BEAUFORT SEA MONITORING PROGRAM

WORKSHOP SYNTHESIS AND SAMPLING DESIGN RECOMMENDATIONS

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DRAFT REPORT

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1.0 EXECUTIVE SUMMARY

[to be provided]

2.0 INTRODUCTION

2.1 GENERAL

This document is an initial attempt at describing • long-term monitoring program for assessing potential effects of anticipated oil and gas development on the United States Beaufort Sea continental ahelf. 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 (NW) and the U.S. National Oceanic and Atmospheric Administration (NOAA) are detailed in Section 2.3. Over the lest 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 Beauf ort sea, NOAA and NNS sponsored a workshop in September 19s3 (Section 2.5). Invited participants included regulators, managers, and scientists from cognizant agencies, as wall as leading scientists with specie lties in aspects of the Beauf ort 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:

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

2.2 STATUTORY MANDATES

Seth MMS and NOAA have ● xtensive statutory and regulatory mends tes to conduct environmental studies and monitoring In marine waters. This section discusses these msndetes. The working relationship which has evolved between the two services ‘to study effects of oil and gas development on the Alaskan Outer Continen tal Shelf is explained in Section 2.3.

The Outer Continental Shelf Lends Act (67 Stat. 462) was passed in 1953 and ● stablished 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 (OCS), 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 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 Lend Management (BLM) as the administrative agency for leasing submerged federal lands, and the U.S. Geological Survey for supervising development end production. The Department of the Interior formulated three major goals for the comprehensive management program for marine minerals:

o To ensure orderly development of the marine mineral resources to meet the energy demands of the nation.

- o To provide for protection of the environment concomitant with mineral resource development.
- o 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, ia 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 men's environment. This goal of environmental protection was assigned to the BLM Environments Studies Progam 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. The effort of this studies program has remained essentially unchanged throughout this last decade; its task is to design studies that:

- o '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,
- o provide information on the ways and extent that Outer Continental She If development can potentially impact the human, marine, biological, and coastal areas,
- o ensure that information already available or being collected under the program is in a form that can be used in the decision-making princess associated with a specific leasing action or with the longer term Outer Continental Shelf minerals management responsibili ties, and
- o Provide a basis for future monitoring of Outer Continental Shelf operations" (43 CFR 3301.7).

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

'(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 araa 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 productive ty of such environments fOr establishing trends in the areas studied and moni tored, 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 af fectad States. TO the extent that other Federal agencies have prepared environ-mental impact statement, are conducting studies, or are moni-toring the affected human, marine, or coastal environment, the Secretary may utilize the information derived the ref rom 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 responsibili ties under this secrion, the secretary may by agreement utilize, with or wi thout 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:

1. 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;
2. to 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
3. to 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 biennially update 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 reset priorities of the 5-year plan if these are not being adequately addressed by any federal agency. 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:

- ova r 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

o 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 pol lution research, development, and monitoring plan.

NOAA has numerous other statutory mandates to conduct, support, or coordinate programs and activities for marine pollution research, development and monitoring; ocean development; and living marine resoruce 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 (wSPA) (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. 9S-21 7), 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 environmental research for all Alaskan OCS areas identified by the Department of the Interior for potential oil and gas development.

The BLM/NOAA working arrangement was formalized in 1980 by a Basic Agreement between BLM and NOAA and the rela tionship has continued tit-h the MMS. The Anchorage, Alaska, MMS Environmental Studies Program, under the direction of the MMS Washington, DC, Headquarters Office, directs the Environmental Studies Program policy and program overview 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 Anchorage MMS 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. OCSEAP is managed by the NOAA Alaska Ocean Assessment Division (oAD) Office located in Juneau, Alaska , and is under the direction of the Rockville, Maryland, NOAA-OAD Headquarters Office. The scope and scientific content of OCSEAP studies are determined annually by a set of Technical Development Plans (TOPS) which are approved by MMS. These TOPS, preps red 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 funded approximatel y 89 research uni ts (RUS) which are wholly or in part related to the Beaufort Sea (U.S. MMS 19B3). Some studies have been directed at summarizing and analyzing existing information, while others have performed extensive field investigations to document baseline conditions. Still others have conducted laboratory (including computer) analyses to explore relationships and sensitivities of various environmental components. Technical areas covered by the RUs hsve ranged broadly through many aspects of the physical, chemical, and biological environments of the area, including the atmosphere, land, and water. Many of these RUs included the kind of repetitive (in epace 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 thst ths area imposes on development. Considerable experience and data have been amassed for the united States Beaufort Sea (especially nearshore) which provide the basis for msny of the thoughta 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)

Beginning in 1978, the MMS (then the BLM) has been directly funding research and monitoring studies in the Beaufort Sea. The focus of these studies has been on species of special concern related to leasing activities (i.e., the endangered bowhead and grey whales). Annual aerial censusing (e.g. , Ljungblad 1980; 19S1; 1982) and studies of the impact of oil- and gas-related disturbances on bowhead whales (e.g. , LGL 1982; Reeves et al. 1983) are of particular relevance to the design of the Beaufort Sea Monitoring Program. A list of studies sponsored by the MMS of endangered whales is provided in Table 2-1.

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 Beauf ort.

TABLE 2-1

WHALE-RELATED RESEARCH FUNDED OF PLANNED BY MMS, 1978-1905

Fiscal	
1978-1979	Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of tbe **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 end **Tracking** Capabilities in **OCS** Lease **Areas**
1980-1981	Tissue Structural Studies and Other Investigations on the Biology of **Endangered** Whales in tha **Beaufort** Sea
1980	**Effects** of **Whale** Monitoring **System** Attachment **Devices** on Whale Tissues
19s0	Effect of Oi 1 on tha Feeding Mechanisms of the **Bowhead** Whale
1981-1984	Development of **Satellite-Linked Methods** of Lsrge Cetacean Tagging and **Tracking Capabi li** ties in **OCS** Lease Areas
1982-1984	Investigation of the Potential Effects of Acoustic Stimuli Associated with Oil and Gaa Exploration/Development on the Behavior of migratory Gray **Whales**
1983 -19s4	Computer Simulation of the Probability of Endangered **Whale** Interaction with Oil spills in the **Beauf** ort, **Chukchi,** and **Bering** Saas
1980-1 984	Possible **Effects** of Acoustic and Other Stimuli Associated with Oi **l** 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 Sits-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** Focal Organisms and **Bowhead** Whales in the Eastern **Beaufort Sea**
1985	**Ecology** and **Behavioral 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**

2.4.4 North S1OPS Borough

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

2.4.5 Stste of Alaska

The State of Alaska, Department of Fish and Game, has several long-term research programs in the Beaufort Sea and on the North S1OPS, some of which receive OCSEAP funding. Aerial surveys of ringed seal winter population densities (Burns and Harbo 1972; Burns et al. 19S1 ; Burns and Kelly 1982) and studies of overwintering char populations (Bendock 19S3) are particularly relevant to the design of a long-term Beauf ort Sea Monitoring Program.

2.4.6 Other U .S. Monitoring Programs

various developments and their associated activities have resulted in requirements for various types and intensities of site-specific monitoring programs (“complete monitoring”) in the Beaufort Sea. In addi ti on, numerous predevelopment “baseline” studies have been conducted by various oi 1 companies in preparation for filing development permi t applications. By far the largest monitoring program to dats in the U.S. Beaufort Sea is thst 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 provided da ta for consideration in the present program design.

Moni toring of specific discharges (e.g., drilling muds) to the Beauf ort Sea is required by the U.S. Environmental protection Agency snd the Alaska Stats Department of Environmental Conservation under the

Rational Pollutant Discharge Elimination System (NPDES). These programs are typically localized and directed at determining the ●xtent of pollutant dispersal in relation to a prescribed mixing zone.

2.4.7 Canadian Beaufort Sea Monitoring

D. Stone (Canadian Department of Indian and Northern Affairs)* described the process by which Canada has bean designing a long-range monitoring program for the Canadian aide of the Beaufort Sea. Oi 1 development in the Canadian Beaufort Sea will soon be moving into the production phase. Stone reported that, during early ●fforta of environmental assessment, managers and decision makers hed been deluged with research topics thought to be of importance by individual scien- tists, 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 utili ty of previous impact assessments (Beanlands and Duinker 19S3) and to use this analysis and the bsst scientific expertise available in formulation of their long-range targets and approaches. Canada is proceeding using adaptive environmental assessment (AEA) techniques (Hailing 197S) at a series of workshops (1 to 2 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 parameters do we care about?" In answer to the latter question, "valued ecosystem components" (VECs) , were defined as those specias that either:

1. are important to human populations,
2. have national or international importance, or
3. provide support for VECs under 1 or 2.

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

Using these criteria, the VECs are restricted to selected marine birds, mamma 1s, and anadromous fish. The AEA looking-outward approach was used to establish 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 Beauf ort Sea. = To fulfill this purpose, the specific objectives of the workshop were to:

- o evaluate existing monitoring techniques for applicability to the Beaufort Sea;
- o introduce and consider any new monitoring concepts that might be relevant to this region;
- 0 reach a consensus (or a majority opinion) on techniques, proven or promising, thst should have high priority for inclusion in the BSMP.

About 20 scientists with expertise in the Beaufort Sea environment and/or with sys tematic 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 Appsndix A. The workshop was held at the Alyeska resort outside of 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 f rom the session (Section 3.1). A reasonable oil and gas development scenario for the Beaufort Sea was presented

(Section 3.2). Monitoring programs in the Beaufort Sea and ●lsewhere 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 Beauf ort Sea and a wide variety of biological, physiological, and biochemical monitoring approaches were also presented (Section 3 .s).

After these presentations, a panel of NOAA and MMS scientists (D. Wolfe, .7. Cimato, C. Manen, J. Geiselman, J. Naumen) met with the workshop convenor (J. Truett) to redefine the monitoring program objectives (Section 2.7) and develop a preliminary monitoring approach (Section 3.6). These panel recommendations were reported to and discussed by the entire workshop.

2.6 STUDY AREA

Strictly speaking, the area of interest for the SSNP could include the entire Diapir Field Planning area (Figure 2-1), including all United States waters from the United States/Canada Border (in dispute) to 162" West longitude and 73" North latitude. However, for practical considerations, the area under consideration includes the Alaskan coastal waters between Point Barrow and the United States/Canada border and out to the ahelf break (about 50 meters) .

Within this broad area, development in the near term (next decade) is likely within the shorefast ice zone and may axtend 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 regiona: Camden Bay, Stefansson Sound (including the Prudhoe Bay area), snd Harrison Bay (Imm 1983).

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

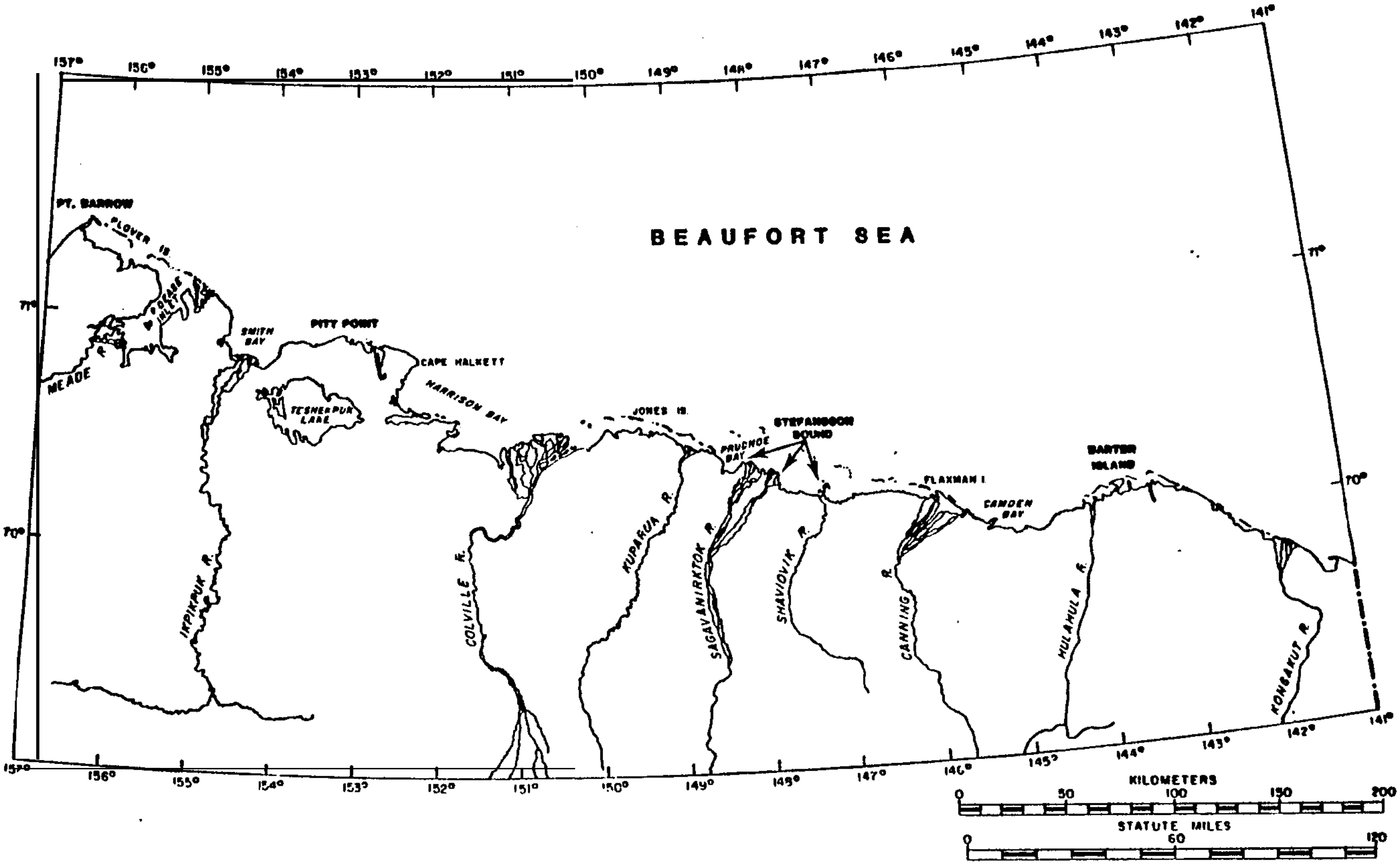


Figure 2- Beaufort Sea study area

panel a specific set of objectives for the BSMP was established as follows:

1. To detect and quantify change that might:
   (a) result from OCS oil and gas activities.
   (b) adversely affect, or suggest another adverse effect on, humans or those parts of their environment by which they judge quality, and
   (c) influence OCS regulatory management decisions.
2. 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 which was first considered by the panel and then by the entire workshop.

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

1. Record and summarize the proceedings of all workshop sesssions.
2. Develop a monitoring program which incorporates 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:

1. SEAMOcean, Inc. (D. Segar) of WheatOn, Maryland.
2. University of Washington, Department of Statistics (J. Zeh) of Seattle, Washington.

3.0 WORKSHOP SUMMARY AND SYNTHESIS

This section contains brief summaries, by major topics, of actual presentations during the course of the Beaufort sea Monitoring Program Workshop. Emphasis in these summaries 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 available in report or published form are not repeated. However, references to published wri tten sources of these descriptions are provided.

3.1 WORKSHOP FRAMEWORK

The purpose of the workshop and its follow-on activities was to establish the design of a Beaufort Sea monitoring program. The framework within which this program was to be designad was elaborated in a series of presentations by representatives from NOAA, WMS, and the workshop convenor. This framework is summarized in this section.

The purpose of the proposed Beauf ort 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. AS described by J. Imm (MMS) and W. Conners (NOAA/National Marine Pollution Planning Office, [NMPPO]), the statutory mandate for this program is twofold: (1) the broad mandate for NOAA to "establish within the Administration a comprehensive, coordinated, and effective ocean pollution. . monitoring program' as directed by the National Ocean Pollution Planning Act of 1978 (Pub. L. 95-273); and (2) the more specific, Department of ths Interior mandate of the Outer Continental Shelf Lands Act (Pub. L. 95-372) provided in Section 2.2.

Neither statute 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, moni toring has been described as a program to gather marine pollution information to warn ● gainst unacceptable impacts of human activities on the marine environment, and to provide a long-term dste base that can be used for evaluating snd 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 Systems [NOS]) that the monitoring program consist of:

> ". . . a aet of repetitive measurements of attributes and phenomena that can be used to document changes in the coastal and marine environments of the Alaskan Seaufort 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. Di scussions also highlighted the need for the end prod ucts of the monitoring program to provide continuing information about environmental quality such that policy and management decisions can be made about human actions that affect that quality.

The Beaufort Sea Monitoring Program 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 (1 983) . While many of these activities do not currently include monitoring in the Beauf ort Sea, and others are of very limited scope in this region, the design that will be developed for the proposed monitoring effort must tske into account that such programs msy be instituted or expanded as f ederal and non-federal development activities increase in this region.

TAELE 3-1

FEDERAL AGENCIES RESPONSIBLE FOR A4ARINE POLLUTION MONITORING

Environmental Protection Agency (EPA)
Moni tors marine pollution compliance.

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

Minerals Management Service (MMS)
Assesses impacts of offshore oil and gaa development.

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. 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, etc.

Outer continental shelf oil and gas development activity in the Beaufort Sea is increasing steadily. At present, Imm repurted that 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 Beauf ort Sea to the east. At present, four exploratory wells have been drilled in the Joint Lease Sale area (Figure 2-1), and application for a development permit is expected for the Sagavanirktok (Sag) River delta. If this development occurs, it will be the first in United States Arctic ice-covered areas. The most likely areas where future development will be concentrated are Harrison say and Stefansson Sound, which incldues Prudhoe Bay (Figure 2-1).

Although the Beaufort Sea marine environment is unique among Onited States coastal waters, there are numerous research and monitoring programs in other coastal areas which have developed techniques 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 and State of Cali f ornia Mussel Watch Programs; the NOAA and EPA Ocean Dumping Programs; the NOAA New York Bight and Hudson-Raritan Estuary Programs; the EPA Chesapeake say Program; the NOAA Puget Sound 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 comprehensi ve body of knowledge regarding the ef f activeness 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 moni toring plan composed of the best avai lable techniques that would effectively assess the impact of oi 1 and gaa development on the Beauf ort 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 which 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:

1. The program should be capable of detecting changes in the Beaufort Sea ecosystem that potentially could be caused by oil and gas development activities.
2. Potentially beneficial, as well as detrimental, changes should be considered.
3. The program should be capable of identifying 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.
4. 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 OSC oil and gas activities.
5. 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 bs instituted in order to prevent further adverse change, and to minimize and redress any adverse impacts, where possible.
6. Although the program should be economically fesaible, cost of the monitoring program should not be a mej or concern at this stege of program design.
7. 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, end other pollutants. However, the effects of development

activities, such as gravel island and causeway cons truction, should also be examined.

8. The monitoring program should address OCS oil- and gas-related effects on the marine environment of the Beaufort Sea from the shoreline out.

9. The program should not address the noncontaminant stresses that an increased human popluation would impose on the marine resources, such as increased hunting.

10. The workshop participants should be aware that MMS and NOAA-NMFS studies of marine mammals, particularly bowhead whales, are curren tl y active and wi 11 continue under the mandates of the Marine Mammal Act and the Endangered Species ACt.

11. Following the workshop, studies of appropriate data sets both from the Beauf ort and elsewhere would be perf ormed (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. Theref ore, statistical cons ideations during the workshop should be of lower priority than identifying the parameters that should be measured.

3.2 FACTORS THAT MAY CAUSE IMPACTS

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 brief ly reviewed by several workshop participants. Since the y 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 say Waterf lood 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 ●xisting habitat and can cause changes in circulation that may affect water quality, nutrient transport, and movements of biota. Construction end operation of facilities create noise (airborne and waterborne) and visual effects that may disrupt biota. Routine discharges (e. g., drilling f luids and cuttings, sewerage, wash watar, brines, etc.) can alter load water and sediment quality and msy 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 potentia 11 y 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 wi th imposed restrictions and the extent of actual impacts is also required. Such permi tting "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 tha cumulative effects of the numerous and varied individual projects and activities anticipated in the coming decades could, in combination, cause larger scale (end longer term) changes in habitat quality and/or in the population 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 Stateas continental shelf, and for other purposes in the Alaskan Beauf ort 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 en marine pollution within the past decade and are now considered to be the primary phase of marine pollution monitoring programs (UNESCO 1980) . The United States nationa 1 mussel watch evolved from a meeting convened in 1975 by the National Academy of Sci ences (WAS) to f ormulate a national marine pollution monitoring program (Barrington 1983). The international mussel watch was then patterned after it (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 se letting sentinel organisms are delineated in Table 3-2.

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 bioavailabi lities in the marine environment. It was also concluded tha t 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 ths principal pollutants, including lead (Schaule and Patterson 1981) and silver (Martin et al. 1983), have shown that many preceding seawa ter measurements of pollutants were erroneous (Quinby-Hunt and Turekian 1983).

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. The y concentrate many chemicals by factors of 102 to 10^5 compared to eeawater 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 axhibit low or undetectable activity of those enzyme systems which metabolize many xenobiotics such as aromatic hydrocarbons and polychlorinated biphen yls (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 repaated ly providing date on short- and long-term temporal changes in concentrations of pollutant chemicals.

7. The y survive under conditions of pollution which often severely reduce or eliminate other species.

8. l'he y can be successf u lly 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 Barrington et al. 1983.

While the National Mussel Watch Program was initially limited to analyses of pollutant concentrations in the sentinel organisms, it later led both directly and indirectly to further research. These complementary studies are not adjunct to mussel watch programs, which provide definitive evaluations of marine pollution. Rather, the y represent the second phase of the progressive mussel watch concept of integrated research, which is designed to yield a quali tative record of the environmental levels of sOme pollutants. This research sequence has been delineated by UNESCO (UNESCO 1980) and summarized in the International Mussel Water RepOrt (NAS 1980) in the discussion on priori ties 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 detected or identified as pollutants as well as those that are well known and routinely measured .”

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 some relatively elevated pollutant concentrations (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 exhibit some relatively elevated pollutant concentrations (mercury, cadmium, and plutonium) which are not directly correlated with anthropgenic 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 concentration (0.6 to 2.5 ppm) are relatively isolated from both anthropogenic inputs of industrial mercury and from natural deposits of mercury-rich minerals. They are, however, the locations of major marine pinniped and sea bird colonies (U.S. BLM 1979), which apparently enrich the bivalve mercury concentration by their locally concentrated discharge of mercury-rich waste products. Detailed discussion of these data have been reported selsewhere (Goldberg et al. 1978; 1983; Barrington et al. 1983), and there is now an extensive literature on other local, state, and international mussel watch studies.

In summary, 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 thet adaptation of a mussel watch program for the Beaufort Sea will be difficult 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 limited. This problem has already been evidenced by the apparent twofold difference in the baseline silver concentration of *Mytilus californianus* and *M. edulis,* even when they inbsbit the same area (San Francisco Bay) of the conterminous United States (Goldberg and Martin 1983; Stephenson et al. 1979).

Finally, Flegal recommended that a Beaufort Sea mussel watch should be patterned after the Unitad States National Mussel Watch Program, and it should include the complementary research which has enabled the national mussel watch data to be properly interpreted. This letter consideration is especially necessary, since comparisons with other mussel watch studies may be qualified by the utilization of arctic species and the differences in temparate and arctic habitats.

3.3.2 EPA Ocean Discharges Monitoring

J. Hastings (SPA Region 10) provided an overview of EPA's monitoring requirements for discharges in the Beauf ort 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 part 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 off shore facilities. Because these are discharges to ocean waters, Section 403(c) of the Clean Water Act requires that EPA's Regional Administrator determine whether they will result in unreasonable degradation of the marine environment. "Unreasonable degradation" basically encompasses the following: significant adverse ecosys tem impacts, a threat to human health, or an unreasonable less 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 issuad--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 ba transported to these areas of concern in sufficient concentrations or quantities to affect them?

Determination of whether unreasonable degradation will occur depends on having sufficient information on the proposed discharges and the affected environment to evaluate 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 wi 11 not result in irreparable--or irreversible--harm, given specific moni toring requirements and other conditions.

TAsLE 3-3

OCEAN DISCHARGE CRITERIA FOR DETERMINATION OF UNREASONABLE DEG RADATION 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 sitsa.
- 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.

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 ●nvironment. Therefore, immediate, specific ●ffects and also long-term cumulative impacts are considered.

Hastings outlined a monitoring study conducted this year at Sohio's Mukluk Island site in Harrison Say, approximately 17 miles north of the mouth of the Colville River. Sohio had plans to drill up to two exploratory walls 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.

EPA determined that there was insufficient information to make a reas enable 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 watera in this area. This leads to uncertainty ovsr 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 19S4 (and possibly again in 1985), to measure any accumulation of drilling muds remaining in tbe survey area.

Using replicate sampling data from drill sites in the Canadian Beaufort Seat the minimum detectable differences in mean sediment chromium concentrations wera calculated (Table 3-4). Based on this, the study design called for a collection of 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 end south) which allow for an assessment of the overall depositional pattern.

TABLE 3-4

MINIMUM DETECTABLE DIFFERENCE-S
IN MEAN SEDIMENT CHROMIUM CONCENTRATIONS
AT $\beta = 0.20$, $\alpha = 0.05$[a]

Number of Replicate	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 usa of tha 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 replicate samples should be analyzed wi 11 be determined. This sampling methodology requi res the collection--but not necessarli y the analysis--of samples from a large number of sites.

'Me data developed from this study will be useful in addressing the ocean di scharge evaluation. This information will also be ● ssential in looking ahead to address impacts and devaiop 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 (Te tra 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 is applicable to the BSMP) requires answers to the following questions:

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

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

1. Sensitivity or susceptibility to impacts.
2. Recreational or commercial importance.
   (Subsistence use should be added for Beaufort Sea.)
3. Trophic or habitat performance.
4. Presence of distributional patterns enabling quantitative assessment.
5. 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 sbund.ante 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 hased 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 and •rror.

3.3.4 Prudhoe Bay Waterf lood 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. Raref action 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 psrmit a reasonable statistical strength. Data provided are shown in Figure 3-1. Additional detail is available in Tetra Tach (1983).

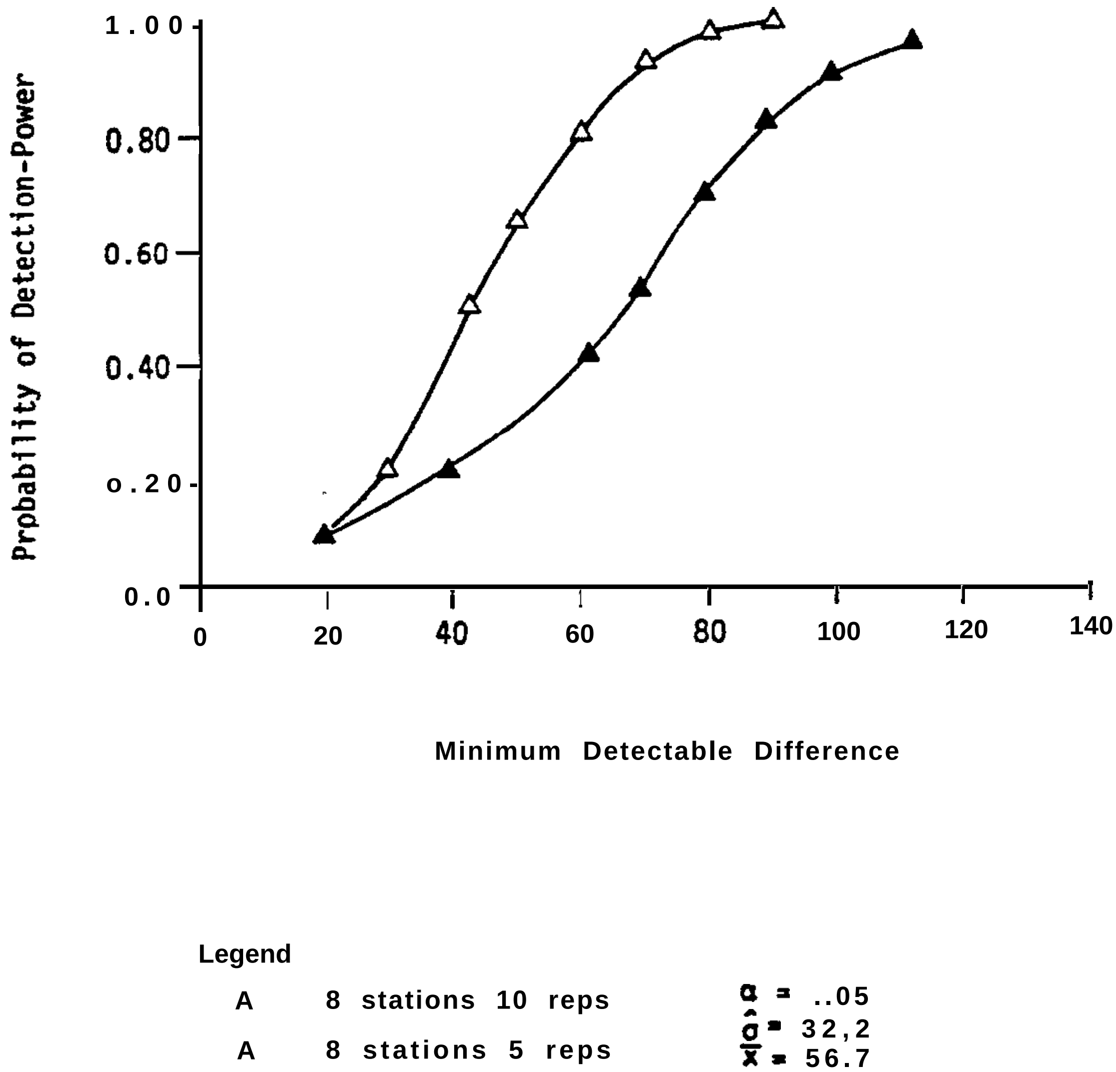


Figure 3-1 Probability of detection versus detectable difference in number of individuals (Tetra Tech 1983)

A general recommendation derived from this statistical ●valuation potentially applicable to the BSMP is the use of stratification to minimize variability. It was also noted that:

1. 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.
2. Increased taxonomic sophistication over the years created an artificial increasing trend in species richness and diversity.
3. 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. Nef f (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, 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 ware 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 indicator of the presence of drilling fluids. Elevated levels were detectable some 6 km downcurrent from ths rigs. Additional detai 1s of this program and its results have been reported by Battelle/WHOI (1983), U.S. Geological Survey (1983), and Science Applications Inc. (1983).

Points of particular relevance to the BSMP were:

- 0 Use of fine fraction only for metals and hydrocarbon analyses.
- 0 Use of an oversampling strategy so thst additional station or replicate samples are available if deemed appropriate.
- 0 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. 'i'he 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 or taxonomy of indigenous benthos, and to examine the somewhat unique hard bottom outcropping 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 at tan- tion because of the anticipated higher 'signal to noise" ratio expected for drilling effluent effects on benthos compared to other aspects of the ecosys tern. 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 ● nvironment of tha Beauf ort Sea is characteristically very different from other areas of the United Statss Outer Continental Shelf because of its proximity to the Arctic ice pack and the existence of fast-ice throughout the entire sea during winter. From October through June, the entire Baauf ort Sea is generally covered with ice. The permanent Arctic peck ice zone is found in deep water and is usually in motion at variable rates up to 35 km psr 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.

Because water and sediment movement, and therefore contaminant movements, within the Beauf ort are profound ly inf luenced 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 drama tical ly reduced and water ax change 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 bean observed), which can persist until either breakup or the pane tration of f reah wa tar runof f 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 off shore, 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: solubili ty 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 unti 1 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, contaminant distributions will be influenced by water, sediment, and suspended movements which are considerably greater than during the winter. For example, summer currents typically average ahout 3 percent of the wind speed, but currents are typically only O. 3 percent of the wind speed during ice-covered periods. Theref ore, transport of contaminants away from the immediate area of the discharge will take place predominantly during the ice-f ree and moving-ice periods.

3.4.2 Circulation

The major features of water circulation pattsrns in the Beaufort Sea were described by Hschmeister. 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 shout 5 to 10 cm/sec. Inshore of the gyre is the Alaskan coastal current system, a complex, reversing current regime which results in a ma an 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 5 to 10 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, ●xcept 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. The lagoon entrances exhibit typical estuarine flow characteristics (often strong vertical stratification, surface outflow, and inflow at depth). The influence of tidal fluctuations (particularly within Simpson Lagoon) is such that, under consistent northeast winda, pulses of colder, more saline water enter the lagoons at each tidal cycle and are transported to the west by the mean current. Uncle r these circumstances, a series of cross-lagoon density fronts may be set up. In those parts of the coastline where the barrier island system is not well developed, the typical northeast winds tend to move surface water off shore. 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 off shore under normal northeast winds, coastal upwelling occurs during these periods.

Strong s term winds occur in the Beauf ort 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 Ssauf ort. Winds f rom the northwest or west cause ons here 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 cods tal 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 mi d-sheld and lagoon surface waters converge.

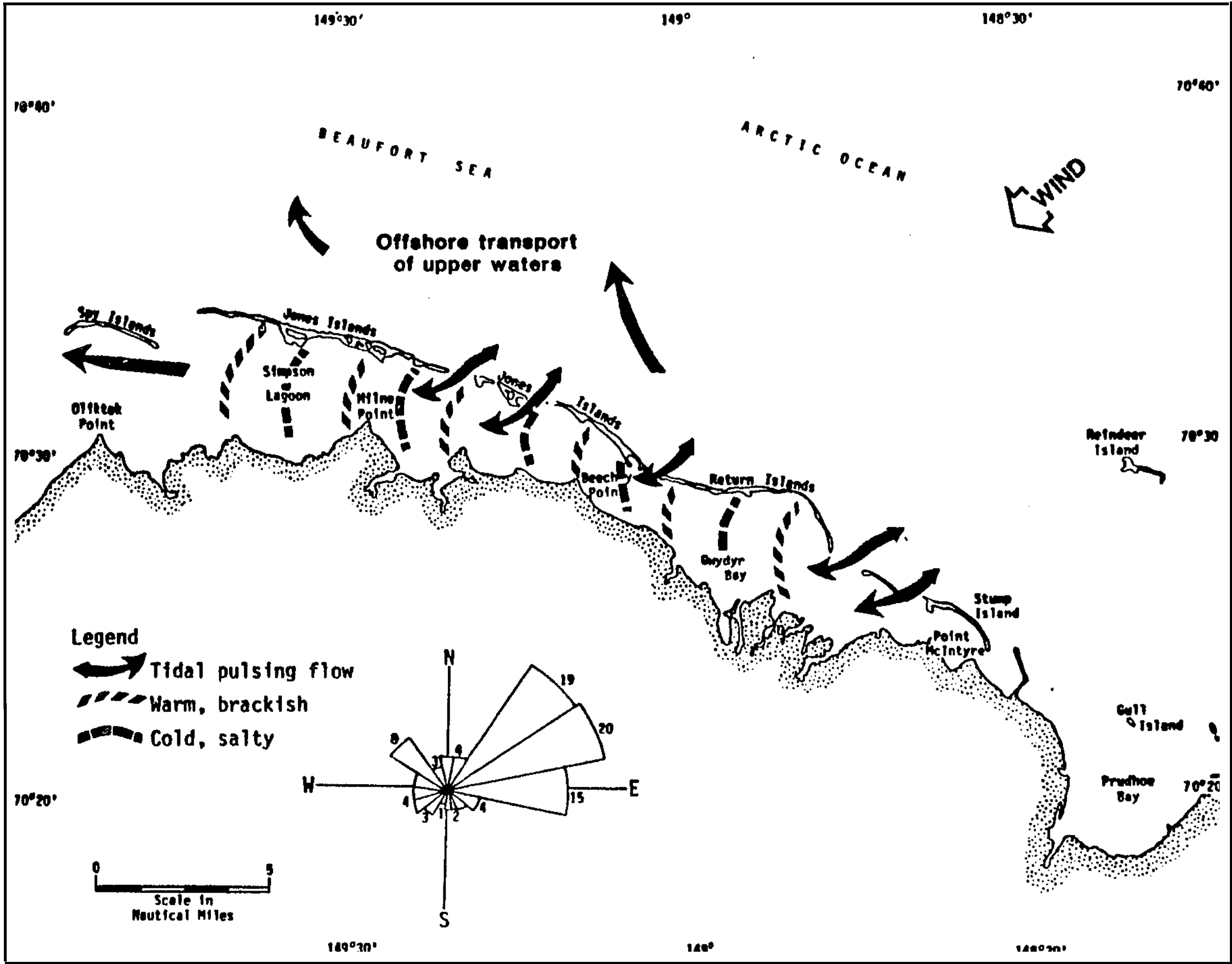


Figure 3-2 Current patterns under northeast wind conditions
Prudhoe Bay to Oliktok Point area

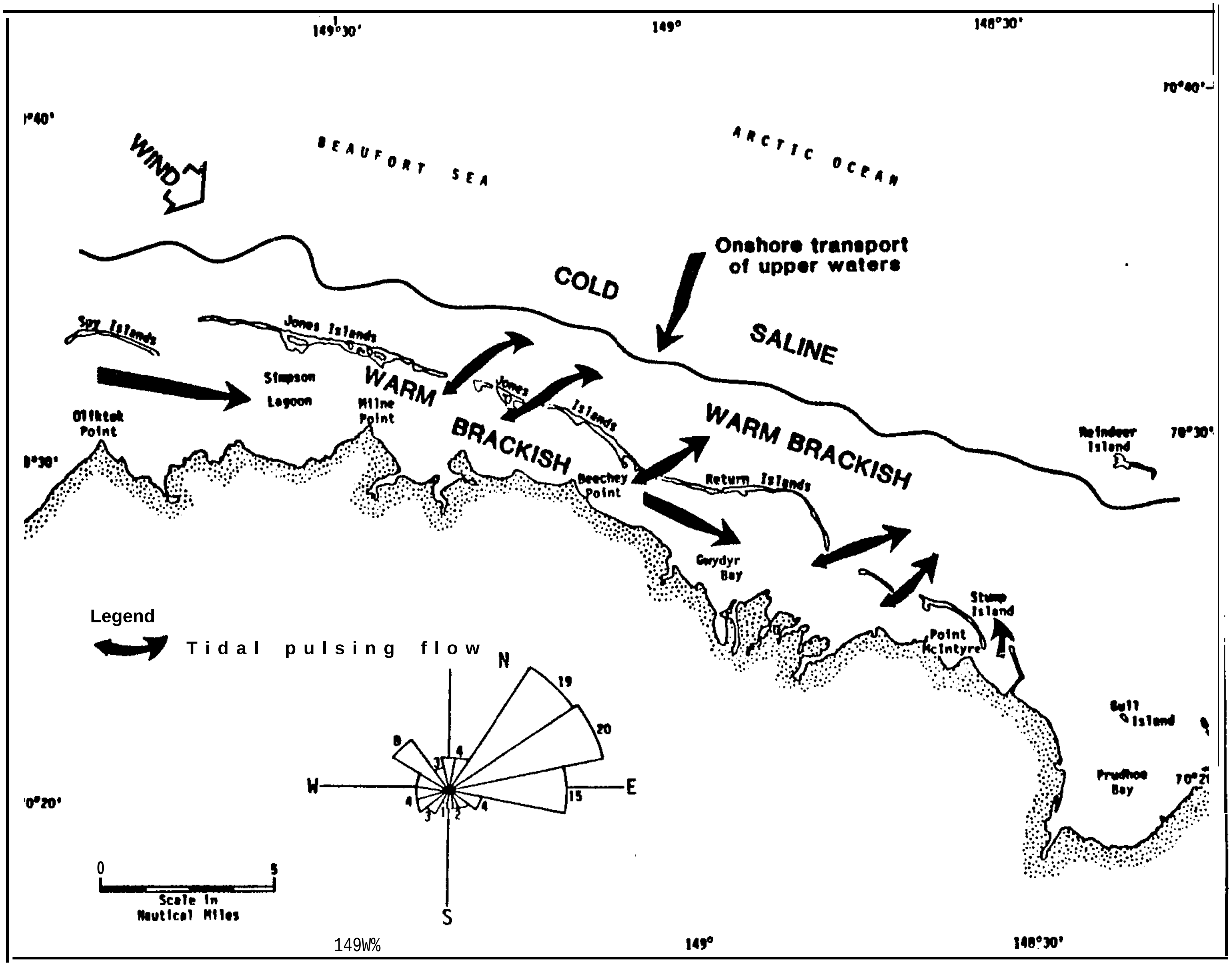


Figure 3-3 current patterns under northwest wind conditions Prudhoe Bay to 01 iktok Point area

In those areas of open coastline where the barrier island chain is not well formed, westerly winds tend to constrain warm, InV-salinity land or river runoff from mixing seaward and, therefore, river discharge plunes are oriented to the east of the river in a relatively narrow region adjacent to the coast.

The three me jor areas of concern for OCS development (Camden Say, Harrison Bay, and the Stef ansson Sound/Simpson Lagoon area) exhibit summer circulation patterns consistent with the descriptions above . Camden Ssy, lying fartheat 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 character sties which wi 11 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 control led primarily by the temperature regime, the extent and timing of ice cover, the wind patterns (particularly during the s-r open season), and the amount and timing of freshwater runoff.

3.4.3 Monitoring Considerations

Hackmeis ter recommended that the Beauf ort moni toring program should include:

1. Meteorologic cal data which are now being routine ly collected at stations between Barter Island and Point Barrow. These data should be processed to express climate changes in terms such as wind f requency and speed roses, and degree days.
2. 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.
3. Temperature, salinity, and other physical data collected in biological studies should be included, integrated, and eva lated to provide a description of water structure variations and permit confirmation of general circulation patterns inferred from metrological data.
4. Routine measurements of a limi tad number of physical parameters (such as water level, water temperature, and salinities) should be made at a small number of stations and should be obtained to aid confirmation of general transport and circulation patterns inferred from meteorological data.

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 spaed and direction, wave height and period, wa ter 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 i a included in Table 3-5.

TABLE 3-5

APPLICATIONS OF REMOTE SENSING TO ENVIRONMENTAL MONITORING IN THE BEAUPORT 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/see.	Telemetry - needed much processing
Water level	Similar	Nearby seafloor	Hourly	
Water temperature	Thermistor, etc.	Nearby seafloor	Hourly	Digital
Water salinity	Current meters, etc.	Nearby aeaf loor	Hourly	Digital
Wa tar 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	cm-ice	Weekly	Human interpreter
Ice temperature	thermistor, etc.	On-ice	Daily	Digital
Ice trensmissivity	Photo cell, etc.	on-ice	Week/month	Human
Dissolve 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

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 and a discussion of the advantages and disadvantages of each ecosystem component for inclusion 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 nearshore where large expanaea 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. Sighest 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 1982; Dunton 1983), primarily because of the lack of herd bottom areas suitable for attachment and because of ice disturbance of the bottom.

However, in limited areas, most notably the 'boulder patch' in Steffanson 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 1983). In these areas kelp productivity provides tha major primary input to the system (Dunton 1983). Because of the limited geographic srea and the resulting uniqueness of the biota of the boulder patch, the area has attained a high political sensi tivi ty. Schell described proprietary research in 1983 showing that waterborne silt from nearby island construct on depressed tha growth of boulder patch kelp.

Pri mar y grazers in the shallow Beaufort Sea are epibenthic and pelagic zooplankton (primarily crustaceans --copepods, myaids, euphausiids) and benthic filter feeders (including bivalves) . In the boulder patch, a chit-on (Amicula) is the dominant macroherbivore. Phytoplankton settling to the bottom are consumed by a variety of infaunal and epi - f aunal detritivores.

other than the boulder patch kelp, Schell did not think that primary producers were suitable for the BSMP because of their high variability in space and time and their expected resiliency if affected in a local area.

3.5.2 Benthos

Infaunal communities in the nearshore areas are stratified by depth. Densi ties are generally low in the bottomfast ice zone inside the 2-m i sobath. In deeper waters, infauna becomes more diverse with polychaetes and bivalves as numerical dominants (Carey 19S1; Feder and Jewett 19S2). In terms of numbers of individuals, a majority of pol ychaetes are tentaculate filter f ceders wi th increasing numbers of deposit feeders and predators below 15 m (Carey 19S1). Bivalves are primari 1 y filter f ceders, although surface deposit f ceders (e.g. Macoma) are also present. G. Robilliard (Woodward-Clyde Consultants Inc.) described studies to evaluate changes in benthic community composition induced by the Prudhoe Bay causeway. Of physical factors teated, infaunal structure was most strongly influenced by sediment grain size and depth. Robilliard pointed out that benthos are 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 in fauna 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 compose 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, ara the primary prey of a variety of important fish and birds in the Beauf ort nearshore. Carbon in these organisms is in turn derived largely from marine primary production (Schell 1982). There is a massive influx of mysids and some amphipods as the bottomfast ice melts from ths shorelines and lifts and breaks up in the lagoons (see Grif fitha 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, Griffitha cone luded that epibenthos was not well suited for inc lusion 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 f i ah--those species spending a majority of the time (spawning, juvenile rearing, and usually overwintering) in fresh or, in some cases brackish, water. Principal marine fish (e.g., Arctic cod, four-horned sculpin) are sufficiently abundant, ubiqui toua, 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 the y are of limi tsd 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, whitef ish, and char), are seasonally abundant in the nearshore of the Beaufort Sea. As described by B. Galloway (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 overwin ter in fresh water or delta areaa from August or September through the following spring. Indications from the Beaufort (Galloway) and the Chukchi (Houghton and Hilgert 1983) are that overwintering does not necessarily occur in the same system as does spawning.

In the Alaska Beauf ort, the most important anadromous species is likely the Arctic cisco, which is the subject of commercial and subsistence fisheries in the Colvil le 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 fi ah have been found in the Colville or in other Alaska rivers, Galloway '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 wea t. Broad and humpback whitef i shes general 1 y ste y closer to their home streams than the ciscoes and, as such, would be more vulnerable to locali zed rather than regionali zed impacts. Arctic char, like Arctic cisco, range widely in the coastal waters. Major populations occur from the Colvi lle east in streams with headwaters in the Brooka Range. In contras t to the situation in the Chukchi Sea, char are not subject to intense commercial or subsistence fishing in the United States Beauf ort Sea. Overwintering and spawning char in upper Colvi lle and Sagavanirktok tributaries have been indexed by aerial survey for several years (Bendock 19s3).

Galloway reported on recent field and laboratory studies (see Griffi ths and Galloway 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. Galloway described density driven and random walk models that have bsen used to predict the movement of anadromous fish around the Prudhoe say causeway. The se unverified models support the theory that anadromous fish movements are governed in part by wa tsr quality conditions encountered. In another modeling effort, Galloway has used population parameters gathered in the Colville Delta commercial fishery to model catch par unit effort in the fishery ovar 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 ths 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, birda 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 mos t abundant of these are waterfowl and shorebirds. When birds firs t 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 hsve 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 identif i ed through earlier work. The y are:

1. Plover Is land
2. Colville Delta and Thetis Island
3. Sagavanirktok River Delta and Howe/Duck Island
4. Cross Island
5. Canning River Delta (ace 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-ha tched 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:

1. Barrow Spit/Plover Island
2. Jones Island/Simpson Lagoon
3. Flaxman Island/Lef fingwell 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 Beauf ort 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 the 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 Beauf ort Sea.

Only a very small number of birds recorded on the Alaskan north slope have been identified by society as ‘important; " that is, identified as a key species or valued ecosys tem components. These may be species li steal by regulatory agencies as “rare and endangered, ” such as the peregrine falcon or eskimo curlew. They also may be species of economic or cultural importance, such as waterfowl which are hunted by sportsmen and native people; or they may be a vary abundant and widely distribute species that is easy to count and may serve as an indicator of change.

Birds can be affected by hydrocarbon development either directly, through contact with oil/fuel, or indirectly, through changes in their habitat and/or focal. 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 ba radially 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 Slops Borough) described in depth the importance of marine mammals to the Inuit people of the North S1OPS 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 spscies makes its spring migration from the Bering Sea in open leads near Barrow, then heads east tu 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 d-ented in Alaska waters at least between the border and Camden Bay. Albert suggested this area may be a critical habitat for the bowhead providing them 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 ware in prehistoric days . The food provided by the whales is highly prizad 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 Beauf ort (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 boat 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 notad where whales were approached by boats and aircraft. By far the greatest source of water-borne 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 off shore from their usual pstterns, increasing overwater distances that must be traveled in the hunt. Concern is also growing that this same displacement may interfere with the Kaktovik hunt.

These native concerns and the bowhead's endangerad status have resulted in a number of recent and ongoing research proj acts on the bowhead whale (Sections 2.4.2 and 2 .4.4) . The status of bowhead research has baen 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 (1983).

Albert reported that next to the bowhead whale, the most impor tent marine mammal in the araa of concern is the ringed seal, followed by the bearded seal. Both are ice-associated species with ringed seals widely distributed acress the landf ast ice zone in winter. Aerial censusing has been conducted by Alaska Department of Fish and Game for several years in various areas of the Beaufort Shelf (e.g., Burna ● t al. 1981 ; Burns and Kelley 1982). These data provide a reliable baseline index of ringed seal numbers in the area. Johnson described use of this aerial censusing of ringed seal holes to assess the effects of ice road construction and operation in the Seal Island sraa off Prudhoe BSy. The technique was sufficiently robust to detect a significant positive correlation of hole density with distance from the ice road and gravel island.

Other marine mammals in the Beaufort Sea such as bearded seal, walrus, and beluga whales were not discussed in any detail at the workshop.

3.6 MONITORING INDICES ANO APPROACHES

3.6.1 Geochemical Indices

Oil and gas exploration and development activities may result in the introduction of hydrocarbon end trace metal contaminants into the Beauf ort Sea ecosys tam. In order to asseas 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. Since both trace metals and hydrocarbons are found naturally in marine ecosys tams, it is usually difficult to interpret dab 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 then the characteristic composition of environmental samples that reflect natural hydrocarbon and trace metal sources. Theref ore, the use of geochemical indices (ratios of elements and compounds, or indices depsndent 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 tha potential use of hydrocarbon indices in the Beauf ort Sea. His presentation was supported by a paper giving de tai led descriptions of the use of various hydrocarbon indices and proposing a sampling and analysis scheme to utilize these indices in moni toring oil and gas development inputs to the Beaufort Sea ecosystem. The remainder of this section summarizes the major points of Boehm' a 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 f ecus on sampling areas where the biota may be exposed to waterborne hydrocarbons snd where hydrocarbon residues may ultimately be transported. Extensive studies of the transport of spi had 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 sre high. Because the resulting water column hydrocarbon concentrations are very low and variable, moni toring of instantaneous hydrocarbon concentration in the water column is of little value except in the area of a major spill. 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 f i ltered 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 wi 11 generally only ha 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 ● xposure of marine benthos to hydrocarbons should ba 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 surface 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 ba 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 aedimented. 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 sane 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 pert 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 sits. In the site-specific sampling program or if there is a spi 11, hydrocarbon analysis should be performed on all samples initially by W fluorescence, which is a good low-cost screening measure, and by a more detailed compositional analysis (gas chromotography and mass spectrometry) on a subset of samples, including those samples showing elevated oil concentrations via the W fluorescence measurements. For the regional sampling, compositional analysis should be psrf ormed on all samples analyzed, although the number of samples taken should be higher than the number analyzed to reduce costs, and al l samples should be stored for future possible analysis.

Compositional data can be used to investigate changes in hydrocarbon levels snd 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 eny samples taken to assess biological population structure and health. The monitoring program should be aware of the existence of numerous natural deeps in the Beauf ort region, including those in Simpson Lagoon, nesr Umiak, and near the Colville River delta which empties into Harrison Say.

Although not extensively addressed by the workshop, metals analysis and analysis of organics, such as lignosulf onates, should be emphasized during monitoring of exploration activi ti es, while hydrocarbon analysis should be emphasized during monitoring of production activities and spill si tuations. 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

TABLE 34

HYDROCARBON INDICATOR COMPOUNDS OR GROUPS

1. Total n-alkanes:	Quantifies n-alkanes from $n\text{-}C_{15}$ to $n\text{-}C_{34}$; 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 $[C_{10}\text{-}C_{20})$:	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 quanti ties of phytane.
4. Total polyaromatic hydrocarbons (PAH):	The sum of 2-5 ringed aromatics is a good quantitative indicator of petrogencic 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 Ratio (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 Ratio (ISO/ALK); Phytane/$n\text{-}C_{18}$ 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 rage. Those parameters are useful indicators of the extent of biodegradation.
8. Pristane/Phytane Ratio:	The source of phytane is mainly petroleum, while pristane is derived from both biological matter and oil. In "clean" samples, this ratio is very 10. 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 moni tor 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 Particle. (i . . . . high silt/clay content) . Small (tens of ppm) additions of petroleum to the sediment cause the ratio to increase dramatically, since n-alkanes {rig/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 activity 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 PAH compounds; fossil fuels are highly enriched in 2-3 ringed PAH and polynuclear organo-sulfur compounds [..9. , 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 PAH sources .
14. Biomarkers :	The pentacyclic triterpane distributions in sediments from the Beaufort Sea are primarily derived from biogenic sources. 22 petroleum is added, the ratio of triterpane stereoisomers changes and oil is detected at low 1*-11.

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 Section 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

Contaminan t inputa to the marine environment can affect the microbial communities either through the introduction of nonindigenous mic roorganisms (usually sewage-related) or through alteration of tba 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 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 should be limited to . the sediments. Moreove, 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-indicatnr organism analyses (e. g., for E. coli and other coliforms) could be misleading since certain pathogens may survive longer then 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 ths region, sewage pollution will not conceivably become significant in the Beaufort, and the simple precautions of compliance monitoring and limited seafood harvesting immediately adjacent to known sewage inputs wi 11 provide tota lly adequa te 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 species ia 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). Nhen hydrocarbons are added to the sediments by spills, this population size increases rapidly, often by several orders of magnitude (to 0.1 percent or more). Populations of hydrocarbon-degraders alao increase in response to chronic low-level inputs. However, the rate of increa se 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 108/9)	MPN(b) Hydrocarbon Utilizers (Number/g)	Percent of Hydrocarbon Utilizers in Total Population
0	4.9	30	6.1 X 10-6
0.5 hours	4.7	40	S.5 x 10-6
72 hours	4.5	40	8.9 X 10-6
1 month	5.0	210	4.2 X 10^{-5}
4 months	6.2	420	6.S X 10-5
8 months	4.s	2,100	4.4 x 10-4
1 year	5.3	2,100	4.0 x 10-4
1 -1/2 years	5.1	2,800	5.5 x 10-4
2 years	5.9	24,000	4.1 x 10-3

(a) Source: Atlas, this workshop.
(b) NNP - 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. ibis approach also has several disadvantages, including the tedious and moderately expensive analytical methodology required and the inherent imprecision of microbial popula tion assays. However, the major disadvantage is that the method does not distinguish between biogenic end petrogenic sources of hydrocarbons snd, therefore, cannot distinguish between oil and gas development related inputs and natural seeps, changes in land runoff (pa at hydrocarbons), 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 in faunal communities. Therefore, it is possible to perf orm microbial community structure analysis in a similar manner to benthic infaunal community structure analysis and to develop indices of contamination comparable to the benthic infaunal index. However, studies of microbial community structure and its response to contamination are not extensive end, consequently, there are only limited dats on which to base interpretation of any observed community structure changes. Further, very extensive and expensive analysis snd data acquisition are required for microbial community structure analysis.

A second type of microbial community analysis which could be appli ed to moni toring for hydrocarbon or heavy meta l contamination of the Beauf ort Sea is the analysis of change in the abundance of plasmids in the population which cede for resistance to these contaminants. 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 tbe lack of knowledge concerning the natural abundance and variabili ty of the appropriate plasmids in the Beauf ort Sea, and the fact that an increase in tba 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 understock.

The final basic approach to monitoring contamination of the marine environment through microbial studies is measurement of the indicator activities of the organisms. 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 in not presently useful in defining pollutant effect. In addition, methodologies for such analyses are tedious and expsnsive.

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 thst chronic or acute contaminant inputs of hydrocarbons, other organics, and heavy metals will become adsorbed 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 described several approaches to the monitoring of biological populations for contaminant-induced ●ffects. 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 which may be caused by the combination of a variety of lethal or sublethal effects on one or more sensitive spacies and/or by changes in the physical or chemical environment which 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 can be used, such as the microbes, plankton, nekton, and epibenthos. Members of the community are counted end 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, rare faction 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 arid/or temporal variability, the causes of which are poorly understock. 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 moni to ring may be particularl y a eve re 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 f luctuations, 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 compli ante monitoring than for the proposed regional program.

Nef f introduced two new approaches to benthi c infaunal moni toring 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 ha sampled. Such sampling would f acili tste 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 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 SYS tam 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 bean directed more toward the development of techniques for measuring the sublethal effects of pollutants on individual organi ams 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 non-pollutant 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-S.

A number of biochemical changes have baen 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 metaboli sm much more precisely than most invertebrates, attempts to apply these same biochemical parameters to benthic invertsbra tes have generally met with little success.

Generally, monitoring of fish populations for pollutant stress is most effectively performed by studying a number of different morpho-logic 1, biochemical, and physiological changes simultaneous y. Fish exposed to pollutants, including petroleum, may respond with a variety of simultaneous changes, including increased disease incidence, and a variety of hi stopa theological 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 organi am became exposed. However, several species of demersal fish appear to make only limi tad migrations and have been shown to be good indicators of pollutant effects at a given sita. In the Beauf ort Sea, the Arctic cud (*Boreogadus saida*), the fourhorn sculpin (*Myoxocephalus quadricornis*), and possibly the Arctic f lounder (*Liopsetta glacialis*) may be sui table monitoring species because of their abundance and generally demersal life style.

TABLE 3-8

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

Measurement Type	DascriptiOn
Ecosys tam 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.9., 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 Ef fects	Activity of toxification/de toxification systems Blood enzymes Tissue biochemical

(a) Source: Nef f, this workshop

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 Oxygenase	Induction	Exposure to petroleum, PCB, dioxin, PAH
Blood Enzymes	Increased activity	Liver damage
Erythrocyte Aladase	Decreased activity	Lead poisoning
Tissue Enzymes	Change in activity	Unknown for most enzymes
Gill Atpases	Change in activity	Impaired osmoregulation
Achease	Oscreased activity	Exposure to organophosphate or organochlorine pesticides or some industrial chemicals
Blood Biochemical	Change in concentration	Acute pollutant stress
Tissue Biochemicals	Change in concentration or tisue distribution	Chronic pollutant stress

(a) Source: Neff, this workshop.

TABLE 3-10

USE OF FISH TISSUE BIOCHEMICAL 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 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 hypoxia, muscle exhaustion
Sialic acid	Gill	Decrease	Mucus hypersecretion, irritation
Glutathione	Liver, kidney	Increase	Pollutant detoxification
Ascorbic acid	Liver, kidney, gill, brain	Increase or Decrease	Mobilization and redistribution for tissue repair and detoxification, chronic stress
Collagen	Bones, connective tissue	Decrease	Ascorbate depletion
Catecholamines	Brain	Decrease	Acute or chronic stress

(a) Source: Neff, this workshop.

Another group of organisms which could be monitored for sublethal stress are 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 bioenerge tic 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 cyto-chemical 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 lead/biological response relationship.

Nef f sugges tsd an appropriate Beauf ort Sea monitoring program might include:

1. Ecological analysis of benthic community characteristics along pollution gradients (age/size structure and reproduction/ recruitment of dominant benthic specis, sediment profile imaging).

2. Chronic sublethal effects studies:

   a. 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)

   b. Reciprocal transplants of bivalve molluscs, such as Asterte, with studies on contaminant bioaccumulation, scope for growth, o/N ratio, condition index, and biochemical composition

   c. Indicator organisms, such as benthic/demersal amphipcds, 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 O (100 percent subsurface deposit feeders) to 100 (100 percent suspension [filter] feeders). The typical response seen off of 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. 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 development petroleum hydrocarbons will be the major potential source of increased organic material in the sediments, means other than ITI might be more effective monitoring tools. 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 felt that this ITI might be of less value than elsewhere as a component of an areawide 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 Saaufort 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 ths last day of the session, D. Wolfe (NOAA) attempted to clarify the significance of monitoring to the management of OCS lands. His premise is that monitoring is, in essence, a managemnt 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 move to ask which of these detected changes are important end finally which are oil and gas related. Rather, the manager should ask in turn:

- 0 What important OCS oil and gas development related effects do we wish to avoid?
- 0 How can we avoid them?
- 0 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 ecos ys tsm are important (human health; valued ecosys tsm components--VECs) in our perception of quali ty of ths environment (e .g. , marine mammals, birds, fish, commercial or subsistence species) . Second, the manner in which the ecosys tern functions to support and sustain the VECs must be understock; 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 Beauf ort Sea include such things as contaminant exposure (hydrocarbons, metals), disturbance effects (noise r activities) , circulation changes (currents, water quality), and oil spills (Section 3.2).

The manager then must go beck to the question: If the sys tam works as we think it does, how can we avoid the pos tulated ● f f ects of concern? Management of activities is typically based on two hypotheses:

1. Regulatory stipula tions, di scharge and receiving wa tar cri taria, etc. will prevent significant near field effects (i.e., outside of a mixing zone or direct impact zone).
2. If You can' t detect effects in the near field there probably won' t be detachable effects in the far field.

These management hypotheses lead to two kinds of monitoring:

1. Compliance Monitoring - for example, inspection or measurement of construction or drilling activities and discharges - to ensure that the activity is conducted as prescribed.
2. Nearfield 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 detscting 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 wi th such far field monitoring programs is that cause-ef feet relationships may be very hard to establish; thus, it may be vary hard to use the knowledge that an impact has occurred to make managment decisions alleviating the cause. Nonetheless, some potential effects may be so important that managers would want to know about them even if they cannot pinpnint 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 asseas changes, their significance, and their causes.

