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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 1

2.0 INTRODUCTION

2.1 GENERAL

This document is an initial attempt at describing a long-term monitoring program for assessing **potential** effects of anticipated oil and gas development on the United States **Beaufort** Sea continental shelf. Various regulatory **mandates** requiring such an assessment be done are described in Section 2.2: the interrelationship among the responsible agencies primarily the U.S. Minerals Management Service (NW) and the U.S. National Oceanic **and Atmospheric Administration** (NOAA) are **detailed in** Section 2.3. Over the last several years these and several other agencies have funded a variety of studies which provide a **basic understanding** of physical and biological conditions **and** interrelationships in the **Beaufort** Sea (Section 2.4).

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

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

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 extensive statutory and regulatory mandates to conduct environmental studies and monitoring in marine waters. This section discusses these mandates. The working relationship which has evolved between the two services to study effects of oil and gas development on the Alaskan Outer Continental Shelf is explained in Section 2.3.

The Outer Continental Shelf Lands Act (67 Stat. 462) was passed in 1953 and established federal jurisdiction over the submerged lands of the continental shelf seaward of states boundaries. The act charges the Secretary of the Interior with responsibility for administering mineral exploration and development of the Outer Continental Shelf (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 Land Management (BLM) as the administrative agency for leasing submerged federal lands, and the U.S. Geological Survey for supervising development and production. The Department of the Interior formulated three major goals for the comprehensive management program for marine minerals:

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

Although this objective has not changed, the Environmental Studies **Program** is now located in the Minerals **Management** Service of the Department of the Interior, after departmental reorganization in 1982. 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 Shelf** 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** process associated **with** a **specific** leasing action or with the longer term Outer Continental **Shelf** minerals management **responsibilities**, 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 authority 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 area or region in a manner designed to provide time-series and data trend information which can be used for comparison with any previously collected data for the purpose of identifying any significant changes in the quality and productivity of such environments for establishing trends in the areas studied and monitored, and for designing experiments to identify the causes of such changes.
- (c) The Secretary shall, by regulation, establish procedures for carrying out his duties under this section and shall plan and carry out such duties in full cooperation with affected States. To the extent that other Federal agencies have prepared environmental impact statements, are conducting studies, or are monitoring the affected human, marine, or coastal environment, the Secretary may utilize the information derived therefrom in lieu of directly conducting such activities. The Secretary may also utilize information obtained from any State or local government, or from any person, for the purposes of this section. For the purpose of carrying out his responsibilities under this section, the secretary may by agreement utilize, with or without reimbursement, the services, personnel, or facilities of any Federal, State, or local government agency. "

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

- 0 ova r **a** broad geographic area including land and **water f rom** the **inner** boundary of the **coastal** zone to **and** including the land underlying and the waters of the high seas;
- 0 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 **pollution** 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 **resource** conservation and utilization. The programs mandated by these other laws complement NOAA's responsibilities under the National **Ocean** Pollution Planning Act. These legislative authorities include the National **Environmental** Policy Act of 1969 (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. 92-538), the **Marine Mammal** Protection Act of 1972 (Pub. L. 92-522), the **Federal Water** Pollution Control Act Amendments of 1972 (**Pub.L.** 92-500), the **Clean** Water Act of 1977 (**Pub.L.** 95-217), the **Fishery** Conservation and Management Act (Pub. L. 94-265), the Sea Grant Improvement Act (**Pub.L.** 94-461), the **Endangered Species Act** (**Pub.L.** 93-205), **and many** others.

2.3 MMS/NOAA COOPERATION IN OCS ENVIRONMENTAL STUDIES

In May 1974, the **BLM** requested that NOAA initiate a program of environmental assessment in the northeastern **Gulf** of Alaska **in anticipation** of a possible oil and gas lease sale in the region early in 1976. The Outer Continental Shelf **Environmental** Assessment Program (**OCSEAP**) was established in 1974 by NOAA **to** manage these studies and others proposed under the **marine** environmental portion of the **Alaska OCS Environmental** Studies Program. **OCSEAP** has continued **to** conduct 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 relationship has continued with 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, prepared by NOAA with funding guidance from MMS, and in coordination with the MMS Anchorage Office, describe the rationale, scope, and content of the individual research units (RUS) to be implemented by OCSEAP.

2.4 ONGOING RESEARCH AND MONITORING PROGRAMS IN THE BEAUFORT SEA

2.4.1 Outer Continental Shelf Environmental Assessment Program

Since 1975, OCSEAP has funded approximately 89 research units (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 have 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 space and/or time) measurements of physical, chemical, or **biological** properties of the environment that are traditionally **performed to develop basic** descriptions of the existing **ecosystems** and the physical and biological **constraints** that the area imposes on development. Considerable experience and data have been **amassed** for the United States Beaufort Sea (especially nearshore) which provide **the** basis for many of **the** thoughts expressed in the workshop (Section 3) and, **to** a lesser degree, **in** the final monitoring program recommendations (Section 5).

2.4.2 Minerals Management Service (MMS)

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; 1981; 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 **Beaufort**.

TABLE 2-1

WHALE-RELATED RESEARCH FUNDED OR PLANNED BY MMS, 1978-1985

Fiscal	
1978-1979	Investigation of the Occurrence and Behavior Patterns of Whales in the Vicinity of the Beaufort sea Lease Area
1979-1985	Aerial Surveys of Endangered Whales in the Beaufort Sea, Chukchi Sea, and Northern Bering Sea
1979-1980	Development of Large Cetacean Tagging and Tracking Capabilities in OCS Lease Areas
1980-1981	Tissue Structural Studies and Other Investigations on the Biology of Endangered Whales in the Beaufort Sea
1980	Effects of Whale Monitoring System Attachment Devices on Whale Tissues
1980	Effect of Oil on the Feeding Mechanisms of the Bowhead Whale
1981-1984	Development of Satellite-Linked Methods of Large Cetacean Tagging and Tracking Capabilities in OCS Lease Areas
1982-1984	Investigation of the Potential Effects of Acoustic Stimuli Associated with Oil and Gas Exploration/Development on the Behavior of migratory Gray Whales
1983 -1984	Computer Simulation of the Probability of Endangered Whale Interaction with Oil spills in the Beaufort , Chukchi , and Bering Seas
1980-1984	Possible Effects of Acoustic and Other Stimuli Associated with Oil and Gas Exploration/Development on the Behavior of the Bowhead Whale
1985	Application of Satellite Linked Methods of Cetacean Tagging and Tracking Capability in OCS Lease Areas
1985	Prediction of Site-Specific Interaction of Acoustic Stimuli and Endangered Whales as Related to Drilling Activities during Exploration and Development of the Diapir Lease Offering Area
1985	Relationship of Distribution of Potential 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 Slope Borough

In recent Years there has been a growing concern among the **Inupiat and Inuit** people of northern Alaska and Canada regarding the **potential effects** of offshore (and onshore) **oil** and gas development on species crucial to their **historical** subsistence life style. **As** a result, the North Slope Borough has 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 State 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 Slope**, some of which receive **OCSEAP** funding. Aerial surveys of ringed seal winter population densities (Burns and **Harbo** 1972; Burns et al. 1981 ; **Burns** and **Kelly** 1982) and studies of **overwintering** char populations (**Bendock** 1983) are particularly relevant to the design of a long-term **Beaufort 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 addition, numerous **predevelopment** "baseline" studies **have** been conducted by various oil **companies** in preparation for filing development **permit** applications. **By** far the largest monitoring program to date in the U.S. Beaufort Sea is that **associated** with the **Prudhoe Bay Unit Owners Waterflood Project** (U.S. Army, Corps of **Engineers** 1980; 1982; 1983). **Benthos**, bird, and fish studies **within** that **program** provided **data** for consideration in the present program design.

Monitoring of specific discharges (e.g., drilling muds) to the **Beaufort** Sea is required by the U.S. Environmental protection Agency and the **Alaska State 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 been designing **a** long-range monitoring program for the Canadian side of the Beaufort Sea. **Oi**l development in the Canadian Beaufort Sea will soon be moving into the production phase. **Stone** reported that, during early **●**fforts of environmental **assessment, managers** and decision makers had been deluged with research topics thought to **be** of importance by individual scientists, and had been forced **to** make decisions based on **political**, rather than biological needs.

To alleviate this situation, Canada embarked on a deliberate plan **to analyze** the **utili**ty of **previous impact** assessments (**Beanlands** and **Duinker** 1983) and **to** use this analysis and the best scientific expertise available in formulation of their long-range **targets** and approaches. Canada is proceeding using adaptive environmental assessment (**AEA**) techniques (Halling 1978) 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 species 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, mammals, 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 Beaufort 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;
- o reach a consensus (or a majority opinion) on techniques, proven or promising, that should have high priority for inclusion in the BSMP.

About 20 scientists with expertise in the Beaufort Sea environment and/or with systematic monitoring programs elsewhere in the U.S. and Canada were invited to the workshop, along with a number of scientists and managers from federal agencies, predominantly MMS and NOAA. A List of attendees and their affiliations is provided in Appendix A. The workshop was held at the Alyeska resort 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 from 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 elsewhere in the United States were described by a series of speakers (Section 3.3). The physical environment of the nearshore Beaufort **Sea** was discussed, along with techniques that have been used for monitoring various physical parameters (Section 3.4). Biological conditions in the **Beaufort** Sea and a wide **variety** of biological, physiological, and biochemical monitoring approaches were also presented (Section 3.5).

After these presentations, a panel of NOAA and MMS scientists (D. **Wolfe**, **W. 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 shelf break (about 50 meters) .

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

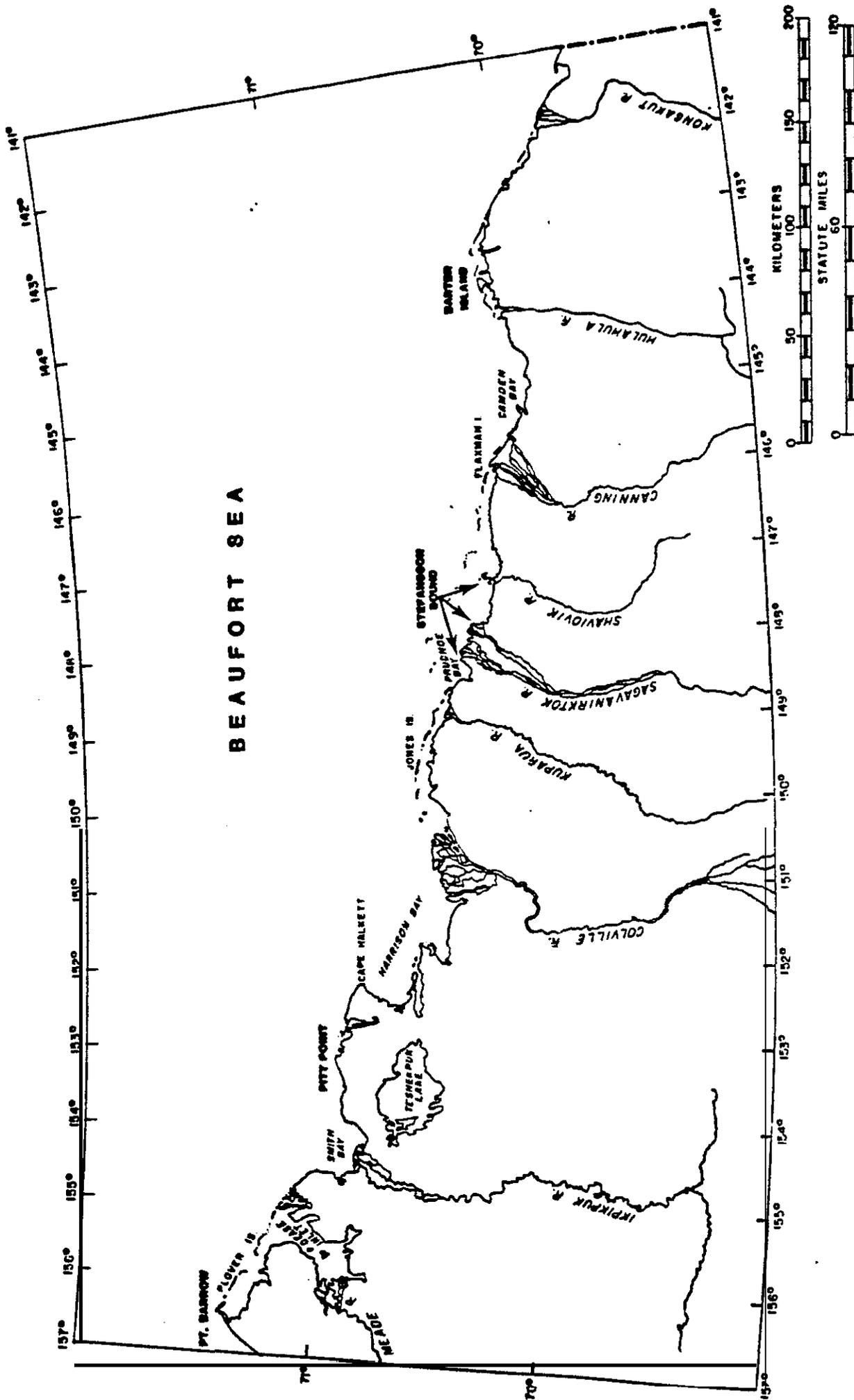


Figure 2- Beaufort Sea study area

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 **sessions**.
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. Boughton 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. **Connors** (**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 against unacceptable impacts of human activities on the marine environment, and to provide a long-term data base that can be used for evaluating and forecasting natural changes in marine ecosystems and the superimposed impacts of human activities (U.S. NOAA 1981). For the Beaufort Sea, it was suggested at the workshop (J. Hameedi, NOAA/National Ocean Systems [NOS]) that the monitoring program consist of:

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

Subsequent discussions suggest that this definition should be interpreted to include the analysis of data gathered to (1) establish a measure of the environmental quality of the Beaufort sea, and (2) relate changes in this quality to causal factors. It was suggested (J. Truett, LGL) that environmental quality should be measured by establishing the status of selected environmental variables in comparison to a desired status. Discussions also highlighted the need for the end products of the monitoring program to provide continuing information about environmental quality such that policy and management decisions can be made about human actions that affect that quality.

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 (1983) . While many of these activities do not currently include monitoring in the Beaufort Sea, and others are of very limited scope in this region, the design that will be developed for the proposed monitoring effort must take into account that such programs may be instituted or expanded as federal and non-federal development activities increase in this region.

TABLE 3-1

FEDERAL AGENCIES RESPONSIBLE FOR MARINE POLLUTION MONITORING

Environmental Protection Agency (EPA)

Monitors marine pollution compliance.

Food and Drug Administration (FDA)

Administers national shellfish sanitation program (also pesticides and metals in fish).

Minerals Management Service (MMS)

Assesses impacts of offshore oil and gas 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** reported 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 Beaufort 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 Bay and **Stefansson Sound**, which **includes Prudhoe Bay** (Figure 2-1).

Although the Beaufort Sea marine environment is unique among United 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 **California** Mussel Watch Programs; the NOAA and EPA Ocean **Dumping** Programs; the NOAA New York Bight and Hudson-Raritan **Estuary** Programs; the EPA Chesapeake Bay 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 **comprehensive body** of knowledge regarding the effectiveness of techniques and **approaches utilized** by these and many other programs. It was intended that this knowledge, combined with many of the workshop participants' experience in **the Beaufort Sea environment**, would enable development of a **monitoring** plan composed of the best available techniques that would effectively assess the impact of **oil** and gas development on the **Beaufort Sea** environment.

Therefore, the workshop participants were charged by **Hameedi** to develop a monitoring program outline for the Beaufort Sea which incorporated those techniques and approaches most likely to be successful (1) **in** identifying changes in the **Beaufort** Sea environment 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 be** instituted in order to prevent further **adverse** change, and to minimize and redress any **adverse** impacts, where possible.
6. Although the **program should be economical ly feasible**, cost of the monitoring **program** should not be a **major** concern at this stage 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**, and other pollutants. However, the effects of development

activities, such as gravel island and causeway construction, 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 population 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 currently active and will 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 Beaufort and elsewhere would be performed (Chapter 4) to aid in design of statistically valid sampling programs (including sampling design, minimum sample size, and field methodologies required to detect significant changes) for parameters and indices recommended by the workshop to be included in the monitoring program. Therefore, statistical considerations during the workshop should be of lower priority than identifying the parameters that should be measured.

3.2 FACTORS THAT MAY CAUSE 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 briefly reviewed by several workshop participants. Since they have been thoroughly discussed in a number of environmental impact statements (EISs) dealing with individual federal permitting actions (e.g., OCS lease sales, U.S. MMS 1982; 1983; Prudhoe Bay Waterflood Project, U.S. Army, COE 1980), they will only be briefly outlined here.

Construction and/or placement of permanent shoreline or offshore structures directly destroys existing habitat and can cause changes in circulation that may affect water quality, nutrient transport, and movements of biota. Construction and operation of facilities create noise (airborne and waterborne) and visual effects that may disrupt biota. Routine discharges (e. g., drilling fluids and cuttings, sewerage, wash water, brines, etc.) can alter local water and sediment quality and may contain compounds that are toxic to or may accumulate in organisms. Operation of high volume water intakes for treatment and waterflooding of oil bearing formations can cause entrapment and impingement or entrainment of large numbers of organisms.

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

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

3.3.1 Mussel Watch

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

Mussel watch programs have provided the first standardized baseline **data** on marine pollution **within** the past decade and are now considered to be **the** primary **phase** of marine pollution monitoring programs (UNESCO 1980). **The** United States national mussel watch evolved from a meeting convened in 1975 by the National Academy of **Sciences** (NAS) **to** **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 selecting 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 **bioavailabilities** in the marine environment. It was also concluded **that** those measurements could be made with relative ease and modest expense **compared** to measurements of pollutant concentrations in **seawater** (Goldberg and Martin 1983). This latter conclusion has since proven fortuitous because **recent seawater** measurements of **some** of the principal pollutants, including lead (**Schaule** and Patterson 1981) and silver (Martin et al. 1983), **have shown that many preceding seawater** 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 10⁵ **compared to** seawater in their **habitat**. This makes measuring trace **constituents** in their tissues often easier to accomplish than analyzing seawater.
 4. Inasmuch as the chemicals are measured in the bivalves, an assessment of biological availability of chemicals is obtained.
 5. **In comparison to** fish and **Crustacea**, most bivalves exhibit low or undetectable activity of those **enzyme systems** which metabolize many **xenobiotics** such as aromatic hydrocarbons and **polychlorinated biphenyls** (PCBS). **Thus**, a more **accurate** assessment of the magnitude of **xenobiotic** contamination in the habitat of the bivalves can be made.
 6. They **have** many relatively **stable** local populations **extensive** enough to be sampled repeatedly **by** providing data 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. **The y** can be **successfuly** 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, they **represent** the second phase of the progressive mussel watch concept of integrated research, which is designed **to** yield a **qualitative** 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 priorities for monitoring programs:

'Analysis of a few samples of mussels or other bivalves for a small number of recognized pollutants will not, in itself, provide any assurance that scientists have determined the quality of **local coastal** waters. Nor would such analyses necessarily constitute a basis for a **rational** program for the long-term protection of the coastal zone. **Thus**, for example, if heavy metals are analyzed, associated research would be required **to** determine whether levels are elevated because of the activities of **people**, and whether higher levels might cause an alteration in local coastal food webs and ecosystems 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 **anthropogenic** inputs. The two mussel **watch** locations (Goldberg et al. 1978; Stephenson et al. 1979) along the west **coast** of the United **States** where **M. californianus** have consistently elevated mercury 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 elsewhere** (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 that 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 inhabit 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 United 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 temperate 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 **Beaufort** Sea. **The EPA regulates** discharges associated with oil and gas operations **in** offshore areas **in Alaska**. Site-specific surveillance monitoring **requirements** are in some cases included as a 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 **dis-**charges 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 **ecosystem impacts, a** threat to **human** health, **or** an **unreasonable** loss of scientific, recreational, aesthetic, or economic values.

In making the determination of whether a discharge will cause unreasonable degradation--and correspondingly in determining whether a permit can be issued--10 factors known as the "**Ocean Discharge Criteria**" are considered (Table 3-3). These criteria address the following major issues: Are there areas of significant biological concern and **will the** discharge be transported **to** these areas of concern in sufficient concentrations or quantities to 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 **will** not result in irreparable--or irreversible--harm, given specific **monitoring** requirements and other conditions.

TAsLE 3-3

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

-
- 0 **Quantities**, composition, and potential for **bioaccumulation** or persistence of the discharged **pollutants**.
 - 0 Potential **transport** of such pollutants.
 - 0 Composition and vulnerability of biological communities ; e.g. , presence of endangered species.
 - 0 Importance of receiving water area to surrounding biological **community**; e.g. , presence of spawning sites.
 - 0 Existence of **special** aquatic sites; e.g. , marine sanctuaries.
 - 0 Potential impacts on human health.
 - 0 Existing or **potential** recreational and commercial fisheries.
 - 0 **Applicable** requirements of **approved Coastal Zone** Management Plans.
 - 0 Marine water quality criteria.
 - 0 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 environment. Therefore, immediate, specific effects and also long-term cumulative impacts are considered.

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

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

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

Using replicate **sampling** data from drill **sites** in the Canadian **Beaufort** Sea the minimum detectable differences in **mean** sediment **chromium** concentrations were calculated (Table 3-4). **Based** on this, the study design called for a collection of 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, <u>mg/dry kg (percent of mean)</u>	
	10 Stations	36 Stations
2	21 (36)	25 (42)
3	15 (25)	18 (31)
4	12 (20)	15 (25)
5	10 (17)	13 (22)

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

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

The data developed from this study will be useful in addressing the ocean discharge evaluation. This information will also be **essential** in looking ahead to address impacts and develop 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**).

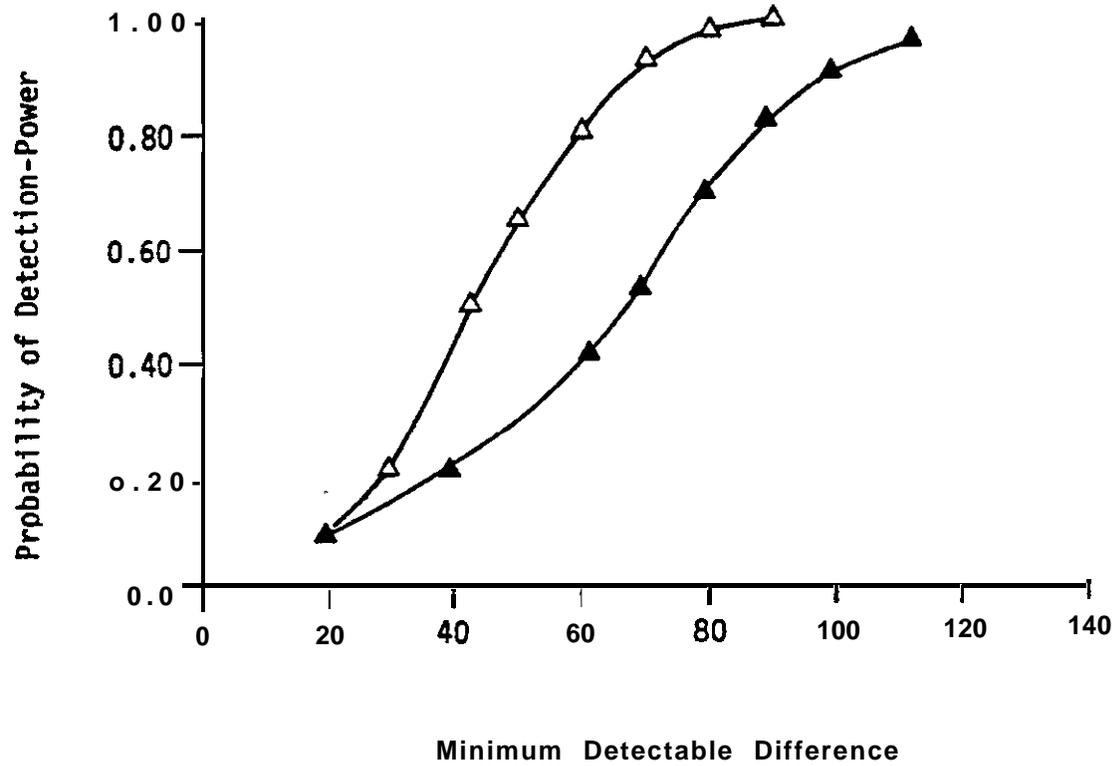
Examples of biotic **groups** in decreasing order of suitability to 301(h) monitoring programs are: **benthic macroinvertebrates, demersal** fishes, kelp **beds**, coral reefs, rocky intertidal, shellfish beds, and **phyto-**plankton.

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

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

3.3.4 Prudhoe Bay Waterflood Benthic Monitoring Program Analysis

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



Legend

A	8 stations 10 reps	$\alpha = .05$
A	8 stations 5 reps	$\frac{s}{\sigma} = 32,2$
		$\bar{x} = 56.7$

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

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

The exclusive **focus** of the study was on the **benthic** environment, including **benthos** and hydrocarbons, as well as on **heavy metals** levels in sediments and **benthos**. The sampling design provided for a broad area, depth stratified coverage of the south side of the bank as well as a radial array around two active drill sites. **An oversampling** approach was used whereby samples from several **stations** were not immediately processed but were stored for possible future use. Eight replicates were **taken** at each station with four cruises per year over 3 years. The number of samples analyzed was **reduced** in the third year. **Barium** and chromium in the fine fraction of **surficial** sediments were used as indicator of the presence of drilling fluids. **Elevated** levels were detectable some 6 **km downcurrent** from the rigs. Additional **details** of this program and its results have been reported by **Battelle/WHOI** (1983), U.S. **Geological Survey** (1983), and 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 that 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. The initial effort was to **examine** the historical **data** base and **establish** a statistically valid sampling design. Reconnaissance cruises are **underway** to better understand poorly studied geographic areas, to improve the state of **knowledge** 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 attention because of the anticipated higher "signal to noise" ratio expected for drilling effluent effects on **benthos compared** to other aspects of the **ecosystem**. A 5-year monitoring program is anticipated using stations both near and **removed** from production platforms.

3.4 PHYSICAL ENVIRONMENT

3.4.1 Ice Conditions

As described by L. **Hachmeister** (Science Applications **Inc.**) and W. **Sackinger** (University of **Alaska**), the physical environment of the **Beaufort** Sea is characteristically very different from other areas of the United States Outer Continental Shelf **because** of **its** proximity to the **Arctic** ice pack and the existence of fast-ice **throughout** the entire sea during winter. From **October** through June, the entire Beaufort Sea is generally covered with ice. **The permanent** Arctic pack ice zone is found in deep water and **is** usually in motion at **variable rates** up to 35 km per

day. **Shoreward** of the permanent pack is a seasonal **pack** ice zone, which extends through **most** of the **stamukhi** zone (an offshore zone of grounded ice, sand, gravel, and rubble) . In winter, grounded fast ice is found in this **stamukhi zone**; farther inshore is a region of **seasonal** floating shorefast ice; and a shallow **coastal** region is **composed** of seasonal **bottom** fast ice.

Because water and sediment movement, and therefore contaminant movements, within the **Beaufort** are profoundly **influenced** by the ice, they are **subject** to great **seasonal** variability. In winter, the presence of ice cover minimizes wind coupling with the water column and, therefore, water movements are **dramatically** reduced and water exchange rates in nearshore areas may be on the order of several months. **In** some coastal lagoons, the **reduction** in water movement, combined **with** the exclusion of salt from the forming ice, **can** lead to very high salinities (up to 180 ppt has been observed), which can persist **until** either breakup or the **retreat** of the ice 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: **solubility** of the contaminants, the matrix **material**, the particulate concentrations in the **water** column, the matrix material density, the time of year the material is introduced, and the level of microbial activity which might modify the

contaminating material. In contrast, contaminant materials introduced on top of the ice will tend to remain **in** place or will **be** wind-dispersed until breakup, when they will be washed through the **ice** by fresh water overflowing the ice, or when they **will be** dispersed at a **point** where the melting ice releases them. While **it** is clear **dispersal** mechanisms that would affect **contaminants** introduced into the **Beaufort** Sea during winter are extremely **complex**, **it** is probable that in **some** cases the dispersion of the **contaminant will** be less than **would be** experienced in the open water season, or less than is encountered in other ice-free oil **development areas**. It also should **be** noted that current regulations require the disposal of drilling muds **on** the ice during fast-ice **periods**. However, spills or other accidental releases of oil or other materials could take place either on or **below** the ice.

During the ice-free period in the **Beaufort**, 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 about 3 percent of the wind speed, but currents are typically only 0.3 percent of the wind speed during **ice-covered** periods. **Therefore**, transport of contaminants away **from** the immediate area of the discharge will take place predominantly during the ice-free and moving-ice periods.

3.4.2 Circulation

The major features of water circulation patterns in the **Beaufort** Sea 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 about 5 to 10 **cm/sec**. Inshore of the gyre is the Alaskan **coastal** current system, a complex, reversing current regime which results in a **mean movement** of water to the east at about **15** to 25 **cm/sec**. In the nearshore zone on the shelf, currents are generally highly variable, mean westerly, wind-driven currents of 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, except within the lagoon system inside the barrier island chain. In these lagoons, the generally warmer and lower salinity water, resulting from the influence of freshwater runoff, is transported westward along the coast and replaced by colder, more saline water flowing into the lagoons through breaks in the barrier island chain. 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 winds, pulses of colder, more saline water enter the lagoons at each tidal cycle and are transported to the west by the mean current. Under these circumstances, a series of cross-lagoon density fronts may be set up. 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 storm winds occur in the Beaufort quite frequently and are generally from the northwest or the west. The frequency of westerly wind occurrence is higher toward the eastern end of the United States coast. Winds from the northwest or west cause storms 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 coastal lagoon system is to the east with warm, low salinity surface water being forced out of the lagoons through the barrier inlets. Therefore, downwelling of surface waters occurs on the inner shelf outside the lagoons where mid-shelf and lagoon surface waters converge.

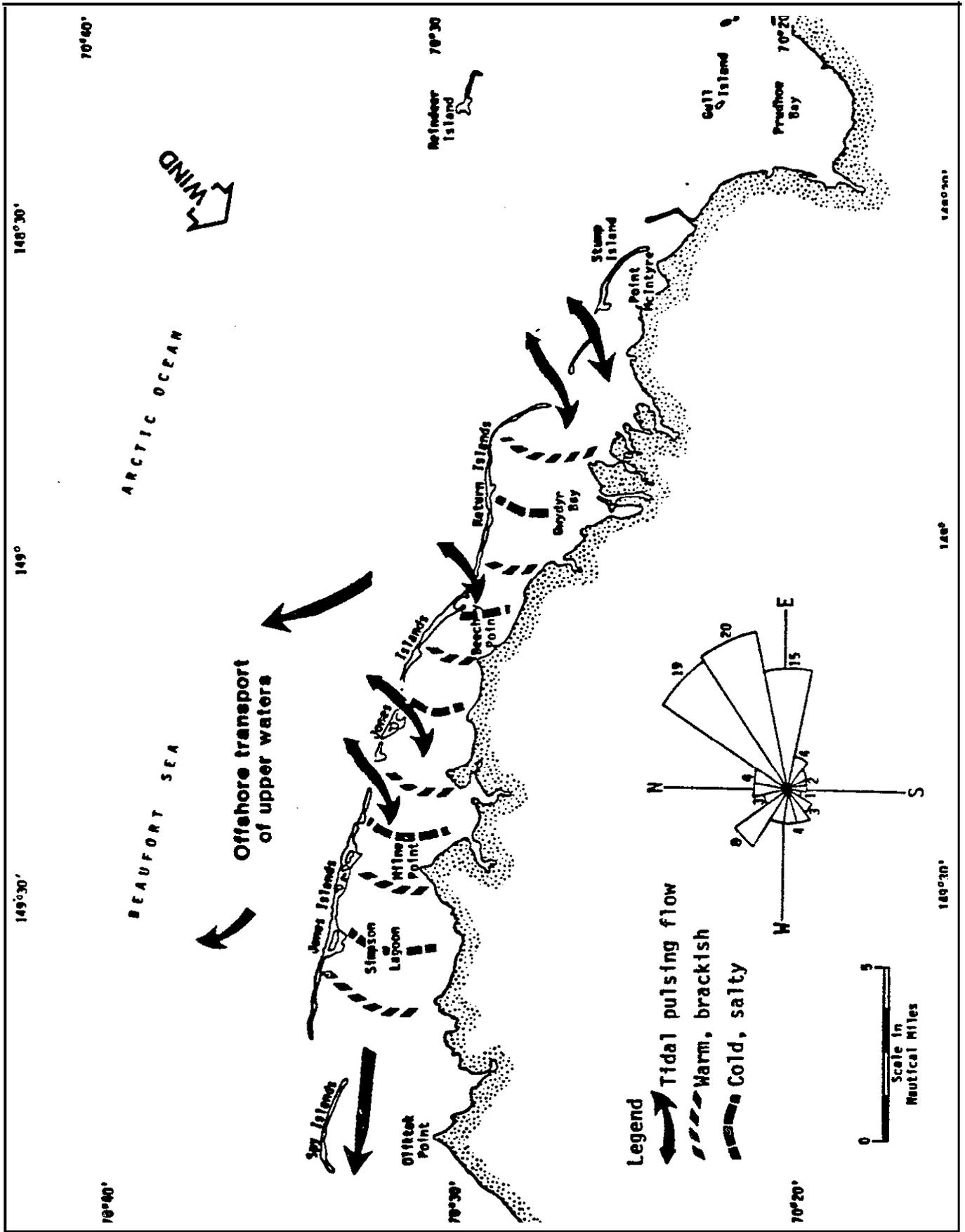


Figure 3-2 Current patterns under northeast wind conditions Prudhoe Bay to Oliktok Point area

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 **plumes** are oriented to the east of the river in **a** relatively narrow region adjacent to the **coast**.

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

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

3.4.3 Monitoring Considerations

Hackmeister recommended that the Beaufort monitoring program should include:

1. Meteorologic cal data which are now being routinely collected at stations between Barter Island and Point Barrow. These data should be processed to express climate changes in terms such as wind frequency 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 evaluated to provide a description of water structure variations and permit confirmation of general circulation patterns inferred from meteorological data.
4. Routine measurements of a limited 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 speed and direction, wave height and period, water level, water temperature, salinity, water current speed and direction, ice extent, ice pressure, and ice thickness. Basic information concerning the most probable sensor, the necessary location of the sensor, the sampling rate, and the mode of data reduction for each of these parameters is included in Table 3-5.

TABLE 3-5

APPLICATIONS OF **REMOTE SENSING**
TO ENVIRONMENTAL MONITORING IN THE BEAUPORT SEA

Physical Parameter	Sensor and System	Location	Sampling Rate	Reduction
Air temperature	Thermistor, etc.	On island or structure	Hourl y	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 seafloor	Hourly	Digital
Water currents	Current meters, etc.	Nearby seafloor	Hourl y	Digital
Ice presence	Satel lite , or photography, or radar	Orbiting, or on-island	Daily	Human interpreter
Ice thickness	Over-ice radar	O n - i c e	weekly	Human interpreter
Ice salinity	Sampling	cm-ice	Weekly	Human interpreter
Ice temperature	thermistor, etc.	On-ice	Daily	Digital
Ice transmi ssivi ty	Photo cell, etc.	on-ice	Week/month	Human
Dissolve oxygen	Special sensors	Water column near island	Hourl y/dail y	Varies
Chemical contaminants	Special sensors	Water column near island	Hourly/dail y	Varies
Sediment load	Photocell, etc.	Water column near island	Hourly/dail y	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 expanses of turbid ice may be formed during fall storms. Phytoplankton productivity during the limited growing season is the major source of organic carbon for most of the upper trophic levels of the **Beaufort** Sea. Highest phytoplankton productivity occurs in areas off Point **Barrow** and just west of the Canadian border. Benthic microalgae is thought to contribute little to the overall energy budget of the **Beaufort** shelf (Schell 1982; Dunton 1983), primarily because of the lack of hard bottom areas suitable for attachment and because of ice disturbance of the bottom.

However, in limited areas, most notably the 'boulder patch' in **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 the major primary input to the system (Dunton 1983). Because of the limited **geographic** area and the resulting uniqueness of the **biota** of the boulder patch, the area has attained a high political **sensitivity**. **Schell** described proprietary research in 1983 showing that waterborne silt from nearby island construction depressed the growth of boulder patch kelp.

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

Other than the boulder patch kelp, **Schell** did not **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. **Densities** are generally low in the **bottomfast** ice zone inside the 2-m **isobath**. In **deeper** waters, infauna **becomes** more diverse with **polychaetes** and bivalves as numerical dominants (Carey 1981; Feder and **Jewett** 1982). In terms of numbers of individuals, a majority of **polychaetes** are **tentaculate** filter feeders with increasing numbers of **deposit** feeders and **predators** below 15 m (Carey 1981). **Bivalves** are primarily filter feeders, although surface deposit feeders (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 tested, **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 **nysids** and **amphipods**, are the primary prey of a variety of **important** fish and birds in the **Beaufort** nearshore. Carbon in these organisms is in turn derived largely from marine primary **production** (Schell 1982). There **is** a massive **influx** of **nysids** and some **amphipods** as the **bottomfast** ice melts from the **shorelines** and **lifts** and breaks up in the lagoons (see Griffiths and Dillinger 1981). **This** onshore movement of **epibenthos** continues intermittently through much of the open-water season, contributing to a very high **temporal** and spatial variability. Because of this variability and their overall abundance, Griffiths concluded that **epibenthos** was not well suited for inclusion in a **quantitative** monitoring program, despite their obvious **importance** to higher trophic levels.

3.5.3 Fish

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

A number of **anadromous** species, primarily **salmonids (ciscoes, whitefish, and char)**, are seasonally abundant in the nearshore 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 overwinter in fresh water or delta areas 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 Beaufort**, the **most important anadromous** species is likely the Arctic **cisco**, which is the subject of commercial and **subsistence** fisheries in the **Colville River** as well as a **subsistence** harvest near Kaktovik. Large numbers of this species (200,000 to 1,000, 000) **overwinter** in the **Colville** from which they emigrate each spring to feed along the coastline. Because no mature fish have been found in the **Colville** or in other Alaska rivers, **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** waters. Broad and humpback whitefishes generally stay closer to their home streams than the **ciscoes** and, as such, would be more vulnerable to localized rather than regionalized impacts. **Arctic char**, like **Arctic cisco**, range widely in the coastal waters. Major populations occur from the **Colville** east in streams with headwaters in the **Brook Range**. In contrast to the situation in the **Chukchi Sea**, char are not subject to intense commercial or subsistence fishing in the **United States Beaufort Sea**. **Overwintering** and spawning char in upper **Colville** and **Sagavanirktok** tributaries have been indexed by aerial survey for several years (**Bendock 1983**).

Galloway reported on recent field and laboratory studies (see Griffiths 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 been 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** ter quality conditions encountered. In another modeling effort, Galloway has used population parameters gathered in the **Colville Delta** commercial fishery to model catch per unit effort in **the** fishery over the years 1967 through 1981. Fit has **been** generally good. **The** predicted **values** tracked well during a major population decline in 1978-1980 that resulted **from** the unexplained loss of an entire year **class** from the population.

3.5.4 Birds

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

By mid-June, most birds have **completed** their migration through the **Beaufort** Sea and many have **dispersed to** tundra nesting **habitats**, away from the coast. However, **a** large number do nest on the barrier islands and in the **river** deltas. **The** most **important** of these **locations** have been **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 (see Figure 2-1)

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

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

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 **Teshkepuk** 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 be 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 Slops **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 Beaufort (or northeast Chukchi) Sea. In addition to major oil spills (not the focus of this workshop), the major pollutant of concern with respect to whales is noise. There is some evidence that levels of noise from normal 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 noted 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 patterns, increasing overwater distances that must be traveled in the hunt. Concern is also growing that this same displacement may interfere with the Kaktovik hunt.

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

Albert reported that next to the bowhead whale, the most important marine mammal in the area of concern is the ringed seal, followed by the bearded seal. Both are ice-associated species with ringed seals widely distributed across the landfast ice zone in winter. Aerial censusing has been conducted by Alaska Department of Fish and Game for several years in various areas of the Beaufort Shelf (e.g., Burns et 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 area off Prudhoe Bay. 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 AND 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 **Beaufort** Sea **ecosystem**. **In order to** assess whether such inputs might affect the ecosystem, it **will** be necessary first **to** determine whether inputs of such **contaminants** occur in quantities sufficient to **significantly** raise the environmental concentrations of these contaminants. Since both trace metals and hydrocarbons are found naturally in marine **ecosystems**, it is usually difficult to interpret data showing changes in the environmental concentration of a particular **metal** or of hydrocarbons. Since natural variation may be large, such data can be reasonably interpreted as demonstrating a significant contaminant input only if dramatic concentration increases are found. However, the elemental and hydrocarbon composition of contaminant inputs is generally significantly different than the characteristic composition of environmental samples that reflect natural hydrocarbon and **trace** metal sources. **Therefore**, the use of **geochemical** indices (ratios of elements and compounds, or indices dependent upon such ratios) can often permit detection of contaminant inputs at much lower **levels** than would measurements of a single element and single or total hydrocarbons. **In addition, these** indices can often be used to identify the sources of such contamination.

P. **Boehm** (**Battelle New England**) presented **detailed** information to the workshop participants concerning the potential use of hydrocarbon indices in the **Beaufort** Sea. His presentation was supported by a **paper** giving detailed descriptions of the use of various hydrocarbon indices

and proposing a sampling and analysis scheme to utilize these indices in monitoring oil and gas development inputs to the Beaufort Sea ecosystem. The remainder of this section summarizes the major points of Boehm's presentation and paper.

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

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

Monitoring of hydrocarbons in sediments should be concentrated in offshore, low-energy areas where fine-grained sediments are found and where hydrocarbons will tend to accumulate. Nearshore sediments will generally only be affected by hydrocarbon contaminants when spilled oil

is **allowed** to **reach** the shore or when great quantities of oil are spilled **and** "tar-mats" are formed. Sediment **analysis** should be performed only on the upper layer of sediments and, if possible, **on a** layer with the smallest thickness that contains all of the inputs since the last sampling period. Since the character of the sediments and **factors** such as **bioturbation** affect the availability of **sedimented** hydrocarbons, the **exposure** of marine **benthos** to hydrocarbons should be **assessed** through analysis of **hydrocarbon** levels in organism tissues, particularly levels in surface deposit feeders (such as Macoma spp.) which feed on the recently deposited 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 be very slow in the Beaufort and oil spilled under ice or trapped within annual ice will not weather significantly. Second, evaporation of oil released to the sea surface will be slow compared to temperate conditions, and this reduced rate of evaporation may prevent the loss of the more toxic **volatile** fraction from the oil before it is sedimented. Therefore, **sedimented** oil **may** be more toxic in the **Arctic** than in **temperate** conditions. Finally, marine bivalves in the Arctic **depurate** oil very slowly, requiring 1 year to "near totally" depurate after an acute exposure and even longer after chronic oil exposure.

