0 = 0.45$ and $f_8^0 = 0.46$. With these optimal sampling fractions Table 1 of Section 2 obtains.

Little is gained in anticipated testing power by taking more than 50 stations and 3 replicates per station. Then $\alpha = 0.05$, $1-\beta = 0.80$, and $\zeta\Delta/(\sqrt{2}\sigma) = 0.47$ is the detectable, pervasive before and after difference. Using 4 replicates at 36 stations is preferable to 3 replicates at 50 stations, according to this table; then $\zeta\Delta/(\sqrt{2}\sigma) = 0.42$.

The above analysis suggests the following conclusions:

- four replicates at each of 36 stations
- 17 stations should be chosen at random from the potential locations available in subregions 3, 9, and 15 of Figure 1.
- 16 stations should be similarly chosen in blocks 4, 11, and 16 of Figure 1.
- one station should be placed at random in subregion 2, one more in 5 or 7, and the remaining one in 10, 13, or 14.
- since ζ=0.93, the detectable subregional change with the design is Δ/σ=0.64, i.e. a change Δ 0.64 times the replication (sampling) error.

In choosing station locations the sites of Shaw (1981) and Kaplan and Venkatesan (1981), which are indicated in Figure 1, might well be included in the randomization scheme.

4.2 Designs for Information Transmission

The components of variation approach in Section 3 of this appendix is proposed. In specifying this model, available baseline data may be taken into consideration.

Assume the random field Z, of measurable quantities consists of the differences at station i, $i=1,\ldots,m$, between before and after measurements, $Z_i = Y_i^A - Y_i^B$, say. Suppose that $Y_i^A = g_j Y_i^B$ for all i in block j, say $i \in j$. Then $Z_i = (g_j - 1)Y_i^B$.

To decompose Z_i into its components of variability, write

$$Z_i = (\delta_i - \overline{\mu_j}) + (\overline{\mu_j} - \overline{\mu}) + \overline{\mu} = s_i + b_j + \mu \quad \text{where } i \in j \ ,$$

$\overline{\mu_j}$ represents the block mean and μ the mean of the region. We regard $\overline{\mu_j}$ as $\sum_{i \in j} Z_i / m_j$ where m_j = number of hypothetical stations in block j and $\overline{\mu}$ as $\sum_j \sum_{i \in j} Z_i / m$ where m = total number of stations. Thus $s_i = Z_i - \sum_{i' \in j} Z_{i'} / m_j = (g_j - 1)(Y_i^B - \overline{Y_j^B})$, $b_j = (g_j - 1)Y_j^B - \sum_{j'} (g_j - 1)\gamma_{j'} \overline{Y_{j'}^B} / m$ and $\mu = \sum_{j'} (g_{j'} - 1)\gamma_{j'} \overline{Y_{j'}^B} / m$, where $\overline{Y_j^B} = \sum_{i \in j} Y_i^B / m_j$ and $\gamma_j = m_j / m$.

The Y_i^B's will be regarded as fixed by the baseline data contours of Naidu et al. (1981b), for chromium, nickel, iron, vanadium, copper, zinc, manganese, and cobalt. Not all of these are of interest but are nevertheless included. Each of these will yield a possibly different optimal design and their inclusion gives an indication of the sensitivity of the method. Not all quantities of interest are in this list because suitable baseline data could not be located.

The $\overline{Y_j^B}$'s can be inferred from the contour maps of Naidu et al (1981). The number of stations, m_j, is obtained from Figure 1 by counting the O's in each of the 17 blocks. The O's on boundaries are on the north and west boundaries of the blocks to which they belong. The number of stations in a block is roughly proportional to the area of the block since stations were placed at equally spaced grid points except when finer spacing was required to define block boundaries. The m_j's are given in Table 3, along with the block areas and means $\overline{Y_j^B}$.

Only the $Var\ (s_i)$'s, $Var\ (b_j)$'s, and $Var\ (\mu)$ are required. The limited amount of baseline data suggests the simplifying assumption that $Var\ (g_j - 1)$ is constant over j. This constant is irrelevant since the expression for canonical correlations is homogeneous. The required results are then just: $Var\ (s_i) \propto (Y_i^B - \overline{Y_j^B})^2$, $Var\ (b_j) \propto (\overline{Y_j^B})^2\ (1 - 2\,\gamma_j) + Var\ (\mu)$ and $Var\ (\mu) \propto \sum_{j'} \gamma_{j'}^2\ (\overline{Y_{j'}^B})^2$.

The $Var\ (b_j)$'s and $Var\ (\mu) = \sigma_\mu^2$ are given in Table 4. Evaluating $Var\ (s_i)$ is more difficult. They might be taken to be proportional to the within-block variance were the latter available. Since it is not, indirect estimates are found.