In summary, Wolfe emphasized ths t:

1. Criteria for variable selection should include:
   a. Value placed on the resource
   b. Credibility of a hypothesized impact mechanism
   c. Perceived risk to the resource
   d. Testability of the hypothesis of impact in terms of statistical strength and expected cost of measurements required.
2. 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).
3. Monitoring must be adaptable to react to changes in OCS development direction and to changes indicated by previous results obtained.
4. Managers and scientists must eak "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, the workshop panel developed a specific set of objectives for the BSMP as follows:

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

3.7.2 Proposed Hypothesea and Approaches to Regionwide Monitoring

The workshop panel developed seven "strawman" hypotheses and methods to tast 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 well each hypothesis fita the stated objectives for the BSMP (Section 3.6.1). Related considerations 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 workship 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 environmental 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 tast and control sites. No discussion took place as to which metals were those of concern. However, earlier in the workshop, barium snd chromium had been identified as the only two heavy metals which 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 felt 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 temporal ly and spa tial ly, is so large that monitoring di ssolved contaminant concentrations would require an impractically large number of samples to 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 felt 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 felt it was important to utilize species indigenous to the Beaufort sea, but the possibility was discussed of monitoring transplanted or laboratory-reared population of suitable indigenous species which are not naturally abundant in all perta of the Beaufort. The question of whether transplanted populations should be caged or introduced into the ●nvironment •t ●ppropriate sites without such ●nclosures 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 sitas in the manner of tha 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. Therafore, 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 wsre included with the trace metal discussions and were 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 tn 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 which should be considered in selecting a sentinel organism species. One of the important considerations in selecting a sentinel species ia the degree of mobility of the organism. A sedentary species sampled from a gi van site will have a body burden of contaminants which generally reflects the degree of contamination at that site. In addition, a sedentary organism is more suitable for caged or transplant ● xparimenta. In contrast, migratory species may reflect contamination of ● nvironments far removed from the sampling site. Therefore, sedentary species are preferred as sentinel organisms since they can provide more information as to the extent end 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 f ood chains, they are known to be more likely to accumulate greater concentrations of hydrophobic pa troleum hydrocarbons through bioaccumula tion and/or bio-magnification. For these reasons, workshop participants felt that hydrocarbon concentrations in selected higher order animals, particularly bowhead whales, should be monitored. Because several of these mammals are statutorily protected, 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 felt that it would be appropriate to include some biochemical and/or histopathological measurements of the ‘health” of the captured animals.

3.7.2.3 Bowhead Whales

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

No monitoring strategy for testing this hypothesis was included in the convenor's presentation of the panel’s recommendations, largely due to lack of time. However, this omission also reflects a disagreement which surfaced a number of times during the workshop as to whether marine mammals should be included in BSMP. Some participants felt that because the bowhead is an andangered species, necessary bowhead research is appropriately and adequately covered under ●xisting MMS programs. Others argued thet the mandate of this workshop was to develop an overall monitoring program for the Beaufort Sea, therefore marine mammals should certainly be included. However, f●w workshop participants were experts in the area of marine mammal research, so even those who felt the moni toring program should include marine mammals were hesi tsnt to make specific recommendations for monitoring them.

Two important points were made in the discussion subsequent to the presentation of the hypotheses and moni toring strategies. The first was that, particularly in the context of Wolfe's "redefinition of monitoring program objectives" with its emphas is on 'Valued Ecosys tern Components, " 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 date 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. The y are reported by Ljungblad et al. (1980; 1981; 1982; 1983) and by Reeves et al. (1983).

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/recrui tment of anadromous fishes.

Several species of anadromous f ish (Arctic and least cisco, broad and humpback whitafiah, Arctic char) qualify as VECs based on commercial and subsistence use or potential uae. As a result of their life history

(Section 3.5.3) they 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 data bases exist which 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 of (CPUE) Arctic cisco in the Colville River commercial fishery. Mr. B. 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 Colvil le. Galloway has compiled these data (1967-1 981) 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 woula 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) then programs would bs initiated to investigate the cause(s) .

The workshop also recommended investigation of other potential date 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 yeara of aerial index counts of char spawning or overwintering in several North Slops rivers (see next section, Figure 4-3).

Legend

— CPUE

-— -- Predicted CPUE

---------- Population estimate

Figure 3-4 Population trends of Arctic cisco based upon CPUE, model, and mark-recapture data from the Helmericks' Commercial Fishery, 1967-1981 (Galloway, this workshop)

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 some 5 to 7 years' of data from systematic aerial counts of flightless male oldsquaws in areas of Simpson Lagoon and has established survey tracks ● lsewhere 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.

The recommended approach for testing of this hypothesis waa to con tinue, 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 likewi ae 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 reslut from OCS activities. It was thought 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 ware not widely sought as a subsistence resource (cf. other weterf owl) and thus are not the most valued avian ecosys tam component.

Nonetheless the workshop consensus was that, given the regionwide abundance of oldsquaw and the existing data base, this monitoring appr oach would be the best indicator of ocs development effects on waterf awl.

3.7.3 Related Considerations

In order to optimize the monitoring program outlined in the preceding section and to ● nsble optimum interpretation of the data generated, the workshop briefly discussed and endorsed several concepts thst should be incorporated into the overall program.

3.7.3.1 Physical Environmental Data

In order to interpret changes in biological populations and in environmental concentrations of chemical contaminant 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 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 ga thering 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 perimeters, such as salinity, temperature, and currents. The information gathered should be capable of identifying anomalies in climate-controlled factors which 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 spscies, primary production, and the availability of f ood for certain species. In addition, abnormally severe or qui ascent weather, particularly during ice f ormation and breakup, and during the open water pe riod, could modify primary production, ice scour, and wind-induced wave and current redistribution of bottom sediments.

The need for "climate" information csn be illustrated by three examples of rapid biological population structure changes which 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 the t this natural event had reduced the Christmas Island birds' focal 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 araa, and therefore, these physical changes resulted in the Chesapeake Bay ef fects. 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 which revealed that anomalous physical conditions caused this event. unusual weather in the winter and spring cabined with a prolonged @ascent period to reduce the flushing rate of shelf bottom waters and to cause onshore movement and concentration of a natural mid shelf phytoplankton bloom. The bloom resulted in anomalously high natural oxygen demsnd, 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 thst unjustified policy decisions concerning contamination of the marine environment could have been made on the basis of biological monitoring data. The se data showed an effect that reasonably could have been caused by pollution, if "climate" inf ormation had not be available. However, in each instance, very limi ted information concerning the anomalous climatic forcing functions opera ti ng during the period when the biological changes took place, combined with a sound basic knowledge of the relevant ecosys tam, 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, this type of information can be obtained primarily from existing observations, such as river flow rate records, weather records, and satellite images. These existing information bases should be routinely accessed for the BSMP and processed to provide, if possible, an annual description of, at least, the following information: monthly (except in the winter) patterns of ice cover and, where possible, estimated thickness; weekly, or more frequent, discharge ratas for the 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 neces sari 1 y compromise the monitoring program and it probably wi 11 not be necessary to develop extenai ve long-term monitoring programs to f il 1 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, if several limited surveys of the plumes were conducted over one or more spring periods, or the information could be inferred on the basis of existing knowledge of plume distribution for some rivers.

In addition to the BSMP, there will continue to be many other ongoing and ps riodic monitoring programs in the Beauf ort Sea, such as discharge compliance programs, for which physical data, including wa tsr column structure and current data, are obtsined. Where appropriate, these data should be acquired on a routine basis by the BSMP and subjected to analysis and interpretation to supplement the mora general regional data discussed previously. Such analyses become particularly important when it is suspected that anomalous climatic conditions may have contributed to any observed biological or chemical contaminant distribution change. Physical data from any moni to ring program should clearl y be incorpora tad in a single da ta management sys tem for maximum utility (see below).

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 sophisticated. For ●xample, hydrocarbon and trace metal analyses will be performed at very low environmental concentrations. Since the monitoring program will be aimed at detecting small changes and trends in these environmental concentrations, it is imperative that the analyses produce consistent, accurate, and reproducible results, both within a given set of samples and over the years of program operation. These results can only be achieved if the measurement program is psrformed 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.

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 end information management system in place. Although conceptually the data and information management system can be added to an existing program, this rarely occurs and, when it does, it ia usually found to be neither possible nor affordable to incorporate data already gathered into a nsw 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 Concentration; 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; and 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 retractive 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 thought that small quantities of all samples should be archived in their original vet atate, frozen to below -80°F. 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 thought to be important that, to the extent possible, all biological and sediment sampling should be coordinated in time snd space. This will provide the maximum ability to interpret changes in the various parameters monitored.

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

The workshop considered in some detail the potential use of measurement techniques which 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

Hypothe sis VI: OCS operations on or near islands may cause changes in nesting popula ti ona of common eiders.

Since at least the late 1970s, concern has baen expressed that activities on or nesr barrier islands might disrupt breeding activities of waterfowl. stipulations attached to recent state and federal lease sales hsve restricted proximity of certain operations (e .g., aerial overflights) to sensitive wildlife hsbitsts. Despi te 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 thase activities could disrupt breeding success. Of particular concern are colonies of common eider thst 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 (e.g., 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 aiders. Permission was granted provided that Sohio operate primarily on the aide 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. 'l'he study included mapping of nesting sites within the colony and observations through the brooding period of nesting behavior and hatching success. A higher thsn usual success rate was reported despite the nearby activities, perhaps because direct close range disturbance of the colony was prohibited. Praker (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 moni toring 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 wimilar 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 biopoli tically sensitive area because of i ta unique epili thic 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).

The community as a whole is very stable from year to year (Dunton 1983) 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 rata of *Laminaria solidungula* because of the ease in making nondestructive measurements and because of its importance in boulder patch energy budgets (Dunton 1983).

Schell reported at the workshop on proprietary studies for Exxon that demonstrated a reduction in *Laminaria* productivity attributed to nearby gravel island construction. Dun ton (19S3) showed a significantly greater mean annual blade elongation for this species at a study sita under clear ice compared with normal growth under turbid ice cover (see Section 4.2.7). Proprietary study reports of the Exxon monitoring may be available in early 1984 expanding the available data base by 2 years.

The workshop recognized that this hypothesis and monitoring approach is most appropriate for site-spscific 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 indica tors of organism health in the Beauf ort monitoring program:

1. Biological effect measurements have generally not been extensively used in monitoring programs since the resulting data are difficult to interpret in a manner which can aid management. Biological health measurement techniques have generally led to

data which 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.

2. Biological health ef feet techniques are not readily applicable to the fish, bird, snd —1 species of major importance in the Beauf ort.
3. Biological health measurements may be more appropriate for near-field effects study or monitoring since it would be easier to relate cause and effect.
4. 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

No specific physical environment monitoring f ield programs were endorsed 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:

1. 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 sits of a specific activity can be monitored more effectively through specific activity stud y or compliance monitoring.
2. Significant broad-scale natural changes in the phys ical environment of the Beaufort can be observed or inferred from information regarding the meteorological forcing functions end certain simple response parameters, such as sea surface tampsrature, 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 variabili ty. Many, if not all, 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 interpretad, as proposed in Section 3.7.3.

3. 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, broad-scale data to identify near-field physical environment changes or anomalies that may affect the biota. In this manner, an assessment can be made aa 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 the re 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 inf auna. As was noted by several participants, inf auna has been the primary or exclusive biological group targetad 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:

1. Major pollutants of concern (drilling fluids, hydrocarbons) will ultimately reside in the sediments where exposure to organisms will be maximized.
2. Inf auna and sessile epi f auna hava limited mobility and are often long lived so that organisms present at a given location and time will hsve been exposed to conditions at that location over an extended period.
3. 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).

4. 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 lead to its exclusion from the workshop recommended monitoring program, is that, in the Beaufort Sea neashore ecosystem there is little proven linkage between infauna and higher trophic levels on 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 cliff erent farther offshore or under ice where there is much less data on trophic relationships. For example, f latfish (e.g., Arctic flounder) are likely predators on inf auna and are increasing ly abundant offshore. It was also noted that bearded seal and walrus (which are becoming increasingly abundant in the western Beauf ort) are heavily dependent on benthos and that mysids and amphipods, which are a major focal source for VSCS, 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 date base (Tetra Tech 1983). He showed, for example, that with 10 replicates par 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 (e.g., due to the Prudhoe Say causeway) then 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.

4.0 STATISTICAL EVALUATIONS

4.1 GENERAL CONSIDERATIONS

Our statistical evaluations were restricted by the raquirament to only examine available date on those variables mandated by the hypotheses end monitoring strategies developed in the workshop synthesis session. The optimal statistical design of a monitoring program without such a constraint would involve considering available date on all possible 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 need to be unconstrained in terms of time and money as well as in terms of variables and hypotheses!

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 ecos ystem being moni tored than could hs 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 which 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 date are inadequate for the solution of the design problem. In those casea, we have attempted to achieve a robust and flexible design which will fill the data gaps. After a year or so of moni tnring, the data obtained should be evaluated to see if modifications to the initial sampling scheme are wsrremted.

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 Alaskan environmental studies program managed by OCSEAP, the Prudhoe Bay Waterf local 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 activi ti es. Only the first of these has been dealt with in our statistical analyses.

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.

H_o2 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 Venketesan (1961) deal wi tb distribution end concentration of hydrocarbons farther offshore. Data on heavy metal concentrations were obtained and summarized by Burrell (1977, 197S) end Naidu et al. (1961 b).

TABLE 4-1

RESTATEMENT OF HYPOTHESES FOR STATISTICAL TESTING

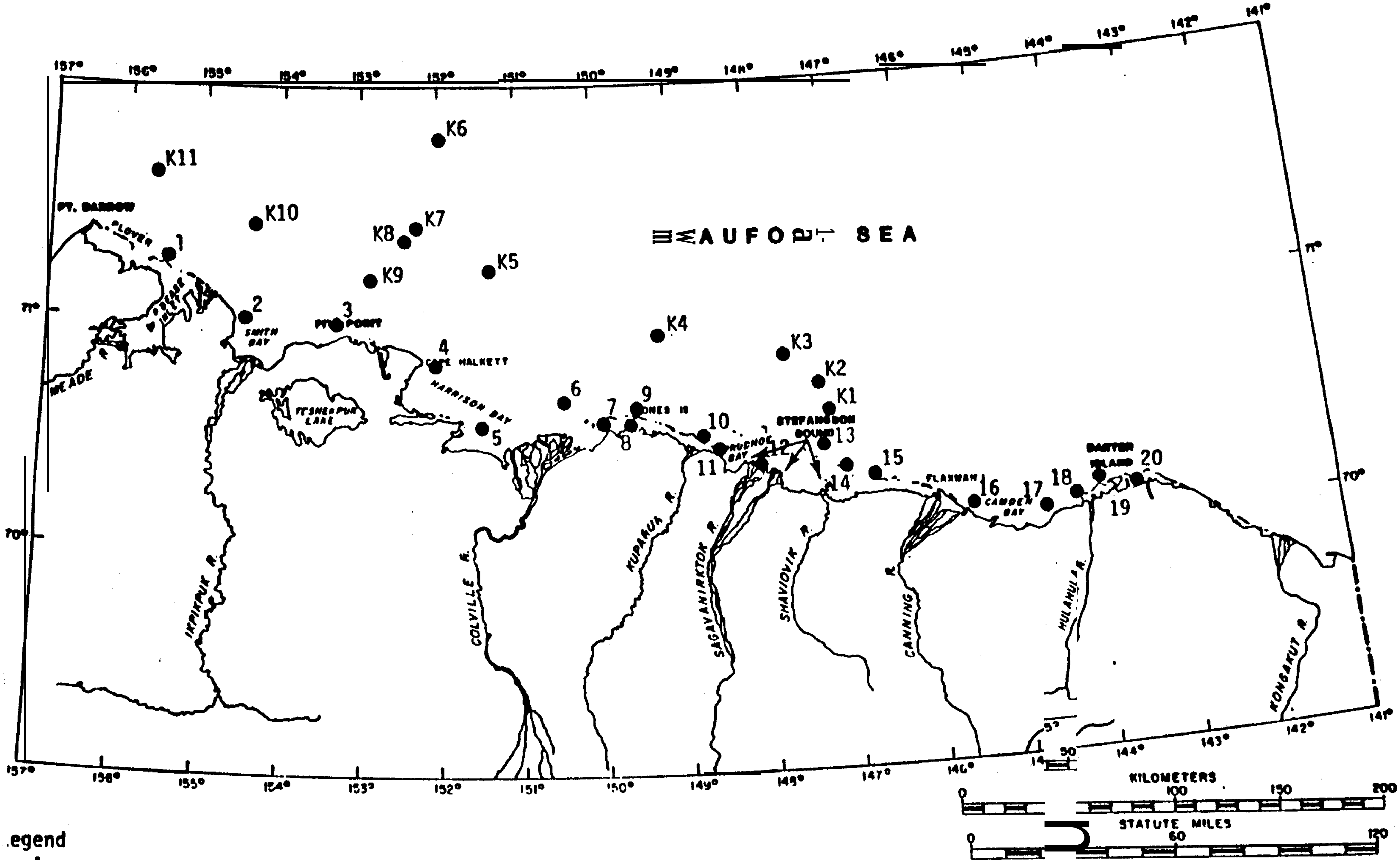
Working Hypotheses[a]		Restatement
I & II	H_o 1	There will be no change in concentrations of selected metals or hydrocarbons in surficial sediments.
	H_o 2	Changes in concentrations of selected ❑etils or hydrocarbons are not related to OCS oil and gas development activity.
	H_o 3	There will be no change in concentrations of selected metals or hydrocarbons in the selected indicator organisms.
	H_o 4	Changes in selected metals in sediments or organisms or hydrocarbon levels will not affect human health or VECs.
III	H_o 1	Fall migration patterns 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 ha no change in density or hatching success of common eiders on islands subjected to disturbance by OCS oi 1 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 <u>Laminaria solidungula</u> in areas of the Boulder Patch nearest OCS oil and gas development activity.
	H_o 2	Changes in <u>Laminaria solidungula</u> productivi ty 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.

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 determination 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. (1981 b).

These data provide a good description of baseline conditions. In general, they indicate an unpolluted environment, although some polycyclic aromatic hydrocarbons (PAH) ware 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 which flow over outcrops, tar sands, etc.

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 spa tial patchiness cannot be separated from site-to-sits 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 assumption about variability in hydrocarbon concentrations that are baaed on measurements made several years ago.



Legend
● 1 Station from Shaw (1977)
● K1 Station from Kaplan and Venkatesan (1981)

Figure 4-1 Area-wide sediment chemistry sampling stations

Source: Boehm, this workshop.

However, there were also problems in using the trace metal data. First, we were unable to obtain date on concentrations of barium, one of the metals of primary intereat 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 taps and dats tabulated in reports. For ● xample, copper and zinc determinations on the taps matched those in Naidu et al. (1981a) but different values ware given for the other metals. Third, while there appeared tu be some replicate samples and analyses, the y were not unambiguously identified. There were no good time aariea 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 sampling sites.

Clearly, a pervasive areawide change could be detacted with any design D while a large point impact affecting only a single site could only be detscted 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, 1, ... k. Finally, we assumed that we can assign probabilities Pi (with $p_1+p_2+...+k=1$) that if .s 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 ha 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 detachable changes depend on the probabilities Pi 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 pos tdevelopment 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 pos tdevelopment sampling was not used in tbis 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:

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

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 sits snd then, at each step, the "best" block for the next site, given that the sites determined at the prevoius 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 vari since. 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, Hamedi, Manen, Zimmerman, and other workshop participants.

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

H_O3 There will be no change in concentration of selected metals or hydrocarbons in the selected sentinel organism(s) .

We were able to obtain few data on tissue concentrations of hydrocarbons and none on heavy me tals in Beauf ort 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 *Myti lus* tissue area available from other Alaskan locations. Our sts tis tical evaluations also relied on the experiences of mussel watch

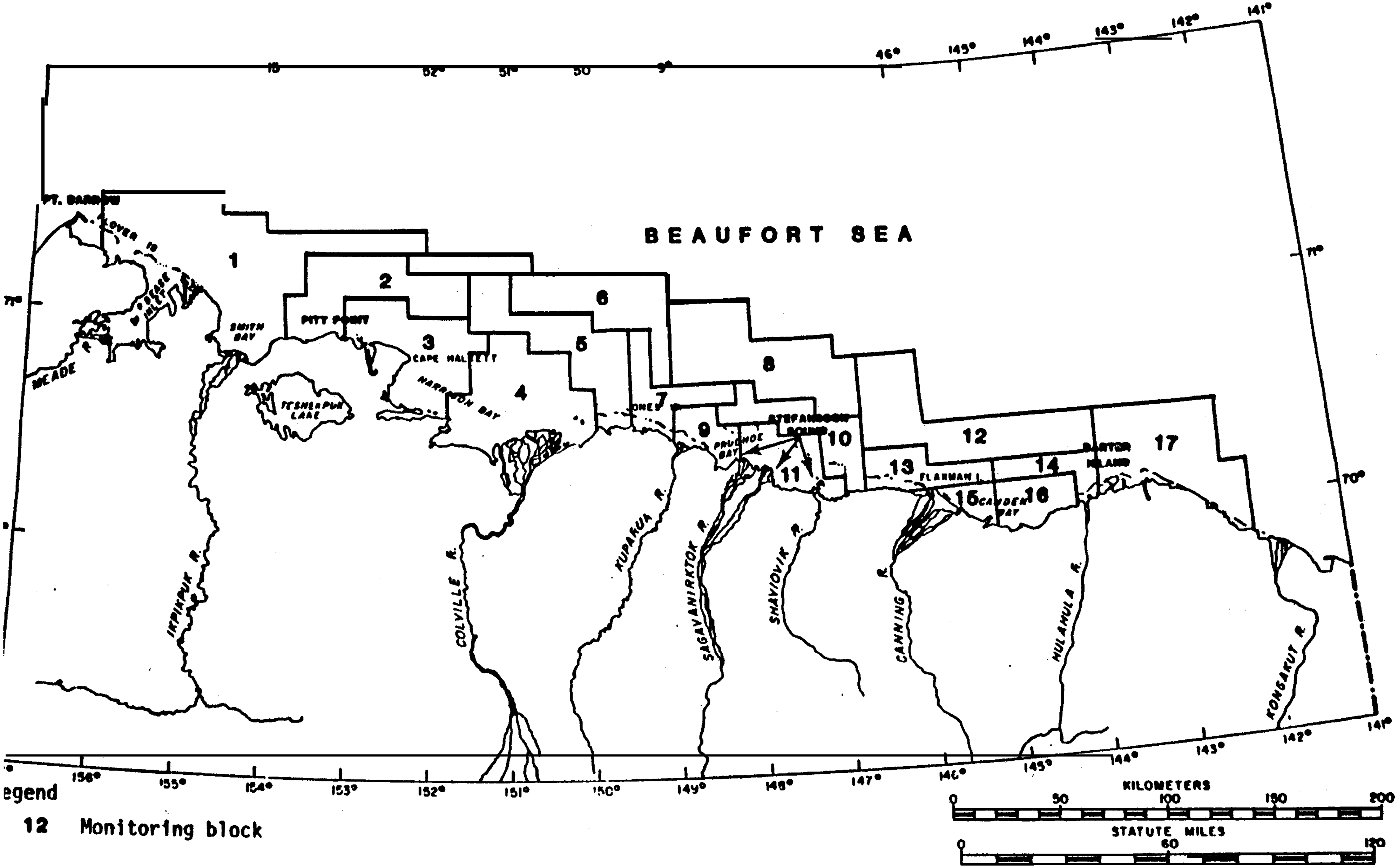


Figure 4-2 Sediment monitoring network block configurations

programs in other areas, summarized for the most part in R. Flegal 's workshop presentation and in The International Mussel Watch (1980).

Shaw (1981) analyzed six samples of approximately 10 g wet weight collected in Elson Lagoon (just •ast of Barrow) and Tigvaviak Island (70″16.1 'N, 147″38 .0'W) using gas chromatography. He found striking 1 y low concentrations of hydrocarbons, many below de tectable levels. For example, the mean concentration of total unsaturated hydrocarbon in the four *Astarte* samples from ElSon Lagoon wss 0.43 mg/kg and the standard deviation, was 0.19 on a wet weight basis. Aroma tic hydrocarbon concentrations were low as well. The values in Shaw (1977) are not precisely comparable 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 ❑easurements from other parts of the world and finds the Alaskan values to be among the lowest. He does not report standard deviations for these measure-ments, but the determinations on standard reference materials in Burrell (1977) indicate that his accuracy and precision meet National Bureau of Standards criteria. Even year-to- year change in metal concentrations appears to be fairly small; cadmium dets rmined 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. These values are comparable to mussel watch values on the United States west coast preeented by Flegal 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 to represent a population for chemical assay a minumum of 25 mussels be used. For the 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 variabili ty due to analytical error, within-site differences, and be~een-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 the report, standard reference materials for trace-level hydrocarbons in mussel tissue cannot be i ssued un ti 1 problems associated with sample homogeneity, storage s tsbi li ty, and matrix effects are resolved. Results by Dunn (1976) on the precision of analyses of mussel homogenates for benzo(a)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 laboratory es was shown in some cases. In other cases, measurements among laboratori es differed by a factor of 2 or even by an order of magnitude or more. These discrepancies accentuate the need for stsndardization of analysis techniques and intra- and interlaboratory calibrations, especially in the earl y stages of the Beauf ort Sea mussel watch.

4.2.3 Bowhead Whale

Rests ted Hypotheses:

H_o1 Fall migration patterns of bowhead wales will not be altered during periods of increased OCS activities in the United Ststes Beaufort Sea.

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

According to Ljungblad et al. (1983), the fall bowhead whale migration appears to have an "offshore" componen t through deep wste rs 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 snd gas development activity and is also most important to humans on the North Slope, especially subsistence huntera from Kaktovik, Nuiksut, and Barrow. We have therefore concentrated en September and October data in our analyses of HOI .

Ljungblad (1983) notes that routes of the fall bowhead migration in the yesra of heavy ice cover, 1980 and 1983, are more difficult either to observe or to predict than in lighter ice years. It is likely that in aevere 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 ba impossible to separate ice-caused from man-caused effects. We hsve therefore restricted our analyses to dats from the light ice years 1979, 1981, and 1982.

Objectives of the fall aerial surveys hsve differed from year to yesr with consequent shifts in areas surveyed and methods used (L jungblad et al. 1983). In 1979 nearly all effort was concentrated near the proposed state/federal oil lease areas, with random north-south trsnsects 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 flighta 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. Aa a result, relatively few random transect survey date were obtained. In 1982, two aircraft were provided for fall towhead studies. Thus, a fairly complete survey of the entire area from 141 'W to 1 57°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 deptha. The first four depth strata in the two eastern sections were adequately surveyed in all three of the years we are considering.

Peek bowhead densities during September and October in 1979, 1981, and 1982 occurred in the 20-m to 50-m stratum. Of the 499 whales observed between these longitudes during September and October of 1979, 19S1, and 1982, 450 were in the 20-m to 50-m stratum. The second highest densities were usually in the 10-m to 20-m stratum but occasionally in the 50-m to 200-m stratum. NO whales were seen in the O-m to 10-m stratum. Absolute density values varied considerably from year to year. For example, confidence ranges given in Table B-13 of Lj ungblad et al. (19S3) indicate that densities in the 20-m to 50-m stratum between 146"W and 150"W ware 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-m and 50-m depth contours. The distance between these contour lines is roughly 20 nautical miles (rim) in the eastern half of the United

States Beaufort, narrowing in much of the western half, particularly north of Harrison say 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 Bsy, can be formulated as a shift to following deeper depth contours, with a 3-m depth change corresponding roughly to 2-rim displacement.

It was not possible to refine Ljungblad's analyses to determine relative densities within the 20-m 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 or 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 which might be attributable to OCS development would be hsrd 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 statistic we propose is the median water depth for bowhe ad 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. For exsmple, the region east of Camden Bay is the region east of 146°W 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 is a particularly robust statistic for defining the center of the migration path, 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-m or 30-m depth contour.

We used the median depth of <u>sightings</u> rather than of <u>individual whales</u> 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 sre 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 19S2 appeared to represent thorough cove rage 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 which 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 ●ast 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 te sts for homogeneity of other years' depth distributions and the 1982 di stribution could also be performed if a more complicated change in the migration path than a simple abif t in the median depth is suspected. This test is discussed in more detail in Appendix C.

We were unable to parf orm any of these tests on the 1979 and 1981 data because water deptha 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 lati tude and longi tude of the sighting and the 30-m depth contour shown on the maps in these reports. Some sightings near the 30-m con tour 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 19S2 data.

In both 1979 and 19S1 there ware more sightings in water depths exceeding 30 m than at shallower depths, so the sample median ia greater than 30. Plots of the sightings indicate that confidence intervals would almost certainly overlap the 19S2 confidence intervals. In all 3 years

TABLE 4-2

NUMBERS OF BOWHEAD SIGHTINGS BY WATER DEPTH AND LONGITUDE DURING SEPTEMBER-OCTOBER TRANSECT SURVEYS IN 1979 AND 1951 [a, b]

Depth	1979 W of 146°W	1979 E of 146°W	1979 Total	1981 W of 146°W	1981 E of 146°W	1981 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. 1983.

considered, the data suggest that the median depth may be slightly greater bstween the Canadian border and Camden Bay than farther west.

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.

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 gst some idea concerning the magnitude of displacement in the axis of migration which should be detectable.

Suppose the 1982 confidence intervals include the true median deptha, and suppose these true medians happen to fall at the lower limi ta of the intervals. Suppose sampling in a future Year produces confidence intervals for that years' 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 tasting 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 ware (39 m, 46 m), compared to the 1982 interval (31 m, 38 m). For sightings east of 146"W longitude, ths 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 7-1/2 nm, respectively. Since these assumptions represent a "worst case" situation among intervals which cover the true medians, it seems likely thst 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 .2.3 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 pa th 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 (Tab le 4-3) f or independence of wa tar 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 testa could be performed en data f rom future surveys to verify that no relationship between group size and depth had appeared.

TABLE 4-3

NUNSEAS OF BOWHEAD SIGHTINGS BY WATER DEPTH
AND NUMBER OF WHALES PER SIGHTING
DURING SEPTEMBER-OCTOBER TRANSECT SURVEYS IN 1979, 19S1 , AND 1982[a ,b]

Depth	Number of Whales				
	1	2	3	>3	Tots 1
≤ 30-m	67	19	3	7	96
> 30-m	90	29	9	13	141
Total	157	4s	12	20	237

(a) Behavioral, search, and E-W line transect surveys omitted.
(b) Source: Ljungblad et al. 19S3.

4.2.4 Anadromous Fish

Reststed Hypotheses:

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

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 (19B3). 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 CPDS and the char estimates 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 af tar. Bendock notes that this change might also contribute to differences in the estimates.

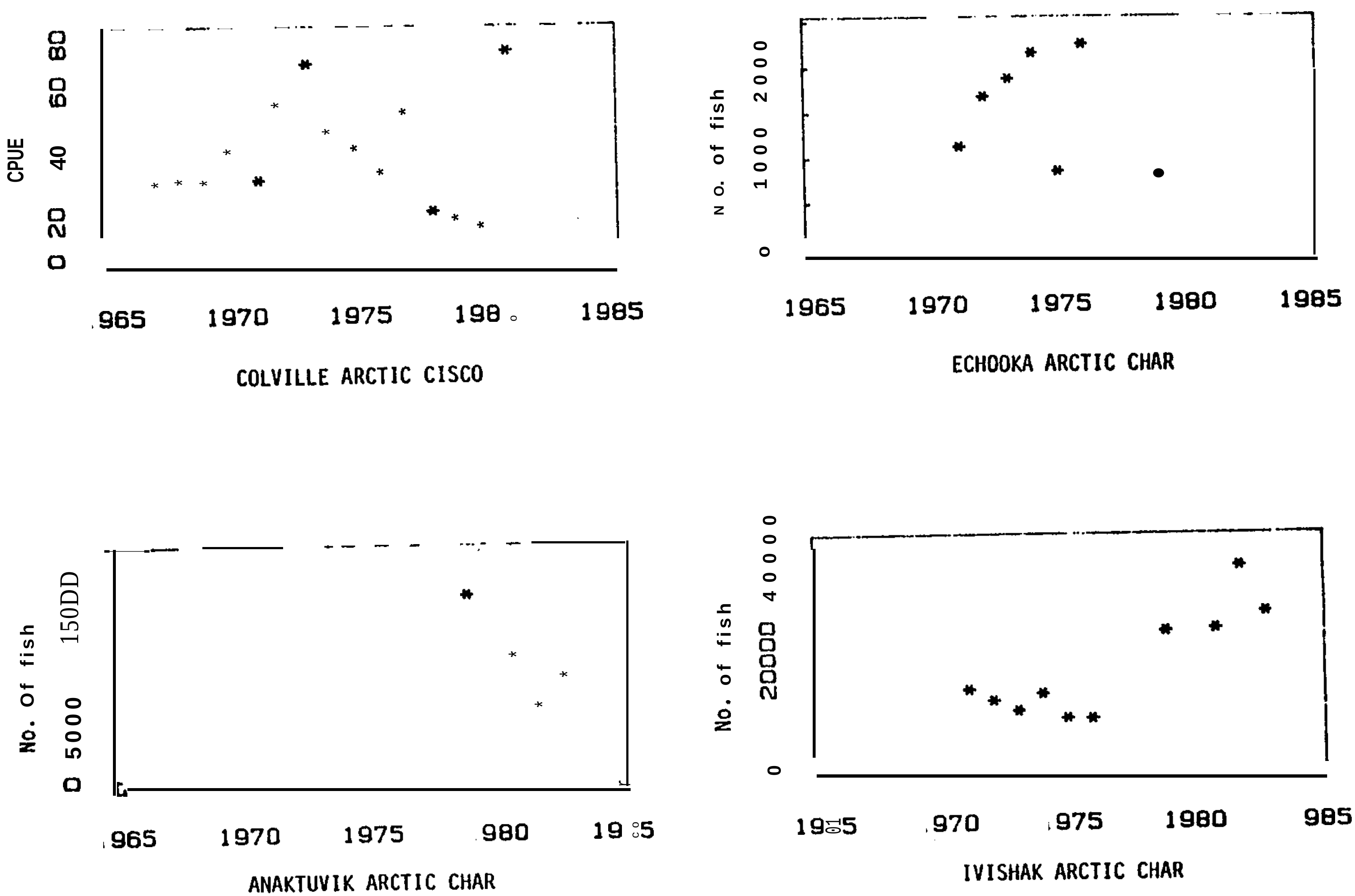


Figure 4-3 Colville Delta CPUE for Arctic cisco and Arctic char
aerial index counts from three North Slope rivers (see text)

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 qui te successful in following trends in CPUE. The largest difference between modeled and observed CPUE was around 28, end most differences were less than 10. The model parameters suggested a strongly density-depsndent stock-recruitment function and an exceptionally high uncatch-able proportion of spawners. The estimated age (k = 5 years) of recruitment of individuals to the fishery was consistent with the age composition date 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 unmatchable spawners, along with other evidence, indicates that this Arctic cisco population msy 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 date points available to fit five model parameter. 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 representad by the model parameters obtained by Gallaway et al. , this relationship would lead to oscillations in population level which would likely far excaed any caused by ccs oil and gas development activity. On the other hand, if the observed fluctuations are caused by such environmental factors as ice condition, these would hsve 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 baseline conditions, we can determine the level of change in mean CPUE which we have a reasonable probabili ty of detecting.

We assume for the purpose of this power calculation that both the baseline sample and a postdevelopment sample of n2 years of Arctic cisco CPUE data from Helmericks' fishery are normally distributed with the same standard deviation: approximately 19. S. 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-1 2b of Dixon and Massey (1969) allows us to determine the power to detect various magnitudes of change in mean CPUE values wi th tests of various levels; (see Appendix C). The detectable changes are given in the following table for level = 0.05.

	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 .s 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 CPUS nearly to zero. Even with 15 years of postdevelopment data, an increase in CPUE must be quits 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 bsen treated as a baseline sample and compared with the data from 197S through 1981, a two-sample t-test would have detected a highly significant decrease in mean CPUE ($p<0.01$). Yet the CPUE in 1982 was higher than in any of the previous years, so the statistically significant decrease in 1978-1981 was due either to random error or, more likely, to population dynsmics and/or environmental condi tions 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 date concerning the population's age structure, reproductive success, and ●nvironmental changes (natural and man-caused) acress several hundred miles of the Uni tad States and Canadian Beauf ort Sea coastline.

4.2.5 Old squaw

Restated Hypotheses:

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

H_o2 Changes in msle 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 sys tam during the summer molting parind (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 stsy the same over the years. sigh use areas such as Simpson Lagoon would always be expected to have higher concentrations then 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.

Pesk oldsquaw densities in Simpson Lagoon occurred on August 15, 1977; July 15, 1978; and July 28/29, 1979 (Table 17 of Johnson and Richardson). 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 (19s1), 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 inadequate survey effort, but they do not offer am explanation of the changes in relative importance of the ares west of Simpson Lagoon both within 1978 and between the 2 years.

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 Jones 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	66.3	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.?	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 Steffansson 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 U.S-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 are 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 1979 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	20.0	103.8	87.3	219.2

Monitoring of molting oldsquaws through aerial surveys continued in 1980, 1981, and 1982. A comparison of oldsquaw distributions in Simpson and stump Island Lagoon 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.

Densi ties of molting oldsquaws were significantly higher in Simpson Lagoon than in Stump Island Lagoon. Estimates obtained by combining date from barrier island and mid-lagoon transects during the molt period for al 1 yeara in which both lagoons were surve yad ere 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 consi derable year-to-year consistence y; 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 (19821 which also support the claim that relative densities are consistent. Surveys of 10 lagoons in the Arctic National Wildlife Refuge in 19S1 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 f rom URI in order to conduct our own analyses of year-to-year patterns in the use of different areas. The only date they were able to provide were collected in 1976, 1977, and 1978. Area surveyed and number of oldsquaws seen ware included in the records, along with identifying information (latitude, longitude, station or transect number, date, time).

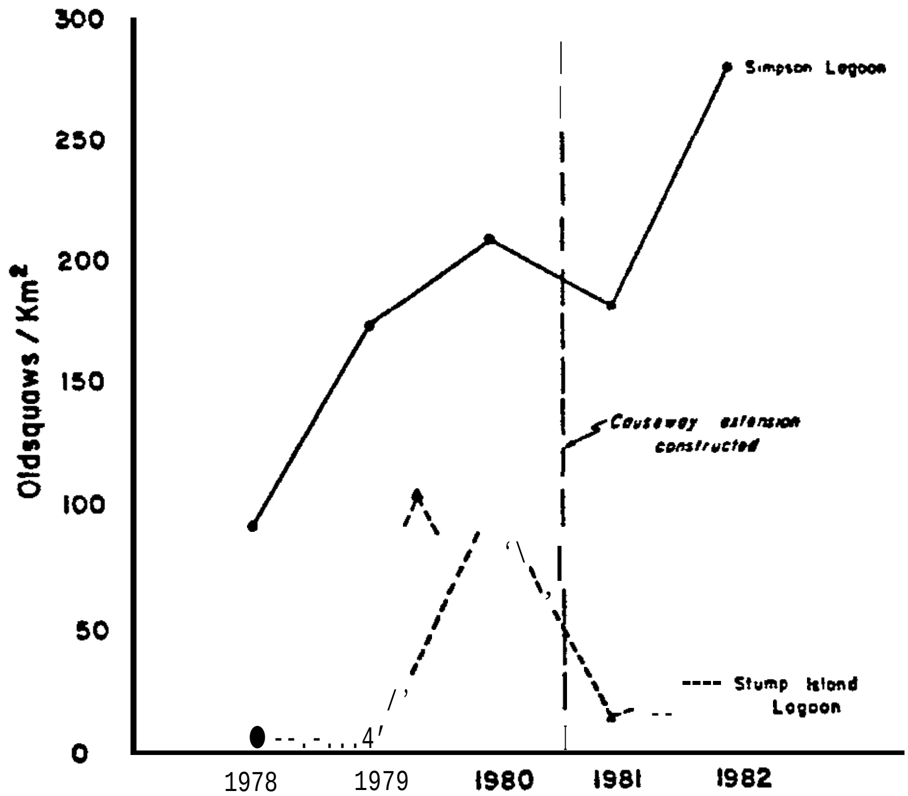


Figure 4-4 **Estimated densities of molting Oldsquaws using Simpson and Stump Island Lagoons (Troy et al. 1983)**

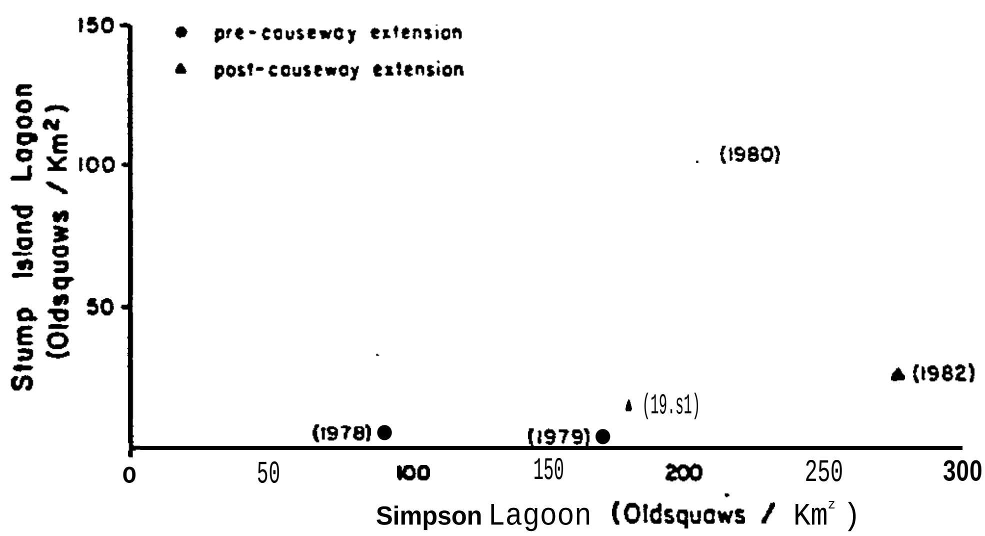


Figure 4-5 **Densities of molting Oldquaws in Stump Island Lagoon in relation to densities in Simpson Lagoon (Troy et al. 1983)**

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 vary 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 cliff ering by as much as a factor of four. In the 1977 and 1978 data there ware 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 datss, latitudes, and longitudes as well.

In Figure 4-6 we plot densities for 6 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. DSta 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.

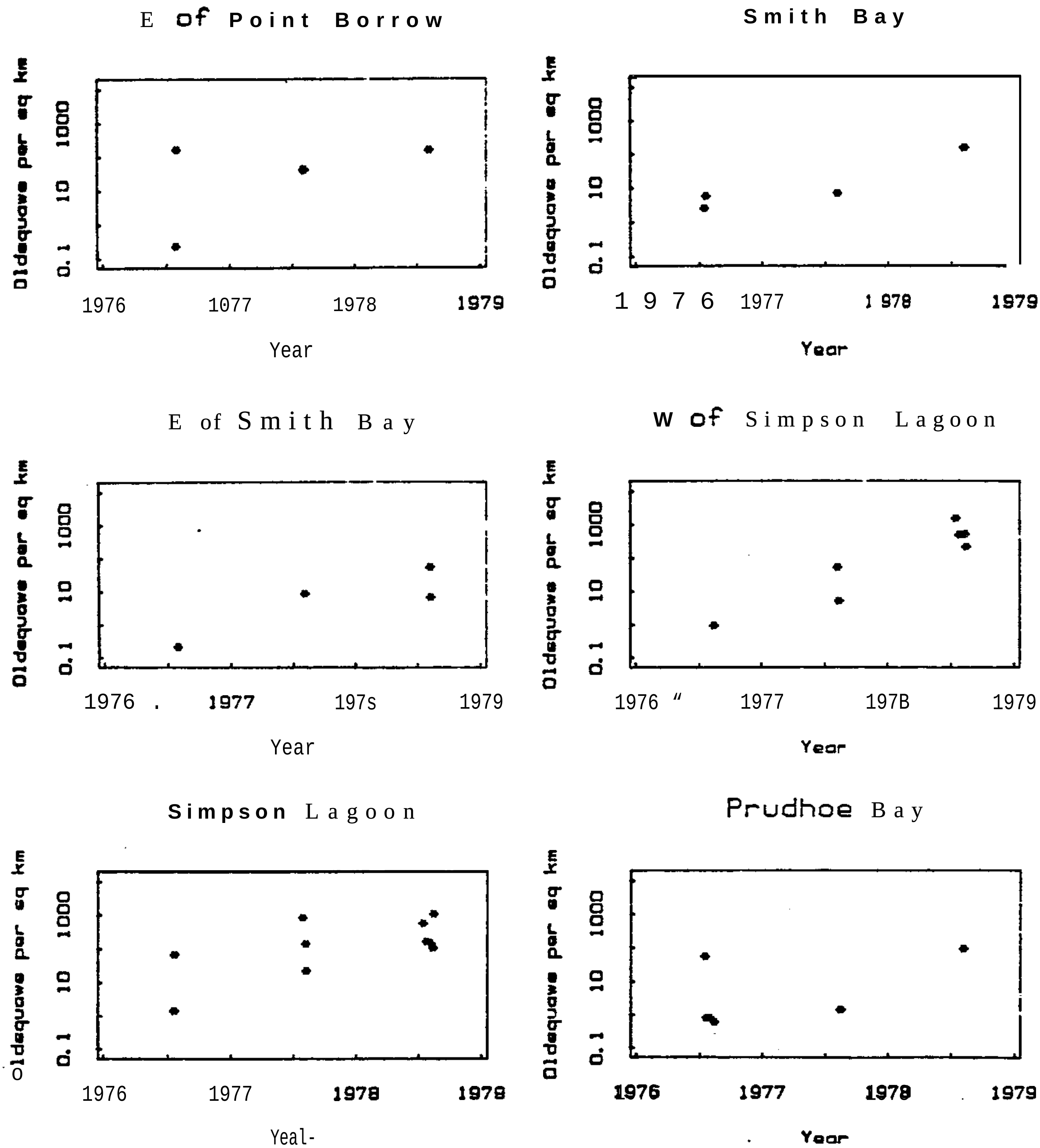
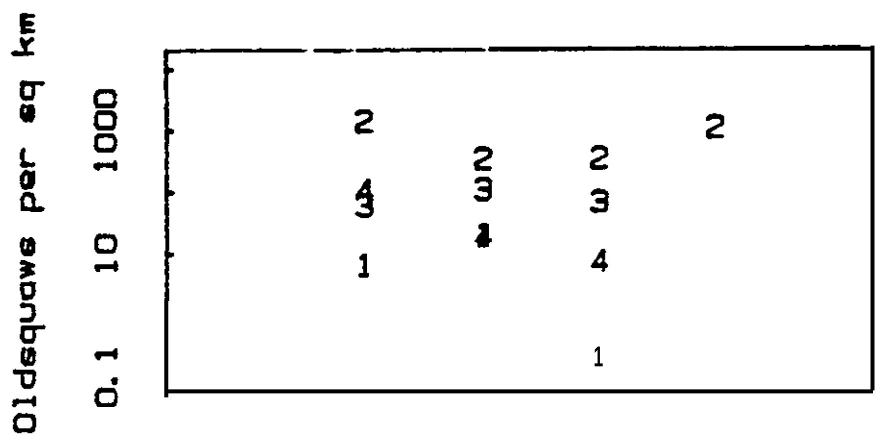


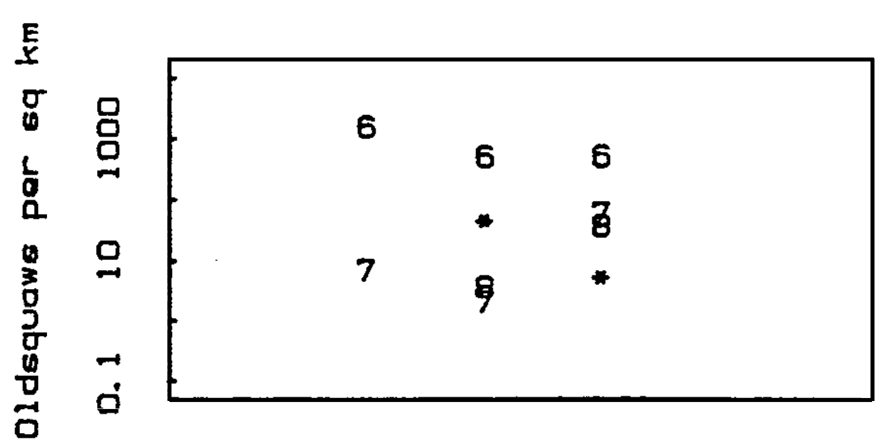
Figure 4-6 Oldsquaw densities in six Beaufort Sea survey areas (Table **4-6) 1976-1978**

Simpson Lagoon



1978 transects. July 15 to August 15

Eastern Harrison Bay



1978 transects, July 15 to August 15
* = transect 11

Figure 4-7 Oldsquaw densities in eastern Harrison Bay and Simpson Lagoon, July - August, 1978

TAELE 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' N	71°15'N	155°29'W	156″01 'W
Smith Bay	70 °50'N	71° 3'N	154°31'W	154°39'W
E. of Smith Say	70°54'N	70°56'N	152°30'W	153°20'W
W. of Simpson Lagoon	70°28'N	70°32'N	149°56*W	150°11'W
Simpson Lagoon	70°29 'N	70'33'N	149″ 6'W	149°55'W
Prudhoe Bay	70″21 'N	70°25'N	148°11'W	148°36'W

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.

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 (1 983) indicated that reports may be available early in 1984. However, the impression given at the workshop by Johnson was that stati sties for nesting densi ty and hatching success are reasonably robus t.

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 neares t OCS oi 1 and gas development activity.

H_o2 Changes in Laminaria solidungula productivity in the Boulder Patch are not releted 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 (his 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 cons trictions into ovate segments of different sizes. The constrictions form in November, e 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 necesary to detach end weigh individual plants at the beginning of the year (in November) end remove and weigh the new segments at the end of the year. Furthermore, Dunton (19B3) shows that there is a strong correlation between blade length 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 • t 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. LCW productivity of the kelp in the Boulder Patch community compared to Canadian High Arctic communities is attributed in pert to the absence of winter photosynthesis.

Dunton (1983) gives annual linear blade growth values (cm) from fall 1976 through fall 1979 at two Boulder Patch dive sites (DS-11 and DS-1 1A) 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-1 1A 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 3978-79.

The year-to-year standard deviation at DS-11, where turbid ice was presumably present all three years, was about 1.3 cm. However, the approximately 55 percent increase in linear growth during the year with clear ice at DS-1 1A 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 ef f acts 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 three years of data at DS-1 1 given by Dunton (1983) as thrae 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 activi ty. Then we can use standard charts such as Table A-1 3 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 we have 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.

5.0 RECOMMENDED SAMPLING DESIGN

5.1 GENERAL

This chapter contains the specific recommendations of the study teem regarding testable hypotheses, statistical design, field and analytical methods, and SPS ti al 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 presentsd in Chapter 4.

Aa noted in Chapter 4, each of the hypotheses adopted by the workshop has been restated as null hypotheses (Ho) 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 end 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 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 be initiated once a change has been detscted. In this way, studies for causality can be directed to specific questions maximizing the utility and cost ef festiveness 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 causali ty usually requires much more laboratory study or field manipulation than strict field monitoring. Stone (Canadian Department of Indian end Northern Affairs) reported that Canada was allocating some 30 percent of their program resources to actual monitoring with the remaining 70 percant going toward studies to aid in understanding of key relationships and sensitivites of VECs. Whi le we have not attempted to detail the studies that might ha necessary to e stablish 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 hava baen 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 suparior to those suggested. Once incorporated into the monitoring program, procedures should be rigid ly 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 recommenda tions of the workshop regarding physical environmental dats, 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 nead for a long-term, areawide monitoring program such aa 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 fore- cast. Secondly, as noted by Wolfe (Section 3..7.1), the first and most sensitive "line of def enae" agains t environmental degradation that could ultimately impact VECs is compliance and site-specific monitoring of individual activities. If, through cons truction and operational stipu- lations (including discharge limitations), degradation below acceptable levels is prevented beyond a defined distance from each activity, then it is vsry unlikely that areawide degradation sufficient to impact VECs would occur .

Finally, it does not appear that all five aspects (hypotheses) of the workship-recommended BSMP approach meet the objectives for the program set forth in Section 3.7.1. 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 stats 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 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 off ice analyses to date heve produced no evidence that such accumulate ons are measurable beyond a few kilometers from a site (e. g., Houghton et al. 1981 ; Menzie 1982). Moreover, sediment levels of ps troleum hydrocarbons and metals that have besn circumstantially linked to carcinogenosis (e.g., in flatfish) are high (Malins et al. 1983) 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 objective 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 ba considered the closest to meeting the BSMP objectives. Even though the selected organisms msy or may not be indigenous, relatively small increases in their body burden should be a reliable early warning that environmental containment 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 Beauf ort Sea:

1. While Mukluk results have been discouraging to data, there are other areas of the Beauf ort where offshore production wi 11 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 e strong political need to document that changes do not occur regardless of how strong a case can ha made, using existing knowledge, that adverse effects would not occur. There is a possibility that pollutant behavior, organism physiology, and population controlling factors are suf ficiently different end 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 stressad by Wolfe (Section 3.7.1) thare 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 end 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 thought to have the greates t chance of detecting increased contaminant levels (sediment chemistry and sentinel organism body burden). While causality of increases observed could be readily established, their significance would be as an early warning of the potential for effects that might eventually reach VECs, rather than as effects that will directly transmit to VECS via the food web. The program will also monitor populations and/or distributions of three species thought to be representative of three maj or 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 meets at least one objective. Moreover, it is likely that there is no practical single monitoring effort that would meet all of the stated objectives.

Therefore the best that can be expected is that the aggregate of the monitoring approaches recommended collectively address the objectives for the program.

5.3 SPECIFIC HYPOTHESES ANO 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.
- H_o2 Changes in concentrations of selected metals or hydrocarbons in 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 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 of subregional but pervasive impacts. It is desirable to reduce the number of blocks to simplify both the assignment of the probabilities pi (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 $p_1=p_2=p_3=0.01$. 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.

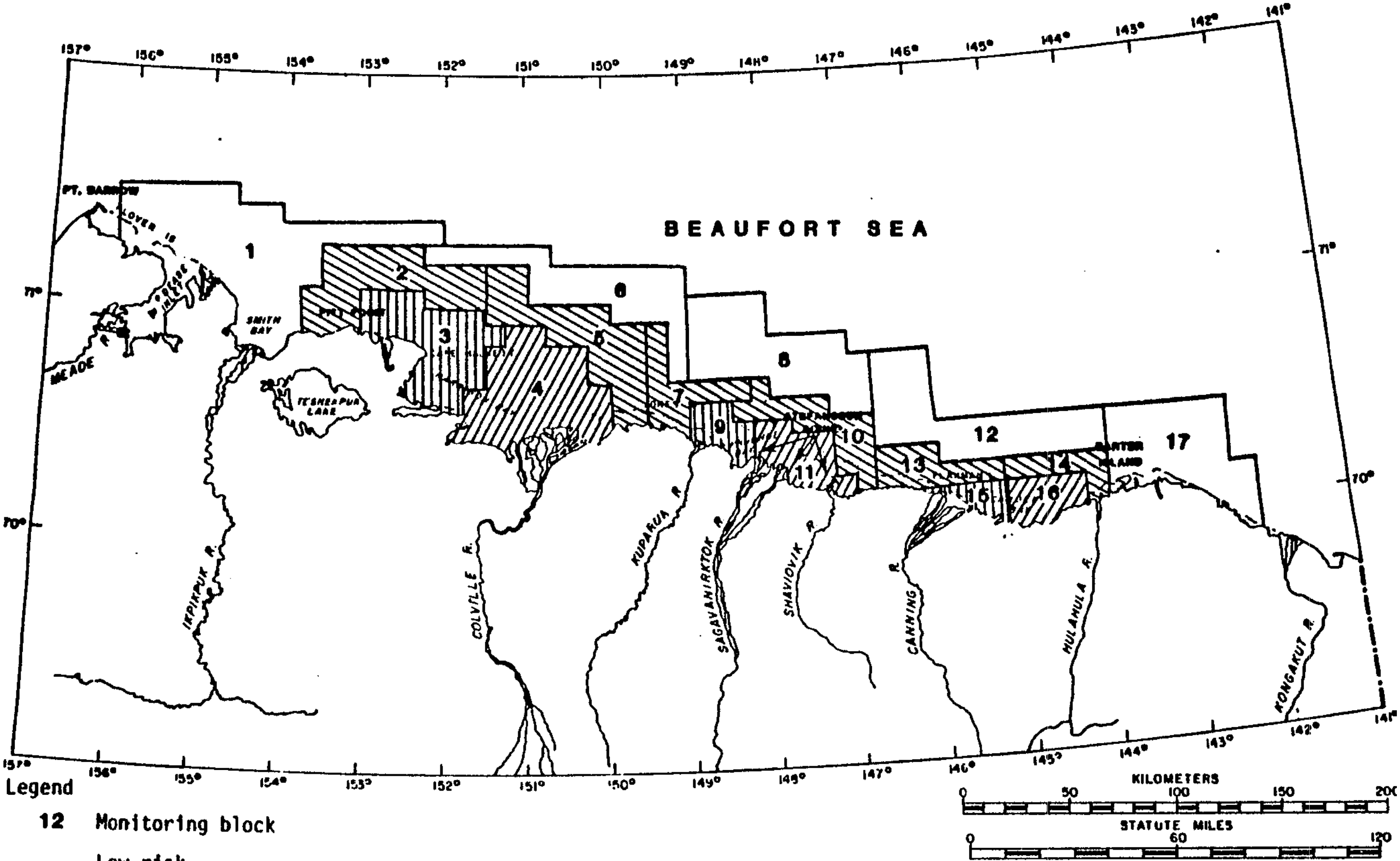
The calculations lead to the following conclusions:

- 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.

A change of approximately half the sampling error in one of the regions with stations can be detected by this network.

In general, stations should be chosen randomly within the regions. However, availability of baseline date at such potential stations as those of Shaw (1981) and Kaplan and Venkatesan (19S1) may dictate that some of these should be included. Similarly, sediment characteristics may eliminate some potential stations since, as discussed below, it is desirable to sample fine rather than coarse sediments.

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. However, we have not yet completed the computation of a design D based on this approach.



Legend

12 Monitoring block

Low risk

Medium risk

High risk

Highest risk

Figure 5-1 Sediment monitoring network blocks showing assumed risk levels and locations of potential sampling site

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 nesd to be definsd. These include the frequency of sampling, the means of col letting 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 yesr for 3 years snd 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 thst 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_o1 of this program, the firat 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 rata of input of selected contaminants to the sediments. The rata that is being assessed is averaged over the 1- to 3-year parind between samplings. Theref ore, ideally the sediment samples col lected should represent only the last 1 to 3 yesrs of accumulation. In an undi sturbed off shore coastal sediment, even one subject to relativel y high accumulation rates, the thickness of a 1-to 7-year sediment layer would be very small, several millimeters at most. However, neat sediments are not undi sturbed and materials representing recent inputs to the sediment surface are nixed 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. Tberef ore, the choice of an appropriate depth of sediment sample to take is a difficult one. It is general ly 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 uae f ul 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 0.7 m^2. For example, a 0.1 m^2 Van Veen grab sampler was utilized in the Georges Bank monitoring program.

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 batter fulfill the requirements, especially the requirement for an undisturbed surface sample. An ongoing contract study currently being pe rf ormed for NOAA includes an evaluation of the various sediment sampling devices available. Since the results of this evaluation are expected to be available bef ore 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 ara not necessary. However, since hydrocarbon concentrations wi 11 be low, reasonable precautions must be taken to avoid contaminate on 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) sub sample 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 ha 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 Beauf ort will be subjected to analysis for hydrocarbon concentrations and concentrations of selected trace metals. The recommended analyses for each sample period are as follows :

1. Path sample (4 replicates at each of 36 stations = 144 samples) should be analyzed for total barium (ss), chromium (Cr), and vanadium (V) concentrations.

2. Each sample should be analyzed for the presence of oi 1 through U'V/f luore scence and 1 replicate from each of 26 a ta tions and al 1 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). From these samples up to 10 should be selected for gas chromatography/mass spectrometry (GC/MS) based on gas chromatography/ flame ionization detector results.

The metals chosen for analysis, Be, Cr, and v, are chosen because Se 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 is 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 othar 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 hierarchial scheme because of the high cost of gas chromotography/mass spectrome try although it should be understood that gas chromatography/mass spectrometry can provide the most information concerning possible sources of hydrocarbons in tha 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 subs tantial information concerning diagnostic pareme ters needed to identif y the sources of hydrocarbons present (see Table 5-1). Gas chromatography/mass spectrometry provides additional de tai led information about a number of important speci f ic hydrocarbon compounds or groups (Table 5-2) and permits examination of a number of additional key source diagnostic parameters (Table 5-1).

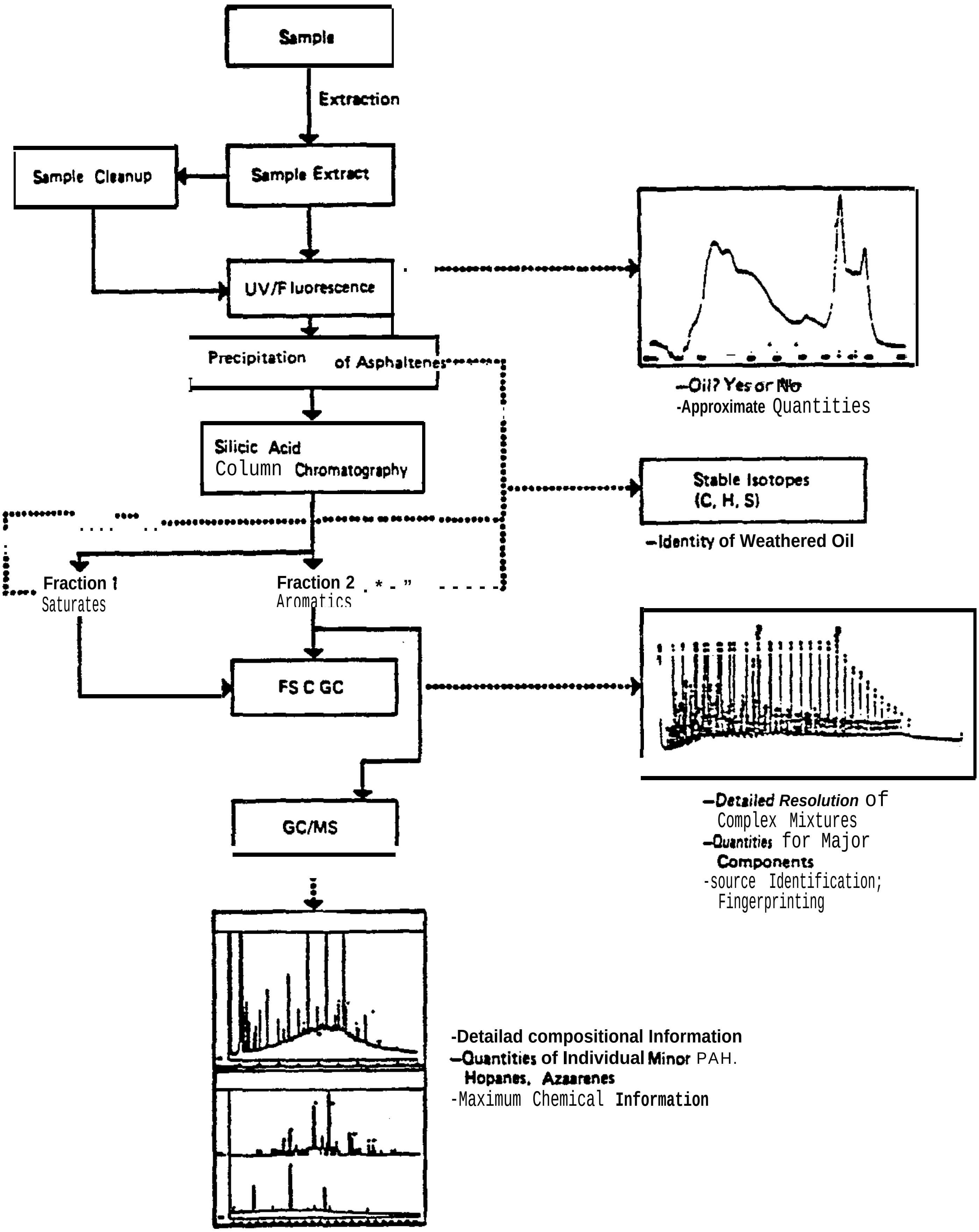


Figure 5-2 Schematic of hierarchical analytical strategy for hydrocarbons (Boehm, this workshop)

TABLE S-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 lC$_I$o-Czo1	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 niwl.
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: Phytane/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 index)	GC/FID	Diagnostic for petroleum additions ranges from S-10 for petroleum-free sample to 1 for petroleum
Unresolved complex mixture (UCM)	GC/FID	Presence may indicate weathered petroleum
Fossil fuel pollution index [PPP11	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
12a	Naphthalene
142	Methyl naphthalenes
156	c-2 naphtha lenes
170	c-3 naphthalenes
184	C_4 naphthalenes
152	Acenaphthene
154	Biphenyl
166	Fluorene
180	Methyl fluorenes
194	C-2 f luorenes
178	Phenanthrene, anthracene
192	Methyl phenanthrenes (anthracene)
206	C-2 phenanthrenes (anthracene)
220	C_3 phenanthrenes
234	C_4 phenanthrenes
202	Fluoranthene, pyrene
216	Methyl f luoranthene or methyl pyrene
228	Chrysene, triphenylene
242	Methyl chrysene
256	c-2 chrysenes
252	Senzopyrene, perylene
184	Dibenzothiophene
198	Methyl dibenzothiophenes
212	C_2 dibenzothiophenes
226	C_3 dibenzothiophenes

(a) Source: Boehm, this workshop.