The sampling plan for hydrocarbon monitoring in the Beaufort should include sediment and biotic measurements, and caged **biota** experiments at the same **sites**. **The** stations sampled should be established hierarchically. Regional or **areawide** stations should include those for which baseline data already exist and which are **located** in probable spill and **depositional** impact zones. These stations should be sampled at 2- to 5-year intervals, with the probable impact zone stations being monitored annually when activities are such **that** impacts may be more likely (e. g., after spills). Site-specific **stations** should be established radially around specific activity **sites**, such as rigs or gravel island construction sites, and should be monitored at least annually during the lifetime of the activity **and** any "recovery" **period**. **These** site-specific **stations**

might reasonably be established **and sampled as** part of **permit compliance** monitoring programs.

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

Compositional **data can** be used **to** investigate **changes** in **hydrocarbon levels** and to determine the origin of the hydrocarbons through a number of indicator **compounds** and **parameters** and several **geochemical** indices. These are listed in **Table 3-6**.

In order to obtain the maximum information from the proposed hydrocarbon analysis **program**, sampling for chemical analysis should be coordinated both in time and in space with any samples taken to assess biological population structure and health. The monitoring **program** should be aware **of** the existence of numerous natural deeps in the **Beaufort** region, including those in Simpson **Lagoon**, near **Umiak**, and near the **Colville** River delta which empties into Harrison Bay.

Although not **extensively addressed** by the workshop, **metals analysis** and analysis **of organics**, such as **lignosulfonates**, should be emphasized during monitoring of exploration **activities**, while hydrocarbon **analysis** should be emphasized during monitoring of production activities and spill **situations**. **Metals**, such as barium or chromium, may be **good** indicators of drilling mud fate and distribution during the exploration phase when **very little** hydrocarbon release **would be** expected. Other metals, such as

TABLE 34

HYDROCARBON INDICATOR COMPOUNDS OR GROUPS

1. Total n-alkanes:	Quantifies n-alkanes from n-C ₁₅ to n-C ₃₄ ; baseline data are available at areawide stations in the Beaufort. This total is directly related to the fineness of the sediment and, hence, to the total organic carbon content.
2. n-alkanes [C ₁₀ -C ₂₀):	Crude petroleum contains abundant amounts of n-alkanes in this boiling range; unpolluted samples are very low in these alkanes.
3. Phytane :	This isoprenoid alkane is low in abundance in unpolluted sediment; crude oil contains significant quantities of phytane.
4. Total polycyclic aromatic hydrocarbons (PAH I):	The sum of 2-5 ringed PAHs is a good quantitative indicator of petrogenic addition if statistical limits are determined. The sum of 2-5 ringed PAH is a better indicator since these components are more prevalent in oil.
5. Saturated Hydrocarbon weathering Ratio (SHWR):	This diagnostic petroleum weathering ratio has been applied to spill situations to determine the degree of weathering. Weathering models may be based on this parameter in conjunction with the next (AWR).
6. Aromatic weathering 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-C ₁₈ Ratio:	These parameters are measures of the relative abundance of branched, isoprenoid alkanes (slower to be biodegraded) to straight chain alkanes in the same boiling range. These 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 low and increases as oil is added.
9. n-alkanes/Total Organic Carbon (TOC):	The ratio of total saturated hydrocarbons (TSH) to TOC, or n-alkanes (a subset of the saturated hydrocarbons) to TOC has been used to monitor oil inputs. In sediments receiving "normal" pollutant inputs within a given region, a specific TSH/TOC or n-alkane/TOC ratio is characteristic of the "geochemical province." TOC, n-alkanes, and other pollutants are associated with finer particles (i.e., high silt/clay content). Small (tens of ppm) additions of petroleum to the sediment cause the ratio to increase dramatically, since n-alkanes (mg/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 addition.
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 PAHs 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 (e.g., dibenzothiophene and its alkyl homologues). This ratio is designed to determine the approximate percentage of fossil fuel to total PAH.
13. Alkyl Homologue Distribution (AHD) curves (relative abundance plots of homologous series, number of alkyl carbons present on side chains or polycyclic aromatic hydrocarbons) :	Used to look at the relative importance of fossil fuel and combustion PAH sources.
14. Biomarkers :	The pentacyclic triterpane distributions in sediments from the Beaufort Sea are primarily derived from biogenic sources. In 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

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

R. Atlas (University of Louisville) **described** the potential application of microbial analysis to monitoring of the **Beaufort** Sea with **respect** to oil and gas activities. Four generic approaches are possible: indicator organisms, indicator species, indicator activities, and community analyses. One or more of these approaches may be used **to** identify effects caused by two possible 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. **Moreover**, the microbial community is much larger in sediments than in other **parts** of the marine ecosystem and, therefore, is easier to study.

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

organisms may require analysis for concentrations of the pathogens themselves. However, unless enormous human population increases occur in this 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 will provide totally adequate protection. No regionwide monitoring for pathogens is justifiable for the foreseeable future.

Although the indicator organism method is the standard approach for assessing sewage contamination in the marine environment, this approach is not applicable to hydrocarbon contamination since no suitable indicator microbe species is known. However, an indicator population approach can be used based on measurements of the number of hydrocarbon-degrading bacteria present in the sample. All natural sediments contain hydrocarbon degraders at low levels (0.01 to 0.001 percent of the microbial community). When hydrocarbons are added to the sediments by spills, this population size increases rapidly, often by several orders of magnitude (to 0.1 percent or more). Populations of hydrocarbon-degraders also increase in response to chronic low-level inputs. However, the rate of increase is slow in the low temperatures of the Beaufort Sea environment, as demonstrated by the observed response to a deliberate input to the sediments of several parts per million of oil (Table 3-7).

TABLE 3-7

RESPONSE OF BEAUFORT SEA SEDIMENT MICROBES TO HYDROCARBON EXPOSURE(a)

Exposure Time	Direct Count (Number x 10 ⁸ /g)	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	5.5 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	6.5 X 10 ⁻⁵
8 months	4.5	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 population** assays. **However**, the major disadvantage **is** that the method does not distinguish between **biogenic** end **petrogenic** sources of **hydrocarbons** and, therefore, cannot distinguish between **oil** and gas development related inputs and natural seeps, changes in **land** runoff (part of 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 perform** 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 and, consequently, there are only limited data on which **to base** interpretation of any observed community structure changes. **Further**, very extensive and **expensive** analysis and data acquisition are required for microbial community structure analysis.

A second type of microbial community analysis which could be **applied to monitoring for** hydrocarbon or **heavy metal** contamination of the **Beaufort** Sea is the analysis of change in the abundance of **plasmids** in the population which code for resistance to these contaminants. Although the **methodology** for this **analysis** is **simple** and less **expensive than** microbial community structure **analysis**, a number of limitations are inherent in the use of this technique. **These** limitations include the lack of knowledge concerning the natural abundance and **variability** of the appropriate **plasmids** in the **Beaufort Sea**, and the fact that an increase in the number of appropriate **plasmids** does not demonstrate a cause-and-

effect **relationship with the** source of pollution. **This causal relationship is** not identifiable since **plasmid** levels will **vary with** any change in natural or **anthropogenic inputs** of hydrocarbons or heavy **metals** and these **responses** are still **poorly** understood.

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

3.6.3 Biological Community Studies, Sublethal Effects Studies

Since suspended solids concentrations in most of the **Beaufort Sea** are normally very high, it is likely that chronic or acute contaminant inputs of hydrocarbons, other organics, and heavy metals will become 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 effects. These methods may be considered in three categories: population structure studies, sublethal effect studies, and sublethal effect studies on sentinel organisms. Population structure studies generally try to identify changes in species composition which may be caused by the combination of a variety of lethal or sublethal effects on one or more sensitive species and/or by changes in the physical or chemical environment 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 and identified; changes are assessed by comparison with reference communities or with samples taken at the station at an earlier time. Because simple comparison of species lists and abundances from sample to sample is usually not informative and always difficult to interpret, population structure data must be reduced into some form of population index. Many such indices have been used including diversity, rare fraction methods, dominance-diversity curves, log-normal distribution, changes in size class distribution, multivariate techniques (e.g., numerical, classification, ordination, discriminant analysis, multiple regression, and canonical correlation), and the benthic infaunal trophic index (Section 3.6.4).

While one or more of these methods may be promising for application in the BSMP, they all suffer from the same major problem. That problem is that natural marine communities, particularly those in coastal waters, exhibit a high degree of small-scale spatial and/or temporal variability, the causes of which are poorly understood. As a result, population structure investigations often produce ambiguous or uninterpretable results. It is seldom possible to separate changes due to natural causes from those due to chronic, or even acute, pollutant inputs. This is particularly true when the pollutant-induced changes are subtle, as would

be expected in the **Beaufort unless** a major spill event occurred. This drawback to population structure **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 benthic **infaunal** **moni** to ring 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 been evaluated for diagnosing pollutant stress in teleost fish. These are summarized in Tables 3-9 and 3-10. Because fish regulate their internal biochemical composition and metabolism much more precisely than most invertebrates, attempts to apply these same biochemical parameters to benthic invertebrates have generally met with little success.

Generally, monitoring of fish populations for pollutant stress is most effectively performed by studying a number of different morphologic, biochemical, and physiological changes simultaneously. Fish exposed to pollutants, including petroleum, may respond with a variety of simultaneous changes, including increased disease incidence, and a variety of histological and biochemical changes. Unfortunately, many species of fish are migratory and are not suitable to use in determining the effects of pollution, since it cannot be determined where the organism became exposed. However, several species of demersal fish appear to make only limited migrations and have been shown to be good indicators of pollutant effects at a given site. In the Beaufort Sea, the Arctic cod (Boreogadus saida), the fourhorn sculpin (Myoxocephalus quadricornis), and possibly the Arctic flounder (Liopsetta glacialis) may be suitable monitoring species because of their abundance and generally demersal life style.

TABLE 3-8

**BIOLOGICAL MEASUREMENTS TO ASSESS DAMAGE
TO OR RECOVERY OF MARINE ECOSYSTEMS^(a)**

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

(a) Source: Neff, this workshop

TABLE 3-9

POTENTIAL **BIOCHEMICAL INDICATORS** OF FISH EXPOSURE **TO** POLLUTION(a)

<u>Parameter</u>	<u>Expected Response</u>	<u>Environmental Interpretation</u>
Me tal lothioneins	Induction	Exposure to Cd, Cu, Hg, Zn
Mixed Function Oxygenase	Induction	Exposure to petroleum, PCB, dioxin, PAH
Blood Enzymes Erythrocyte Aladase	Increased activity Decreased activity	Liver damage Lead poisoning
Tissue Enzymes Gill Atpases Achease	Change in activity Change in activity Oscreased activity	Unknown for most enzymes Impaired osmoregulation Exposure to organophospha te or organochlorine pesticides or some industrial chemicals
Blood Biochemical	Change in concentration	Acute pollutant stress
Tissue Biochemicals	Change in concentration or ti a sue 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 **bioenergetic** balance and energy **partitioning**, such as **scope** for growth, ratio of oxygen consumed to nitrogen excreted, **growth** efficiency, **growth** rate, condition index, biochemical composition; and histological and **cytochemical** changes, including mutation. One major advantage of **caged** sentinel organism experiments is that these biological tests can be used in conjunction with measurements of body burdens of **specific** contaminants to provide information concerning the pollutant lead/biological response relationship.

Neff suggests an appropriate **Beaufort** Sea monitoring **program** might include:

1. Ecological analysis of **benthic** community characteristics along pollution gradients (age/size structure and reproduction/recruitment of dominant benthic **species**, 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 Asterete, with studies on contaminant **bioaccumulation**, scope for growth, O/N ratio, condition index, and biochemical composition
- c. **Indicator** organisms, such as **benthic/demersal** amphipods, with studies on seasonal abundance patterns, distribution, reproduction, size/age **structure** of **populations**, length/weight regression, O/N ratio, **and** digestive enzyme activity.

3.6.4 Infaunal Trophic Index

J. word (University of Washington) discussed the history of use of the **Infaunal Trophic** Index (ITI) as a tool **to** define the area of influence of municipal waste discharges, primarily off southern California. The ITI is formed for an **infaunal** sample based on the categorization of organisms by feeding types. Values can range from 0 (100 **percent** subsurface deposit feeders) to 100 (100 **percent** suspension [filter] feeders) . The typical response 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 the 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** and 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 **ecosys tsm** are **important** (human health; valued **ecosys tsm components--VECs**) in our perception of **quali** ty of the **environ-ment** (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 understoock; then causal mechanisms through which **OCS** activities may affect **VECs** must be **postulated**. The question of how well the potential **causal** mechanisms **are** understood and the likelihood of their acting in such a fashion as to measurably affect the **VECs** must also be addressed. Potential **causal mechanisms** in the **Beaufort Sea** include such things as **contaminant exposure** (hydrocarbons, metals), disturbance effects (**noise r activities**), **circulation changes** (currents, **water quality**), and **oil spills (Section 3.2)**.

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

1. Regulatory **stipulations**, **discharge** and receiving **water criteria**, etc. will prevent significant near field effects (i.e., outside of a mixing zone or direct impact zone).
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 detecting effects. If effects are detected, then diagnostic studies may be warranted **to** establish the specific **pollutant** or activity causing the effect in question. If the effects are of sufficient concern, then management may opt to alter stipulations/criteria for future similar activities.

A third type of monitoring program (**that** which **was** the primary focus of this workshop) is required where there are concerns for broad-scale

changes in the **health or numbers** of important populations. A major **problem** with such **far field** monitoring programs **is** that **cause-effect** relationships may be very hard **to** establish; thus, it may be very hard to use the **knowledge** that **an impact has** occurred **to** make **management** decisions alleviating the cause. Nonetheless, some **potential** effects may be so **important** that managers would want to know about them even **if** they cannot pinpoint the cause.

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

In summary, Wolfe emphasized the following:

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 ask **"Do we understand the system well enough to suggest that OCS activity is likely to cause a major change in that variable in a way that can be ascribed to oil and gas development?"**

As described in Section 2.7, 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 Hypotheses and Approaches to **Regionwide** Monitoring

The workshop panel developed seven "**strawman**" hypotheses and methods to test **each**. The hypotheses and the methods for testing them would comprise the **BSMP**. These hypotheses and a summary of panel discussions surrounding each were presented **to** the full workshop for discussion in the final plenary session. This section provides a statement of each of the first five hypotheses **and** the rationale behind each as presented at the workshop. This section also includes an analysis of how well each hypothesis fits 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 **workshop** but considered more applicable in site-specific monitoring programs, as well as monitoring approaches considered by the panel/workshop but not included in the "**strawman**" program, are **treated** in Section 3.7.4.

3.7.2.1 Trace **Metals**

Hypothesis: Certain trace metals **may** accumulate in the **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 test and control sites. No discussion took place **as** to which **metals** were **those** of concern. However, earlier in **the** workshop, barium and 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 **spatial ly**, is so large that monitoring **dissolved** 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 parts of the **Beaufort**. The question of whether **transplanted populations** should be

caged or introduced into the environment at appropriate sites without such enclosures was not addressed. Also not discussed was the related question of whether the indicator species would be monitored at sampling sites throughout the Beaufort (i.e., at all sediment sampling locations) or whether monitoring would be restricted to intertidal and shallow water sites in the manner of the National Mussel Watch Program.

3.7.2.2 Petroleum Hydrocarbons

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

This hypothesis is essentially parallel to the hypothesis regarding trace metal accumulation. Therefore, the suggested strategy for testing this hypothesis is identical to that discussed for metals in the previous section. Deliberation by workshop participants of such questions as the use of sediment versus water samples, the choice of a sentinel organism, and the potential use of caged versus natural populations were included with the trace metal discussions and 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 to be of greater potential importance as environmental contaminants in the Beaufort, the best sentinel species for hydrocarbon monitoring should be selected.

Section 5.2.2 of this report details the factors which should be considered in selecting a sentinel organism species. One of the important considerations in selecting a sentinel species is the degree of

mobility of the organism. A sedentary **species** sampled from a **given site** will have a **body** burden of contaminants which generally reflects the degree **of contamination at that site**. In addition, a sedentary organism **is** more **suitable** for caged or transplant **experiments**. In contrast, migratory species **may** reflect **contamination** of **environments** far removed from the sampling site. Therefore, **sedentary** species are preferred as sentinel **organisms** since they can provide more information as to the extent and possible source of any contamination. Nonetheless, the most important of the **VECs** were judged by **workshop** participants to be those that **are** highly migratory, including whales and seals. **Because** these higher order animals have a generally higher lipid content than do lower order animals and because they are at the top of marine **food** chains, they are known to be more likely **to** accumulate greater concentrations of hydrophobic **petroleum** hydrocarbons through **bioaccumulation** 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 endangered species, necessary **bowhead** research is

appropriately and adequately covered under existing **MMS** programs. Others argued that the mandate of this workshop was to develop **an** overall monitoring program for the **Beaufort** Sea, therefore marine **mammals** should certainly **be** included. However, few workshop participants were **experts** in the area of **marine** mammal research, so even those who felt the **monitoring** program should include marine mammals were hesitant to make specific **recommendations** for monitoring them.

Two important points were made in the discussion subsequent to the presentation of the hypotheses and **monitoring** strategies. The first was that, particularly in the context of Wolfe's "redefinition of monitoring program objectives" with its **emphasis** is on 'Valued **Ecosystem** Components, " **bowhead** whales, **walrus**es, and ringed and bearded seals should certainly **be** considered.

Second, it was suggested by C. **Cowles (MMS)** that approaches to testing the hypothesis regarding **bowhead** whales should be **examined** as part of the post-workshop study design. In particular, existing aerial survey data should be carefully evaluated to determine what level of displacement in the fall migration path could be detected using aerial survey techniques.

Aerial surveys to determine the routes of **bowheads** during the fall **migration through the** Beaufort Sea have been conducted since 1979. They 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/recruitment** of **anadromous** fishes.

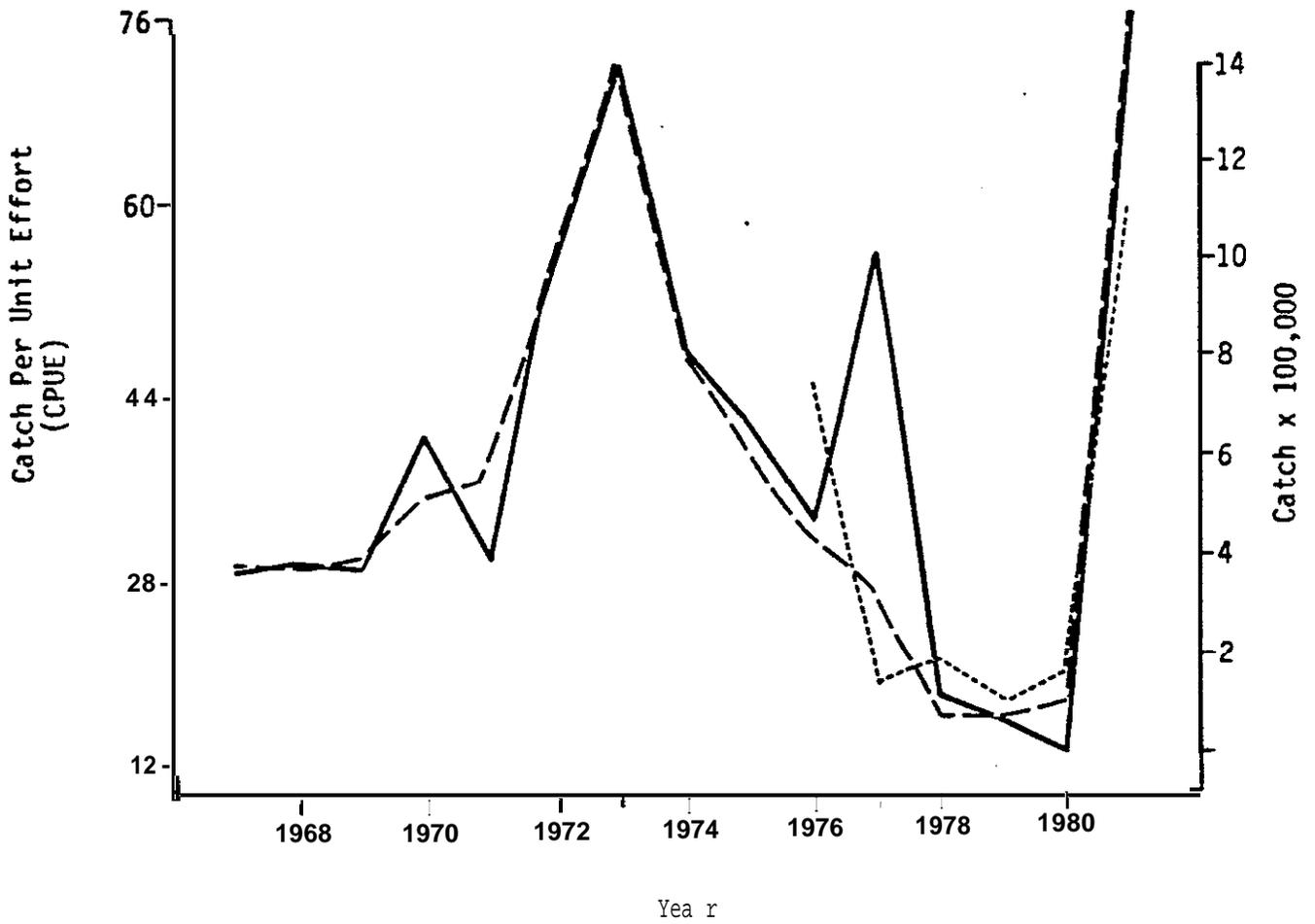
Several species of **anadromous** fish (Arctic and least **cisco**, broad and humpback whitefish, Arctic char) qualify as **VECs** based on commercial and subsistence use or potential use. As a result of their life history

(Section 3.5.3) 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 Colville**. Galloway has compiled these **data** (1967-1981) and used them along **with** recaptures of marked fish **to calculate** a population estimate for Arctic **cisco overwintering** in **the Colville**.

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

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



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** elsewhere on the U.S. **Beaufort** coast. Johnson noted that, while absolute numbers of **oldsquaw** may vary due to unrelated factors acting during their winter absence from the **Beaufort** sea, the relative abundance from place to place in the **Beaufort** was fairly constant.

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

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

3.7.3 Related Considerations

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

3.7.3.1 Physical Environmental Data

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 gathering and assessment of physical environmental data which can be used to identify variations in the "climate" or physical regime. The physical environmental data and data assessment needed for this purpose do not necessarily include detailed field descriptions of physical parameters, such as salinity, temperature, and currents. 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 species, primary production, and the availability of food for certain species. In addition, abnormally severe or quiet weather, particularly during ice formation and breakup, and during the open water period, could modify primary production, ice scour, and wind-induced wave and current redistribution of bottom sediments.

The need for "climate" information can be illustrated by three examples of rapid biological population structure changes 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 **th**at 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 area, and therefore, these physical changes **resulted** in the Chesapeake **Bay** effects. Third, the **catastrophic** kill of shellfish in the New York Bight during the summer of 1976 was initially ascribed to pollution until existing data were **examined** which revealed that anomalous physical conditions caused this event. Unusual weather in the winter **and** spring combined **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 demand, and the anomalously low oxygen resupply resulted in the **anoxia** and the shellfish kill.

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

The **BSMP** should incorporate **an** assessment approach to the **physical** regime which **is designed to** cost-effectively permit identification of **anomalous** regional-scale physical events. **In general**, 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 rates 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 necessarily compromise **the** monitoring **program** and it probably **will** not be necessary to develop extensive long-term monitoring programs to **fill** the gaps. For example, if remote sensing images of river plume extent are not routinely **available**, this information could be inferred **with** sufficient certainty from river discharge rates and wind **data**, 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 **periodic** monitoring **programs** in the **Beaufort** Sea, such as discharge compliance programs, for which physical data, including water **column** structure and current data, are obtained. Where appropriate, these data should be **acquired** on a routine basis by the BSMP and subjected **to** analysis and **interpretation** to supplement the more general **regional** data discussed previously. Such analyses become particularly important when it is **suspected** that anomalous climatic conditions may have contributed to any observed biological or chemical contaminant distribution **change**. Physical data from any **monitoring** **program** should **clearly** be incorporated in a single **data** management **system** 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 example, hydrocarbon and trace metal analyses will be performed at very low environmental concentrations. Since the monitoring program will **be aimed at detecting** small changes and trends in these environmental concentrations, it is **imperative** that the analyses produce consistent, accurate, and reproducible results, both within a given set of samples and over the years of program operation. **These** results can only be achieved if the measurement program is performed under rigorous quality control and quality **assurance** procedures. **These** procedures would require strict adherence to written field and laboratory procedures and full traceability of samples. They would also require the use of reference samples, when **possible**, and **intercalibration** studies among laboratories participating both in the **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** and 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 is usually found **to** be neither possible nor affordable to incorporate data **already** gathered into a new management **system**. For the **BSMP** to be successful, a comprehensive data and information management **system** should be **established** at the outset of the program. This **system** will **be** particularly **important** to the program, since much of the physical and environmental data critically needed to interpret any changes observed in the parameters of primary interest

(i. e., contaminant 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, **over-sampling** 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 and space. This will provide the maximum ability to interpret changes in the various parameters monitored.

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

The workshop considered in some detail the potential use of measurement techniques 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 nationwide monitoring approaches covered in Section 3.7.2.

3.7.4.1 Common Eider Nesting

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

Since at least the late 1970s, concern has been expressed that activities on or near barrier islands might disrupt breeding activities of waterfowl. stipulations attached to recent state and federal lease sales have restricted proximity of certain operations (e.g., aerial overflights) to sensitive wildlife habitats. Despite such stipulations, some concern remains that specific activities, which by their nature require closer approaches to sensitive areas (e.g., nesting habitats), may be permitted on a case-by-case basis and that these activities could disrupt breeding success. Of particular concern are colonies of common eider that breed on certain sand islands as well as the lone United States breeding population of snow geese that use an island in the Sagavanirktok Delta (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 eiders. 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. The study included mapping of nesting sites within the colony and observations **through the brooding period** of nesting **behavior** and hatching success. A higher than usual success rate was reported despite the nearby activities, perhaps because direct close range disturbance of the colony was prohibited. 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 **monitoring** of the effects of nearby activities on other island nesting colonies. However, it was considered appropriate in the context of site-specific rather than regionwide impact monitoring. As such, no action is required for the BSMP until activities approach important islands. At that time a **program similar to that** employed at Thetis Island would be designed to monitor the **specific** effects of the project in question.

3.7.4.2 Boulder Patch Kelp

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

As described in Section 3.5.1, the **"Boulder Patch"** in **Stefansson** Sound has become a **biologically** sensitive area because of its unique **epithic** 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 rate 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. Dunton (1983) showed a significantly greater mean annual blade elongation for this **species** at a study site under clear ice compared with normal growth under turbid ice cover (see Section 4.2.7). Proprietary study reports of the Exxon monitoring 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-specific activities such as that described by Schell rather than as part of a **regionwide** monitoring program. In the event that development activities encroach on the boulder patch such that a reasonable impact mechanism can be postulated, a program using the techniques of Dunton et al. (1982) would be designed to monitor changes in kelp growth rates.

3.7.4.3 Indicators of Organism Health

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

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 effects techniques **are** not readily applicable to the fish, bird, and species of major importance **in** the **Beaufort**.
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 **field 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 sites of a specific activity can be monitored more effectively through specific activity study or compliance monitoring.
2. Significant broad-scale natural changes in the **physical** environment of the **Beaufort** can be observed or inferred from **information** regarding the meteorological forcing functions and certain simple response **parameters**, such as sea surface temperature, ice cover, and river flow rates. Knowledge of such changes is needed to assess whether any observed biological population changes can **be** explained by natural **climatic variability**. **Many**, 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 interpreted, 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 as to whether these near-field physical environment changes are caused by broad-scale natural variations or the **OCS** activity.

3.7.4.5 **Benthos**

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

1. Major pollutants of concern (drilling fluids, hydrocarbons) will ultimately reside in the sediments where exposure to organisms will be maximized.
2. **Infauna** and **sessile** epifauna have limited mobility and are often long **lived** so that organisms present at a given location and time will have **been exposed to** conditions at that location over an extended **period**.
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** data 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) than it is **to** detect significant decreases. **However**, it was also noted that assemblage **variables** (diversity, richness, ●tc.) 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 requirement to only examine available data on those variables mandated by the hypotheses and **monitoring** strategies **developed** in the workshop synthesis session. The optimal **statistical** design of a monitoring program without such a constraint would involve considering available data 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 be gathered by the statisticians, even with a great deal of effort, so their choices are likely to be reasonable ones. Similarly, the restriction of **statistical** analyses to available **data** is sensible when there is a need to obtain answers quickly.

The price 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 data are inadequate for the solution of the design problem. **In** those cases, we have attempted **to** achieve a robust and flexible design which will fill the data gaps. After a year or so of monitoring, the **data** obtained should **be** evaluated to see if **modifications to** the initial sampling scheme **are** warranted.

Data sources **for** our evaluations have been computerized files provided by the Laboratory for the Study of Information Science **at** the University of Rhode **Island (URI)** **as well as published** reports and papers. In the latter category, final reports of principal investigators in the 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_0) (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_{01} There will be no change in concentrations of selected metals or hydrocarbons.
- H_{02} 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** th distribution end concentration of hydrocarbons farther offshore. Data on heavy **metal** concentrations were obtained and **summarized** by **Burrell** (1977, 1978) end **Naidu** et al. (**1961 b**).

TABLE 4-1

RESTATEMENT OF HYPOTHESES FOR STATISTICAL TESTING

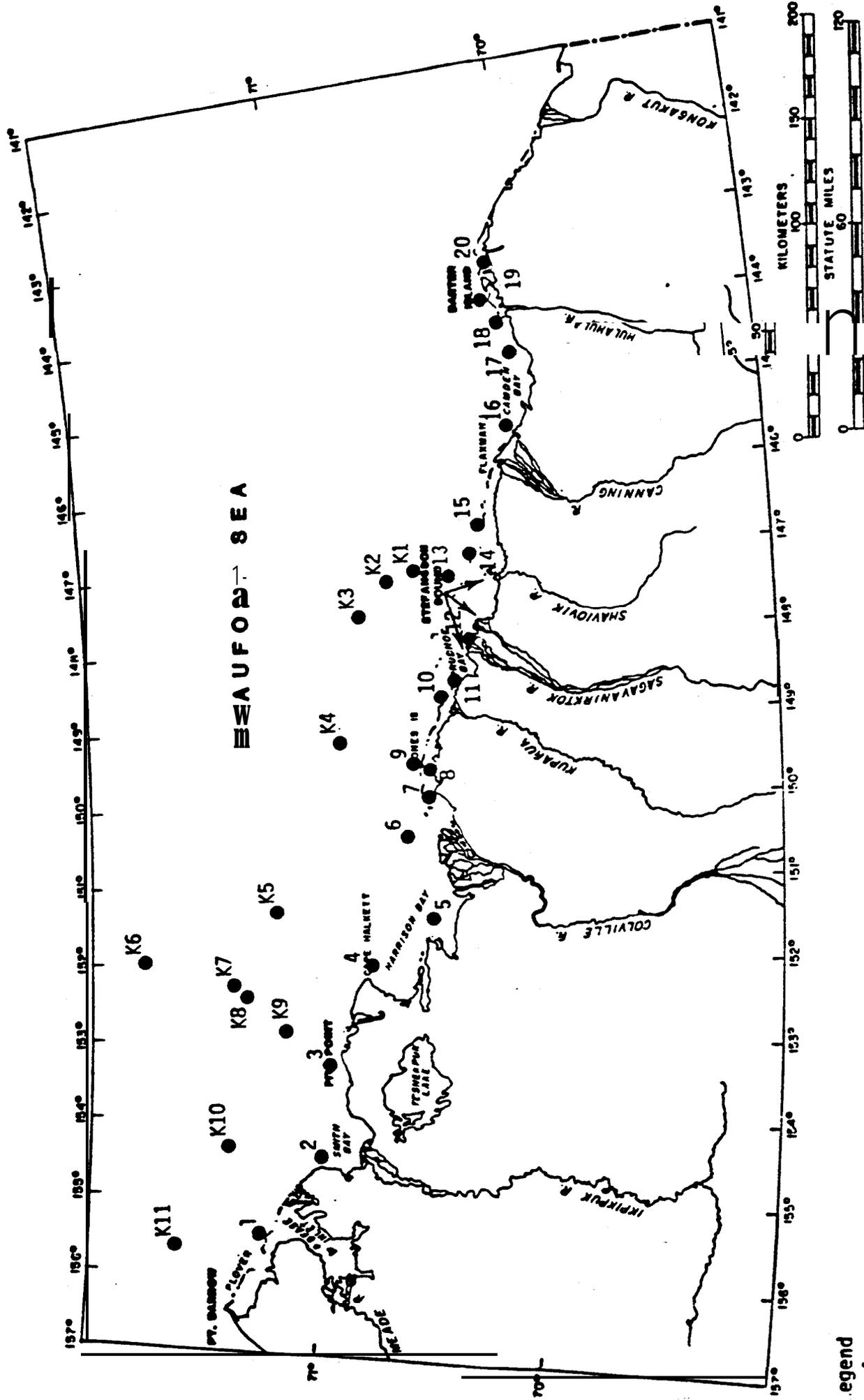
Working Hypotheses (a)		Restatement
I & II	H ₀ 1	There will be no change in concentrations of selected metals or hydrocarbons in surficial sediments.
	H ₀ 2	Changes in concentrations of selected metals or hydrocarbons are not related to OCS oil and gas development activity.
	H ₀ 3	There will be no change in concentrations of selected metals or hydrocarbons in the selected indicator organisms.
	H ₀ 4	Changes in selected metals in sediments or organisms or hydrocarbon levels will not affect human health or VECs .
III	H ₀ 1	Fall migration patterns of bowhead whales will not be altered during periods of increased OCS activity in the United States Beaufort Sea.
	H ₀ 2	Changes in bowhead migration patterns are not related to ocs oil and gas development activity.
IV	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.
V	H ₀ 1	There will be no change in relative densities of molting male oldsquaw in four Beaufort Sea index areas.
	H ₀ 2	Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.
VI	H ₀ 1	There will be no change in density or hatching success of common eiders on islands subjected to disturbance by OCS oil and gas development activity.
	H ₀ 2	Changes in density or hatching success of eiders on gravel islands are not related to OCS oil and gas development activity.
VII	H ₀ 1	There will be no change in productivity of Laminaria solidungula in areas of the Boulder Patch nearest OCS oil and gas development activity.
	H ₀ 2	Changes in Laminaria solidungula productivity in the Boulder Patch are not related to OCS oil and gas activity.

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

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) were found in higher than expected concentrations by both Shaw (1981) and Kaplan and Venkatesan (1981), perhaps due to natural oil seeps and/or input from rivers 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 spatial patchiness cannot be separated from site-to-site variability. Temporal variability cannot be assessed since each site was sampled only one time. The validity of comparisons between the offshore and nearshore stations is also questionable since they were analyzed by different investigators. The interlaboratory comparisons of trace hydrocarbon analyses reported by Hilpert et al. (1977) and Chesler et al. (1978) indicate that while intralaboratory precision in determination of, say, hydrocarbons in the gas chromatograph (GC) range in sediment samples, is of the order of +25 percent, determinations of this and other parameters of interest by different laboratories may differ by factors of 10 or more. Since analytical methodology for the determination of hydrocarbons in sediments is evolving at a rapid rate, it seems unwise to incorporate into the design of the monitoring network assumption about variability in hydrocarbon concentrations that are based on measurements made several years ago.



Legend

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

Source: Boehm, this workshop.

Figure 4-1 Area-wide sediment chemistry sampling stations

However, there were also problems in using the trace metal data. First, we were unable to obtain data on concentrations of barium, one of the metals of primary interest for monitoring **impacts** of **OCS** development activities since **it is an** important constituent of drilling muds. Second, there were many discrepancies **between data** received on taps and data **tabulated** in reports. **For** example, copper and zinc determinations on the taps matched those in **Naidu** et al. (1981a) but different values were given for the other metals. Third, while there **appeared** to be some replicate samples and analyses, they were not unambiguously identified. There were no good time areas **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** detected with any design D while a large **point** impact affecting only a single site could only be detected if that site belonged to D. Since the former assumption about the nature of the **change** leads to an overly optimistic view of its detectability and the latter to an overly pessimistic one, we adopted an intermediate assumption concerning the nature of the change.

We supposed that the Beaufort Sea from the Canadian border to Point Barrow can be partitioned into a relatively small number, k , of subregions or blocks. We assumed further that an impact caused by development activities would be confined **to** one of these blocks and that it **would** affect each site in the block equally. The blocks **are** labeled using an index i , $i=1, 1, \dots, k$. Finally, we assumed that **we** can assign

probabilities P_i (with $p_1 + p_2 + \dots + p_k = 1$) that if a change occurs then it will occur in block i .

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

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

- 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 is the same for all sites in a given block, a site-specific component, and a component due to sampling error at the sampled site.

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 sites and then, at each step, the "best" block for the next site, given that the sites determined at the previous step are to be sampled.

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

- H₀2 Changes in concentrations of selected metals or hydrocarbons in . . . organisms are not related to OCS oil and gas development activity.
- H₀3 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 metals in Beaufort Sea bivalves. Shaw (1981) reports hydrocarbon concentrations in tissues of clams (Astarte sp. and Liocyma sp.) collected from the nearshore Beaufort Sea in the summer of 1978. Shaw (1977) analyzed concentrations in Macoma balthica, Mya arenaria, and Mytilus edulis.

A few measurements of heavy metals (Burrell 1977, 1978) and hydrocarbons (Chesler et al. 1977; Wise et al. 1979; Shaw et al. 1983) in Mytilus tissue area available from other Alaskan locations. Our statistical evaluations also relied on the experiences of mussel watch

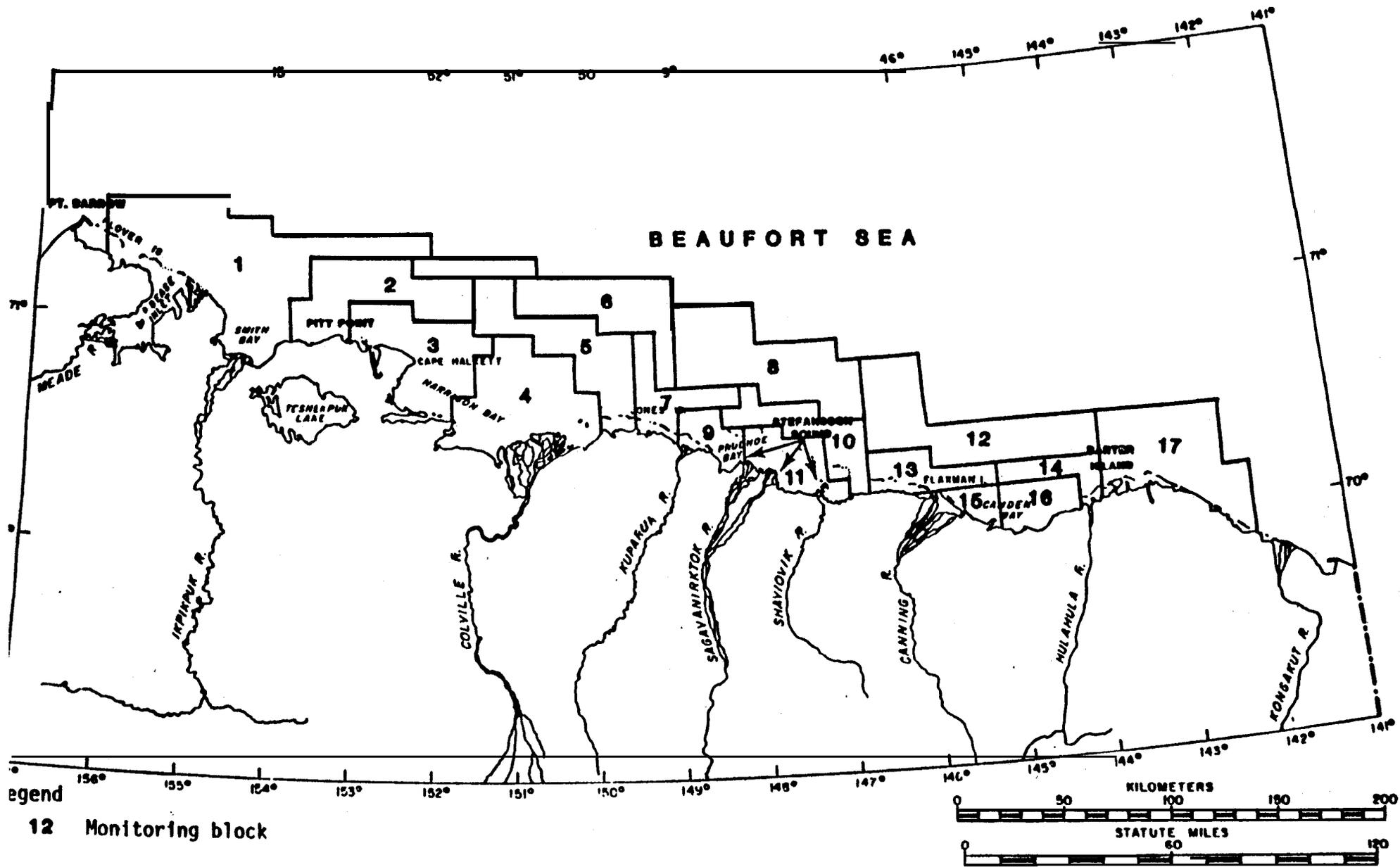


Figure 4-2 Sediment monitoring network block configurations

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 east of **Barrow**) and **Tigvaviak Island** (70°16.1 'N, 147°38 .0'W) using gas chromatography. He found strikingly low concentrations of hydrocarbons, many below detectable levels. For example, the mean concentration of total unsaturated hydrocarbon in the four **Astarte** samples from Elson Lagoon was 0.43 mg/kg and the standard deviation, was 0.19 on a wet weight basis. Aromatic 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 measurements from other parts of the world and finds the Alaskan values to be among the lowest. He does not report standard deviations for these measurements, 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 determined from a summer 1975 sample was 4.5 mg/kg while the summer 1976 value was 6.3 mg/kg (dry), giving a concentration mean of 5.4 mg/kg and a sample standard deviation of 1.3. These values are comparable to mussel watch values on the United States west coast presented 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 minimum 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 variability due to analytical error, within-site differences, and between-site differences. This sort of analysis of variance is needed if the power to detect changes of various magnitudes under a given sampling scheme is to be computed and an optimal monitoring plan determined. Thus multiple pools of individuals from each site and multiple analyses of each pooled sample are needed at least at the beginning of the monitoring program (see Section 5.2.2).

The International Mussel Watch (1980) stresses the importance of intercalibration of analytical results. For metal concentrations, +20 percent of the certified value is cited as a reasonable standard of accuracy on a reference material.

According to the report, standard reference materials for trace-level hydrocarbons in mussel tissue cannot be issued until problems associated with sample homogeneity, storage stability, and matrix effects are resolved. Results by Dunn (1976) on the precision of analyses of mussel homogenates for benzo(a)pyrene using subsamples of 20 to 30 g of tissue found standard deviations of analytical results ranging from 3.2 to 8.1 percent of the mean. Wise et al. (1979) compared laboratories' determinations of total extractable hydrocarbons, total hydrocarbons in the GC elution range, pristane/phytane ratio, and concentrations of the most abundant aliphatic and aromatic hydrocarbons for mussel samples. Good agreement among laboratories was shown in some cases. In other cases, measurements among laboratories differed by a factor of 2 or even by an order of magnitude or more. These discrepancies accentuate the need for standardization of analysis techniques and intra- and interlaboratory calibrations, especially in the early stages of the Beaufort Sea mussel watch.