From data supplied on tape by URI, discussed in Section 4.2.1, for Simpson Lagoon, the coefficient of site variation within that block could readily be estimated. This value was then assumed for the 17 blocks in our study.

These coefficients for the Simpson Lagoon are estimated in the obvious way. For the small samples of copper, nickel, chromium and cobalt (n about 10 in each case), one value was trimmed from either extreme before computing the estimates. For the larger samples (n about 30) of iron, manganese, zinc and phosphorous, two such values were trimmed from either extreme. The resulting coefficients of variation were: chromium–0.22, nickel–0.20, iron–0.37, vanadium–1.29, copper–0.22, zinc–0.61, manganese–0.5285, and cobalt–0.25.

Given the dubiousness of the assumption of the constancy of the coefficient of variation over blocks, it is not a large additional step to the assumption of a constant site component of variance as well. This plus the component of sampling variance in the Simpson Lagoon study, $\sigma_{sites}^2 + \sigma^2$ say, can then be estimated by $\sigma_{sites}^2 + \sigma^2 =$ (metal mean × coefficient of variance)^2. Finally, σ^2 was taken somewhat conservatively to be $\frac{1}{2}$ of the latter value. The resulting values for $\sigma_{sites}^2 = \sigma^2$ appear in Table 4.

The blocks to be sampled or resampled are chosen sequentially, one at a time, in descending order of importance. Because of the lengthy computing times involved, our analysis confines itself to finding an optimal design for monitoring chromium deposition. Given that a design has already been derived in the last section by other means, this restriction does not seem unreasonable. We look to these results for guidance in implementing the earlier design. Our goal, then, is to modulate the earlier design in the light of the results obtained here.

The obtained block sampling sequence in order of importance is:

5	6	17	12	2	3	14	1	13	16
8	15	4	7	10	11	9	1	6	8
17	12	5	4	2	3	10	7	11	1
6	8	17	14	12	5	4			

Calculations were terminated after these 37 choices since the incremental increases in the size of *Inf* were under 1 percent at this point.

The allocation implied by this method is roughly proportional to area since the blocks are somewhat similar in terms of their cross correlations.

4.3 Recommended Sampling Strategy

In our view the strategy in Section 4.1 of this appendix is the more appropriate in the present context because the risks of impact in the various subregions may be reasonably well assessed. The strategy suggested by the results of Section 4.2 should, however, not be ignored. It is more robust, that is, less sensitive to potential errors in the evaluation of risk. So as an overall strategy we would advocate that additional stations be added to the first design to accommodate the needs of the second according to budgetary limitations. Thus in Table 5 we give the minimum and maximum values for each subregion. Choosing the minima will give the allocation of Section 4.1 while the maxima will give the direct combination of the allocations of 4.1 and 4.2. At least 4 replications per station would be required.

TABLE 3. Block means for various rescaled quantities as inferred from the contour maps of Naidu et al. (1981b)

Block	Area[1]	m_j	1/10 × Cr	1/10 × Ni	Fe	1/10 × V	1/10 × Cu	1/10 × Zn	1/100 × Mn	1/10 × Co
1	47	15	7.5	4.5	3.0	15.0	3.0	9.0	9.0	2.0
2	22	7	8.0	4.5	3.5	13.5	2.5	9.0	6.0	1.5
3	21	6	8.0	5.0	3.0	11.0	3.5	8.0	6.0	1.5
4	26	8	6.0	3.0	2.5	10.5	2.5	8.0	4.5	1.0
5	25	8	10.0	4.5	3.0	12.0	4.0	8.5	6.0	2.0
6	29	12	10.0	5.0	3.5	18.0	4.5	9.0	21.0	3.0
7	10	5	6.0	4.0	2.5	13.5	2.5	8.0	4.5	1.0
8	30	12	7.0	5.0	3.0	13.5	3.5	9.0	21.0	3.0
9	7	3	5.0	3.0	2.0	7.5	2.0	8.0	4.0	1.0
10	13	5	6.0	4.0	2.5	12.0	2.0	9.0	4.5	1.0
11	9	5	5.0	5.5	2.0	9.0	2.0	8.0	4.0	1.0
12	31	10	8.0	4.0	3.0	13.5	3.5	10.0	4.5	1.5
13	9	3	8.0	4.0	3.0	12.0	3.0	9.5	4.5	1.0
14	6	4	8.0	4.0	3.5	12.0	3.0	10.0	4.5	1.5
15	3	2	8.0	4.0	3.0	12.0	3.0	10.0	4.5	1.0
16	6	3	8.0	4.0	3.5	12.0	3.0	10.0	4.5	1.5
17	27	11	9.0	5.0	4.0	16.0	3.5	11.0	6.0	2.0
Total	321	119								
$\overline{X}$			7.7	4.40	3.0	13.3	3.2	9.0	8.5	1.8
Δ^2			2.4	0.57	0.30	7.2	0.55	1.5	37.0	0.48

[1]Areas in units of 25 nautical sq. mi.