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.

5.3.2 Biological Monitors/Sentinel Organisms

5.3.2.1 General

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

H_o2 Changes in concentrations of selected metals or hydrocarbons in . . . organisms are not related to OCS oi 1 and gas development activity.

H_o3 There will be no change in concentration of selected metals or hydrocarbons in the selected sentinel organism(s).

As noted in Section 3.7.2, the workshop recommended use of indigenous species as bioindicators if at all possible. Ideally, 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 authora (Butler et al. 1971; Haug et al. 1974; Phillips 1980). The mOst recent listing of these attributes was made by participant at the Mussel watch II meeting held in Honolulu in November 1983 and is as follows (Segar 1983):

- o A simple correlation should exist between the pollutant content of the organism and the average pollutant concentration in the surrounding water.
- o The organism should accumulate the pollutant wi thout being ki 1 led by the levels encountered in the environment.
- o The organism should be sedentary in order to be representative of the study area.
- o The organism should be abundant throughout the study area.
- o The organism should be sufficiently long lived to allow the sampling of more than a l-year class, if desired.
- o The organism should be of reasonable size, giving adequate tissue for analysis.
- o The organism should be easy to sample and hardy enough to survive in the laboratory, allowing deputation before analysis (if desired) and laboratory studies of pollutant uptake.
- o The organism should tolerate brackish water.
- 0 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 wi 11 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 Beauf ort Sea ideally should be carefully compared with appropriate mytilid species (*M. edulis* or *californianus*) with regard to its behavior whan 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 ability to metabolize metals or hydrocarbons), several species of Beaufort Sea bivalves ware suggested at the workshop and in 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 actual sizes 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 shel 1 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 baen widely used in marine pollution studies; thus, there is a good body of information on sensitivites, uptake, and deputation 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 par individual in Boulder Patch samples (Dunton et al. 19S2). *Musculus niger* is larger but is found in deeper water end is less common. Based on this information, *Cyrtodaria* appears to be the best indigenous suspension f ceder available. However, there appears to

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 ahel la 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 les 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. 19S2.
(e) Source: Scott 19133.

be little information on its pollutant metabolism. Shaw (1981) obtained sufficient samples of Astarte spp. and Liocyma app. for hydrocarbon analyses but did not specify the collection means or the number of individuals composing 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 ia Mytilus edulus 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 ahips or barges (Fader end Jewett 1981). Mytilus shells are among the most abundant bivalve shells on beaches in the southeast Chukchi Sea (Houghton, Dames & Moore personal observation) and are reportedly abundant on herd bottom areas in the northeast Chukchi as well (Dunton 1983b) . Thus, there would appear to be no physiological barrier to adult MYti lus living in the Beauf ort 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 Beauf ort Sea, and the uncertain phys iological 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:

1. Collection and analysis of indigenous spacies.
2. Transplantation and analysis of M. edulis.

Indigenous Spacies. An effort should be made early in the open wa tar season to collect adequate 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, the operation can probably bsat 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. Large clams would be identified end held on board live. After 4 to 6 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 this sampling should be repsated 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 program. 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 opsn water season.

If several hundred or more of a given species are recovered from any location they 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 is followed, 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

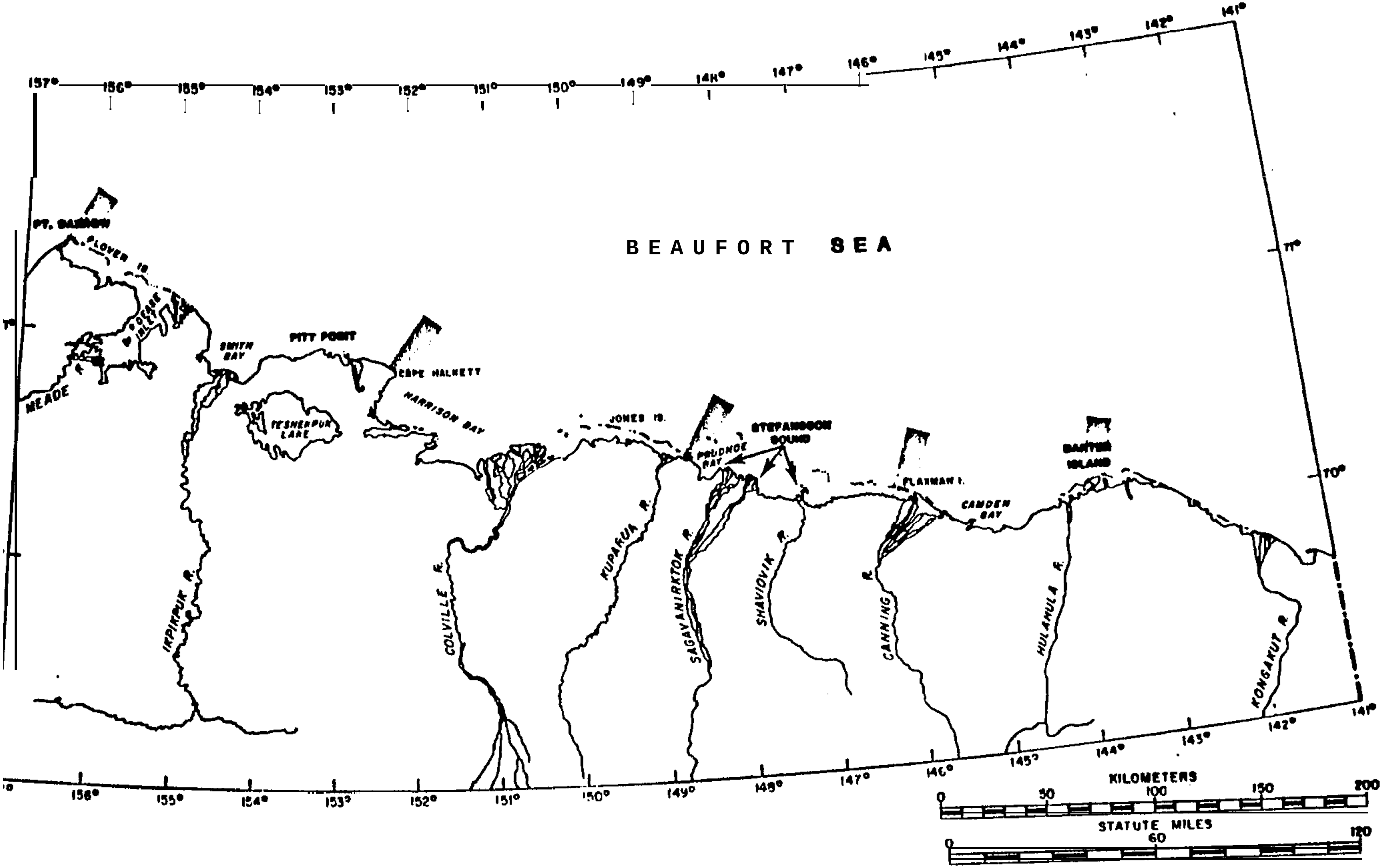


Figure 5-3 Suggested locations for mussel watch stations

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 one at either Barrow or Kaktovik would be the locations of choice to provide industrial and relatively clean sites. However, it might be possible to conduct the entire pilot study out of Prudhoe BSY.

Organisms would be ●xposed in cages anchored at a minimum of three locations including at least two "control* locations at different depths snd 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 ba 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 bod y burden. At present the national mussel watch protocol does not call for deputation of the gut contents of test organisms (Flegal, this workshop) although there is an ongoing controversy on the subject. For suspension feeders 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, deputation 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 leas t. 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 3 to 5 replicate (pooled) 30 9 samples should be quick frozen for subsequent dissection snd analysis. A second similar lot should be held on beard in clean, filtered (0.45) sea water flowing or frequently replaced at ambient temperature for 24 houra prior to freezing. If available, a third lot could be held for 48 hours. Mussels when initially procured (f rom elsewhere in Alaska} should be similarly treated to provide the " pre-exposure" bod y 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. At least five replicate pooled samples should be analyzed for metals and hierarchical analysis of hydrocarbons as described in Section 5.3.1.3. 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.

The present mussel watch protocol calls for homogenize tion of a fairly large number of individual samples and analysis of a single sample drawn from the pooled homogenate (Flegal, this workshop 1. This approach provides no definition either of variability wi thin groups of similarly exposed organisms or of within-laboratory analytical variability. Our suggested approach (analysis of fine replicate [pooled] samples) will provide some local data on the former (organisms within sample) variability. It would be relatively easy to also estimate analytical variability 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 ●fficient 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. Aa in the National Mussel Watch program and the sediment chemistry monitoring (Section 5.3.1), 3 years should be sufficient to ●stablish base3ine conditions (assuming this sampling is completed before ma j or changes in contami nant 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 Hypotehses I and Ii, H_o1 or H_o3) would be cause to greatly increase monitoring of contaminant levels in higher organisms including VECs (marine mammals, waterf owl, anadromous fish). This would provide data to investigate H_o4 and answer the question of transmutability of effects to higher trophic levels.

5.3.3 Marine Mammals

5. 3.3.1 Continuation of Aerial Transect Surveys

Restated Hypotheses:

H_o1 Fall migration patterns 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 di stances over which monitoring must be done for this propose are too great to be covered by nearshore systems. Aerial survey techniques ware 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 III. 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. (19S3), along with the additional analyses which we have discussed in Section 4.2.3.

The following points regarding survey methodology should be stressed:

a. 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 di stingui shed from the random N-S line transects and omitted from calculations of median sighting depths. Sighting deptha on the line trarsecta should, of course, be recorded as accurately as possible.
b. If the 1982 survey is to be used as a baseline, survey effort in the different bathymetric zones in the future surveya must be comparable to the 1982 effort. Table S-5 of Ljungblad et al.

(1983) indicates that in 1982 survey time was roughly proportional to the area to be surveyed across the ●ntire United states Beaufort from the Canadian horder to Point Barrow and north to 72 'N latitude with the following exceptions:

i. Areas with water depth exceeding 2,000 m received little attention.

ii. Areas with depths from 200 m to 2,000 m were less thoroughly surveyed in the eastern half of the region.

iii. The most intensive effort was in the depth range from 10 m to 50 m thought to cover the nearshore migration psth.

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 displacement of the migration into this deeper water which might occur. From a statistical standpoint, we recommend using the 1982 survey as a baseline rather thsn combining the 1979, 1981, and 1982 data because the earlier surveys had very little coverage of offshore areas and thus 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).

Clearly, if there were to be a dramatic displacement of a portion of the migrating population into waters beyond the shelf break, surveys comparable to the 1982 effort might fail to detect it using our median depth analysis. However, it seems unlikely that OCS development activities would cause a sudden shift of this magnitude.

Table S-5 of Ljungblad et al. (1983) 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 ebsence of changes in the behavior of the migrating bowheads.

For example, we omitted from our analyses a large number of sightings near Demarcation Ray because they were made on E-W transect lines which did not provide a random sample of possible sighting deptha. 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 f ceding patterns.

c. If there is a desire to focus on a particular subregion of the Beauf ort such as the area between the Canadian border and Camden Bay, survey effort can be increased in this subregion to obtain more sightings from which to compute the median depth. Increasing the number of sightings will increase ths power to detect a displacement in the axis of migration for the subregion.

d. 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 over-simplification. Ice coverage should continue to be recorded during the aerial surveys. It might bs possible to develop models for the axis of migration which incorporate dats on ice conditions if surveys are conducted in heavy as well as light ice years.

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 (H_O2), 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 ba only circumstantial (the shift occurred during periods of increased activity) . It is therefore important to continue the sorts of studies reported by Reeves et al. (1983) to look for correlations between whale behavior and such OCS activities as seismic vessel operations. These behavioral studies need w be conducted separately from the transect surveys discussed in Section 5.2 .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 tha 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 which it has been possible to collect. The unavoidable problems encountered in conducting these studies are well summarized by Reeves et al. (19S3).

Our main recommendations for future behavioral studies are as follows :

a. Methods of assessing and recording bowhead behavior and the attendant environmental conditions (e.g., sonabuoy recordings of noise) should ba 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) help to facilitate the required communication and coordination among investigators.

b. Standardized formats for behavioral data in a computerized date base should be established. Such a data beae containing date from different years and investigator 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 near shOre 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 end approximately locate bowhead vocalizations within a 10- to 20-kilometer radius.

This approach may wel 1 be preferable to aerial survey for monitoring bowhead use of feeding areas near Barter Island and Demarcation Bay, for example. Hydrophores could monitor these areas continuously if desired, while aerial "survey coverage is limi ted 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 PSSS beyond visible range of the ice camps. We suggest that if this spring effort proves successful, the equipment used 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 bowhe ad numbers or densities, they would not f lag 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-affective method for obtaining population size ● stimates. 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. (19S3) , 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 anal yses and analyses of future years ' data may require the development of s tetisti cal techniques for ad j usting 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. 19s0; 1981) who suggests that such surveys should be repeatsd every 2 to 3 years to monitor long-term trends i n distribution and abundance. Site-specific monitoring of seals in relation to development activities thought 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 19S1) should be monitored for levels of hydrocarbons and trace metals. This will provide a growing data base againat which to test the most important of our monitoring program hypotheses regarding effects on human health.

5.3.4 Anadromous Fish

Restated Hypotheses:

$H_0 1$ There will be no change in catch per unit of effort (CPUE) in the Colville River Arctic cisco fishery.

$H_0 2$ 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 thst factors unrelated to oil and gas development (i .e. , natural population cycles, variability) may lead to rejection of $H_0 1$. 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 Galloway (Section 4.2.3 and Galloway et al. 1983) may offer a greater sensitivity to detect real development-related effects on anadromous fish populations than merely testing each year's CFUE 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 (Galloway et al. 1983). with verification and calibration of the model and its input parameters, it would be a useful adjunct to the RSMP. Once the model is verifisd and calibrated, a statistically significant increase in the discrepancy between predicted and actual CPUE values should be easier to establish thsn it would be to establish that a given year's CPUE has changed from its "baseline condi ti on." If this increased discrepancy between predicted and actual CPUE occurred (statistically significant or not), it would be cause to examine available population data and da= 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 causali ty for changes observed without an extensive da ta base on possibly related factors. At present, it is not even certain where these fish spawn (Gallowa Y et al. 1983); hence, interpretation of observed changes is extremely tenuous and based only on what we know of a brief portion of their life history. Although we did not psrf orm statistical analyses on aerial Arctic char index counts in North Slops rivers (Figure 4-3), it is possible that these estimates may be as good as Arctic cisco CPUE for ❑ onitoring anadromous fish numbers in the Beaufort Sea. In the Ivishak River, for instance, the 1971-1976 data all fall within a very narrow range (8,570-1 3,958 fish). Dats from 1979-1983 likewise fall within a reasonably narrow, albeit very different, range (24,403-36,432 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.

5.3.5 Oldsquaw

Restated Hypotheses:

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

H_O2 Changes in male oldsquaw distribution patterns are not related to OCS oi l and gas development activity.

Inadequacy es in the data available to us preventad 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 distributiona 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 daya between July 15 and August 15 should catch the psak of the molt and also help to average out di fferances in counts caused by tine-of-day effects and unavoidable differences in survsy aircraft used, visibility, etc. Of course, any such differences which csn be avoided by stratification should be.

Second, transects should be very precisely defined and faithfully repeated. The available dats 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 snd on visibility conditions should be included since the density estimation procedure may nesd to adjust for these factors. Field survey techniques (number of observers, flight lines, dats 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 tha 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 HOI 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 perhaps 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 sub jetted to disturbance by OCS oi 1 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 feel that this approach is appropriate for the regi onwide monitoring program, primarily because of the limited number and di stribution 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 res trictions on the permi tted activities may not fully protect the nesting colony.

If HOI as statad 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:

HOI 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.

As a simple measure of change in the Boulder Patch, the recommendation in the concluding session of the workshop was to monitor annual productive ty of *Laminaria* whenever OCS development activities which might af feet i t were going on in the vicinity of the Boulder Patch. We concur with this approach for this hypothesis. Howeve r, as indicated in Section 3.7.4, we do not feel 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. (1 982) once a year, preferably in late fall, on 20 or more *Laminaria solidungula*.

If measurements are being made 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 which 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 ●ntire patch as well as detect changes in discrete locations within the patch. Similar effort should be directed at other Boulder Patches subsequently discovered which support comparable biota.

Physical measurements which will be needed to support the analyses of the kelp data include measurements of ice transparency at each station and currents, at least for monitoring related to some site-specific activity.

If H_o1 as stated above is rejected, this would imply the t kelp productivi ty in areas of the Boulder Patch nearest oil and gas development activity is reduced, in comparison with productivity in areas removed f rom 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 submission of data in s specified National Oceanographic oats 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:

1. Submitted data often contain serious errors (see, for example, Zeh et al. 1981) which are never corrected.

2. 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 errora (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.

3. Investigators often do not know how to obtain subsets of previously collected data relevant to their interests from NoDC.

4. 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 Sase supervised by a single data manager end staff. To the greatest extent possible, this data base should physically contain

●ll date collected by all agencies (NOAA, MMS, EPA, etc.) in the Beaufort Sea monitoring effort. Pressure could also be brought to bear on industry 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 parson to obtain data directly or at least to find out what data are available and where they might be obtained.

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

1. In consultation with funding agencies and investigators., determining formats for submitting data seta to the data base. NODC formats may be appropriate in many cases.

2. Obtaining data from investigators in a timely manner.

3. Developing date checking programs or using existing ones to ensure that data submitted are free of illegal or inappropriats 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.

4. If the formats used for submitting the data, such as NODC formats, require accessing several types of records to obtain identifying information and measurements associated with a single sample, developing programs which allow easy selection and reformatting of data into files appropriate for statistical analysis. In some cases, this may require considerable processing of the raw data, for example to determine area surveyed f rom aerial survey transect date.

5. Providing data on magnetic taps in industry-s tandard formats or by direct transmission over phone lines between computers in response to authorized requests for data. If costs are associ- ated with this servica, being prepared to give cost estimates for fulfilling particular requests.

The last two functions of the date 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 responsibili ties mentioned above, they were not able to fill all our data needs or resolve inconsistencies which 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 A

LIST OF ATTENDEES

BEAUFORT SEA MONITORING PROGRAM WORKSHOP
ALYESKA RESORT, ANCHORAGE, ALASKA
27-29 SEPTEMBER 1983

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List of Attendees
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APPENDIX B

DETAILED STATISTICAL APPROACH TO SEDIMENT CHEMISTRY MONITORING

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 testiig 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 environmentalists, 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 tailed 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 idealty require a different design from the rest. The problem of simultaneously accommodating them all in a single design is a familiar one. A solution 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 specitied size would be detected. This criterion is adopted in Section 2.

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

The paucity of data about spatial covariation (between sites) and temporal covari at ion (between times) requires the use of intuition, qualitative experience, accumulated knowledge end so on. These are turned into 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 as always, common sense is called for in implementing the design. And the design will change in time with the 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. The monitoring network must itself be monitoring.

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 21'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 estreme 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 tbe 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 tbe start of development (drilling, for example, at a particular site). Second, sites from areas of likely impact are admitted as possible quasi-controls. These do increase the power of tbe test even though they are not controls, strictly speaking.

Again, following Green (1979), we take as the null hypothesis, tbe assumption of no time x 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 tbe F-test has tbe noncentrality parameter $\delta^2 = 2K\sum_{i \in D} (Z_i - \overline{Z}_D)^2/\sigma^2$ where $\overline{Z}_D = \sum_{i \in D} Z_i/I$ with I tbe 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 pi ≥ 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 A, to each of tbe 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 end hence uncertain. For convenience relabel the zones, if necessary, so that $p_1 \leq \leq p_k$.

Let S = $S_D = \sum_{i \in D} (Z_i - \overline{Z}_D)^2$ so that $\delta^2 = 2KS/\sigma^2$. Suppose D gauges n_j sites in block j. If tbe impact were to occur in zone j, $\overline{Z}_D$ = [(I-)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 $0 \leq f_j \leq 1$, $\sum f_j = 1$.

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, $j=1,\ldots,k$ are:

$$f_j^0 = 0,\ j=1,\ldots,m$$

$$= (1-\lambda/p_j)/2,\ j=m+1,\ldots,k$$

where $\lambda=\lambda_m = (k - m - 2)/\sum_{j=m+1} p_j^{-1}$ and m is either 0 or the solution of $p_m \leq \lambda_m < p_{m+1}$ 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 $2KI\Delta^2\zeta^2/\sigma^2$. 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 $\zeta|\Delta|/\sigma$-values when the size and power of the test are 0.05 and 0.50, respectively.

TABLE 1. The values of $\zeta|\Delta|/\sigma$ 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 $L_{m+1} < 0 \leq L_m$ where $L_m = (k-m-2)p_m^{-1} - p_{m+1}^{-1} - \ldots - p_k^{-1}$, if such an m exists. Otherwise, m = 0. Observe that, of necessity, $m \leq k-3$ if $k \geq 3$ 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 hegin with m=2 when we consider

$L_m = L_2 = p_2^{-1} - p_3^{-1} - \ldots - p_5^{-1} = -5.83$. *Since* $L_1 = L_2 < 0$ also, we must take $m = 0$, and $\lambda = (5-0-2)/(p_1^{-1} + \ldots + p_5^{-1}) = 0.0836$. 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 would in this case be about the same as those given in the above table.

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 dividing by $\zeta = 0.778$.

3.0 INFORMATION NETWORKS

The future benefits that may be derived from a network cannot atl 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 C stands for gauged, U for ungauged.

There is a *priori* uncertainty about Z which we assume is expressible in terms *of* probabilities. Uncertainty about C 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 C are related. An optimal choice of C will maximize tbe amount of "information" in C about U.

To formalize this let $Inf = I(U,G) = [-E\log p_0(U)] - [-E\log p(U \mid c)]$. the reduction in the *entropy* of U *resulting* from observing G, averaged over C. Equivalently, $Inf = E\log[p(U \mid C)/p_0(U)]$, Shannon's index of information transmission. This can be resealed as $Inf \rightarrow A Inf$ 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 C = C(D). The optimal D maximizes $I(U(D),C(D))$.

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 $I(U,C) = -\frac{1}{2}\log|I-R|$ where $R = Diag\{\rho_1^2, \ldots, \rho_l^2\}$ and $\rho_1 \geq \cdots \geq \rho_m$ are the canonical correlation coefficients between U and C.

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.

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

Next, adopt a components of variance model. AU 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 tbeee 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 woutd 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, I?, 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. Its not clear that any gain in the realism of the model would be offset by the 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 $l=40$ and $m=200$ potential sites, there are 2.05 x 10^{4*}

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 tbe 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^i'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 $d_0 = Diag\{\sigma_1^2, \ldots, \sigma_{m-1}^2\}$ and m is the total number of sites, j_r in general denotes tbe column r-vector all of whose elements are L σ_W^2 and σ_i^2 are respectively the variances of W and S{. 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, $f_U(1-f_U) f_G(1-f_G) = \lambda$, 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 $f_U = \sum_{i \notin D} s_i$ and $f_G = \sum_{i \in D} s_i$. Consequently, $\lambda = (\sum_{i \notin D} s_i)(1 - \sum_{i \notin D} s_i)(\sum_{i \in D} s_i)(1 - \sum_{i \in D} s_i)$. This is approximately, if the s_i's are small, $A \approx (\sum_{i \notin D} s_i)(\sum_{i \in D} s_i)$. 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, $\sum_{i \in D} S_i$ 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 $a_1 \leq \leq a_R$, 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 $\sum_E a_j = (z + A)$ and $\sum_F a_j = (y + B)$. It is worthwhile interchanging z and Y if and only if $(x + A)(y + B) - (y + a)(x + B) = (z-g)(B-A) < O$. i.e. if and only if $x < y, A < B$ or $z > y, A > B$. 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 Uke (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 St'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 $\sum_U = \sigma_\#^2 j_{m-n} j_{m-n}^T + \sigma_S^2 I_{m-n}$ and $\sum_G = \sigma_\#^2 j_n j_n^T + (\sigma_S^2 + \sigma^2) I_n$. It follows that $\sum_U^{-1} \sum_{UG} \sum_G^{-1} \sum_{GU} = I \mu\nu j_{m-n} j_{m-n}^T$ where $\mu = \sigma_\#^2 (\sigma_S^2 + \sigma^2 + I\sigma_\#^2)^{-1}$ and $v = \sigma_\#^2(\sigma_S^2 + (m - I)\sigma_\#^2)^{-1}$. The only non-zero eigenvalue of this matrix is $A = I(m-I)\mu\nu$, 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.

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
lOO	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	0.6662
)00	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

An examination of Table 2 shows how this information-baaed methodology works. When a station is added to D, uncertainty about S^i (ignoring sampling error) is removed from that of tbe 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 sc = 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.

4.0 APPLICATIONS

In consultation with others involved in the Beaufort monitoring program, the block map given in Figure 1 was constructed. This 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 fines 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, B?, R10, 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, bB. Then (B4, B11, B16) → b7, B2 → b6, (B5, B?) → b5, (B10, B13, B14) → b4, B1 → b3, (B6, B8) → b2 end finally (B12, B17) → bl. 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 end b6 are medium and b1, b2, b3 are low. Retell 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, bl) ere 45, 25 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	36	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 testii power by taking more than 50 stations and 3 replicates per station. Then a= 0.05, $1-\beta=0.80$, and $\zeta\Delta/\sigma= 0.47$ is the detectable, pervasive before end after difference. Using 4 replicates at 36 stations is preferable to 3 replicates at 50 stations, according to this table; then $\zeta\Delta/\sigma= 0.42$.

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 $\zeta= 0.93$, the detectable subregional change with the design is $\Delta/\sigma= 0.45$, i.e. a A half the size of the replication (sampling) error.

In choosing station locations the sites of Sbaw (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 basetine data may be taken into consideration

Assume the random field Z, of measurable quantities consists of the differences at station i, $i = 1,\dots,m$, between before end 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

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

$\overline{\mu_j}$ 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. (1981 b), 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 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: $Var\ (S_i) \propto (Y_i^B - \overline{Y_j^B})^2$, $Var\ (f_{J_j}) \propto (\overline{Y_j^B})^2 (1 - 2\gamma_j) + Var\ (\mu)$ 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 witbin 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, $\sigma^2_{sites} + \sigma^2$ say, can then be estimated by $\sigma^2_{sites} + \sigma^2$ = (metal mean X coefficient of Variance)^2. Finally, σ^2 was taken somewhat conservatively to be $\frac{1}{2}$ of the latter value. The resulting values for $\sigma^2_{sites} = \sigma^2$ appear in Table 4.

A suboptimal design can now be found in the manner described in Section 3. The lengthy computing times required even for this somewhat coarse grid of 119 stations have delayed the presentation of an alternative sampling strategy using the information-based approach. This will be provided in a supplementary report.

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

Block	Area[1]	m_j	1/10 x Cr	1/10 x Ni	Fe	1/10 x V	1/10 x Cu	1/10 x Zn	1/100 x Mn	1/1C x 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	&o	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	16.0	4.5	9.0	21.0	3.0
i'	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	6.0	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	Lo
14	6	4	6.0	4.0	3.5	12.0	3.0	10.0	4.5	1.5
15	3	2	6.0	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								
$\bar{X}$			7.7	4.40	3.0	13.3	3.2	9.0	6.5	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 x Cr	1/100 x Ni	Fe	1/100 x V	1/100 x Cu	1/100 x Zn	$(1/100)^2$ x Mn	1/100 x 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	3 6	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	64	22	11	274	17,0	71	363	7.5
7	10	5	38	16	6.5	182	6.6	65	30	1.3
B	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	26	2.2
13	9	3	65	17	9.3	152	9.4	92	31	1.3
14	6	4	6 4	1 7	12.2	150	9.3	100	30	24
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
1?	27	11	71	22	13.8	224	10.9	105	120	3.6
Total	321	119								
τ^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	0.67	6.4	11	0.34

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Final Report

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ACKN

I would like to express my gratitude to the many NOAA staff who participated in this study. The tide gauges and current meters were flawlessly prepared by T. Jackson, while the CTD system was set up by S. Macri. The off icers and crew of the NOAA ship FAIRWEATHER provided enthusiastic support, Bosun Herb Padilla deserves special credit for his organization of the deck. Dr. M. Jawed Hameedi waa the technical authority and provided useful advice to us despite his move (concurrent with the pro j ect) from Juneau to Anchorage.

Professor Tom Royer of the Institute of Marine Science at the University of Alaska lent his experience in the region to the project. He provided all the runoff and freshwater discharge data as well as numerous references which were used in this study.

The field work was performed by Randy Kashino and Dale McCullough of Dobrocky Seatech. The data recovery rate (100%) speaks for their expertise. The data processing and tidal analyses were performed by Allan Blaskovich of Dobrocky Seatech.

This study was funded by the Minerals Management Service, U.S. Department of the Interior, through interagency agreement with the National Oceanic and Atmospheric Administration, U. S. Department of Commerce, as part of the Outer Continental Shelf Environment Assessment Program.

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1.0 INTRODUCTION

During June and August 1984, tidal height, current and CTD data were collected in the Western Gulf of Alaska principally as input to a numerical model of the continental shelf circulation. The model will he used to help assess the risks associated with a potential oilspill and will aid in the sale of leases by the Minerals Management Service.

The field program was carried out by Dobrocky Seatech technicians R. Kashino and D. McCullough from the NOAA vessel FAIRWEATHER. Current meters, tide gauges, acoustic releases and CTD were furnished and prepared by NOAA, while Seatech designed and fabricated the moorings. Seven tide gauges and four current meter moorings of two current meters each were deployed in June and all instruments were recovered in August. The data recovery was 100% attesting to the care taken in instrument set-up by NOAA's Pacific Marine Environmental Laboratory and the thoroughness of the field technicians. Details of the field program may be found in the field report (September 1984).

Current meters and tide gauge deployment sites are shown in Figure 1.1 along with the locations of the cross-shelf CTD transects. CTD measurements were also made at the current meter sites in order to permit computation of the internal tide modal structure. Specifics of the deployments of the tide gauges and current meters are given in Tables 1.1 and 1.2.

Aanderaa model RCM-4 current meters were used at all locations. The current meters recorded temperature, conductivity and pressure as well as speed and direction. A 15 minute sampling interval was used. Modified Savonius rotors were used on all instruments with the exception of the shallow meter at Sanak Island where an Alekseyev rotor was employed to reduce aliasing due to surface waves.

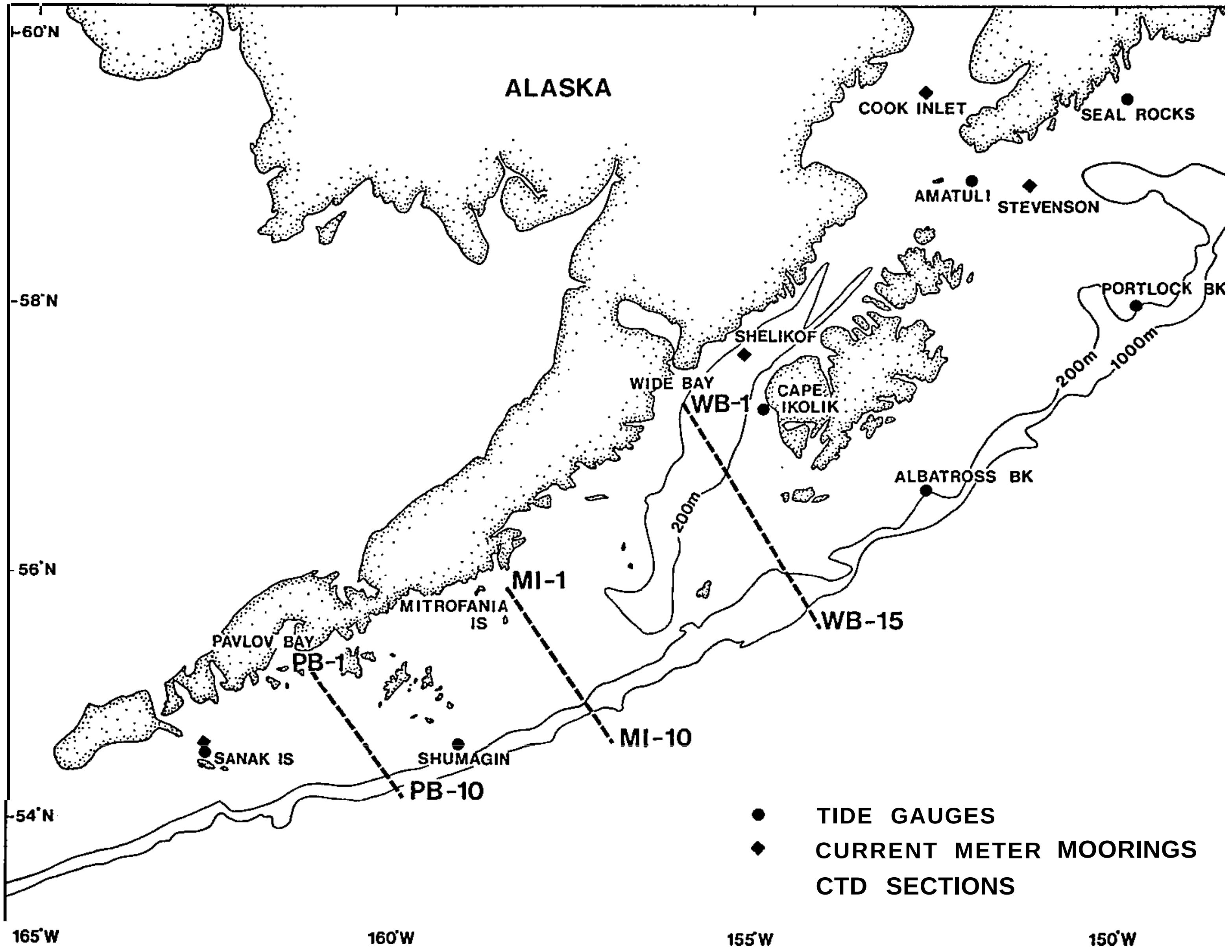

Figure 1.1 **Location of Current Meters, Tide Gauges and CTD sections.**

TABLE 1.1
CURRENT METER DEPLOYMENT SPECIFICS

Location		Water Depth (m)	C.M. NO.	C.M. Depth (m)	First Good Record (GMT)		Last Good Record (GMT)	
Stevenson Entrance North of Portlock Bk	58°53'73N	113	2493	45	1800	13 June 84	0945	9 Aug 84
	150°57'23W		1807	75	1800	13 June 84	0945	9 Aug 84
Cook Inlet	59°35'02N	62	3710	36	0430	14 June 84	2015	9 Aug 84
	152°29'00W		3614	52	0430	14 June 84	2015	9 Aug 84
Shelikof Strait	57°39'00N	250	3127	40	2130	14 June 84	1400	10 Aug 84
	155°03'33W		1812	150	2130	14 June 84	1400	10 Aug 84
Sanak (Deer Island)	54°35'25N	49	3185*	18.5	1000	16 June 84	0445	13 Aug 84
	162°43'77W		1987	38.5	1000	16 June 84	0445	13 Aug 84

All current meters were equipped with temperature, conductivity and pressure sensors.

Sampling interval was 15 minutes on all current meters.

*This current meter was modified to utilize the Alekseyev rotor now available from Aanderaa.

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TABLE 1.2

TIDE GAUGE DEPLOYMENT SPECIFICS

Location			Depth (m)	T.G. No.	First Good Record (GMT)		Last Good Record (GMT)	
Albatross Bank	56°33'48N	152 °26'95W	163	107	1200	12 June 84	0407.5	8 Aug 84
Portlock Bank	58°01'03N	149°29'58W	174	205	0100	13 June 84	1615	8 Aug 84
Seal Socks	59°29'93N	149°29 '57W	112	18s	1000	13 June 83	0430	9 Aug S4
Amatuli Island	59°00' 13N	I51050'03W	168	87	2230	13 June 84	1400	9 Aug S4
Cape Ikolik	57°15'00N	154°45 '30W	62	120	0100	15 June 84	2315	10 Aug 84
Shumagin (Simeonof Is)	54°31'93N	15805 8'08W	192	119	2000	15 June 84	1907.5	11 Aug 84
Sanak (Deer Is)	54°35'25N	162°43'77W	48	209	1000	16 June S4	0452.5	13 Aug 84

Sampling interval was 7.5 minutes for all tide gauges.

All tide gauges were Aanderaa model TG3A; a 7.5 minute sampling interval was used.

The current meters were deployed on taut line moorings of 1/4" 7 x 19 wire rope. Buoyancy was provided at the top of the mooring, above the lower current meter and above the acoustic release. Train wheels were used for anchors. Tide gauge moorings consisted of concrete blocks with recesses for the tide gauge. Sketches of each mooring type are presented in Figures 1.2 through 1.6. All moorings were suspended in the water column then gently lowered to the bottom with a device which releases upon loss of tension.

1.1 DATA REDUCTION

The Aanderaa data tapes were translated and converted to physical units using calibrations supplied by NOAA. Salinities were computed from temperature, conductivity and pressure with the UNESCO (19S0) formula.

Time series plots were produced for each instrument and are available in our Data RepOrt (Greisman 1984). Also produced were progressive vector diagrams, stick plots and histograms. These products aided in quality control as well as in forming a general impression of the data set.

Harmonic analyses of the tide gauge data and tidal stream analyses of the current meter data were performed using the methods of Foreman (1977 and 197S). The complete analyses are presented in Appendix 1.

Tables 1.3 and 1.4 show the tidal analyses for the largest constituents for the heights and currents respectively. Greenwich phase is used throughout. In the tidal stream analyses MAJ represents the amplitude of the semi-major axis of the tidal ellipse; MIN represents the semi-minor axis of the ellipse. The sign of MIN indicates the sense of rotation; positive implies anti-clockwise and negative clockwise. INC is the orientation of the northern semi-major axis of the ellipse anti-clockwise

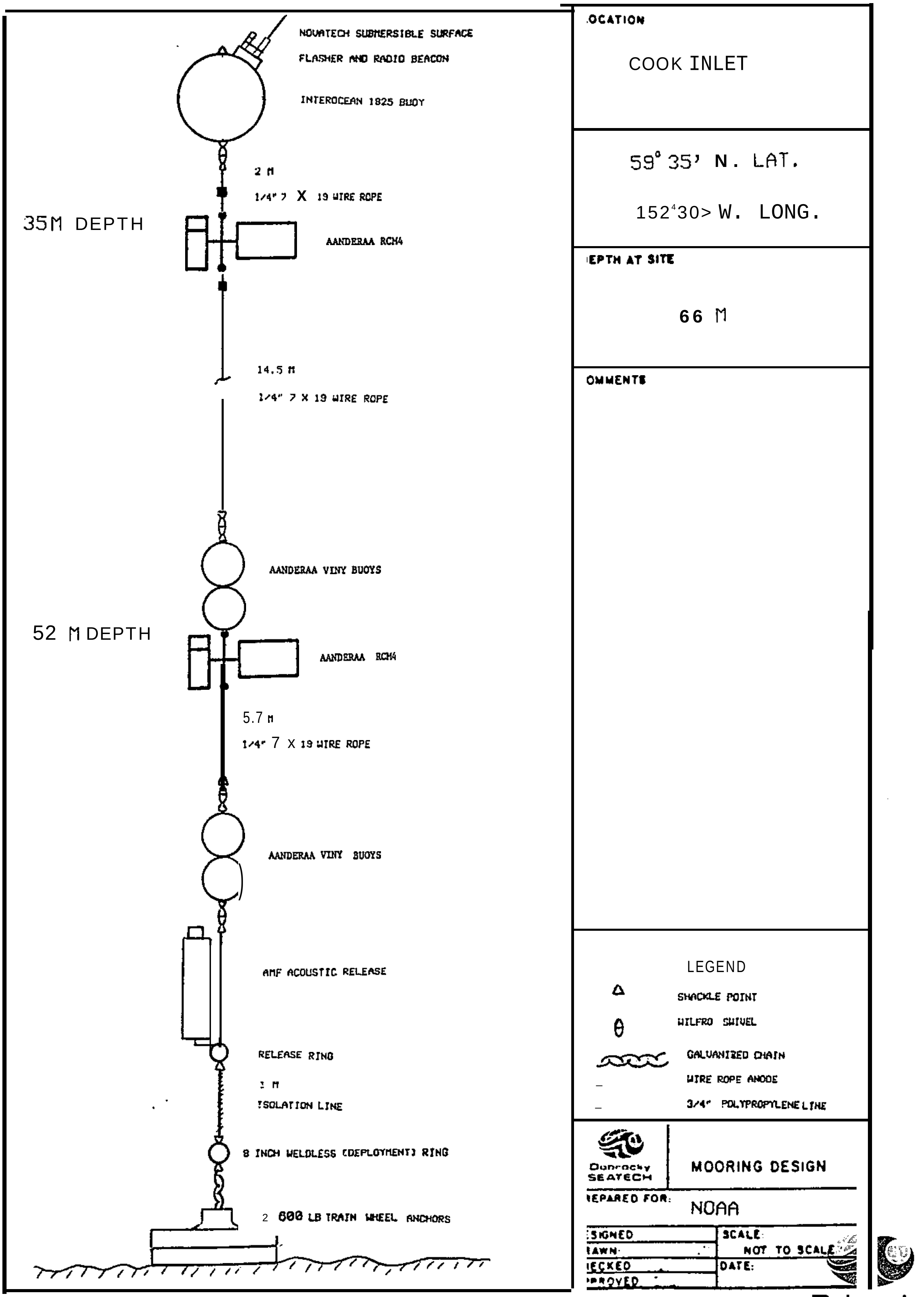

Figure 1.2 Mooring configuration at Cook Inlet

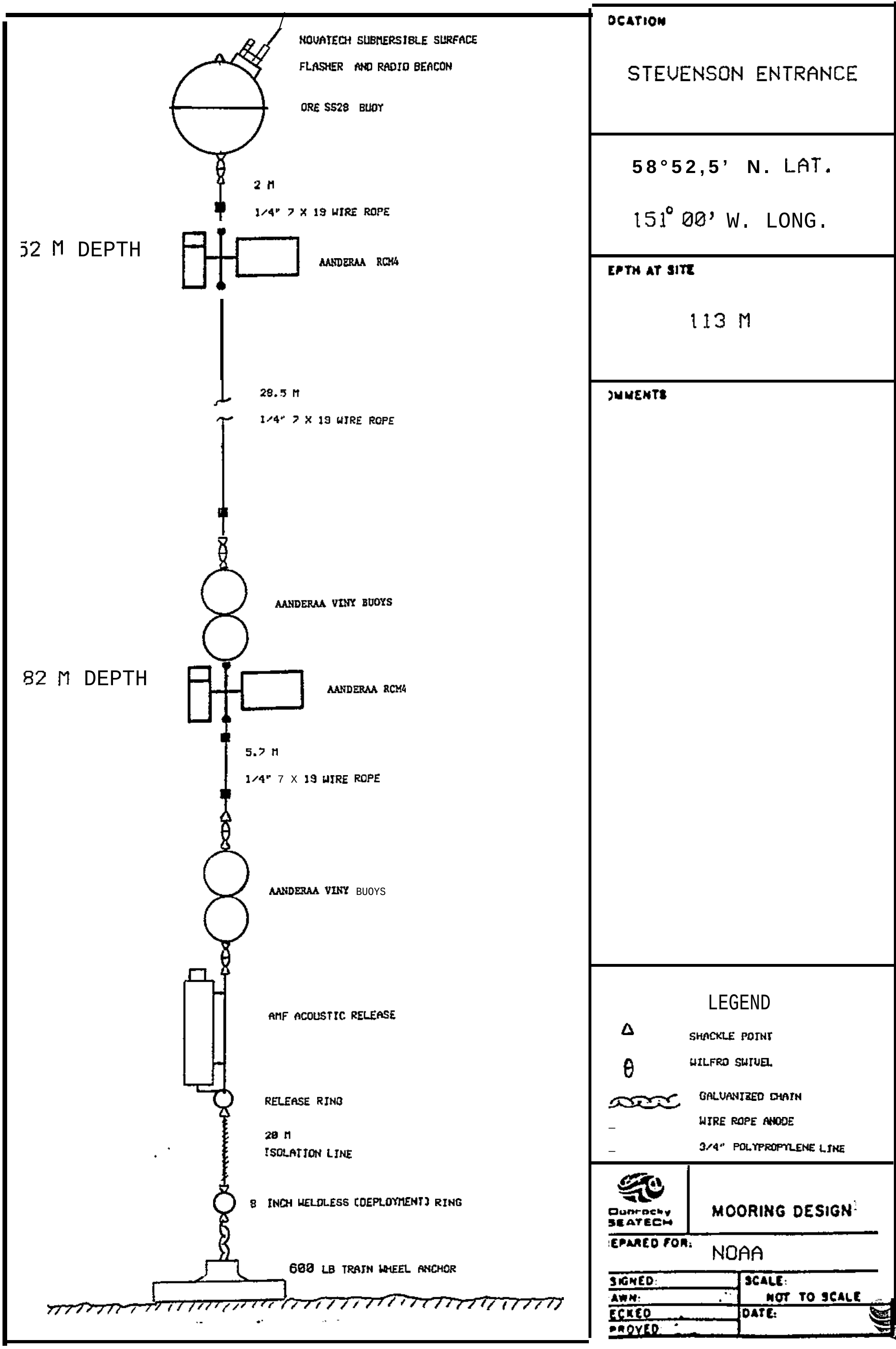

Figure 1.3 Mooring Configuration at Stevenson Entrance

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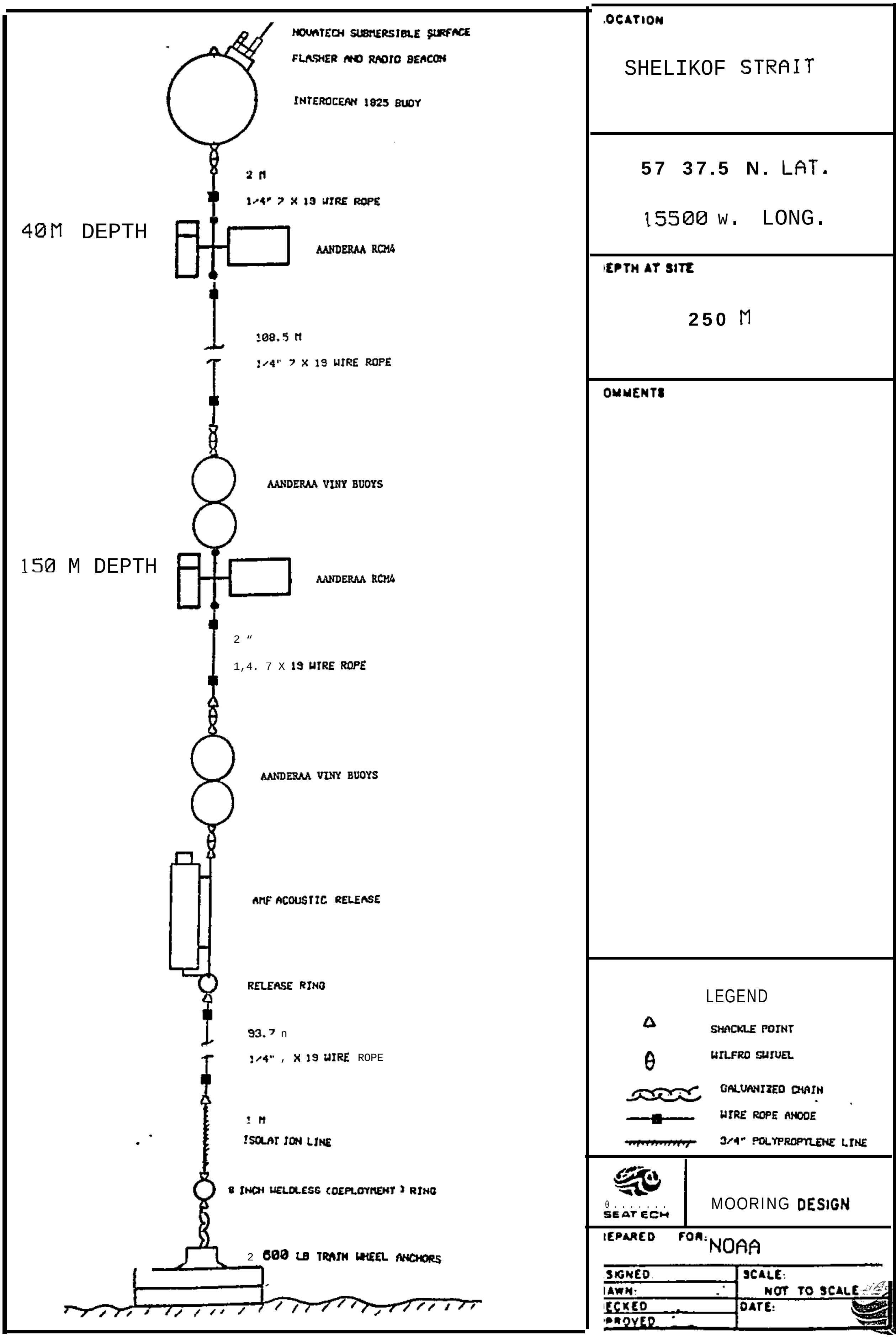

Figure 1.4 **Mooring Configuration at Shelikof Strait**

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SEATECH

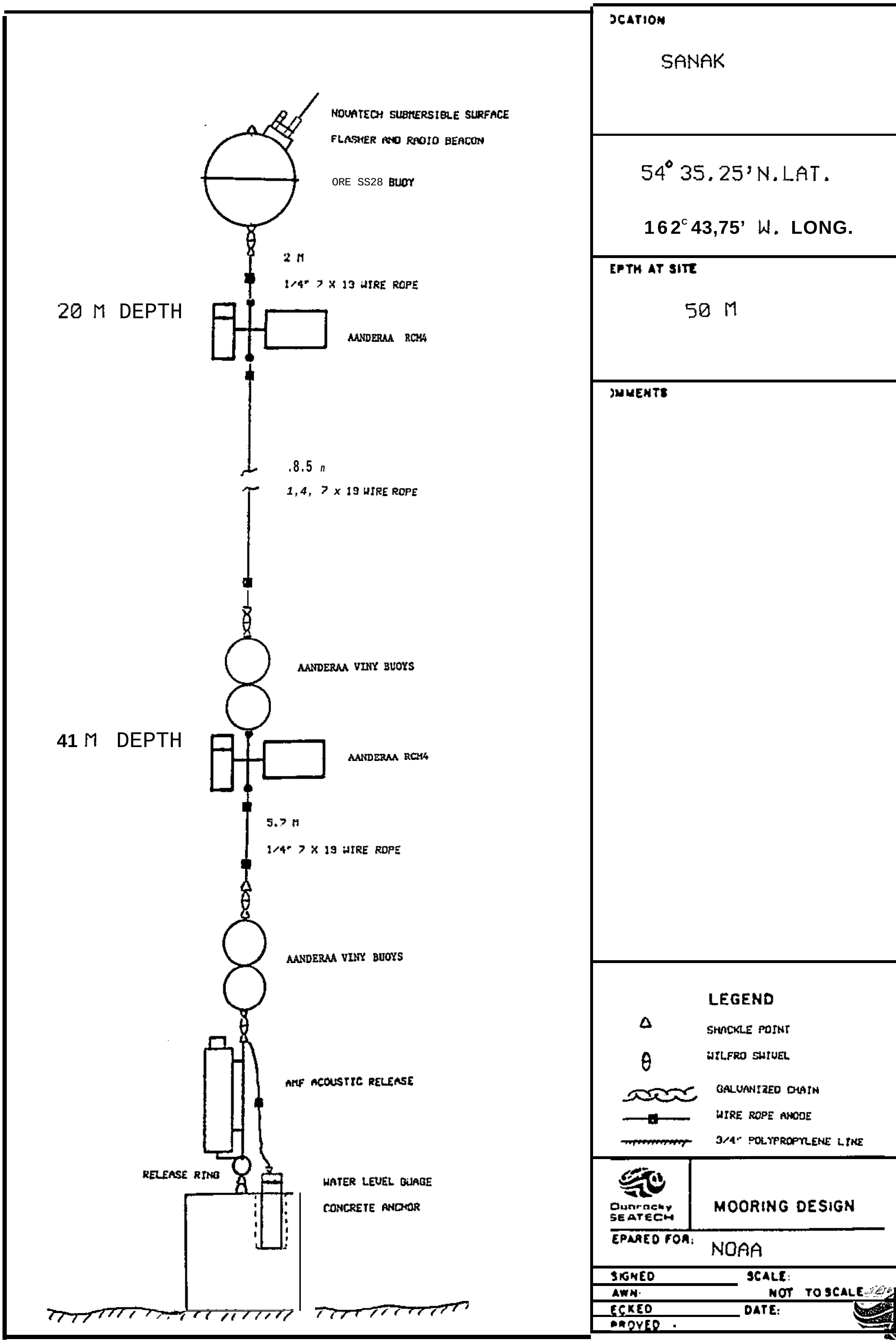

Figure 1.5 Mooring ConfigUration at Sanak

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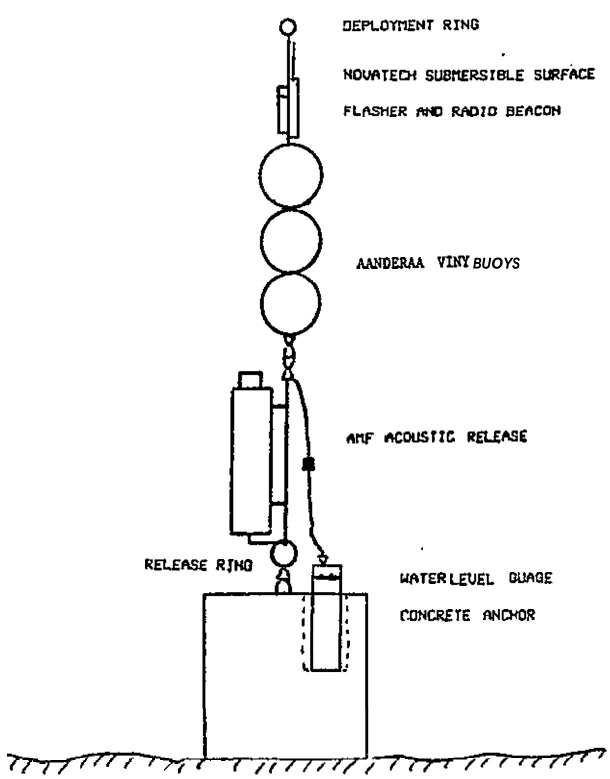
PORTLOCK BANK 58 00'N. LAT. 149 30' W. LONG. 200 M
SEAL W 59 30'N. LAT. 152 30' W. LONG. 100 M
ALBATROSS BANK 56 30'N. LAT. 153 00' W. LONG. 200 M
SIMEONOFF ISLAND 54 30'N. LAT. 159 00' W. LONG. 20 M
AMATULI ISLAND 59 00' N. LAT. 152 00' W. LONG. 20 M
CAPE IKOLIK 59 15'N. LAT. 154 45' W. LONG. 20 M



TIDE GAUGE MOORING

COMMENTS

LEGEND

SHACKLE POINT
WILFRO SWIVEL
GALVANIZED CHAIN
WIRE ROPE ANODE
3/4" POLYPROPYLENE LINE

Dobrocky SEATECH

MOORING DESIGN

PREPARED FOR: NOAA

DESIGNED	SCALE: NOT TO SCALE
DRAWN	
CHECKED	DATE:
APPROVED	

Figure 1.6 **Mooring Configuration for the Tide Gauges**

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TABLE 1.3
MAJOR TIDAL CONSTITUENTS
AMPLITUDES (METRES) AND GREENWICH PHASES

STATION	Principal Lunar Diurnal O_1 A	G	Soli -Lunar Declinational (Divisional) K_1 A	G	Larger Lunar Elliptic (Semi-Diurnal) ‘2 A	G	Principal Lunar (Semi-Diurnal) ‘2 A	G	Principal Solar (Semi-Diurnal) S_2 A	G	$? = \frac{K_1 + O_1}{M_2 + S_2}$
Sanak	.2691	269.93	.5041	293.03	.1331	314.13	.6306	330.12	.1579	003.55	0.981
Port lock Bk .	.2916	252.72	.5572	276.60	.1902	278.57	1.0140	293.48	.2499	334.36	0.672
Seal Sk.	.2846	256.09	.5431	279.69	.2216	274.53	1.1975	289.94	.3016	331.25	0.552
Cape, Ikolik	.3070	265.70,	.5928	.289 .37	.2770	303. 52	1.3889	317. $?3	.3757	001.87	0.510
Shumagin	.2769	266.50	.5175	289.08	.1371	302.39	.6713	317.25	.1690	353.99	0.945
Albatross Bk.	.2905	255.04	.5528	278.29	,1698	279.03	.8940	294.57	.2171	334.37	0.759
Amatuli 1s.	.3082	262.95	.5834	287.24	.3011	297.41	1.5548	312.60	.4184	357.54	0.452

TABLE 1.4

TIDAL **STREAM ANALYSES**

INCLUDING TIDAL **HEIGHT ANALYSES FROM NEARBY** TIDE **GAUGES**

STATION	DEPTH	O_1 MAJ	MIN	INC	G	A	G	K_1 MAJ	MIN	INC	G	A	G
Stevenson	54	3.7	-0.78	98	14			6.6	-2.2	101	41		
St evenson	82	3.5	-1.7	91	22			6.4	-3.5	108	36		
Amatuli 1						.308	263					.583	287
Shelikof Str .	46	1.8	-0. 13	39	227			3.4	0.08	41	244		
Shelikof Str.	157	1.5	-0.06	49	205			3.0	-0.15	48	226		
C. Ikolik						.307	266					.593	289
Sanak	20	2.3	-1.1	177	105			4.0	-2.0	167	145		
Sanak	41	3.5	-0.90	1	274			7.,	-3. 1	166	136		
Sanak						.269	270					.504	293
Cook 1..	35	9.5	-0.70	79	224			19.0	-3.5	77	244		
Cook In.	52	8.0	-0.07	69	220			17.6	-3.4	78	239		

STATION	DEPTH	N_2 MAJ	MIN	INC	G	A	G	M_2 MAJ	KIN	INC	G	A	G	S_2 MAJ	MIN	INC	G	A	G
Stev.....	54	5.9	1.5	94	51			30.2	0.62	102	66			10.1	0.59	97	112		
Stevenson	82	6.o	-0.3	9 4	55			36.3	1.65	, 91	76	. .	.	11.6	1.10	84	126		
Amatuli 1						.301	297					1.555	31:					.418	358
Shelikof St,.	46	2.5	0.7	39				13.8	-.02	40	251			4.5	-.03	41	297		
Shelikof Str.	157	3.1	1.0	46	233			14.9	.60	43	248			4.3	.14	41	296		
C. Ikolik						.277	304					1.389	31;					.376	002
Sanak	20	0.7	-0.3	90				3.1	.47	1%3	285			1.1	-.11	77	336		
Sanak	41	0.s	-0.5	64	239			4.1	1.08	90	253			1.5	-.61	30	267		
Sanak						.133	314					.631	33(					.158	004
Cook In.	35	14.4	-2.4	81	285			73.5	-3.9	78	308			19.8	-2.5	84	352		
Cook In.	52	3.2	-3.6	83	279			59.8	-2.0	74	305			14.8	-1.8	84	346		

NOTE: Semi-major and semi-minor ellipse axes in CMS^{-1}; INC is inclination of the northern semi-major axis anti-clockwise from east; G is the Greenwich phase
A tidal height amplitude in metres.

from east (mathematical rather than geographic convention). G is the Greenwich phase and represents the time at which the rotating velocity vector coincides with the northern semi-major axis of the ellipse.

The CTD data were translated, calibrated versus bottle casts, and vertical profiles plotted for each cast. The profiles are presented in the data report. Listings of roughly 1 m depth averaged values were produced for use in preparing cross sections.

More details on the data reduction are available in the data report.

1.2 OVERVIEW OF TSS DATA

98.6% of the variance in the tide gauge records is due to tidal oscillations while 67% of the variance in the current meter records is tidal. In addition, the mean flows recorded at the current meters were about 4 cm s^{-1}, i.e. roughly an order of magnitude smaller than the tidal currents. Clearly the flow kinetic energy in the region is dominated by tides during the summer. However, from our data set we cannot address the winter period when easterly gales may have a great influence upon circulation on the shelf.

1.3 ANALYSES UNDERTAKEN

In Section 2 of this report conclusions based upon the distribution of properties (the CTD data) are presented and discussed. These include computations of dynamic height topographies and geostrophic current speeds and directions.

Section 3 comprises analyses of the tidal oscillations. Cotidal charts, tidal energy propagation and internal tides are discussed.

Section 4 deals with the non-tidal, specifically tbe subtidal, oscillations. We found ourselves somewhat limited in these analyses because of the relatively short period of measurement. Tbe two month period between June and August 1984 is, of course, too short to address seasonal signals such as gross changes in the wind field and seasonal runoff variations. Nevertheless, aspects of the forcing of long period oscillations in the Western Gulf of Alaska, particularly Shelikof Strait are discussed.