4.2.3 Bowhead Whale

Restated Hypotheses:

H₀1 Fall migration patterns of **bowhead whales** will not be altered during periods of increased **OCS** activities in the **United States Beaufort Sea**.

H₀2 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" component through deep waters north of the shelf break in August and a "nearshore" component which usually passes through the region between **mid-September** and **mid-October**. It is the nearshore component which is of interest since it is this component which is most vulnerable to disturbance by **OCS** oil and gas development activity and is also most important to humans on the North Slope, especially subsistence hunters from **Kaktovik, Nuksut,** and Barrow. We have therefore **concentrated** on September and October data in our **analyses** of HOI .

Ljungblad (1983) notes that routes of the fall **bowhead** migration in the years of heavy ice cover, 1980 and 1983, are more difficult either to observe or to **predict** than in **lighter** ice years. It is likely that in severe ice years, any effects of **OCS** oil and gas development on the whales * migration **path** would be small relative to effects of the ice conditions. It would likely be impossible to separate ice-caused from **man-caused** effects. We have therefore restricted our **analyses** to data from the light ice years 1979, 1981, and 1982.

Objectives of the fall aerial surveys have differed from year to year with consequent shifts in areas surveyed and methods used (**Ljungblad et al.** 1983). In 1979 nearly all effort was concentrated near the proposed **state/federal** oil lease areas, **with random** north-south transects flown **in** a block between 146°W and 149°W longitude and bounded on the north by the 70°40'N latitude line. There **were** a few flights north of **this** block to 71°20'N, west to 151°W, and east to 143°W but almost no

effort in **the rest** of the United States **Beaufort Sea**. In **1981** there was again almost no effort offshore, i.e., north of the 200 meter (m) **isobath**, and almost none west of **153°W**. In addition, an attempt was made to conduct both behavioral studies and surveys of relative abundance and migration routes using the same **airplane**. As a result, relatively few **random** transect survey data were obtained. In **1982**, two aircraft were provided for fall towhead studies. Thus, a fairly complete survey of the entire area **from 141°W to 157°W** and north to 72°N could be conducted. In addition, monitoring of seismic operations, whale **behavior** (including responses to geophysical vessels), and migration timing was possible.

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

Peak towhead 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, 1981, 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 0-m to 10-m stratum. Absolute density values varied considerably from year to year. For example, confidence ranges given in Table **B-13** of **Ljungblad et al.** (1983) indicate that densities in the 20-m to 50-m stratum between 146°W and 150°W were significantly different in 1981 and 1982.

These analyses indicate strongly that during light ice years, the vast majority of **bowheads** in the nearshore fall migration travel **between** the 20-m and 50-m depth contours. The distance between these contour lines is roughly 20 nautical miles (nm) in the eastern half of **the United**

States **Beaufort**, narrowing in much of the western half, particularly north of Harrison Bay and near Point **Barrow**. Thus, the hypothesis of a seaward displacement of the fall migration path, particularly in the region between the Canadian border and Camden Bay, can be formulated as a shift to following deeper depth contours, with a 3-m depth change corresponding roughly to 2-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 on when and where survey effort is concentrated, as well as on such external factors as visibility conditions. Therefore, we would expect to see statistically significant between-year density differences like those of Table B-13 within any set of subregions considered. Differences which might be attributable to OCS development would be hard to distinguish from those due to a combination of these other factors.

What is needed is a simple statistic which adequately defines an axis of migration. The statistic we propose is the median water depth for bowhead sightings on random N-S transect surveys conducted during September and October. In other words, we define the observed axis of migration as the depth contour such that half the sightings during these surveys were at shallower (or equal) depths and half at deeper (or equal) depths. This sample median can be computed for the whole Beaufort coastline or for a subregion defined by longitude. For example, 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 sightings rather than of individual whales seen for several reasons. The first is that the depths used in computing the median need to represent independent **random** observations if we wish to derive confidence intervals for the population **median**. The water depths corresponding to the individual whales in a group when a group is sighted are clearly not independent; in fact, they are all the same. secondly, although **Ljungblad** (1983) is not aware of any differences in **sightability** of bowheads as a function of **water** depth, counting sightings rather than individuals would help remove biases due to such differences if any did exist. For example, if individuals spent more **time** at the surface at one depth than at another **and** were thus more likely to be seen, and if groups which were actually the same size were sighted at each depth, more individuals might be counted in the first group than in the second.

We omitted E-W search transects because water depths of sightings along such transects are clearly not a **random** sample of depths of all possible sightings; depths for a search along the 30-m contour will all be close to **30 m**. In order for the sample median of sighting depths to accurately represent the **axis** of migration, all depths which the migrating population uses must be adequately sampled. The **N-S** line

transect surveys in September and October of 1982 appeared to represent thorough coverage of the depth range of interest.

Tests for a displacement in the axis of migration assume that there is a "true" axis of migration, the median depth for all possible bowhead sightings 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 east of 146°W longitude, based on 41 sightings, is (37 m, 42 m).

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

We were unable to perform any of these tests on the 1979 and 1981 data because water depths were not given in Ljungblad et al. (1980) or Ljungblad et al. (1982). However, a rough comparison between these years and 1982 was performed by assigning 1979 and 1981 sightings to categories of less than or equal to 30-m depth and greater than 30-m depth using the latitude and longitude of the sighting and the 30-m depth contour shown on the maps in these reports. Some sightings near the 30-m contour may have been incorrectly assigned in this analysis due to inadequate resolution of the maps. However, the results, shown in Table 4-2, appear to be consistent with the 1982 data.

In both 1979 and 1981 there were more sightings in water depths exceeding 30 m than at shallower depths, so the sample median is greater than 30. Plots of the sightings indicate that confidence intervals would almost certainly overlap the 1982 confidence intervals. In all 3 years

TABLE 4-2

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

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

(a) **Behavioral**, search, and E-W line transect surveys omitted.

(b) Source: **Ljungblad** et al. 1983.

considered, the data suggest that the median depth may be slightly greater between 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 get 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 depth, and suppose these true medians **happen** to fall **at** the **lower** limit 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 were (39 m, 46 m), **compared to** the 1982 interval (**31** m, 38 m). For sightings east of 146°W longitude, the **corresponding** intervals are (43 m, 48 m) and (37 m, 42 m).

Under our assumptions concerning the true medians, these results would represent detection of differences of $46 - 31 = 15$ m, or roughly 10 nm, and $48 - 37 = 11$ m, or roughly 7-1/2 nm, respectively. Since these assumptions represent a "worst case" situation among intervals which cover the true **medians**, it seems likely that the power of this test to "detect a displacement of 5 nm to 10 nm in the axis of migration is fairly high.

However, these rough calculations depend on a number of assumptions about past and future surveys. These **are** addressed in Section 5.2.3 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 (Table 4-3) **f or independence of wa** ter depth **and** group size which showed no dependence in the 1979, 1981, and 1982 data. **A chi-square** test for independence of row and column classifications in this table gave a **chi-square** value of 1.77, which is not significant ($p < 0.5$). **Tests** on data for each year separately also indicated no significant relationship between water depth and **number** of whales per sighting. Similar tests **could** be **performed** on data **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, 1981, AND 1982^(a, b)

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

(a) Behavioral, search, and E-W line transect surveys omitted.

(b) Source: **Ljungblad et al. 1983.**

4.2.4 Anadromous Fish

Restated Hypotheses:

H₀1. There will be no change in catch per unit of effort (CPUE) in the Colville River Arctic cisco fishery.

H₀2 Changes in Arctic cisco CPUE are not related to OCS oil and gas development activity.

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

These data are plotted in Figure 4-3. Catch per unit effort (CPUE) is plotted for the Arctic cisco data. Both the cisco CPUE and the char 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 after. Bendock notes that this change might also contribute to differences in the estimates.

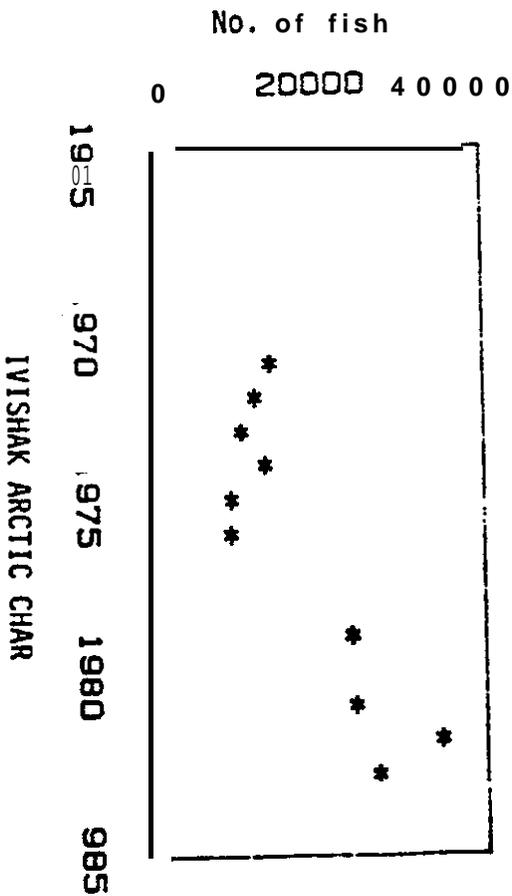
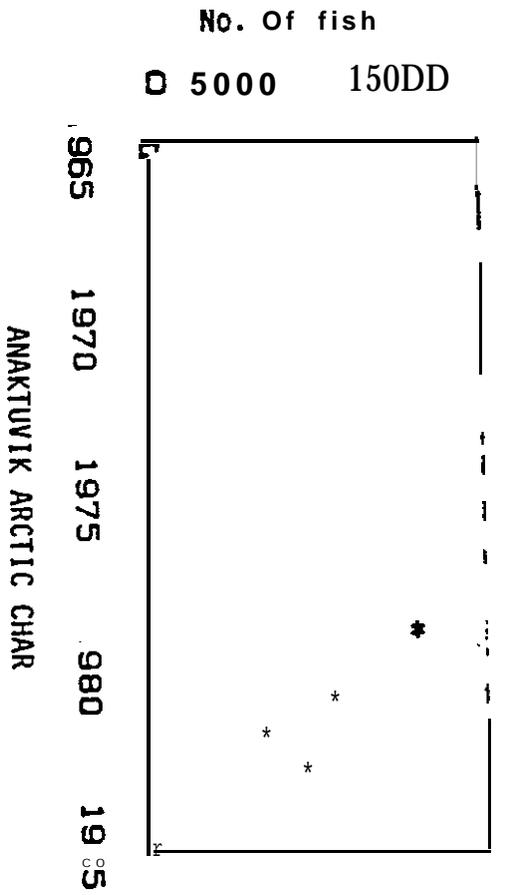
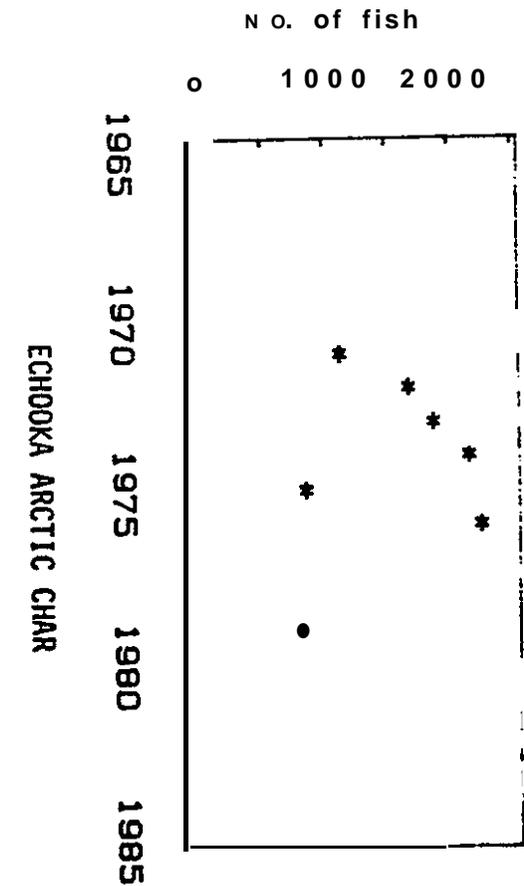
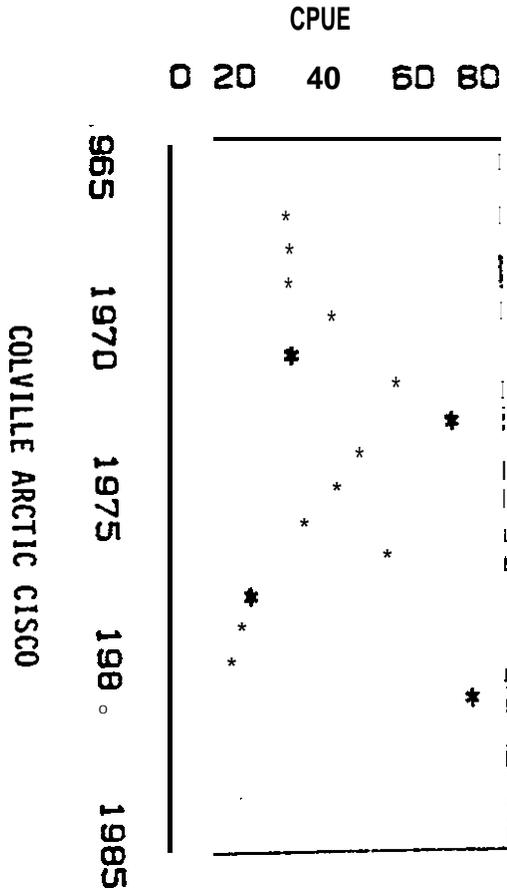


Figure 4-3 Colville Delta CPUE for Arctic cisco and Arctic char aerial index counts from three North Slope rivers (see text)

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

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

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

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

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

We assume for the purpose of this power calculation that both the baseline sample and a postdevelopment sample of n_2 years of Arctic cisco CPUE data from Helmericks' fishery are normally distributed with the same standard deviation: approximately 19.5. We would perform a one-sided two-sample t-test if we wished to detect a decrease in mean CPUE which might be due to development. Then Table A-1 2b of Dixon and Massey (1969) allows us to determine the power to detect various magnitudes of change in mean CPUE values with tests of various levels; (see Appendix C). The detectable changes are given in the following table for level $\alpha = 0.05$.

n_2	Power				
	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 .5 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 quite large to be detectable with high probability.

In spite of these odds, **changes** may **well be** detected among years. For example, if the **data** from 1967 through 1977 had been **treated** as a baseline sample and compared with the **data** from 1978 through 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 dynamics and/or environmental **conditions** ignored by this simplistic statistical analysis. **Thus**, if H_0 above were rejected in the future monitoring of the fishery, the assignment of cause would require a considerable amount of additional data concerning the **population's** age structure, reproductive success, and environmental changes (natural and man-caused) across several hundred miles of the United States and Canadian **Beaufort** Sea **coastline**.

4.2.5 Oldsquaw

Restated Hypotheses:

- H_0 1 There will be no change in relative densities of molting male **oldsquaw** in four **Beaufort** Sea index areas.
- H_0 2 Changes in male **oldsquaw** distribution **patterns** are not related to OCS oil and gas development activity.

The workshop **proposal** for testing for change in the distribution **patterns** of birds incorporated the approach **suggested** by Johnson in his presentation. **Oldsquaw** ducks were selected over other species for monitoring because they are the most ubiquitous local waterfowl in the summer and fall. Aerial surveys of **males** in the lagoon system during the summer molting period (mid-July to mid-August) were **recommended**.

Since the birds **are** flightless for **about a** month after molting, they are particularly vulnerable **to** oil spills or other disturbances. They are **also** easier to monitor then, since they stay in one place long enough to be counted.

Although absolute numbers of birds **per square kilometer** vary greatly from year **to** year, it **was** maintained that relative concentrations in particular areas stay the same over the years. High use areas such as Simpson Lagoon would always be **expected to** have higher concentrations than other areas **in** the absence of environmental changes.

A great deal of background data on **oldsquaw** distributions is available (see, for example, Johnson and Richardson (1981) and the references cited therein). **Johnson** and Richardson report on intensive aerial surveys of the Jones Islands-Simpson Lagoon system conducted in **1977, 1978, and 1979**. **Areas** east and west of Simpson Lagoon **were** also surveyed.

The transects flown are described in Table 4-4. Survey **procedures** were standardized as much as possible. **However,** three different **types** of aircraft (**both** helicopter and fixed-wing) were used. In addition, bird counts were recorded at different time increments in different years.

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 (1981), comparing mean **oldsquaw** densities in the Simpson Lagoon area with areas to the east and west, do not appear to support the contention that relative concentrations in different areas are constant **from year to year** or even within the molting period in a given year. If we extract the relevant **data** from these figures, we obtain **Table 4-5**. Johnson and Richardson argue that the low densities east of Simpson Lagoon **in 1978 may be** due to inadequate survey effort, but they do not offer an explanation of the changes in relative importance of the areas 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 Joins Islands, 2! to w.
2	37.0	Lagoon-south shoreline of barrier islands	From W end Spy 2s., 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 93., E to Beechey Pt.
s	33.8	Mainland tundra	4 km inland from Simpson Lagoon, E to W.
b	13.8	Mid-lagoon	Harrison Bay from 6 km S of Oliktok 9s., 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	35.7	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 2s. 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 2s.
15	152.1	Lagoon-south shoreline of barrier islands	From W end Arey 2s., 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 Scald 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

UNWEI GHTED MEAN DENSITIES OF OLDS QUAWS DURING THE MOLTING PERIOD
1979 AND 1979, IN SIMPSON LAGOON AND AREAS TO THE EAST AND WEST

Area	Date				
	7/1 5/78	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** (1982) which also support the **claim** that relative densities are consistent. Surveys of 10 lagoons in the Arctic National Wildlife Refuge in 1981 and 1982 **yielded** densities which showed a high year-to-year correlation (**r=0.92, P< 0.001**) .

We requested all available aerial survey data on **oldsquaw** during the July 15-August 15 molting period 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).

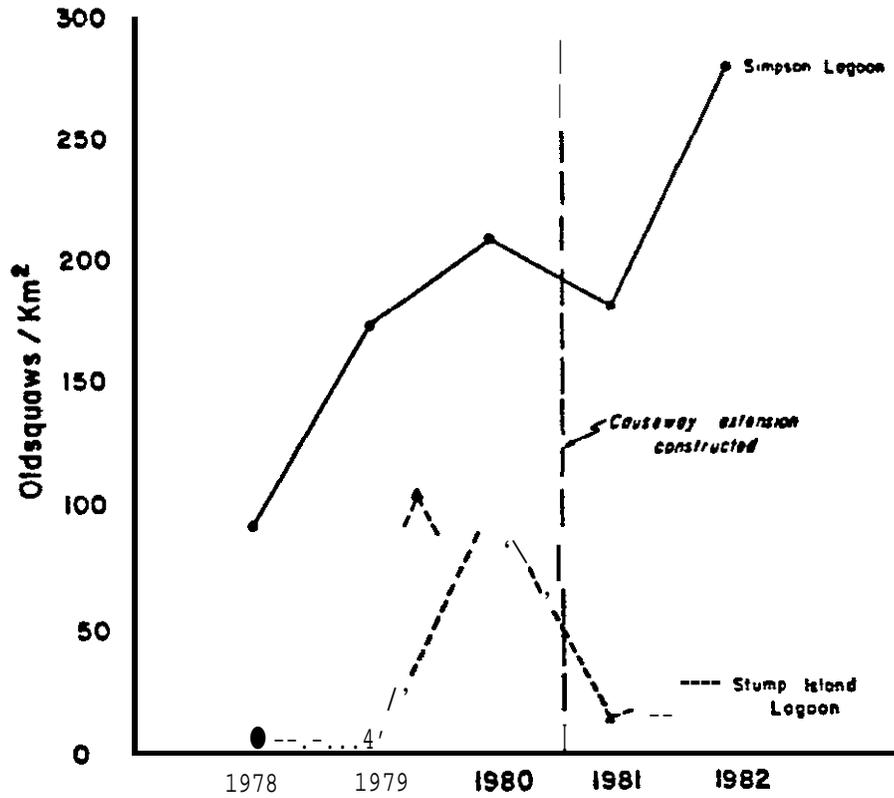


Figure 4-4 Estimated densities of molting Oldsquaws using Simpson and Stump Island Lagoons (Troy et al. 1983)

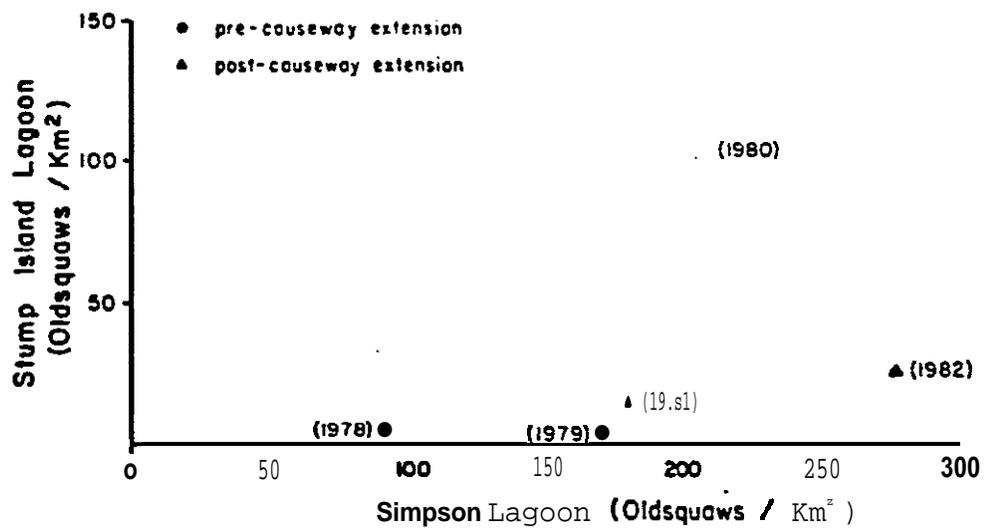


Figure 4-5 Densities of molting Oldsquaws in Stump Island Lagoon in relation to densities in Simpson Lagoon (Troy et al. 1983)

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.

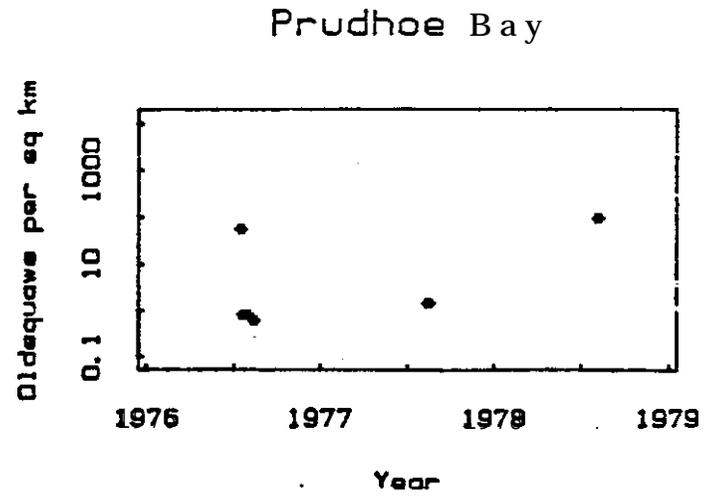
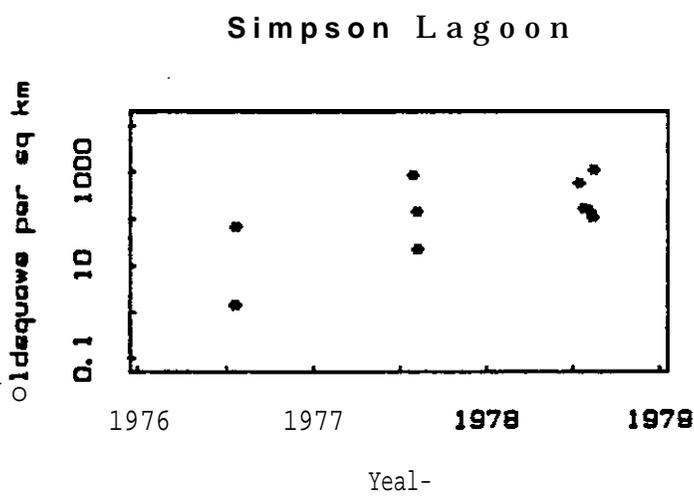
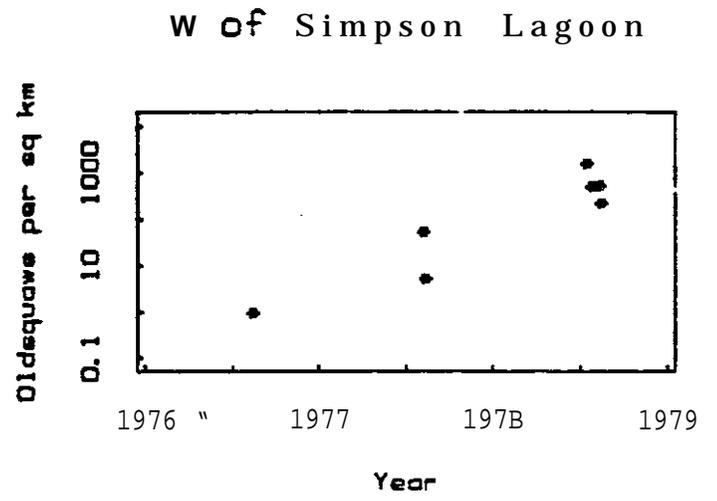
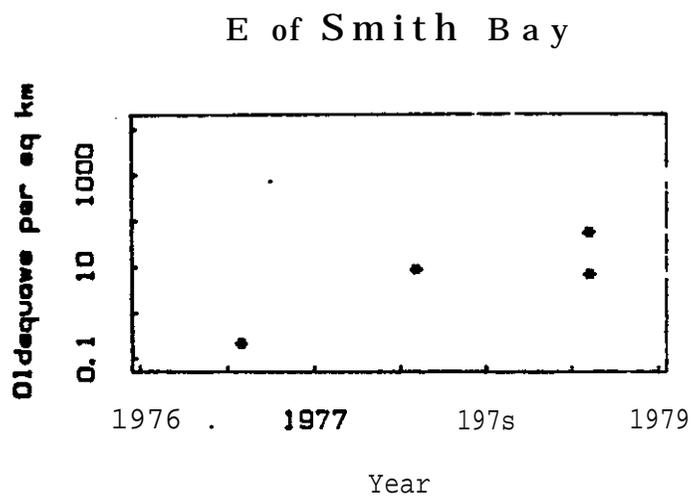
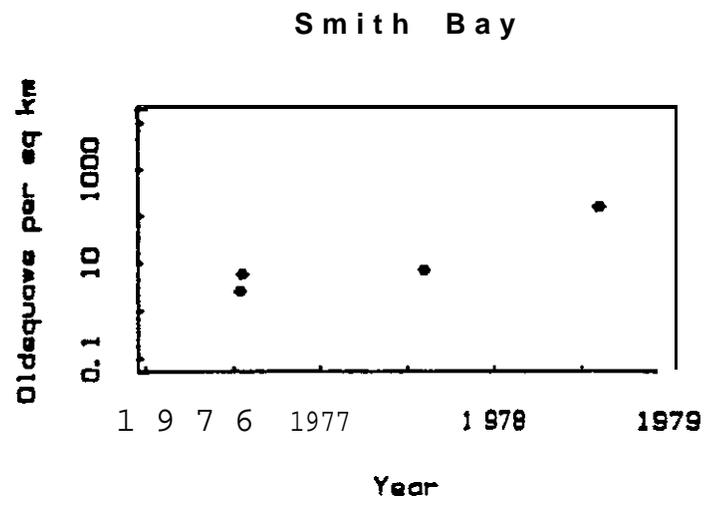
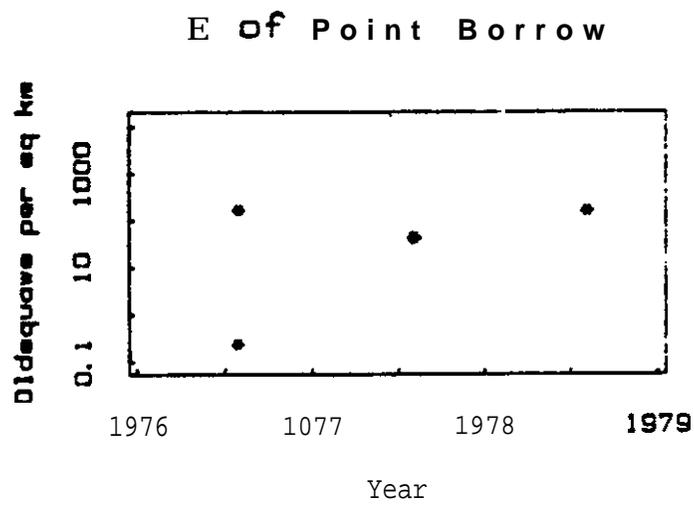
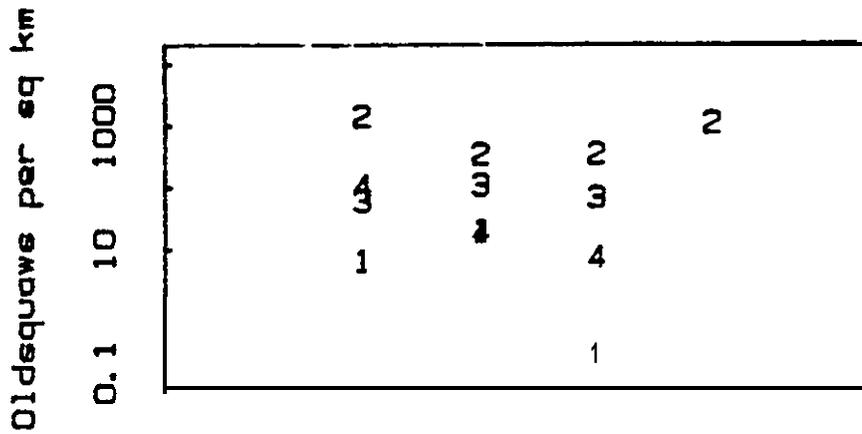


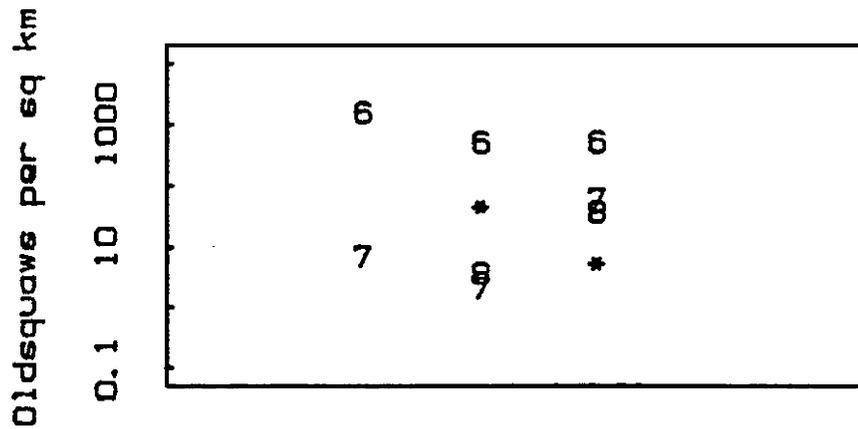
Figure 4-6 Oldsquaw densities in six Beaufort Sea survey areas (Table 4-6) 1976-1978

S i m p s o n L a g o o n



1978 transects. July 15 to August 15

E a s t e r n H a r r i s o n B a y



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:

- H₀1** 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.
- H₀2** Changes in density or hatching success of eiders on islands are not related to OCS oil and gas development activity.

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

4.2.7 Boulder Patch Kelp Community Structure

Restated Hypotheses:

- H₀1** There will be no change in productivity of Laminaria solidungula in areas of the Boulder Patch nearest OCS oil and gas development activity.
- H₀2** Changes in Laminaria solidungula productivity in the Boulder Patch are not related to OCS oil and gas development activity.

Only partial information on annual productivity of kelp (Laminaria solidungula) in the Boulder Patch was available. Dunton et al. (1982) provided a graph (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 constrictions into ovate segments of different sizes. The constrictions form in November, a new ovate segment appears by the following February, and the most rapid growth occurs in late winter and early spring. Linear growth is slowest in late summer and fall. Thus, a single measurement of segment length in late summer or fall provides a good indication of a year's growth. These measurements can be made with little disturbance of the plant.

To measure the P:B ratio, on the other hand, it is necessary to detach and weigh individual plants at the beginning of the year (in November) and remove and weigh the new segments at the end of the year. Furthermore, Dunton (1983) 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 et al. (1982). We were then able to compute rough annual

linear growth values of 24 cm for November 1978 to November 1979 and 27 cm for November 1979 to November 1980. The mean of these two measurements is 25.5 cm and the approximate sample standard deviation of the annual measurements about this mean is 2 cm.

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

Dunton (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 1978-79.

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 effects of OCS development activity, and the latter will not be detectable.

If **we** assume that **annual linear growth values can** be adjusted for turbidity, for example by analysis of **covariance**, then we can get some idea of detectable change by looking **at** the three **years of data at DS-1 1** given by Dunton (1983) as three groups **in** an analysis of variance. Suppose a fourth group consists of data from a year with a **change** in growth caused by OCS development **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 team regarding testable hypotheses, statistical design, field and analytical methods, and spatial and temporal scale for programs included in the BSMF. These recommendations are based on our analysis of information presented at the workshop, related information reviewed in the course of our effort on this project, our experience in similar projects, and especially the statistical analyses presented in Chapter 4.

As noted in Chapter 4, each of the hypotheses adopted by the workshop has been restated as null hypotheses (H₀) against which monitoring program results can be tested (Table 4-1). Each of the workshop-generated hypotheses has at least two distinct components requiring separate null hypotheses and proofs: "The first hypothesis deals with proof that a change has occurred; the second with proof that the observed change was caused by oil and gas activities. In most cases, the programs 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 detected. In this way, studies for causality can be directed to specific questions maximizing the utility and cost effectiveness of information gained.

Establishment of direct causality is rare in marine pollution monitoring studies. More frequently, circumstantial evidence is gathered linking statistically significant changes in physical or chemical aspects of the environment (known or suspected of causing impacts) with statistically proven changes in the target variable. To establish direct causality usually requires much more laboratory study or field manipulation than strict field monitoring. Stone (Canadian Department of Indian and Northern Affairs) reported that Canada was allocating some 30 percent of their program resources to actual monitoring with the remaining 70 percent going toward studies to aid in understanding of key

relationships **and sensitivities** of **VECs**. **While** we have not attempted to detail the studies that might be necessary to **establish** causality, we have **tried** to identify avenues of research that might achieve this goal.

In describing field **studies** recommended for inclusion in the **Beaufort** monitoring **program**, we have been as specific as **possible** using the best information available to us and our best scientific judgment. **We** recognize that each of our detailed recommendations may not be the only technically sound approach. Nonetheless, we urge that other approaches **be** incorporated at the start of the program only if they have been demonstrated to be superior to those suggested. Once incorporated into the monitoring **program**, procedures should be rigidly adhered to (see section 3.7.3 .2) unless alternate approaches **are** proven **superior**. Even then, it may be desirable to continue the old **method** along with the new for a sufficient **period** to establish the relationship between the two.

In addition to the recommended **approaches** described in this section, **we** feel strongly that the monitoring program cannot succeed without full implementation of **recommendations** of the workshop regarding physical environmental data, quality assurance, **data** management, **oversampling** and archiving, and coordination of physical, chemical, and biological sampling, as **described** in **Section 3.7.3**.

5.2 MONITORING RATIONALE

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

levels is prevented beyond a defined distance from each activity, then it is very unlikely that areawide degradation sufficient to impact VECs would occur .

Finally, it does not appear that all five aspects (hypotheses) of the workshop-recommended BSMP approach meet the objectives 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 state of knowledge it is very difficult to hypothesize a realistic development scenario that would result in a significant regionwide effect on waterfowl or anadromous fish that could not be linked to a specific obvious event or action (e.g., major mortalities due to an oil spill; losses to impingement or entrainment at a large seawater intake) . Once seismic exploration is complete this may apply to bowhead whales as well. Increasing levels of petroleum hydrocarbons or 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 office analyses to date have produced no evidence that such accumulations are measurable beyond a few kilometers from a site (e. g., Houghton et al. 1981 ; Menzie 1982). Moreover, sediment levels of petroleum hydrocarbons and metals that have been circumstantially linked to carcinogenesis (e.g., in flatfish) are high (Malins et al. 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 be considered the closest to meeting the BSMP objectives. Even though the selected organisms may or may not be indigenous, relatively small increases in their body burden should be a reliable early warning that environmental 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 Beaufort Sea:

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

Finally, while the five workshop hypotheses selected for inclusion in the BSMP do not each fully meet the stated objectives for the program this may be the result of setting overly idealistic objectives. In reality, the program as designed will monitor two aspects of the environment thought to have the greatest 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 major groups about which we

indeed care very much (marine mammals, **waterfowl, and anadromous** fish) but for **which** we may have difficulty in establishing causality for **any changes** observed.

Thus, while none of the individual approaches selected meets all of the objectives established for the **BSMP**, each 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 AND APPROACHES

5.3.1 Sediment Chemistry Network

5.3.1.1 Statistical Design

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

- H₀1** There will be no change in concentrations of **selected** metals or hydrocarbons.
- H₀2** 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 p_i (described in Section 4.2.1) **and** the subsequent calculations.

The subregions where the probability of an oil spill, say, was particularly high might not be the same as the areas at highest risk of increased barium in the sediments from drilling muds, so a monitoring network optimal under all scenarios is probably unattainable. We illustrate in Figure 5-1 the specification of a network based on one reasonable reduction which treats regions 12 and 17, 6 and 8, and 1 as low-risk blocks with $p_1=p_2=p_3=0.01$. 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 data at such potential stations as those of Shaw (1981) and Kaplan and Venkatesan (1981) 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.

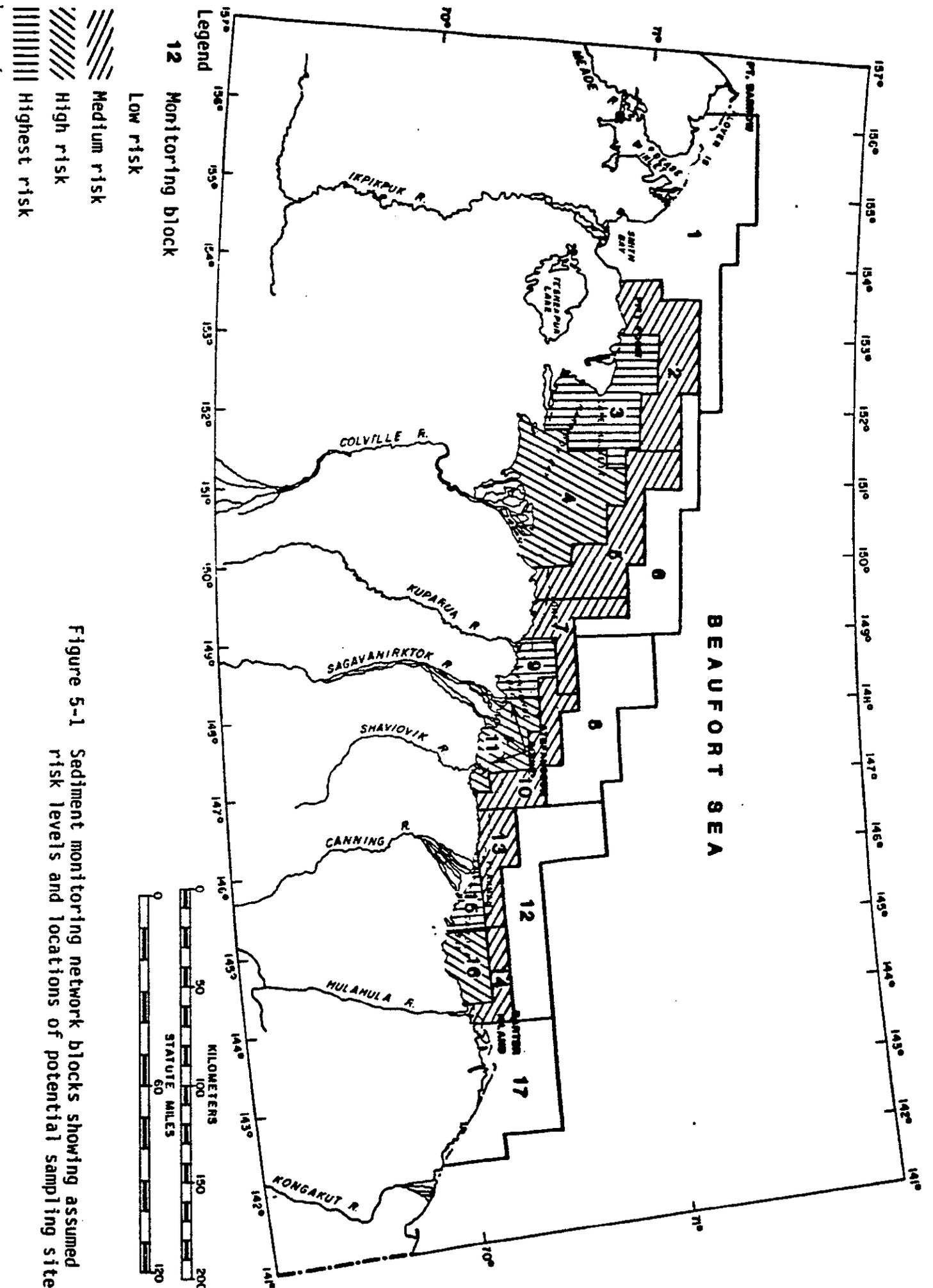


Figure 5-1 Sediment monitoring network blocks showing assumed risk levels and locations of potential sampling site

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** need **to** be defined. **These** include the frequency of sampling, the means of **col** lecting the sample, and the sample **handling** and storage needs during transportation **to** the laboratory and **to** sample archives.

The frequency **of** sampling should **to** some extent be determined by the rate of growth of **OCS** activities at **any** given time. However, unless these activities **become** much more extensive than currently foreseen, it is **suggested** that a complete set of **sediment** samples be obtained from the 36 selected **station locations** during each of the years 1984, 1985, and 1986 and thereafter every 3 years. **Based** on **experience** elsewhere, it is reasonable to believe that **OCS** oil and gas activity would not lead **to** major increases in concentrations of the contaminants of interest within less than a 3-year **period, except** within close proximity of a development site (within the compliance monitoring **area**) or in the event of a major accidental spill. Therefore, **unless** an increase is observed during the first 3 years of the monitoring **program**, a sampling **interval** of once a year for 3 years and every 3 years thereafter represents a reasonable frequency. Sampling in each of the first 3 years will serve to **demonstrate whether** changes are likely to occur that are more rapid than would be observed by sampling **every** 3 years. In addition, if no contaminant concentration changes are observed, as anticipated by the working hypothesis **H₀1** of this program, the first 3 years of data will provide a statistically stronger baseline from which to measure any future changes.