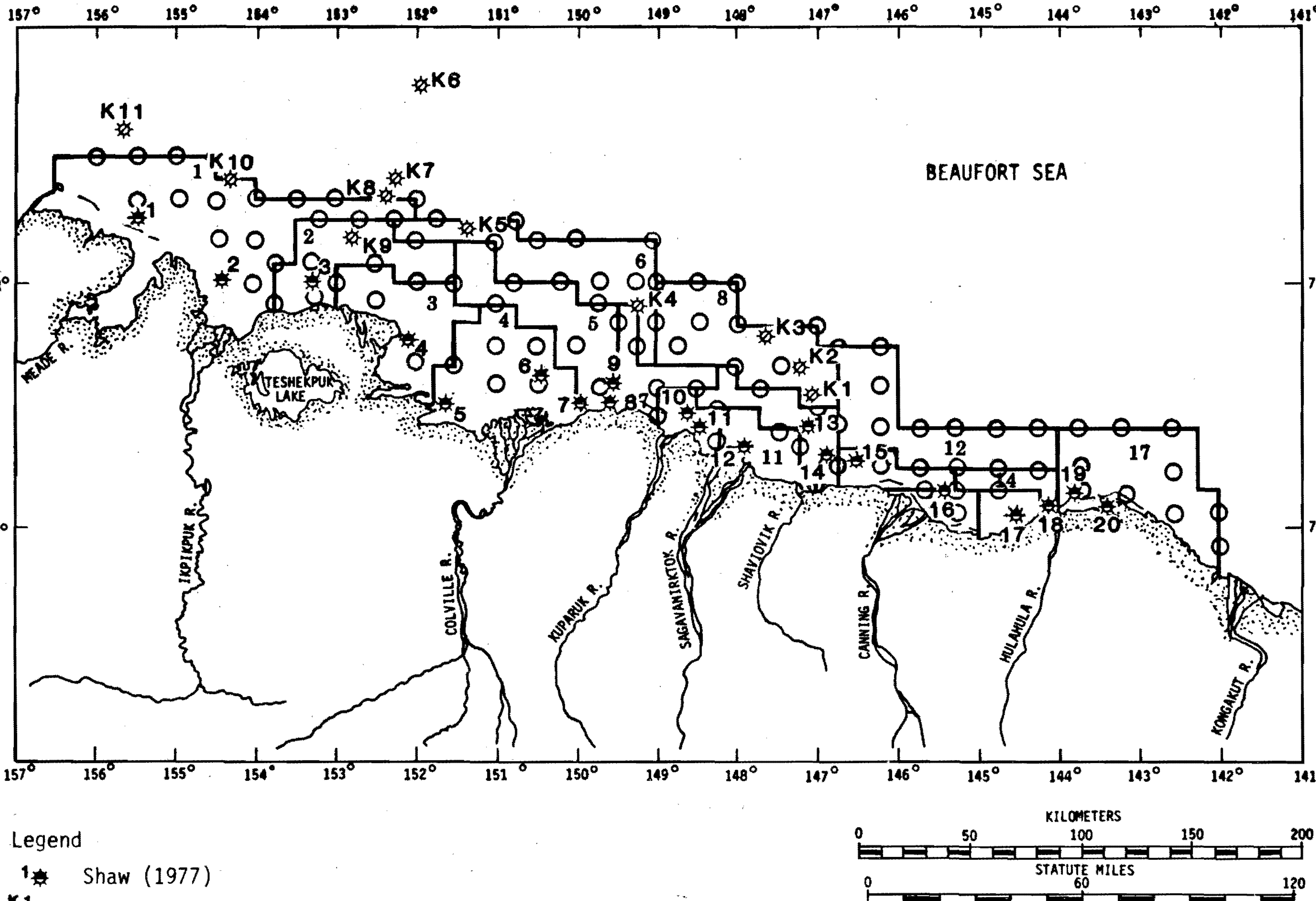
TABLE 4. Block components of variation.