2.0 PROPERTY FIELDS

(Salinity, Temperature, Density, Dynamic Topography)

The results of the June and August 19S4 CTD surveys are discussed in this section. Field methods, calibration and quality control of the data were presented in the data report. It should be borne in mind that these data are of fair quality only probably due to the poor condition of the CTD winch slip rings.

2.1 CSOSS SECTIONS

Cross sections of temperature, salinity and sigma-t were prepared for the Pavlov Bay, Mitrofania Island and Wide Bay sections for both June and August . The locations of these sections are shown in Figure 2.1. Salinity, temperature and sigma-t sections are presented in pairs for June, then August to enhance the reader's appreciation of temporal changes. It should be remembered that the data are non-synoptic, the occupation of stations along each section having consumed about one day.

2. 1.1 Temperature

The most striking feature of the temperature sections (Figures 2.2, 2.3, 2.8, 2.9, 2.14, 2. 15) is the pronounced warming of the surface layers to about. 50 m depth between June and August. Surface temperature increased about 5° C during this period both over the continental shelf and slope. Since the measured mean flows are on the order of 5 cm s^{-1}, the temperature field would have been advect ed only about 200 km between June and August. The warming of the surface layers is, therefore, almost certainly due to local insolation. The water column is everywhere temperature stratified below a few meters depth with the exception of the Trinity Islands Bank shown in the Wide Bay Section. Here the temperature is nearly constant with depth in both June and August likely due to strong

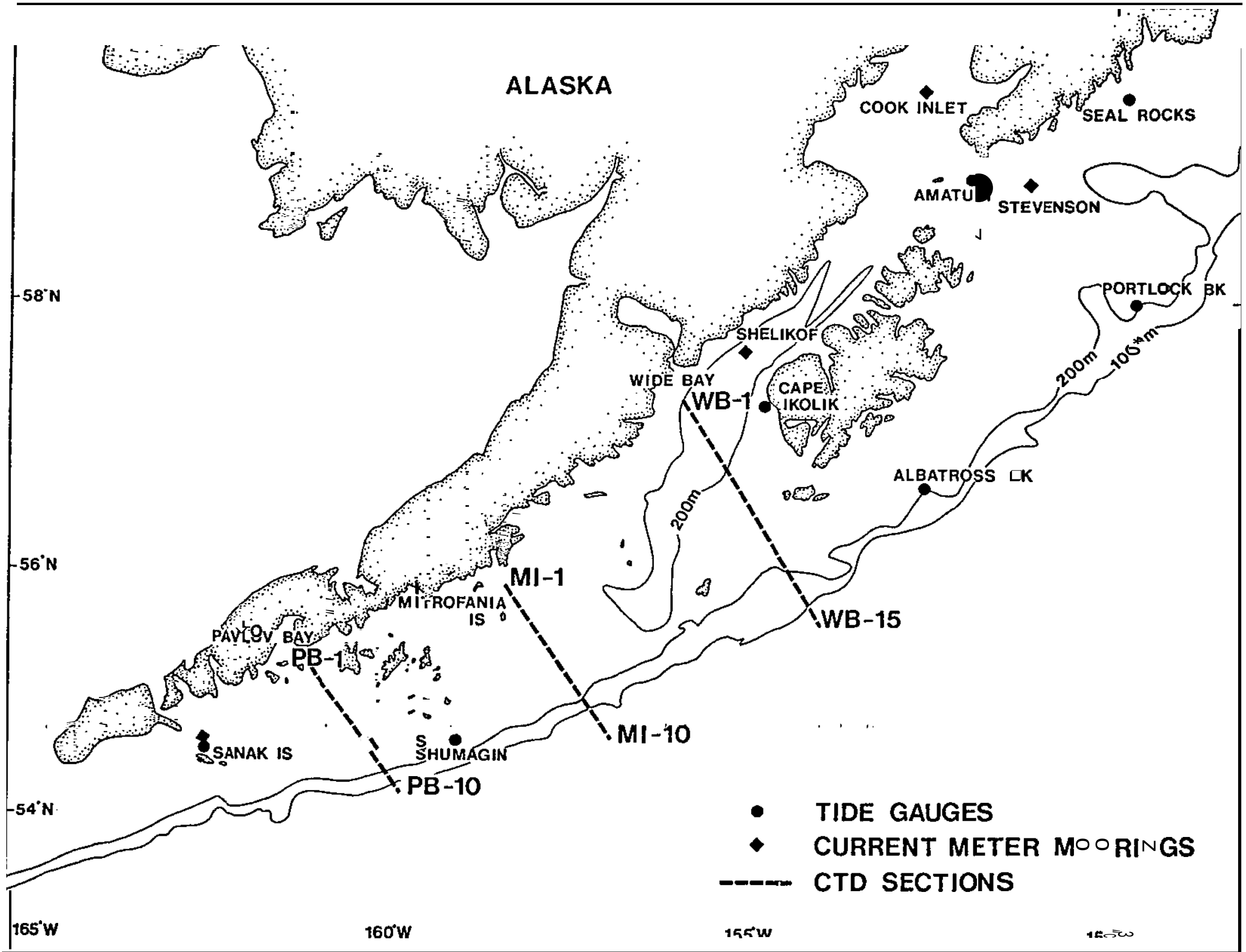


Figure 2.1 Location Chart for S, T, σ_t cross sections.

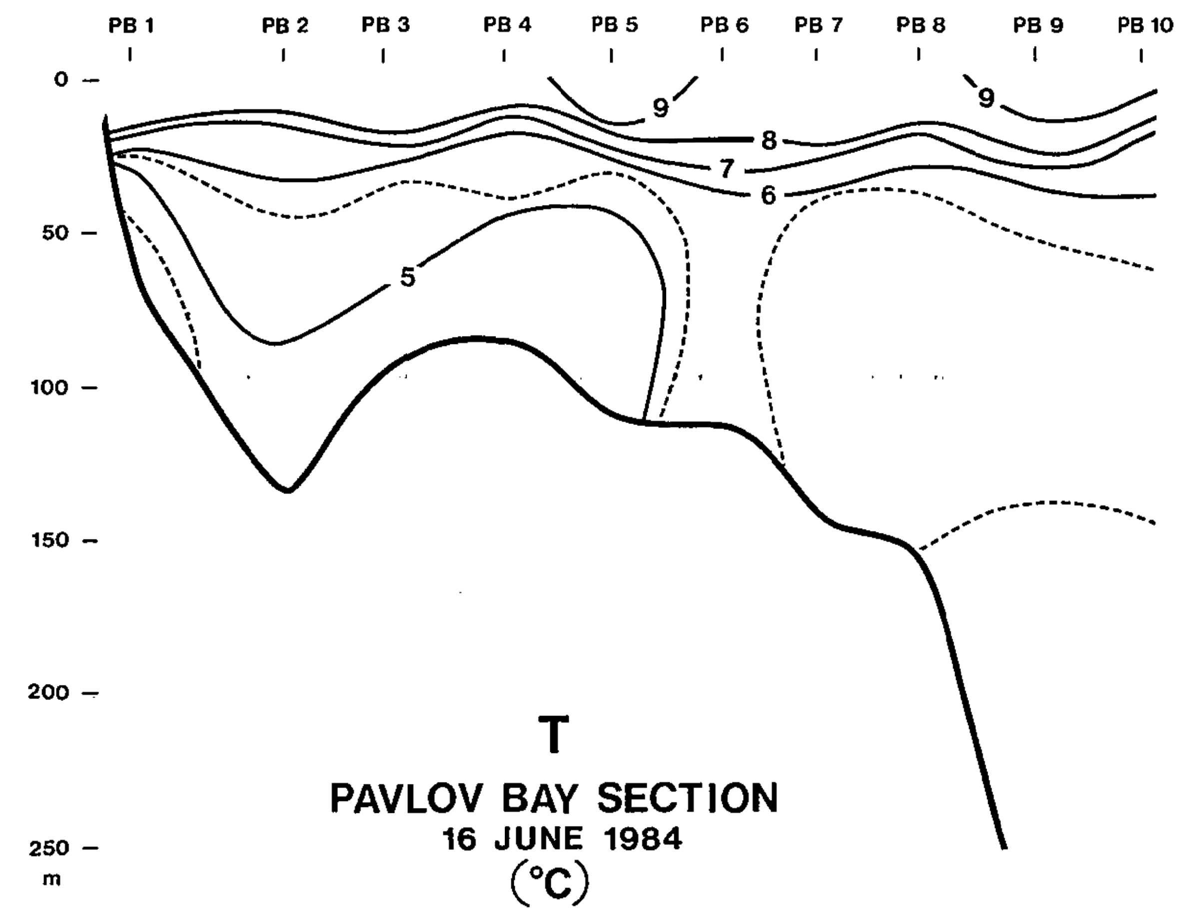
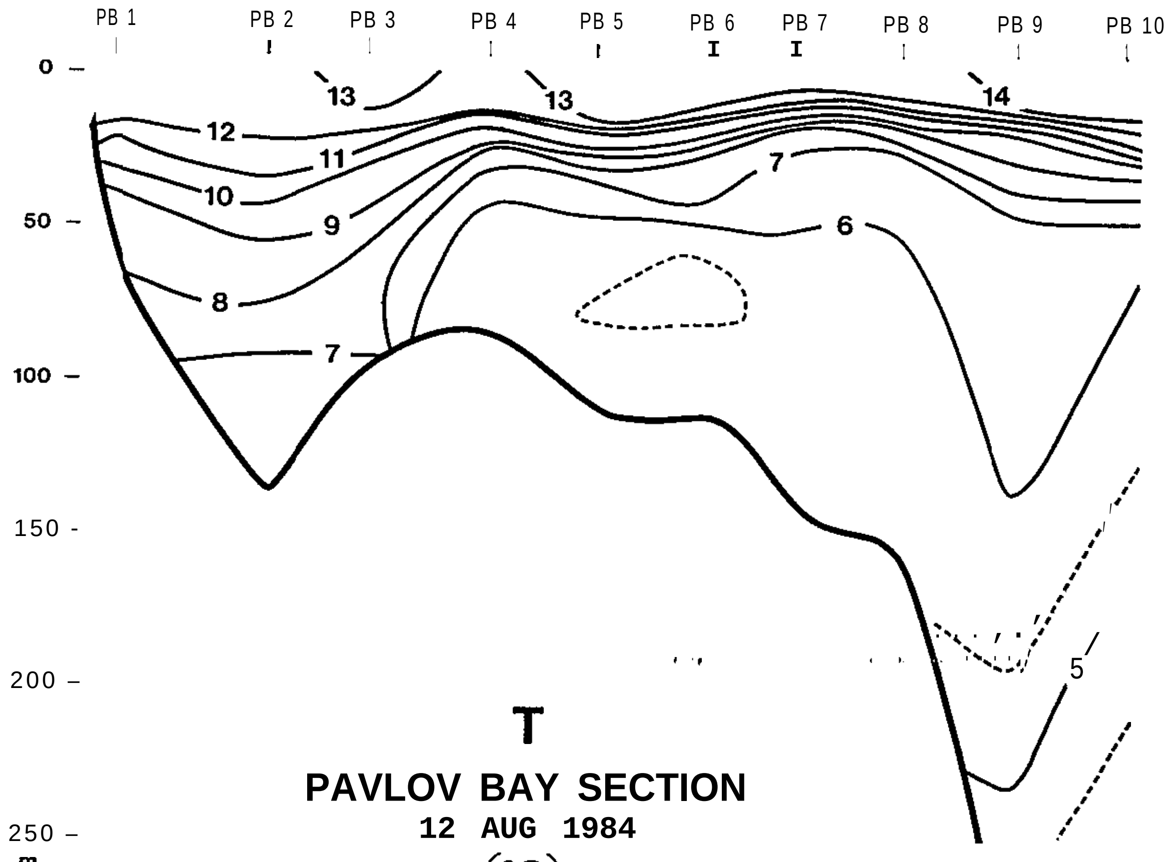


Figure 2.2 Temperature Section Pavlov Bay June



T

PAVLOV BAY SECTION

12 AUG 1984

(°C)

Dobrocky SEATECH

Figure

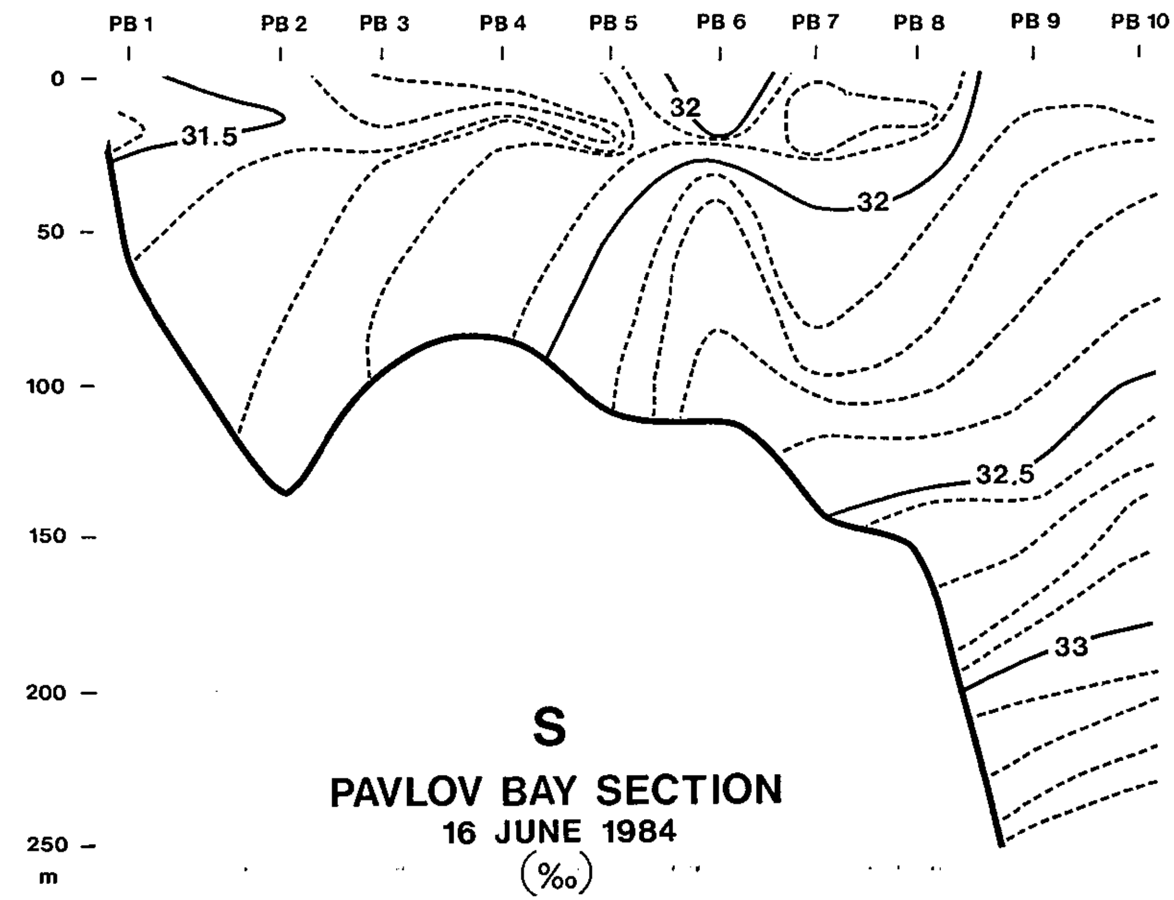


Figure 2.4 Salinity Section Pavlov Bay June

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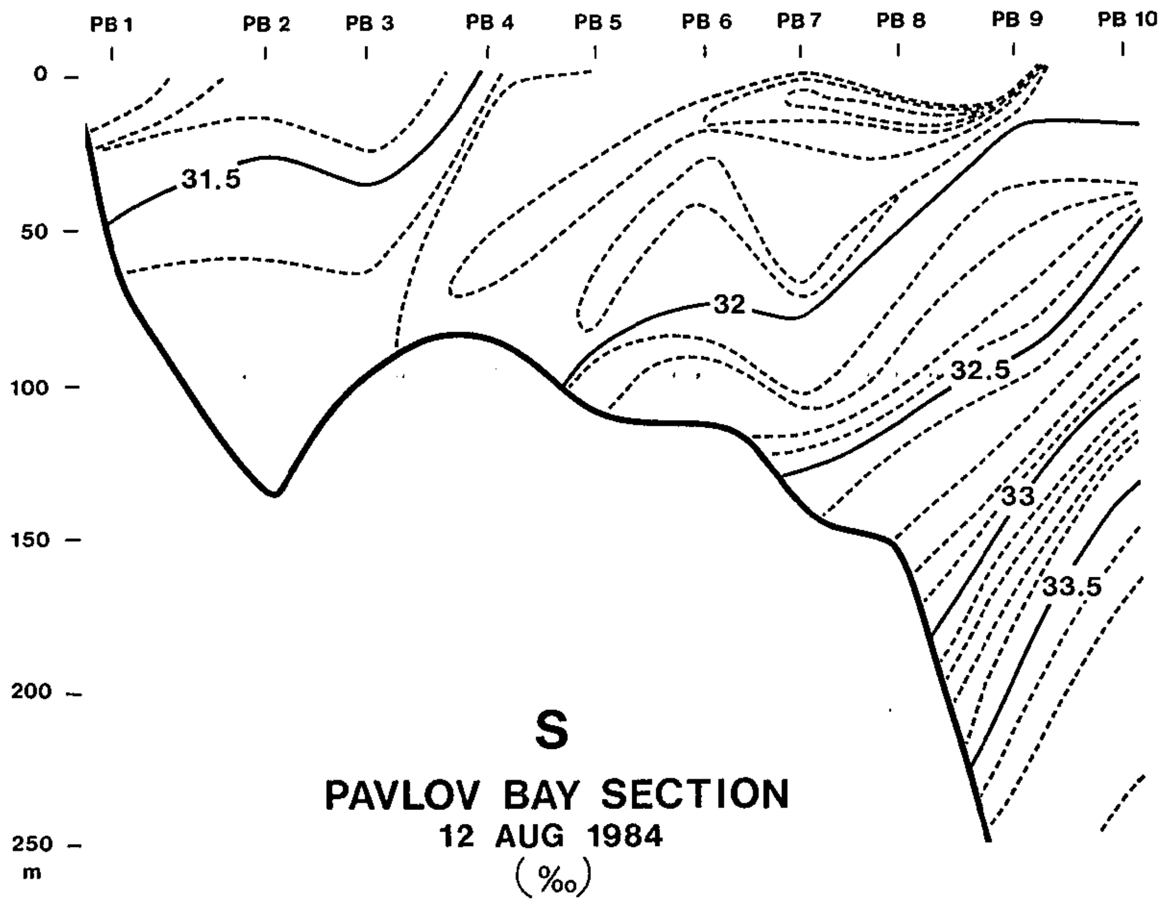

Figure 2.5 Salinity Section Pavlov Bay August

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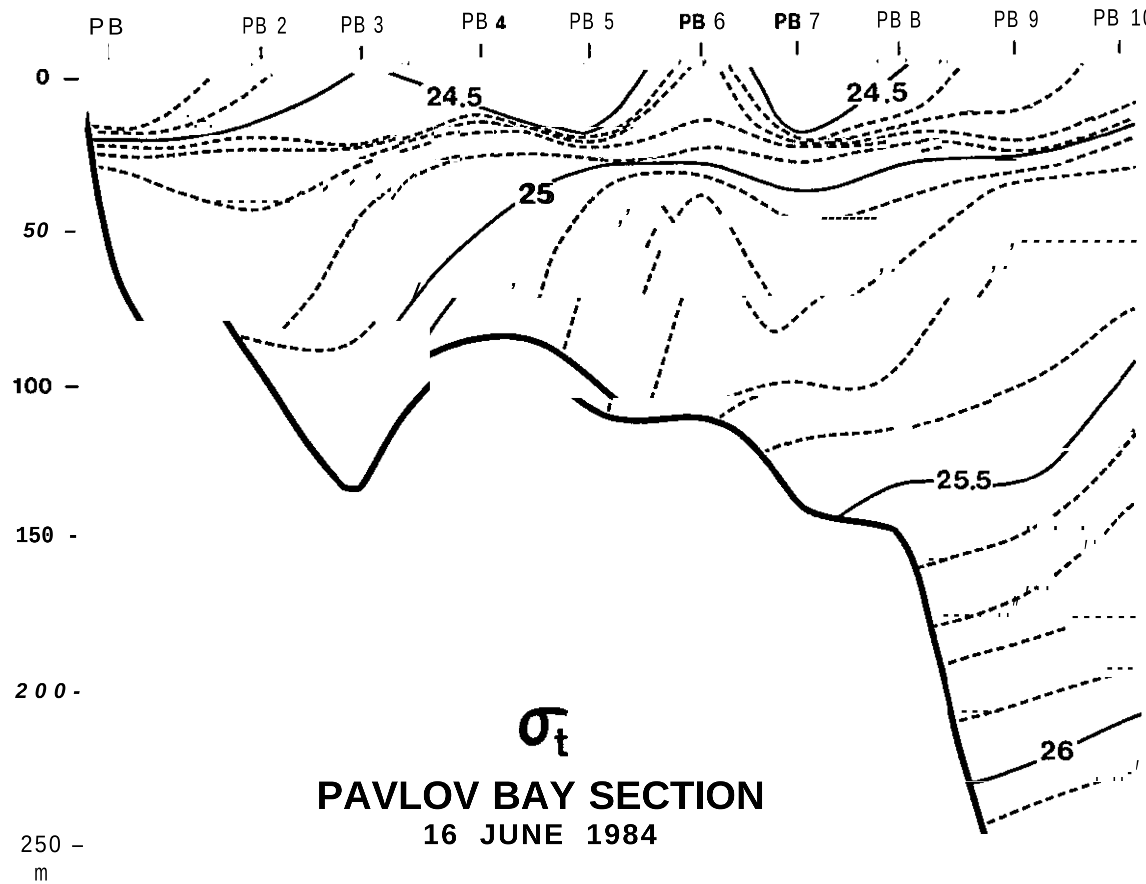

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Figure 2.6 Sigma-t Section Pavlov Bay June

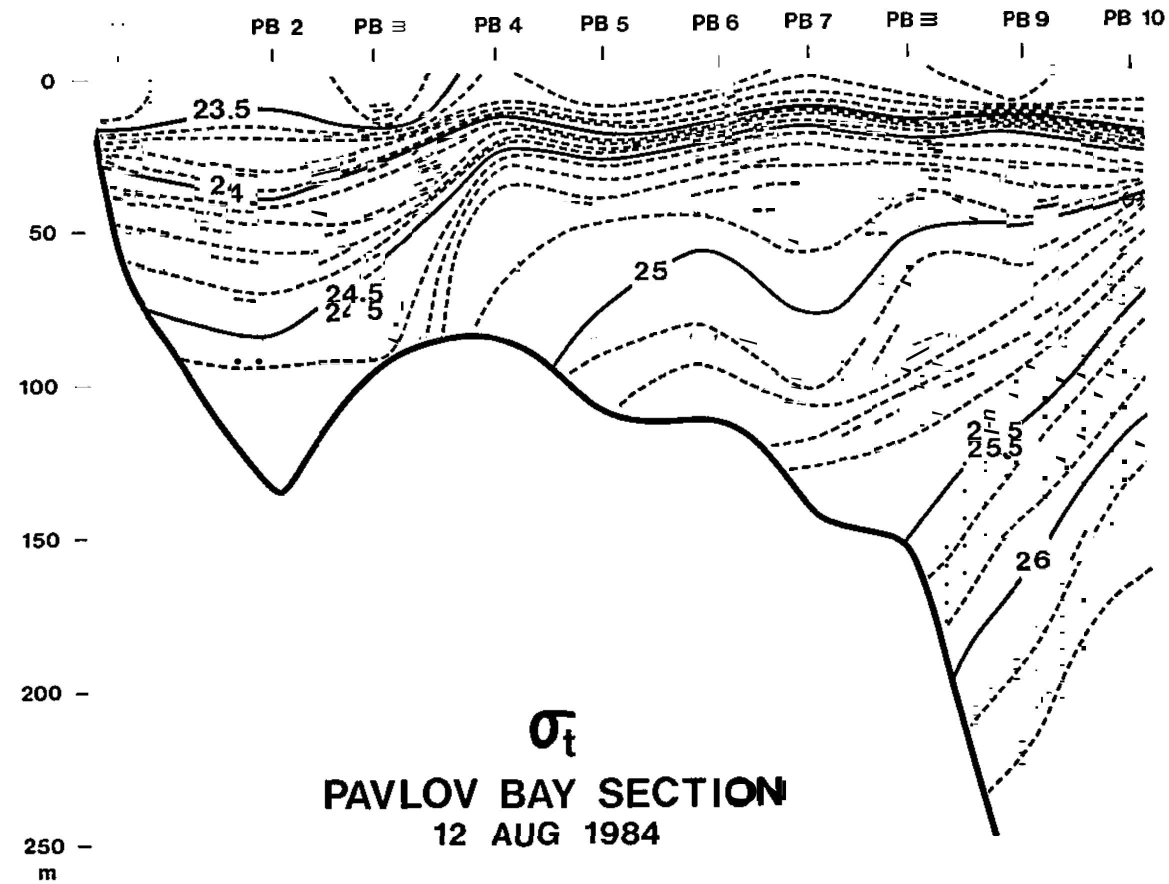


Figure 2.7 Sigma-t Section Pavlov Bay August

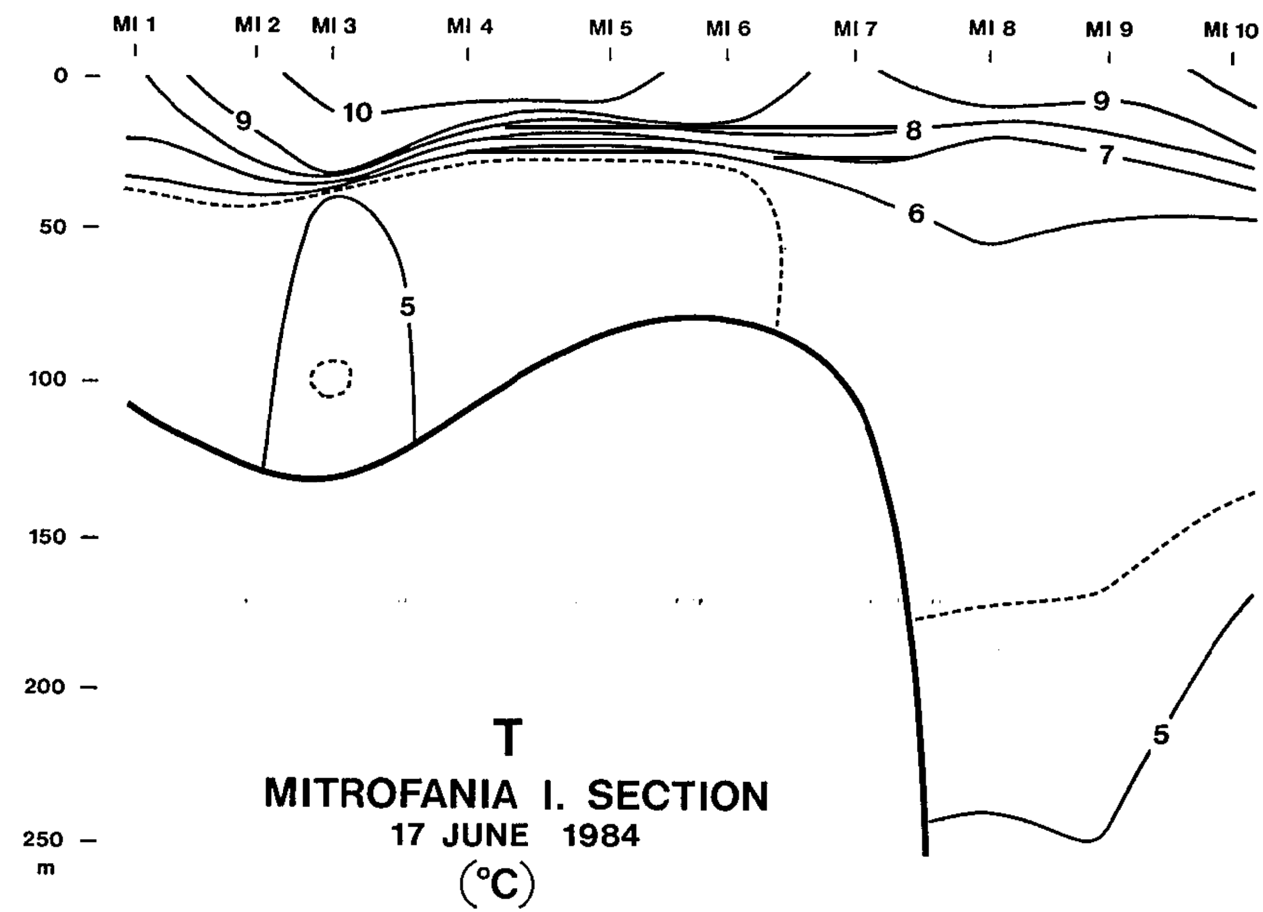


Figure 2.8 Temperature Section Mitrofania Island June

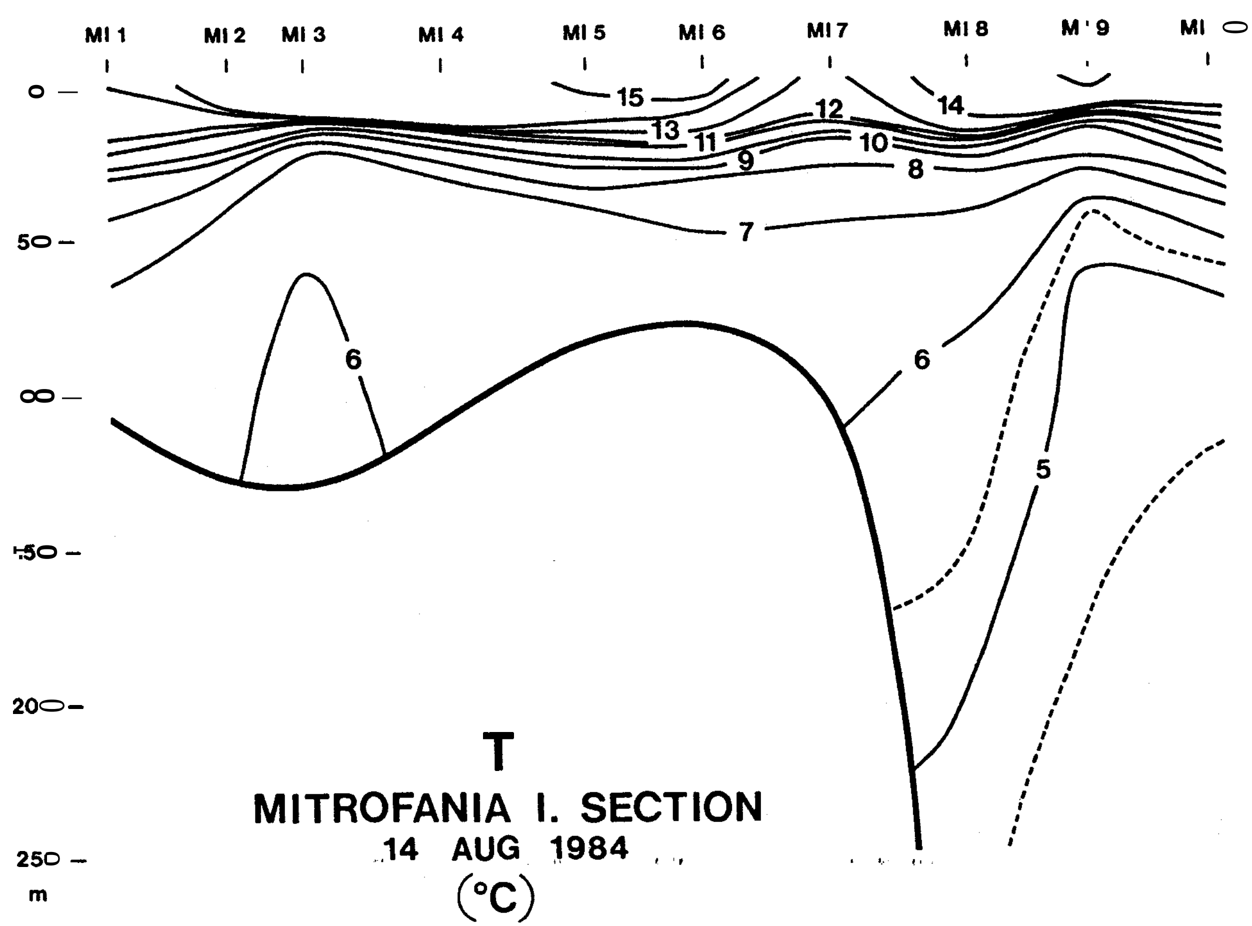
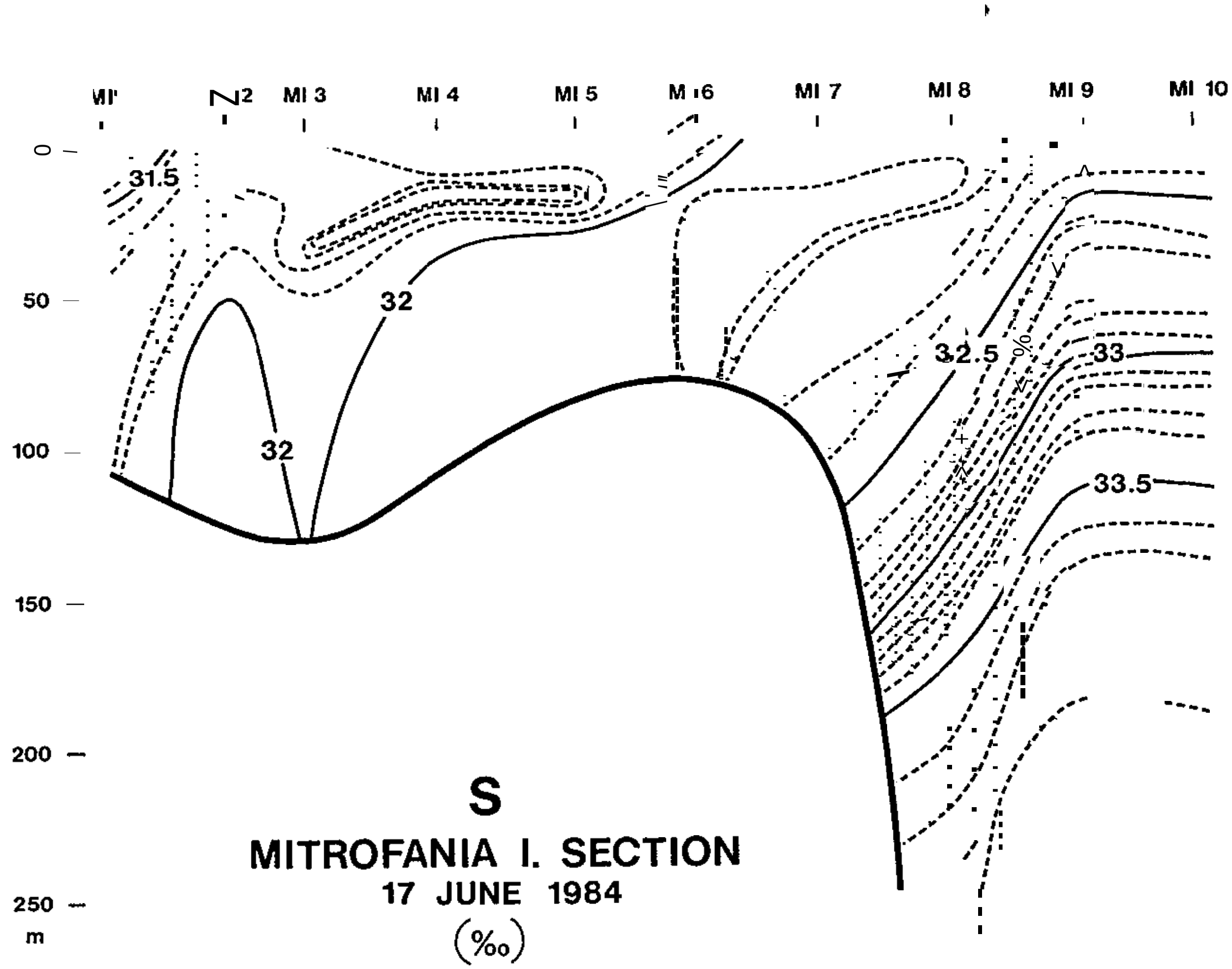


Figure 2.9 Temperature Section Mitrofania Island August



Dobrocky SEATECH

Figure 2.10 Salinity Section Mitrofania Island June

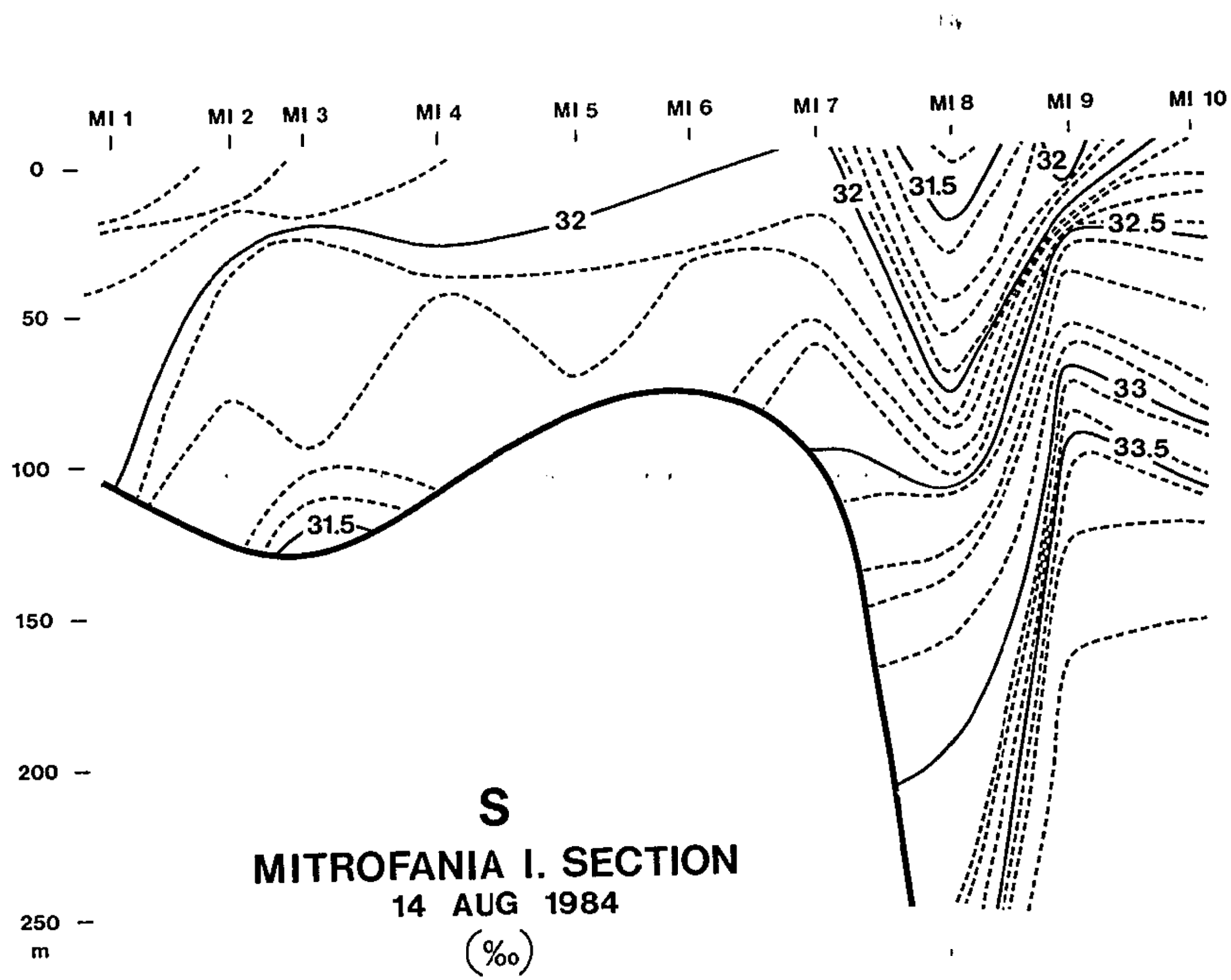


Figure 2.11 Salinity Section Mitrofania Island August

Dobrocky SEATECH

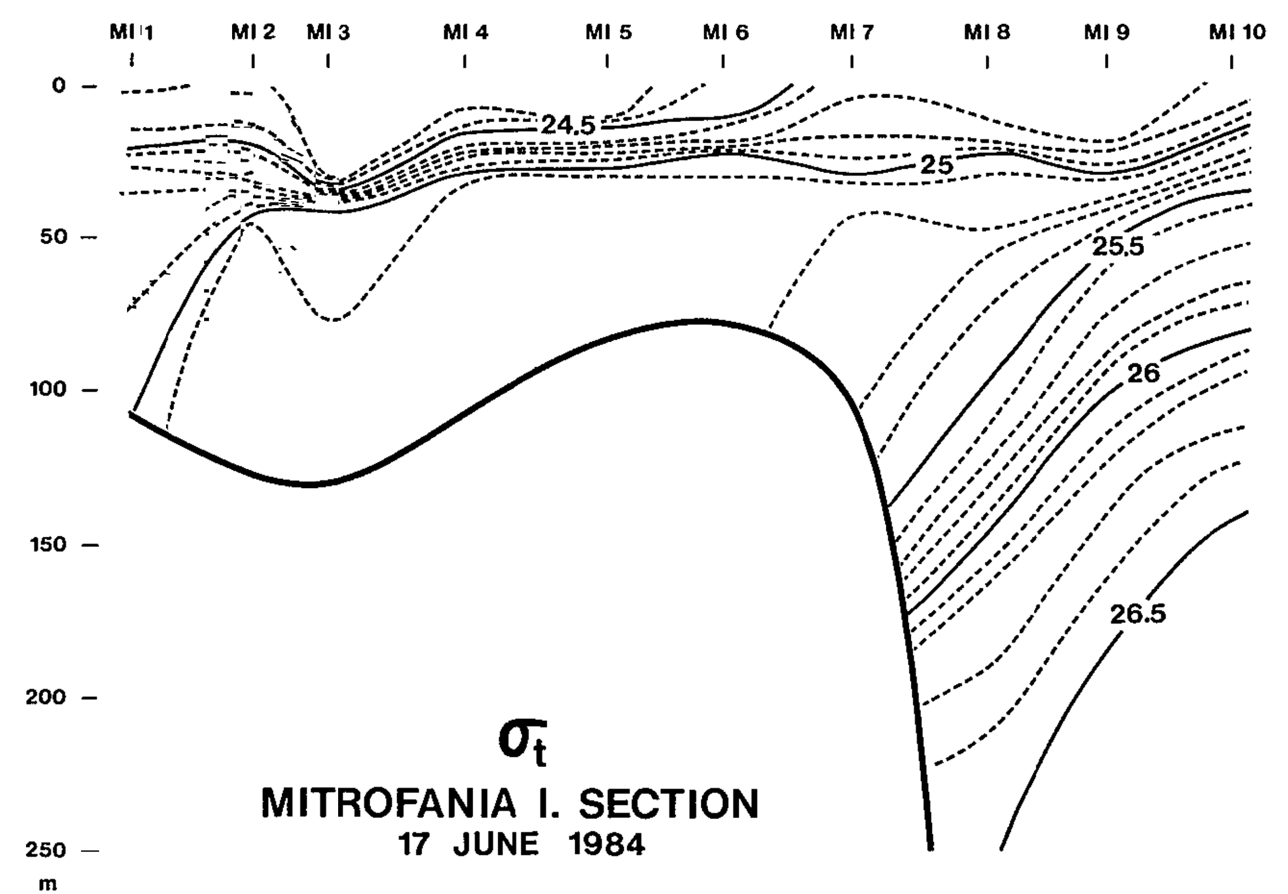


Figure 2.12 Sigma-t Section Mitrofania Island June

Dobrocky SEATECH

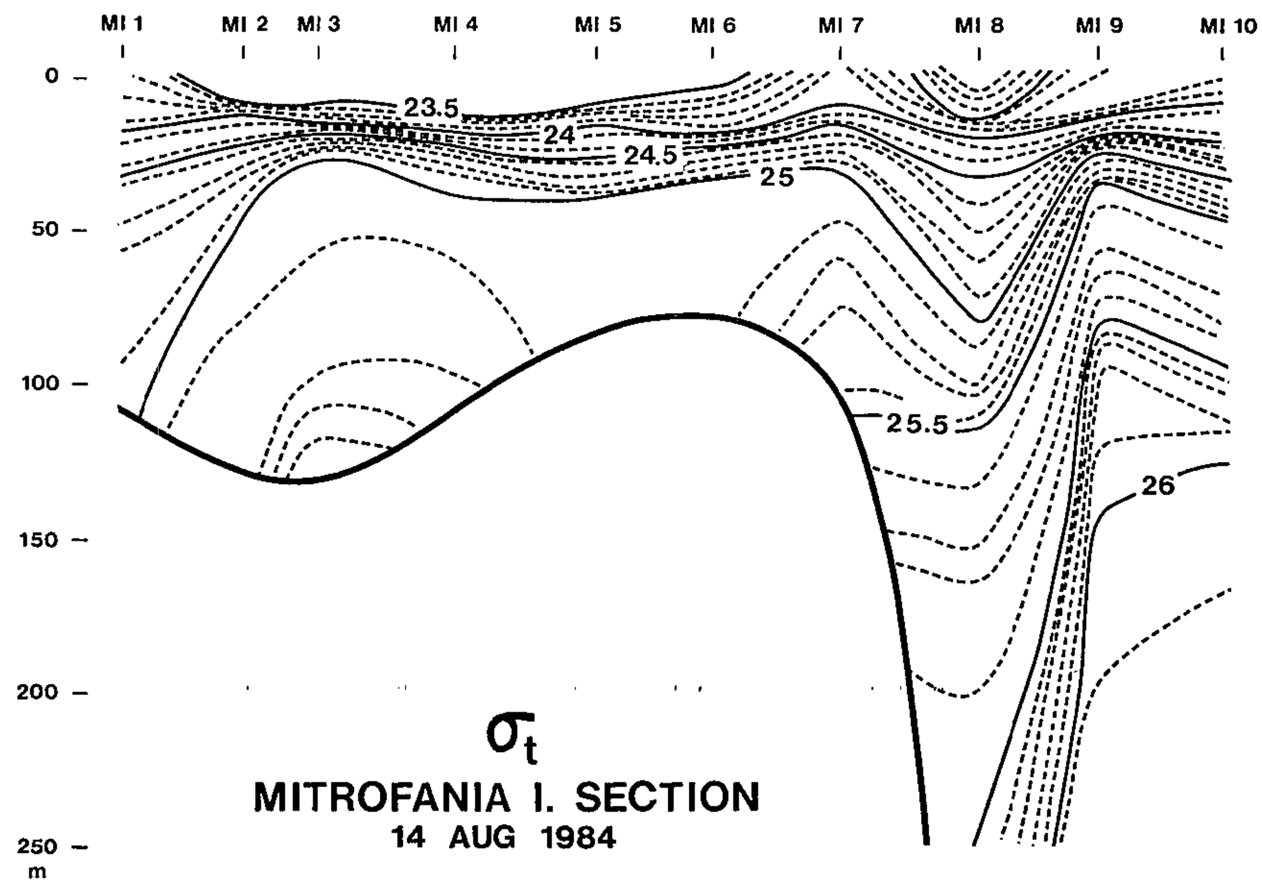


Figure 2.13 Sigma-t Section Mitrofania Island August

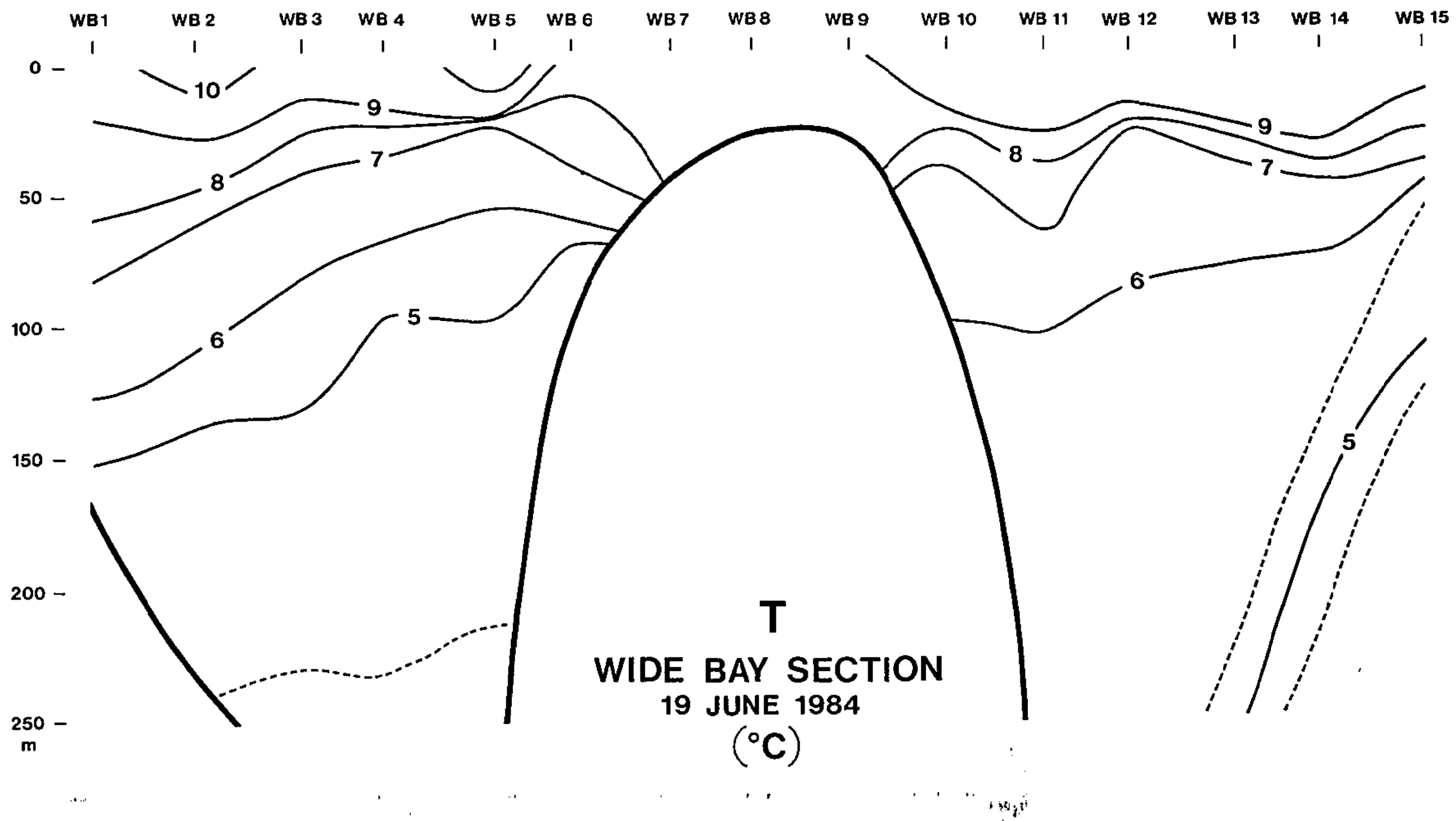


Figure 2.14 Temperature Section Wide Bay June

Dobrocky SEATECH

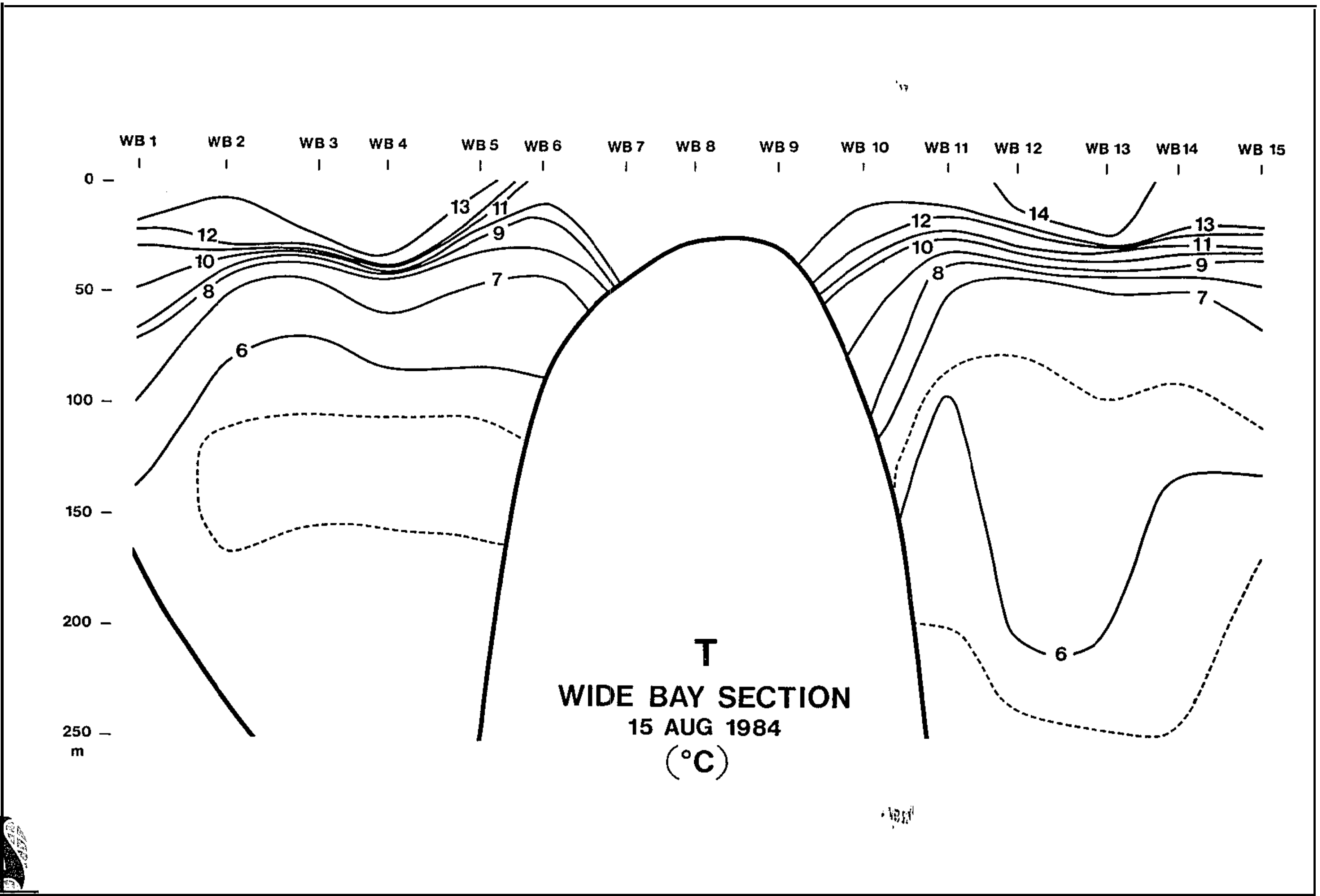
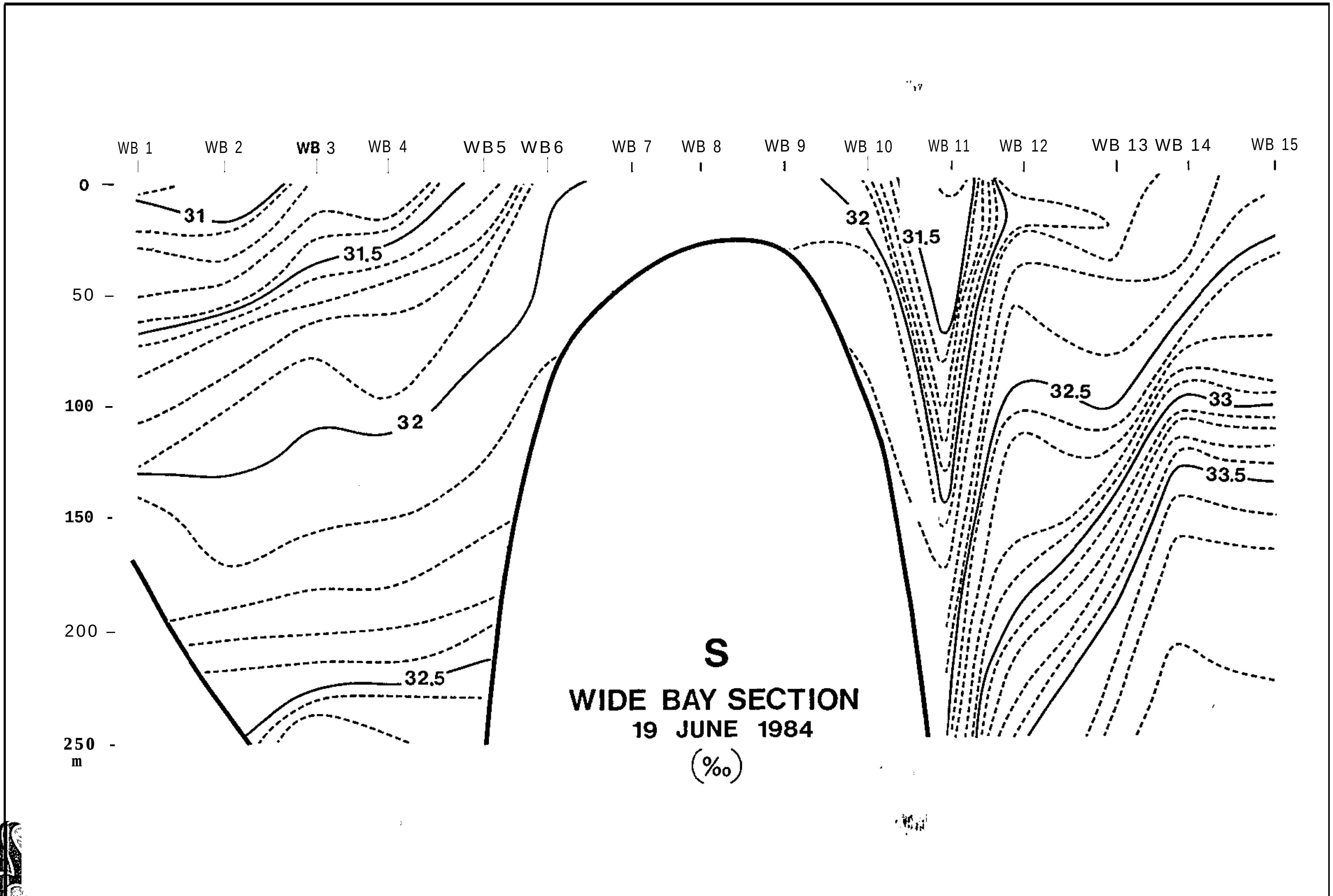


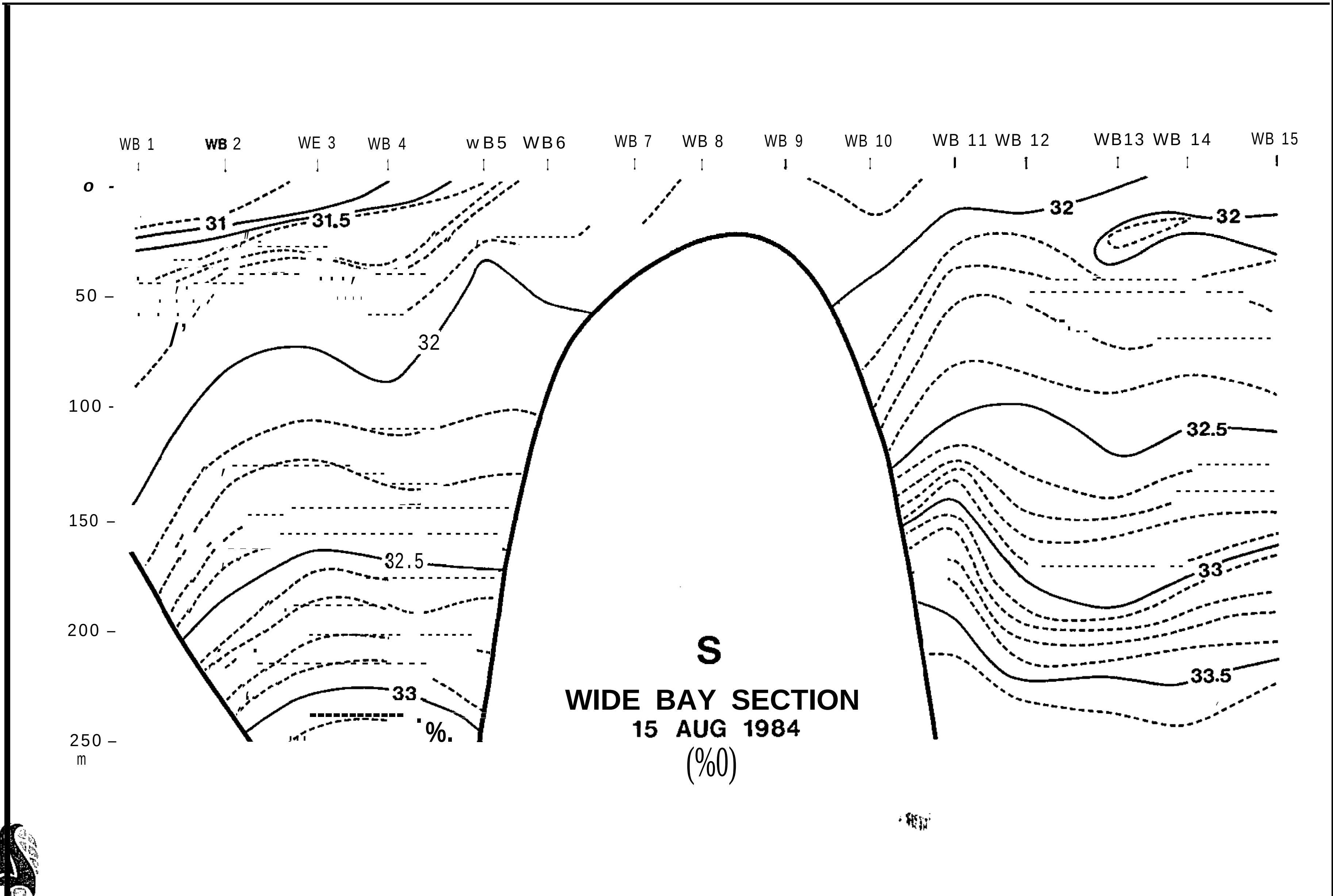
Figure Temperature Section Wide Bay August

Dobrocky SEATECH



Dobrocky SEATECH

Figure 2.16 Salinity Section Wide Bay June



Dobrocky SEATECH

igure 2.17 Salinity Section Wide Bay August

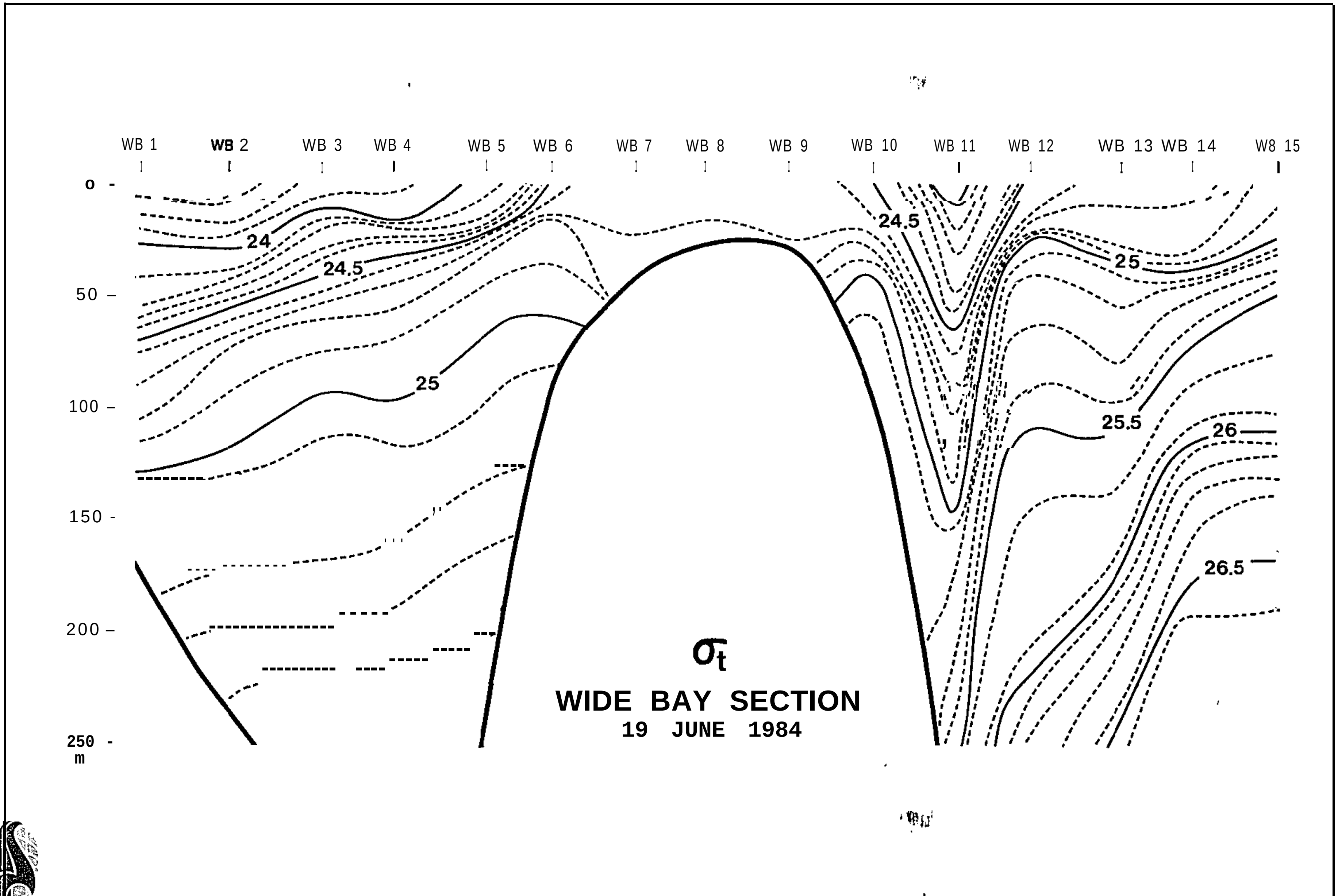


Figure 2.18 Sigma-t Section Wide Bay June

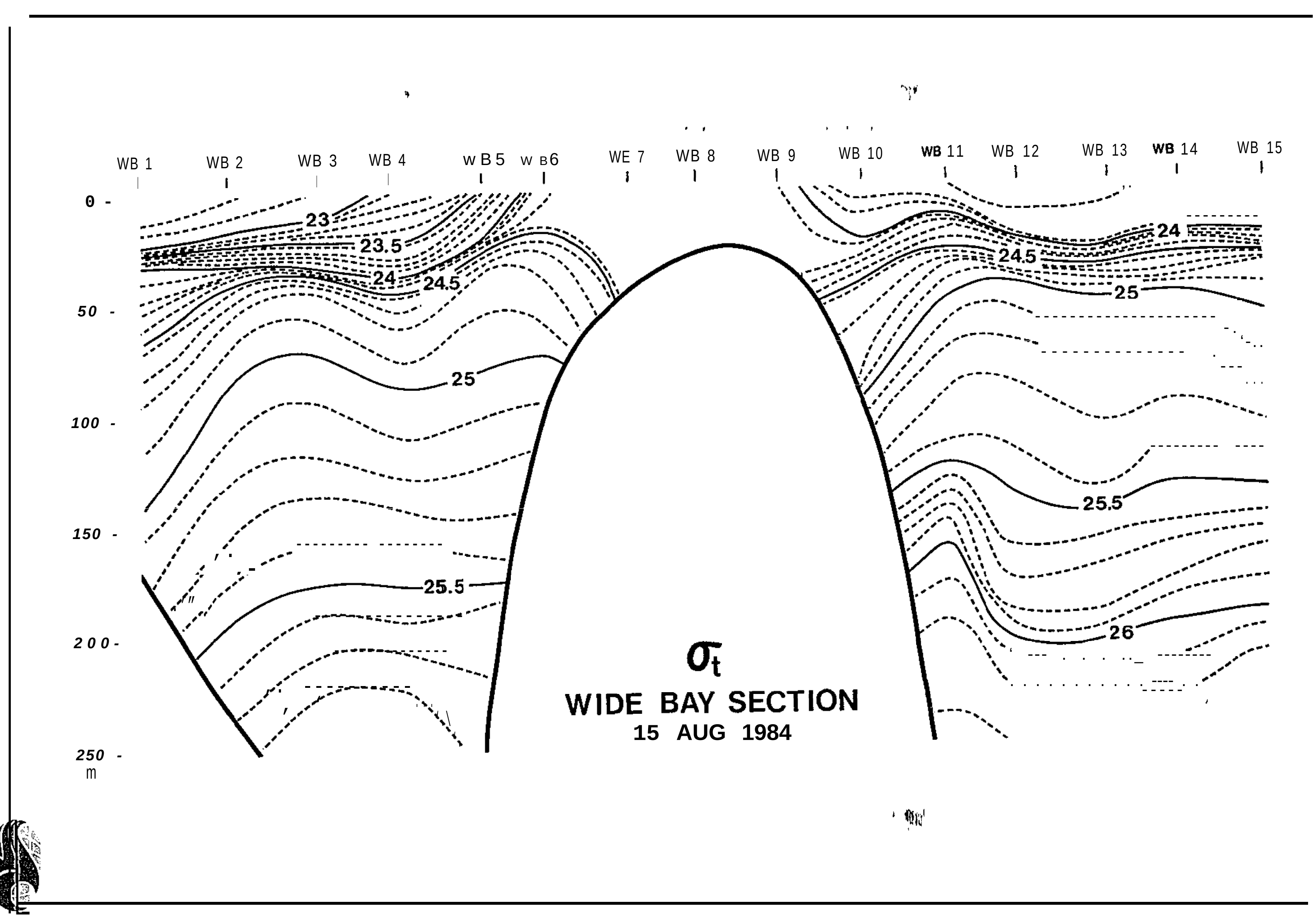


Figure 2.19 Sigma-t Section Wide Bay August tidal mixing in this shallow region. Vertical homogeneity of the water column over Port lock Bank reported by Schumacher et al (1978) and Schumacher and Reed (1980) was also attributed to tidal mixing. It is likely that rest rat if i cation occurs, at least in the upper layers, during periods of maximum river discharge.