The objective of the sediment chemistry monitoring **program** is to **assess** changes in the rate of input of **selected** contaminants to the sediments. The rate that is being assessed is averaged over the 1- to 3-year period **between samplings**. **Therefore**, ideally the sediment **samples col lected** should represent **only the** last 1 **to** 3 years of accumulation. In an **undisturbed** off shore **coastal** sediment, even one subject **to relatively** high accumulation **rates**, the thickness of a 1-to 7-year sediment

layer would **be** very **small**, several **millimeters** at most. However, neat sediments are not **undisturbed** and materials representing recent inputs to the sediment surface are mixed with previously deposited materials through physical resuspension, **bioturbation**, and, in the **Beaufort Sea**, ice scour. The depth of this reworking is **highly** variable and dependent upon many **different** physical and biological factors. Therefore, the choice of an appropriate depth of sediment **sample** to take **is** a difficult one. It is generally made through a compromise between a desire to take the narrowest **possible** surface layer, in order to best represent recent inputs, and practical considerations which limit **the** thickness of **the** sample. Usual practice is to **obtain an** undisturbed core or grab of sediment 10 cm or more in depth and **to** remove for **analysis** the top 1 cm of sediments.

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

Since the **program** requires trace metal and hydrocarbon analysis **subsamples**, as well as **subsamples** for archiving, a substantial quantity of sediment is required and the sampler must provide a large enough sample. The minimum quantity of each sample **required** will probably **be** on the order of several hundreds **of** grams and the sample will, therefore, **have to be** obtained from a sediment surface area of close **to** 0.7 m². For example, a 0.1 m² 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** better fulfill **the requirements**, especially **the** requirement for an undisturbed **surface** sample. An ongoing contract study currently being **pe rf or med** 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 **ultratr ace** concentration metal analysis is not envisaged, rigid clean room techniques on board ship are not necessary. However, since hydrocarbon concentrations **wi ll** 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 **sub samples** 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 **oil** through U'V/f **fluorescence** and 1 **replicate** from each of 26 **stations** and all 4 replicates from 10 **selected stations** should be analyzed for individual hydrocarbons **and** groups of hydrocarbons through gas **chromatography (GC)** with a flame ionization **detector (FID)**. 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 **vislikelyto** 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 other analytical techniques **may** be appropriate. The technique adopted should be periodically tested for accuracy and reproducibility through analyses of appropriate standard reference materials.

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

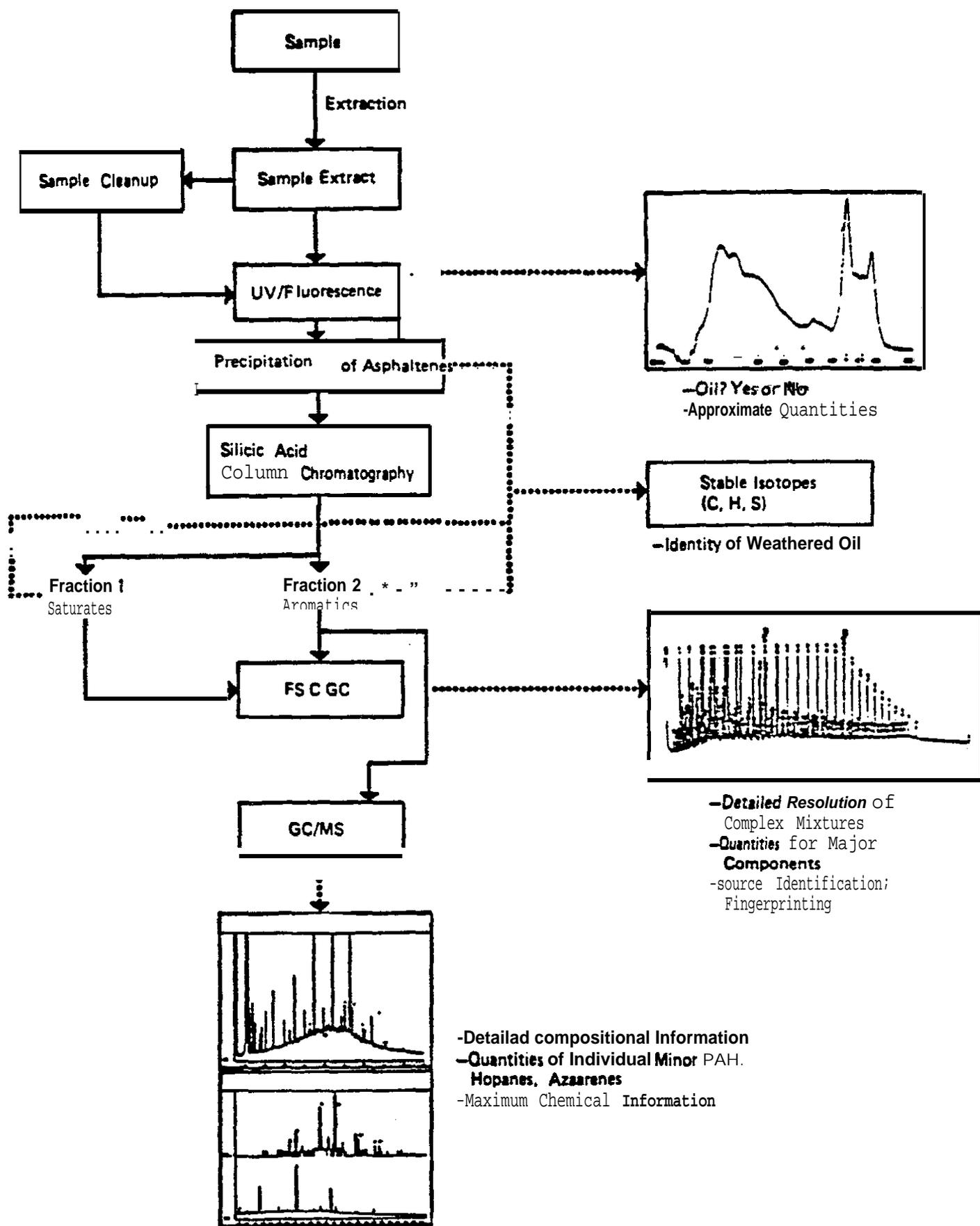


Figure 5-2 Schematic of hierarchical analytical strategy for hydrocarbons (Boehm, this workshop)

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 C ₁₀ -C ₂₁	GC/FID	Key subset of n-alkane value in baseline samples; increases with additives of petroleum
Phytane	GC/FID	Key petrogenic isoprenoid alkane of very low abundance in pristine sediments and oil.
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 5-10 for petroleum-free sample to 1 for petroleum
unresolved complex mixture (UCM)	GC/FID	Presence may indicate weathered petroleum
Fossil fuel pollution index (FFPI)	GC/MS	Ratio of fossil fuel-derived PAH (2-3 rings) to total (fossil + pyrogenic + diagenetic) PAH
Alkyl homolog distributions (AHD) of PAH	GC/MS	Relative quantities of alkylated to unsubstituted compounds within each homologous family indicates source of hydrocarbons
Aromatic weathering ratio (AWR)	GC/MS	Rate and extent of weathering of petroleum residues in samples
Molecular biomarkers (triterpanes, steranes)	GC/MS	Presence of certain stereoisomers of these cyclic alkanes is a powerful indicator of petroleum additions

(a) source: Boehm, this workshop.

TABLE 5-2

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

m/e Ion Search	Compound Identification
12a	Naphthalene
142	Methyl naphthalenes
156	c-2 naphthalenes
170	c-3 naphthalenes
184	C₄ naphthalenes
152	Acenaphthene
154	Biphenyl
166	Fluorene
180	Methyl fluorenes
194	C-2 fluorenes
178	Phenanthrene, anthracene
192	Methyl phenanthrenes (anthracene)
206	C-2 phenanthrenes (anthracene)
220	C₃ phenanthrenes
234	C₄ phenanthrenes
202	Fluoranthene, pyrene
216	Methyl fluoranthene or methyl pyrene
228	Chrysene, triphenylene
242	Methyl chrysene
256	c-2 chrysenes
252	Senzopyrene, perylene
184	Dibenzothiophene
198	Methyl dibenzothiophenes
212	C₂ 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 :

- H₀2** Changes in concentrations of selected metals or hydrocarbons in . . . organisms are not related to **OCS oi 1** and gas development activity.
- H₀3** 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 authors (Butler et al. 1971; Haug et al. 1974; Phillips 1980). The most recent listing of these attributes was made by participants 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 without being killed 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 1-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.
- o Kinetics of the contaminant in the organism should be understood.

Very few species are known well enough to conclude whether or not they fulfill all of these requirements and, therefore, additional research will generally be needed before a candidate species can be proven acceptable for use in a sentinel organism program. Certain mytilid species have been extensively studied and are widely used as sentinel organisms; thus, substantial data bases exist for them. . Therefore, any new species used as a sentinel organism in the Beaufort Sea ideally should be carefully compared with appropriate mytilid

species (M. edulis or californianus) with regard to its behavior when subjected to contamination of its environment. Only in this way will it be possible to relate the magnitude and importance of any change in contaminant concentrations in the Beaufort sentinel organisms to what is known about marine pollution impacts in other areas.

5.3.2.3 Candidate Indigenous Species

Ignoring for a moment the problem described above (that little is known of their ability to metabolize metals or hydrocarbons), several species of Beaufort Sea bivalves were 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 shell sizes of Astarte borealis and Macoma calcarea were among the largest in Carey's collections. M. calcarea was relatively abundant in shallow water (5 m) on the Pitt Point transect; however, the depth in the sediments favored by this species would make it difficult to collect. M. calcarea is nonetheless the best candidate for a surficial deposit feeder. M. calcarea has the added benefit that its congener M. balthica has been widely used in marine pollution studies; thus, there is a good body of information on sensitivities, uptake, and depuration of pollutants by the genus that may be applicable to M. calcarea as well.

Of the suspension feeders, Cyrtodaria and Liocyma which are very abundant in shallow water (5 m), are generally small in the Beaufort-- usually less than 20 mm. Of the mytilids (mussels), Musculus discors is locally very abundant where a substrate is present for attachment (e.g. , in the Boulder Patch). Average size is small, however, with an average weight of 0.03 grams per individual in Boulder Patch samples (Dunton et al. 1982). Musculus niger is larger but is found in deeper water and is less common. Based on this information, Cyrtodaria appears to be the best indigenous suspension feeder available. However, there appears to

TABLE 5-3

SUMMARY OF CHARACTERISTICS OF POTENTIAL BEAUFORT SEA INDICATOR SPECIES

Species (feeding type)	Maximum Length (mm)(a)	Prudhoe Bay (b)	Abundance (n0. /m ²)		Notes
			Pitt Point (depth) (c)	Boulder patch(d)	
<u>Portlandia arctica</u> (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)
<u>Musculus discors</u> (suspension)	40	--	--	69.2	Average biomass in Boulder Patch was 2.1 g/m ² plus 0.19 g/m ² for smaller unidentified <u>Musculus</u>
<u>Musculus niger</u> (suspension)	45	--	--	--	Reported in 27 to 101 m of water.(a)
<u>Astarte borealis</u> (deposit(?); may filter inter- stitial water)	55	--	--	1.6 (as <u>Astarte</u> sp.)	To 40 mm shell common in Beaufort Sea. (e)
<u>Macoma calcarea</u> (surficial deposit)	54	--	232 (5 m) 22 (10 m)	0.4	Good size but patchy ; live deep in sediments. (e)
<u>Lyocyma fluctuosa</u> (suspension)	33	32	644 (5 m) 182 (10 m)	--	usually less than 15 mm.(a)
<u>Cyrtodaria kurriana</u> (suspension? ^(a))	40	25	304 (5 m)	--	usually less than 30 mm.(a) Less than 20 mm in the Beaufort sea. (e)

(a) Source: Bernard 1979.

(b) Source: Feder and Jewett 1982.

(c) Source: Carey (1981) (highest densities only) .

(d) Source: Dunton et al. 1982.

(e) Source: Scott 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 is **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 ships or barges (**Fader** and **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 hard **bottom** areas in the northeast **Chukchi** as well (**Dunton 1983b**) . Thus, there would **appear to** be no physiological barrier to adult **Mytilus** living in the **Beaufort** Sea although there may be a barrier **to** reproduction or simply a geographic barrier formed by the extensive distances lacking undisturbed (by ice) hard substrates.

5.3.2.4 Recommended Approach to Establishing a Beaufort Sea Mussel Watch

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

1. Collection and analysis of indigenous species.
2. **Transplantation** and **analysis** of **M. edulis**.

Indigenous Species. An effort should be made early in the open water 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 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 and 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** repeated 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 open 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

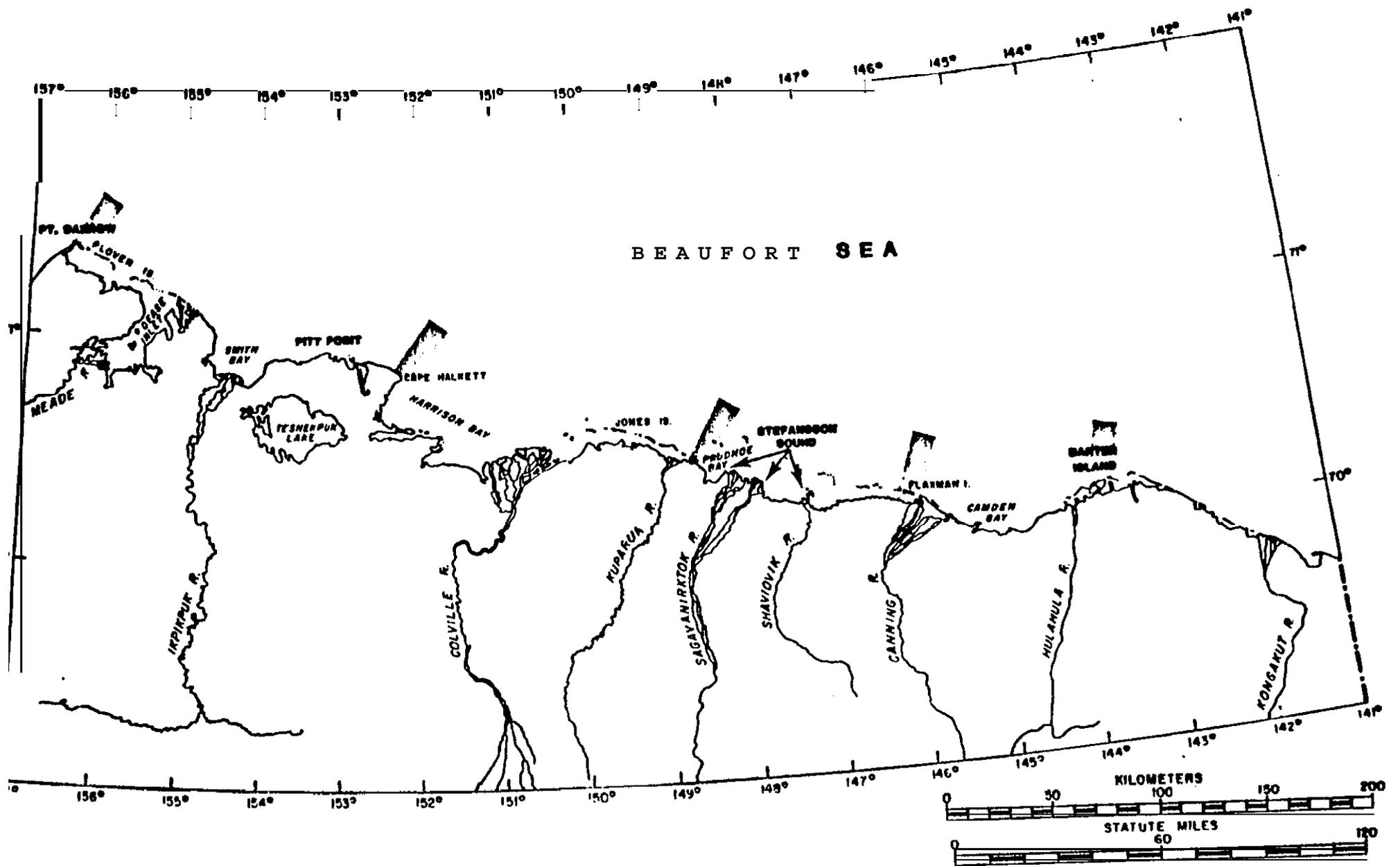


Figure 5-3 Suggested locations for mussel watch stations

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 Bay.

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

A random subsample of each species should be taken at the time of capture for initial analysis of body burden. At present the national mussel watch protocol does not call for 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 least. 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 and analysis. A second similar lot should be held on board in clean, filtered (0.45) sea water flowing or frequently

replaced **at ambient temperature** for 24 hours 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 within 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 efficient possible study for future years. It is expected that caged organism sampling should occur in the same five areas (coincident with sediment sampling stations) shown on Figure 5-3 for sampling natural bivalve Populations. At each area, stations should be occupied at two different depths. As in the National Mussel Watch program and the sediment chemistry monitoring (Section 5.3.1), 3 years should be sufficient to establish baseline conditions (assuming this sampling is completed before major changes in contaminant input rates occur). Subsequent sampling every 3 years should be adequate to detect long-term trends. However, more frequent sampling could be instituted if increasing contaminant inputs occur or if increased levels are measured during sediment monitoring.

If H_03 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_02 that these increases are due to oil and gas development activity.

An increase in contaminants in sediments or in indicator species (rejection of Hypotheses I and II, H_01 or H_03) would be cause to greatly increase monitoring of contaminant levels in higher organisms including VECs (marine mammals, waterfowl, anadromous fish). This would provide data to investigate H_04 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_01 Fall migration patterns of bowhead whales will not be altered during periods of increased OCS activity in the United States Beaufort Sea.

H_02 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. (1983), 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 entire United States Beaufort from the Canadian border 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 path.

This general distribution of survey effort seems appropriate for detecting subtle shifts in migration path. It is important to continue to expend enough effort at depths exceeding 50 m to detect any 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 than 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 absence 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 depths. If a future survey covered this area more thoroughly with random N-S line transects and if, in fact, the whales congregate at the relatively shallow depths where they were seen during the nonrandom transects in 1982, the future data might indicate a shift in the axis of migration toward shore although the whales had made no changes in their migration and feeding patterns.

- c. If there is a desire to focus on a particular subregion of the Beaufort 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 the 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 oversimplification. Ice coverage should continue to be recorded during the aerial surveys. It might be possible to develop models for the axis of migration which incorporate data on ice conditions if surveys are conducted in heavy as well as light ice years.

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_02), the question of whether it was caused by OCS oil and gas development, ice conditions, or other factors will remain unanswered. Rejection of H_01 , as restated, would strongly imply that the shift was due to OCS oil and gas activity

although causality would be only circumstantial (the shift occurred during periods of increased activity) . It **is** therefore **important** to continue the 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 to 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 the presence of such sounds. "Huddling" behavior was observed by Reeves et al. at the onset of seismic noise in some cases but in the absence of any known disturbance in other cases. The lack of conclusive results is not surprising, considering the small number of **independent** behavioral observations which it has been possible to collect. The unavoidable problems encountered in conducting these studies are well summarized by Reeves et al. (1983).

Our main recommendations for future behavioral studies are as follows :

- a. Methods of assessing and recording **bowhead** behavior and the attendant environmental conditions (e.g., **sonabuoys** recordings of noise) should be standardized **between** different **years** and/or different **investigators** to the greatest extent possible. Workshops such as the Second Conference on the Biology of the **Bowhead** Whale (Albert et al. 1983) help to facilitate the **required** communication and coordination among investigators.
- b. Standardized **formats** for behavioral **data** in a computerized data base should be established. Such a data base containing data 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 and approximately locate bowhead vocalizations within a 10- to 20-kilometer radius.

This approach may well be preferable **to** aerial survey for monitoring **bowhead** use of feeding areas **near** Barter Island and Demarcation **Bay**, for example. Hydrophones could monitor these areas continuously if desired, while aerial "survey coverage is **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 pass 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-effective method for **obtaining** population size estimates. This census and other studies **aimed at** determining **health** and fecundity of the population should clearly continue to be funded. **As** noted by Reeves et al. (1983), a reduction in **bowhead** population size or physical condition **would** be of greater concern than the displacement in migration **path** which the effort described in Section 5.3.3.1 is designed to monitor.

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

Other marine mammals, **most** notably ringed seals, are also **VECs** in the **Beaufort** Sea. Albert noted that surveys of ringed seal density in the **Beaufort** have been **conducted** for the **past** 5 to 7 years by J. Burns of the Alaska Department of Fish and Game (Burns et al. 1980; 1981) who suggests that such surveys should **be** repeated every 2 to 3 years to monitor long-term trends in distribution and abundance. Site-specific monitoring of seals in relation to development activities 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** 1981) should be monitored for levels of hydrocarbons and **trace** metals. This will provide a growing data base against which to test the most important of our monitoring program hypotheses regarding effects on human health.

5.3.4 Anadromous Fish

Restated Hypotheses:

H₀1 There will be no change in catch per unit of effort (CPUE) in the Colville River Arctic cisco fishery.

H₀2 Changes in Arctic cisco CPUE are not related to OCS oil and gas development activity.

The workshop recommended approach of continued monitoring of catch data from the Colville River Arctic cisco commercial fishery is an obvious requisite for testing of this hypotheses. However, our statistical analysis (Section 4.2.4) shows a high probability that factors unrelated to oil and gas development (i .e. , natural population cycles, variability) may lead to rejection of H₀1 . 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 CPUE against the baseline of earlier values. For the years 1976 through 1981, the CPUE predicted by the Deriso model appears to fall relatively close to the actual value (e.g. , +20 percent) except in 1977 when the predicted value was about half the actual (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 verified and calibrated, a statistically significant increase in the discrepancy between predicted and actual CPUE values should be easier to establish than it would be to establish that a given year's CPUE has changed from its "baseline condition. " If this increased discrepancy between predicted and actual CPUE occurred (statistically significant or not), it would be cause to examine available population data and data on recent natural or man-caused environmental changes in the Beaufort Sea for an explanation. In all likelihood, it will not be possible to firmly

establish **causality** for changes observed without an extensive **data** base on possibly related factors. At present, it is not even certain where these fish spawn (**Galloway 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 perform statistical **analyses** on aerial Arctic char index counts in North Slope rivers (Figure 4-3), it is possible that these estimates **may** be as good as Arctic **cisco CPUE** for monitoring **anadromous** fish numbers in the **Beaufort** Sea. In the **Ivishak** River, for instance, the 1971-1976 data all fall within a very **narrow range** (8,570-13,958 fish). Data 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:

- H₀₁ There will be no change in relative densities of molting male **oldsquaw** in selected Beaufort Sea index areas.
- H₀₂ Changes in male **oldsquaw** distribution patterns are not related to **OCS oil** and gas development activity.

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

First, there do appear to be **some** relatively consistent patterns in **oldsquaw** distribution during the summer molting period. However, between-year variability in the timing of the molt and within-season variability in densities estimated by aerial **survey** are so high that

multiple surveys within each **area** and season are mandatory. Four surveys approximately every 10 days between July 15 and August 15 should catch the peak of the molt and also help to average out differences in counts caused by time-of-day effects and unavoidable differences in survey aircraft used, **visibility**, etc. Of course, any such differences which can be avoided by stratification should be.

Second, transects should be very precisely defined and faithfully repeated. The available data indicate that transects on the lagoon-side shores of barrier islands and mid-lagoon transects should be used. Transects should be of similar lengths so that densities computed from them will represent comparable survey effort in areas of similar size. Monitoring should include, from west to east, transects in **Elsion 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 (**Elsion** Lagoon for example) where important **oldsquaw** molting areas are not covered by the existing transects.

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

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

sections may be helpful in determining the best transects to **use** for monitoring **and** what levels of change could **be** detected.

If 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:

- H₀1** There will be no change in density or hatching success of **common** eiders on islands subjected to disturbance by **OCS oil** and gas development activity.
- H₀2** 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 regional **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 stated above is rejected, this would imply that density or hatching success of eiders on the island subjected to disturbance by oil and gas activity has changed (declined) relative to success on control islands not subjected to disturbance. In this case, the oil and gas activity is strongly (although circumstantially) implicated as the cause of the decline. Testing of H_02 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_02 Changes in Laminaria solidungula productivity in the Boulder Patch are not related to OCS oil and gas development activity.

As a simple measure of change in the Boulder Patch, the recommendation in the concluding session of the workshop was to monitor annual productivity of Laminaria whenever OCS development activities which might affect it were going on in the vicinity of the Boulder Patch. We concur with this approach for this hypothesis. However, as indicated in Section 3.7.4, we do not 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. (1982) 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 **entire 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 **H₀1** as stated above **is** rejected, this would imply the **t** kelp **productivity** in areas of the Boulder Patch nearest oil and gas development activity is reduced, in comparison with productivity in areas removed **from** such activity. In this case the oil and gas activity is strongly (although circumstantially) implicated as the cause of the **reduced** productivity. Testing of **H₀2** 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 a specified National Oceanographic Data Center

(NODC) format. This is a first **step** in providing **an** accessible data base, but **it** is not enough. There are several problems with this approach:

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 errors (misidentified measurements) and even greater redundancy than was originally **contemplated** since new **files** arranged on a sample-by-sample basis must be created by investigators each **time** they wish to conduct statistical analyses.

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., **deter-**mining 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**

BEA UFORT SEA MONITORING PROGRAM WORKSHOP
ALYESKA RESORT, ANCHORAGE, ALASKA
27-29 **SEPTEMBER** 1983

APPENDIX A

List of Attendees
BEAUFORT SSA MONITORING PROGRAM WORKSHOP
ALYESKA RESORT , ANCHORAGE , ALASKA
27-29 SEPTEMBER 1983

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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 testing the hypothesis of no change against some natural alternative. A general approach to the design of such a network is provided in Section 2 of this appendix. A key feature is the incorporation of the uncertainty about where such an impact might occur.

This objective seems unduly restrictive. The **data** provided by **this** network will be used for many purposes both seen and unforeseen by **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 ideally 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 specified size would be detected. **This** criterion is adopted in Section 2.

In the absence of a uniquely defined objective, **Caselton and Zidek** (1983) adopt an information transmission criterion. A **particular** set of "gauged sites is "good" if it provides 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 and **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 Z_i 's with $i \in D$ will, in fact, be measured (with error) once D is **specified**.

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

We address a case between these extremes. Suppose K replicate measurements of Z_i are taken at each gauged site $i \in D$. Their variability is assumed constant over i and indicates the precision of the process of measurement. Changes

will be measured against this variance. Measurements taken on successive occasions will also include a component of temporal variability. The lack of data makes time series modeling impossible. Two strategies are adopted to reduce the impact of time effects which, if ignored, would obscure changes due to development alone. These are suggested by Green (1979). First, measurements at each site in D are made on just two occasions which closely bracket the start of development (drilling, for example, at a particular site). Second, sites from areas of likely impact are admitted as possible quasi-controls. These do increase the power of the test even though they are not controls, strictly speaking.

Again, following Green (1979), we take as the null hypothesis, the assumption of no time 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 the F -test has the noncentrality parameter $\delta^2 = 2K \sum_{i \in D} (Z_i - \bar{Z}_D)^2 / \sigma^2$ where $\bar{Z}_D = \sum_{i \in D} Z_i / I$ with I the number of elements in D and σ^2 the sampling variance. To maximize the power of this test we will seek the D which maximizes δ^2 and confine ourselves to a special case which admits an explicit solution.

Suppose the region may be partitioned into k blocks or zones and that the impact is confined to one of these blocks, say 'i', with probability $p_i \geq 0$, $\sum_{i=1}^k p_i = 1$. Furthermore, the impact is uniform over the block in which it occurs, adding a constant amount, say A , to each of the sites in this block. The random impact field so obtained would seem to describe to a first approximation both impacts due to catastrophes and those subregional, pervasive changes due to site development even when the locations of these sites remain to be fixed end hence uncertain. For convenience relabel the zones, if necessary, so that $p_1 \leq p_2 \leq \dots \leq p_k$.

Let $S = S_D = \sum_{i \in D} (Z_i - \bar{Z}_D)^2$ so that $\delta^2 = 2KS / \sigma^2$. Suppose D gauges n_j sites in block j . If the impact were to occur in zone j , $\bar{Z}_D = [(I-n_j)0 + n_j \Delta] / I = f_j \Delta$ where $f_j = n_j / I$, the sampling fraction in block j . And $S_D = (I-n_j)(0 - \bar{Z}_D)^2 + n_j(\Delta - \bar{Z}_D)^2 = I \Delta^2 f_j (1-f_j)$. 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, $j=1, \dots, k$ are:

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

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

where $\lambda = \lambda_m = (k - m - Z) / \sum_{j=m+1}^k p_j^{-1}$ 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 $\zeta | A | / \sigma$ -values when the size and power of the test are 0.05 and 0.50, respectively.

TABLE 1. The values of $\zeta A / \sigma$ 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 $L_m = (k - m - 2)p_m^{-1} - p_{m+1}^{-1} - \dots - p_k^{-1}$, 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, .3, and .4. Since $L_5 < 0$, $L_4 < 0$, and $L_3 < 0$ in any case with $k=5$, our search for m can begin with $m=2$ when we consider

$L_m = L_2 = p_2^{-1} - p_3^{-1} - \dots - p_5^{-1} = -5.83$. Since $L_1 = L_2 < 0$ also, we must take $m = 0$, and $\lambda = (5 - 0 - 2) / (p_1^{-1} + \dots + p_5^{-1}) = 0.0836$. The optimal sampling fractions are $f_1^0 = f_2^0 = f_3^0 = (1 - \lambda \sqrt{.1}) / 2 = 0.08$, $f_4^0 = 0.36$ 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 at all be specified in advance. Even the specifiable objectives will be various and call for somewhat different designs from case-to-case. Caselton and Zidek (1983) circumvent these difficulties by an approach which may be suboptimal in specific cases but which would seem, overall, to be quite sensible. Their design maximizes, in a sense which will now be made precise, the amount of information which can be generated.

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

As in Section 2, the design D , consists of a subset of site-labels, the "gauged" sites. The remainder are ungauged sites. Decompose Z as $Z(U, C)$ 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 the amount of "information" in C about U .

To formalize this let $\text{Inf} = I(U, C) = [-E \log p_0(U)] - [-E \log p(U | C)]$, the reduction in the entropy of U resulting from observing C , averaged over C . Equivalently, $\text{Inf} = E \log [p(U | C) / p_0(U)]$, Shannon's index of information transmission. This can

be resealed as $\ln f \rightarrow A \ln f$ where A is the utility per unit of information or monetary value per unit of information, for example. The dependence of $\ln f$ 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 $R = \text{Diag} \{\rho_1^2, \dots, \rho_m^2\}$ and $\rho_1 \geq \dots \geq \rho_m$ 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 will 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 , $j=1, \dots, k$. At the next level is a **site-specific** component: S^i , $i=1, \dots, m$. Finally, at the gauged sites there is a component for sampling error which would be negligible under replicated sampling. Assume all of these components are independent.

The **covariance matrix** for the **resulting** model would have a block structure. Off-diagonal blocks would all be $\sigma_B^2 J_r$, where J_r is a square matrix of 1's and r is an appropriate dimension. The diagonal block corresponding to block j would have off-diagonal elements $\sigma_B^2 + \sigma_j^2$, where $\sigma_j^2 = \text{Var}(B_j)$, $j=1, \dots, k$; its diagonal elements for site i would be $\sigma_B^2 + \sigma_j^2 + \sigma_i^2$ if it is **ungauged** where $\sigma_i^2 = \text{Var}(S^i)$, $i=1, \dots, m$. 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. It is 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 $\ln f$** for every choice of D , with the size of D fixed. In practice such a computation would be impossible. Even when $I=40$ and $m=200$ potential sites, there are $2.05 \times 10^{4*}$

possible choices for D .

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

To gain some insight into the operation of this methodology, assume the block effects are zero. Then $U^i = W + S^i$ and $G^j = W + S^j + E^j$. 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 $d_0 = \text{Diag}\{\sigma_1^2, \dots, \sigma_{m-1}^2\}$ and m is the total number of sites, j_r in general denotes the column r -vector all of whose elements are 1. σ_W^2 and σ_i^2 are respectively the variances of W and S^i . A similar calculation gives $\sum_G = \sigma_W^2 j_n j_n^T + d$ where $d = \text{Diag}\{\sigma^2 + \sigma_{m-n+1}^2, \dots, \sigma^2 + \sigma_m^2\}$ 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 $\sum_{UG} \sum_G^{-1} \sum_{GU} \approx \sigma_W^4 \text{tr}(d^{-1}) [1 - \sigma_W^2 \text{tr}(d^{-1})] j_{m-n} j_{m-n}^T$. 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 $K = \sigma_W^4 [1 - \sigma_W^2 \text{tr}(d^{-1})] \text{tr}(d^{-1}) [1 - \sigma_W^2 \text{tr}(d_0^{-1})]$. There is only one such eigenvalue, $f_U (1 - f_U) \cdot f_G (1 - f_G) = \lambda$, say, where $f_U = \sigma_W^2 \text{tr}(d_0^{-1})$ and $f_G = \sigma_W^2 \text{tr}(d^{-1})$.

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 $f_U = \sum_{i \in D} s_i$ and $f_G = \sum_{i \in D} s_i$. Consequently, $A = (\sum_{i \in D} s_i)(1 - \sum_{i \in D} s_i)(\sum_{i \in D} s_i)(1 - \sum_{i \in D} s_i)$. This is

approximately, if the s_i 's are small, $A \approx \left(\sum_{i \in D} s_i \right) \left(\sum_{i \in D} s_i \right)^{-1/2}$. It follows since $I = \log(1-\lambda)^{-1/2}$ 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 $a_1 \leq \dots \leq a_R$, how should these be partitioned into sets E and F in order to maximize the product $\left(\sum_E a_j \right) \left(\sum_F a_j \right)$. 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 $(x + A)(y + B) - (y + A)(x + B) = (z - y)(B - A) < 0$. i.e. if and only if $x < y, A < B$ or $x > y, A > B$. This observation can be applied sequentially to reach an optimum. Consider, for example, the sequence 1, 2, 3, 4, 5, which is to be partitioned optimally into sets of size 2 and 3. The sequence of steps is as follows, with "NC" denoting "no change":

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

The process has converged at step (4) although six steps 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 S_i 's are assumed small.

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

A few values of Inf are give in Table 2 below. In every case s_y , 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_c for gauged sites.				
m	s_c	I	Inf	
50	0.025	5	0.0543	
		10	0.1068	
		25	0.2379	
		30	0.2749	
	0.05	5	0.0543	
		10	0.1068	
		25	0.2379	
		30	0.2749	
	100	0.025	10	0.1091
			20	0.2003
			50	0.4030
			60	0.4557
0.05		10	0.1979	
		20	0.3416	
		50	0.6214	
		60	0.6662	
200		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 the uncertain field. Beyond this it becomes a transmitter of

information about the remaining **ungauged** sites. So there is a considerable total gain from adding a new station to D when D is **small**. As D increases the **amount of uncertainty** decreases. In **all** cases the gain in transmission by increasing D is eventually offset by the reduction in the number of receiving stations and on balance I_{nf} begins to decline.

Well before **this** stage is reached. a point **will** be found where the reduction in uncertainty is negligible. This yields a practical limit for I , the size of D . Suppose, for example, $m=500$. Then if $s_U = 0.05$ and $s_C = 0.04$, going from $I = 15$ to 16 produces only a one percent improvement. On the other hand, if $s_U = 1$ and $s_C = 0.6$, 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** lines of latitude **which** are **five** minutes (of a degree of latitude) apart. The vertical boundaries lie along lines which are separated by the same **distance**.

4.1 A **Design** for Testing

To apply the theory of Section 2 these 17 primary blocks may be combined in various ways to represent **different** kinds of subregional but pervasive impacts, Blocks 3, 9 and 15, say, **B3, B9 and B15** are very high risk areas because of expected locations of high development activity and the prevalent east to west currents. B4, **B11 and B16** are next in order "of riskiness, say "high" for short. Then come **B2, B5, 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)** → b1. Other combinations **are** obviously possible. We have not systematically explored all these possibilities.

To assign **riskiness probabilities**, observe that **b8** is the very high risk zone, b7 is **high**, **b4, b5** 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**, b1) are 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 $O=f_1^0 = f_2^0 = f_3^0$ 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 test power by taking more than 50 stations and 3 replicates per station. Then $\alpha = 0.05$, $1-\beta = 0.80$, and $\zeta\Delta/\sigma = 0.47$ is the detectable, pervasive before and after difference. Using 4 replicates at 36 stations is preferable to 3 replicates at 50 stations, according to this table; then $\zeta\Delta/\sigma = 0.42$.

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 Δ half the size of the replication (sampling) error.

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

4.2 Designs for Information Transmission

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

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

To decompose Z_i into its components of variability, write

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

$\bar{\mu}_j$ represents the block mean and μ the mean of the region. We regard $\bar{\mu}_j$ as $\sum_{i \in j} Z_i / m_j$ where $m_j =$ number of hypothetical stations in block j and $\bar{\mu}$ as $\sum_j \sum_{i \in j} Z_i / m$ where $m =$ total number of stations. Thus $s_i = Z_i - \sum_{i \in j} Z_i / m_j = (g_j - 1)(Y_i^B - \bar{Y}_j^B)$, $b_j = (g_j - 1)Y_j^B - \sum_{i \in j} (g_j - 1)\gamma_j \bar{Y}_j^B / m$ and $\mu = \sum_j (g_j - 1)\gamma_j \bar{Y}_j^B / m$, where $\bar{Y}_j^B = \sum_{i \in j} Y_i^B / m_j$ 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 \bar{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 \bar{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: $Var(s_i) \propto (Y_i^B - \bar{Y}_j^B)^2$, $Var(b_j) \propto (\bar{Y}_j^B)^2 (1 - 2\gamma_j) + Var(\mu)$ and $Var(\mu) \propto \sum_j \gamma_j^2 (\bar{Y}_j^B)^2$.

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

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

These coefficients for the Simpson Lagoon are estimated in the obvious way. For the small samples of copper, nickel, chromium and cobalt (n about 10 in each

case), one value was trimmed from either extreme before computing the estimates. For the larger samples (n about 30) of **iron**, manganese, **zinc** and phosphorous, two such values were trimmed from either extreme. The resulting **coefficients** of variation were: **chromium-0.22**, nickel-0.20, iron- **0.37**, vanadium-1.29, copper- **0.22**, **zinc-0.61**, **manganese-0.5285**, and **cobalt-0.25**.

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

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. (1991b)

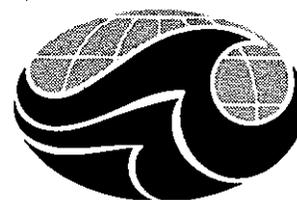
Block	Area ¹	m_j	1/10 x Cr	1/10 x Ni	Fe 1/10	1/10 x V	1/10 x Cu	1/10 x Zn	1/100 x Mn	1/10 x Co
1	47	15	7.5	4.5	3.0	15.0	3.0	9.0	9.0	2.0
2	22	7	8.0	4.5	3.5	13.5	2.5	9.0	6.0	1.5
3	21	6	8.0	5.0	3.0	11.0	3.5	8.0	8.0	1.5
4	26	8	8.0	3.0	2.5	10.5	2.5	8.0	4.5	1.0
5	25	8	10.0	4.5	3.0	12.0	4.0	8.5	6.0	2.0
6	29	12	10.0	5.0	3.5	16.0	4.5	9.0	21.0	3.0
7	10	5	6.0	4.0	2.5	13.5	2.5	8.0	4.5	1.0
8	30	12	7.0	5.0	3.0	13.5	3.5	9.0	21.0	3.0
9	7	3	5.0	3.0	2.0	7.5	2.0	8.0	4.0	1.0
10	13	5	6.0	4.0	2.5	12.0	2.0	9.0	4.5	1.0
11	9	5	5.0	5.5	2.0	9.0	2.0	8.0	4.0	1.0
12	31	10	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	1.0
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										
r_{sides}^2			1.5	0.41	0.61	146	0.25	15	10	0.099		
σ_{μ}^2			4.7	1.6	0.77	15	0.67	6.4	11	0.34		

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July 12, 1985

Final Report

Western Gulf of Alaska Tides and Circulation

by

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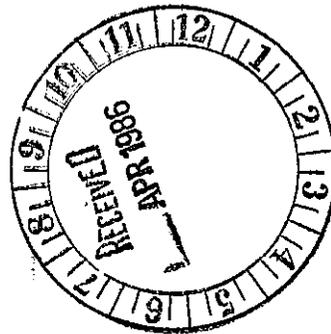


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ACKN ██████████

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 officers 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 was the technical authority and provided useful advice to us despite his move (concurrent with the project) 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.

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 be 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.



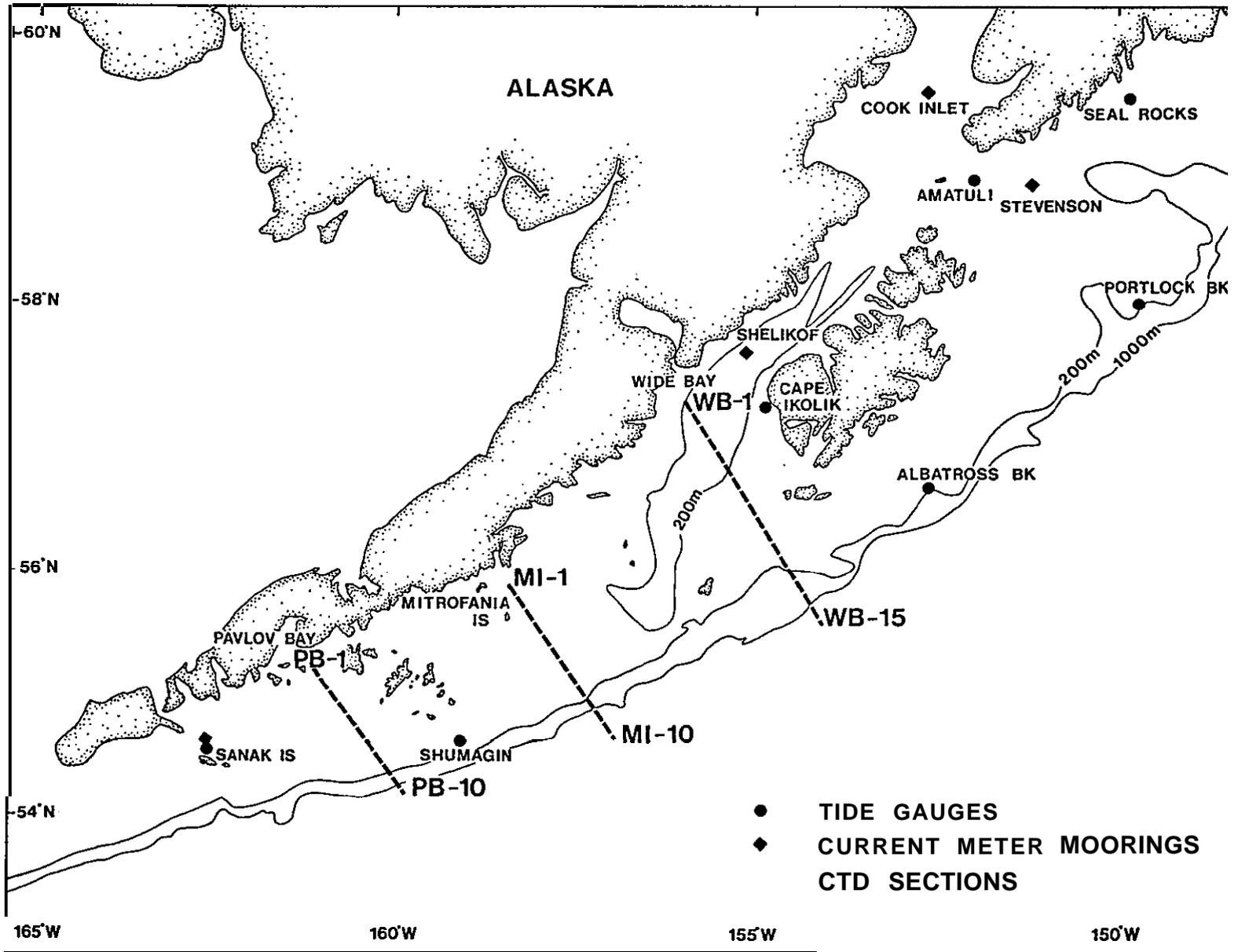


Figure 1.1 Location of Current Meters, Tide Gauges and CTD sections.