Block	Area	m_j	1/100 × Cr	1/100 × Ni	Fe	1/100 × V	1/100 × Cu	1/100 × Zn	$(1/100)^2$ × Mn	1/100 × Co
1	47	15	47	17	7.5	184	7.6	67	72	3.3
2	22	7	61	19	12	176	6.4	78	43	2.3
3	21	6	62	24	8.9	124	11.9	64	44	2.4
4	26	8	36	9	6.2	111	6.3	62	30	1.2
5	25	8	91	19	8.6	140	14.7	69	43	3.8
6	29	12	84	22	11	274	17.0	71	363	7.5
7	10	5	38	16	6.5	182	6.6	65	30	1.3
8	30	12	44	22	7.9	161	10.7	71	363	7.5
9	7	3	28	10	9.3	69	4.7	67	27	1.3
10	13	5	38	16	6.5	147	4.5	81	30	1.3
11	9	5	28	29	4.4	90	4.5	65	26	1.3
12	31	10	58	15	8.3	167	11.1	90	28	2.2
13	9	3	65	17	9.3	152	9.4	92	31	1.3
14	6	4	64	17	12.2	150	9.3	100	30	2.4
15	3	2	67	17	9.5	155	9.6	103	31	1.3
16	6	3	65	17	12.4	152	9.4	101	31	2.5
17	27	11	71	22	13.8	224	10.9	105	120	3.6
Total	321	119								
σ^2_{sites}			1.5	0.41	0.61	146	0.25	15	10	0.099
σ^2_{μ}			4.7	1.6	0.77	15	0.87	6.4	11	0.34

TABLE 5. Minimum and maximum number of stations per block.

Block	Number of Stations	Block	Number of Stations	Block	Number of Stations
1	0 - 3	7[3]	0 - 2	13[4]	0 - 1
2	1 - 2	8	0 - 3	14[4]	0 - 2
3[1]	2 - 15	9[1]	1 - 14	15[1]	1 - 14
4[2]	3 - 13	10[4]	0 - 2	16[2]	1 - 11
5[3]	0 - 3	11[2]	2 - 12	17	0 - 3
6	0 - 3	12	0 - 3		

[1] The total number of stations in blocks 3, 9 and 15 need not exceed 17.
[2] The total number of stations in blocks 4, 11 and 16 need not exceed 16.
[3] Blocks 5 and 7 together should contain at least one station.
[4] Blocks 10, 13 and 14 should together contain at least one station.



Legend

1 Shaw (1977)

K 1 Kaplan and Venkatesan (1981)

○ Monitoring locations

Figure B-1 Sediment Monitoring Network Blocks Showing Locations of Past Sediment Sampling and Potential Sampling Sites

APPENDIX C
STATISTICAL BACKGROUND FOR CONFIDENCE INTERVALS AND TESTS

1.0 CONFIDENCE INTERVALS FOR MEDIANS

We used the approach of Breiman (1983) to obtain confidence intervals for medians. In Section 4.2.3 such intervals were computed for the median water depth for all possible bowhead sightings which might have been made during the nearshore fall (September-October) migration in 1982. There were $n = 103$ such sightings during random $N-S$ transect survey flights. Let $x_{(1)} \leq x_{(2)} \leq \cdots \leq x_{(n)}$ represent the observed water depths corresponding to these sightings, arranged in order from shallowest to deepest. Let $x_{0.5}$ denote the median we seek to estimate. Let $[0.5\,n-k]$ denote the smallest integer greater than or equal to $0.5\,n-k$.

Then Breiman shows that for large n, a 100 γ percent confidence interval for $x_{0.5}$ is given approximately by $[x_{([0.5\,n-k])}, x_{([0.5\,n+k])}]$ where $k = 0.5z\sqrt{n}$, and if Z is an $N(0,1)$, or standard normal, random variable, then z is defined by $P(-z \leq Z \leq z) = \gamma$. For example, when $\gamma = 0.99$, $z = 2.58$. We obtained the 99 percent confidence interval for the overall axis of migration in 1982 using this approximation.

For small n, $6 \leq n \leq 65$, values of k such that a 95 percent or 99 percent confidence interval is $[x_{(k)}, x_{(n-k+1)}]$ are given in Table VII.3 of the *CRC Handbook* (Beyer, 1968). The interval for the region east of 146°W longitude reported in Section 4.2.3 was obtained using this table.

2.0 TESTS FOR DIFFERENCES IN DISTRIBUTIONS

Breiman (1983) discusses tests for differences between distributions in Chapter 9. Derivation of the two-sample Wilcoxon, or Mann-Whitney, test and the chi-square (χ^2) test for homogeneity are given by Breiman, and we will not repeat them here. The tests are available in standard statistical packages such as Minitab (Ryan et al., 1980).