Although the contours have been substantially smoothed, wave-like features sti 11 appear on the isotherms particularly at the shallower depths. Such waves are not surprising in light of the strong internal tides (discussed in Section 3.2.2).

2. 1.2 Salinity

Unlike the temperature sections, the salinity sections (Figures 2.4, 2.5, 2.10, 2.11, 2.16, 2. 17) do not show a pronounced temporal change. There is some indication of freshening over the shelf in the Pavlov Bay section but this process is not apparent in the other two sections. Extremely strong horizontal salinity gradients were measured over the continental slope on the Mitrof ania Island section in August (Figure 2.11) and the Wide Bay section in June (Figure 2. 14) . These gradients are well mirrored in the sigma-t sections, the latter variable being dominated by salinity at low tempertures.

2.1.3 Sigma-t

As a non-linear function of temperature and salinity, sigma-t is more strongly dependent upon salinity at low temperatures and, conversely, more dependent upon temperature at high temperatures. The result in the Western Gulf of Alaska is that sigma-t temporal changes parallel those of temperature in the near surface layers and of salinity in the deeper layers. At all three sections (Figures 2.6, 2.7, 2.12, 2.13, 2.18, 2.19) the density stratification in the upper 50 m approximately doubled between June and August while the deeper stratification remained almost constant. In June very strong horizontal gradients of density were observed over the continental slope in the Wide Bay Section (Figure 2. 18). Similarly strong horizontal gradients were observed over the continental slope in the Mitrofania Island section in August (Figure 2. 13) . This feature may have been advected, or propagated, along the slope between June and August; the mean advection speed would be about 4 cm s^{-1}. The gradients are suggestive of an anticyclonic (clockwise) eddy of about 13 km in radius. Similar features were described by Favorite and Ingraham (1977) and Schumacher et al, (1979). An eddy whose signature is visible in the mass field should have a radius roughly comparable to the internal Rossby radius which is defined as

$$r = \sqrt{\frac{g\Delta\rho}{\rho} h} \Big/ f \qquad (2\text{-}1)$$

where g is gravity, ρ density, h is the thickness Of the surface layer and f is the Coriolis parameter over the continental slope. r has a value of between 6 and 12 km so that this eddy-like feature is of appropriate size to satisf y dynamic balances. In particular if the eddy were generated by baroclinic instability it would correspond closely in size to the most unstable (and therefore predominant) wavelength (if wave length = 2r) according to Mysak, et al (1981) . The agreement between the apparent eddy radius and the internal Rossby radius supports the observations but does not necessarily imply formation by baroclinic instability.

The presence of anticyclonic (clockwise) eddies over the continental slope raises the possibility of cross-slope exchange of water and nutrients due to instabilities. For example, baroclinic instabilities are characterized by turbulent property exchanges across the mean flow and thus along the mean pressure gradient (Smith, 1976) . These cross depth gradient fluxes can be visualized as the breaking of waves on the isopycnal surfaces when the slopes of the surfaces exceed critical values. The “breaking waves” propagate along the initial isopycnal slope, i.e. across the mean flow.

It will be seen in the next sections that the station spacing is not quite small enough to properly resolve spatial variability of the size of the internal Rossby radius. While this drawback has little effect upon qualitative representation of the distribution of properties, it limits the utility of the dynamic method by which geostrophic currents are computed from horizontal density gradients.

2.2 DYNAMIC HEIGHTS , GEOSTROPHIC CURRENTS

Geostrophic shears can be integrated from an assumed level of no motion to yield estimates of the baroclinic geostrophic current prOf ile. This long-standing method has both its strong adherents and detractors. The latter are critical of some of the assumptions of the "Dynamic Method" and have shown that they do not apply in many regions. For the present data set the most important limitations are lack of synopticity and, to a lesser extent, insufficiently dense station spacing.

Tbe thermal wind equations, from which the dynamic method arises, assume a steady flow. Implicit is that vertical motion of the isopycnals is negligible. In the presence of a strong internal wave field, however, this is simply not the case. Several investigators have surmounted the obstacle of time-varying flows in computations of geostrophic currents by averaging density measurements over a tidal cycle. Such a procedure is extremely consumptive of ship time and was not attempted in our field work. The computed dynamic heights and geostrophic currents therefore neither represent a tidal average nor an instantaneous realization of the flow. We would suggest that where the mean flow energy is small compared to the tidal energy, geostrophic current computations do little more than yield a qualitative view of the flow field.

In order to produce stream lines of the geostrophic flow, the dynamic height anomaly between selected pressure surfaces was plotted and contoured. The charts for June and August are presented on the same page for ease of comparison in Figure 2.20 through 2.23. Figure 2.20 shows the dynamic height topography of the surface relative to 10 decibars. The plots are an indication of the density of the mixed layer; the larger anomalies representing less dense water. The influence of warmer and fresher waters nearshore is shown. The anomalies increased between June

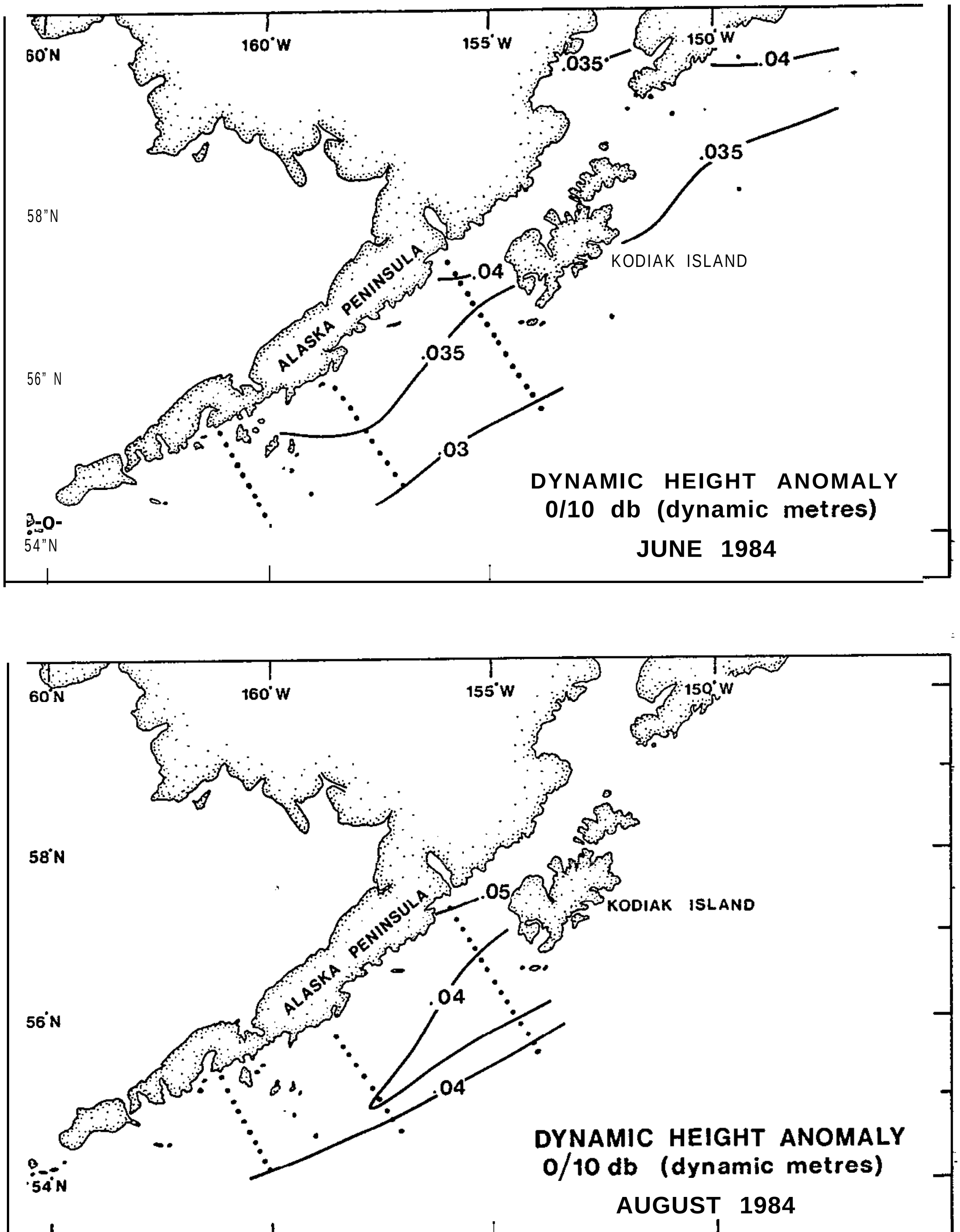


Figure 2.20 Dynamic Height Topography 0/10 db June and August 1984

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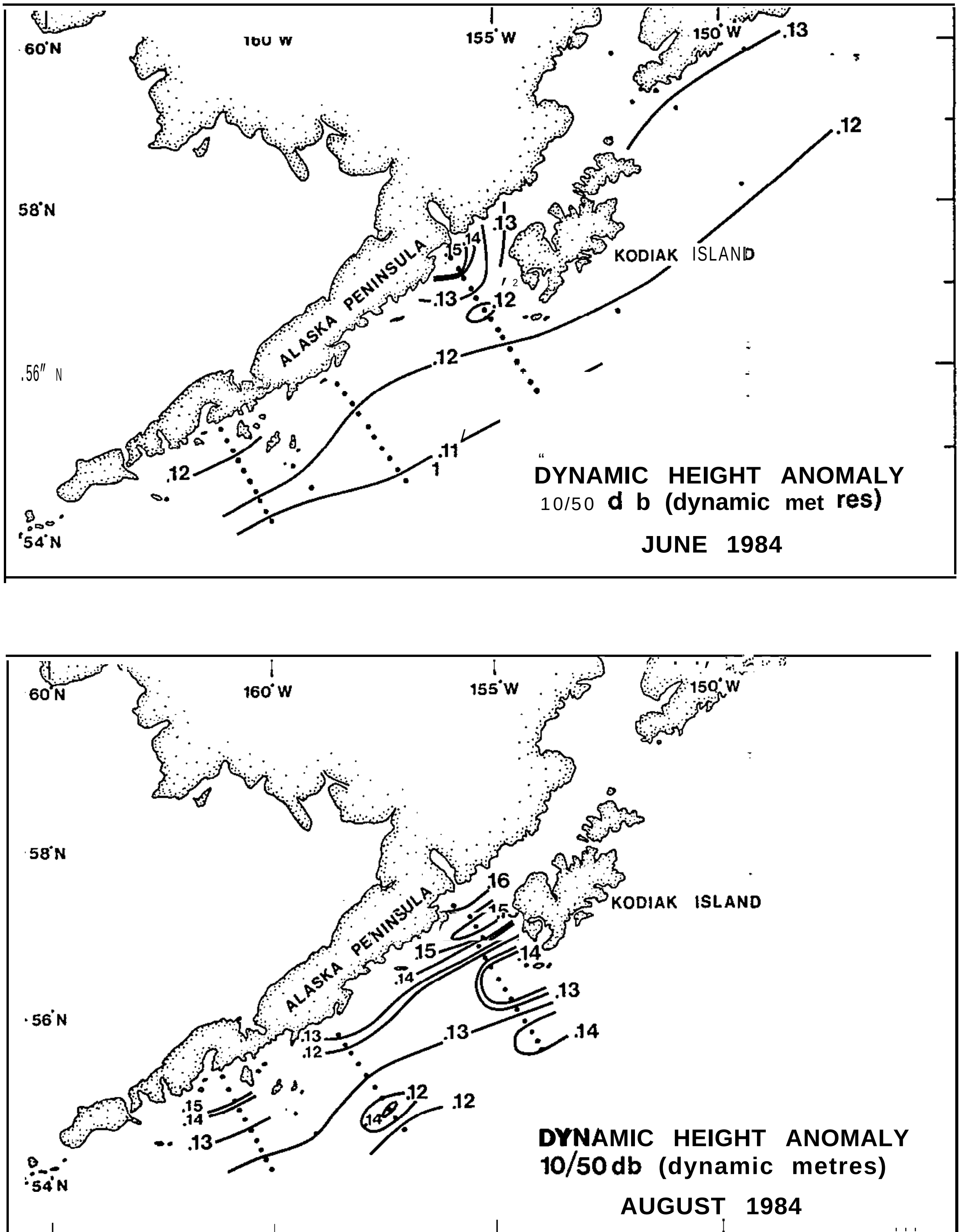


Figure 2.21 Dynamic Height Topography 10/50 db June and August 19S4

and August due to continued insolation. Figures 2.21 and 2.22 represent the topography of the 10 and O db surfaces relative to 50 db. The geostrophic flow field in the upper 50 m is thus portrayed.

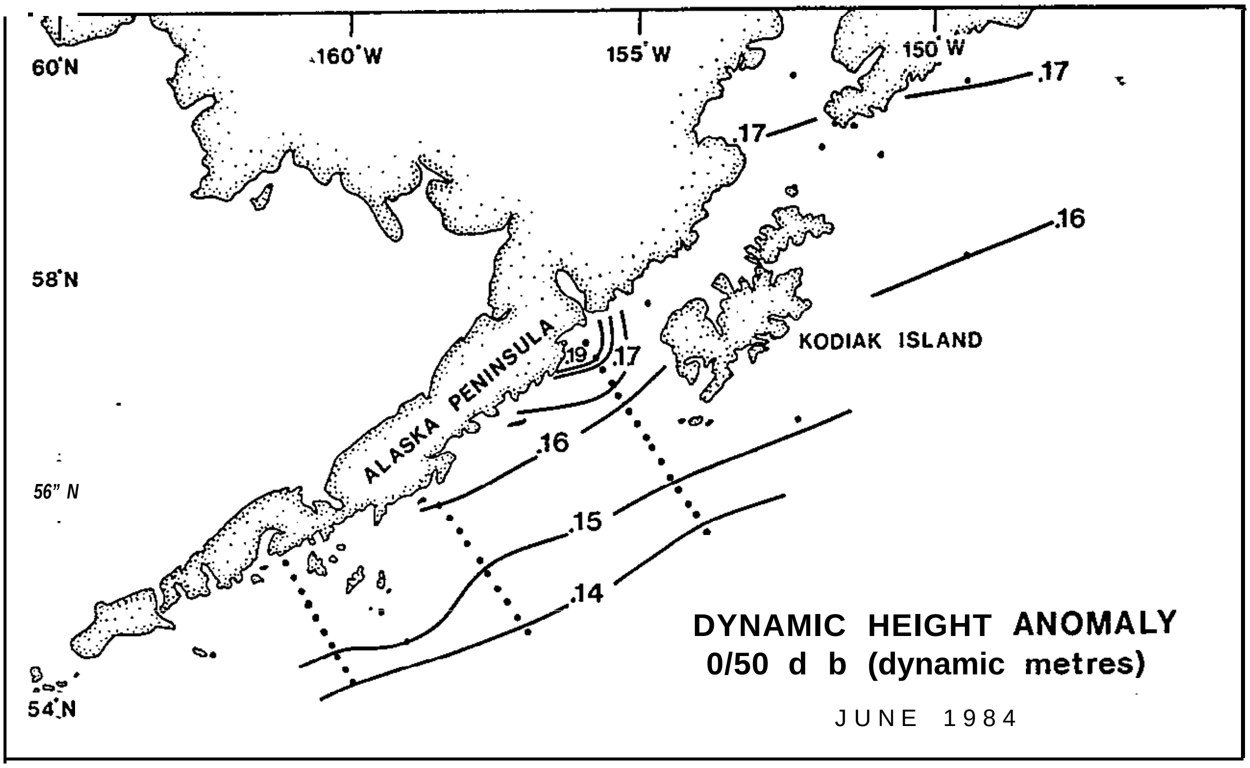
The velocity differences between surfaces can be computed by

$$\Delta u = \frac{10 \Delta D}{fL} \qquad (2\text{-}2)$$

where Δu is the velocity difference, ΔD is the cliff erence in dynamic height anomaly between two stations, f is the Coriolis parameter and L is the distance between stations. The 10/50 db and 0/50 db charts show that the geostrophic velocity shear in the upper layers was generally less than 10 cm s^{-1} and on average across the shelf about 3 cm s^{-1}. The 10/50 and 0/50 db charts are virtually identical demonstrating the density gradients in the upper 10 m contributed little to the geostrophic f low field. Considerably more horizontal structure was present in August than in June above the 50 decibar surface probably due to increased river discharge toward the end of summer which introduced fresher water. Both the freshening itself and the enhanced stratification promoting heating of the surface layers would have contributed to the contrast between June and August . However, the mean flow (for example through the Wide Bay or eastern most section) changed little between June and August. The mean velocity in the upper 50 m was southwestward at a speed of about 2 or 3 cm s^{-1} relative to 50 db.

Figure 2.23 shows the dynamic topography of the 10 db surface relative to 100 db. Vertical velocity shear is most apparent along and near the shelf break where vertical velocity differences in June are on the order of 8 cm s^{-1} and the direction of flow is to the southwest. In August the flow along the shelf break is about 4 cm s^{-1} and generally directed toward the northeast. An outflow on the order of 5 cm s^{-1} is directed southwestward from Shelikof Strait in both June and August. This figure is in fairly good agreement with the mean flow measured over the two month period at the current meter at 46 m depth in Shelikof Strait.

In all the dynamic height topography charts the mean flow from the shore to the shelf break is directed toward the southwest in agreement with tbe contemporary view of tbe Alaska Coastal Current regime, e.g. Royer (81).



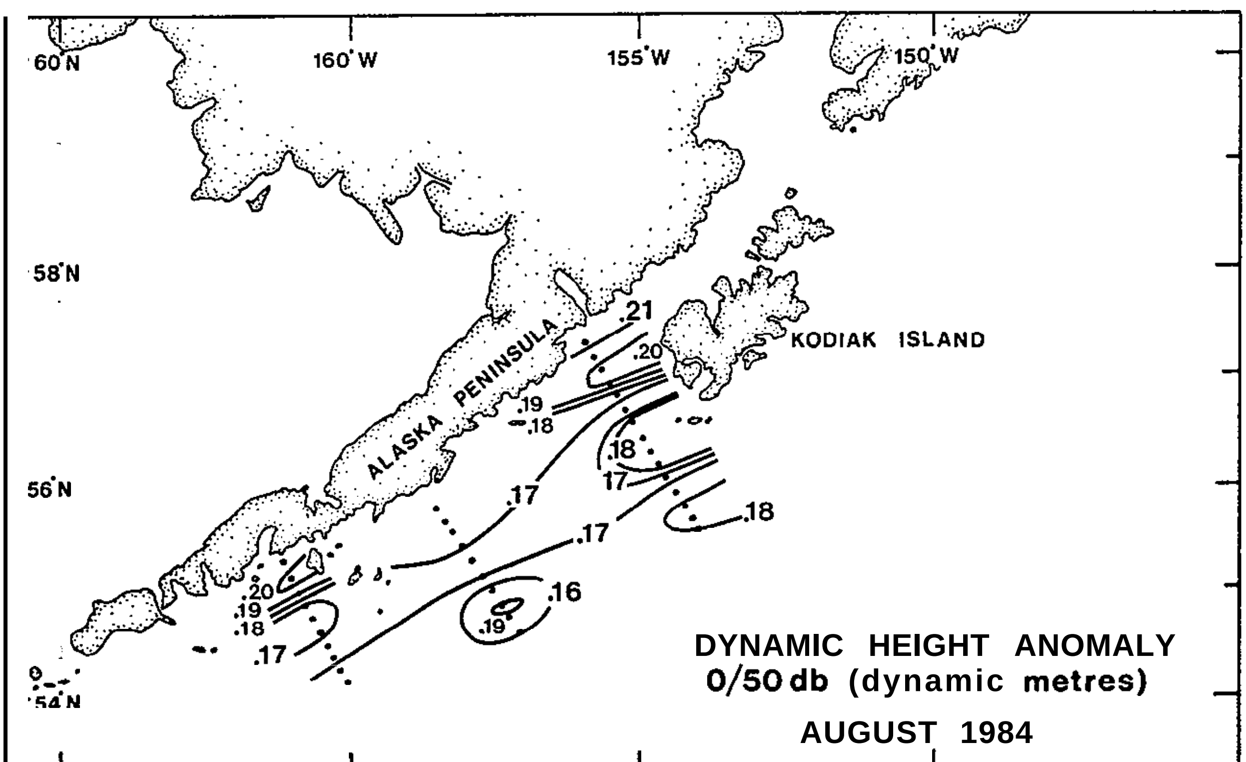
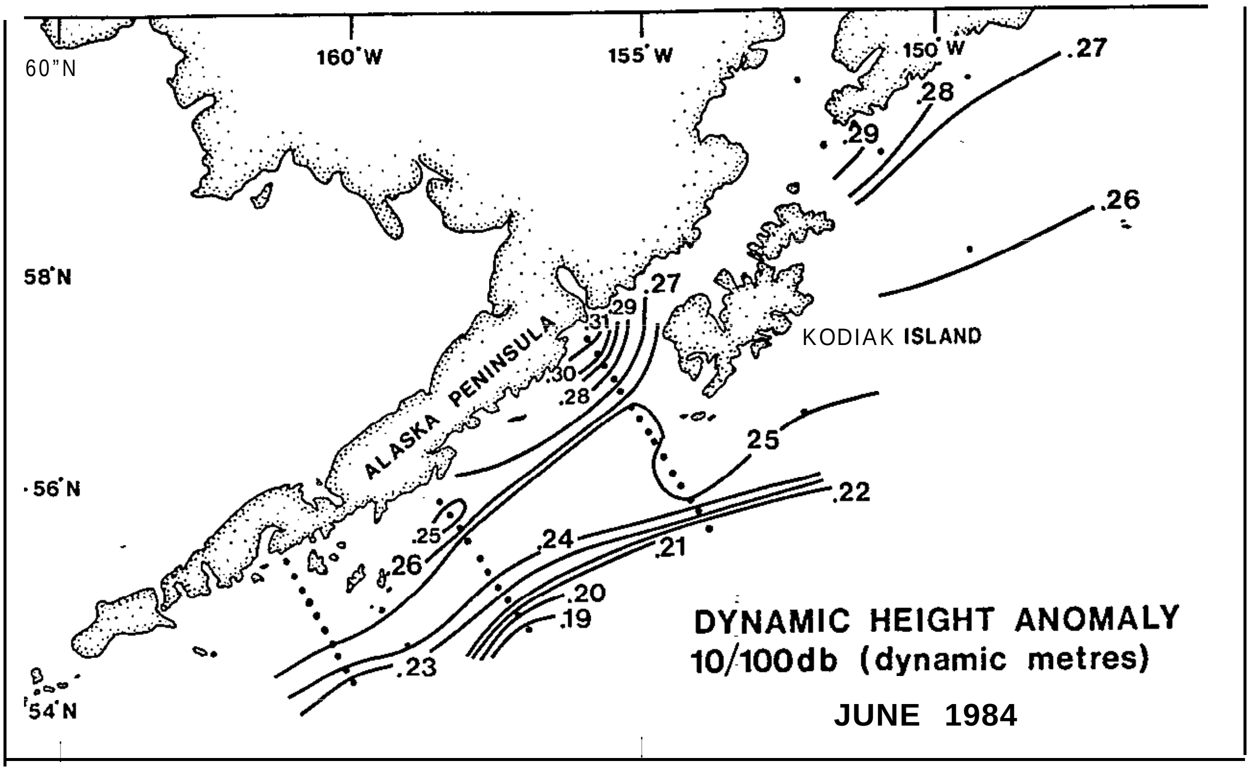


Figure 2.22 Dynamic Height Topography 0/50 db June and August



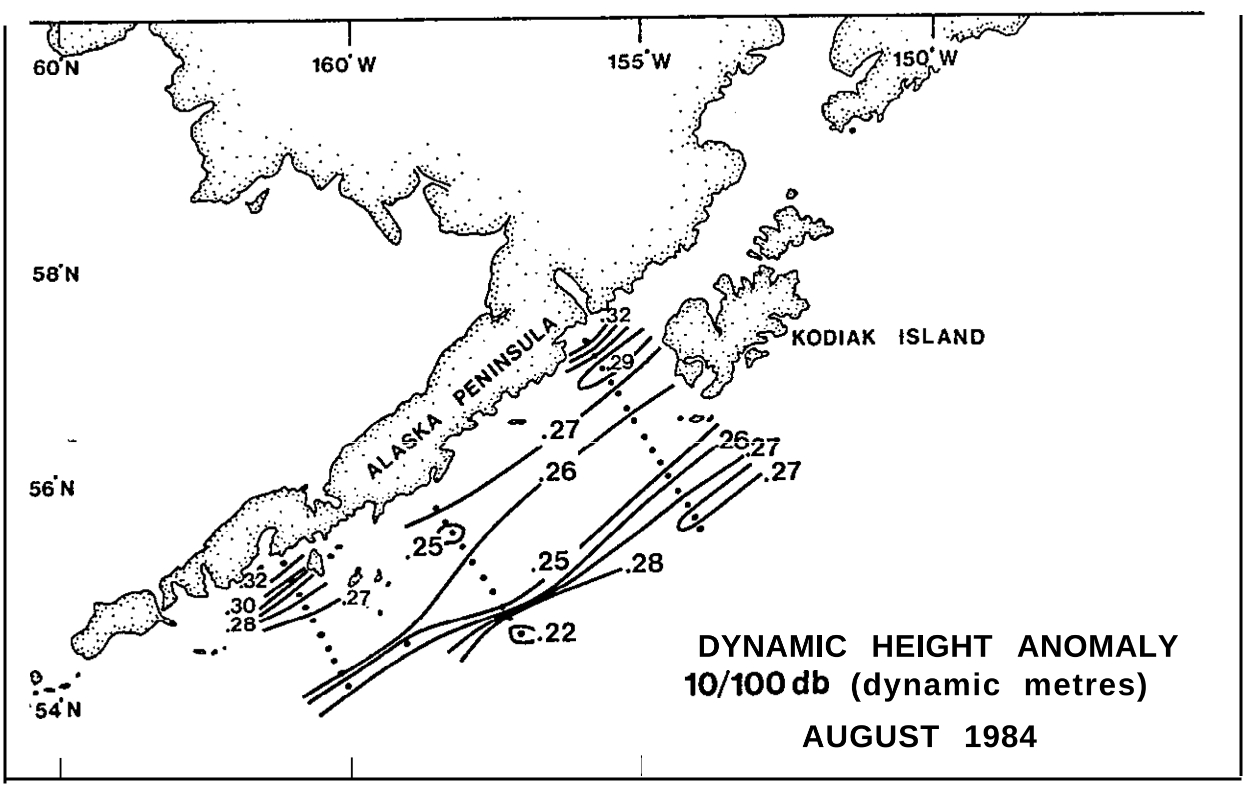


Figure 2.23 Dynamic Height Topography **10/100 db June and August**

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An attempt was made to establish a level of no motion across the shelf and to unify the geostrophic shears into cross section of velocity. In author's view the procedure is more artistic than quantitative. Such cross sections of velocity do, however, give a sense of structure of the velocity field. Isotachs for June and August are presented for each of the sections in Figure 2.24 through 2.29. Tbe details of the structure are clearly limited by the station spacing which was somewhat larger than the internal Rossby radius of def ormation. In addition, the quality of the CTD data is rather poor and spurious structures may have been introduced to these cross sections.

2.3 SURFACE SALINITIES AND TEMPERATURES

Charts of the surface salinity and temperature distributions during June and August are shown in Figures 2.30 through 2.33.

The 32.0 ppt surface isohaline appears to follow the shelf break during botb June and August. values are similar to those reported by Reed et al, (1979). There is an indication of the freshening of the surface waters in Shelikof Strait during the summer, but the sampling stations were very sparse in that region. The salinity increased monotonically offshore in agreement with the concept of a runoff driven southwesterly flow along the shelf. No salinity minimum was found over the shelf break as has baen reported by Favorite and Ingraham (1977) or Royer and Muench (1977) for Spring conditions. It appears, rather, that summer conditions prevailed during the period June through August 1984.

The surface temperature charts show mainly a general increase in temperature due to insolation over the summer. There is an indication of the presence of cooler surface waters near-shore than offshore in both months probably due to relatively cold river discharge. The cross-shelf horizontal temperature gradients remain almost constant between June and August.

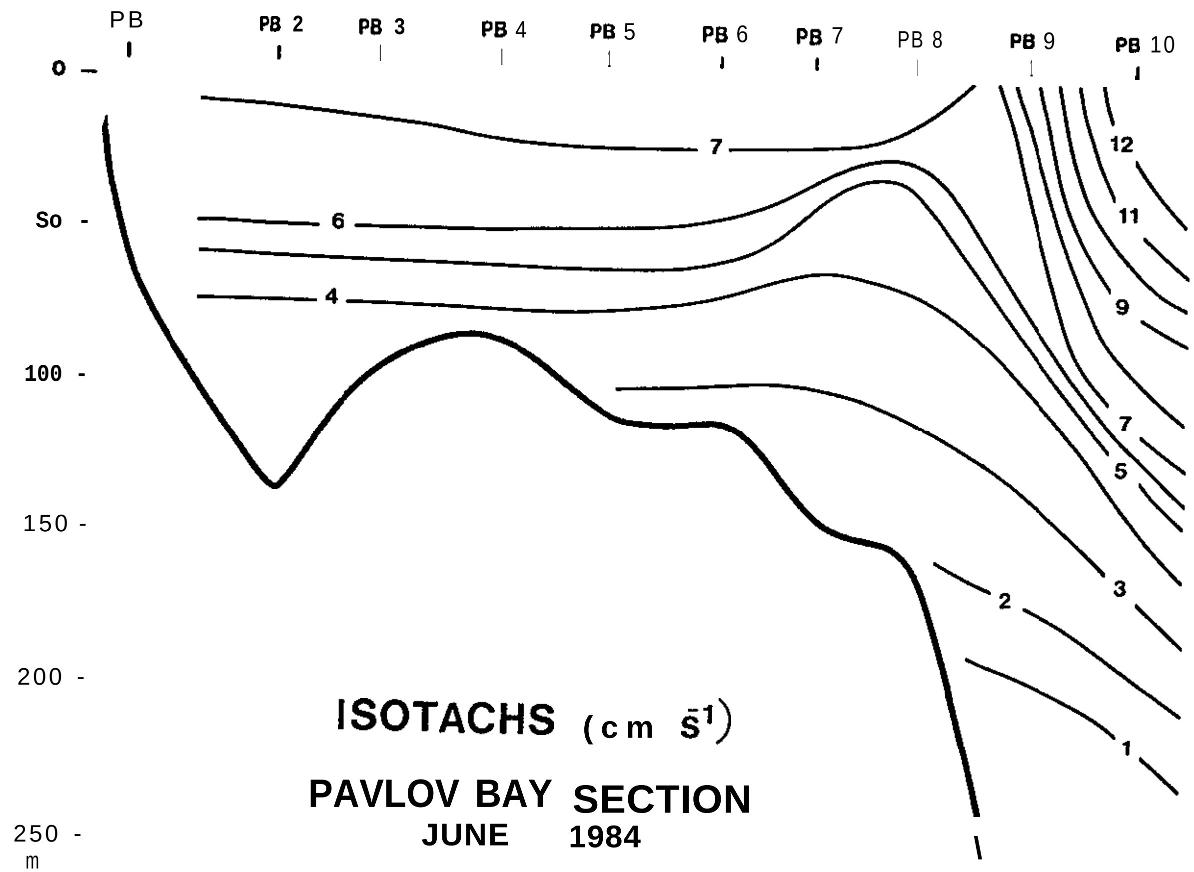

Figure 2.24 Positive flows are out of the page, i.e. to the southwest.

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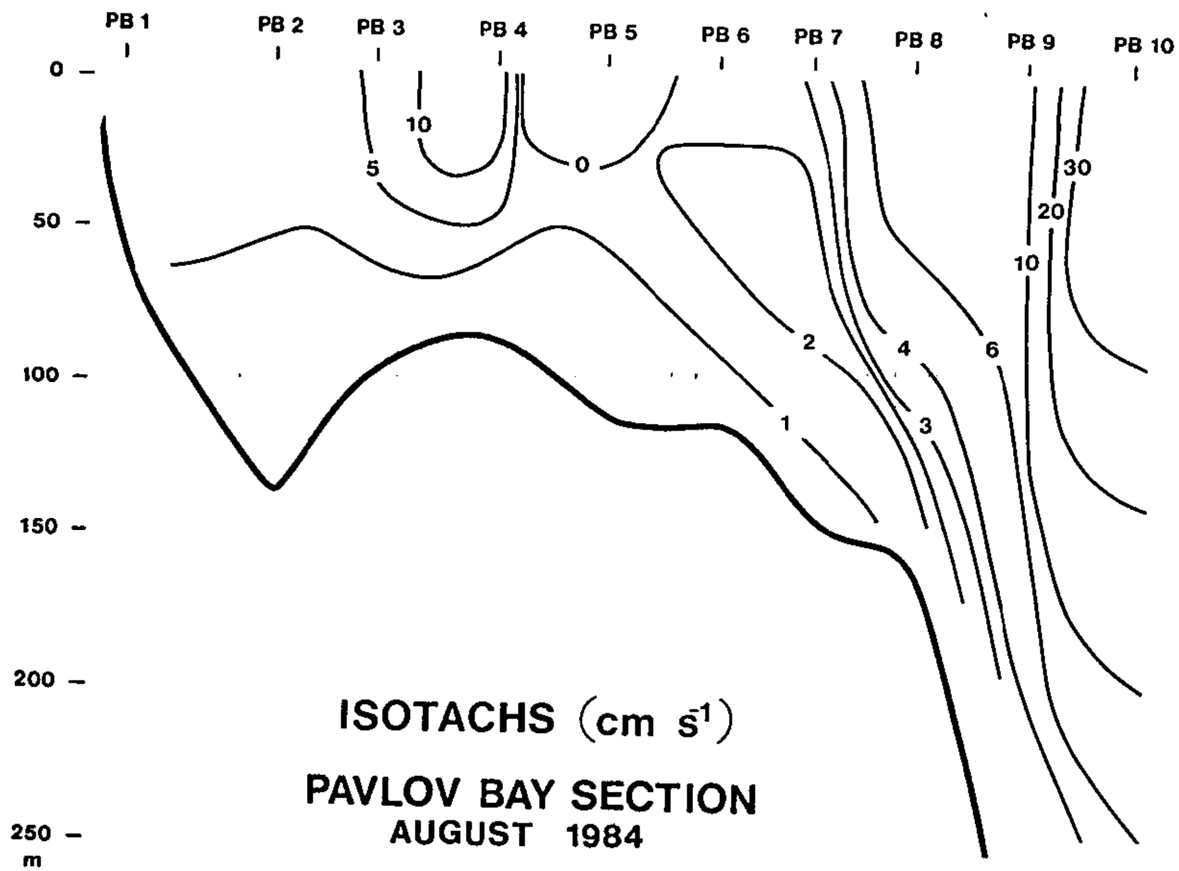

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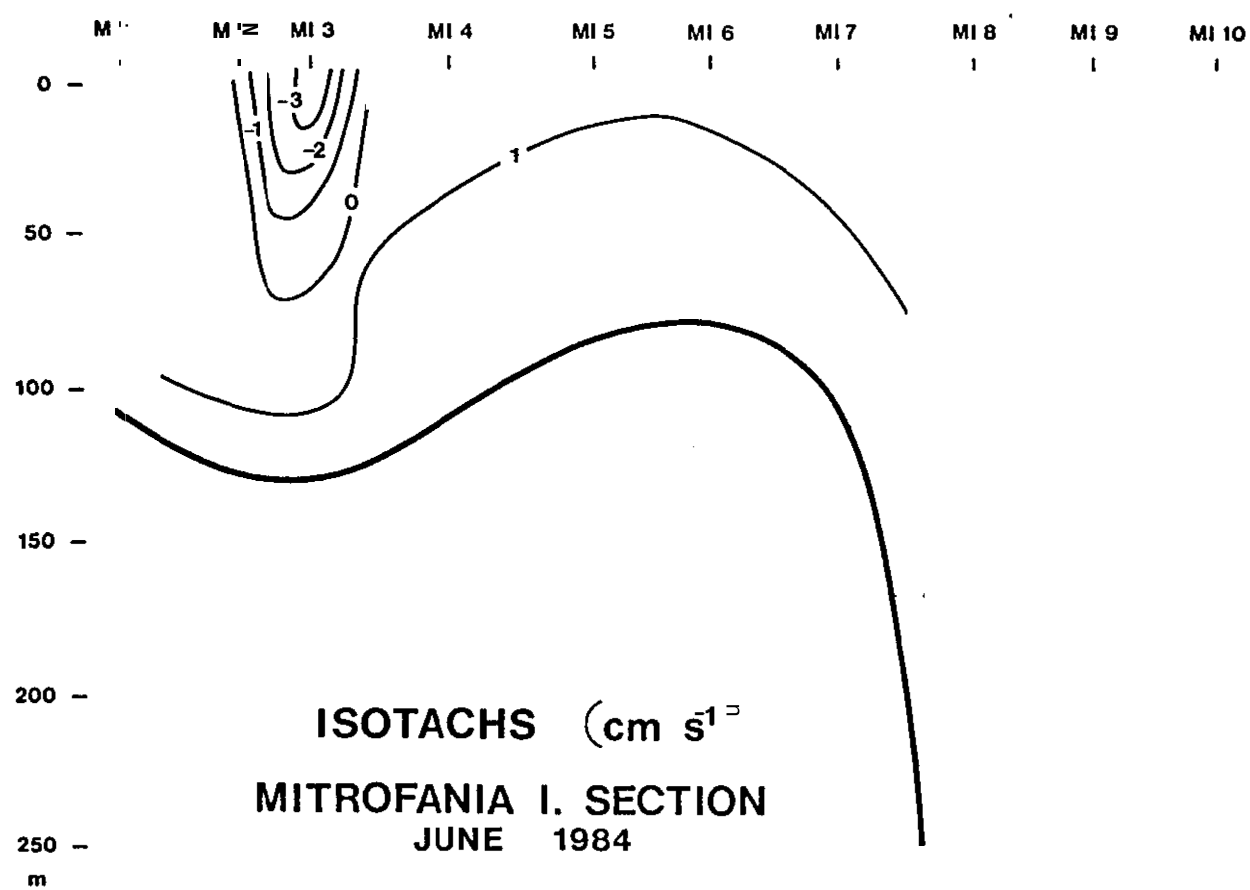

Figu... Positive flows are out of the page, i.e. to the southwest.

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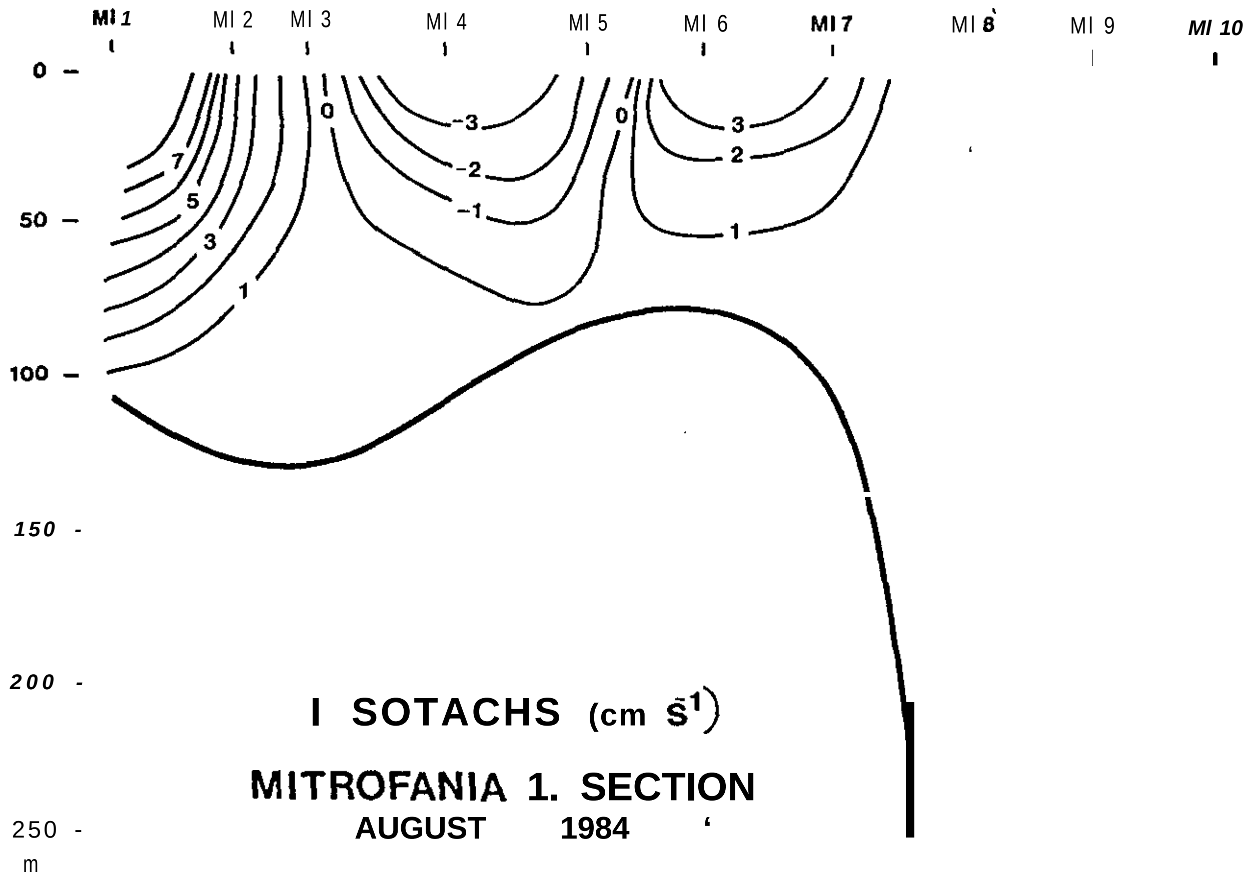
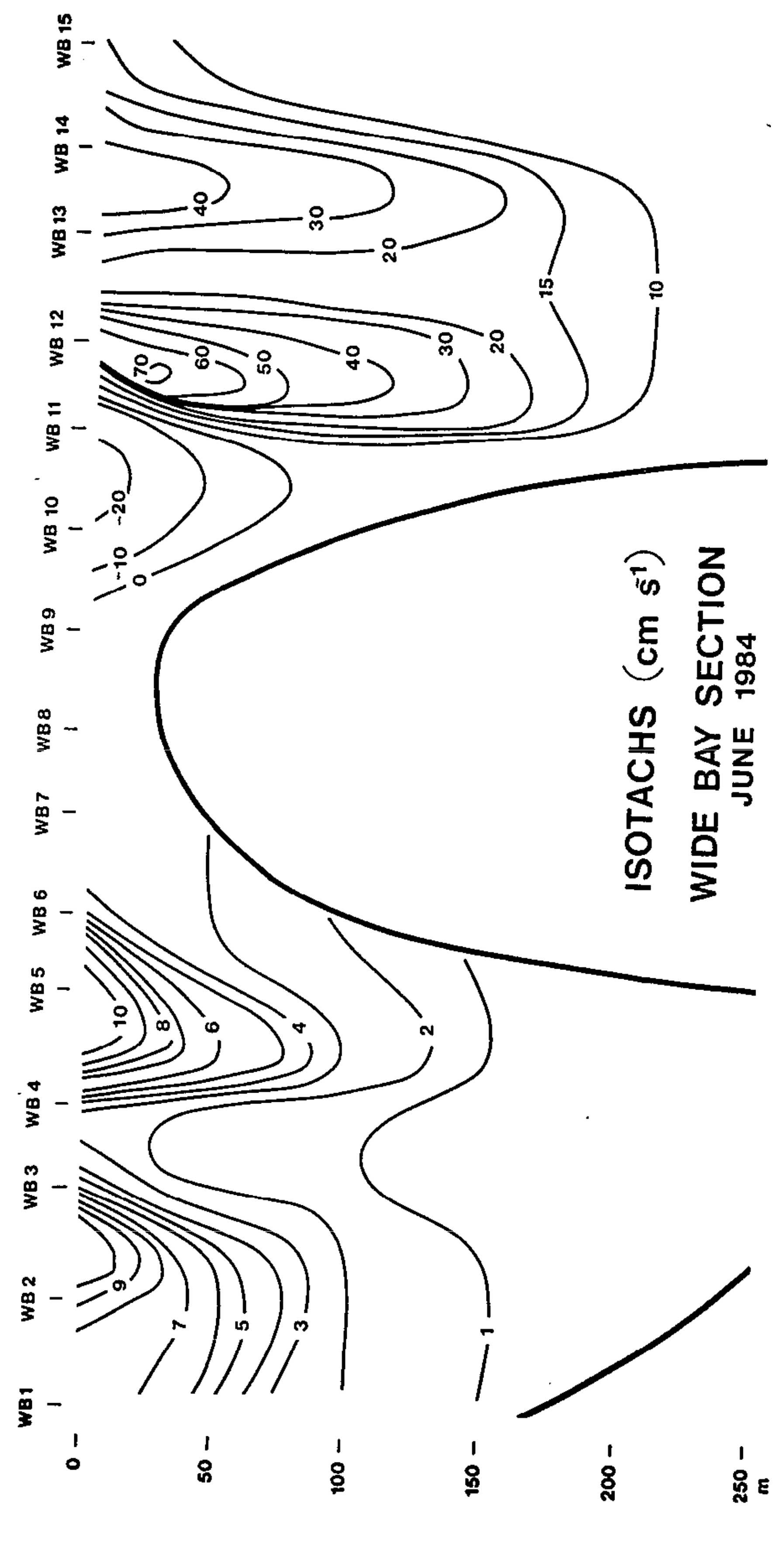


Figure 2.27 Positive flows are out of the page, i.e. to the southwest


ISOTACHS (cm s⁻¹)
WIDE BAY SECTION
JUNE 1984
WB1
WB 2
WB 3
WB 4
WB 5
WB 6
WB7
WB8
WB9
WB 10
WB 11
WB 12
WB13
WB 14
WB 15
0
50
100
150
200
250
m

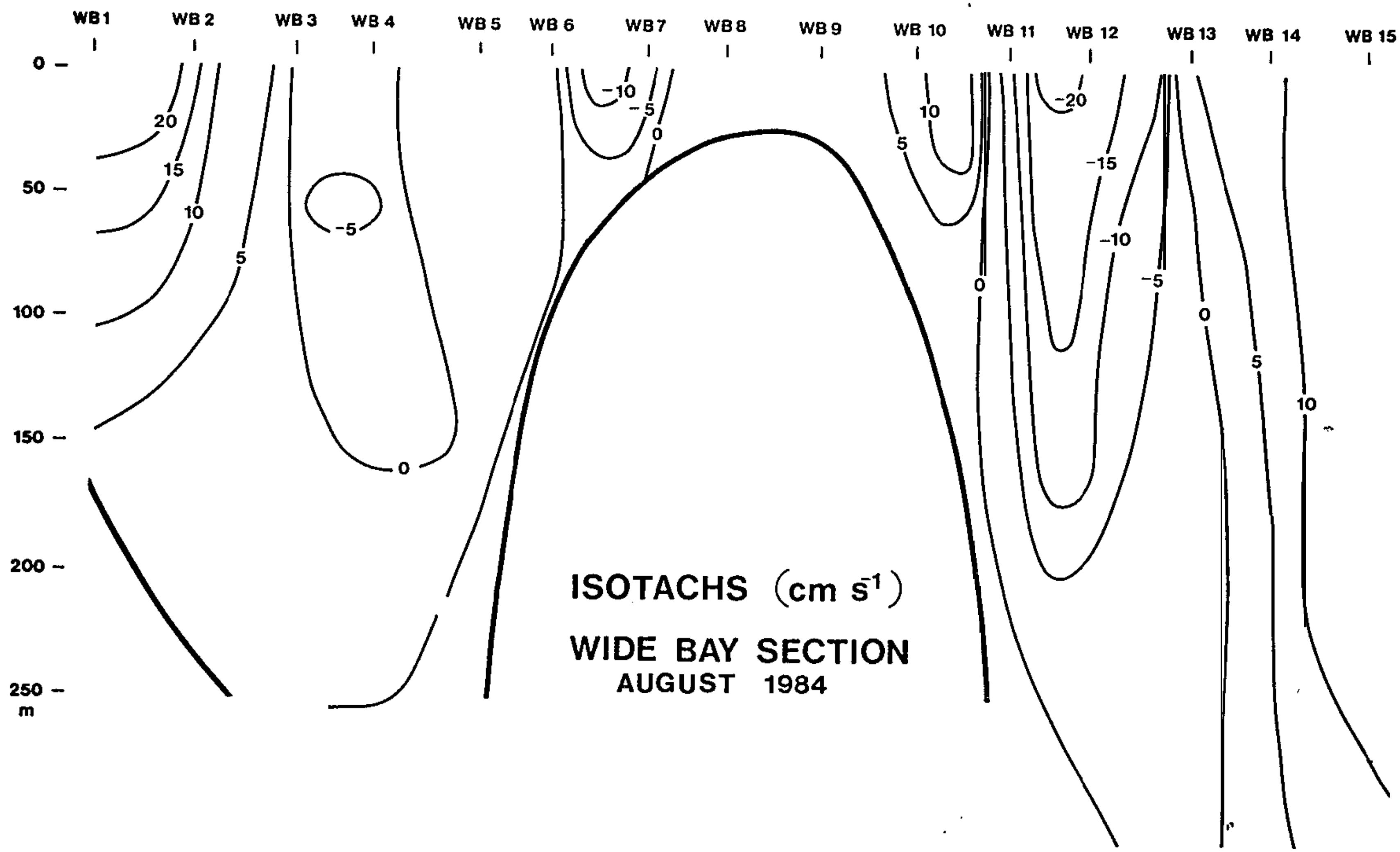


Figure 2.29 Positive flows are out of the page, i.e. to the southwest

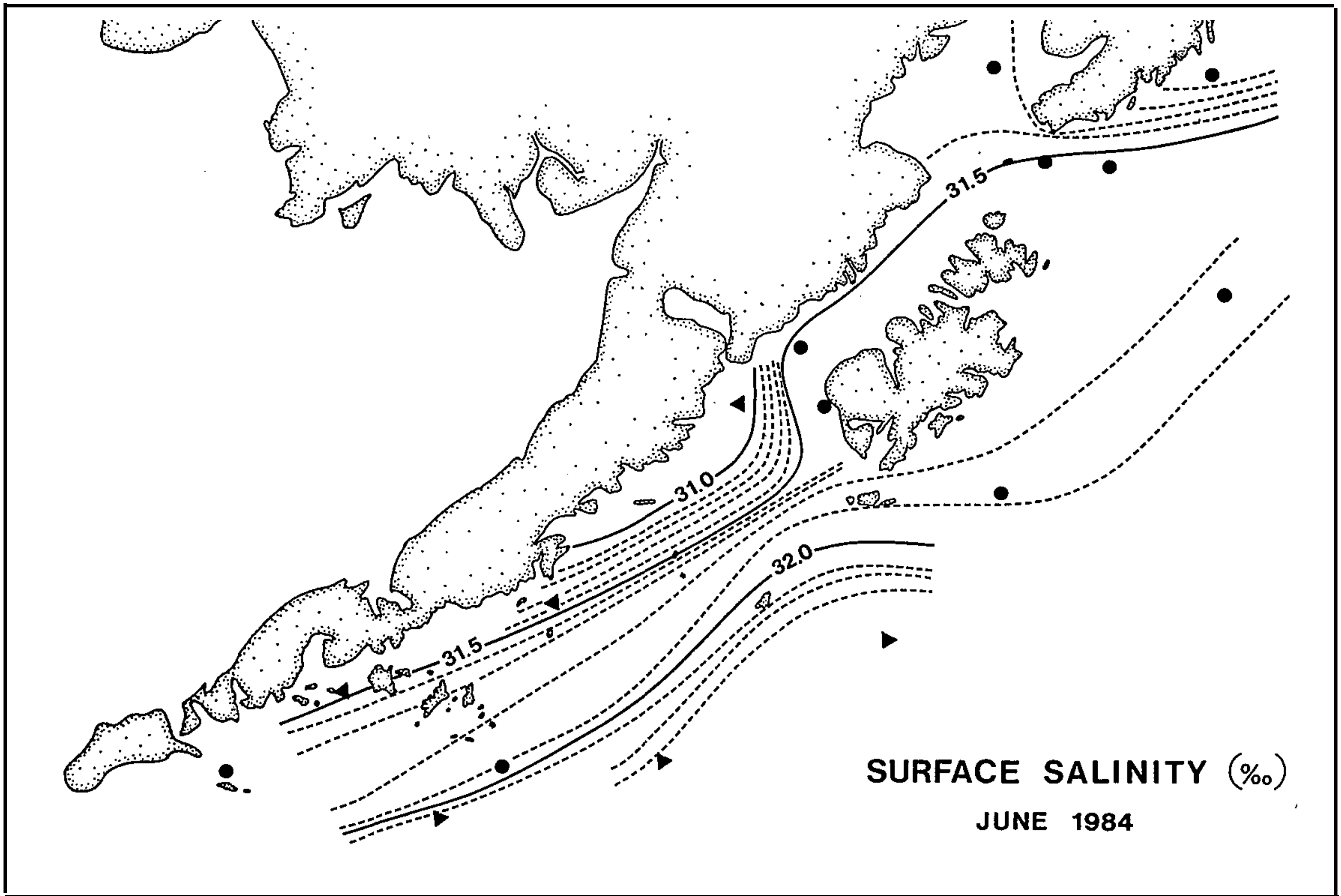
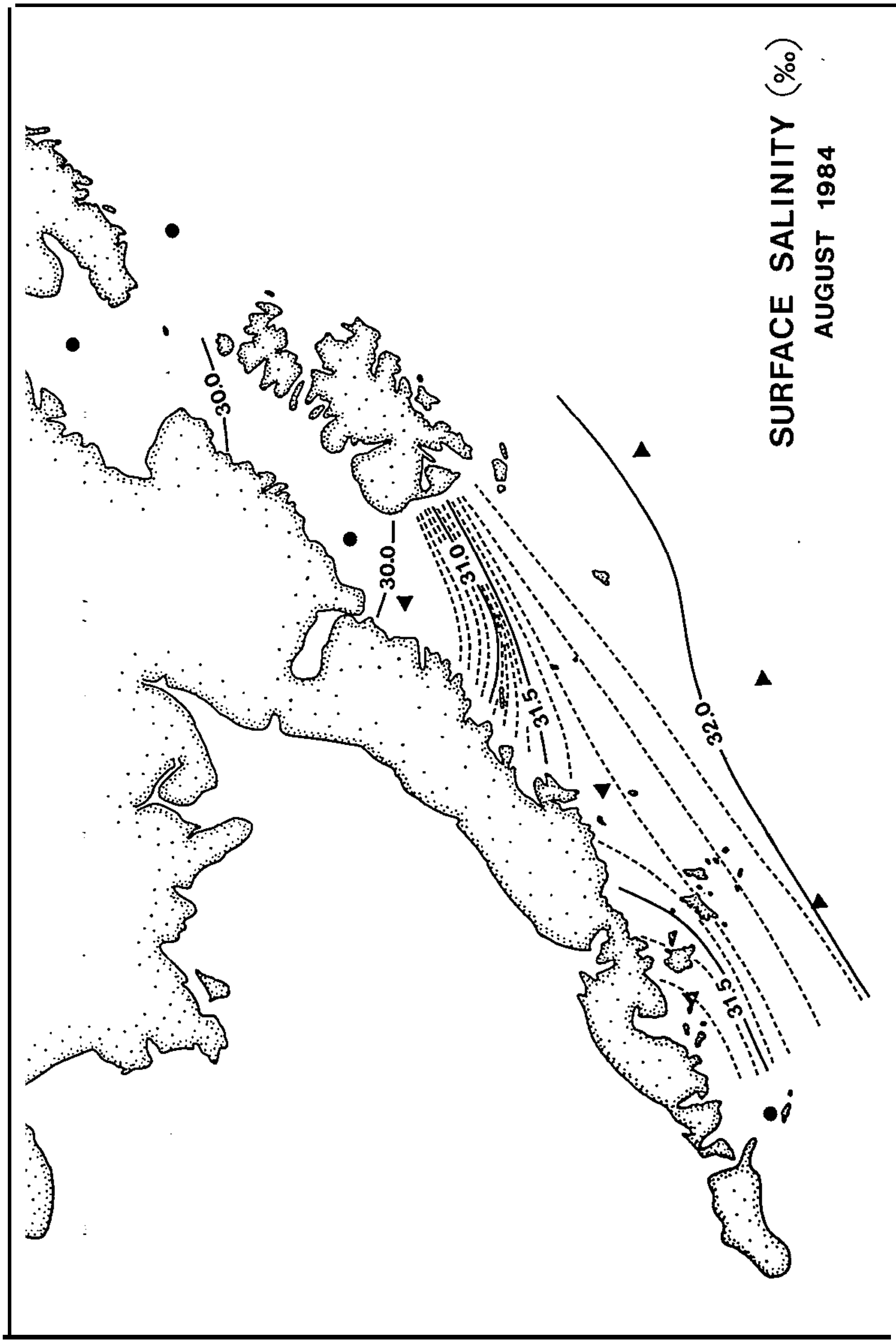