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	113	2493	45	1800 13 June 84	0945 9 Aug 84
North of Portlock Bk	150°57'23W	1807	75	1800 13 June 84	0945 9 Aug 84
Cook Inlet	62	3710	36	0430 14 June 84	2015 9 Aug 84
	59°35'02N 152°29'00W	3614	52	0430 14 June 84	2015 9 Aug 84
Shelikof Strait	250	3127	40	2130 14 June 84	1400 10 Aug 84
	57°39'00N 155°03'33W	1812	150	2130 14 June 84	1400 10 Aug 84
Sanak (Deer Island)	49	3185*	18.5	1000 16 June 84	0445 13 Aug 84
	54°35'25N 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.

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 9Aug 84
Amatuli Island	59°00'13N 151°05'03W	168	87	2230 13 June 84 1400 9 Aug 84
Cape Ikolik	57°15'00N 154°45'30W	62	120	0100 15 June 84 2315 10 Aug 84
Shumagin (Simeonof Is)	54°31'93N 158°05'08W	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 84 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

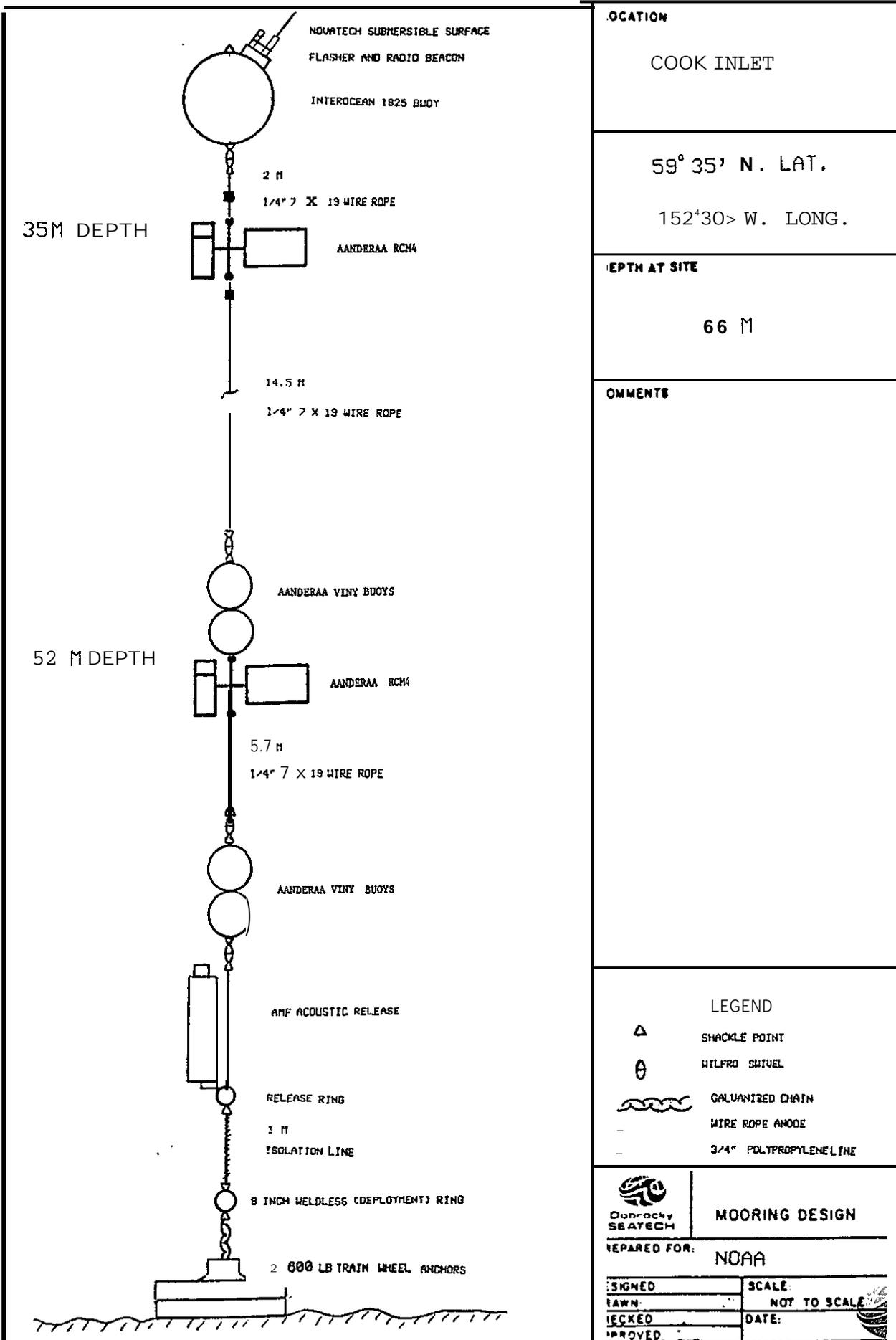
The Aanderaa data tapes were translated and converted to physical units using calibrations supplied by NOAA. Salinities were computed from temperature, conductivity and pressure with the UNESCO (1980) formula.

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 1978). 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





LOCATION
COOK INLET

59° 35' N. LAT.
152° 30' W. LONG.

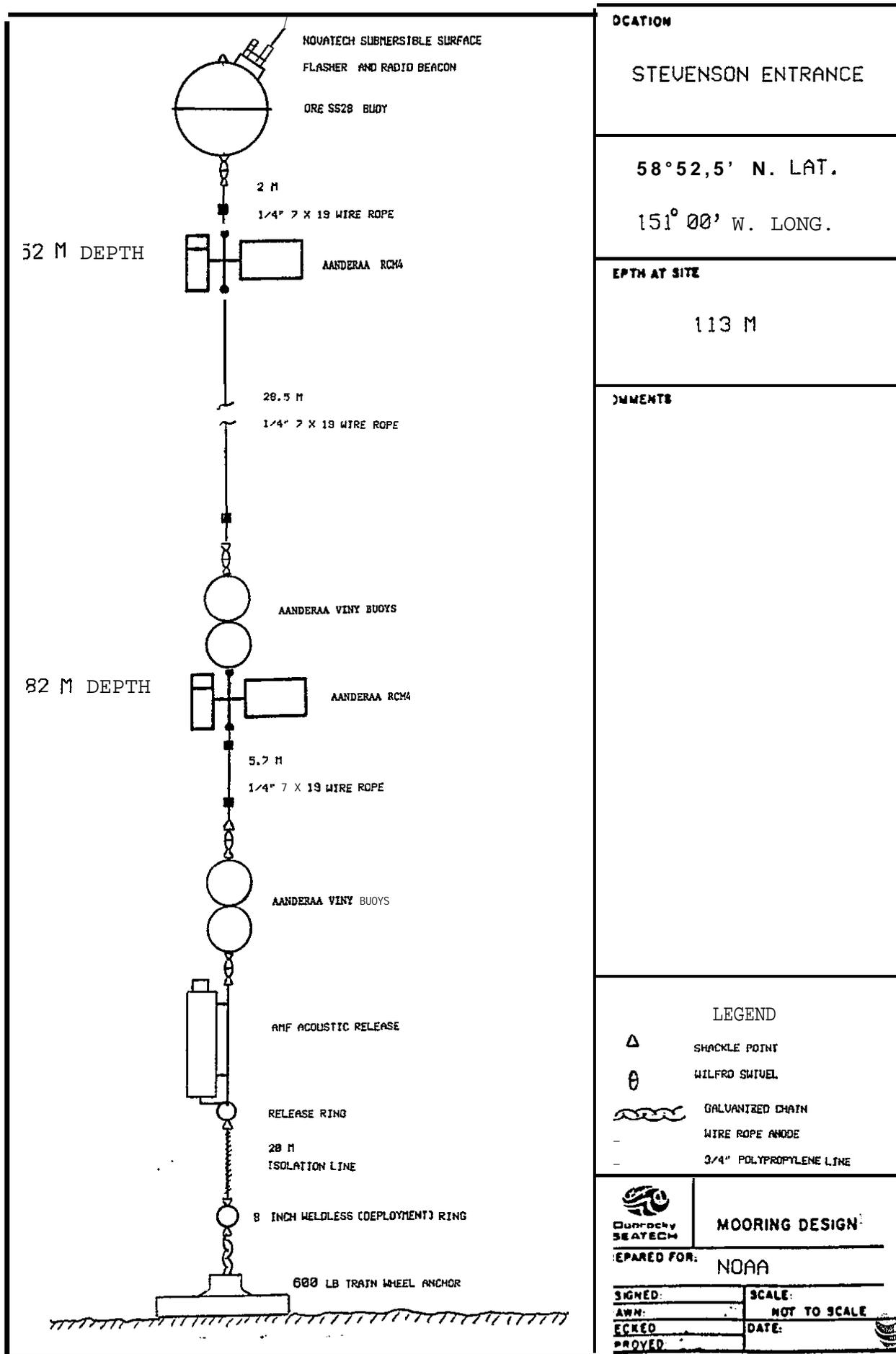
DEPTH AT SITE
66 M

COMMENTS

LEGEND
 △ SHACKLE POINT
 ○ WILFRO SWIVEL
 GALVANIZED CHAIN
 - WIRE ROPE ANODE
 - 3/4\"/>

	MOORING DESIGN	
	PREPARED FOR: NOAA	
SIGNED	SCALE:	
DRAWN	NOT TO SCALE	
CHECKED	DATE:	
APPROVED		

Figure 1.2 Mooring configuration at Cook Inlet



LOCATION

STEVENSON ENTRANCE

58°52,5' N. LAT.

151°00' W. LONG.

DEPTH AT SITE

113 M

COMMENTS

LEGEND

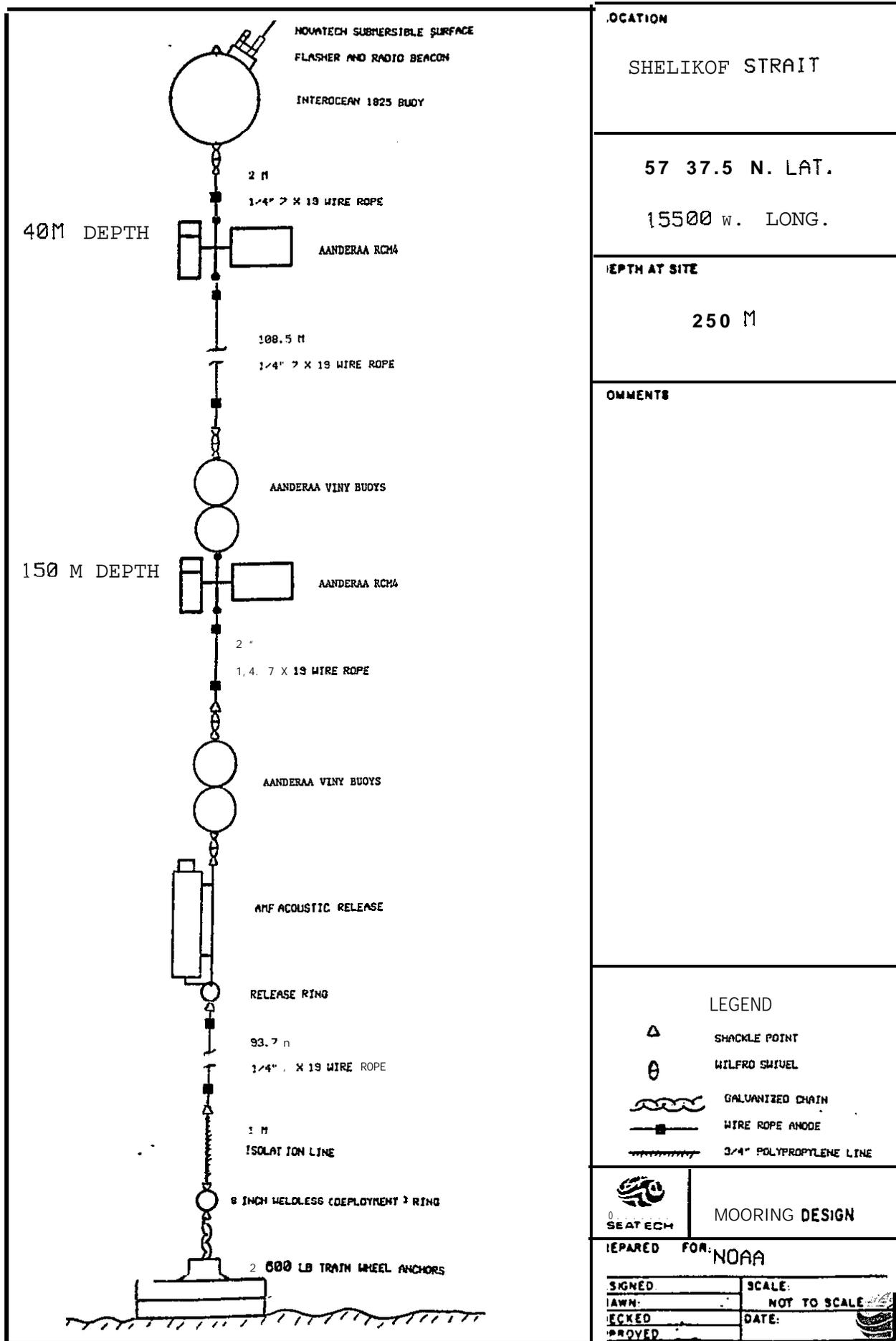
- △ SHACKLE POINT
- ⊙ WILFRO SHUTTEL
- ⌘ GALVANIZED CHAIN
- WIRE ROPE ANODE
- 3/4" POLYPROPYLENE LINE

MOORING DESIGN

PREPARED FOR: NOAA

SIGNED:	SCALE:
DRAWN:	NOT TO SCALE
CHECKED:	DATE:
APPROVED:	

Figure 1.3 Mooring Configuration at Stevenson Entrance



LOCATION
SHELIKOF STRAIT

57 37.5 N. LAT.
15500 W. LONG.

DEPTH AT SITE
250 M

COMMENTS

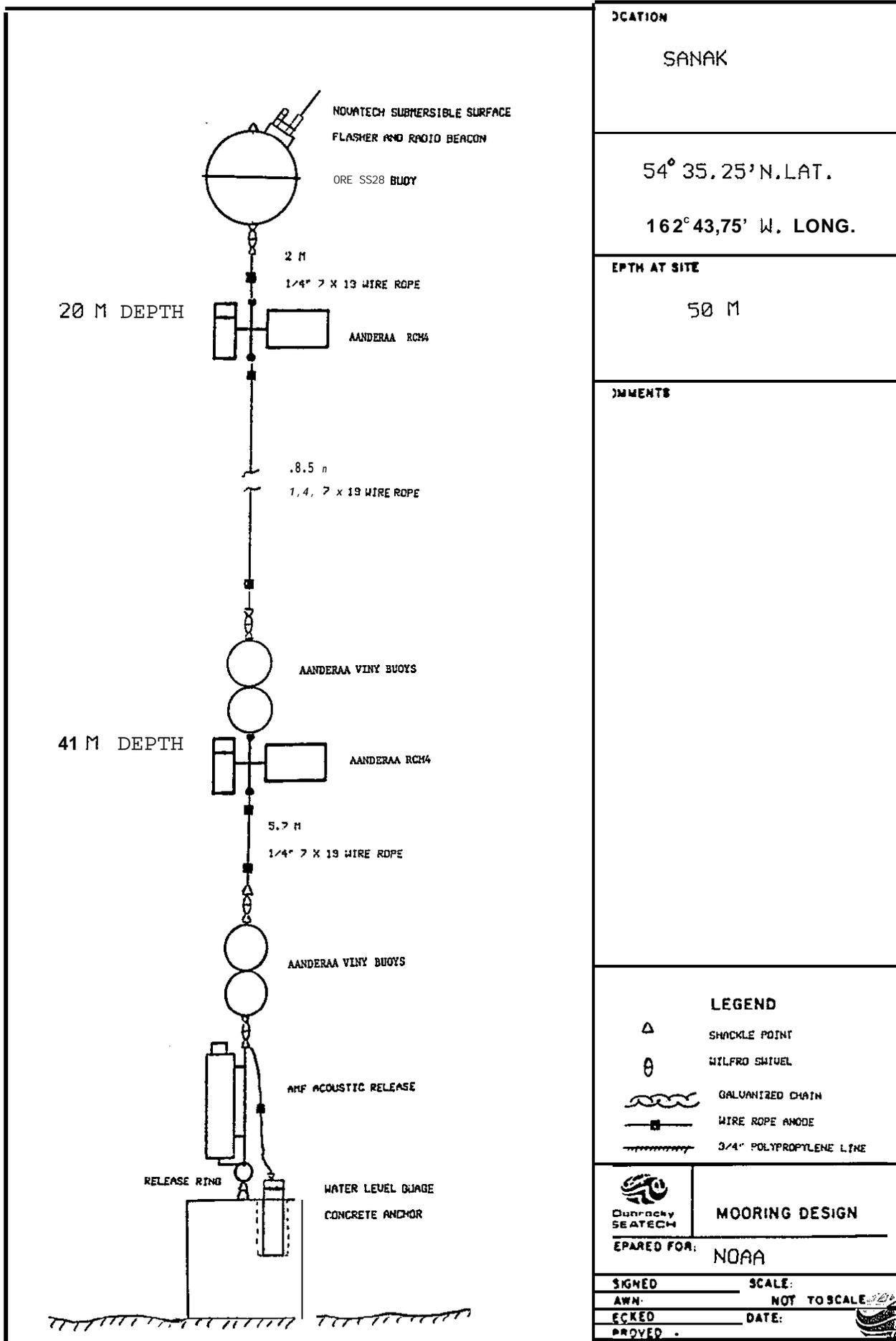
LEGEND
 △ SHACKLE POINT
 ⊙ WILFRO SWIVEL
 [Wavy line] GALVANIZED CHAIN
 [Line with square] WIRE ROPE ANODE
 [Line with diagonal lines] 3/4" POLYPROPYLENE LINE

SEATECH MOORING DESIGN

PREPARED FOR: NOAA

SIGNED	SCALE:
DRAWN	NOT TO SCALE
CHECKED	DATE:
APPROVED	

Figure 1.4 Mooring Configuration at Shelikof Strait



LOCATION
SANAK

54° 35.25' N. LAT.
162° 43.75' W. LONG.

DEPTH AT SITE
50 M

COMMENTS

LEGEND
 △ SHACKLE POINT
 ○ WILFRO SHIVEL
 GALVANIZED CHAIN
 WIRE ROPE ANODE
 3/4\"/>

MOORING DESIGN
 PREPARED FOR: NOAA

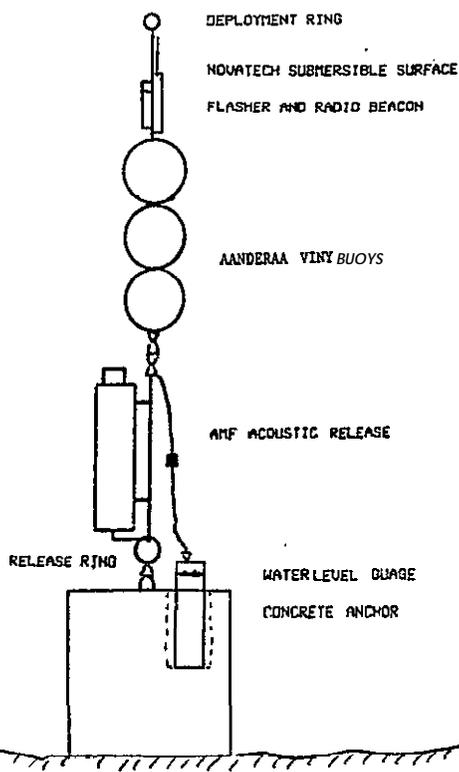
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 AWN: _____ NOT TO SCALE
 CHECKED: _____ DATE: _____
 APPROVED: _____

Figure 1.5 Mooring Configuration at Sanak

POR TLOCK BANK 58 00' N. LAT. 149 30' W. LONG. 200 M
 SEAL W 59 30' N. LAT. 152 30' U. LONG. 100 M
 ALBATROSS BANK 58 30' N. LAT. 153 00' U. LONG. 200 M
 SIMONOFF ISLAND 54 30' N. LAT. 153 00' U. LONG. 20 M
 ANATUL I ISLAND 55 00' N. LAT. 152 00' U. 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



MOORING DESIGN

NOAA	
SIGNED	SCALE:
AWN:	NOT TO SCALE
CHECKED	DATE:
APPROVED	



Figure 1.6 Mooring Configuration for the Tide Gauges

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

STATION	Principal Lunar Diurnal		Soli -Lunar Declinational (Divisional)		Larger Lunar Elliptic (Semi- Diurnal)		Principal Lunar (Semi-Diurnal)		Principal Solar (Semi-Diurnal)		$\rho = \frac{K_1 + O_1}{M_2 + S_2}$
	A	O ₁ G	A	K ₁ G	A	'2 G	A	'2 G	A	S ₂ G	
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	317.5?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 Is.	.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						K ₁					
		MAJ	MIN	INC	G	A	G	MAJ	MIN	INC	G	A	G
Stevenson	54	3.7	-0.78	98	14			6.6	-2.2	101	41		
Stevenson	82	3.5	-1.7	91	22			6.4	-3.5	108	36		
Amatuli 1												.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												.593	289
Sanak	20	2.3	-1.1	177	105			4.0	-2.0	167	145		
Sanak	41	3.5	-0.90	1	274			7.1	-3.1	166	136		
Sanak												.504	293
Cook In.	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						M ₂						S ₂					
		MAJ	MIN	INC	G	A	G	MAJ	MIN	INC	G	A	G	MAJ	MIN	INC	G	A	G
Stevenson	54	5.9	1.5	94	51			30.2	0.62	102	66			10.1	0.59	97	112		
Stevenson	82	6.0	-0.3	9	4	55		36.3	1.65	91	76			11.6	1.10	84	126		
Amatuli 1																		.418	358
Shelikof Str.	46	2.5	0.7	39				13.8	-0.02	40	251			4.5	-0.03	41	297		
Shelikof Str.	157	3.1	1.0	46	233			14.9	.60	43	248			4.3	.14	41	296		
C. Ikolik																		.376	002
Sanak	20	0.7	-0.3	90				3.1	.47	183	285			1.1	-0.11	77	336		
Sanak	41	0.5	-0.5	64	239			4.1	1.08	90	253			1.5	-0.61	30	267		
Sanak																		.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 the subtidal, oscillations. We found ourselves somewhat limited in these analyses because of the relatively short period of measurement. The 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 1984 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, Mitrofanina 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 advected 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



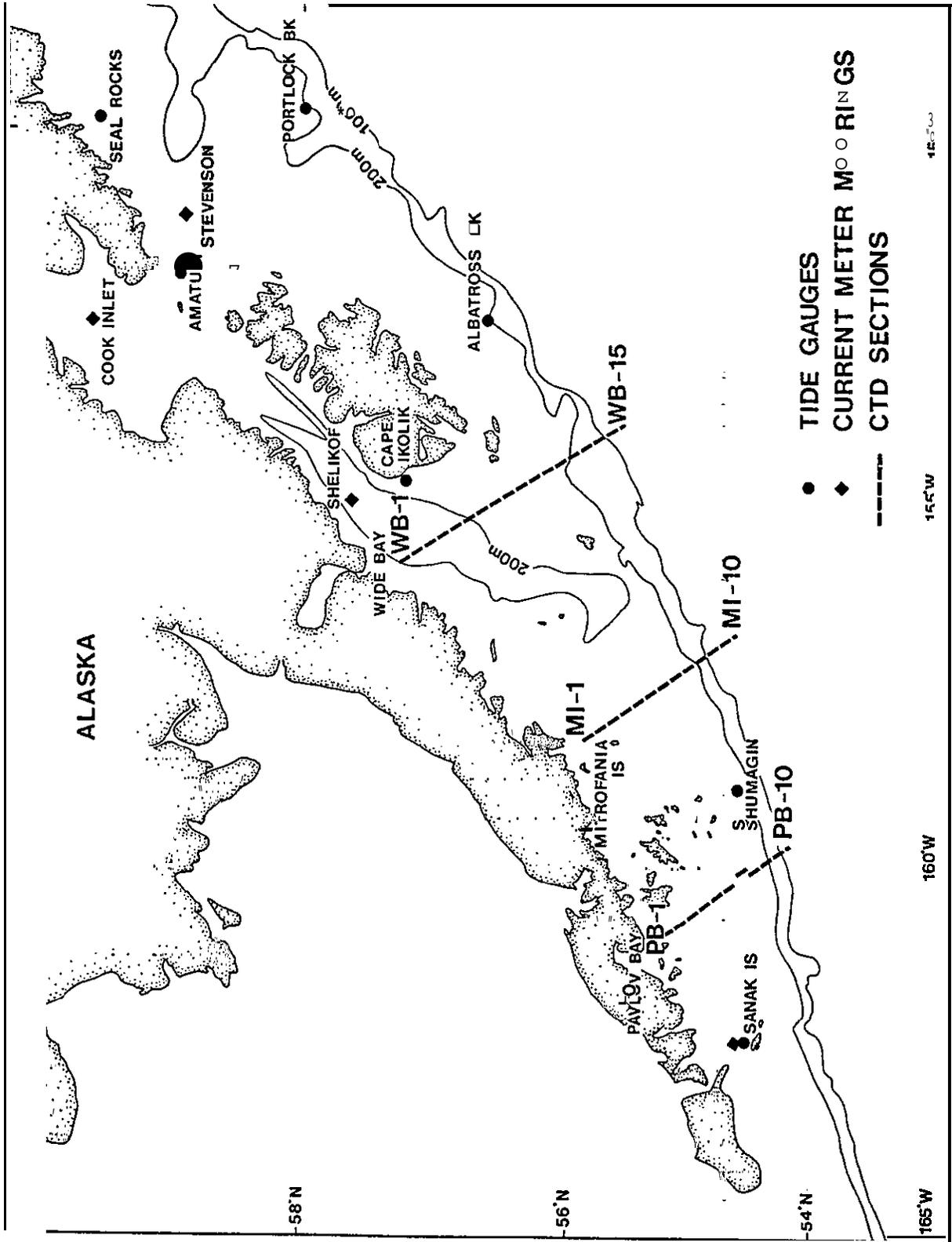
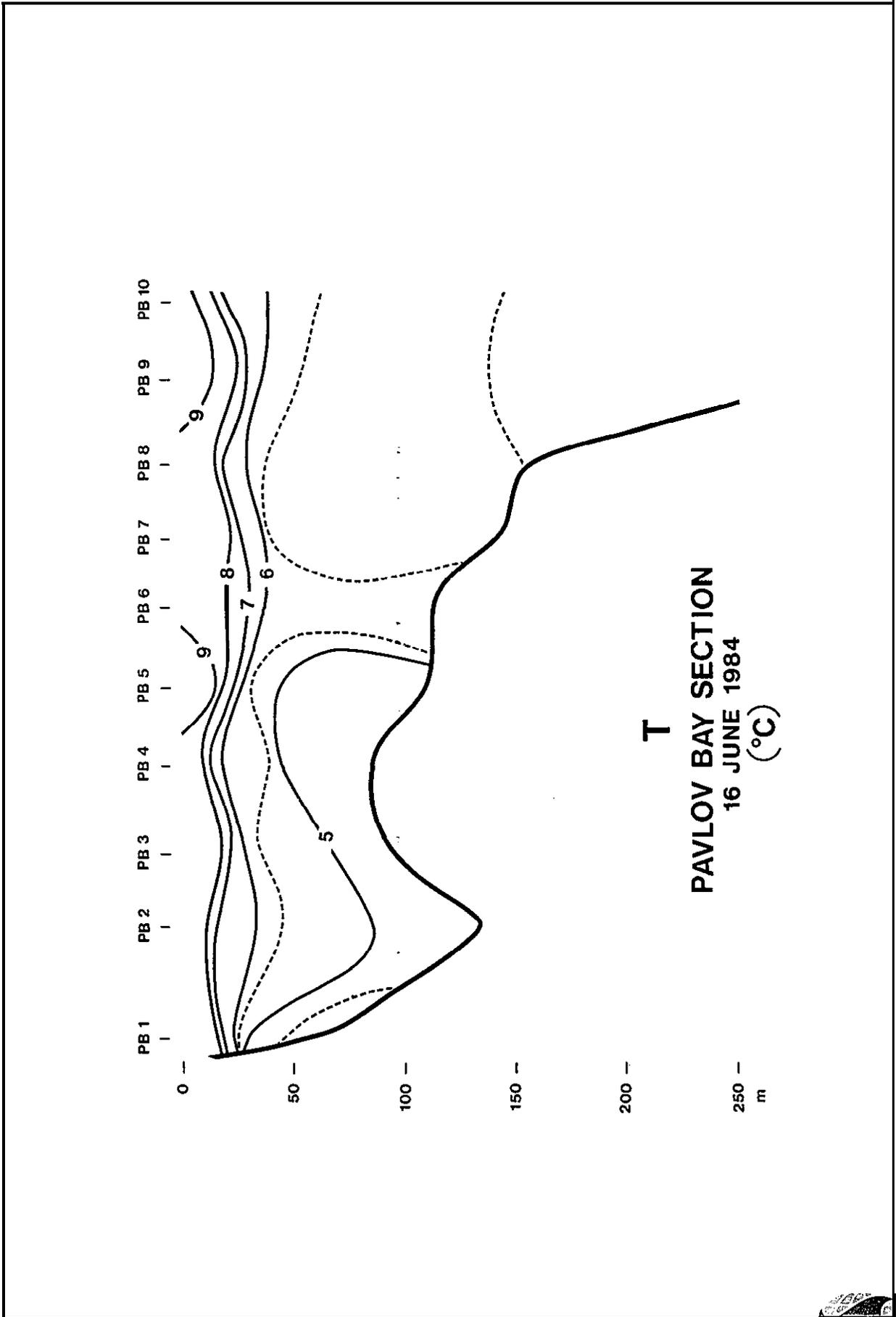
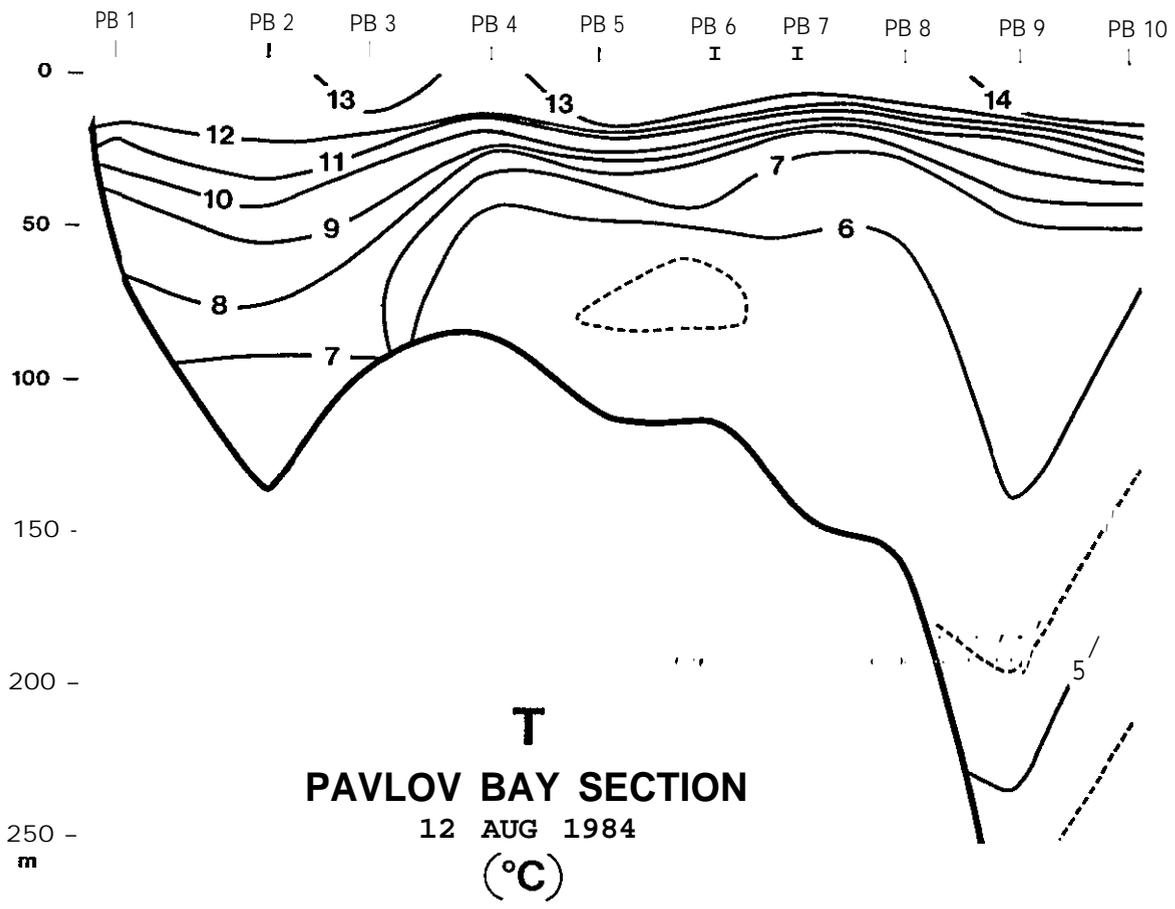


Figure 2.1 Location Chart for S, T, σ_t cross sections.



T
PAVLOV BAY SECTION
16 JUNE 1984
(°C)

Figure 2.2 Temperature Section Pavlov Bay June



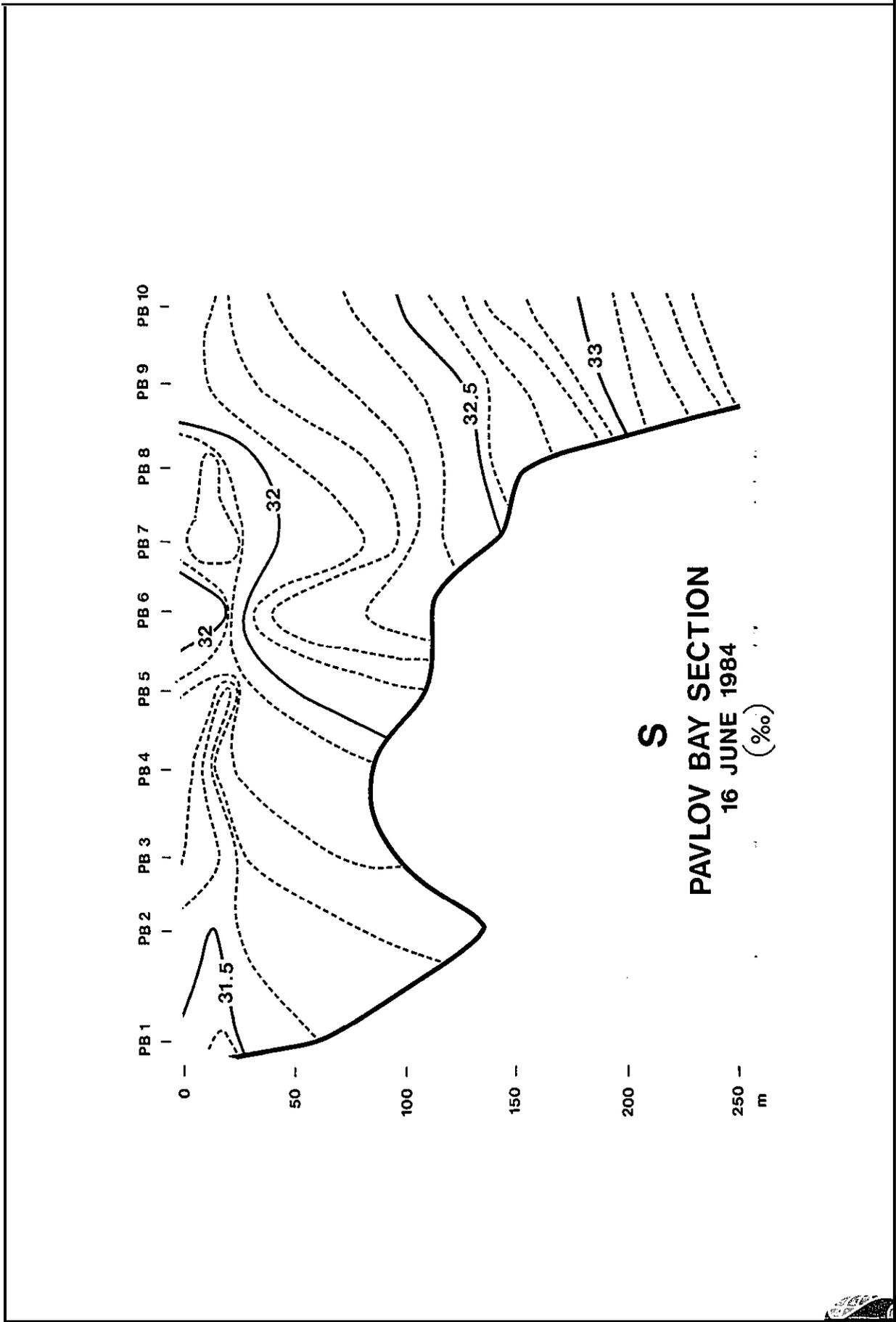
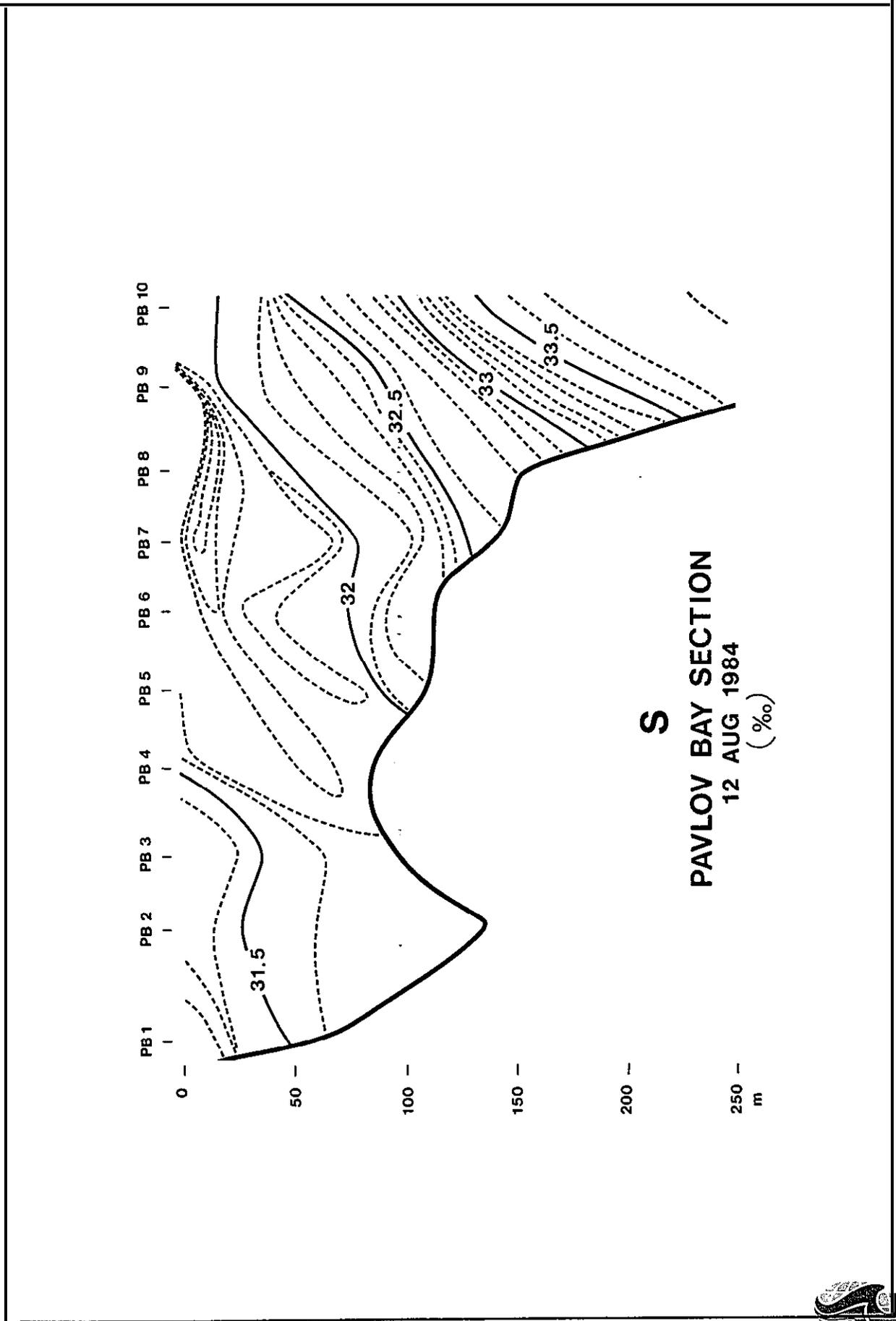


Figure 2.4 Salinity Section Pavlov Bay June



S
PAVLOV BAY SECTION
12 AUG 1984
(‰)