The table for the χ^2 test on the overall distribution of water depths z discussed in Section 4.2.3 might be:

Year	$z < 20m$	$20 \leq z < 30$	$30 \leq z < 40$	$40 \leq z < 50$	$z \geq 50m$	Total
1982	16	21	31	17	18	103
Another year	-	-	-	-	-	-
Total	-	-	-	-	-	-

where the number to be filled in for the second year would be number of sightings in each of the indicated depth ranges.

The asymptotic theory on which the χ^2 test is based does not hold when the expected number of sightings in some categories is small, say <5. Thus, when the total number of sightings is small, a smaller number of depth categories must be used. For example, a more appropriate table for latitude east of 146°W longitude would be:

Year	$z < 35m$	$35m \leqq z \leqq 45m$	$z \geqq 45m$	Total
1982	9	21	11	41
Another year	-	-	-	-
Total	-	-	-	-

if the second year had roughly the same number of sightings.

3.0 LEVELS AND POWERS OF TESTS, CHOICE OF LEVEL

We recommended in Section 4.2.3 that the Mann-Whitney test for a shift in median depth of bowhead sightings be done at the 1 percent level since it will need to be performed at least three to five times if the tests of the 1979 and 1981 data versus 1982 are included. The analyses of that section indicate that we have reasonable power to detect changes of the magnitude of interest even if tests are done at the 1 percent level.

Recall that *power* is the probability of rejecting the null hypothesis of no change when it is false and therefore detecting the change. Recall that the *level* α of a test represents the probability that the null hypothesis will be rejected when it is in fact true due to random error. Thus, for a single test at the 1 percent level ($\alpha = 0.01$) the probability that the null hypothesis will be accepted when it is in fact true is $1-\alpha = 0.99$.

Now, suppose we perform five independent tests of the same true null hypothesis with $\alpha = 0.01$ in each test. The probability that we will accept the null hypothesis all five times is $0.99^5 = 0.951$. Hence, the probability that we will incorrectly conclude at least one time out of five that the null hypothesis is false and a shift has occurred is 1 - 0.951 = 0.049. That is to say, our overall level is approximately 5 percent. The same calculation when the individual tests are done at the 5 percent level gives an overall level of $1-0.95^5 = 0.226$, or nearly 23 percent.

The results are not very different if we allow for the possibility that the repeated tests are dependent. In this case, if the individual tests are at the 5 percent level, the probability of concluding at least one time out of five that a shift had occurred when, in fact, it had not, might be as high as 25 percent. This result is derived from Bonferroni's Inequality (Montgomery and Peck, 1982).

4.0 POWER OF ANALYSIS-OF-VARIANCE TESTS

Standard charts of power of analysis-of-variance tests such as Table A-13 in Dixon and Massey (1969) can be used to determine detectable changes. We illustrate the technique with the linear blade growth data for kelp at DS-11 given by Dunton (1983) and discussed in Section 4.2.7 of this report.

From his Figure 2 we obtained the following values:

Year	Sample Size	Blade Growth, cm.	Standard Deviation
1976-77	$n_1 = 11$	24.8	10.0
1977-78	$n_2 = 32$	22.2	8.0
1978-79	$n_3 = 42$	24.1	6.2

and from them a pooled estimate of residual variance $\hat{\sigma}^2 = 55.6$ and an overall mean $\mu = 23.7$ which we assume was the true mean in all three years: $\mu_1 = \mu_2 = \mu_3 = \mu$. Now assume that the sample size n_4 in a fourth year of sampling is, say, $n_4 = 20$ and the mean $\mu_4 = \mu + \Delta$ so that the new overall mean is $\overline{\mu} = \mu + \Delta/4$. Then the parameter Φ in Table A-13 of Dixon and Massey (1969) is given by

$$\Phi^2 = \frac{1}{k\sigma^2}\sum_{i=1}^{k} n_i(\mu_i - \overline{\mu}) = \frac{1}{222.4}(11\frac{\Delta^2}{16} + 32\frac{\Delta^2}{16} + 42\frac{\Delta^2}{16} + 20\frac{9\Delta^2}{16}) = \frac{1}{222.4}\frac{265}{16}\Delta^2$$

since $k = 4$. Then $\Phi = 0.27\Delta$.

Using the chart with $\nu_1 = k - 1 = 3$ and $\nu_2 = \sum_{i=1}^{k} n_i - k = 101$ and assuming we wish to test at level $\alpha = 0.05$, we obtain the following table of detectable differences vs. power.

Power = 1-β	Φ	Δ, *cm*
0.50	1.2	4.4
0.70	1.5	5.6
0.80	1.7	6.3
0.90	1.9	7.0
0.95	2.1	7.8

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