Figure 2.30 Surface Salinity June



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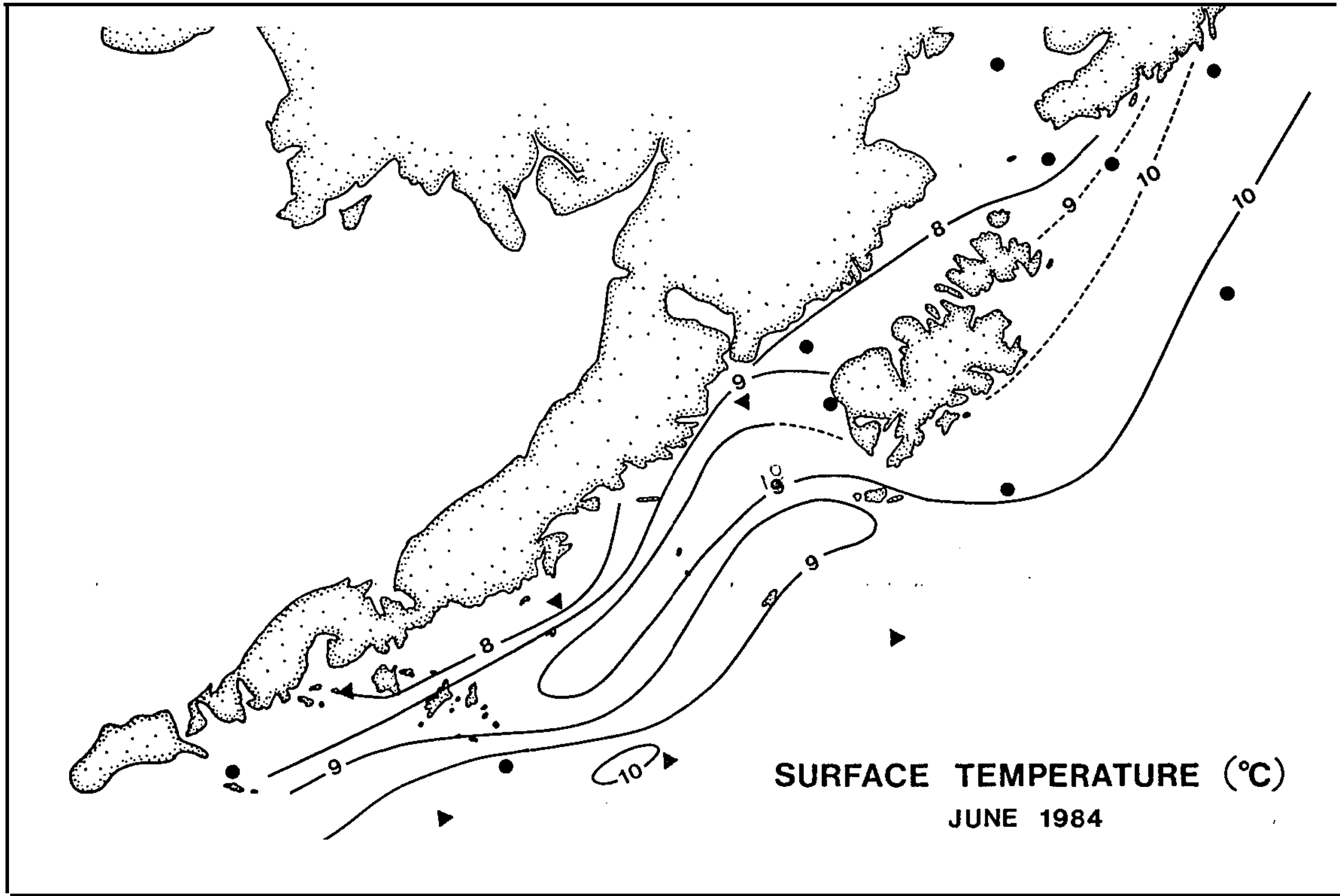

Figure 2.32 Surface Temperature June

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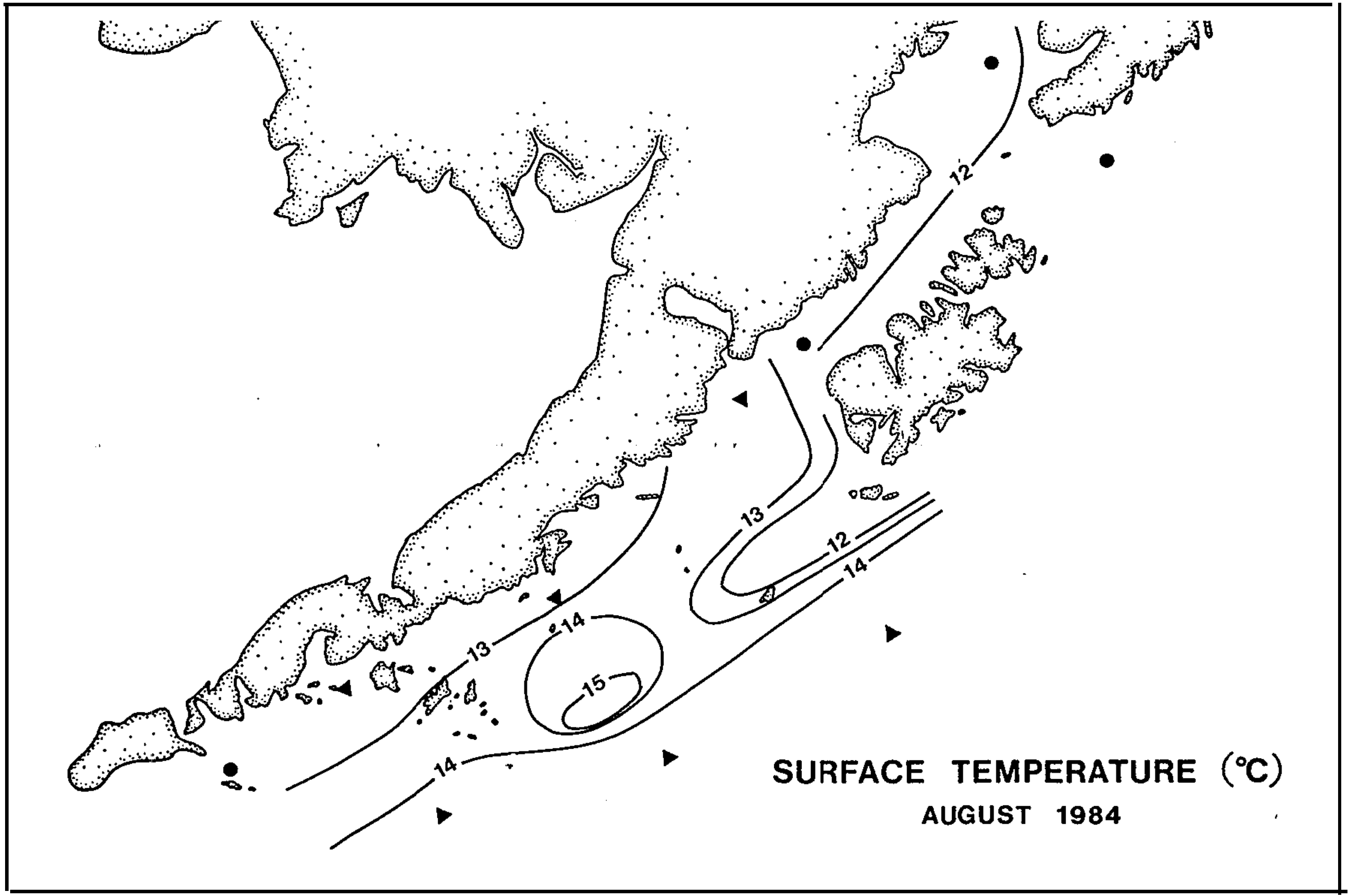

Figure 2.33 Surface Temperature August

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3.0 TIDAL OSCILLATIONS

In this report we examine the tidal and subtidal components of the spectra of sea surface and current oscillations separately. The forcing function for the tides is deterministic and well understood so the tidal section of the report can be quantitative in nature. On the other hand, sub-tidal oscillations, including the mean flow may be forced or maintained through a variety of mechanisms so that several statistical procedures have been employed. These are discussed in Section 4.

3.1 TIDAL HEIGHT

The tidal analyses show that the tides in the region are mixed, mainly semi-diurnal. Form numbers (the ratio of the two largest diurnal to the two largest semi-diurnal components) vary between 0.51 and 0. 9S. Since the relative magnitudes of the tidal constituents vary substantially among the seven tide gauge locations, it is useful to examine the total tidal oscillation as represented by the spring tidal range.

The largest tides of the year occur when the K_1 component is in phase with the M_2 and S_2 components (usually around the solstices). A good approximation of the maximum tidal range can be computed from

$$R_{max} = 2(M_2+S_2+N_2+K_1+O_1) . \qquad (3\text{-}1)$$

These ranges are listed below in Table 3.1 along with the estimated maximum ranges at Anchorage and Kodiak.

The highest tides in the region of study occur at Seal Rock, Cape Ikolik and Amatuli Island. The causes for these high ranges are likely shoaling and the reflection of substantial tidal energy from the coast with the attendant formation of partially standing tide waves. Tidal energy propagation is addressed in Section 3.2.

Table 3.1 Maximum Tidal Ranges

Location	Range (m)
Sanak	3.39
Portlock Bank	4.61
Seal Rock	5.10
Cape Ikolik	5.88
Shumagin	3.54
Albatross Bk.	4.25
Amatuli Is.	6.33
Anchorage (estimate)	11.3
Kodiak (estimate)	4.0

Cotidal charts for the four largest constituents have been plotted and are presented in Figures 3.1 through 3.4. These charts show lines of equal Greenwich phase (cophase lines) and equal amplitude (corange lines) . In all cases the tide appears to propagate from northeast to southwest, but there is a suggestion (from the sparse data points) that the tidal propagation is onto the shelf west of Kodiak Island. In non-dissipative (frictionless) systems the corange lines should be normal to the cophase lines. This is roughly the case for the M2 constituent on the outer shelf. The amplitude of the M2 constituent increases toward Cook Inlet indicating either pronounced shoaling or that some of the tidal energy is reflected in that area. However the Tide Tables show a six hour phase lag between Seldovia and Anchorage indicative of a progressive wave and little reflection. The increase in amplitude in Cook Inlet is, therefore, probably due solely to the decrease in depth.

The S_2, K_1 and O_1 cotidal charts display cophase and corange lines which are parallel - suggestive of a progressive wave in which energy is transported, eventually being dissipated by bottom friction.

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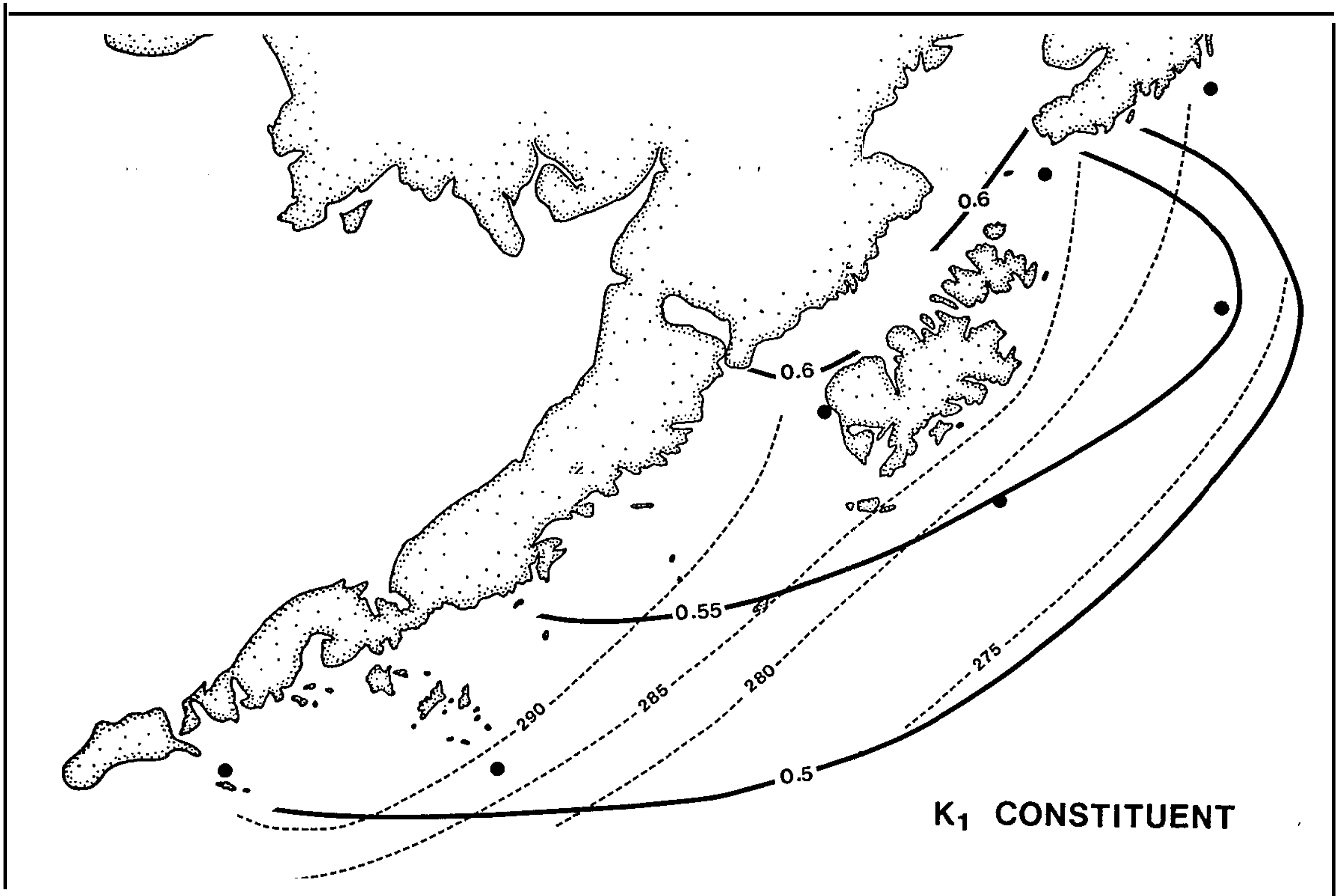
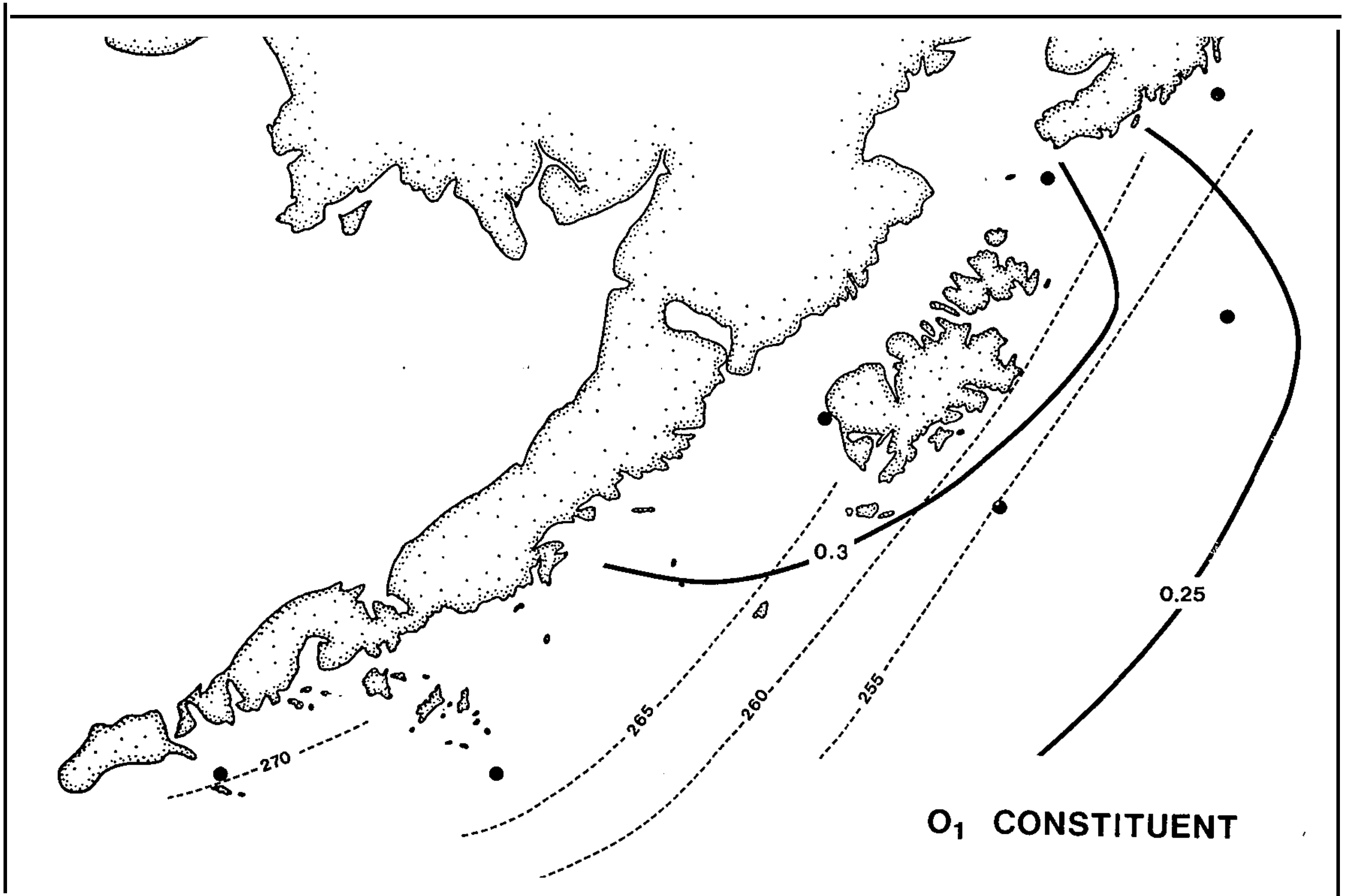


gure
relative to
in metres, cophase lines (dashed) in degrees



--gure ... Cotidal ... ophase lines (dashed in degrees relative to Greenwich

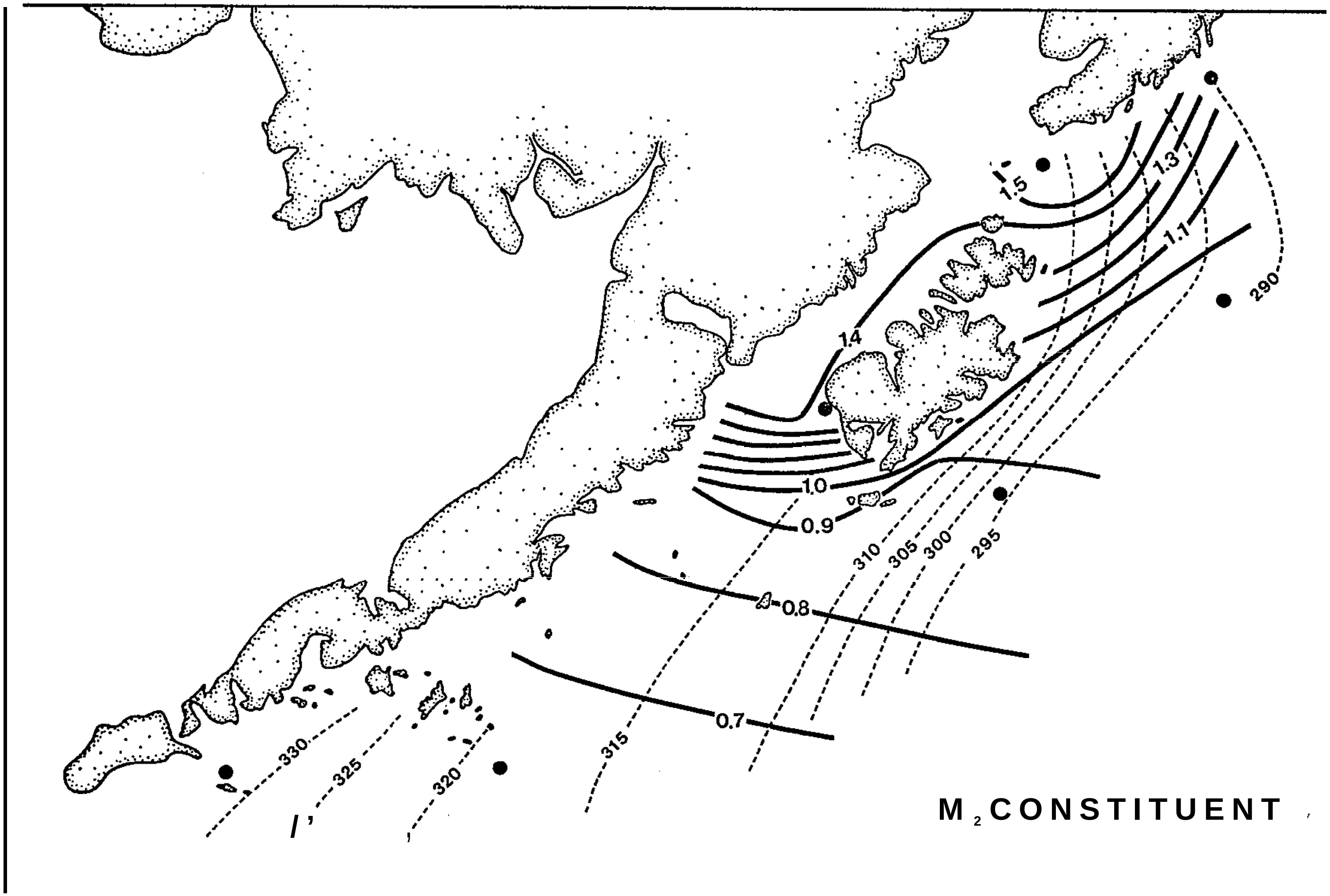


Figure 3.3 Cotidal chart for the M_2 corange line (solid) in metres, cophase lines (dashed) in degrees relative to Greenwich

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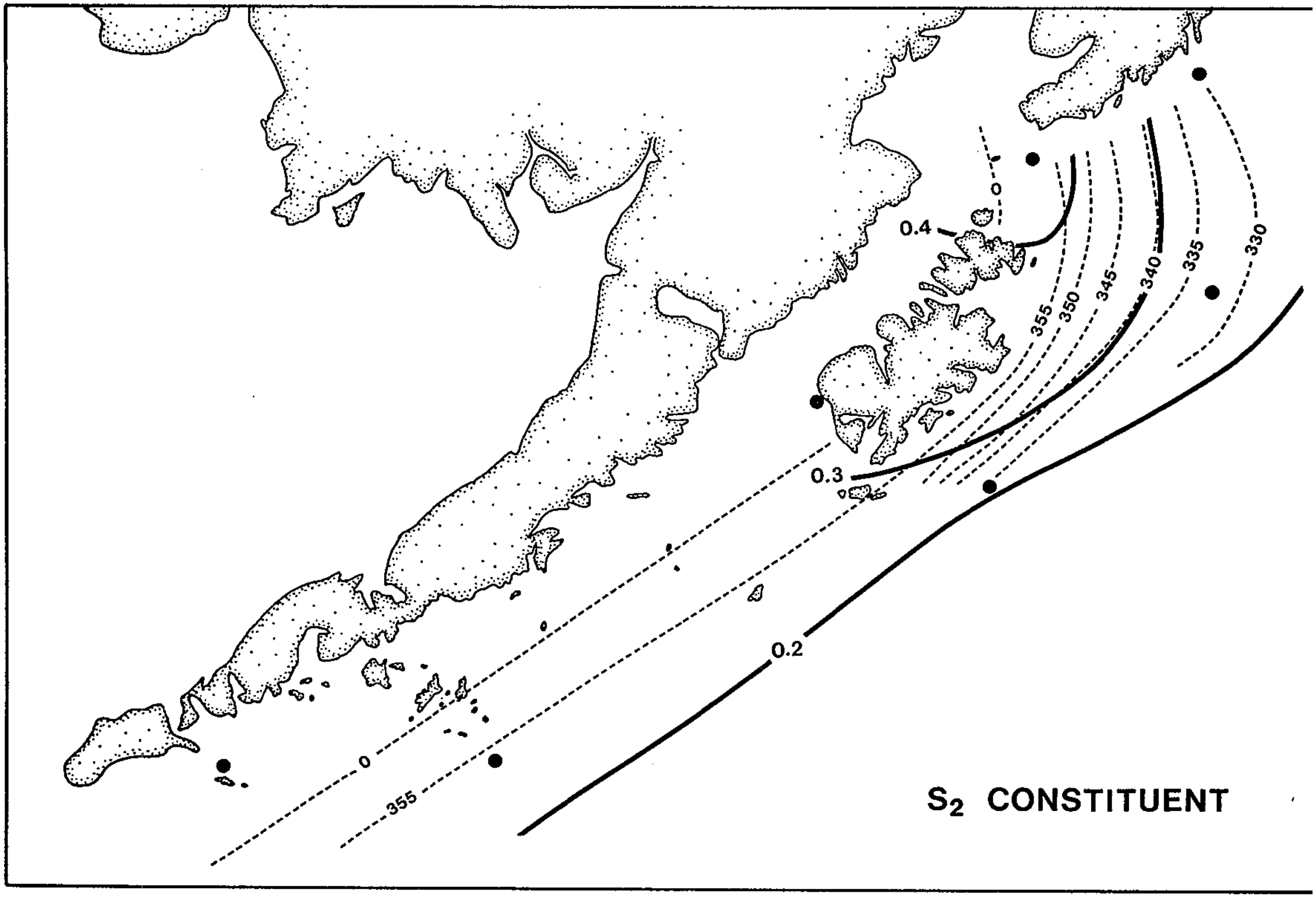

Figure 3.4 Cotidal chart for the S_2 corange line (solid) in metres, cophase lines (dashed) in degrees relative to Greenwich

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Although the cotidal charts are very rough, one can gain some confidence in them by noting that for the M_2, S_2 and K_1 constituents the bottom topography is quite well reflected in the speed of the waves as determined by the distance between cophase lines: the propagation speed is lower over Portlock Bank than in other areas.

3.2 TIDAL CURRENTS

3.2.1 Tidal Energy Propagation

The power propagated per unit width of a tide wave or energy flux can be computed using the results of the tidal stream and tidal height analyses. The energy flux per unit width integrated over depth and over the tidal period for any constituent is

$$E = \rho gh \frac{1}{2\pi} \int_0^{2\pi} A \cos(nt) V \cos(nt + \theta) dt \tag{3-2}$$

(e. g. Platzman, 1971) where E is the energy flux, ρ is the density of sea water, g is gravity, h is the depth, A is the amplitude of the tidal height oscillation, V is the amplitude of the tidal current, n is the frequency of the constituent and θ is the phase difference between the tidal height and tidal current. Integration of equation 3-2 yields

$$E = 1/2\ P\ ghAV\cos\theta. \tag{3-3}$$

Thus when the tidal current is in phase with the tidal height (maximum current at high water) a purely progressive wave is present, there is no reflection, and all tidal energy is propagated in the direction of the major axis of the tidal ellipse. When the current is 900 out of phase with the tidal height, then the tide wave is purely standing in character, there exists complete reflection and no net energy flux.

Visual comparison of the current and pressure time series from the Cook Inlet mooring (harmonic analysis of the pressure record from the current meters is inadvisable due to limited resolution) yields a near zero phase difference implying progressive tide waves which dissipate much of their energy on the extensive flats in Cook Inlet. On the other hand, the tidal height and current are about 66" out of phase at the Shelikof Strait mooring; characteristic of little energy propagation and a tide wave nearly standing in character.

The practical significance of these observations is that maximum currents occur roughly mid-way between low and high tide in Shelikof Strait but closer to low and high tide in southern Cook Inlet.

Quantitative evaulation of the energy flux by equation 3-3 is possible where tide gauges and current meters are in close proximity. The pressure sensors. on the current meters were not of great enough precision to permit reliable tidal analyses. We have computed the tidal energy flux per meter of channel width for the four largest constituents. It should be noted that the direction of energy propagation is along the major axis of the tidal ellipse. This direction is given in the tidal stream analysis with a $\pm$ 180. ambiguity, but the current phase is computed according to the direction of the semi-major axis specified. If a negative energy flux resulted from the calculation for Table 3.2, then a 1800 correction was applied to the direction Of the semi-maj or ellipse axis given in the tidal analyses. The DIR column of Table 3.2 therefore shows the actual direction of tidal energy flux.

The tidal current constituents used in the computations were approximately the barotropic components of the tidal current constituents (exactly for M_2). The barotropic component was computed from knowledge of the modal structure and the tidal currents at two depths (see section 3.2.2) . The most confidence can be placed" on the results from Sanak where the current meters and tide gauges were on the same mooring. The Cape Ikolok tide gauge and Shelikof Strait current meter appear to yield logical results while the Amatuli Island gauge and Stevenson Entrance meters display a peculiar phase lag.

Table 3.2 Tidal Energy Flux

Location	A (m)	v (m/s)	θ (")	h (m) (Approx)	DIR ('True)	Power (kw/m)
O_1						
Sanak	0.27	0.029	- 10	45	091	1.8
Ikolik-Shelikof	0.31	0.016	50	200	046	3.2
Amatuli-Stevenson	0.31	0.036	245	100	176	2.4
K_1						
Sanak	0.50	0.056	153	45	104	5.s
Ikolik-Shelikof	0.59	0,032	54	200	045	11.4
Amatuli-Stevenson	0.5s	0.065	249	100	166	7.0
M_2						
Sanak	0.63	.034	36	45	349	4.0
Ikolik-Shelikof	1.39	.145	6S	200	048	77.3
Amatuli-Stevenson	1.55	.287	241	100	173	111.6
S_2						
Sanak	0.16	.011	64	45	37	0.2
IkOlik-Shelikof	1.39	.044	65	200	46	7.2
Amatuli-Stevenson	0.42	.101	239	100	179	11.3

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Tidal energy propagation for all the constituents appears to be north-eastward into Shelikof Strait. The mean phase lag between the tidal heights and currents at the southwestern end of Shelikof Strait is about 60 degrees which implies that about half the tidal energy is reflected.

At Sanak, tidal energy is propagated to the north and east (between 349" and 104o true) . The diurnal constituents propagate nearly eastward while the semi-duirnal constituents nearly northward. There appears to be no consistency among constituents regarding the standing/progressive nature of the tide waves.

At Stevenson Entrance all four tidal constituents appear to propagate energy to tbe south. The current meters at this site exhibit comparable Greenwich phases and tbe phase difference between heights and currents is nearly constant. An error in timing is theref ore very unlikely. Also unlikely is the presence of an amphidrome on Portlock Bank for all the tidal constituents. The phase differences between the Amatuli gauge and the Cook Inlet current meters are less than 100 for the semi-duirnal constituents thus consistent will the notion of a progressive wave in southern Cook Inlet and substantial tidal energy dissipation over tbe shallows there (independent confirmation of our current measurements in Cook Inlet exist in the report of Patchen et al, (1981)) . At this writing we are unable to explain the apparent anomalous southward propagation of tidal energy in Stevenson Entrance.

The magnitude of tbe tidal energy flux in the vicinity of Kodiak Island is about 90 kilowatts per meter of channel width. Using 25 km as an appropriate width f Or Shelikof Strait, this amounts to about 2.25 x 109 watts, about O. 1 % of the tidal energy in the world ocean (LeBlond and Mysak, 197 S). The data appear to indicate that the tidal energy flux is northeastward into Shelikof Strait. Presumably much of this energy is dissipated in Cook Inlet but the apparent southward energy flux at Stevenson Entrance is still puzzling.

3.2.2 Internal Tides

Internal tides may be generated on the continental slope and can account for substantial phase differences between near surface and deep flows. In addition to the velocity signature of such oscillations, there exist concomitant vertical oscillations of the density surfaces. Unlike the surface or barotropic tides, the internal tides are characterized by velocity and displacement fields which are functions of depth.

The vertical velocity can be represented as:

$$w = W(z) \exp[i(kx - nt)] \tag{3-4}$$

where w is the vertical velocity, W(z) is the depth varying amplitude of the velocity fluctuation, k is a horizontal wave number vector and n is the angular frequency of the wave. The vertical mode structure can be found from the linearized internal wave equation:

$$\frac{\partial^2}{\partial t^2}(\nabla^2 w) + N^2(z)\nabla_h^2 W + f^2 \frac{\partial^2 w}{\partial z^2} = 0 \tag{3-5}$$

where N (z) is the Vaisala frequency = $\sqrt{-\frac{g}{\rho}\frac{\partial \rho}{\partial z}}$, and f is the Coriolis parameter. Substitution of eq 3-4 into eq 3-5 yields

$$\frac{d^2W}{dz^2} + \left[\frac{N(z) - n^2}{n^2 - f^2}\right] k^2 W = 0 \tag{3-6}$$

(Further details of internal wave dynamics can be found in Phillips, 1966.) Solution of eq. 3-6 can be performed numerically if the distribution of density with depth is known. Such solutions yield a vertical structure of vertical velocities. The Z derivative of the vertical velocity is proportional to the horizontal velocity so that a normalized distribution of horizontal velocity amplitude as a function of depth can be computed.

Mode structures were computed from the June and August CTD data taken at the current meter moorings.

The structures of the first modes for vertical displacements and horizontal velocities for the M_2 constituent are shown in Figure 3.5 along with the density structure in Cook Inlet in August. Note that the maximum horizontal velocity associated with internal tides occurs at the surface and that zero horizontal velocity occurs at a depth of 25 meters where the vertical excursion of the isopycnals and the vertical velocity are the greatest.

The modal structures for the horizontal velocities yield relative magnitudes of the internal oscillation at various depths. For example, at the Cook Inlet mooring in August the amplitudes of the internal velocity oscillations at the two current meters are in the ratio of -O .27/-0 .36. The amplitudes of the first internal (baroclinic) and surface (barotropic) tidal oscillations can be computed from this mode structures and the tidal stream analyses of two current time series.

For a given tidal frequency, n, tine combined amplitude and phase of the oscillations at the current meters is obtained from the tidal stream analyses. If only the oscillations along the major axes of the tidal ellipses are considered then the oscillations may be represented by

$$V_i = A_i \cos (nt - G_i) \qquad (3\text{-}7)$$

where i = 1,2 for shallow, deep, v_i are the total tidal velocities, A_i are the amplitudes of these velocities and G_i are the Greenwich phases. If m_i are the normalized amplitudes of the velocity fluctuations then the amplitudes and phases of the baroclinic and barotropic oscillations can be computed. These are:

$$BT = \frac{m_1 A_2 \sin \varphi}{(m_1 - m_2) \sin \alpha} \qquad \text{(barotropic amplitude)} \qquad (3\text{-}8)$$

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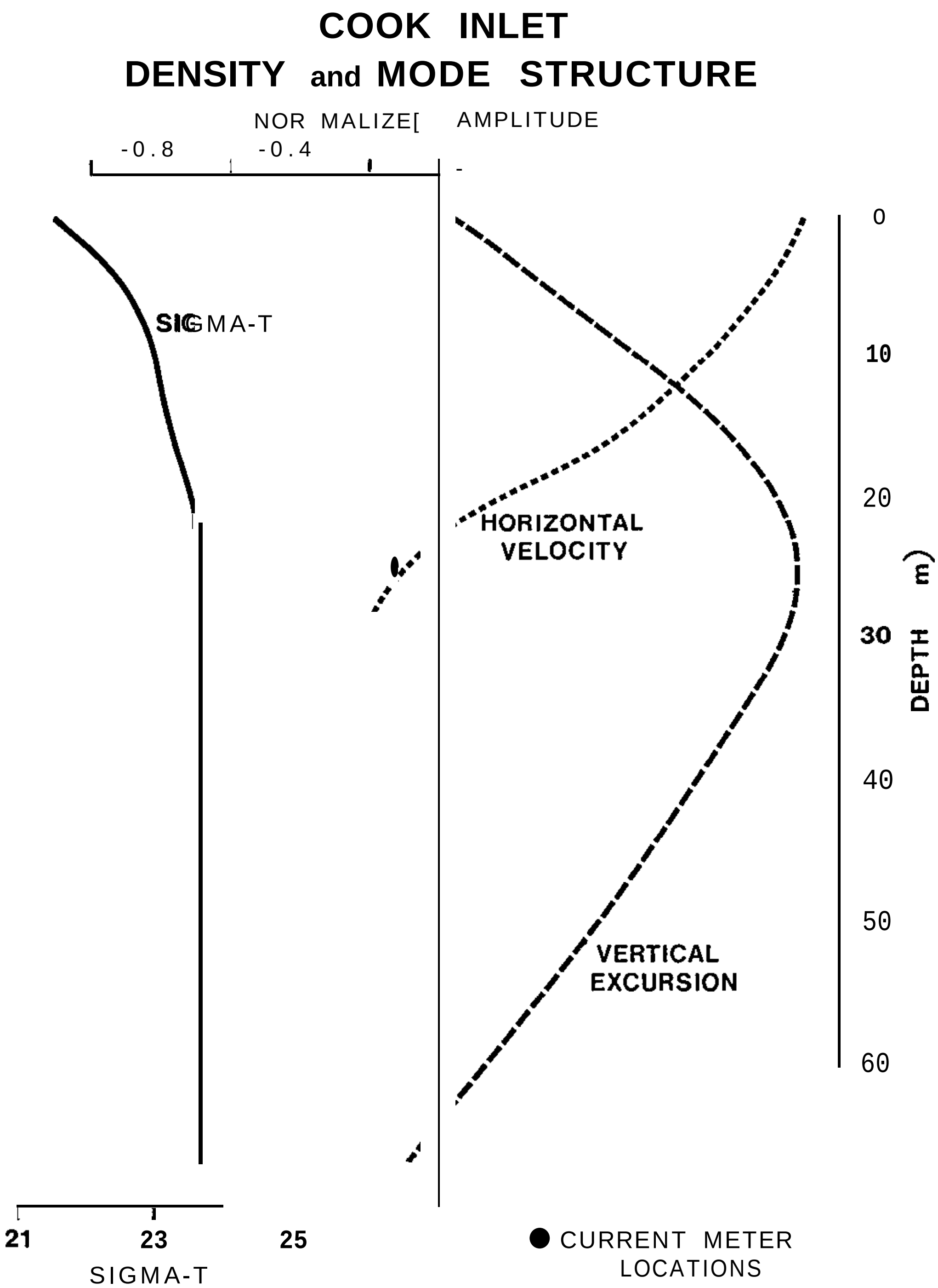

Figure 3.5 Lowest Internal Mode Structure for the M_2 Constituent in Cook Inlet

$$\tan\alpha = \frac{m_1 A_2 \sin\varphi}{m_1 A_2 \cos\varphi - m_2 A_1} \qquad \text{(barotropic phase)} \quad (3\text{-}9)$$

$$BC = \frac{A_2 \sin\varphi}{(m_2 - m_1)\sin\beta} \qquad \text{(baroclinic amplitude)} \quad (3\text{-}10)$$

$$\tan\beta = \frac{A_2 \sin\varphi}{A_2 \cos\varphi - A_1} \qquad \text{(baroclinic phase)} \quad (3\text{-}11)$$

where $\varphi = G_1 - G_2$ and α and β are phases relative to G_1.

Where possible we used the average stratification (June and August) at the mooring sites to compute the mode structures. These often varied considerably due to the vertical oscillation of the isopycnals. Ideally the density data from which the modes were computed would have been measured over a tidal cycle and averaged. Recognizing the limitations of our density profile data we computed the baroclinic and barotropic modes for the largest (M_2) tidal constituent to obtain an estimate of the internal oscillations, these are listed in Table 3.3.

By far the largest internal tides appear to occur at the Cook Inlet mooring. Indeed examination of the temperature and salinity time series from the meter at 35 m depth in Cook Inlet shows temperature and salinity oscillations of about 0.4° and 0.4°/00, respectively. Using the temperature and salinity gradients measured in June and August we can estimate the height of the internal tide

$$H \simeq \frac{\Delta T}{\partial T/\partial z} \simeq \frac{\Delta s}{\partial s/\partial z} \qquad (3\text{-}12)$$

where H is the height of the internal tide and AT and AS are the tidal excursions of the temperature and salinity values (assuming negligible horizontal gradients). Equation 3-12 yields values of about 30 meters for the vertical excursion of a water parcel at a mean depth of 35 m in Cook Inlet. Such a vertical excursion would produce a horizontal velocity which can be approximated by:

Table 3.3 **Barotropic and Baroclinic** Velocities For The M_2 **Tidal** Constituent (Amplitudes in **cm/s**)

Cook Inlet

$BT = 96.2 \cos(nt - 2.8° - G_1)$

$BC = -58.6 \cos(nt - 12.8° - G_1)$

Shelikof Strait

$BT = 14.5 \cos(nt + 1.7° - G_1)$

$BC = -1.3 \cos(nt + 30.9° - G_1)$

Stevenson

$BT = 28.7 \cos(nt - 3.5° - G_1)$

$BC = 17.4 \cos(nt - 47.6° - G_1)$

Sanak

$BT = 3.4 \cos(nt - 3.5° - G_1)$

$BC = -1.6 \cos(nt - 67.2° - G_1)$

$$V(\text{internal}) = \left(\frac{g}{h}\right)^{1/2} \left(\frac{\Delta \rho}{\rho}\right)^{1/2} \eta \qquad (3\text{-}13)$$

where ρ is the density, g gravity, η the amplitude of the internal wave and h the depth over which $\Delta\rho$ is computed. Eq. 3-13 yields a value of about 35 cm s^{-1} for the fluid velocity associated with internal waves of tidal period in Cook Inlet. This is in qualitative agreement with the amplitude presented in Table 3.3; surprisingly so. Clearly an internal wave of 30 m height in 65 m water depth is no longer a small amplitude wave and many of the assumptions of the theory are inadequate.

Our conclusion here is that substantial internal wave energy of tidal period is present in Cook Inlet. Without tidally averaged CTD data, we cannot confidently ascribe precise amplitudes to these oscillations; however, our observations as well as our computations show that internal tides are present in Cook Inlet. It is therefore unlikely that a purely barotropic tidal model will adequately represent this region.

4.0 SUBTIDAL OSCILLATIONS

In this section the energy associated with subtidal oscillations is discussed and an attempt made to relate it to atmospheric driving forces. The region is, of course, dominated by tidal oscillations, the tidal kinetic energy accounting for between 50% and 95% of the total kinetic energy. The spectral distribution of energy is shown for the longshore velocity component in Shelikof Strait in Figure 4.1. In Cook Inlet, for example, the mean flows are about 5 cm s^{-1} while the tidal flows exceed 80 cm s^{-1}. For the purposes of this section the tidal oscillations can be considered "noise" and thus for the subtidal oscillations the signal to noise ratio is generally poor. For example any effect due to sea breezes of diurnal period would be completely masked by the tidal flows.

4.1 MEAN FLOWS

The mean velocities recorded over the two month deployment period are shown in Table 4.1. At Stevenson Entrance a weak mean flow to the southeast at depth and south southwest at mid-depth may be due to outflow from the Cook Inlet area. The vertical shear of the alongshore velocity is in the same sense as that measured in Shelikof Strait however, so that the Stevenson Entrance regime could be considered to be linked to Shelikof Strait. It should be noted that mean westerly flow in Stevenson Entrance is suggested in the dynamic topographies of Favorite and Ingraham (1977). In Cook Inlet the mean flow is east northeast at both depths, differing in direction by about 450 from the orientation of the Inlet. It is probable that the recorded mean flows in Cook Inlet are due largely to rectification of strong tidal flows. Such rectification is indicated in the presence of "shallow water" tidal constituents of substantial size. The MK3 and M4 components (terdiurnal and quarter-diurnal respectively) are both of comparable magnitude to the mean flow. The presence of these "difference frequencies" indicates that non-linear effects also produce "sum frequencies". For example the M4 constituent (lunar quarter-diurnal) is a

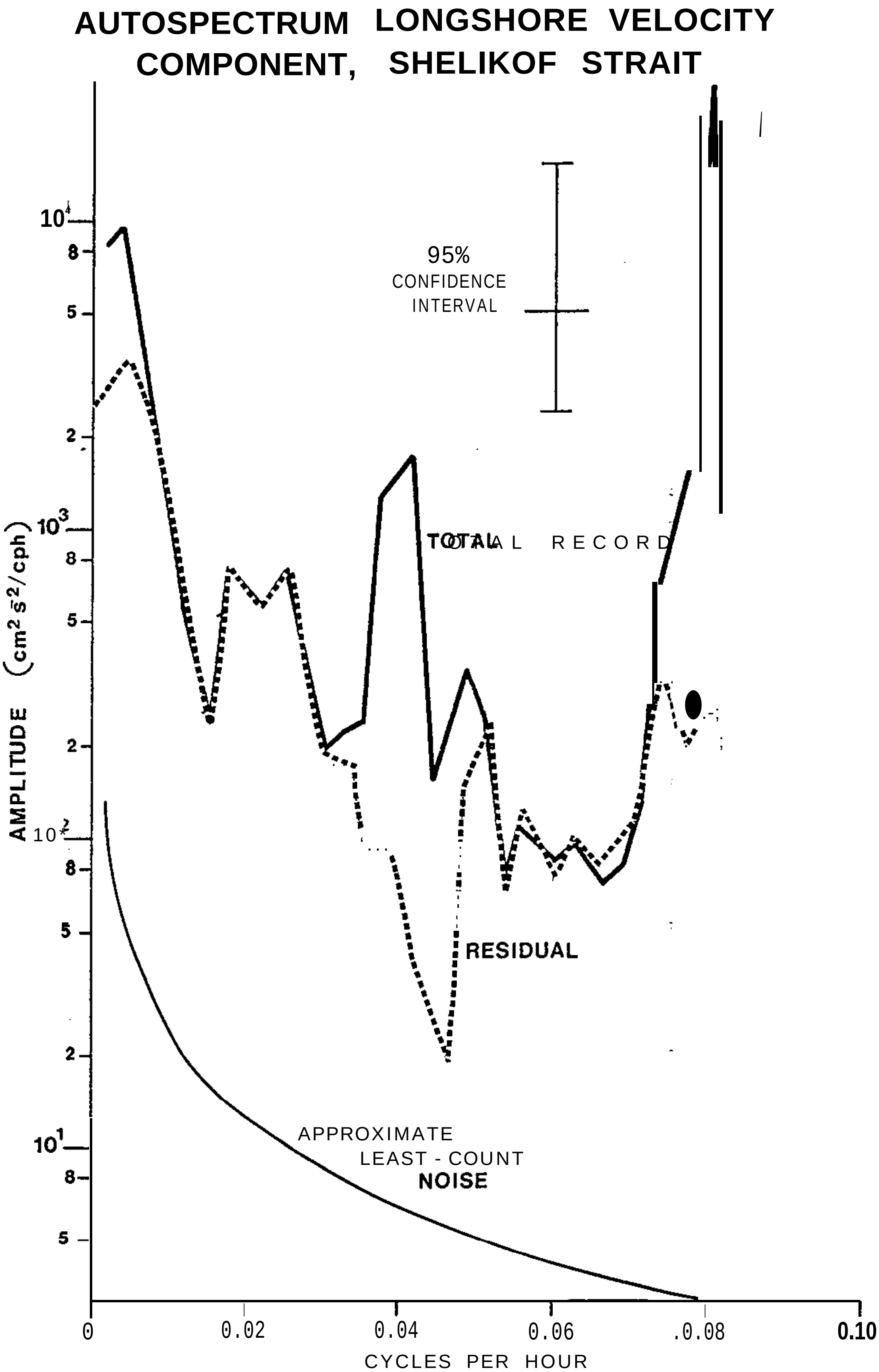

Figure 4.1 Autospectrum alongshore (225° T) component 46 m depth in Shelikof Strait

Table 4.1 Mean Velocities at the Eight Current Maters

Location	Instrument Depth (m)	Water Depth (m)	Speed (cm s-1)	Direction 'True
Stevenson	54	113	2-.1	212
Entrance.	82		2.6	135
Cook	35	66	4.3	07s
Inlet	52		5.6	064
Sanak	20	50	2.3	254
Island	41		3.1	299
Shelikof	46	25o	3.8	210
Strait	157		1.3	037

manifestation of the shoaling of the M_2 constituent. Also associated with the generation of the M_4 constituent is the generation of a DC (mean flow component). The process is perhaps best envisaged as the beating of two tidal constituents. The beat frequencies are the sum and difference of the two frequencies. In the limit as the two constituents approach an identical frequency, oscillations of twice the fundamental frequency and zero frequency are produced.

At Sanak, where the tidal amplitudes are much smaller, the shallow water tidal constituents are of negligible size and the mean flows at botb 20 and 41 meters depth are directed roughly toward the west. This mean flow is generally reflective of the flow of the coastal current.

In Shelikof Strait moderate tidal currents and deep water combine to minimize non-linear tidal effects. The shallow water constituents are small and the mean flows are representative of quasi-steady processes. At the shallow meter the flow is toward the southwest, while at the lower meter it is toward the northeast. Such a velocity distribution is characteristic of an estuarine flow in which the fresher lighter waters move seaward compensated by a slower, but vertically more extensive return f low. Schumacher et al, (1978) suggested that the inflow of deep water into Shelikof Strait occurs to balance the loss of deep water entrained by the outflowing surf ace waters. Further observations will be necessary to fully describe the estuarine-like flow in Shelikof Strait.

4.2 LOW FREQUENCY FLOWS

The region within about 20 km of the southern Alaska Coast is dominated by the Alaska Coastal Current according to Royer (1981) . Maximum speeds can be over 60 cm s^{-1} and transports can exceed 1 x 10^6 m^3 s^{-1}. Royer attributed the variations in the current to variations in freshwater discharge and found wind stress to be a very minor influence. The annual cycle of increasing stratification in early fall and decreasing stratification in late winter changes the magnitude of the internal Rossby radius. Royer mentioned this variation but did not seem to link it with tbe width of the current itself. In fact, as the stratification increases, the coastal current will become wider.

The Shelikof Strait current meter mooring of the present study was located approximately 14 km offshore of the Alaska Peninsula. The internal Rossby radius in Shelikof Strait during the deployment was between 3.5 km in June and 6.5 km in August. Data from Xiong and Royer (1984) indicate that the maximum internal Rossby radius that might be encountered in Shelikof Strait is about 16 km and would occur in fall at the peak of the freshwater discharge. If the intensity of the flow is proportional to

$$\exp(-y/r_i) \tag{4-1}$$

where y is the offshore distance then the strength of the current from its centerline to the mooring would be reduced by a factor between 10 and 50. It is, therefore, unlikely that flow or flow variations associated with the Alaska Coastal Current would have been measured at the Shelikof Strait mooring or at any of the others deployed during this study.

In order to test the above hypothesis, we employed data for the daily discharges of the Knik and Susitna Rivers (kindly supplied by Professor Royer) to represent the freshwater discharge along this section of the coast. The combined discharge of these rivers peaks in July-August at about 1000 m3 s^{-1} . The daily mean discharges of these rivers and the alongshore velocity component at 46 m depth in Shelikof Strait are plotted in Figure 4.2. There is no apparent correlation between the discharge and the current; certainly the reversals of the current are not reflected in discharge. The possibility, of course, exists that the currents are driven by freshwater discharge far "upstream", for example, along the coast of southeast Alaska. However, the lengths of the present current records do do not permit comparison over the monthly time scales which would be required to investigate such a driving mechanism.

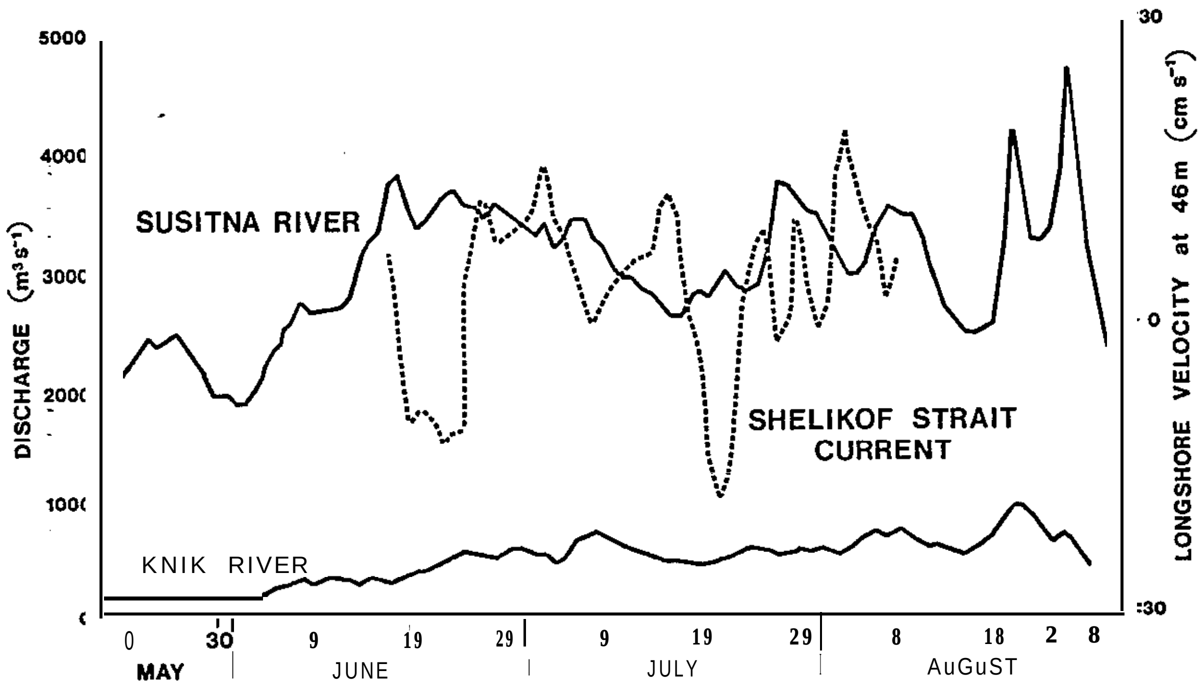

Figure **4.2 Daily discharges of the Knik and Susitna Rivers (solid lines) and the mean daily alongshore component of flow at 46 m depth in Shelikof Strait (broken line) .**

The well defined variations in the flow through Shelikof Strait are apparent in either the time series data (Appendix 2) or the tidal analyses (Appendix 1). Energy at the MM (lunar monthly) and MSF (luni-solar fortnightly) is relatively high and not reflective of the ratios of the astronomical forcing functions at these frequencies to that at the N2 frequency (9% and less than 1% of M2 respectively). Presence of energy at these frequencies more properly indicates long period oscillations.

In that there appeared to be no correlation between the Shelikof Strait currents and freshwater discharge, we investigated possible atmospheric driving of the currents.

Figure 4.1 shows the autospectra of the alongshore (225° T) velocity 'component for the raw time series and for the time series with the tidal oscillations removed (residual) . The principal tidal frequencies are in the region of 0.04 and 0.08 cycles per hour. The curve at the bottom of the figure represents the noise level due to the resolution limitations of -the current meter. The 95% confidence interval is shown. For the spectrum of the residual currents there is significant energy near 0.02 cph (50 hours) as well as at the very low end of tbe spectrum (periods of about 15 to 20 days).

For the lowest frequencies we cannot precede with a meaningful cross-spectral analyses since only three or four realizations of oscillations of these periods occur in our two month records. We have, however visually compared the velocity time series with time series based upon the sea surface atmospheric pressure data obtained from the Naval Fleet Numerical Oceanography Center at Monterey.

Using the six hourly pressure grid (grid spacing approximately 300 km) we computed geostrophic winds. These winds were then decomposed into alongshore and offshore components. In addition, we computed surface wind stress by 1) rotating the geostrophic velocity vector 20° counter-clockwise to account for Ekman turning; 2) taking 70% of the geostrophic velocity to simulate the frictional dissipation in the boundary layer; 3) squaring the wind speed and 4) applying a drag coefficient of 1.2×10^{-3}. These procedures can be expressed as:

$$\vec{\tau} = |\vec{\tau}| \exp(i\gamma) = \rho_a C_D (0.7W)^2 \exp[i(\delta + 20°)] \quad (4.2)$$

where $\vec{\tau}$ is the surface wind stress vector, ρ_a is the density of air, CD the drag coefficient, W the geostrophic wind speed δ the direction of the geostrophic wind vector anti clockwise from east γ and the direction of the surf ace stress vector. It should be borne in mind that the precise magnitudes of the drag coefficients, air density and the ratio of 10 m wind speed to geostrophic wind speed are unimportant in coherence computations.

The longshore and offshore components of the surface stress vector were then plotted versus time. Comparison of current, wind and wind stress component tires series yielded no striking correlation. Time series plots of the current velocity components in Shelikof Strait: and tbe atmospheric pressure gradient, windspeed and wind stress are shown in Appendix 2. Although long period variations spanning about 10 days are clearly present in the current records these are not mirrored in the meteorological records. Either these variations are not locally driven, are driven by a non-meteorological process, the surf ace pressure grid is too coarse to resolve the Shelikof Strait winds, or an agency other than wind stress is responsible for the current oscillations. The oscillation are probably not attributable to baroclinic instabilities since these are thought to have periods in Shelikof Strait of about four days (Mysak et al, 1981) .

4.3 SUBTIDAL OSCILLATIONS OF PERIOD LSSS THAN SEVEN DAYS

In this range of the spectrum we have enough realizations to apply cross-spectral techniques. Since we are dealing with synoptic scale atmospheric pressure maps, however, wavelengths greater than 600 km only can be rigorously addressed. Table 4.2 lists the periods at which coherence above the 95% confidence level were found between variables.

The fluctuations in the cross-shelf sea surface slope (between Ikolik and Albatross Bank) were coherent with the longshore wind stress at periods of about 35 hours. The a longshelf (Ikolik-Amatuli) sea surface slope was coherent in this range of periods with both the longshore and offshore wind stress.

Table 4.2 **Periods** for Which Significant Coherence Were **Found**

	Alongshore Wind Stress	Onshore Wind Stress
Shelikof Strait		
47 m Current Components		
alongshore	5 days	
offshore		
Shelikof Strait		
157 m Current Components		
alongshore	7 days, 3 days	5 days
off shore	35 hours	
Cross-shelf Pressure Gradient		
(Ikolik-Albatross)	35 hours	
Along-shelf Pressure Gradient		
(Ikolik-Amatuli)	35 hours	35 hours

Clearly, the cross-shelf sea surface slope (Ikolik-Albatross) responds to alongshore shore wind-stresses of periods of just over one day (the time lag is about 12 hours). The alongshore sea surface slope however (Ikolik-Amatuli) responds significantly to both alongshore and onshore wind stress.

The shallow alongshore currents appear to respond primarily to alongshore stress oscillations of about five day period while the deeper alongshore currents appear to respond to both alongshore and offshore stresses.

If we assume that both current meters are located within the geostrophic interior of the fluid, that is outside the surface and bottom Ekman layers, then the behavior of the cross-shelf pressure gradient should mirror that of the alongshore current component. Inspection of Table 4.2 reveals that this is not the case. Additionally, it is difficult to explain the high coherence between the onshore wind stress and the along-shelf pressure gradient.

Unfortunately, we cannot draw conclusions from the observed coherence. We can only speculate that the geostrophic winds are not a good indication of the atmospheric forcing over Shelikof Strait. It is likely that the local topography greatly alters the wind field, e.g. , as described by Kozo (1980).

The oscillations in Shelikof Strait, therefore, are still unexplained. It is extremely unlikely that they are driven by coastal freshwater discharge so that the remaining mechanisms are the atmospheric pressure field, wind stress or wave-like instabilities.

5.0 SUMMARY

5.1 PROPERTY FIELDS

Between June and August 1984, the surface temperature increased by ahout 5°C in the Western Gulf of Alaska due to insolation. Cross sections of density revealed an eddy-like feature of dimensions comparable with the internal Rossby radius which propagated (or was advected) westward at a speed of about 4 cm s^{-1}. If the feature was associated with baroclinic instability, then a mechanism for cross slope exchange of water and nutrients was present.

The station spacing and the lack of synopticity of tbe CTD limit tbe tbe utility of tbe computed geostrophic currents. In general, however, westerly flows as bigb as 60 cm s^{-1} were computed over the continental slope while westerly flows up to 10 cm s^{-1} were computed over the continental shelf.

Tbe property distributions were similar to those reported by previous investigators.

5.2 TIDAL OSCILLATIONS

The tides. in the region are mixed, mainly semi-diurnal with spring tide ranges of between 3.5 and 6.5 m. Cotidal charts show the major tidal constituents propagating from northeast to southwest with some suggestion of shoreward propagation weat of Kokiak Island. Computations of tidal energy flux are generally consistent with the cotidal charts with the exception of the Stevenson Entrance location. At this site, southward propagation of energy is computed.