Figure 2.5 Salinity section Pavlov Bay August

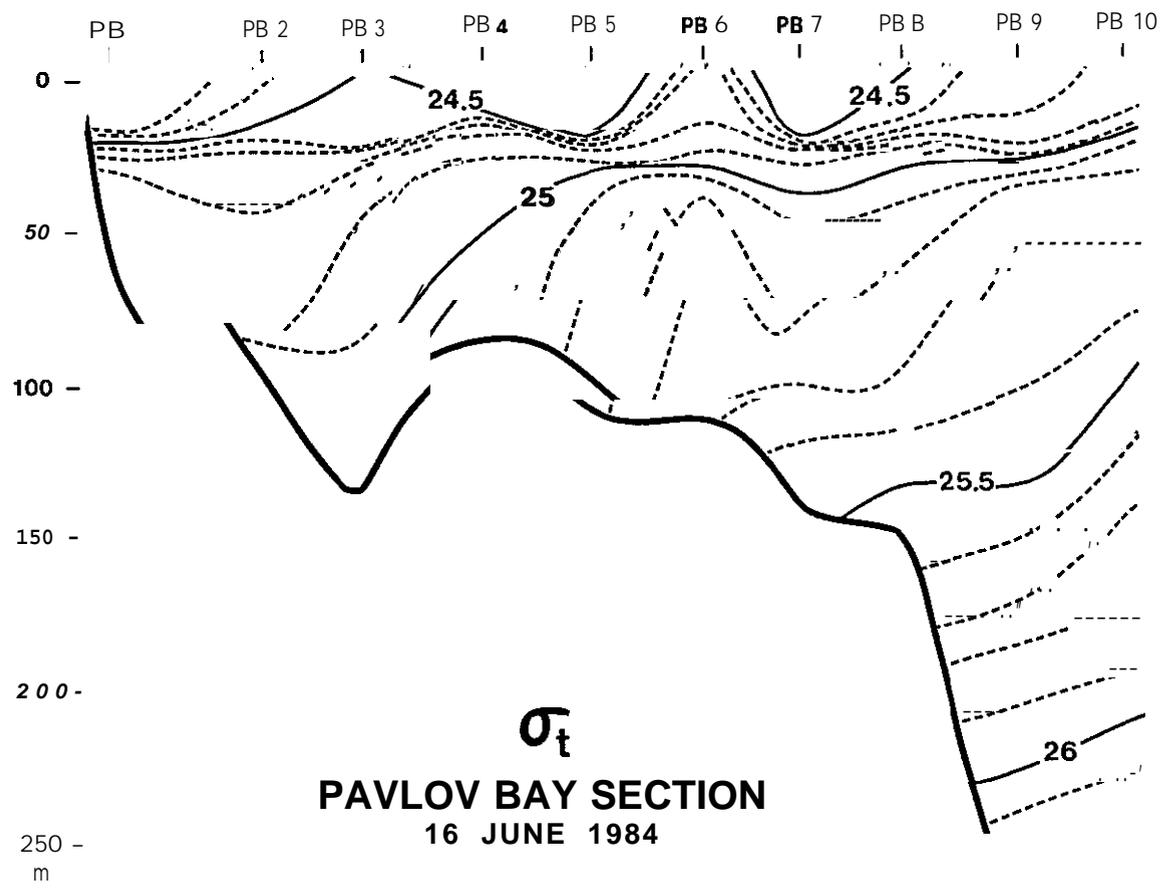


Figure 2.6 Sigma-t Section Pavlov Bay June

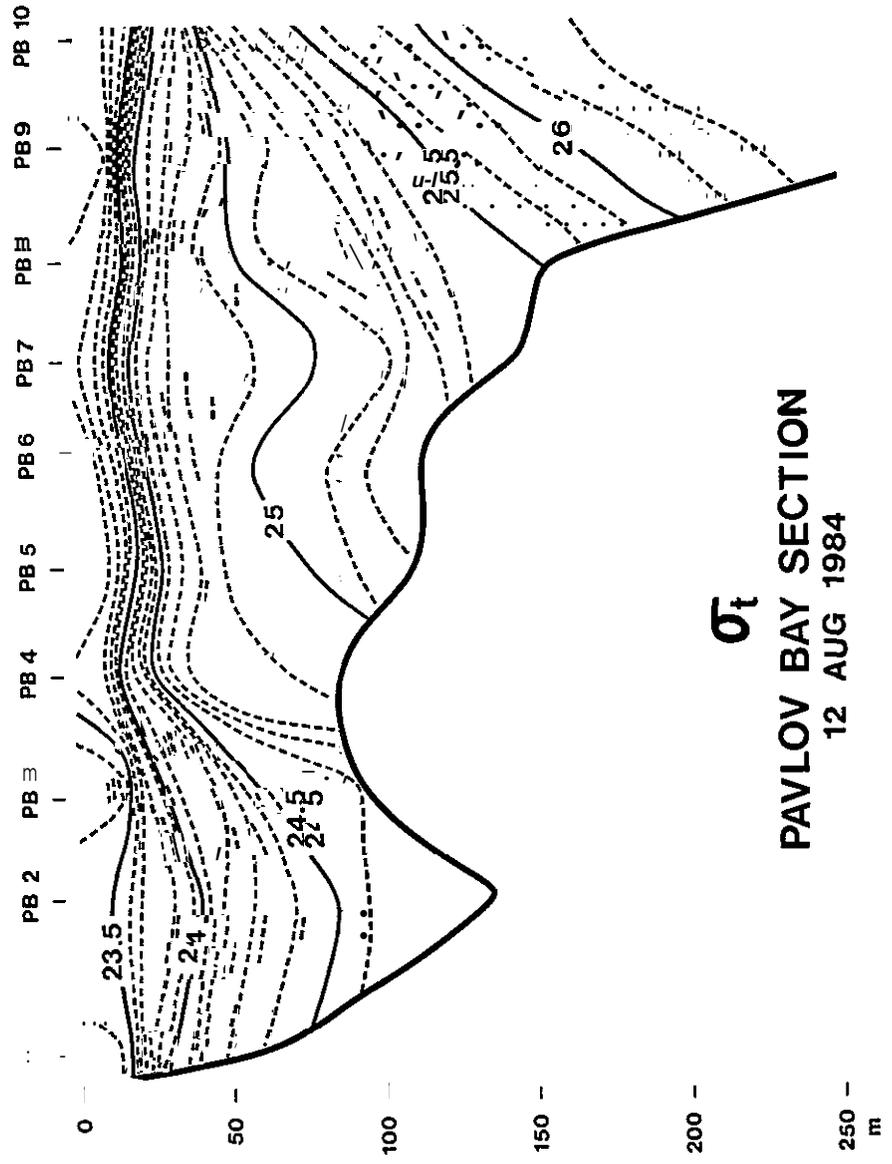
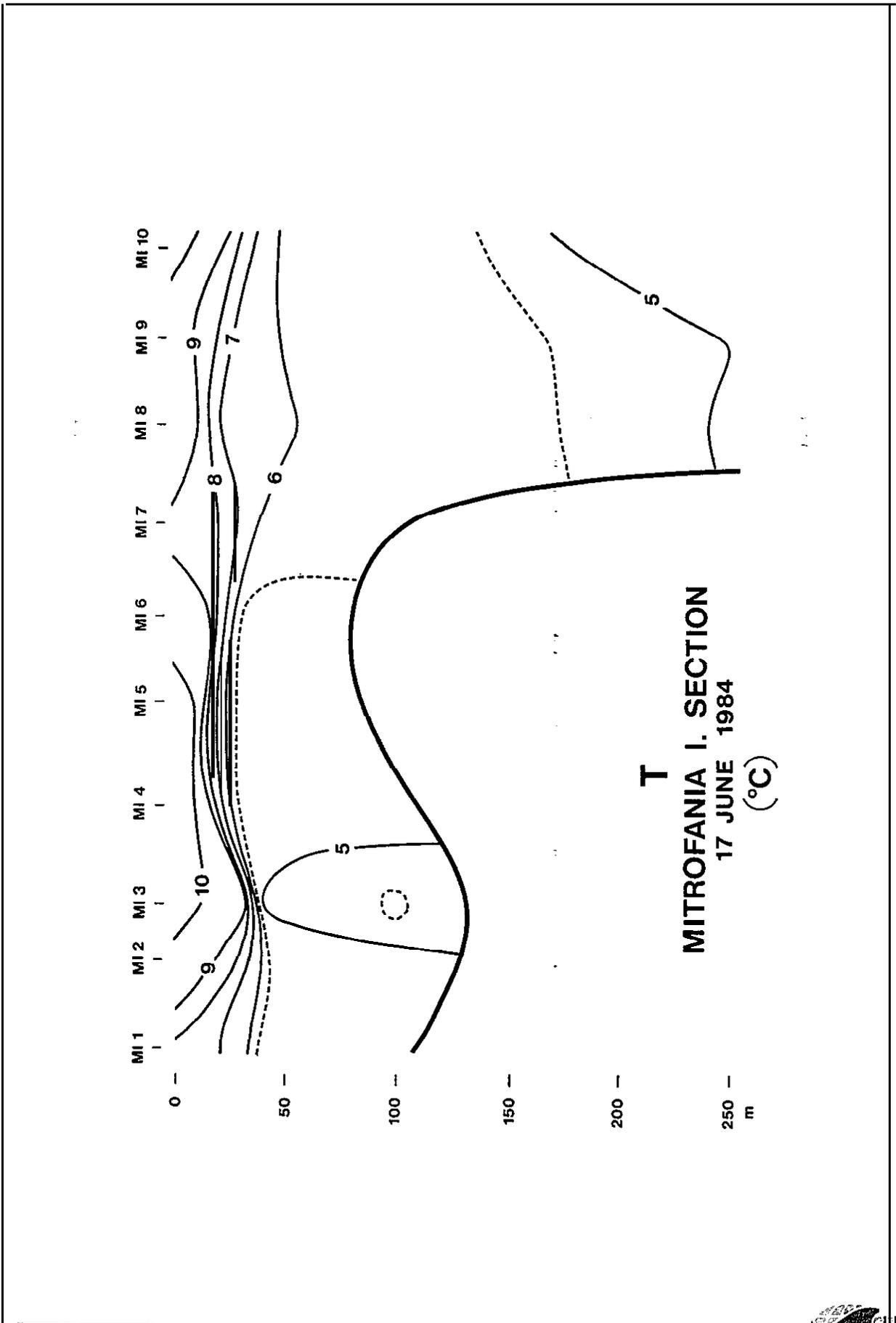


Figure 2.7 Sigma-t Section Pavlov Bay August



T
MITROFANIA I. SECTION
17 JUNE 1984
(°C)

Figure 400 Temperature Section Mitrofanía Island June

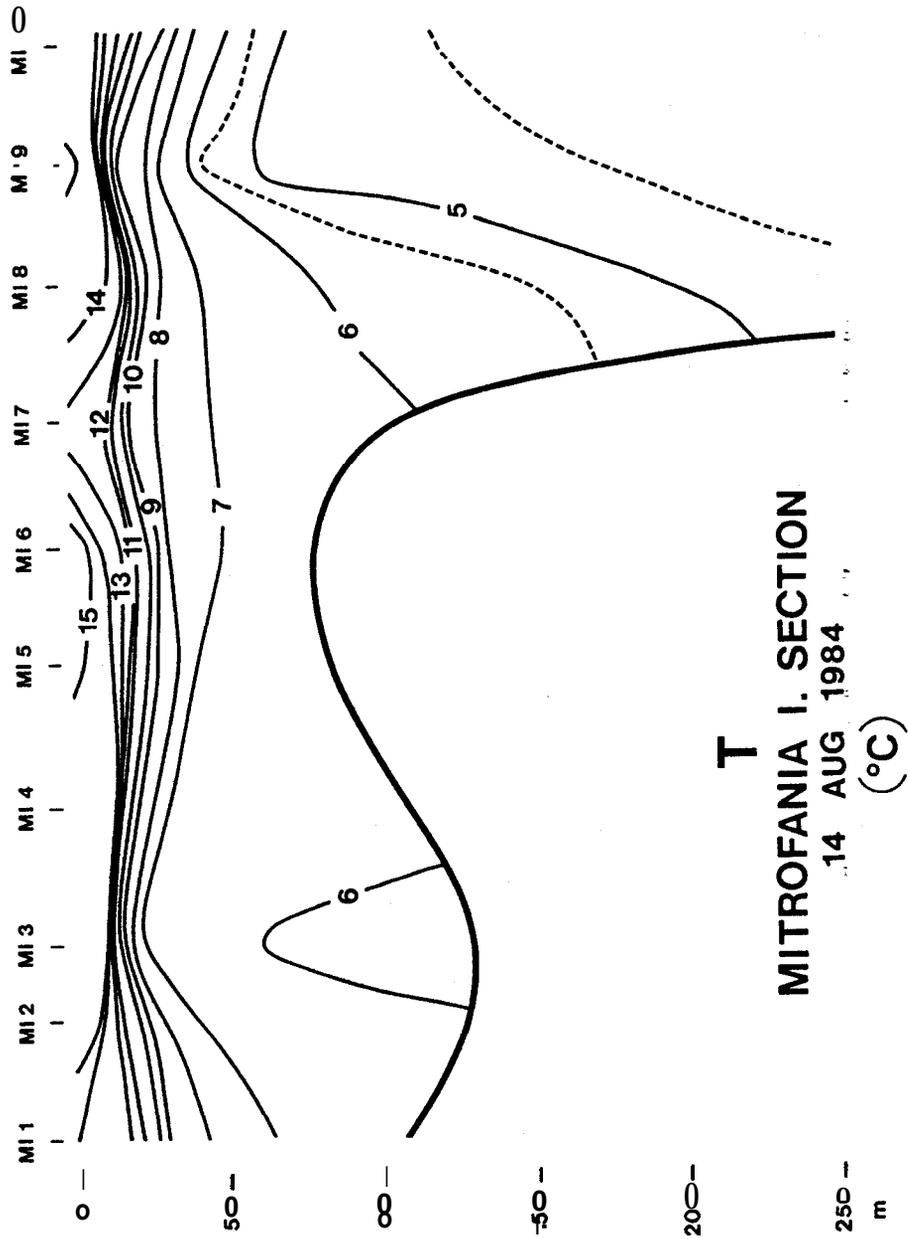


Figure 2.9 Temperature Section Mitrofanía Island August

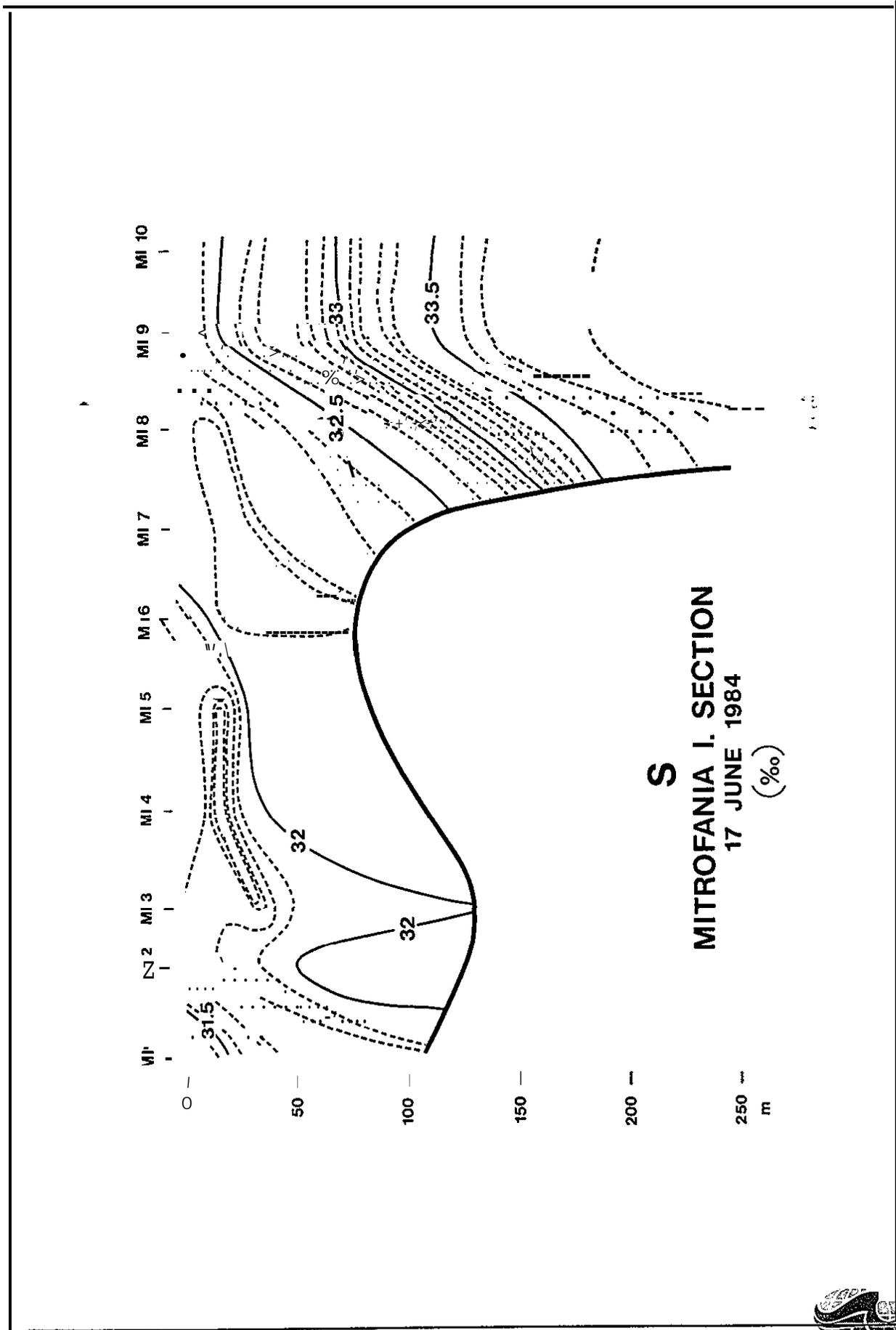


Figure 2.10 Salinity Section Mitrofanía Island June

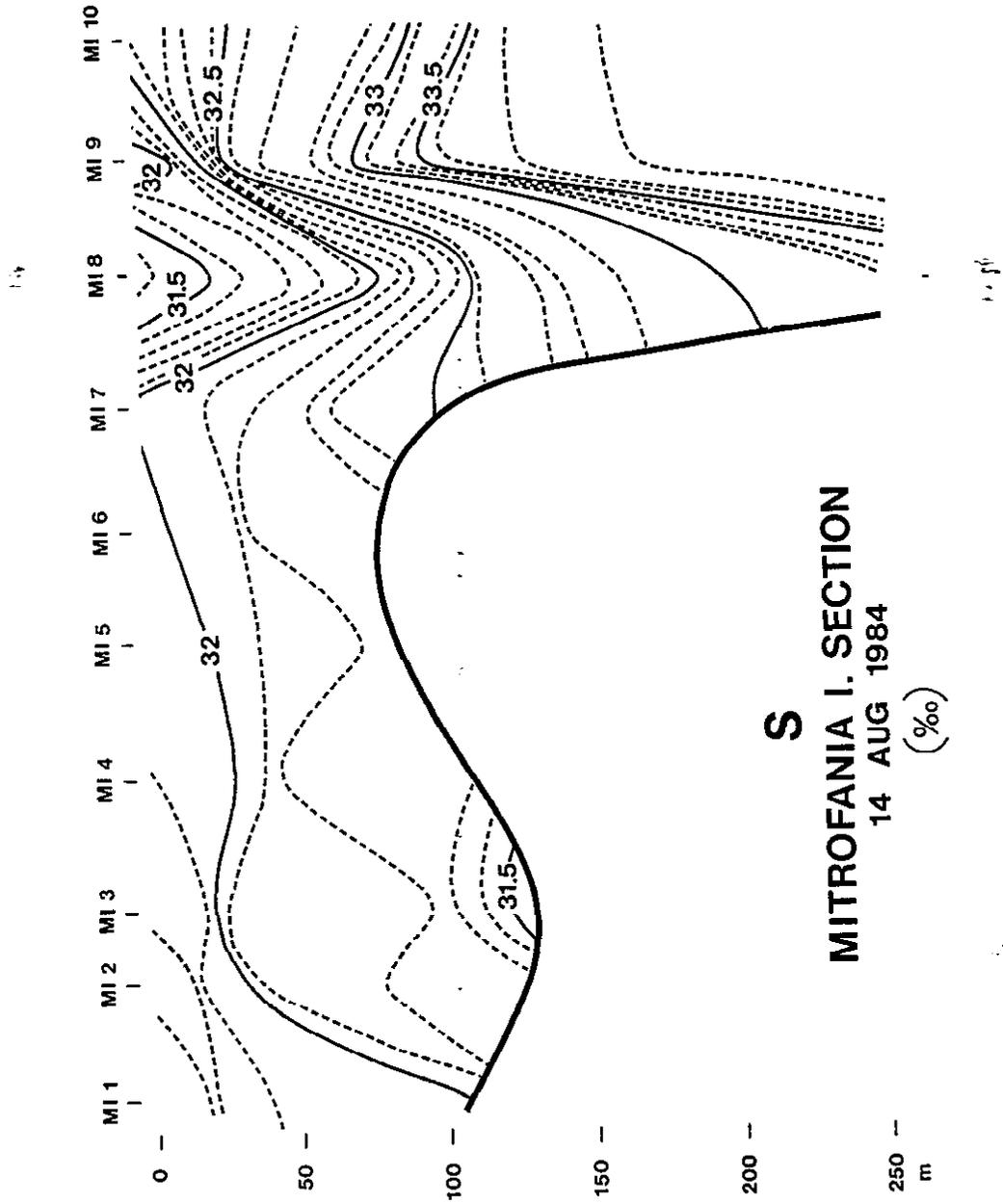


Figure 2.11 Salinity Section Mitrofanía Island August

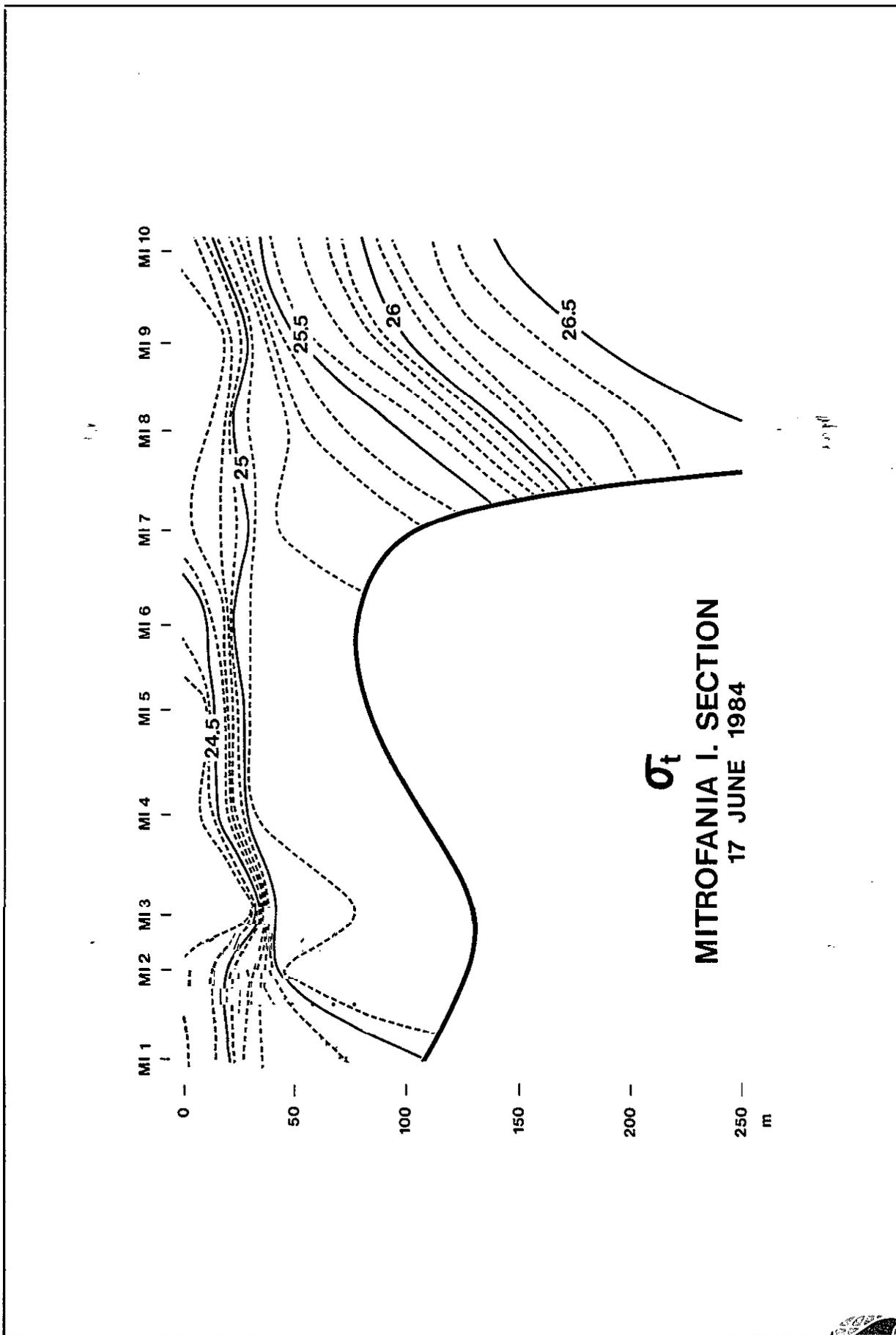
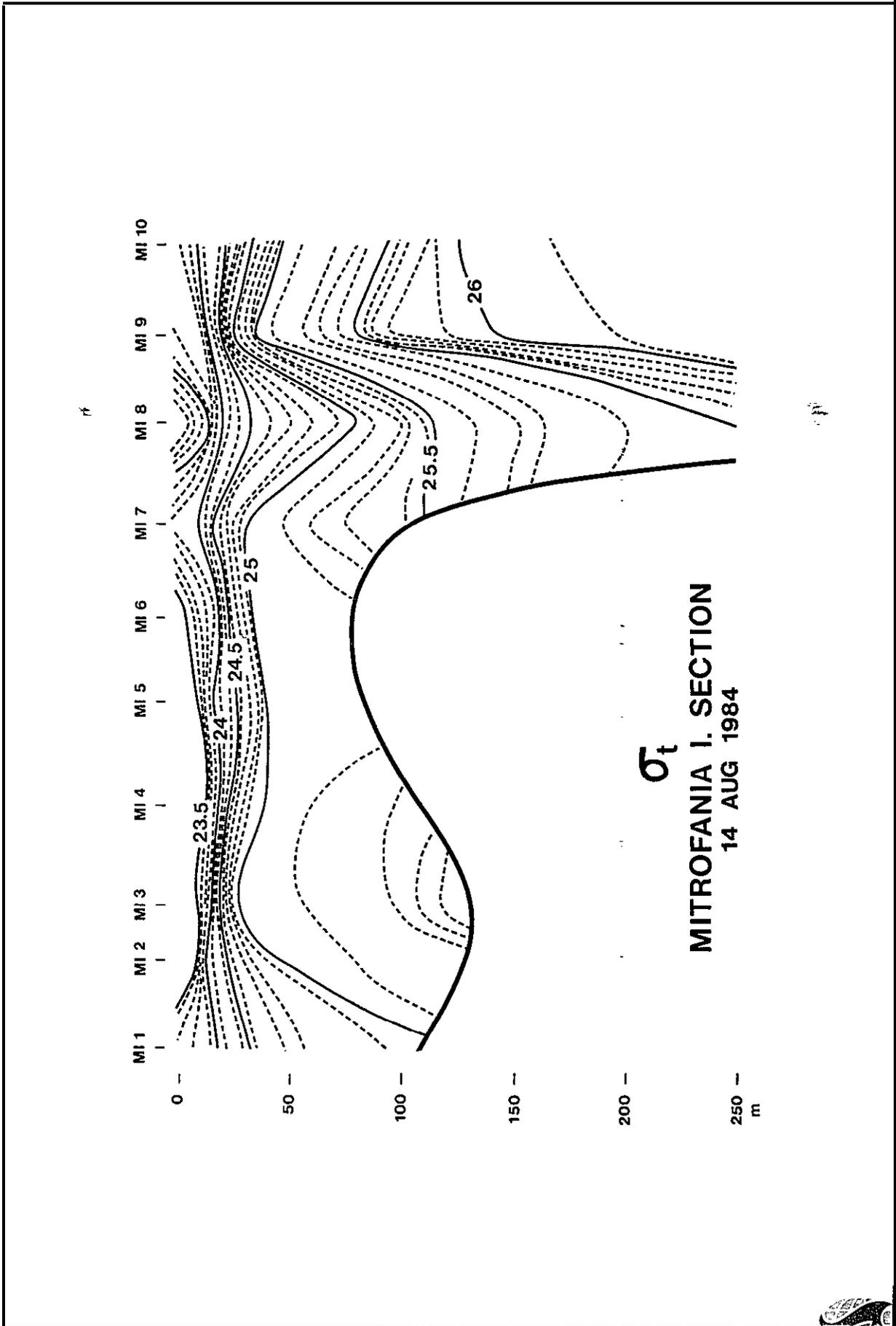