Substantial tidal period internal wave energy was computed for the M_2 constituent in Cook Inlet. Internal tide waves have associated velocity, amplitudes and heights of about 50 cm s^{-1} and 30 m respectively. The implication is that a 60 m height internal tide wave is present at spring tide. In 65 m water depth such an oscillation is extremely unlikely without strong non-linearities in the flow field. A purely linear-barotropic tidal model will, therefore, likely be inadequate to predict the flow field in Cook Inlet.

5.3 SUBTIDAL OSCILLATIONS

Tbe current data collected during this study were inadequate to address variations in the Alaska Coastal Current for two reasons: first, the records" are only two months long and, 'second, the moorings were located no closer than 15 km to the coast. The offshore length scale of the current during June-August is expected to be between 3 and 7 km so that tbe current meters would not have sensed the coastal current.

Mean flows ranged between 1.3 and 5.6 cm s^{-1}, and were directed generally southwestward along the 'shelf with two important exceptions. In Shelikof Strait, the mean flow at depth was northeastward implying an estuarine type of flow regime there. In Cook Inlet the mean flows was east by northeast nearly across tbe inlet. Tbe Cook Inlet mean flows are probably a manifestation of a secondary circulation the most likely driving force for which is tidal rectification.

No success was achieved in relating the variations in the geostrophic winds with the variations in the flow on the continental shelf. We speculate that this is due to ageostrophic atmospheric flow caused by tbe presence of coastal mountains.

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Tidal analyses

Appendix 1”

GULF OF ALASKA

ANALYSIS Of HOURLY TIDAL HEIGHTS

STN: AMATULI ISLAND LAT : 59 0 7.8 N
DEPTH : 167 M LONG: 1S1 50 1.8 W
START : 2300Z 13/ 6/84 END: 14002 9/ 8/84
NO.OBS. = 1360 NO.PTS.ANAL. = 1360 MIDPT: 600Z 12/7/84

	NAME	FREQUENCY (CY/HR)	A (M)	G
	----	----------	---	
1	Zo	0.00000000	166.2659	0.00
2	. MM	0.00151215	0.0257	145.38
3	MSF	0.00202193	0.0323	328.20
4	ALP1	:0.03439657	0.0068	62.74
5	2Q1	.0.03570635	0.0137	303.66
6	Q1	.0.03721850	0.0468	271.60
7	01	0.03873065	0.3082	262.95
8	NO1	0.04026860	0.0214	331.62
9	K1	0.04178075	0.5834	287.24
10	J1	0.04329290	0.0200	324.87
11	001	.0,04403054	0.0092	293.79
12	UPSI	.0.04634299	0.0033	270.03
13	EPS2	0.076 17730	0.006s	169.58
14	MU2	0.07768947	0.0470	213.74
15	N2	0.07099922	0.3011	297.41
16	M2	0.060s1139	1.5548	312.60
17	L2	0.08202356	0.0125	294.06
18	S2	0.08333331	0.4184	357.54
19	ETA2	0.08507365	0.0199	302.03
20	MO3	0.11924207	0.0127	194.15
21	M3	0.120?6712	0.0022	46.03
22	MK3	0.12229216	0.0171	218.41
23	SK3	0.12511408	0.0059	219.66
24	MN4	0.15951067	0.0070	322.32
25	M4	0.16102278	0.0163	359.70
26	SN4	0.16233259	0.0010	356.16
27	MS4	0.16384470	0.0084	58.07
28	S4	0.16666669	0.0037	37.73
29	2MK5	0.202%0355	0.0058	211.90
30	2SK5	0.20844740	0.0013	50.83
31	2MN6	0.24002206	0.0016	359.03
32	M6	0.24153417	0.0045	53.37
33	ZMS6	0.24435616	0.0021	146.80
34	2SM6	0.24717808	0.0012	88.31
35	3MK7	0.20331494	0.0010	265.07
36	M8	0.32204562	0.0014	272.69

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS OF HOURLY TIDAL HEIGHTS

STN: ALBATROSS BANK LAT: 56 33 28.8 N
DEPTH: 165 M LONG: 152 26 57.0 W
START : 1200Z 12/ 6/84 END: 4002 8/ 8/84
NO.OBS.= 1361 NO.PTS.ANAL.= 1361 MIDPT: 20002 10/ 7/84

	NAME	FREQUENCY (CY/HR)	A (M)	G
	----	---------	---	---
1	20	0.00000000	164.4422	0.00
2	MM	0.00151215	0.0206	165.74
3	MSF	0.00282193	0.0155	333.31
4	ALP1	0.03439657	0.0045	170.37
5	2Q1	0.03S70635	0.0096	320.29
6	Q1	0.03721850	0.0432	256.19
7	01	0.03073065	0.2905	255.04
8	NO1	0.04026860	0.0154	318.87
9	K1	0.04178075	0.5528	278.29
10	J1	0.04329290	0.0243	312.61
11	001	0.04483084	0.0089	315.17
12	UPS1	0.04634299	.0.0011	.211.94
13	EPS2	0.0'/617730	0.0077	“’”’”203.52
14	MU2	0.0776S947	0.0177	170.66
15	N2	0.07899922	0.1698	279.03
16	M2	0.08051139	0.8940	294. S7
17	L2	0.00202356	0.0142	313.45
18	S2	0.08333331	0.2171	334.37
19	ETA2	0.0850736S	0.0094	275.77
20	M03	0.11924207	0.0021	232. 3a
21	M3	0.12076712	0.0017	230.21
22	MK3	0.12229216	0.0025	226 . 88
23	SK3	0.12511400	0.0009	152.34
24	MN4	0.15951067	0.0004	55. 15
25	M4	0.1610227B	0.0007	216.40
26	SN4	0.16233259	0.0006	344.03
27	MS4	0.16384470	0.0009	99. 80
28	S4	0.16666669	0.0011	191.48
29	2MK5	0.20280355	0.0009	163.82
30	ZSK5	0.20844740	0.0008	282. 14
31	2MN6	0..?4002206	0.0001	163.15
32	M6	0.24153417	0.0013	150.91
33	2MS6	0.24435616	0.0011	255 .4a
34	2SM6	0.24717808	0.0003	271.15
35	3MK7	0.28331494	0.0006	252.30
36	M8	0.32204562	0.0003	316.73

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS OF HOURLY TIDAL HEIGHTS

STN: SHUMAGIN LAT : 54 31 55.8 N
DEPTH : 193 M LONG: 158 58' 4.8 W
START : 2000Z 15/ 6/84 END: 1900Z 11/ 8/84
NO.OBS.= 1368 NO.PTS.ANAL.= 1369 MIDPT: 700Z 14/ 7/84

	NAME	FREQUENCY (CY/HR)	A (M)	G
	----	-.--------	---	---
1	ZO	0.00000000	192.0029	0.00
2	MM	0.00151215	0.0148	176.47
3	MSF	0.00202193	0.0232	0.27
4	ALP 1	0.03439657	0.0052	293.93
5	2Q1	0.03570635	0.0066	292.27
6	Q1	0.03721850	0.0510	271.57
7	01	0.03873065	0.2769	266.50
8	NO 1	0.04026860	0.0244	322.55
9	K1	0.04178075	0.5175	289.08
10	J1	0.04329290	0.0129	310.2B
11	001.	0.04483084	0.0106	273.33
12	UPS 1	0.04634299	0.0042	316.70
13	EPS2	0.07617730	0.0037	239.99
14	MU2	0.07768947	0.0173	188.56
15	N2	0.07899922	0.1371	302.39
16	M2	0.08051139	0.6713	317.25
17	L2	0.08202356	0.0147	351.66
18	S2	0.08333331	0.1690	3s3.99
19	ETA2	0.00507365	0.0083	322.62
20	MO3	0.11924207	0.0014	352.73
21	M3	0.12076712	0.0017	222.90
22	MK3	0.12229216	0.0006	2S0.66
23	SK3	0.12511400	0.0007	215.00
24	MN4	0.15951067	0.0003	199.91
25	M4	0.16102278	0.0011	232.74
26	SN4	0.16233259	0.0002	58.20
27	MS4	0.16384470	0.0003	112.42
28	S4	0.16666669	0.0017	199.84
29	2MK5	0.20280355	0.0020	197.44
30	2SK5	0.20644740	0.0002	195.38
31	2MN6	0.24002206	0.0009	266.61
32	M6	0.24153417	0.0014	318.15
33	2MS6	0.24435616	0.0014	346.82
34	2SM6	0.24717000	0.0005	43.08
35	3MK7	0.20331494	0.0010	260.95
36	MB	0.3.2204562	0.0009	301.68

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS OF HOURLY TIDAL HEIGHTS

STN: CAPE IKOLIK — LAT: 57 15 0.0 N

DEPTH: 62 M — LONG: 154 45 18.0 W

START: 100Z 15/ 6/84 — END: 2300Z 10/ 8/84

NO.OBS.= 1367 NO.PTS.ANAL.= 1367 MIDPT: 1200Z 13/ 7/84

	NAME	FREQUENCY (CY/HR)	A (M)	G
1	Zo	0.00000000	61.2714	0.00
2	MM	0.001S1215	0.0183	1S4.76
3	MSF	0.00282193	0.0260	1.68
4	ALP1	0.03439657	0.0032	3S2 .93
5	2Q 1	0.03570635	0.0113	306.23
6	Q1	0.03721850	0.0515	271.30
7	01	0.03873065	0.3070	26S. 70
8	NO1	0.04026860	0.0245	327. 00
9	K1	0.04178075	0.5928	289 .37
10	J1	0.04329290	0.0192	329. 1s
11	001	0.04483084	0.0116	274.81
12	UPSI	0.04634299	0.0047	307.11
13	EPS2	0.07617730	0.0062	289.65
14	MU2	0.07768947	0.0261	212.33
15	N2	0.07899922	0.2770	303.52
16	M2	0.08051139	1.3889	317.00
17	L2	0.08202356	0.0202	319.81
18	S2	0.08333331	0.3757	1.87
19	ETA2	0.08S07365	0.0201	31S.96
20	M03	0.11924207	0.0054	99.62
21	M3	0.12076712	0. 00s4	11.0s
.22	MK3	0.12229216	0.0167	155.14
23	SK3	0.12511408	0.0096	202.21
24	MN4	0.15951067	0.0086	199.64
25	M4	0.1610ZZ78	0.0299	220. so
26	SN4	0.16233259	0.0036	241.71
27	MS4	0.16384470	0.0127	287. 22
28	S4	0.16666669	0.0054	317.39
29	2MK5	0.20280355	0.0040	169.34
30	2SK5	0.20844740	0.0011	266.61
31	2MN6	0.24002206	0.0024	141.00
32	M6	0.241S3417	0.0043	152.29
33	2MS6	0.24435616	0.0031	212.66
34	2SM6	0.24717808	0.0008	153.50
3s	3MK7	0.28331494	0.0008	336.89
36	M8	0.32204562	0.0014	9.47

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS OF HOURLY TIDAL HEIGHTS

STN: SEAL ROCKS   LAT: 59 29 5S.8 N
DEPTH: 114 M   LONG: 149 29 34.2 W
START: 1000Z 13/ 6/84   END: 400Z 9/ 8/84
NO.OBS.= 1363 NO.PTS.ANAL.= 1363 MIDPT: 1900Z 11/ 7/84

	NAME	FREQUENCY (CY/HR)	A (M)	G
1	ZO	0.00000000	113.3633	0.00
2	MM	0.00151215	0.0234	133.86
3	MSF	0.00282193	0.0403	356.06
4	ALP 1	0.03439657	0.0061	90.30
5	2Q 1	0.03570635	0.0117	308.39
6	Q1	0.03721850	0.0410	263. e4
7	01	0.03873065	0.2846	256.09
8	NO 1	0.04026060	0.0172	325.07
9	K1	0.04178075	0.5431	279.69
10	J1	0.04329290	0.0209	316.09
11	001	0.04483084	0.0088	302.19
12	UPS 1	0.04634299	0.0021	252.49
13	EPS2	0.07617730	0.0053	148.33
14	MU2	0.0776S947	0.0340	176.16
15	N2	0.07899922	0.2216	274.53
16	M2	0.08051139	1.1975	289. 94
17	L2	0.08202356	0.0109	305. e4
18	S2	0.08333331	0.3016	331.25
19	ETA2	0.08S07365	0.0121	273.02
20	MO3	0.11924207	0.0036	179.17
21	M3	0.12076712	0.0012	290.42
22	MK3	0.12229216	0.0043	191.79
23	SK3	0.12511408	0.0031	162.93
24	MN4	0.15951067	0.0013	334. 68
25	M4	0.16102278	0.0085	13.66
26	SN4	0.16233259	0.0015	3.70
27	MS4	0.16304470	0.0042	114.67
28	S4	0.16666669	0.0007	290.37
29	2MK5	0.20280355	0.0018	245.35
30	2SK5	0.20844740	0.0015	268.12
31	2MN6	0.24002206	0.0022	320.05
32	M6	0.24153417	0.0062	41.30
33	2MS6	0.24435616	0.0024	117.96
34	2SM6	0.24717808	0.0014	38.02
3s	3MK7	0.28331494	0.0007	328.63
36	M8	0.32204S62	0.0013	336.99

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS OF HOURLY TIDAL HEIGHTS

STN: PORTLOCK BANK LAT: 58 0 1.8 N
DEPTH : 178 M LONG: 149 29 34.8 W
START : 100Z 13/ 6/84 END: 1600Z 8/ 8/84
NO.OBS.= 1360 NO.PTS.ANAL. = 1360 MIDPT: 800Z 11/ 7/84

	NAME	FREQUENCY (CY/HR)	A (M)	G
1	Zo	0.00000000	177.0711	0.00
2	MM	0.00151215	0.0272	156.61
3	MSF	0.002S2193	0.0218	341.60
4	ALP1	0.03439657	0.0041	112.08
5	2Q1	0.03570635	0.0104	312.84
6	Q1	0.03721850	0.0424	258.27
?	01	0.03873065	0.2916	252.72
8	NO1	0.04026860	0.0171	318.75
9	K1	0.04178075	0.5572	276.60
10	J1	0.04329290	0.0227	313.52
11	00 1	0.04483084	0.0094	301.53
12	UPS1	0.04634299	0.0014	232.87
13	EPS2	0.07617730	0.0007	153.79
14	MU2	0.07760947	0.0273	184.22
15	N2	0.07S99922	0.1902	27S.57
16	M2	0.08051139	1.0140	293.40
17	L2	0.08202356	0.0094	299.76
18	S2	0.08333331	0.2499	334.36
19	ETA2	0.08S07365	0.0093	278.04
20	MO3	0.11924207	0.0029	263.94
21	M3	0.12076712	0.0027	249.16
22	MK 3	0.12229216	0.0014	207.67
23	SK 3	0.12511408	0.0009	112.25
24	MN4	0.15951067	0.0003	293.32
25	M4	0.16102Z7B	0.0015	297.13
26	SN4	0.16233259	0.001s	324.41
27	MS4	0.16384470	0.0010	49.75
28	S4	0.16666669	0.0002	17.43
29	2NK5	0.20280355	0.0016	150.97
30	ZSKS	0.20844740	0.0009	288. 21
31	2MN6	0.24002206	0.0006	336.75
32	M6	0.24153417	0.0023	61. 4B
33	ZMS6	0.24435616	0.0007	129.92
34	2SM6	0.24717808	0.0008	55.71
35	3MK7	0.28331494	0.0000	81.17
36	M8	0.32204S62	0.0011	169.50

GULF OF ALASKA

ANALYSIS OF HOURLY TIDAL HEIGHTS

STN: SANAK — LAT: S4 3S 15.0 N
DEPTH : 51 M — LONG: 162 43 46.2 W
START : 11002 16/ 6/84 — END: 400Z 13/ 8/84
NO.OBS.= 1386 NO.PTS.ANAL. = 1386 MIDPT: 7002 15/ 7/84

	NAME	FREQUENCY (CY/HR)	A (M)	G
1	20	0.00000000	51.0813	180.00
z	MM	0.00151215	0.0097	210.41
3	MSF	0.00282193	0.0220	8.72
4	ALP 1	0.03439657	0.0043	2S6 .34
5	2Q 1	0.03570635	0.0040	312.70
6	Q1	0.03721850	0.0476	274.00
7	01	0.03S73065	0.2691	269.93
8	NO 1	0.04026860	0.0244	324.25
9	K1	0.04178075	0.5041	293.03
10	J1	0.04329290	0.0096	299.74
11	00 i	0.04483084	0.0113	291.54
12	UPS1	0.04634299	0.0024	341.03
13	EPS2	0.07617730	0.0038	228.10
14	MU2	0.07768947	0.0173	196.83
15	N2	0.07899922	0.1331	314.13
16	M2	0.08051139	0.6306	330.12
17	L2	0.08202356	0.0173	347.43
18	S2	0.08333331	0.1579	3.55
19	ETA2	0.08507365	0.0074	337.79
20	MO3	0.11924207	0.0025	13.46
21	M3	0.12076712	0.0023	24S .32
22	MK3	0.12229216	0.0027	53.03
23	SK3	0.12511408	0.0017	319.22
24	MN4	0.15951067	0.0014	73.10
25	M4	0.16102278	0.0006	89.53
26	SN4	0.16233259	0.0012	119.45
27	MS4	0.163%4470	0.0009	222.07
28	S4	0.16666669	0.0027	219.40
29	2MK5	0.20280355	0.0022	181.33
30	ZSK5	0.20844740	0.0027	184.51
31	2MN6	0.24002206	0.0030	128.19
32	M6	0.24153417	0.0095	139.34
33	2MS6	0.24435616	0.0069	202.12
34	2SM6	0.24717008	0.0021	254.16
3s	3MK7	0.28331494	0.0022	303.21
36	M8	0.32204562	0.0016	341.89

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM

AMPLITUDES HAVE BEEN SCALED ACCORDING TO APPLIED FILTERS

STN: STEVENSON ENTRANCE LAT: '58 53 43.0 N
DEPTH: 54 M LONG: 150 57 13.8 W
START: 2000Z 13/ 6/84 END: 800Z 9/ 8/84

	NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
1	Zo	0.00000000	2.111	0.000	57.8	180.0	122.2	237.8
z	MM	.0.0015121S	3.924	-2.361	45.0	55.4	10.5	100.4
3	MSF	0.00282193	2.861	-2.021	84.7	68.2	343.6	152.9
4	ALP1	0.03439657	0.476	-0.391	179.0	156.0	337.0	334.9
5	2Q1	0.03570635	0.728	0.126	109.4	93.1	343.7	202.5
6	Q1	0.03721850	1.000	0.344	97.5	17.0	279.5	114.5
7	01	0.03873065	3.742	-0.774	98.1	13.7	275.6	111.8
8	NO1	0.04026860	0.258	0.040	106.4	156.6	50.2	263.1
9	K1	0.04178075	6.571	-2.157	100.6	40.5	300.0	141.1
10	J1	0.04329290	0.558	0.438	126.2	75,9	309.8	202.1
11	001	0.04483084	0.450	-0.140	75.4	349.8	274.5	65.2
12	UPS1	0.04634299	0.395	0.097	7.3	12.6	5.3	19.9
13	EPS2	0.07617730	1.338	0.774	74.1	304.2	230.2	13.3
14	MU2	0.07768947	2.474	0.503	67.2	31.9	324.6	9%.9
15	N2	0.07899922	5.889	1.478	93.5	50.5	317.0	143.9
16	M2	0.08051139	30.198	0.621	102. i	66.3	324.1	168.4
17	L2	"0.08202356	1.484	-0.096	116.5	37.0	2eo. 5	153.5
18	S2	0.08333331	10.086	0.591	97.2	112.3	15.1	209.5
19	ETA2	0.08507365	1.137	0.717	80.1	100.2	20.1	180.3
20	MO3	0.11924207	0.645	0.246	74.4	182.6	108.2	257.1
21	M3	0.12076712	0.545	-0.231	17.1	228.3	211.2	245.4
22	MK3	0.12229216	1.015	0.195	50.4	280.5	230.1	331.0
23	SK3	0.12511408	0.417	0.173	25.5	329.1	303.6	354.6
24	MN4	0.1s9510.s7	0.141	-0.060	98.3	6.9	268.6	105.2
25	M4	0.16102270	0.691	0.538	5.7	'259.3	253.6	265.0
26	SN4	0.16233259	0.415	-0.185	126.4	262.2	135.8	28.5
27	MS4	0.16384470	0.526	-0.342	2.0	357.1	355.0	359.1
28	S4	0.16666669	0.651	0.354	43.5	319.7	276.3	3.2
29	2MK5	0.20280355	0.922	0.247	55.3	283.3	228.0	338.6
30	ZSK5	0.20044740	0.167	0.105	149.7	214.2	64.4	3.9
31	2MN6	0.24002206	0.535	-0.153	15.8	303.1	287.3	318.8
32	M6	0.24153417	0.923	-0.041	36.3	310.8	274.5	347.2
33	2MS6	0.24435616	0.720	-0.050	S8.9	328.8	269.9	27.7
34	2SM6	0.24717800	0.525	0.128	134.8	9s.0	323.?.	232.7
3S	3MK7	0.28331494	0.492	0.110	101.4	233.6	132.2	335.0
36	M8	0.32204562	0.330	0.135	151.1	45.9	254.7	197.0

Dobrocky SEATECH

GULF OF ALASKI?

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM
AMPLITUDES HAUE BEEN SCALED ACCORDING TO APPLIER FILTERS

STN: STEVENSON ENTRANCE		LAT:	58 53 43.0 N
DEPTH : 82 M		LONG:	150 57 13.8 W
START: 20002 13/ 6/84		END:	6002 9/ 8/84

	NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
1	20	0.00000000	2.576	0.000	134.9	180.0	45.1	314.9
2	MM	0.00151215	3.302	-0.8013	30.9	50.5	19.7	01.4
3	MSF	0.002S2193	2.993	-1.034	17.5	149.0	131.5	166.5
4	ALP1	0.03439657	0.221	-0.191	70.4	202.2	131.8	272.6
S	2Q1	0.03570635	0.424	-0.006	69.0	63.S	3s4.5	132.5
6	Q1	0.03721S50	0.826	0.220	59.6	54.5	354.9	114.1
7	01	0.03873065	3.456	-1.668	91.3	21.5	290.2	112.8
B	NOI	0.04026860	0.268	0.138	10.0	109.7	99.7	119.7
9	Ki	0.04178075	6.411	-3.464	10R.3	35.9	287.6	144.3
10	J1	0.04329290	0.931	0.647	66.9	69.2	2.3	136.2
11	001	0.04483084	0.343	0.130	82.8	55.6	332.8	138.4
12	UPS1	0.04634299	0.248	0.085	166.1	324.1	158.1	130.2
13	EPS2	0.07617730	1.490	0.759	60.7	357.s	296.8	58.2
14	MU2	0.37768947	2.926	0.764	26.1	57.s	31.7	83.9
15	N2	0.0789S922	5.988	-0.342	94.1	55.1	321.0	149.3
16	M2	0.08051139	36.348	1.649	91.2	76.0	344.7	167.2
17	L2	0.08202356	3.619	2.749	1.0	20.6	19.6	21.6
18	S2	0.08333331	11.584	1.104	83.6	126.3	42.7	210.0
19	ETA2	0.08507365	0.820	0.024	95.6	67.9	332.3	163.5
20	MO3	0.11924207	0.323	-0.026	60.0	352.2	292.3	52.2
21	M3	0.12076712	0.252	0.121	136.3	16.3	240.0	152.6
22	MK3	0.1.2229216	0.809	-0.112	33.4	40.8	7.4	74.3
23	SK3	0.12511408	0.271	0.036	32.5	85.7	53.2	118.2
24	MN4	0.15951067	0.983	0.046	79.4	92.0	12.6	171.4
25	M4	0.16102278	1.492	0.128	24.7	127.5	102.8	152.2
26	SN4	0.16233259	1.139	0.294	150.7	238.2	87.6	28.9
27	MS4	0.163S4470	0.461	-0.179	57.3	151.4	94.2	208.7
28	S4	0.16666669	0.672	0.618	107.4	215.4	108.0	322.8
29	2MK5	0.20280355	0.679	0.233	40.2	7.4	327.2	47.7
30	2SK5	0.20844740	0.125	0.079	96.0	171..2	75.2	267.1
31	2MN6	0.24002206	0.310	-0.054	.96.4	85.4	349.0	181.8
32	M6	0.241S3417	0.2S3	0.167	58.8	320.1	261.3	19.0
33	2MS6	0.24435616	0.474	0.131	41.4	45.7	4.3	87.1
34	2SM6	0.24717008	0.220	-0.003	105.0	188.3	83.3	293.3
35	3MK7	0.28331494	0.558	0.182	140.2	307.0	166.8'	87.2
36	M8	0.32204562	0.299	-0.172	15.4	80.4	73.1	103.B

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM
AMPLITUDES HAUE BEEN SCALED ACCORDING TO APPLIED FILTERS

STN: COOK INLET — LAT: 59 35 1.2 N
DEPTH: 35 M — LONG: 152 29 0.0 U
START: 5002 14/ 6/84 — END: 18002 9/ 8/84

	NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
1	Zo	0.00000000	4.304	0.000	12.1	360.0	347.9	12.1
2	MM	0.00151215	1.922	1.178	117.8	16S.3	47.4	283.1
3	MSF	0.00282193	4.297	-1.351	99.1	264.3	165.2	3.4
4	flLPl	0.03439657	0.591	-0.411	95.0	26.4	291.4	121.5
5	2Q1	0.03570635	0.757	-0.323	108.6	256.8	148.3	5.4
6	Q1	0.03721050	1.892	0.090	91.8	241.0	149.1	332.8
7	01	0.03873065	9.482	-0.695	78.s	223.7	145.2	302.3
8	NO1	0.04026860	0.897	-0.069	105.1	290.7	185.6	3s.s
9	K1	0.0417s075	19.006	-3. S27	77.4	243.9	166.5	321.2
10	J1	0.04329290	0.602	0.184	54.4	292.2	237.8	346.6
11	001	0.04483084	0.837	-0.097	104.2	264.7	160.5	9.0
12	UPS1	0.04634299	0.428	0.020	124.4	237.3	112.9	1.6
13	EPS2	0.07617730	1.706	-1.474	51.9	193.8	141.9	.245.6
14	MU2	0.37768947	6.366	-0.209	96.6	199.5	102.9	296.2
15	N2	0.07899922	14.444	-2. 391	81.2	285 .2	204.0	6.4
16	M2	0.08051139	73.533	-8.936	78.1	308.4	230.3	26.5
17	L2	0.08202356	1.290	1.098	6.6	357.0	350.4	3.6
la	S2	0.0s333331	19.821	-2.525	84.1	352.1	26S .1	76.2
19	ETA2	0.08507365	i. 028	-0.461	95.4	278.3	183.0	13.7
.20	M03	0.11924207	1.905	-0.115	70.3	112.1	41.7	182.4
21	113	0.12076712	1.271	-0.679	74.7	29.7	315.1	104.4
22	MK3	0.12229216	2.642	-0.081	84.6	145.0	60.4	229.6
23	SK3	0.12511408	1 .306	-0.512	57.0	207.1	150.1	264.2
24	MN4	0.15951067	0.941	-0.658	92.7	161.7	69.0	254.4
25	M4	0.16102278	2.622	-1.012	65.7	179.0	113.3	244.6
26	SN4	0.16233259	0.362	-0.100	75.8	239.5	163.8	315.3
27	MS4	0.16384470	0.922	-0.193	77.2	215.0	137.s	292.3
28	S4	0.16666669	0.867	-0.400	9.6	23.6	13.9	33.2
29	2MK5	0.20280355	0.973	-0.022	10B. 1	304.2	196.1	52.2
30	2SK5	0.20844740	0.273	-0.148	44.3	175.9	131.6	220.2
31	2MN6	0.24002206	0.517	-0.007	158.6	194.8	36.2	353.4
32	M6	0.241S3417	0.833	-0.077	49a	101.3	S1.6	151.1
33	2MS6	0.24435616	0.593	-0.218	154.4	334.4	180.0	128.7
34	2SM6	0.24717808	0.384	-0.044	171.3	352.0	180.6	163.3
35	3MK7	0.28331494	0.s31	-0.118	149.4	109.0	319.5	258.4
36	M8	0.32204562	0.424	-0.178	4.3	328.9	324.7	333.2

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM

AMPLITUDES HAVE BEEN SCALED ACCORDING TO APPLIED FILTERS

STN: COOK INLET | LAT: 59 35 1.2 N
DEPTH: 52 M | LONG: 152 29 0.0 W
START: 500Z 14/ 6/84 | END: 2200Z 13/ 7/84

	NAME	FREQUENCY (CY/HR)	MAJOR (cm/s)	MINOR (CM/S)	INC	G	G+	G-
1	Zo	0.00000000	5.464	0.000	25.9	360.0	334.1	25.9
2	MSF	0.00282193	3.256	-1.136	110.4	248.8	138.4	359.2
3	2Q1	0.03570635	1. 04s	-0.400	55.8	343.4	287.6	39.2
4	Q1	0.03721850	1.980	-0.183	70.6	236.5	165.8	307.1
5	01	0.03873065	7.990	-0.067	69.0	220.4	151.4	289.4
b	NO1	0.04026860	0.679	0.122	120.4	323.8	203.4	84.2
7	K1	0.04178075	16.570	-3.415	78.0	238.6	160.7	316.6
8	J1	0.04329290	1.078	0.115	7.4	286.4	279.0	293.7
9	001	0.04483084	1.061	0.298	114.7	272.9	158.2	27.7
10	UPS1	0.04634299	0.429	-0.256	36.0	220.9	184.9	257.0
11	N2	0.07899922	13.229	-3.590	83.2	278.7	195.6	1.9
12	M2	0.08051139	59.845	-1.996	74.2	304.8	230.6	19.0
13	S2	0.08333331	14.814	-1.754	83.6	346.3	262.7	69.9
14	ETA2	0.08507365	1.108	-0.948	10.2	260.2	250.0	270.4
15	MO3	0.11924207	2.104	-0.622	62.2	112.4	50.2	174.7
16	M3	0.12076712	1.449	-0.530	59.0	53.7	354.7	112.7
17	MK3	0.12229216	2.352	-0.228	62.8	150.4	87.6	213.3
18	SK3	0.12511408	1.771	-0.904	67.8	213.9	146.1	281.8
19	MN4	0.15951067	1.277	-0.474	65.1	250.3	185.2	315.4
20	M4	0.16102278	1.528	-0.046	115.3	105.2	349.9	220.6
21	MS4	0.16304470	0.699	0.146	158.7	206.1	47.3	4.%
22	S4	0.16666669	0.088	-0.686	2.8	348.5	345.7	351.3
23	2MK5	0.20280355	1.314	0.168	83.1	296.9	213.8	20.0
24	2SK5	0.20044740	0.517	-0.106	21.9	200.9	179.1	222.8
25	2MN6	0.24002206	0.768	-0.380	97.5	310.0	212.5	47.5
26	M6	0.24153417	0.880	-0.106	14.8	40.9	26.1	55.7
27	2MS6	0.24435616	0.468	-0.309	133.8	314.6	180.7	88.4
28	2SM6	0.24717808	0.532	-0.065	4S.2	239.6	194.4	284.9
29	3MK7	0.28331494	0.692	-0.296	167.5	116.8	309.3	284.4
30	me	0.32204562	0.439	-0.298	55.8	287.3	231.5	343.1

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM

AMPLITUDES HAVE BEEN SCALED ACCORDING TO APPLIED FILTERS

STN: SANAK LAT : S4 35 15.0 N

DEPTH : 20 M LONG: 162 43 46.2 W

START: 1200Z 16/ 6/84 END: 300Z 13/ 8/84

	NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
1	ZO	0.00000000	2.261	0.000	15.7	160.0	164.3	195.7
2	MM	0.00151215	0.426	0.084	94.4	173.3	78.9	267.8
3	MSF	0.002S2193	2.939	-0.146	0.9	146.9	146.0	147.8
4	ALP1	0.03439657	0.527	0". 040	18.6	84.1	65.5	102.7
5	2Q1	0.035?0635	0.469	0.091	64.3	117.5	53.3	181.8
6	Q1	0.03721S50	0.251	-0.019	54.8	227.3	172.5	282.0
7	01.	0.03S73065	2.2S5	-1.082	176.8	104.7	287.9	281.5
8	NO1	0.04026860	0.480	-0.077	94.7	35.3	300.6	130.0
9	K1	0.04178075	3.981	-1.997	166.9	145.2	338.3	312.1
10	J1	0.04329290	0.726	-0.440	10.2	349.9	339.6	0.1
11	001	0.044830s4	0.232	0.197	41.6	38.9	357.3	80.5
12	UPS1	0.04634299	0.345	0.004	32.5	344.0	311.4	16.5
13	EPS2	0.07617730	1.098	-0.810	4.2	112.7	108.5	116.9
14	MU2	0.07768947	0.420	-0.150	12.1	97.9	70.8	95.0
15	N2	0.07899922	0.6S4	-0.261	89.9	269.0	179.1	359.0
16	M2	0.08051139	3.121	0.469	112.8	285.1	172.3	37.9
17	L2	0.08202356	0.984	0.133	65.3	341.8	276.5	47.1
18	52	0.08333331	1.091	-0.110	76.6	335.5	258.9	52.1
19	ETA2	0.08507365	0.403	-0.033	56.0	213.8	157.s	269.8
20	MO3	0.11924207	0.231	0.035	91.2	186.5	95.3	277.7
21	M3	0.12076712	0.153	-0.032	3.8	355.3	351.5	359.2
22	MK3	0.12229216	0.324	-0.227	138.6	237.0	98.4	15.5
23	SK3	0.12511400	0.237	0.001	125.9	195.3	69.5	321.2
24	MN4	0.15951067	0.247	0.013	77.5	29S.1	217.6	12.6
25	M4	0.1610227B	0.255	-0.045	20.2	117.8	97.6	138.0
26	SN4	0.16233259	0.068	-0.040	23.1	104.3	161.2	207.4
27	MS4	0.16384470	0.218	-0.133	149.1	30.3	241.1	179.4
20	S4	0.16666669	0.239	-0.025	94.1	231.3	137.2	325.4
29	2MK5	0.202S0355	0.092	0.064	75.1	344.7	269.7	59.8
30	2SK5	0.20844740	0.131	0.060	168.8	25S.3	86.5	64.0
31	2MN6	0.24002206	0.204	0. 0s0	70.3	46.2	335.9	116.5
32	M6	0.24153417	0.349	0.086	108.5	104.4	355.9	212.9
33	2MS6	0.24435616	0.323	-0.023	39.2	100.6	61.3	139.8
34	2SM6	0.24717808	0.127	0.007	179.6	246.0	66.5	65.6
35	3MK7	0.20331494	0.168	-0.042	57.0	208.8	151.7	265.8
36	M8	0.32204562	0.050	-0.004	76.4	141.7	65.3	218.1

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM

AMPLITUDES HAVE BEEN SCALED ACCORDING TO APPLIED FILTERS

STN:	SANAK	LAT:	54 35 15.0 N
DEPTH:	41 M	LONG:	162 43 46.2 W
START:	1200Z 16/ 6/84	END :	2002 13/ 8/84

		FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
1	Zo	0.00000000	3.086	0.000	150.8	360.0	209.2	150.8
2	MM	0.00151215	1.195	-0.687	14S.6	307.9	162.3	93.5
3	MSF	0.00282193	1.414	0.176	170.3	329.5	159.2	139.9
4	ALP1	0.03439657	0.421	-0.306	86.3	296.9	210.6	23,3
5	2Q1	0.03570635	0.32,?	-0.016	9.1	154.6	145.5	163.7
6	Q1	0.03721850	0.659	-0.023	33.7	284.4	250.7	318.1
7	01	0.03873065	3.465	-0.904	1.0	274.4	273.4	275.4
8	NO1	0.04026860	0.544	0.063	12.6	325.2	312.6	337.8
9	K1	0.04178075	7.146	-3.135	165.6	135.7	330.2	301.3
10	J1	0.04329290	1.040	-0.267	160.3	168.7	8.4	328.9
11	001	0.044830s4	0.754	-0.216	163.7	152.4	348.7	316.0
12	UPS1	0.04634299	0.271	-0.057	125.2	213.9	88.7	339.0
13	EPS2	0.07617730	0.624	0.063	5.9	285.7	279.8	291.6
14	MU2	0.07768947	0.470	-0.125	16.9	25.5	74.8	112.5
15	N2	0.07899922	0.786	-0.4S6	64.3	238.5	174.3	302.8
16	M2	0.08051139	4.121	1.0?7	89.6	252.6	163.0	342.3
17	L2	0.08202356	0.731	-0.162	98.1	91.0	352.9	189.1
18	S2	0.08333331	1.476	-0.607	30.1	267.4	237.4	297.5
19	ETA2	0.08507365	0.056	0.023	164.1	14.6	210.5	178.8
20	MO3	0.11924207	0.402	-0.135	153.0	256.5	103.5	49.5
21	M3	0.12076712	0.117	-0.065	76.5	9.2	292.8	85.7
22	MK3	0.12229216	0.394	-0.063	89.0	293.6	204.6	22.5
23	SK3	0.12511408	0.314	-0.108	9.0	99.0	89.9	108.0
.24	MN4	0.15951067	0.322	-0.089	35.9	158.8	122.9	194.7
25	M4	0.1610227B	0.110	-0.011	65.1	52.3	347.2	117.4
26	SN4	0.16233259	0.180	0.068	55.7	162.1	106.5	217.8
27	MS4	0.16384470	0.123	0.004	112.0	140.9	28.9	252.9
28	S4	0.16666669	0.190	0.145	11.7	125.4	113.7	137.1
29	2MK5	0.20280355	0.244	-0.030	16.2	50.6	34.4	66.8
30	2SK5	0.20S44740	0.082	-0.037	94.3	95.7	1.4	189.9
31	2MN6	0.24002206	0.333	-0.027	118.6	133.4	14.8	252.0
32	M6	0.24153417	0.271	0.195	85.0	107.0	22.0	192.0
33	2MS6	0.24435616	0.296	-0.037	72.0	163.2	91.2	235.2
34	2SM6	0.24717808	0.058	0.033	96.8	292.4	195.5	29.2
3S	3MK7	0.2S331494	0.110	0.031	85.2	197.0	111.8	282.2
36	M8	0.32204S62	0.118	-0.031	110.3	272.9	162.6	23.2

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM
AMPLITUDES HAVE BEEN SCALED ACCORDING TO APPLIED FILTERS

STN: SHELIKOF STRAIT LAT: 57 39 0.0 N
DEPTH: 46 M LONG: 155 3 19.8 W
START: 23002 14/ 6/84 END: 1200Z 10/ 8/84

	NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
1	ZO	0.00000000	3. 839	0.000	59.8	180.0	120.2	239a
2	MM	0.00151215	12.868	5.271	116.3	261.9	145.7	18.2
3	MSF .	0.00282193	5.479	-0.565	28.5	223.2	194.7	251.6
4	ALP1	0.03439657	0.531	0.356	45.6	161.5	115.9	207. i
5	2Q1	0.03570635	0.741	0.473	5.2	39.0	33a	44.1
6	Q1	0.03721850	0.978	0.273	104.6	299.5	195.0	44.1
7	01	0.03873065	i .754	-0.126	3s.9	227. i	188.2	266.0
8	NO1	0.04026S60	0.429	-0.014	119.5	25.3	265.8	144.7
9	K1	0.04178075	3.449	0.076	41.3	243.6	202.4	284. 9
10	J1	0.04329290	0.616	-0.240	99.4	330.9	231.5	70.3
11	001	0.04483084	0. 252	0.044	44.6	135.1	90.4	179.7
12	UPSI	0.04634299	0.199	0.106	145.8	174.8	29.0	320.6
13	EPS2	0.07617730	0.873	0.833	5.7	331.7	326.1	337.4
14	MU2	0.07768947	0.979	-0.165	31.1	228. 7	197.6	[illegible]
15	N2	0.07899922	2.529	0.692	3a.5	230.2	191.7	26a. 7
16	M2	0.08051139	13.766	-0.023	39.9	250.7	210.9	290.6
17	L2	0.00202356	2.234	0.772	119.5	156.9	37.4	276.5
18	S2	0.08333331	4.S16	-0.032	41.2	297. i	255.9	33a. 3
19	ETA2	0.08507365	1.105	0.417	ass	221. a	136.3	307.2
20	M03	0.11924207	0.292	0.249	125.3	137.4	12.1	262.7
21	M3	0.12076712	0.47s	0.040	143.8	269.2	125.4	53.1
22	MK3	0.12229216	0. 306	-0.031	11.5	126.0	114.6	137.5
23	SK3	0.12511408	0.191	0.064	25.4	155.0	129.6	180.5
24	MN4	0.15951067	0.289	0.019	171.3	253.5	82.2	64.9
25	M4	0.16102278	0.s27	0.118	13.3	34a. 0	334.7	1.3
26	SN4	0.16233259	0.374	-0.117	110.8	289. i	178.3	40.0
27	MS4	0.16384470	0.351	0.032	7.5	0.5	353.0	8.0
28	S4	0.16666669	0.347	0.257	157.4	171.8	14.4	329.2
29	2MK5	0.20280355	0. 386	0.136	170.2	315.9	145.6	126.1
30	2SK5	0.20844740	0.206	0. 03s	95.1	223.7	128.6	318.8
31	2MN6	0.24002206	0.141	0.073	123.6	196.4	72a	320.0
32	M6	0.24153417	0.132	-0.060	104.5	293.9	189.4	38.5
33	2MS6	0.24435616	0.212	0.11s	177.4	157.8	340.4	335. i
34	2SM6	0.24717800	0.239	0.158	57.7	252.9	195.2	310.5
35	3MK7	0.28331494	0.307	-0.007	73.6	337.1	263.5	50.7
36	M8	0.32204562	0.170	0.087	109.3	33.1	283.9	142.4

Dobrocky SEATECH

GULF OF ALASKA

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM

AMPLITUDES HAVE BEEN SCALED ACCORDING TO APPLIED FILTERS

STN: SHELIKOF STRAIT — LAT: S7 39 0.0 N

DEPTH: 1s7 M — LONG: 155 3 19.8 W

START: 2300Z 14/ 6/84 — END: 1200Z 10/ 8/84

	NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
1	ZO	0.00000000	1.343	0.000	S2.6	360.0	307.4	S2.6
2	MM	0.00151215	5.314	2.274	123.6	263.7	140.1	27.3
3	MSF	0.00282193	4.241	-1.419	48.3	205.2	157.0	253.5
4	ALP1	0.03439657	0.245	0.011	151.7	104.5	312.8	2S6 .2
s	2Q1	0.03s7063s	0.241	0. 080	80.6	18.9	298.2	99.s
6	Q1	0.03721850	0.514	0. 277	103.9	299.9	196.1	43.s
?	O1	0.03873065	1.496	-0.061	49.4	20s. 1	155.7	2S4. 5
8	NO1	0.04026860	0.241	0.121	161.S	80.5	279.0	242.0
9	K1	0.04178075	2. 9S6	-0.140	47.9	226.4	178.5	274.3
10	J1	0.04329290	0.396	-0.006	132. 1	342.2	210.1	114.3
11	001	0.044030s4	0.285	-0.013	94.8	239.6	144.8	334.4
12	UPS1	0.04634299	0.301	0.090	155.2	209.8	S4.5	5.0
13	EPS2	0.07617730	0.591	0.260	141.3	317.0	175.7	98.3
14	MU2	0.07768947	0. 482	0.349	53.2	147.0	93.9	200.2
15	N2	0.07699922	3.111	1.006	4s.s	233.4	[illegible]	279.2
16	M2	0.080s1139	14.670	0.598	43.0	248.2	205.2	291.3
17	L2	0.0S2023S6	1. 72S	0.210	119.2	138.4	19.2	2S7. 6
18	S2	0.00333331	4.333	0.141	46.8	296.0	249.2	342.8
19	ETA2	0.08507365	0.602	-0.114	49.3	269.9	220.5	319.2
20	MO3	0.11924207	0.308	0.068	45.0	136.3	91.3	181.3
21	M3	0.12076712	0.251	0.008	87.5	2S9. 9	172.4	347.4
22	MK3	0.12229216	0. 496	-0.073	30.1	164.3	134.2	194.4
23	SK3	0.12S11400	0.246	-0.144	170.0	66.2	256.2	236.1
24	MN4	0.15951067	0.208	0.150	33.1	204.0	170.9	237.2
25	M4	0.16102278	0.307	0.014	114.4	299.6	185.2	54.0
26	SN4	0.16233259	0.169	-0.019	175.4	7.5	192.1	183.0
27	MS4	0.16304470	0.239	0.043	108.3	6.3	258.0	114.6
28	54	0.16666669	0.205	0.100	46.1	220.3	174.2	266.3
29	2MK5	0.2028035S	0. 187	0. 03B	42.S	114.6	72.1	1s7. 1
30	2SK5	0.20044740	0. 12s	0.057	90.7	96.5	5.8	187.1
31	2MN6	0.24002206	0. 141	0.054	12.0	10.4	358.5	22.4
32	M6	0.24153417	0.103	-0.060	53.4	313.s	260.2	6.9
33	2MS6	0.24435616	0.111	-0.010	163.9	246.3	82.4	50.3
34	2SM6	0.24717808	0.111	0.071	18.5	306.2	287.7	324.7
35	3MK7	0.20331494	0.156	0.050	27.5	3s9. 7	332.2	27.3
36	M8	0.32204562	0.098	-0.009	68.3	31.0	322.7	99.3

Dobrocky SEATECH

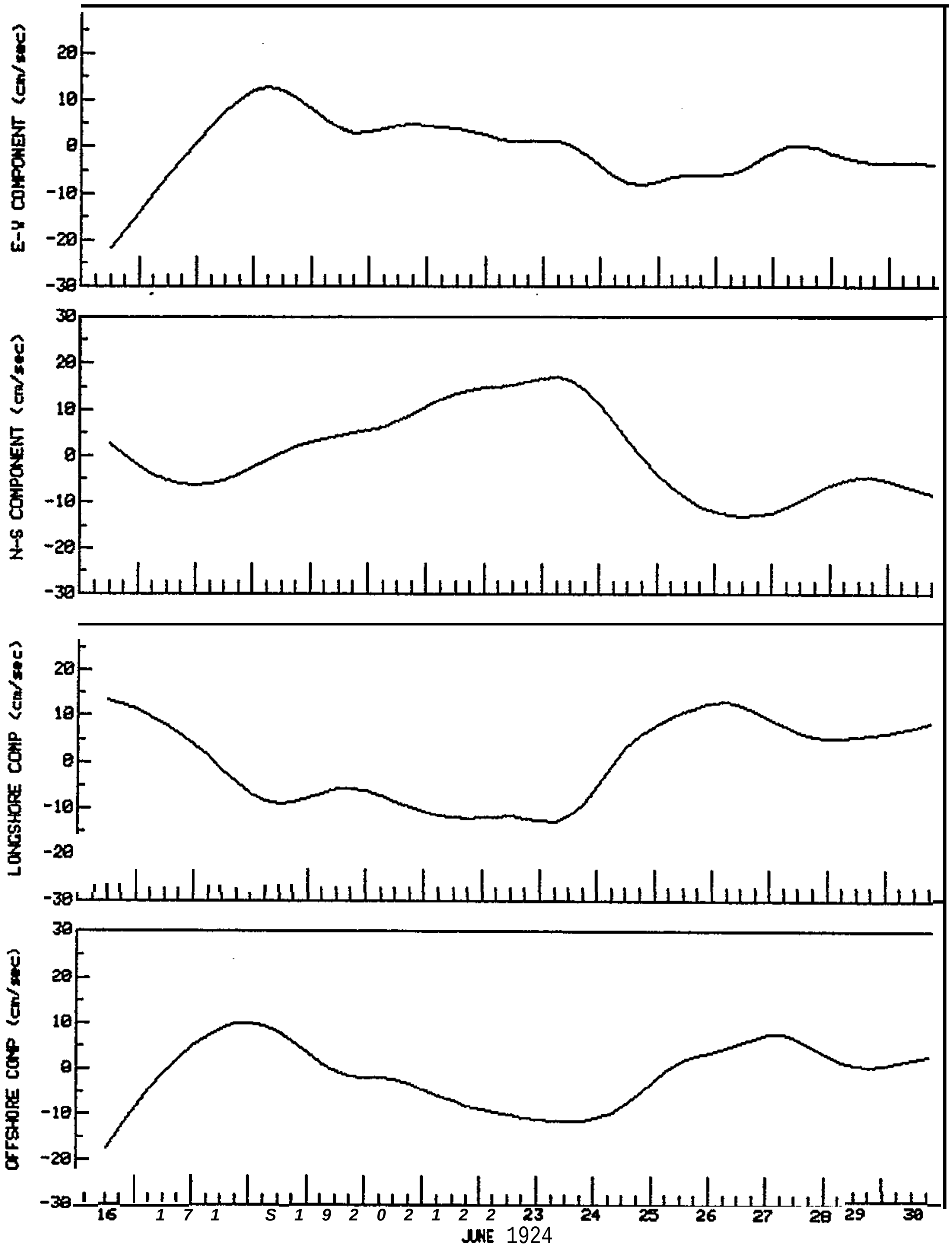
Time series filtered velocity geostrophic wind, surface wind stress

Appendix 2

TIME SERIES OF U, V AND LONGSHORE, OFFSHORE COMPONENTS

SHELIKOF STRAIT METER 3127 DEPTH(m) 46 TYPE FILTERED

57 39' 00"N 155 03' 19. 8"W AANDERAA RCM DT(min) 360

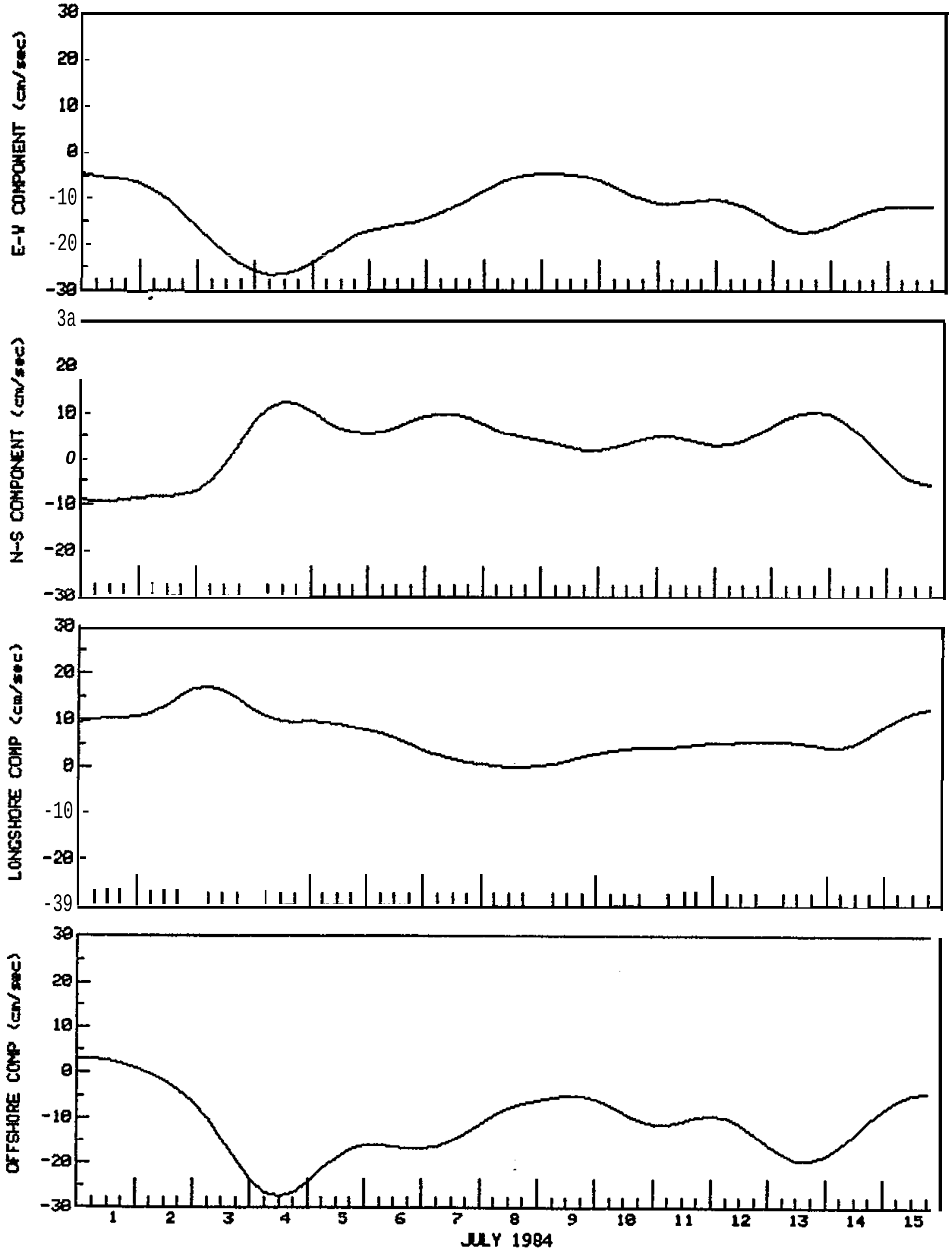


Dobrocky SEATECH

TIME SERIES OF U, V AND LONGSHORE, OFFSHORE COMPONENTS

SHELIKOF STRAIT　METER 3127　DEPTH(m) 46　TYPE FILTERED

57 39' 00"N　155 03' 19.8"W　AANDERAA RCM　DT(min) 360



Dobrocky SEATECH

TIME SERIES OF U, V AND LONGSHORE, OFFSHORE COMPONENTS

SHELIKOF STRAIT METER 3127 DEPTH (m) 46 TYPE FILTERED

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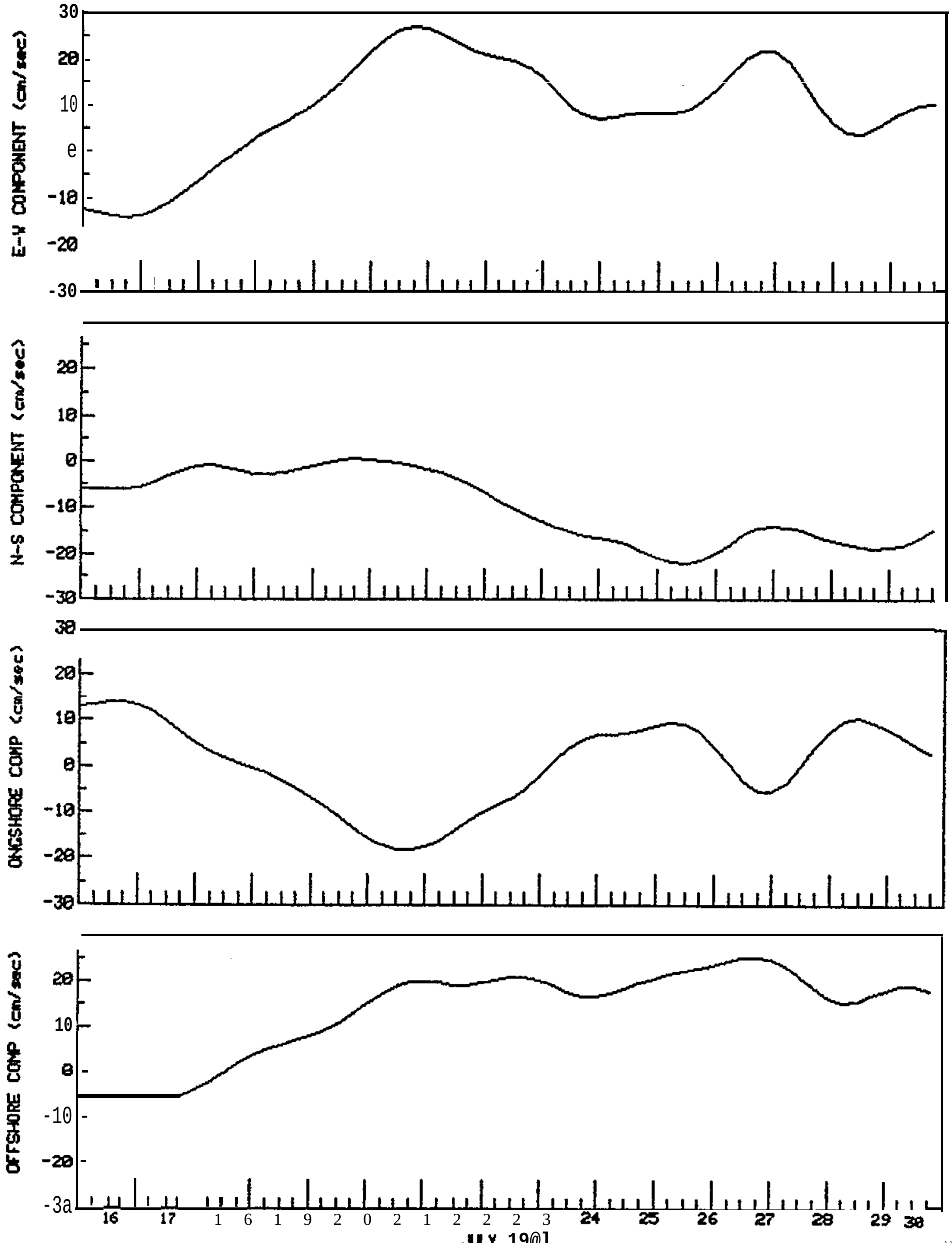
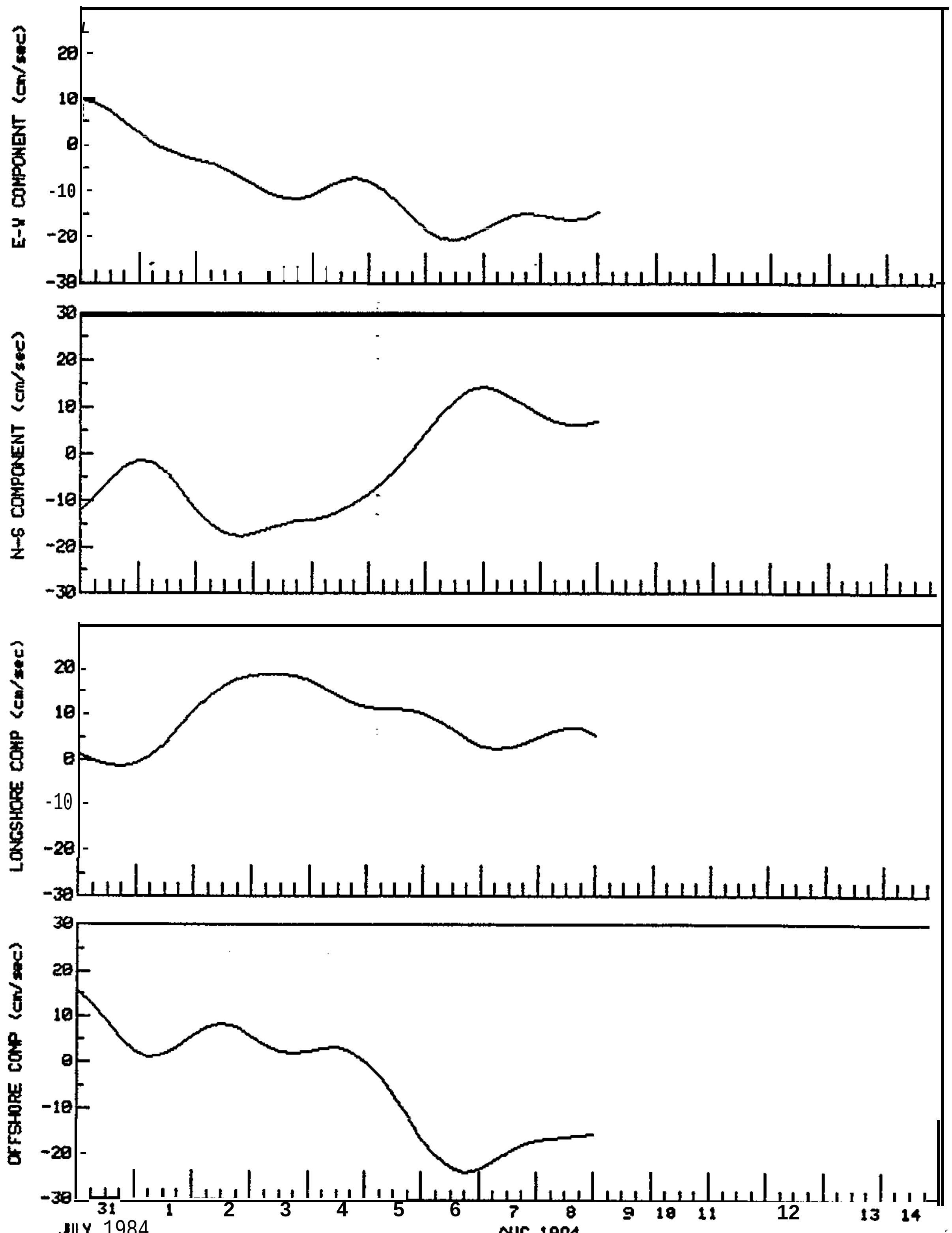


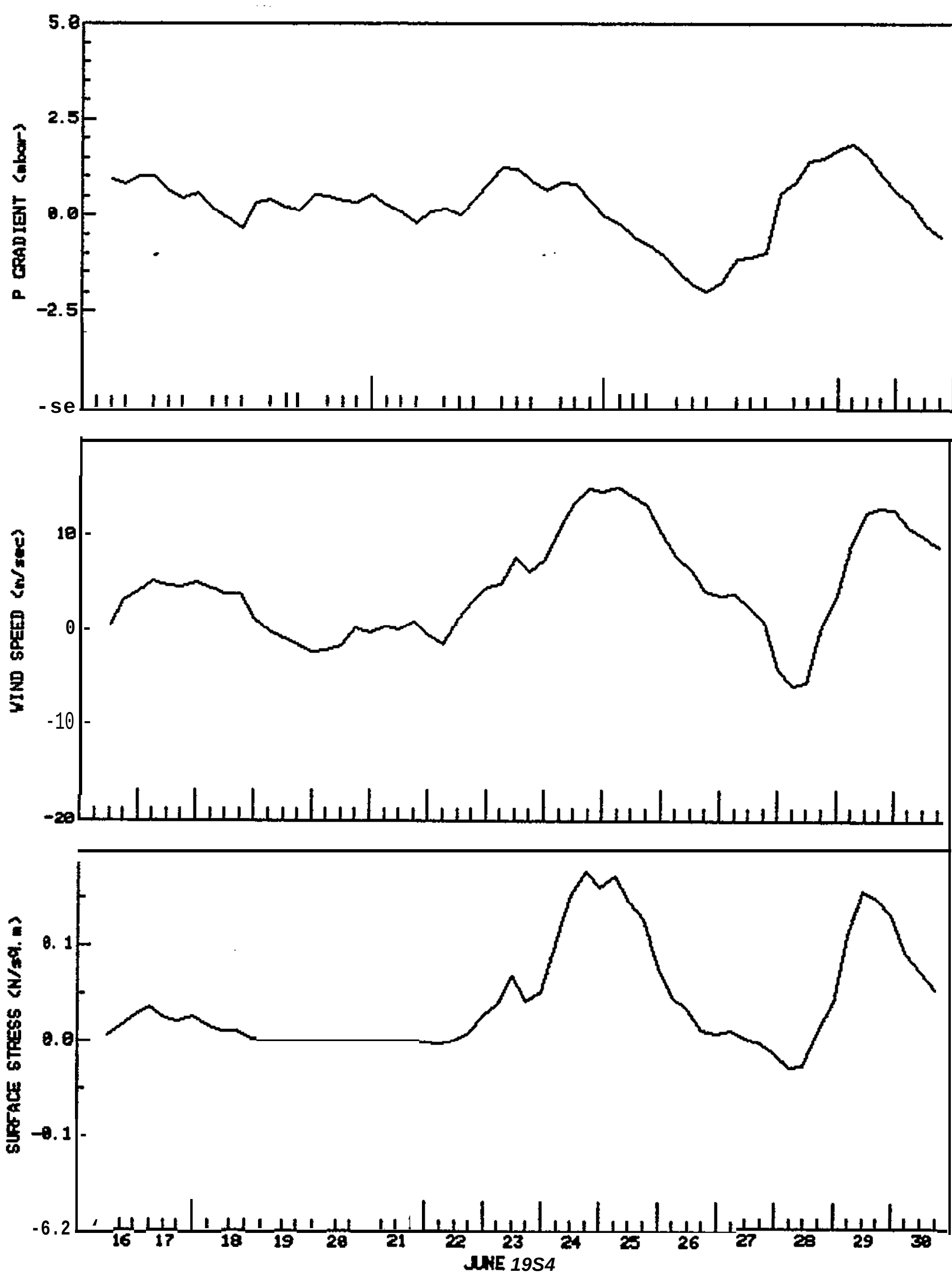
Dobrocky
SEATECH

TIME SERIES OF U, V AND LONGSHORE> OFFSHORE COMPONENTS
SHELIKOF STRAIT METER 3127 DEPTH(m) 46 TYPE FILTERED
57 39' 00"N 155 03' 19.8"W AANDERAA RCM DT(min) 360



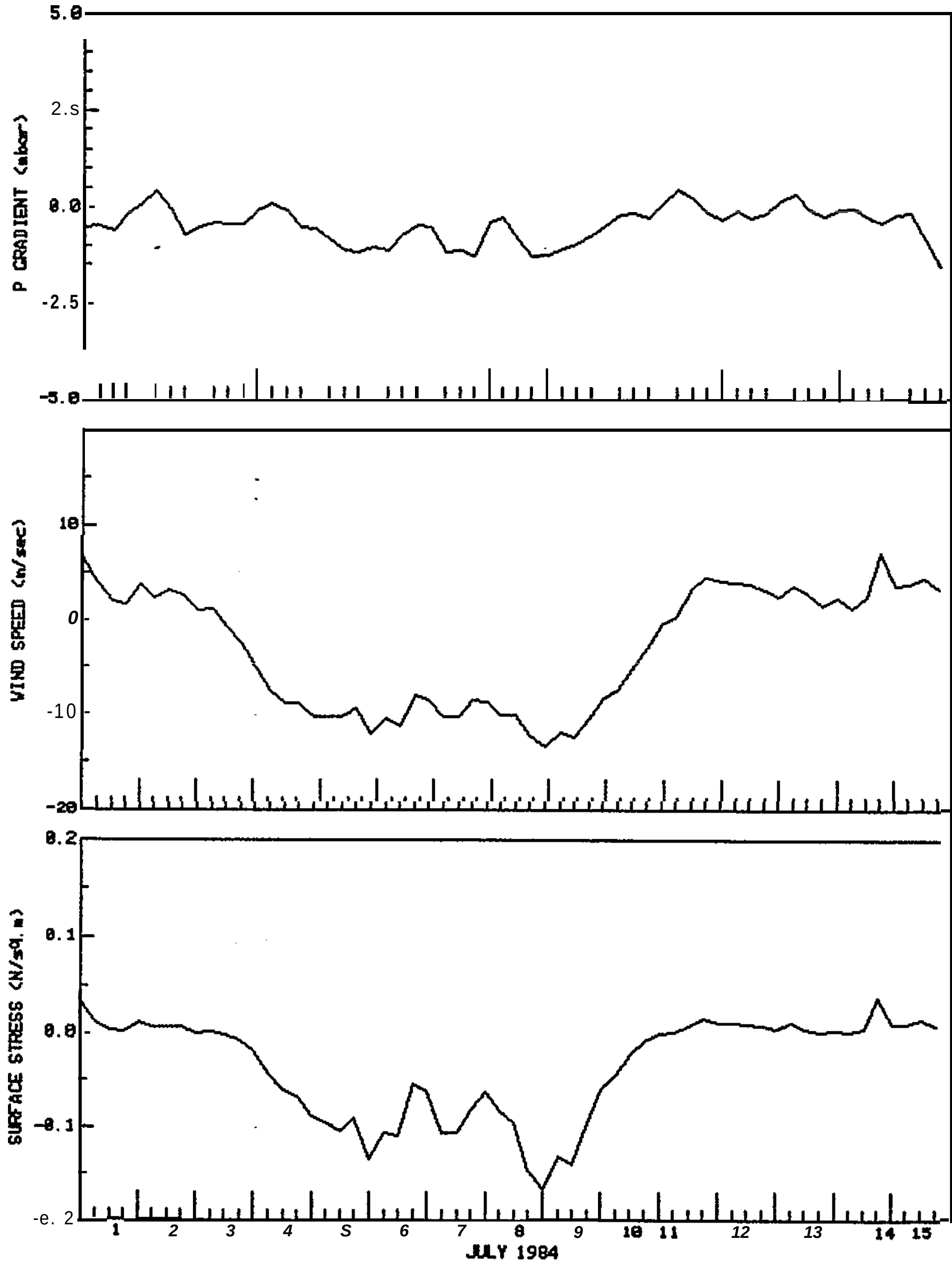
Dobrocky SEATECH

TIME SERIES OF OFFSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
SHELIKOF STRAIT DT(min) 3613



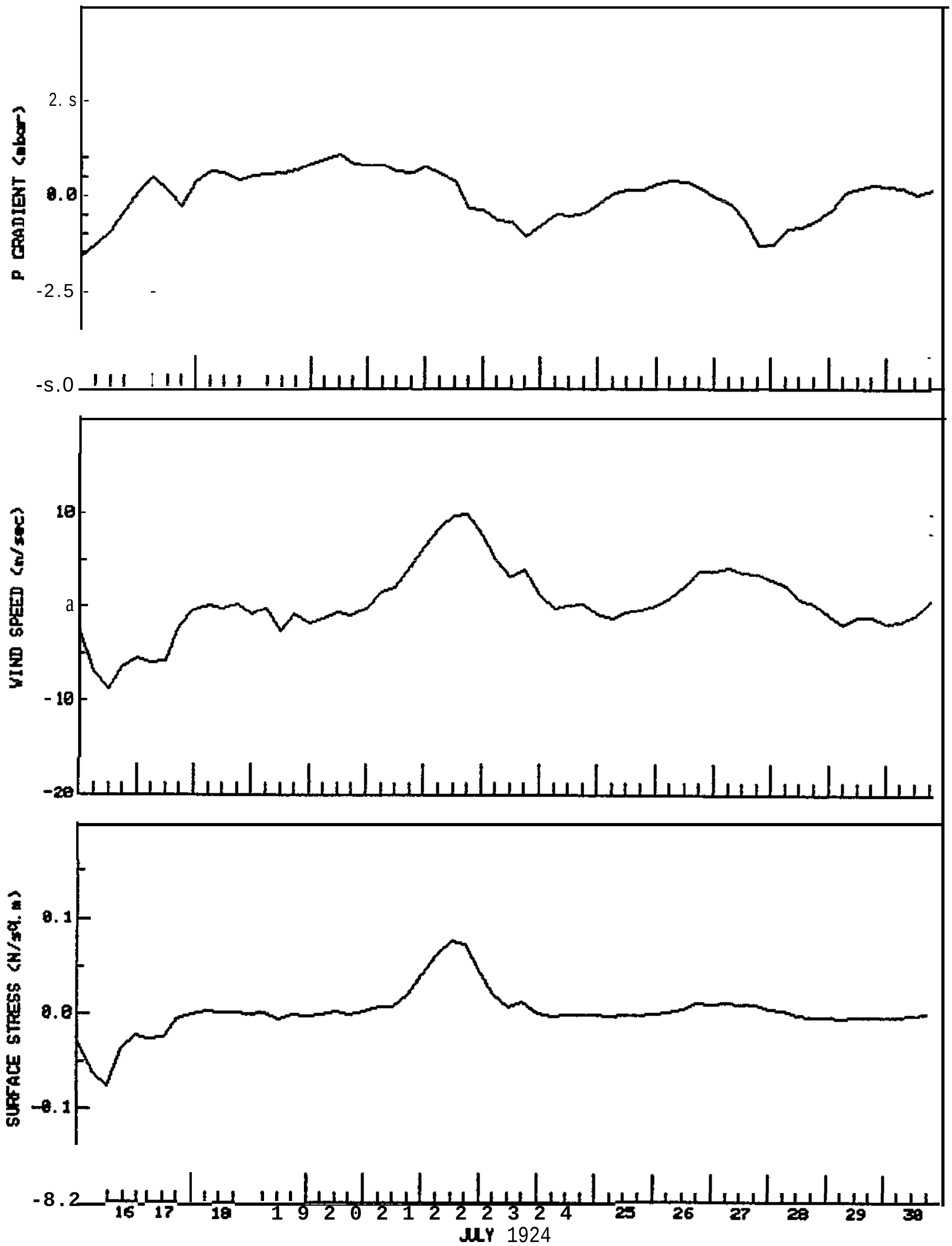
Dobrocky SEATECH

TIME SERIES OF OFFSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND FIND SURFACE WIND STRESS
SHELIKOF STRAIT DT(min) 360

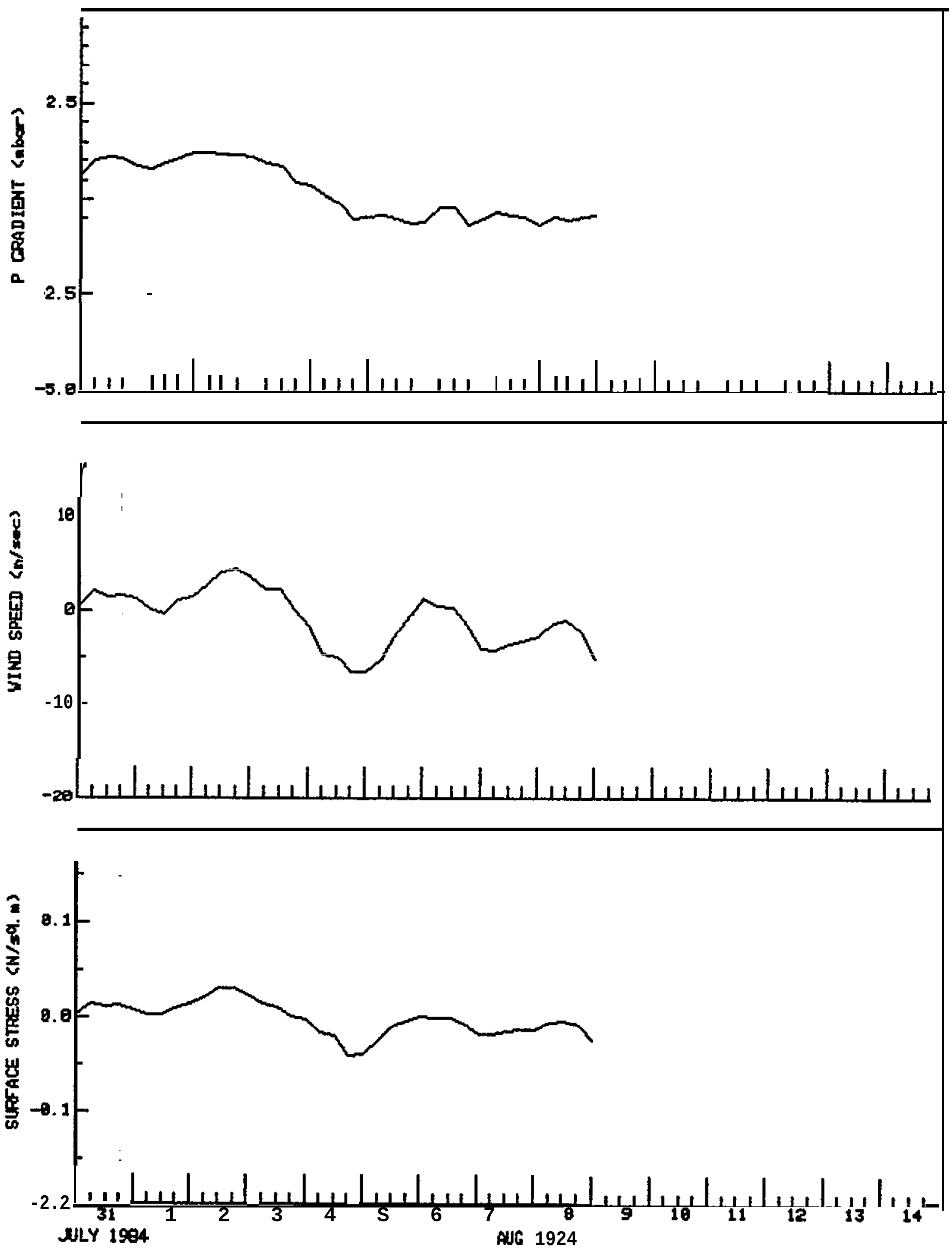


Dobrocky SEATECH

TIME SERIES OF OFFSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
SHELIKOF STRAIT DT(min) 360

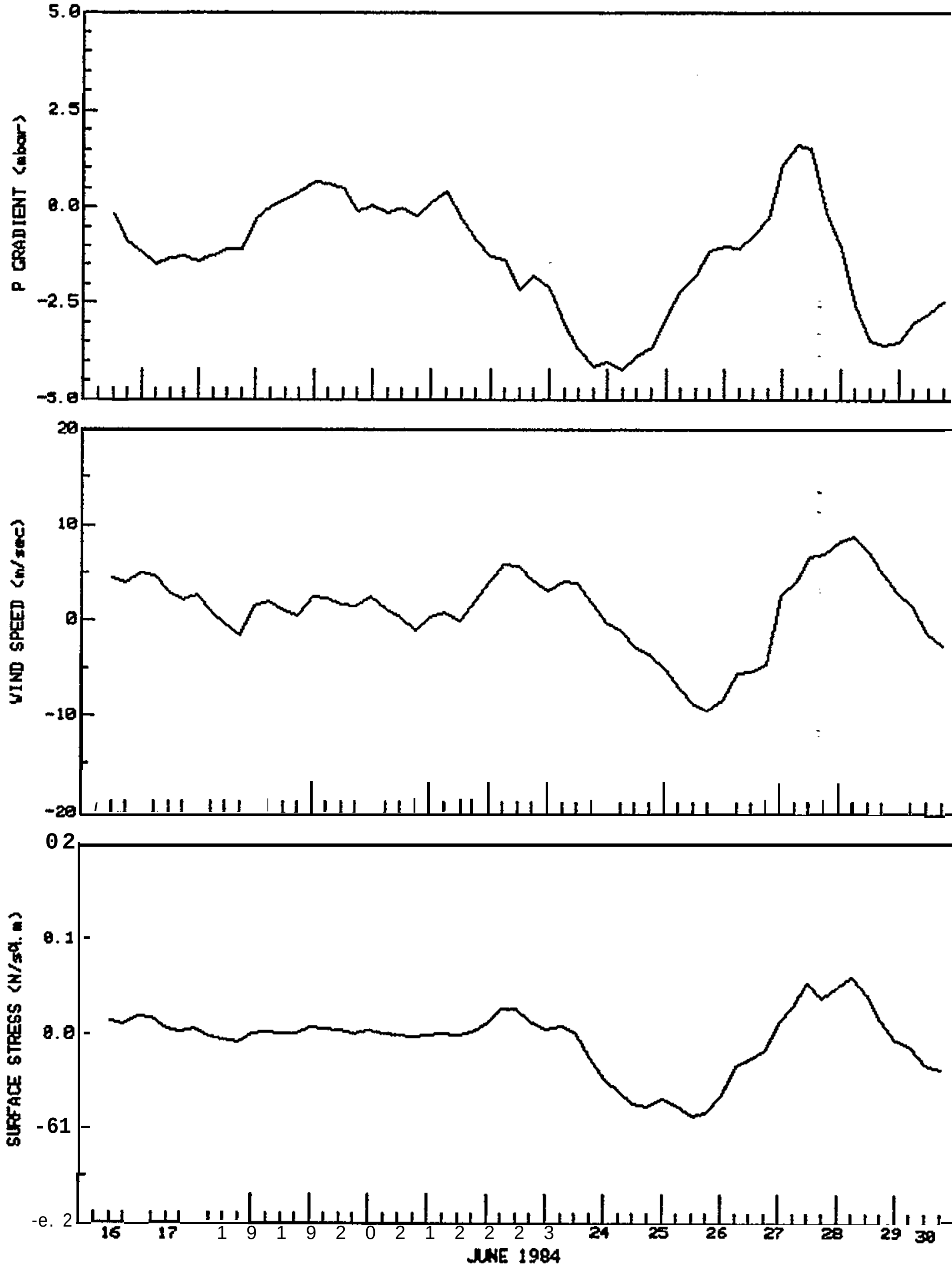


TIME SER [ES OF OFFSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND FIND SURF(Y2E WI ND STRESS
SHELIKOF STRAIT DT(min) 360



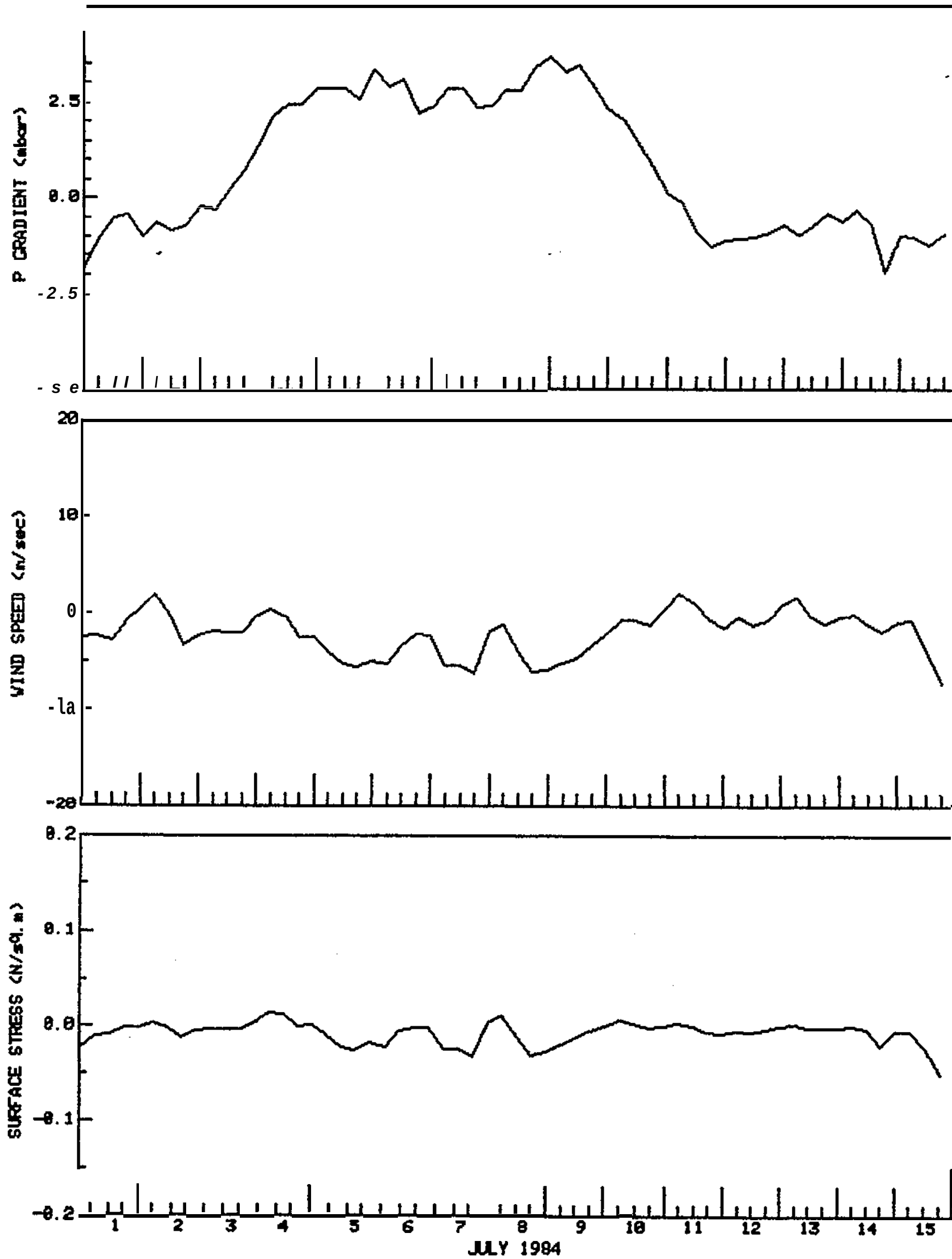
Dobrocky SEATECH

TIME SERIES OF LONGSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
SHELIKOF STRAIT DT(min) 360



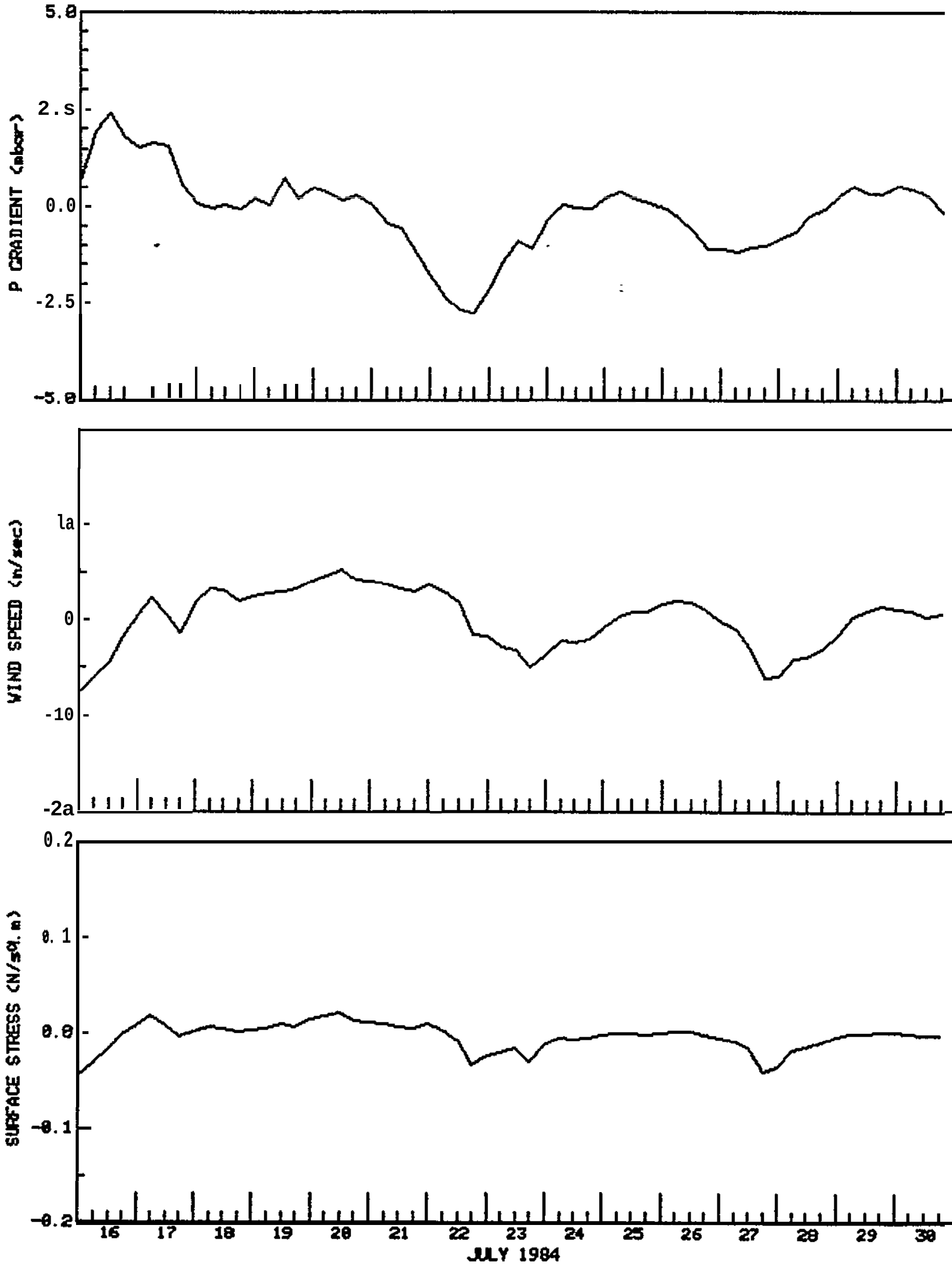
Dobrocky SEATECH

TIME SERIES OF LONGSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
SHELIKOF STRAIT DT(min) 360



Dobrocky SEATECH

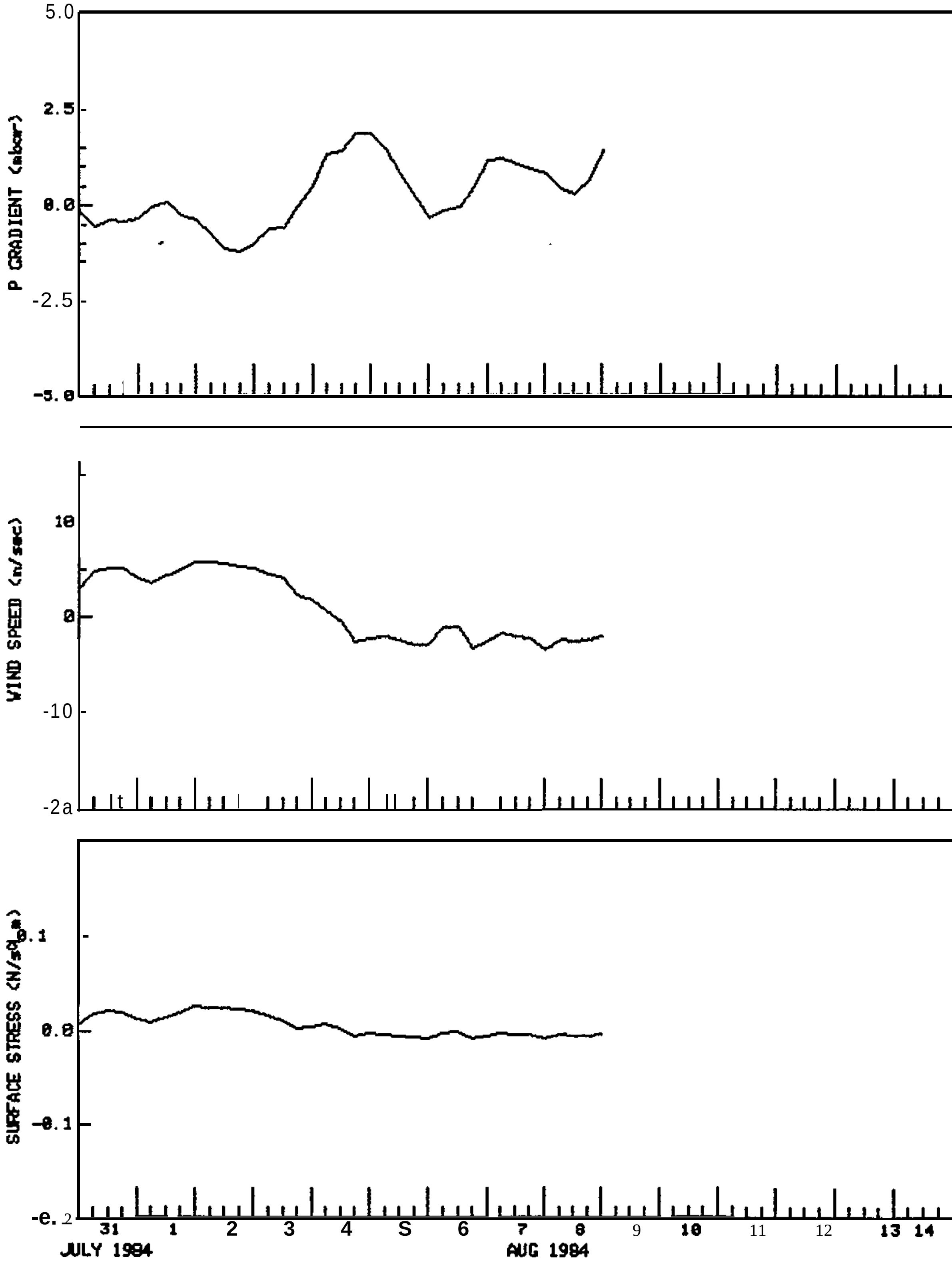
TIME SERIES OF LONGSHORE COMPONENT OF
PRESSURE GRADIENT, , GEOSTROPHIC WIND AND SURFACE WIND STRESS
SHELIKOF STRAIT DT(min) 360



Dobrocky
SEATECH

TIME SERIES OF LONGSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS

SHELIKOF STRAIT DT(min) 360



Dobrocky
SEATECH

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Calgary, Alta. T2R 0E4
(403) 231-9494

GE-AK 86

4507

RU 663

REMOTE SENSING DATA ACQUISITION, ANALYSIS AND ARCHIVAL

FEB 1987 RECEIVED

AK - OCSEAP

REMOTE SENSING

by

William J. Stringer

1/4/88

FOURTH QUARTERLY REPORT

October 1 - December 31, 1986

OCSEAP Research Unit ~~267~~ 663

Submitted to

National Oceanic & Atmospheric Administration
Ocean Assessments Division
Alaska Office
PO Box 56
Anchorage, Alaska 99513

February 1987

Geophysical Institute
University of Alaska
Fairbanks, Alaska 99775-0800

FOURTH QUARTERLY REPORT
October 1 - December 31, 1986
OCSEAP Research Unit 267
Contract #50ABNC 600041

ACTIVITIES THIS QUARTER

1. Assistance to RU 625 (J. Brueggeman) . This study occupied the bulk of our activities during this quarter. The work consisted of providing ice-related data which could be usad in conjunction with Brueggeman's whale sightings in the Bering Sea. The whale sightings (about 3, 000) have been coded in terms of latitude and longitude. The objective of our efforts was to provide data which could be used to determine whether a meaningful statistical relationship could ba found between these sightings and ice parameters such as concentration, type (thickness) and ice edge location (including polynya boundaries) .

Fortunately the software which had been developed for our ongoing polynya analysis as well as some of the digital polynya boundaries could be used for this analysis. However, it was necessary to digitize additional data from the years already analyzed as well as data from years which had not yet been digitized for polynya analysis.

Specifically, the newly digitized data consisted of the following:

1. Data for the Anadyr Polynya was added. We had not previously digitized this polynya because it lies beyond the NOAA-OCSEAP O .S. study area. However, the whales are international travelers so this data set needed to be added. Data for January, February, March and April of 1978 and 19S3 were added to existing files and new files were created for data for January 1986.

2. The Bering Sea ice edge far January, February, March, and April of 1979 and 1983 was added mostly to existing files. However, for a few dates new files were created. Entirely new files were created for January 1986.

Material delivered to Brueggemen at the end of this quarter consisted of:

1) Magnetic tape captaining all files of Bering Sea ice and Anadyr, St. Lawrence Island, and St. Matthews Island polynyas.

2) Print-out maps of the data set described in 1) above.

3] Tabular print-outs of areal extent and perimeter lengths of polynyas listed above as well as other polynyas which occasional 1 y occur within the study area.

4) Tabular evaluation of ice conditions at 113 specified locations representing whale sightings and locations of no whale evidence. (This was essentially a trial run for a larger follow-on project which is described in "Next Quarter Activities. "

The above materials were delivered to Brueggeman's research unit during an on-site working visit by Richard Grotefendt, Brueggeman's assistant.

2. Polynya Analysis. Despite the diversion of effort to the whale studies, some progress was reads in the study of polynya size. Three additional years' data were digitized: 1977, 1979, and 1983, including the Anadyr pol ynya. In addition, the Anadyr polynya was added to the data for 1975 and 1986. Our previous work on the statistics of the Chukchi Sea resulted in tbe identification of 1979 and 1983 as relative maximum and minimum years of open water. Hence these are interesting years' data for comparison purposes.

Although we have not yet digitized all the years' data available to us, we decided to at least start examining the results in order to begin identifying the most useful and meaningful analysis functions. As a first step in this direction it was determined to calculate median polynya values for four major polynya systems as a function of month.

This has turned out to be a useful exercise because we have had to confront several concepts related to polynyas. As a background, it is instructive to first consider the World Meteorological Organization definition of a polynya - "an irregularly shaped opening enclosed by ice. As opposed to a fracture, the sides of a polynya could not be refitted to form a uniform ice sheet. Polynyas may contain brash ice or uniformly thinner ice than the surrounding ice. " Thus, areas of thin ice surrounded by thicker ice may be considered pol ynyas. Very often on satellite imagery polynyas can be seen with areas of obviously open water general 1 y surrounded by ice but on the down-wind side the transition f rom water to ice is often fairly uniform and it is difficult to determine where to draw the polynya boundary in this area. We have taken the boundary to be the transition between dark gray and light gray (an ice thickness of around 10cm) . However, in many cases this determination is a bit arbitrary. In any case, this is the definition we have used in determining what constitutes a polynya.

The size of polynyas is interesting from the consideration of salt and energy budgets for tbe water bodies which contain them. And, if one is considering the long term effects of these phenomena polynya size as a function of time is a critical measure. However, satellite measurements that depend on cloud-free conditions are by nature irregular in frequency and therefore, same scheme must be utilized to transform measurements made at irregular intervals into measures at regular intervals.

One logical approach to this transformation is to determine a measure of a central tendency far the quantity in question over periods sufficiently long to contain several measurements but sufficiently short to represent a characteristic period of time. In our case, we chose a month as a characteristic period, implying that any one measure within the month was as good as any other (i .e. statistical trends of less than a month's duration are **not** significant) . Of course there is another tacit understanding here; that each measure is statistically independent. To accomplish this, the measurements should be sufficiently separated that they da not essential ly represent two measures of the same value. The satellite data are inherently separated by one day at a minimum. Although we have assumed that this is sufficient temporal separation for an independent measurement, we may need to address this question in detail later.

The next **topic for consideration is the measure of central tendency to be employed. Of the three, average, median and** mode, we chose median for the following reasons. In some cases polynyas join to the open ocean or other polynyas for a while. What is their area then, and what does "area" mean in this case? The polynyas can 't be ignored in these cases and therefore simply deleting the observation f ram the data set is statistically unsound. On the other hand, so is adding an arbitrari ly large number to a set to be averaged. For this reason we did not take an average value. Mode is difficult to determine for a limited data set and would tend to emphasize values from strings of data from short time periods within the month - just the sort of data we would wish to reemphasize. Median values on the other hand, are not unduly influenced by a few arbitrarily large values at one end of the data set and tend to deemphasize the importance of continuous strings of data (provided they are short compared to the entire data set) . 'Therefore, we have chosen to determine median monthly values of polynya sizes.

However, this is not the end of the need for definitions. We soon realized that "polynya size" means size of an existing polynya. Thus one could argue that times when the polynya location was frozen or the polynya open to the ocean on one side could arguably be deleted from the data set if one is interested in the actual size of the polynya. On the other hand, as a measure of a process such as salt rejection during freezing, the fact that the polynya is frozen over or completely open is of great importance. Therefore, for this pilot study, we calculated median polynya sizes based on both data set definitions. Finally, we have listed the maximum polynya size observed during each month to give come indication of the variability in polynya size which occurred during the month. These results are shown in Table I.

Table I lists polynya median sizes by month for 1974 (except January and February) , 1975, 1977, 1979, 1983 and 1986 using both data set definitions for median determination, and maximum polynya size for the first 6 months of each year. The polynyas 1 isted are defined by Table 2 and Figure 1.

Figure 1 is a map showing the approximate location of persistent polynyas in the study area where they are given letter designations. Table II is the key between the letter designations and the name given each polynya. However, two of the polynyas for which areas are listed in Table I are actually aggregate po lynyas compiled in order to give an idea of tbe total polynya areas in the study area. "St. Lawrence" is the sum of St. Laurence, North (E) and St. Lawrence, South (D) . (However, usually only one is open at a tine.) Norton Sound (K) is the single polynya at the eastern end of Norton Sound. Kotzebue (Q) is the polynya which occurs between pack ice and fast ice in outer Kotzebue Sound. Chukchi is the sum of Cape Lisburne - Paint Lay (T), Pt. Lay - Icy Cape (U) and Icy Cape - Pt. Barrow (V] . (Often these polynyas join to form a single polynya - this phenomenon occurs within a number of pol ynya systems, making the tracking of the size of a designated polynya a tricky matter.)

These data have not been analyzed further. Our plan is to perform a multivariate analysis of polynya sizes versus time.

3. Data Acquisition and Projects Conducted for OCSEAP Management. We have provided enhanced AVHRR imagery in the vicinity of Kotzebue Sound and in the Beaufort Sea to OCSEAP management. The letters of transmittal - attached as Appendix 1, describe this work.

4. Data Received and Archived. We have continued to obtain and archive dai ly NOAA AVHRR satellite imagery of the OCSEAP study areas around Alaska. Because of the three-to-four times daily coverage of Alaska by these satellites, we cannot possibly afford to purchase a copy of each at the $10.00 per copy rate charged. Thus we select only the best images (approximately three per day and purchase them in positive transparency format directly from the receiving station at Gilmore Creek) . (our experience has shown us that positive transparencies retain the highest information content for analysis and reproduction purposes of all data formats other than digital tapes.)

NOAA AVHRR

positive transparency format

In addition to the positive transparency format data, we also receive hard copy facsimile transmission positive prints that have been used by the weather service. There 1s a great quantity of these prints as they represent at least one copy of

hard copy facsimile transmission positive prints each day' 3image and sometimes digital enlargements and enhancements of particular areas. These are sent to us by the weather service about a month after they are transmitted from Gilmore Creek. We archive these data (although the image quality is considerably diminished from that of the positive transparency) because *some* feature of interest to OCSEAP investigators may be found on one of these images which did not appear on an image judged to be one of the day's "best" images. Following these criteria, we archived approximately 270 positive transparencies and 2700 positive facsimile prints this quarter.

Our "Quick-Look" ground station received a total of 66 images from Landsats 4 and 5. This relatively small data set is a result of cloudy weather in late fall and a conscious effort to obtain only useful (relatively cloud-free) imagery. These images are often digitally enhanced and enlarged with copies of these products archived as wel l as the standard 1: 1M scale print. In some instances we have obtained images at times when the sun was below the horizon - yet ice conditions are easily observed. This is an additional value of our ground station and image enhancement capability.

1 LANDSAT 4/5

We also continue to receive and archive the NOAA/NAVY ice **charts published weekly and the drifting** buoy data published monthly by the Polar Ocean Center in Seattle. Finally, this quarter we acquired Side-Looking Airborne Radar imagery of the Beaufort Sea as part of a data search (see Appendis II). Normally we only monitor the acquisition of this data because of its limited value and not so 1 imited expense.

1 ice charts

1 drifting buoy

S

ACTIVITIES NEXT QUARTER

1. Assistance to Brueggeman (RO 625). We are creating a program to distinguish whether a given station is within or outside a polynya from the digitized data. When completed, al 1 3000 nf Brueggeman's whale/no whale data wi 11 be tested for correlation with polynyas.

2. Polynya Analysis. We will continue our analysis of polynya data. Emphasis this quarter will be applied to determining trends and significance of polynya extent data similar to and including the data reported here in Table I.

3. Data Acquisition. We will continue to acquire and archive Landsat and AVHRR satel 1 ite imagery as well as NOAA/Navy ice charts and ice drifting buoy data.

FUNDS EXPENDED

As of December 31, 1986 we have expended $101,940 of a total authorized $205,799.

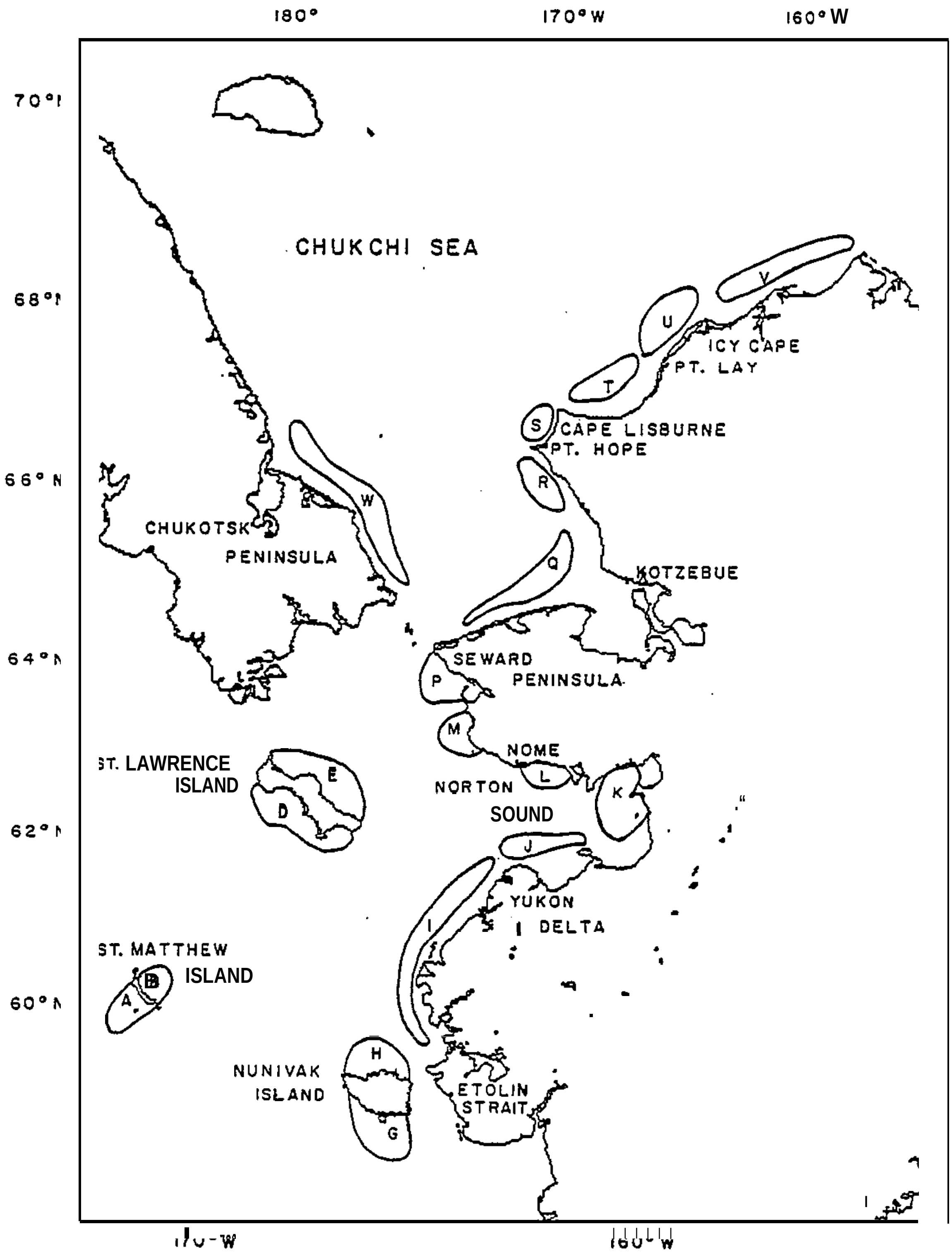

Figure 1. Map showing approximate location of persistent polynyas in the Bering Sea/ Chukchi Sea study area.

TABLE I. **Tabulation of Polynya Area Medians for Six Months over Six Years.**

JANUARY

Polynya	1975 Median Area* km²	1975 Median Area** km²	1975 Maximum Area km²	1977 Median Area* km²	1977 Median Area** km²	1977 Maximum Area km²
St. Lawrence	3120	3120	27100	2260	2260	3140
Norton Sound	218	1610	2590	0	1 400	3420
Kotzebue	360	3940	11 100	4520	5820	7860
Chukchi	0	0	1650	283	2500	18200

Polynya	1979 Median Area* km	1979 Median Area** km	1979 Maximum W-es km	1983 Median Area* km	1983 Median W-es** km	1983 Maximum Area km
St. Lawrence	Open	Open	Open	1880	1940	3440
Norton Sound	1670	1700	7620	1630	1660	8950
Kotzebue	0	1490	1490	0	1550	4840
Chukchi	785	3800	15800	0	585	1920

Polynya	1986 Median Area* km	1986 Median i%-es*++ km	1986 Maximum Area km
St. Lawrence	2000	2000	10500
Norton Sound	1380	1 SC10	4230
Kotzebue	452	620	1780
Chukchi	1050	1 050	7410

FEBRUARY

Polynya	1975 Median Area* km	1975 Median Area** km	1975 Maximum Area km	1976 Median Area* km	1976 Median Area** km	1976 Maximum Area km
St. Lawrence	1720	3240	8550	740	820	2570
Norton Sound	8640	9280	30400	.564	708	6060
Kotzebue	10600	10600	14900	o	670	927
Chukchi	15700	15700	36100	0	0	0

Polynya	1977 Median Area* km	1977 Median Area** km	1977 Maximum Area km	1979 Median Area* km	1979 Median Area** km	1979 Maximum Area km
St. Lawrence	1640	1640	2780	2350	4580	10200
Norton Sound	1130	1130	9120	788	853	17600
Kotzebue	0	0	0	1020	2260	7040
Chukchi	0	673	5640	1830	2150	3300

Polynya	1983 Median Area* km	1983 Median Area** km	1983 Maximum Area km
St. Lawrence	2 (:)&o	2060	3360
Norton Sound	1260	1260	1720
Kotzebue	o	4500	4500
Chukchi	0	2640	4340

MARCH

Polynya	1974 Median Area* km	1974 Median Area** km	1974 Maximum Area km	1975 Median Area* km	1975 Median Area** km	1975 Maximum Area km
St. Lawrence	1640	3680	9620	4280	4370	13200
Norton Sound	1420	2500	9220	1600	3110	25000
Kotzebue	0	458	458	2660	2850	7300
Chukchi	0	260	831	1020	1020	7440

Polynya	1976 Median Area* km	1976 Median Area** km	1976 Maximum Area km	1977 Median Area* km	1977 Median Area** km	1977 Maximum Area km
St. Lawrence	8790	9500	20200	1630	1720	6290
Norton Sound	1640	1670	7460	0	2090	11400
Kotzebue	0	1400	3030	0	0	0
Chukchi	0	925	1580	0	728	1440

Polynya	1979 Median Area* km	1979 Median Area** km	1979 Maximum Area km	1983 Median Area* km	1983 Median Area** km	1983 Maximum Area km
St. Lawrence	2200	2200	8180	2600	2600	11s00
Norton Sound	5780	5780	15500	9260	9260	16s00
Kotzebue	314	3350	9600	0	238	30s
Chukchi	1260	1680	4410	1020	2100	3900

APRIL

Polynya	1974 Median Area* km	1974 Median Area** km	1974 Maximum Area km	1975 Median Area* km	1975 Median Area** km	1975 Maximum Area km
St. Lawrence	56S0	5680	90100	2770	3260	10900
Norton Sound	10300	10300	132C)CI	1080	2390	5920
Kotzebue	0	0	0	1170	3000	3910
Chukchi`	0	331	4170	1290	5350	28200

Polynya	1976 Median Area* km	1976 Median Area** km	1976 Maximum Area km	1977 Median Area* km	1977 Median Area** km	1977 Maximum Area km
St. Lawrence	5180	5500	1 2000	2580	4040	14400
Norton Sound	2380	2380	5590	1440	2230	6560
Kotzebue	0	327	327	0	151	237
Chukchi	0	248	421	0	952	2690

Polynya	1979 Median Area* km	1979 Median Area** km	1979 Maximum Area i:m	1983 Median Area* km	1983 Median Area** km	1983 Maximum Area km
St. Lawrence	13600	5650	Open	4890	2230	Open
Norton Sound	16500	13soc)	Open	16300	103C)0	Open
Kotzebue	722	786	Open	221	960	1490
Chukchi	1360	17.?0	7200	1180	1310	9570

JUNE

Polynya	1974 Median Area* km	1974 Median Area** km	1974 Maximum Area km	1975 Median Area* km	1975 Median Area** km	1975 Maximum Area km
St. Lawrence	Open	Open	Open	Open	Open	Open
Norton Sound	Open	Open	Open	34400	34400	Open
Kotzebue	0	0	Open	259	346	Open
Chukchi	10000	10000	25700	40300	40300	50500

Polynya	1?76 Median Area* km	1?76 Median &-es** km	1?76 Maximum Area km	1977 Median Area* km	1977 Median Area** km	1977 Maximum Area km
St. Lawrence	Open	Open	Open	Open	Open	Open
Norton Sound	Open	Open	Open	Open	Open	Open
Kotzebue	0	0	0	444	444	Open
Chukchi	7300	7300	14200	6600	6600	23000

Polynya	1979 Median Area* km	1979 Median Area** km	1979 Maximum Area km	1983 Median Area* km	1983 Median Area** km	1983 Maximum Area km
St. Lawrence	Open	Open	Open	Open	Open	Open
Norton Sound	Open	Open	Open	Open	Open	Open
Kotzebue	Open	Open	Open	542	572	Open
Chukchi	5710	8040	open	943	943	12000

s

JULY

Polynya	1974 Median Area* km	1974 Median Area** km	1974 Maximum Area km	1975 Median (%-es* km	1975 Median Area** km	1975 Maximum Area km
St. Lawrence	Open	Open	Open	open	Open	Open
Norton Sound	Open	Open	Open	Open	Open	Open
Kotzebue	Open	Open	open	Open	Open	Open
Chukchi	18400	18400	Open	5460	5460	Open

Polynya	i 97.5 Median Area* km	i 97.5 Median 4h-es** km	i 97.5 Maximum Area km	1977 Median Area* km	1977 Median Area** km	1977 Maximum Area km
St. Lawrence	Open	Open	Open	Open	Open	open
Norton Sound	Open	Open	Open	Open	Open	Open
Kotzebue	Open	Open	Open	Open	Open	Open
Chukchi	1090c1	1 0900	Open	23100	23100	Open

Polynya	i 983 Median Area* km	i 983 Median Area** km	i 983 Maximum Area km
St. Lawrence	Open	Open	Open
Norton Sound	Open	Open	Open
Kotzebue	open	Open	Open
Chukchi	5440	5440	Open

*Median of all possible area determinations of the polynya. It includes those where the polynya was frozen over (area = 0), and those where the polynya has become part of the open ocean.

**Median of area determinations excluding those cases where the polynya was frozen over (area =0) as well as those where the polynya has become part of the open ocean.

TABLE II. IDENTIFICATION OF POLYNYI.

LOCATION OF POLYNYI	CODED DESIGNATION ON ALASKA BASE MAP
St. Matthew Island, South	A
St. Matthew Island, North	B
8St. Lawrence Island, South	D
St. Lawrence Island, North	E
Nunivak Island, South	G
Nunivak Island, North	H
Etolin Strait-Yukon Delta	I
Yukon Delta	J
Norton Sound	K
Nome	L
Seward Peninsual, South	M
Seward Peninsula, North	P
Kotzebue	Q
Cape Thompson-Pt. Hope*	R
Pt. Hope-Cape Lisburne	S
Cape Lisburne to Pt. Lay**	T
Pt. Lay to Ice Cape**	U
Ice Cape to Pt. Barrow**	V
Chukotsk Peninsula	W
Anadyr Polynya	Y

* Carleton (1975)

** Chukchi Polynya (Stringer, 19S2)

APPENDIX I

November 11, 1986

Dr. Jawed Hameedi
NOAA/Ocean Assessments Div.
Alaska Office
P.O. Box 56
Anchorage, AK 99513

Dear Jawed:

Enclosed with this Letter are copies of the data you requested. The latest moderately clear day in your study area before your cruise was August 26 (Julian day 238) and the earliest clear day afterward was September 28 (Julian day 271). The data are all from northbound passes and therefore the images all appear upside down.

For day 238 we have a regional scale band 1 (visual wavelengths) image. Perhaps the greatest value of this image is that it shows the location of cloud-free data. Next, we have the band 1 digital enlargement and enhancement, and finally, the band 4 (thermal IR) digital enlargement and enhancement. Here each 1°C temperature increment is denoted by a separate gray value.

For day 271 we bare again a regional image--only this time it is band 4 (thermal IR). One interesting feature of this image is the temperature difference between the two separate cloud regimes. Following this is a band Z (near IR) band digitally enlarged image (a band 1 image will be requested-- I am not sure why they provided this image, as band 1 shows sediment plumes best). Finally, we have a band 4 digital enlargement and enhancement with 1°C temperature increments.

It's interesting to me that the surface temperature pattern appears to have remained somewhat constant over this period. It would also be interesting to monitor the surface temperature pattern over an entire open water season.

Please tell Erdogan we are starting on his Beaufort Sea data and hope to have results for him soon.

Best regards.

Bill *Stringer*

BS:jd

December 5, 1986

Dr. Jawed Hameedi
NOAA/Ocean Assessments Div.
Alaska Office
P.O. Box 56
Anchorage, AK 99513

Dear Dr. Hameedi:

Enclosed wick this letter *is* the visible band image of the southern Chukchi Sea I promised. As you can see, the land is almost as dark as the ocean and some sediment can be seen as a gray level between these two (and in most -sea, physically between them as well). I don't think we would see any more detail here regardless of how much contrast stretch was applied. However, I am willing to attempt it if you chink it worthwhile.

Meanwhile, I have acquired transparencies of the thermal band images and am prepared to produce as many copies of them as might be ==@=f-

1 should also let you knew that I am pulling some materials together as per a request from Dale Kinney for an MMS publication. It isn't a big project and I'm sore than happy to da it.

Finally, I should express our (myself, Jan, Joanne and Mark) appreciation to OCSEAP for the contract extension. It has done a lot for our morale in *au* otherwise uncertain time.

Sincerely,

Bill Stringer

BS:jd

December 5, 1986

Erdogan Ozturgut
NOAA/NOS/OAD
701 C Street
PO Box 56
Anchorage, AK 99513

Dear Dr. Ozturgut:

Enclosed with this letter is the first attempt to obtain Beaufort Sea imagery during this October. Please don't be depressed and don't throw them out just yet. These images were obtained on Julian days 276 (Oct. 3), 279 (Oct. 6) and 282 (Oct. 9). They are from the thermal band and have the same grey scale versus temperature that was used for the images of the Chukchi Sea sent earlier. White is the freezing temperature of seawater and the grey steps are in 1 °C increments warmer. As you can see, it was mostly colder than that.

Before I go any further I should tell you that I have another grey scale version in the works that should show more detail and that will be sent along shortly.

Meanwhile we might look at these images for a minute. The pair from Oct. 9 shows the most detail and I will discuss it first. I have indicated the location of Barrow and Harrison Bay on this image. Note that the data ber is upside down at the top. This results from the happenstance that these data came from a northbound satellite. Also, I have indicated on the more southerly image approximately where the second image overlays it. (Mackenzie Bay is in the more southerly image but it was too cold to see any detail here.) Once you become oriented to this image you can see quite a bit of temperature structure in the open water/partially frozen area of the Beaufort Sea. This is worth saving because the next version will most likely show a lot more structure in the ice, but less in this area. Thus, together they should give a more complete picture of ice conditions in the region.

The other two sets of images have me puzzled for the moment. It is possible that they were accidently obtained from an area further offshore. For the time being I can say no more about them. The mystery may become solved when we see the next set of images.

Sincerely,

Bill stringer

BS:jd

P.S. Just in case they may have taken Beaufort Sea radar data at this time, I have placed an inquiry with Canada's Ice Centre for a catalog of their data. A comparison of radar and thermal IR data might be very useful.

APPENDIX II

GO AHEAD FOR NEW CALL
ETT GA 0053376I/A*
GEOPH INST FBK

I2 03 1828V
DOE AESICE OTT

GEOPH INST FBK
ZCZC 09 FAIRBANKS, ALASKA USA, 03, DECEMBER, 1986

TO: F.E. GEDDES
SENIOR ICE CLIMATOLOGICAL TECHNICIAN
ICE CENTRE ENVIRONMENTAL CANADA
365 LOURIER AVENUE WEST
JOURNAL TOWER SOUTH
OTTAWA, CANADA KIA OH3
TELEX: 053-3761 DOE AES ICE OT

DEAR MR. GEDDES:
WE WOULD LIKE TO PURCHASE COPIES OF RADAR IMAGERY OF THE ALASKAN/CANADIAN COAST FROM MACKENZIE BAY WESTWARD. COULD YOU PLEASE ADVISE US OF COVERAGE WHICH HAS OCCURED BETWEEN SEPTEMBER, 1985 AND PRESENT. ALSO PLEASE ADVISE US OF YOUR CURRENT COST SCHEDULE.

THANK YOU.

WILLIAM J. STRINGER
UNIVERSITY OF ALASKA - FAIRBANKS
GEOPHYSICAL INSTITUTE
TELEX 35414
DOE AESICE OTT
......
1830EST 002.40

TIME 005.2 MINS

RCV20453 08:56 12/17/86

GEOPH INST FBK

DOE AESICE OTT
FOLLOWING FOR WILLIAM J STRINGER
UNIVERSITY OF ALASKA
GEOPHYSICAL INSTITUTE

REUR TELEX 041286

THERE HAVE BEEN 45-50 FLIGHTS ALONG THE ALASKAN COAST FROM SEPTEMBER 1985 TO PRESENT, THE MAJORITY OF WHICH ARE IN THE JUNE TO SEPTEMBER PERIOD. THE COST PER NEGATIVE DUPLICATE IS 140 DLRS CDN PLUS COURIER CHARGES. A LISTING OF ALL FLIGHTS CAN BE MAILED IF SO DESIRED.

GEDDES
ICE CLIMATOLOGY OTTAWA
161840
GEOPH INST FBK

DOE AESICE OTT

TOD DEC 17 86

CONVERS2 034 12/18/86

GEE
3761
18 86 1543 02749F
PH INST FBK

E ESE OT

PH INST FBK

C 027 FAIRBANKS ALASKA USA 18 DEC 1986
N GEDDES
CLIMATOLOGY OTTAWA
EX 0533761 DOE AESICE OTT

YOUR TELEX 12/17/86

ASE MAIL LISTING OF ALL FLIGHTS ALONG ALASKAN COAST
WEEN SEPT 85 TO PRESENT AS YOU OFFERED. IF YOU
A FLIGHT BETWEEN OCT 1 AND OCT 20, 1986 WE WISH TO
ER IT NOW AND WILL FORWARD $120 DOLLARS CANADIAN PLUS
RIER CHARGES VIA ANY MEDIUM YOU SUGGEST

ANK YOU,
STRINGER
LEX 35414 GEOPH INST FBK
E AESICE OTT
ME 001 X MINS

Bill —
What shall I
charge for this?
Doug

Environment Canada / Environnement Canada

Atmospheric Environment Service / Service de l'environnement atmosphérique

Ice Centre Environment Canada
365 Laurier Avenue Weet
Journal Tower South, 3rd Fir.
Ottawa, Canada KIA 0H3

Your file Votre référence

Our file Notre référence
8280 -6(ACIC)

12 September, 1985

Geophysical Institute
University of Alaska
C.T. Elvey Building
Room **608**
Fairbanks, Alaska 9977 S-0800
ATTN: Mr. Bill Stringer

Dear Mr. Stringer:

Aug 8, 1985

Enclosed, as requested in your telex and purchase order (51771-4912) dated 14 August 1985, please find the following:

A. Negative Duplicate and logs for NDZ flight 1464 - 19 June 1985

B. Negative duplicate and logs for NDZ flight 1475 - 07 July 1985

C. Negative duplicate and logs for NDZ flight 1476 - 08 July 1985

Positive paper prints can also be obtained if so desired. An invoice will be forwarded as soon as costs have been determined.

Yours truly,

F.E. Geddes

F.E. Geddes
Senior Ice
Climatological Technician

Enclosure

ICEC086STRINGER

RC 20465 07:01 12/19/86

00 DEC 19 86

RC 20466 07:03 12/19/86

DOE ALICE ORC

GEOPH INST FBK

ATTN W. STRINGER

FOLLOWING IS A LIST OF DATES FOR FLIGHT SLAR IN YOUR AREA OF INTEREST

1985

SEPT 7 14 16 20 22 24 29
OCT 3 4 5 7 9 11 19 20
NOV 12

1986

FEB 14
MAY 17
JUNE 28
JULY 1 4 7 12 17 20 22 23 28 31
AUG 3 6 7 9 12 21 26 27 30
SEPT 5 11 14 16 19 21 23 29
OCT 27

REGARDS
GEODES
ICE CLIMATOLOGY
1910SSEST

GEOPH INST FBK

DOE ALICE OT

100 DEC 19 86

OS 10D

Telex

459 3961

Reply

Ref your telex of 12/19/86 please send copies of radar imagery from Sept 29 and Oct 27 1986. I ~~ha~~ have generated a purchase order for $240 ~~pr~~ for imagery ~~and~~ plus $60 for courier costs payable to Ice Central Canada PO number 54225-4610, Geophysical Institute, University of Alaska. Payment will be by check unless you specify otherwise. Thank you. Bill Stringer

54225-4610

CONVER82 149   08:35 12/22/86

ELSEL
0537761
DEC 22 86 0828 008191
GEOPH INST FBK

DOE AESICE OTT

UNABLE TO TRANSMIT FOLLOWING MESSAGE TO YOU ON 12/19/86. YOUR
TELEX KEPT REGISTERING A NF OR NC. LOOKS OK NOW.

ZCZC 032 FAIRBANKS ALASKA USA 19 DEC 1986
ATTN: GEDDES
ICE CLIMATOLOGY
TELEX: 053-3761
BT
REF: YOUR TELEX OF 12/19/86

PLEASE SEND COPIES OF RADAR IMAGERY FROM SEPT. 29 AND OCT. 27 1986.
I HAVE GENERATED A PURCHASE ORDER FOR $240 FOR IMAGERY PLUS $60
FOR COURIER COSTS PAYABLE TO ICE CENTRAL, CANADA. P.O. NUMBER IS
54223-4610, GEOPHYSICAL INSTITUTE, UNIVERSITY OF ALASKA. PAYMENT
WILL BE BY CHECK UNLESS YOU SPECIFY OTHERWISE. THANK YOU

BILL STRINGER
TELEX 35414 GEOPH INST FBK
K
DOE AESICE OTT

TIME 002.7 MINS

Dee
Finally got
this out —
Barry