Figure 2.12 Sigma-t Section Mitrofanias Island June



σ_t
MITROFANIA I. SECTION
14 AUG 1984

Figure 4.13 Sigma-t Section Mitrofanias Island August

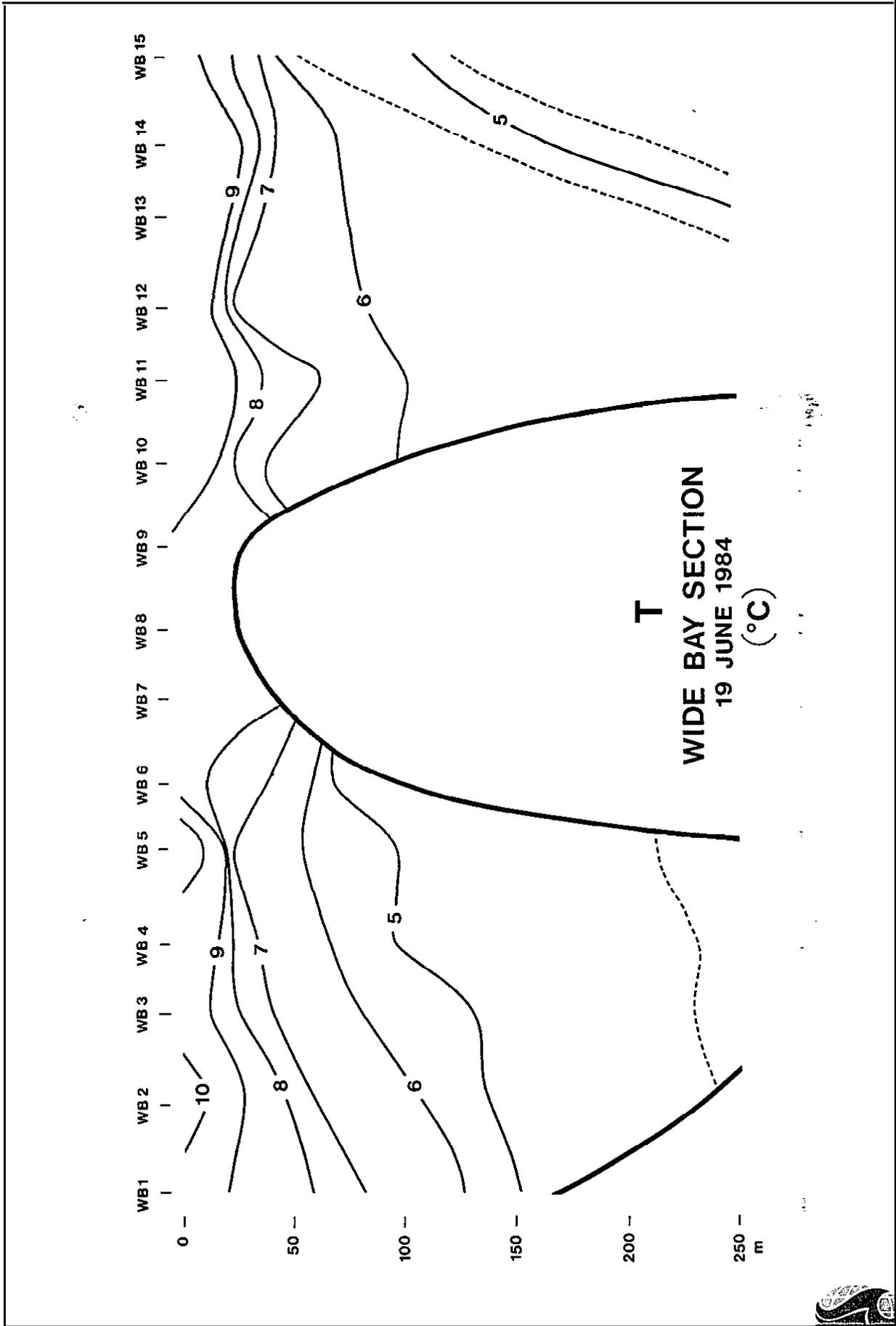


Figure 2.14 Temperature Section Wide Bay June



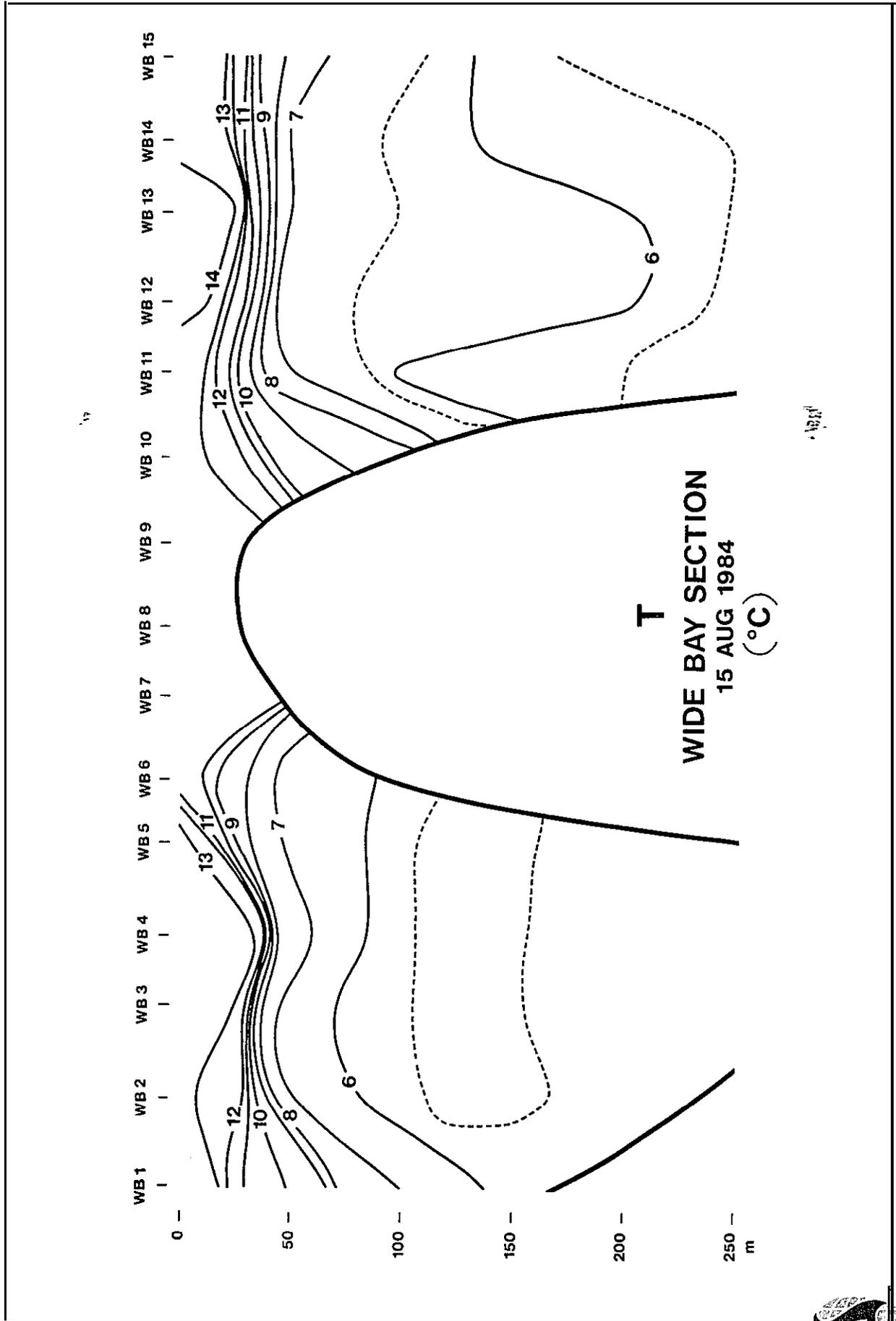


Figure 10. Temperature section Wide Bay August

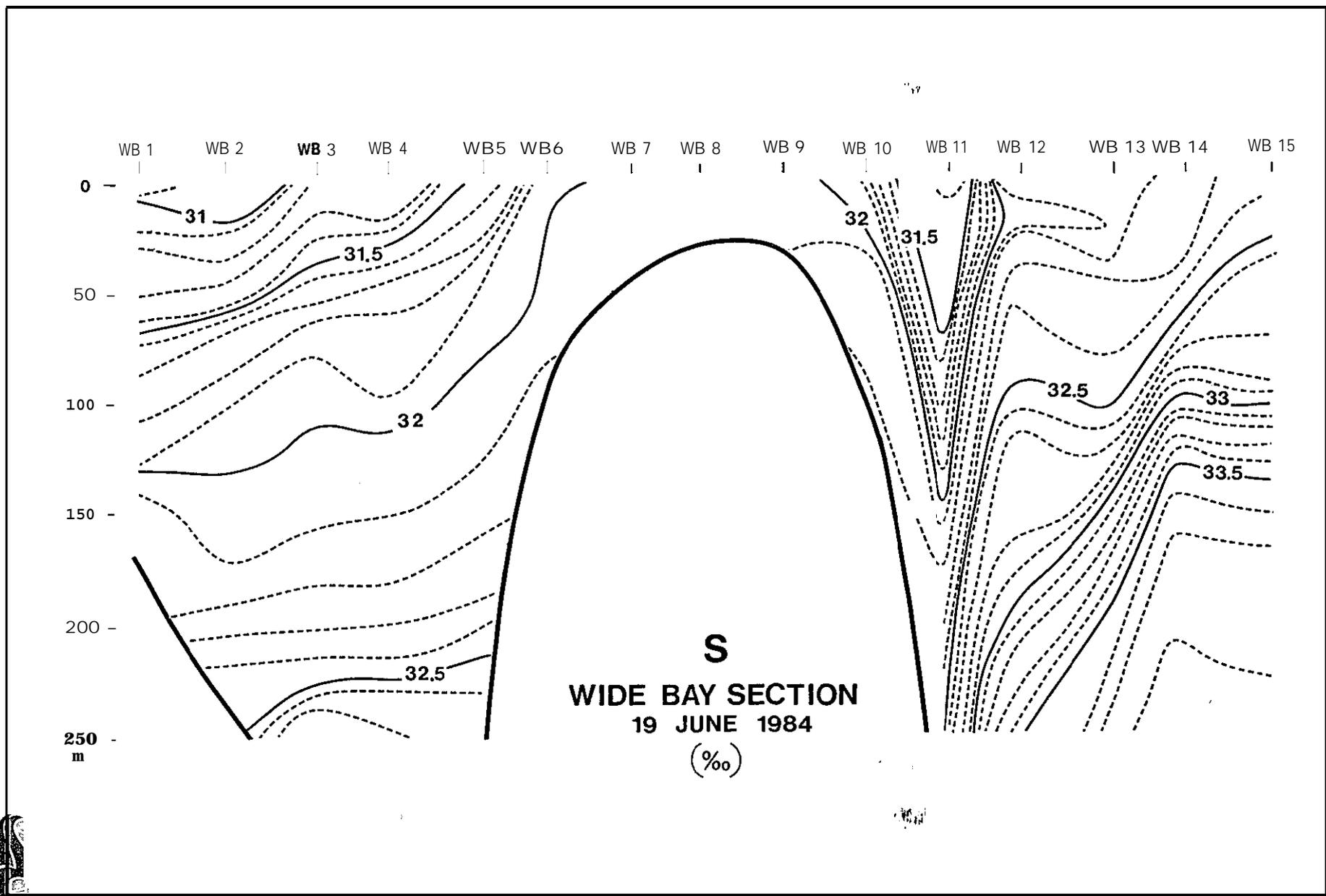


Figure 2.16 Salinity Section Wide Bay June

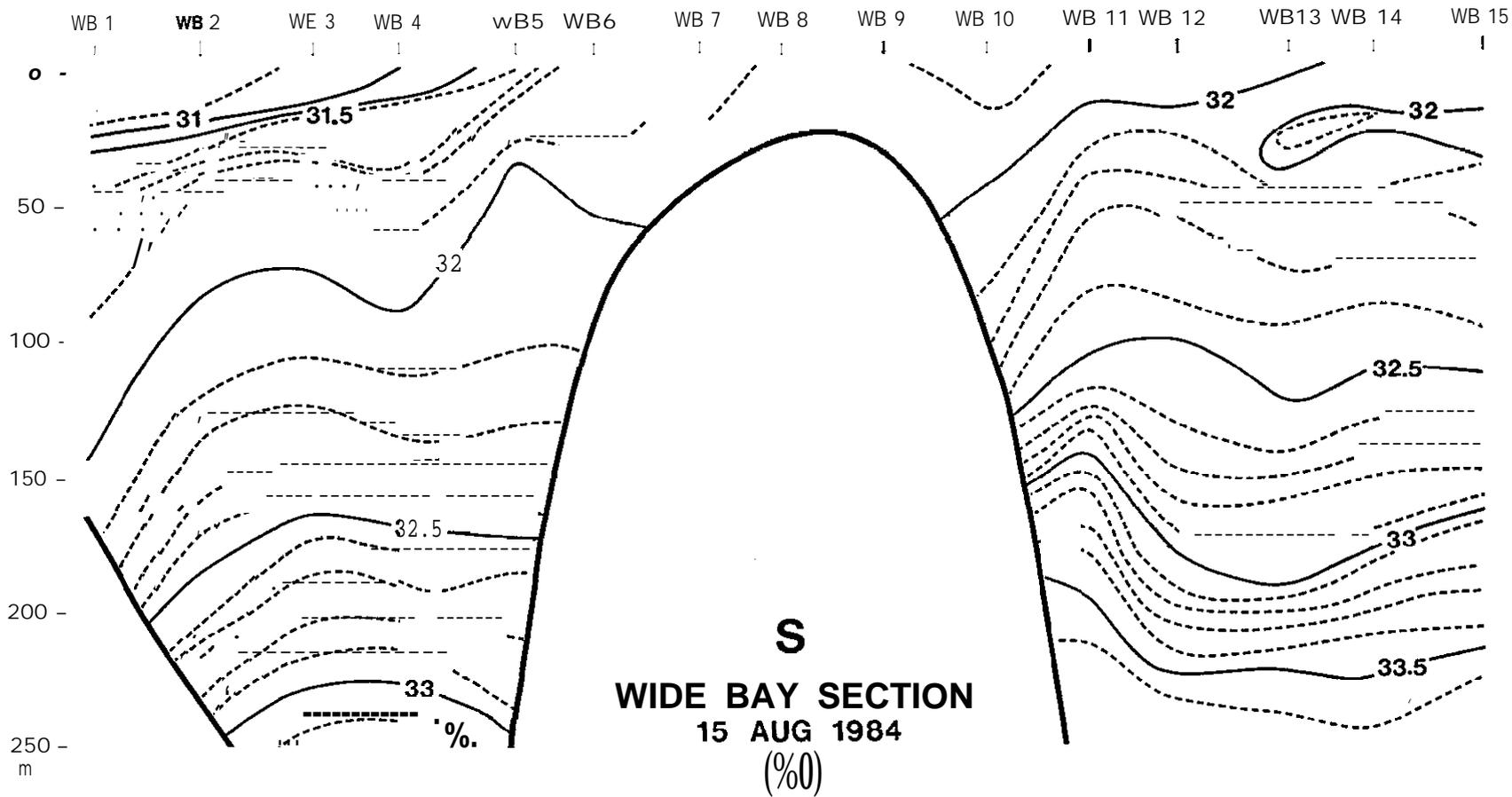


Figure 2.17 Salinity Section Wide Bay August

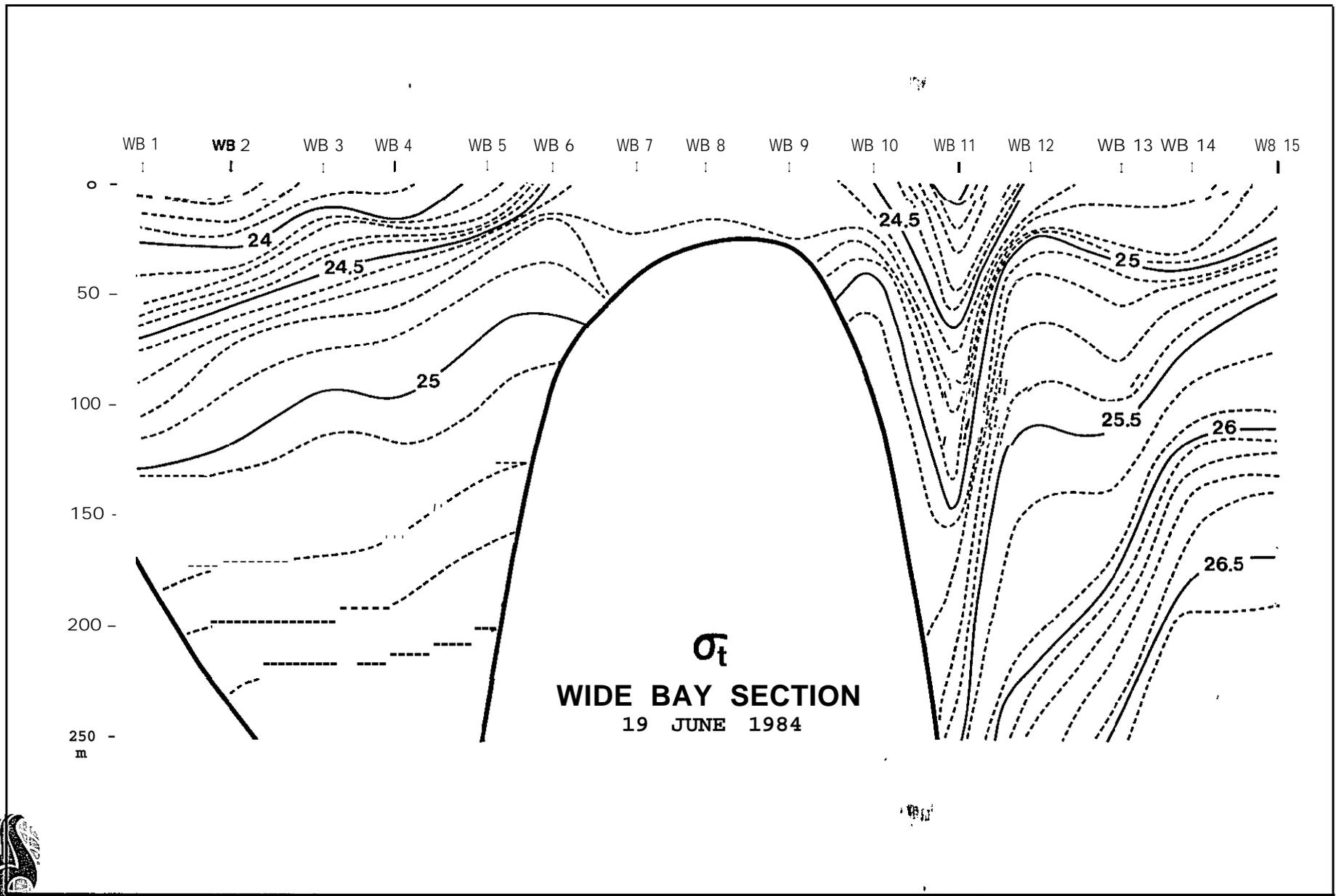


Figure 2.18 Sigma-t Section Wide Bay June

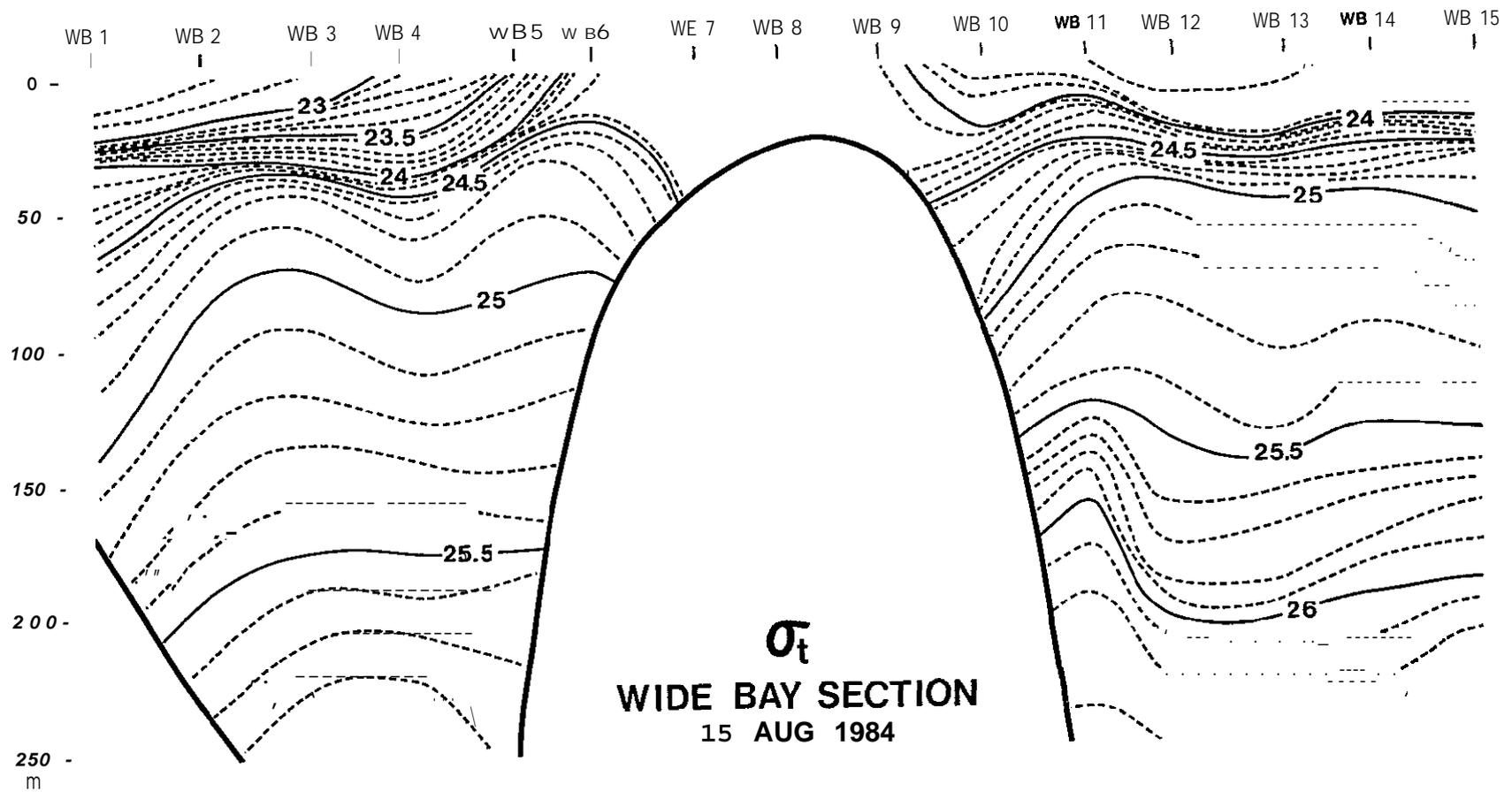


Figure 2.19 Sigma-t Section Wide Bay August

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 stratification occurs, at least in the upper layers, during periods of maximum river discharge.

Although the contours have been substantially smoothed, wave-like features still 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 Mitrofanina 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 temperatures.

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 Mitrofanina 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

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

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 satisfy 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 profile. 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.

The 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



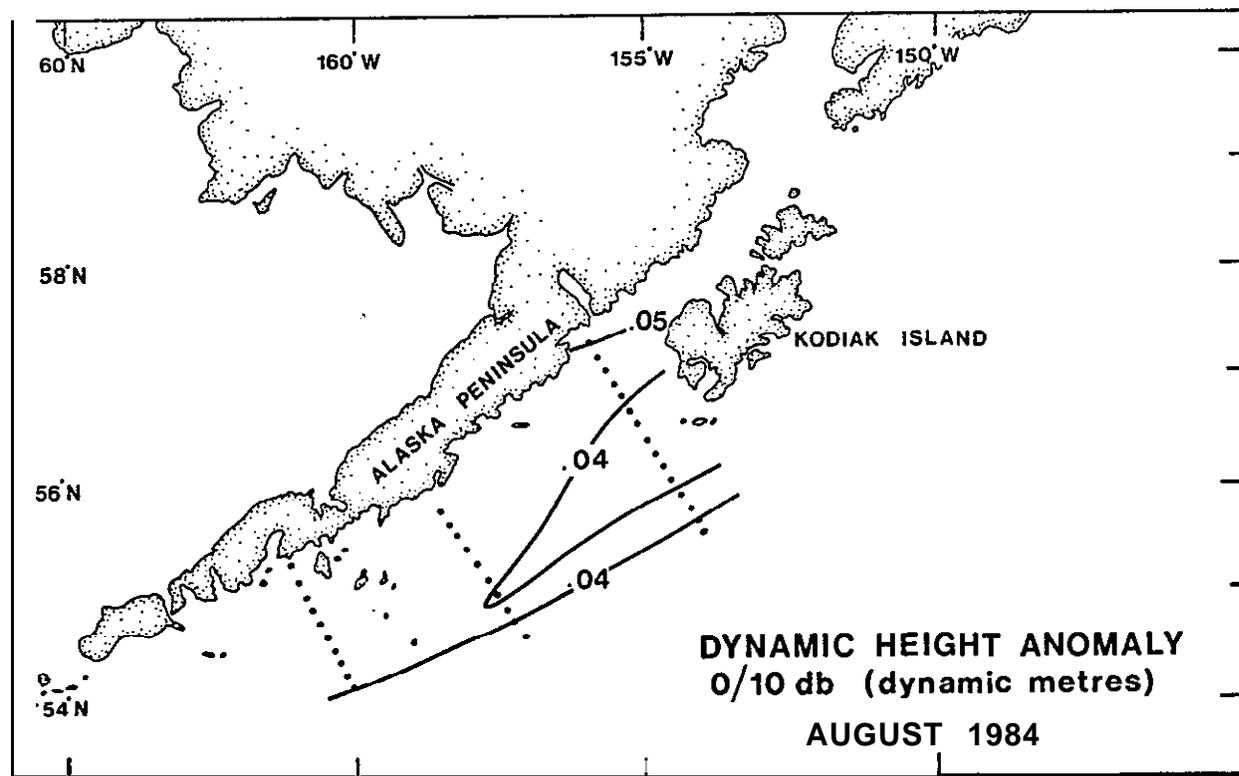
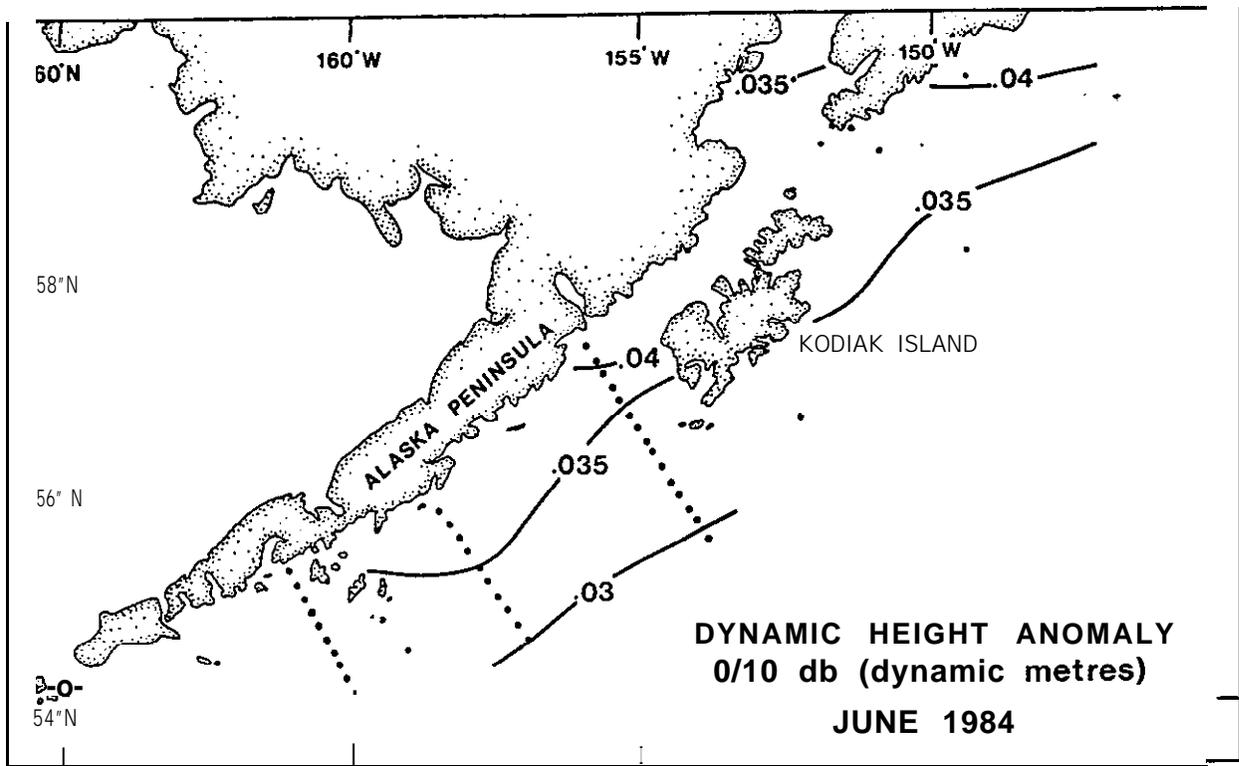


Figure 2.20 Dynamic Height Topography 0/10 db June and August 1984



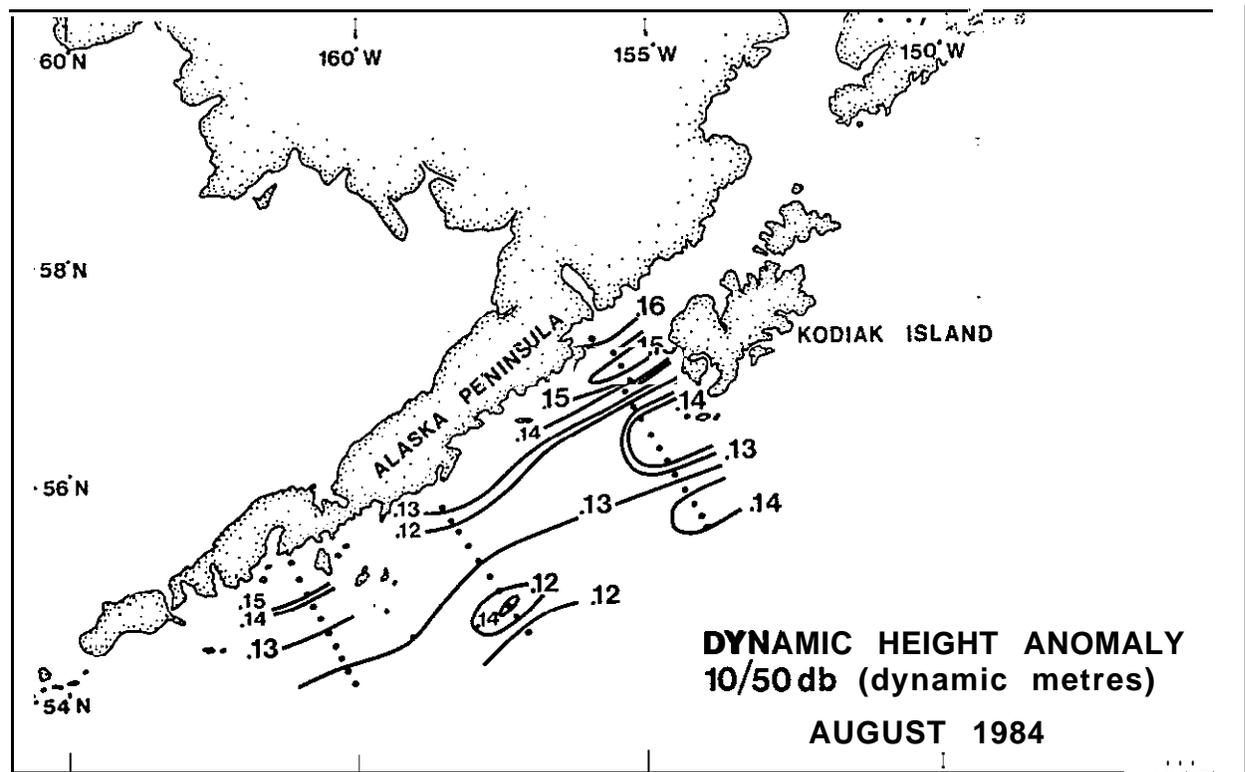
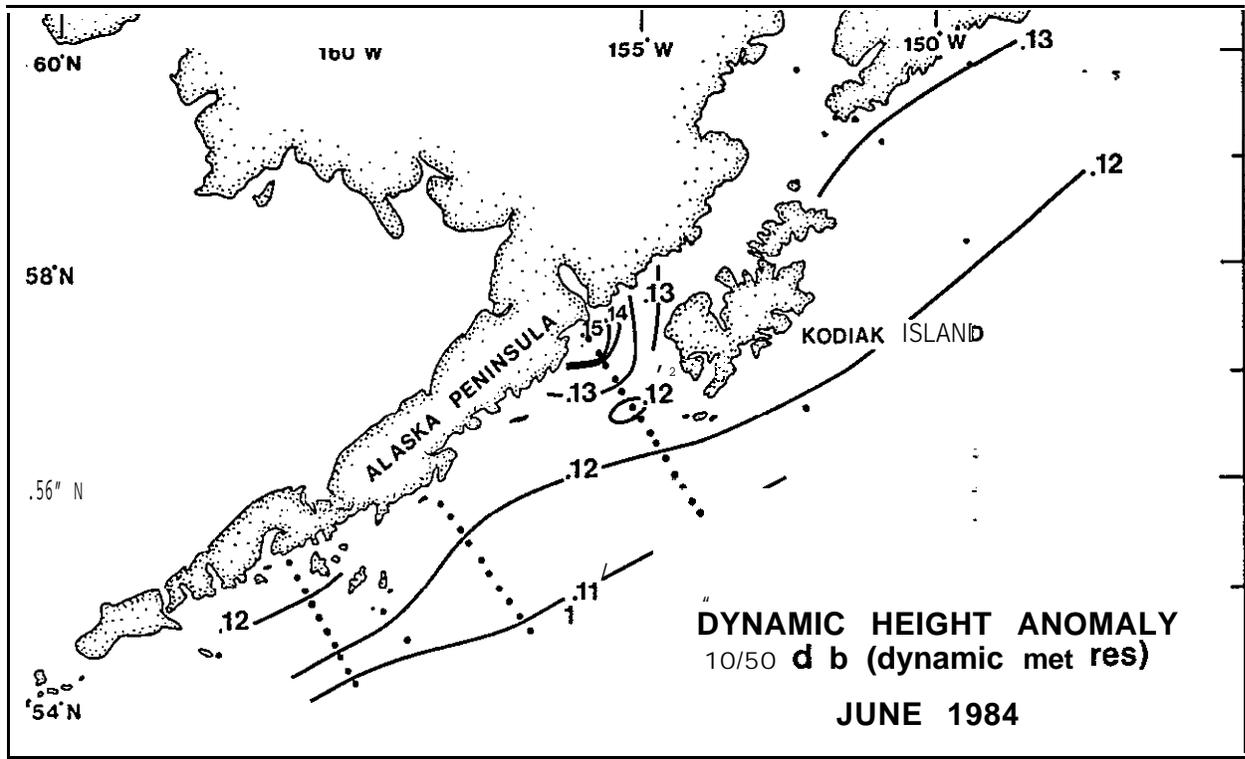


Figure 2.21 Dynamic Height Topography 10/50 db June and August 1984



and August due to continued insolation. Figures 2.21 and 2.22 represent the topography of the 10 and 0 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

$$\Delta u = \frac{f \Delta D}{fL} \quad (2-2)$$

where Δu is the velocity difference, ΔD is the difference 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 flow 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 the contemporary view of the Alaska Coastal Current regime, e.g. Royer (81)



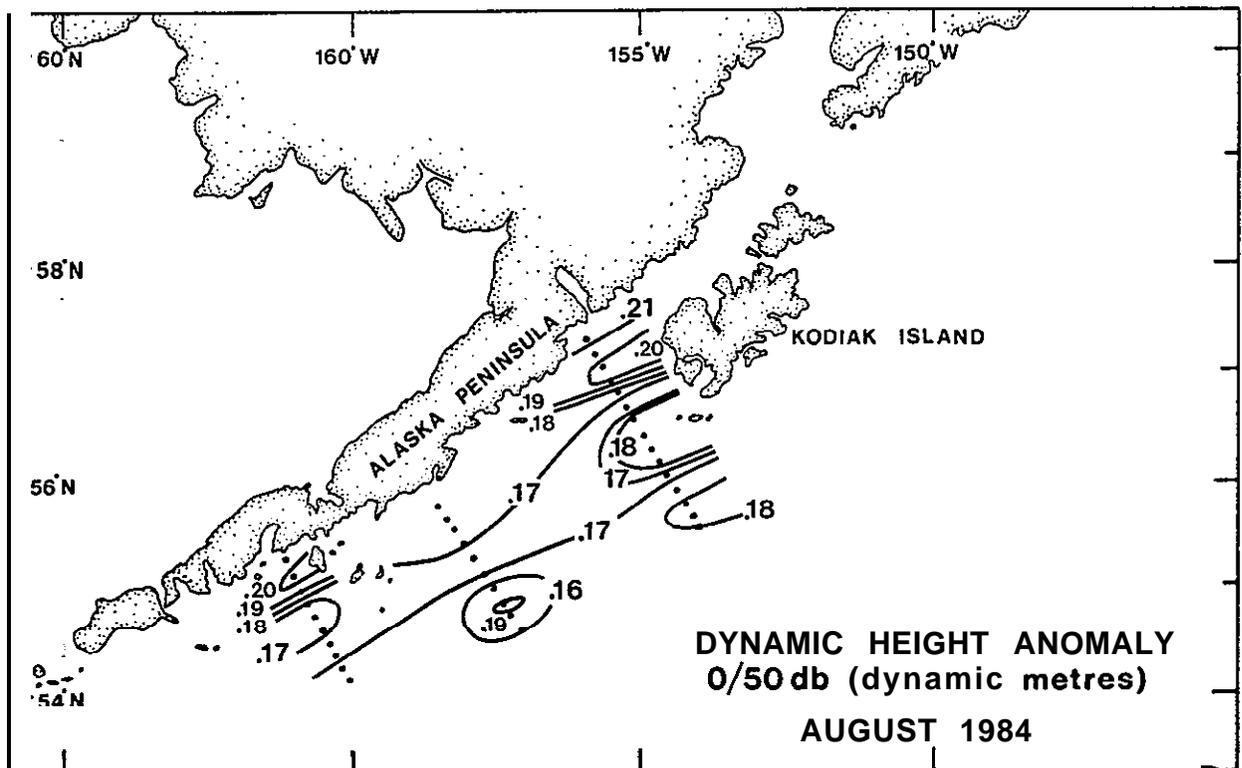
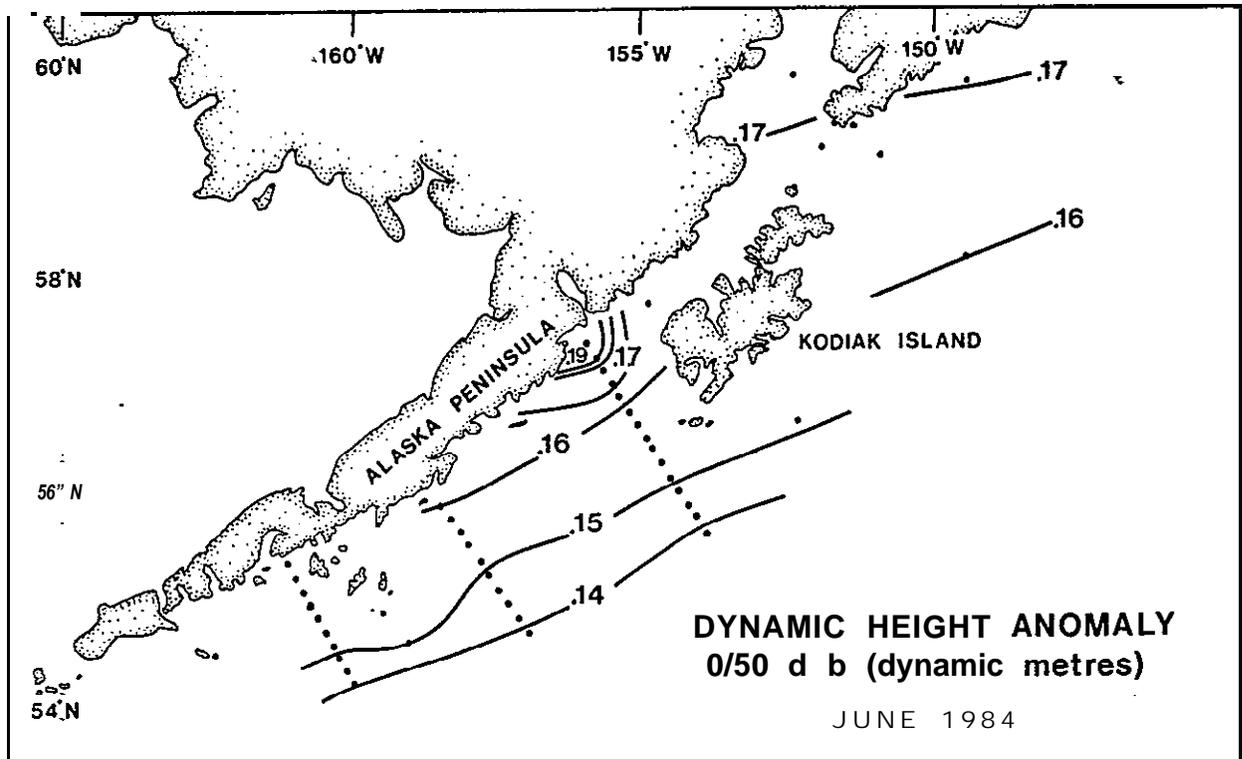


Figure 2.22 Dynamic Height Topography 0/50 db June and August

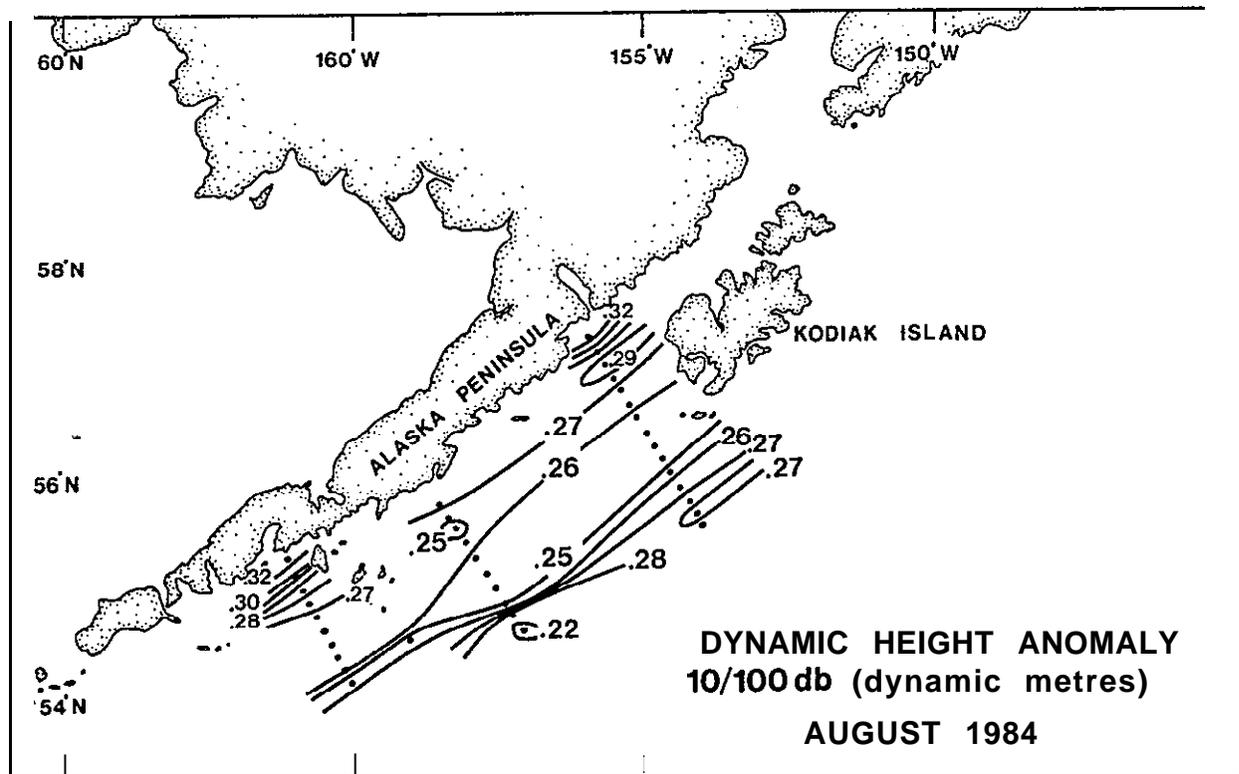
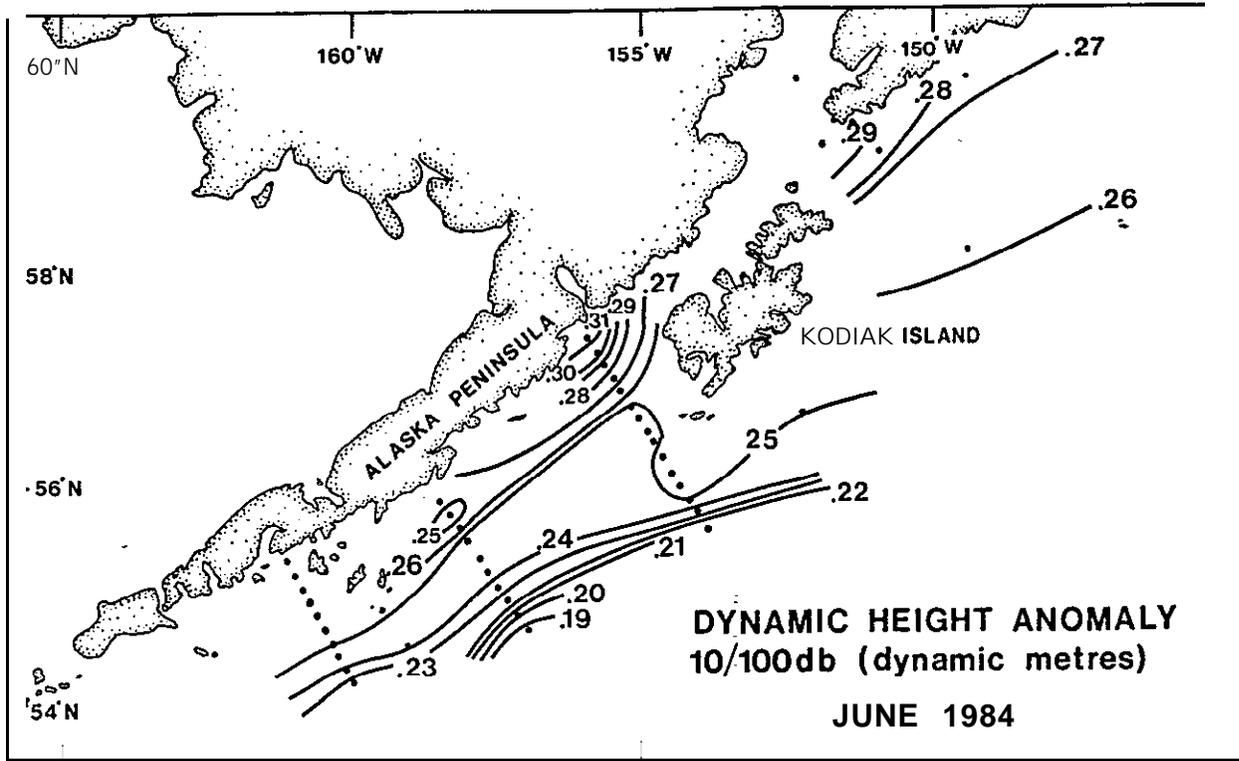


Figure 2.23 Dynamic Height Topography 10/100 db June and August

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. The details of the structure are clearly limited by the station spacing which was somewhat larger than the internal Rossby radius of deformation. 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 both 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 been 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.



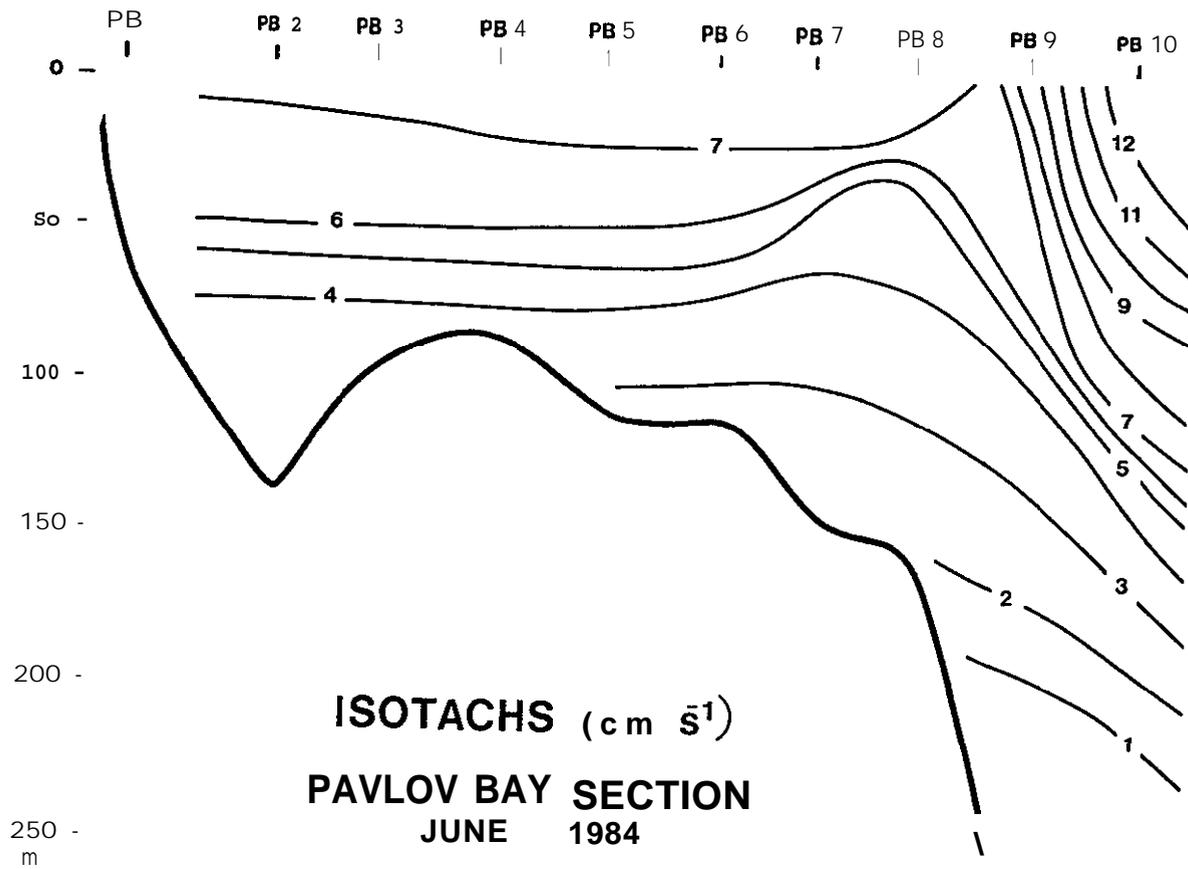


Figure 2.24 Positive flows are out of the page, i.e. to the southwest.

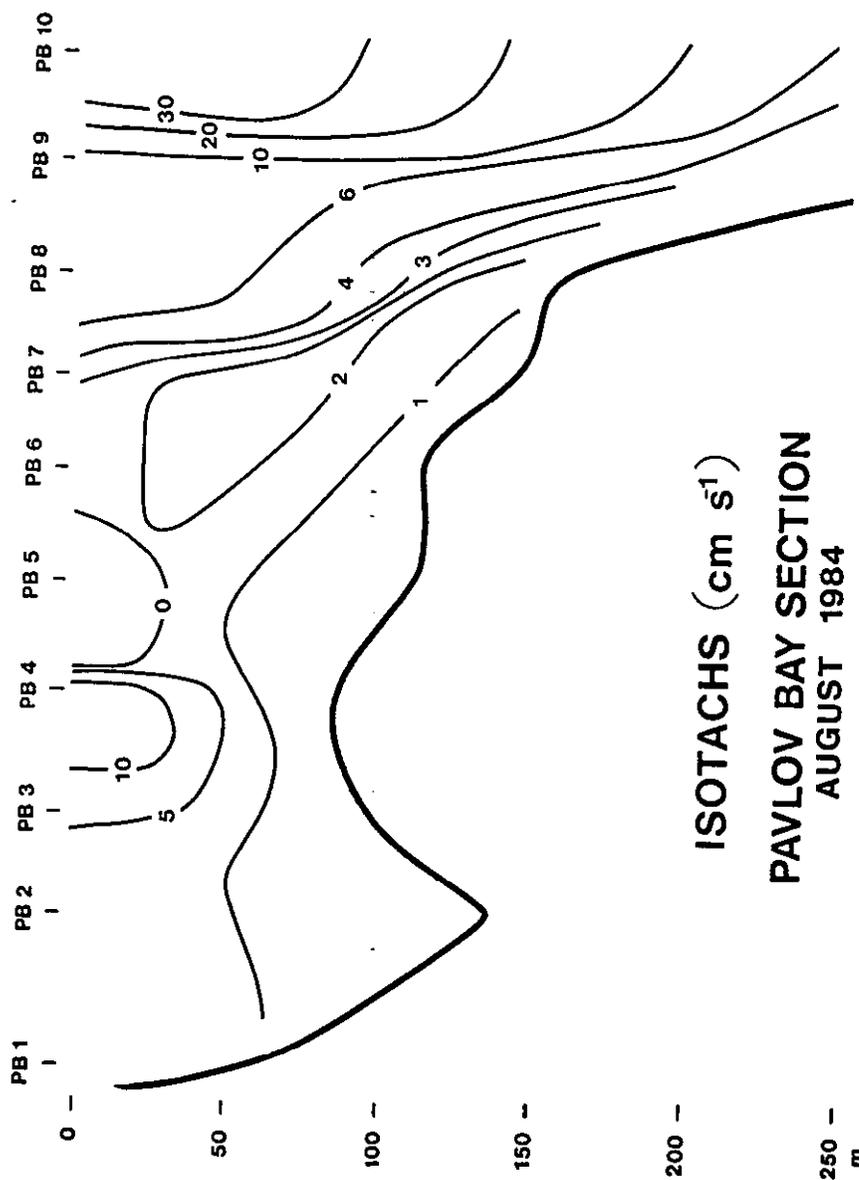
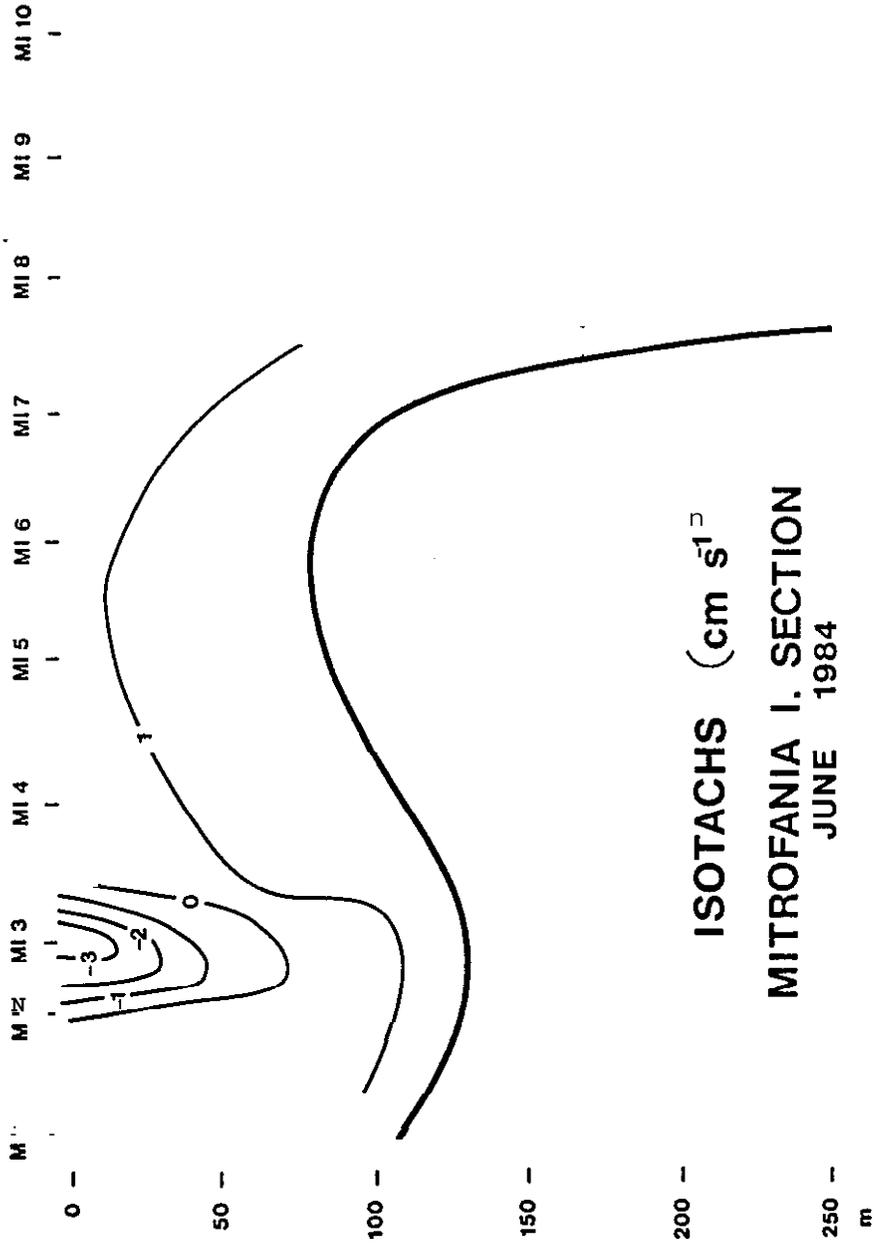


Figure 10. Pavlov Bay section, August 1984. The section is oriented southwest.



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ISOTACHS ARE OUT OF LINE PAGE, I.E. TO THE SOUTHWEST.



Dobrocky
SEATECH

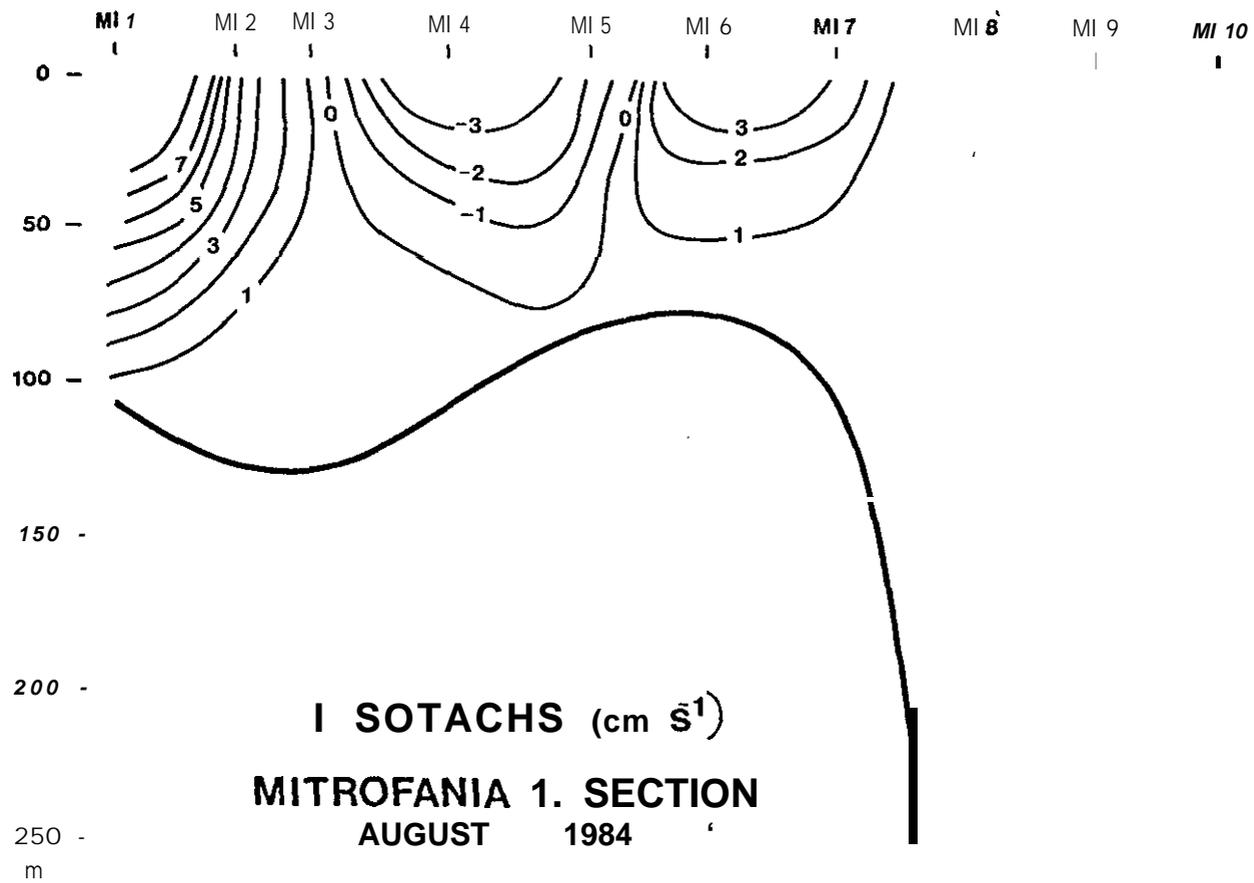
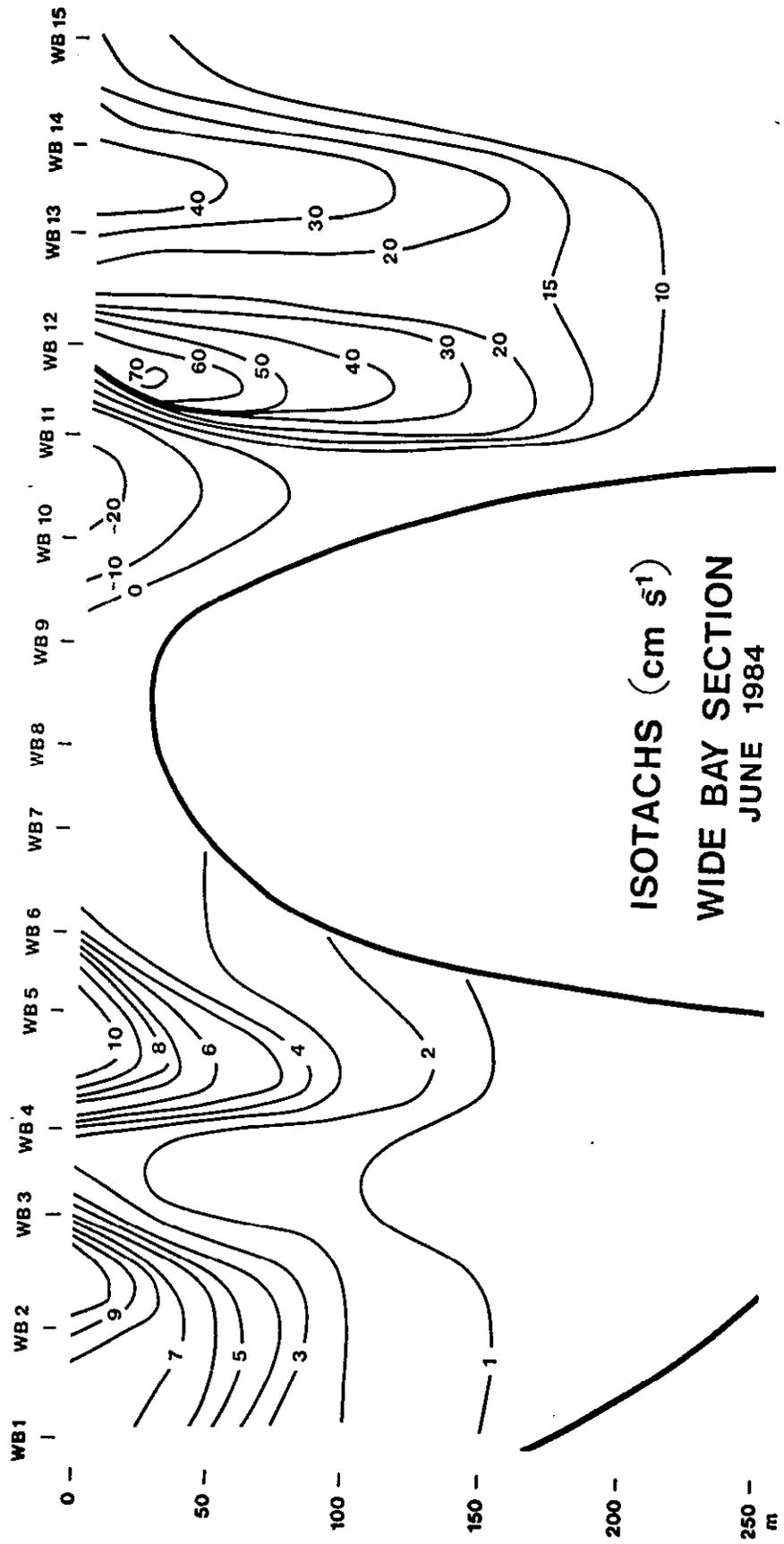


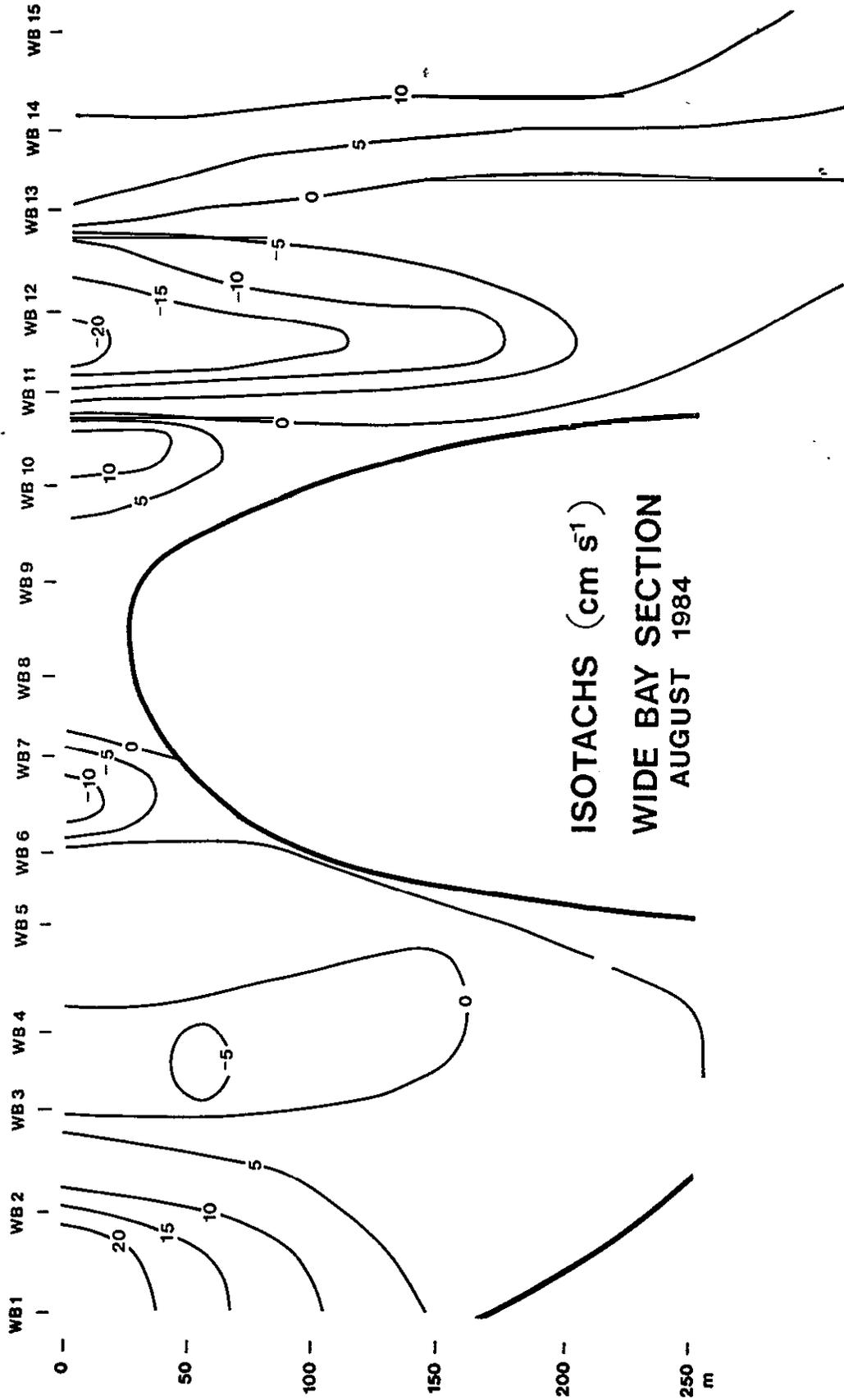
Figure 2.27 Positive flows are out of the page, i.e. to the southwest



ISOTACHS (cm s⁻¹)
WIDE BAY SECTION
JUNE 1984

P





ISOTACHS (cm s^{-1})
WIDE BAY SECTION
AUGUST 1984

ISOTACHS ARE PLOTTED OUT OF THE PAGE, I.E. TO THE SOUTHWEST



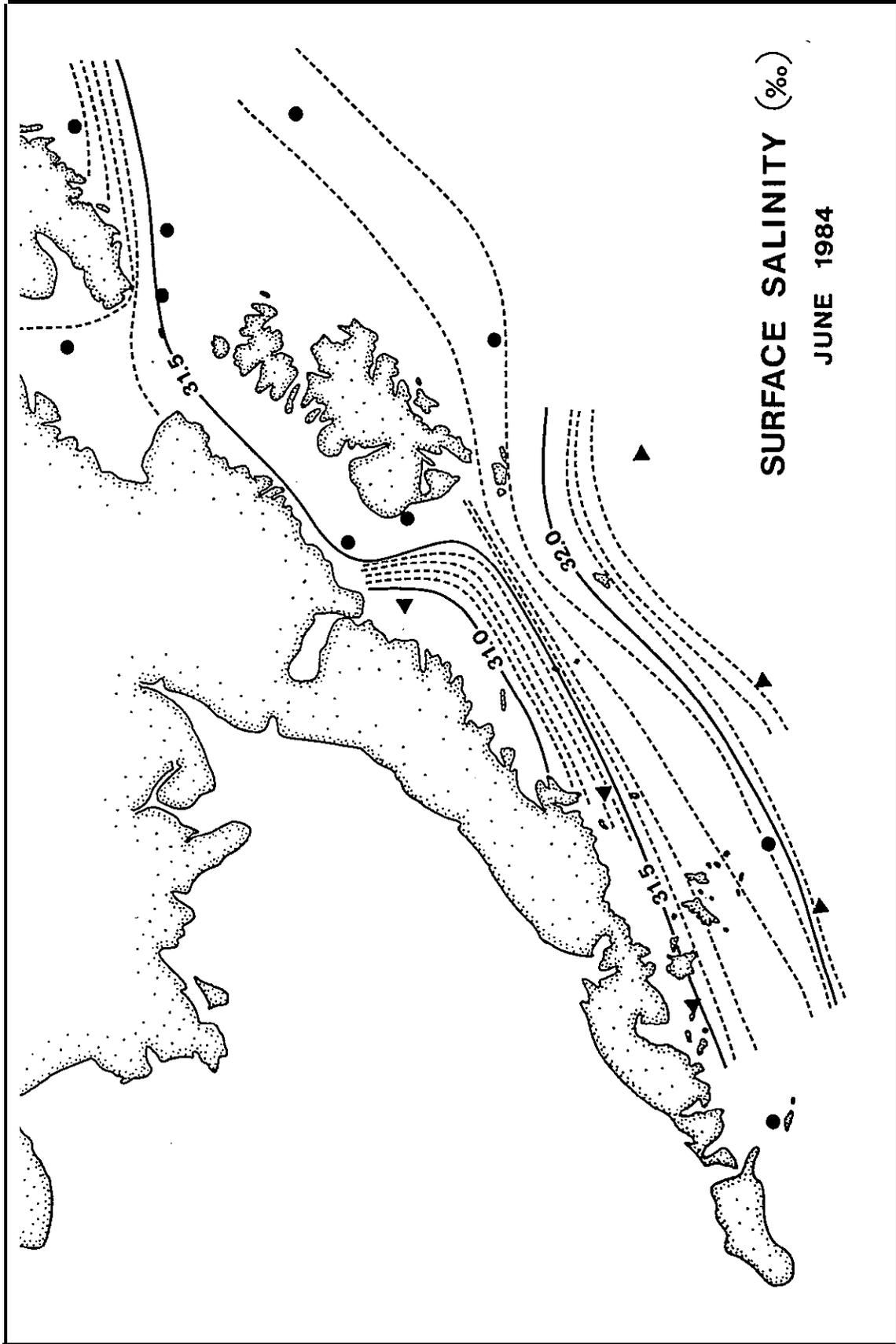
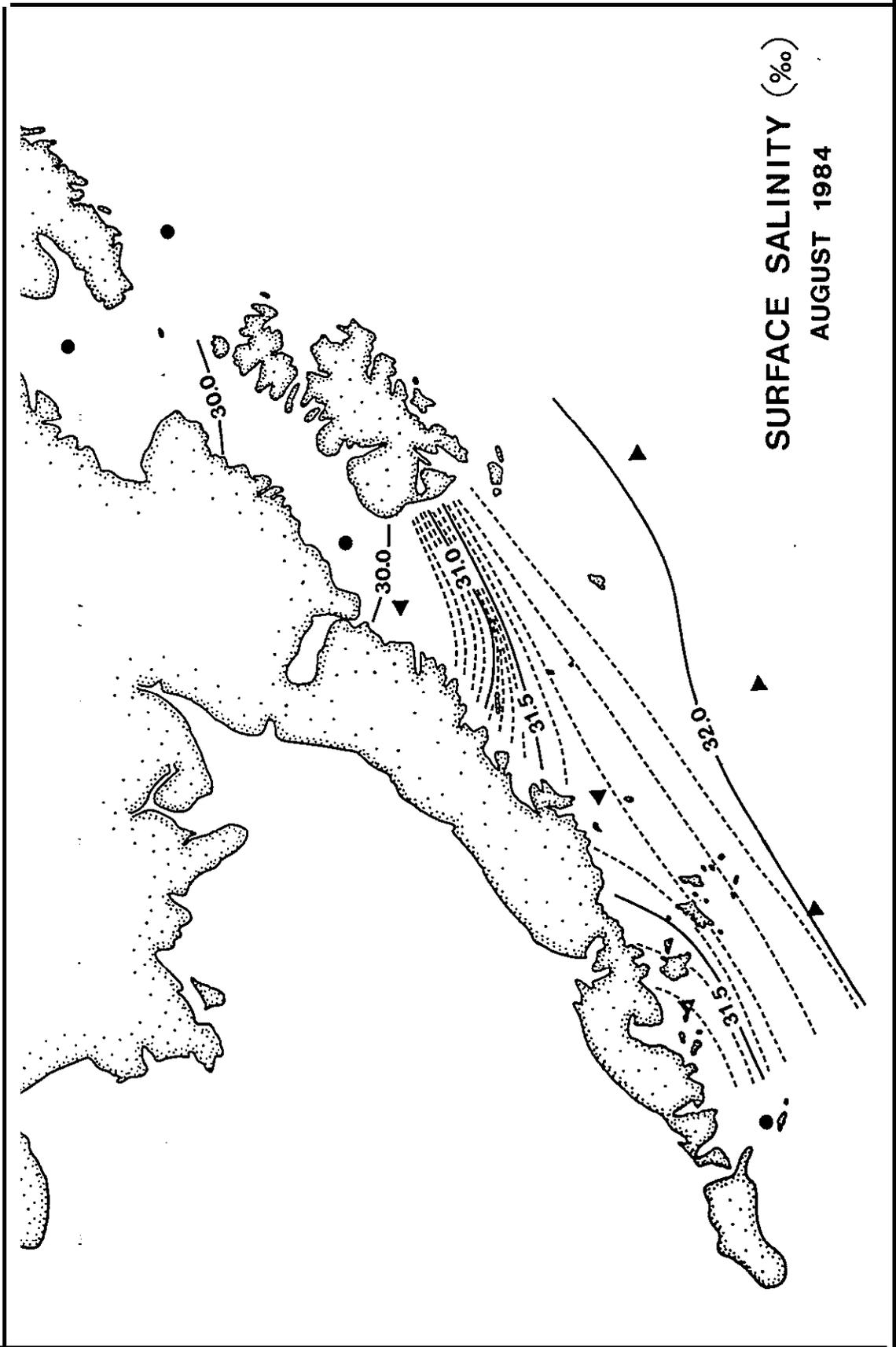


Figure 4.30 Surface Salinity June



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SURFACE SALINITY (‰)
AUGUST 1984

gure

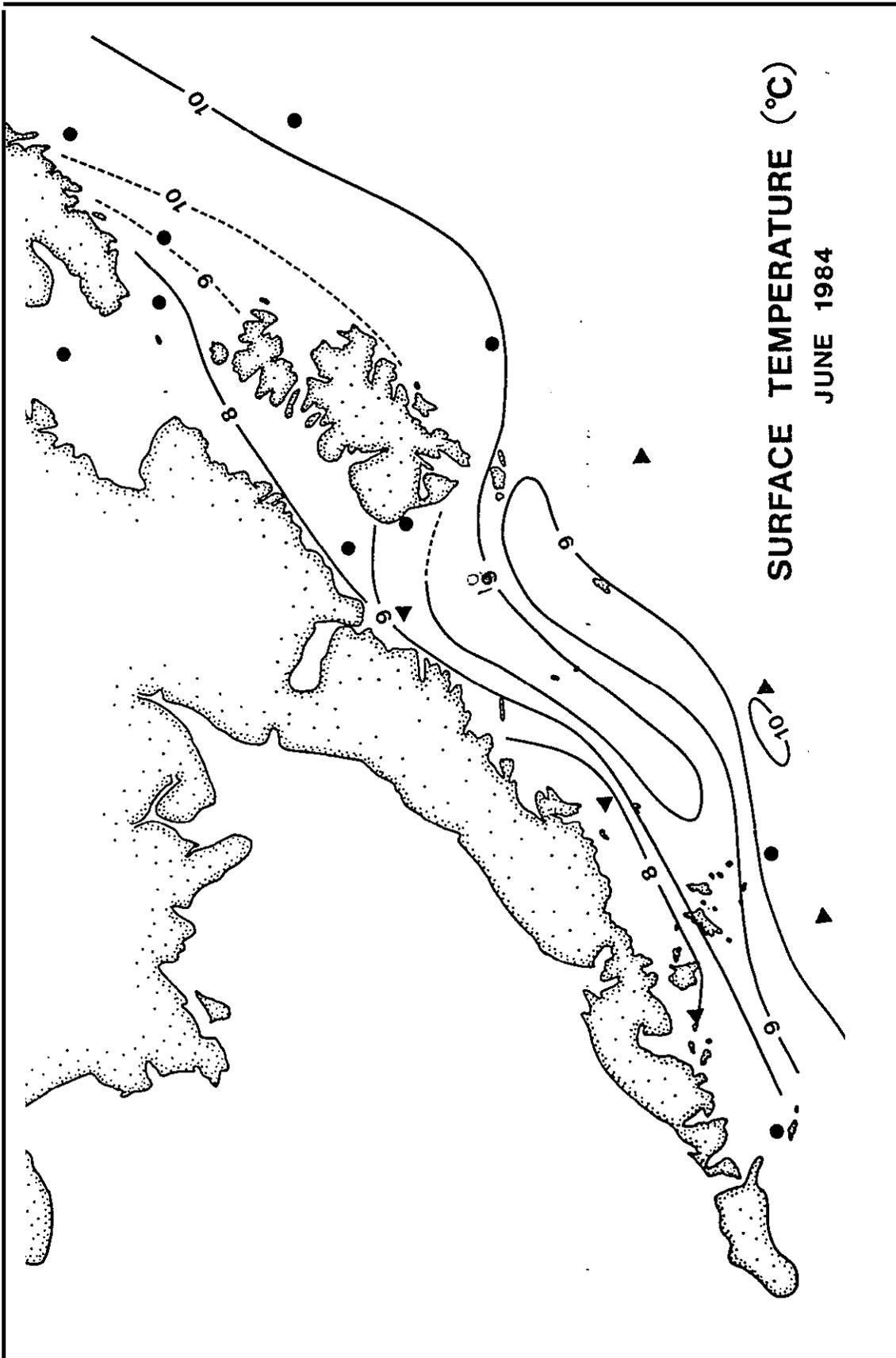
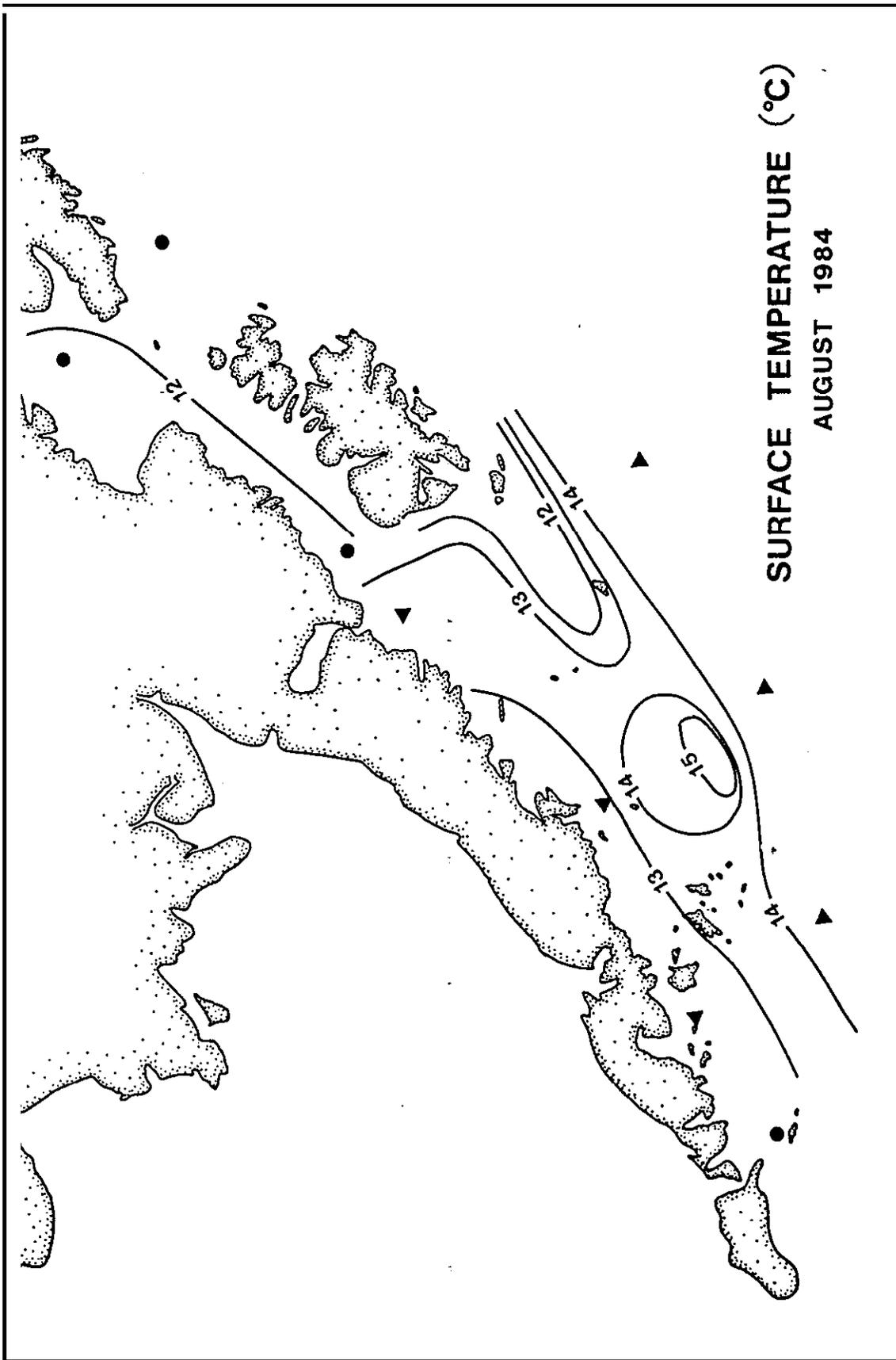


Figure 4.24 Surface Temperature June



SURFACE TEMPERATURE (°C)
AUGUST 1984

RYJURE 4033 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 0.95. 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

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

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.



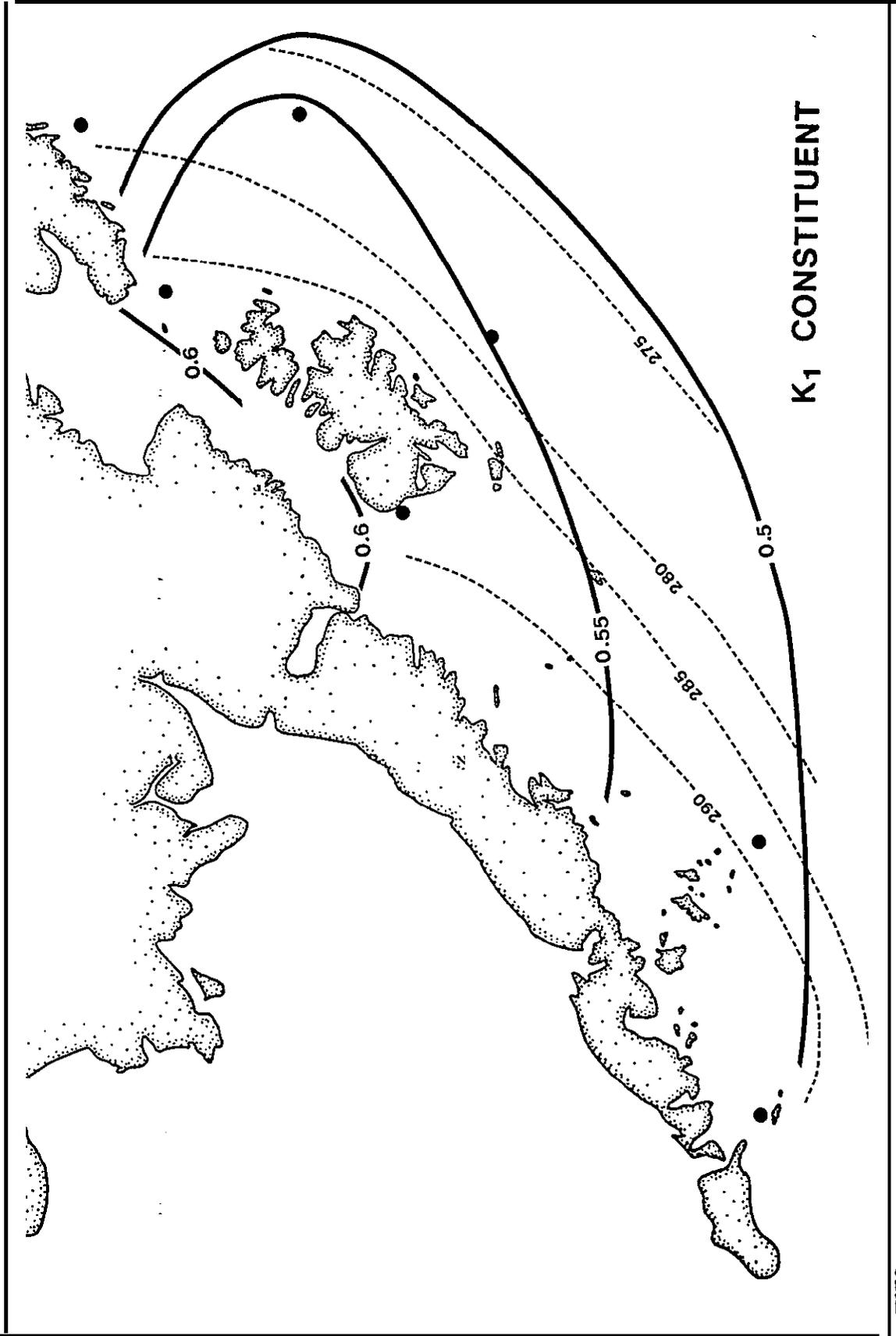
Table 3.1 **Maximum Tidal Ranges**

<u>Location</u>	<u>Range (m)</u>
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.

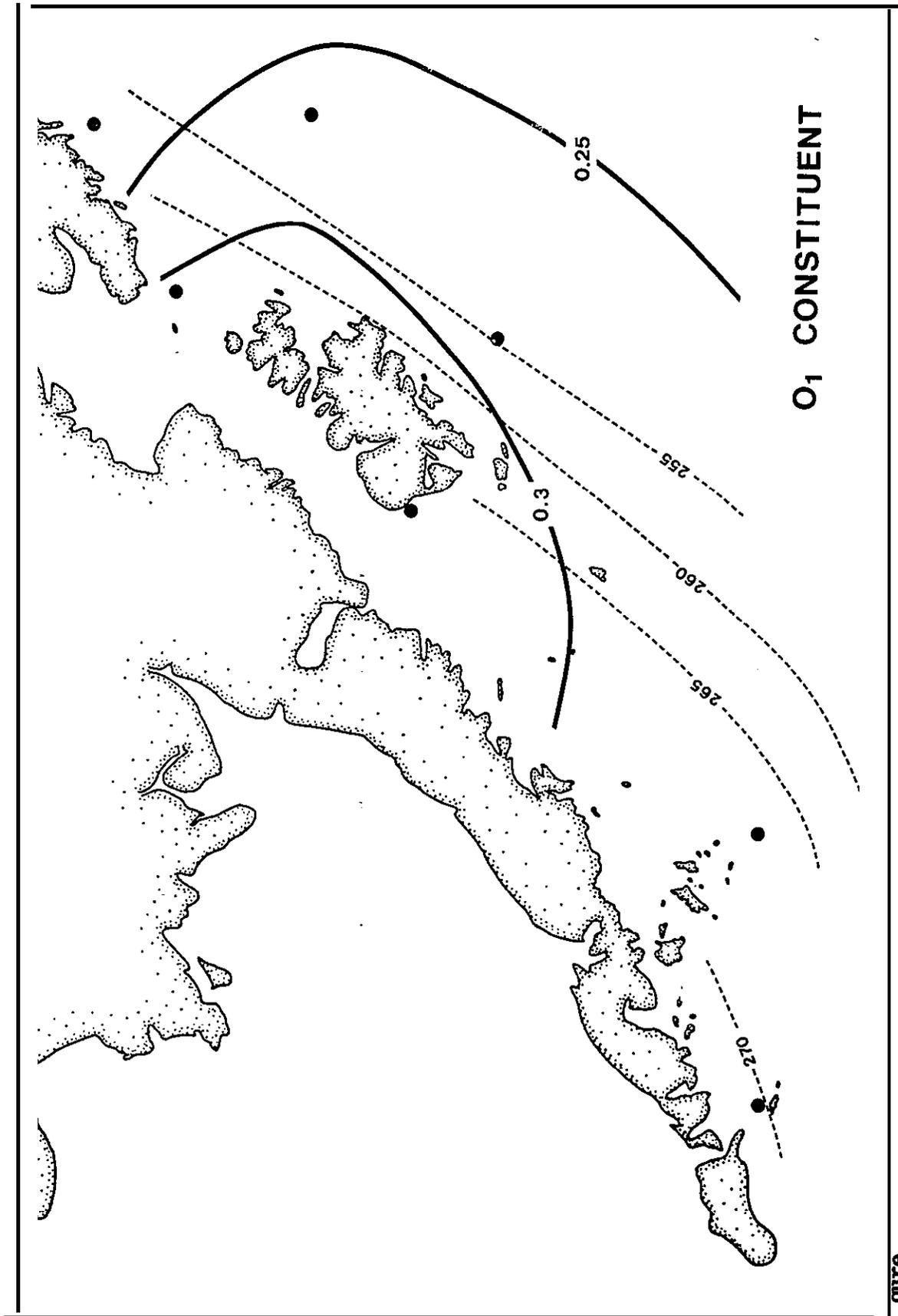
The S_2 , K_1 and O_1 cotidal charts display cophase and corange lines which are parallel - suggestive of a progressive wave in which energy is transported, eventually being dissipated by bottom friction.





K1 CONSTITUENT

gure relative to
--- wave phase lines (dashed) in degrees



O₁ CONSTITUENT

---gure --- relative to Greenwich
dashed lines (dashed in degrees

relative to Greenwich



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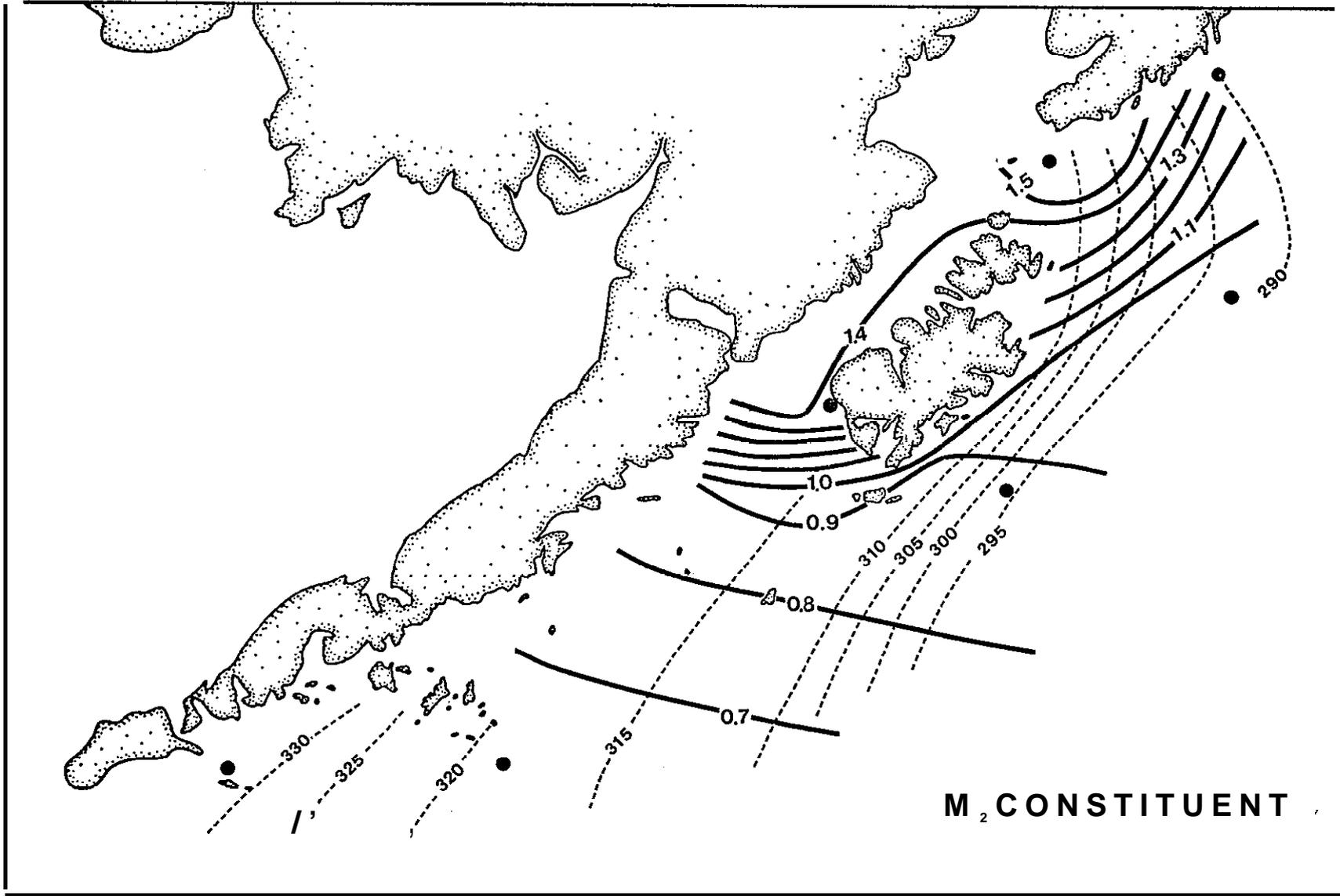


Figure 3.3 Contour chart for the M₂ corange line (solid) in metres, phase lines (dashed) in degrees relative to Greenwich

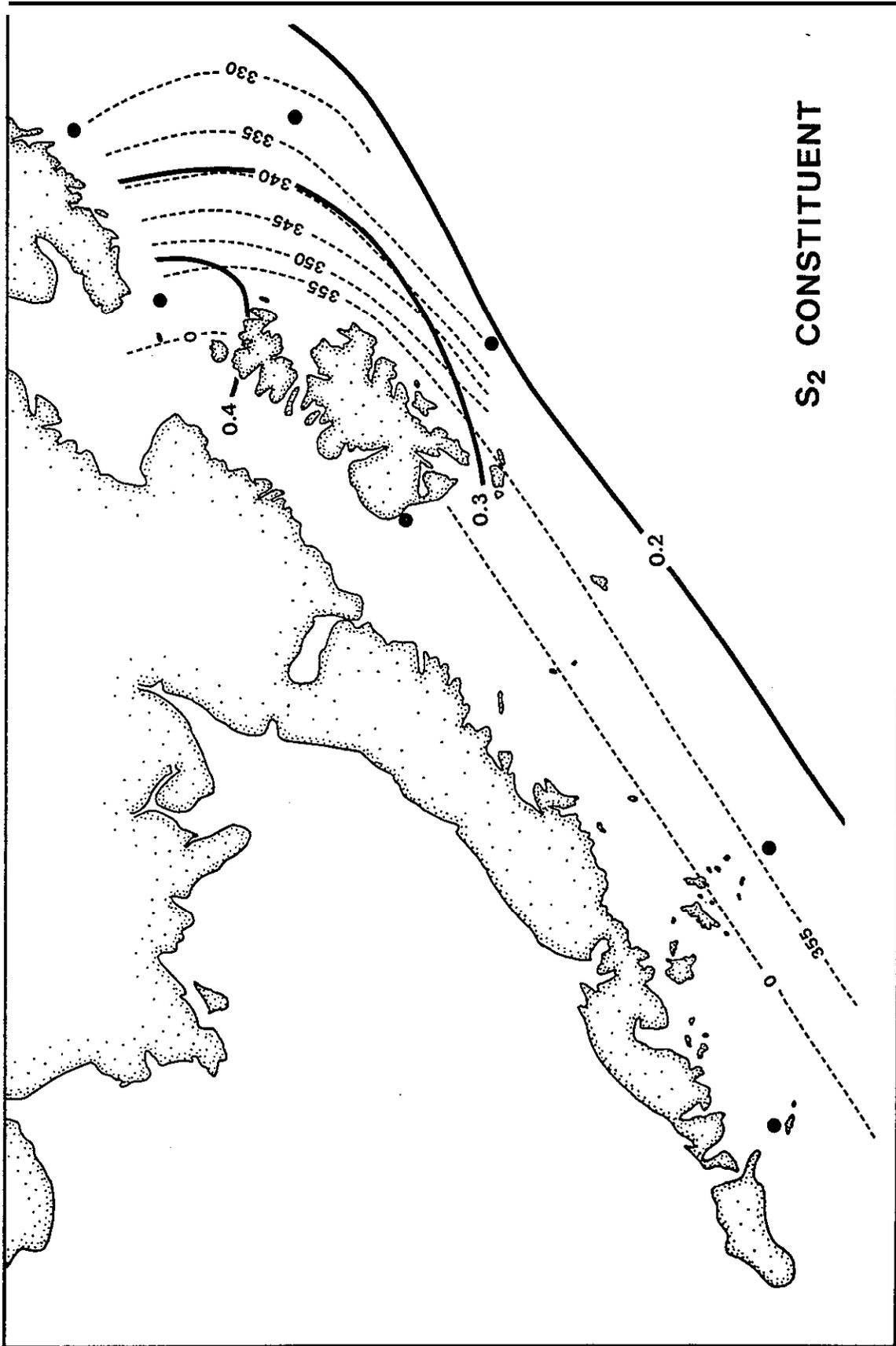


Figure 3.4 Cotidal chart for the S₂ corange line (solid) in metres, cophase lines (dashed) in degrees relative to Greenwich



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

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

(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

$$E = 1/2 \rho ghAV \cos\theta. \quad (3-3)$$

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 90° 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 evaluation 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 ± 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 180° correction was applied to the direction of the semi-major 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 ($^{\circ}$)	h (m) (Approx)	DIR ($^{\circ}$ True)	Power (kw/m)
O₁						
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
K₁						
Sanak	0.50	0.056	153	45	104	5.8
Ikolik-Shelikof	0.59	0.032	54	200	045	11.4
Amatuli-Stevenson	0.58	0.065	249	100	166	7.0
M₂						
Sanak	0.63	.034	36	45	349	4.0
Ikolik-Shelikof	1.39	.145	68	200	048	77.3
Amatuli-Stevenson	1.55	.287	241	100	173	111.6
S₂						
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



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 104° true). The diurnal constituents propagate nearly eastward while the semi-diurnal 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 the south. The current meters at this site exhibit comparable Greenwich phases and the phase difference between heights and currents is nearly constant. An error in timing is therefore 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-diurnal constituents thus consistent with the notion of a progressive wave in southern Cook Inlet and substantial tidal energy dissipation over the 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 the 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 for Shelikof Strait, this amounts to about 2.25×10^9 watts, about 0.1% of the tidal energy in the world ocean (LeBlond and Mysak, 1978). 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:

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

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:

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

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

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

(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 $-0.27/-0.36$. 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 , the 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

$$V_i = A_i \cos (nt - G_i) \quad (3-7)$$

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:

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



COOK INLET DENSITY and MODE STRUCTURE

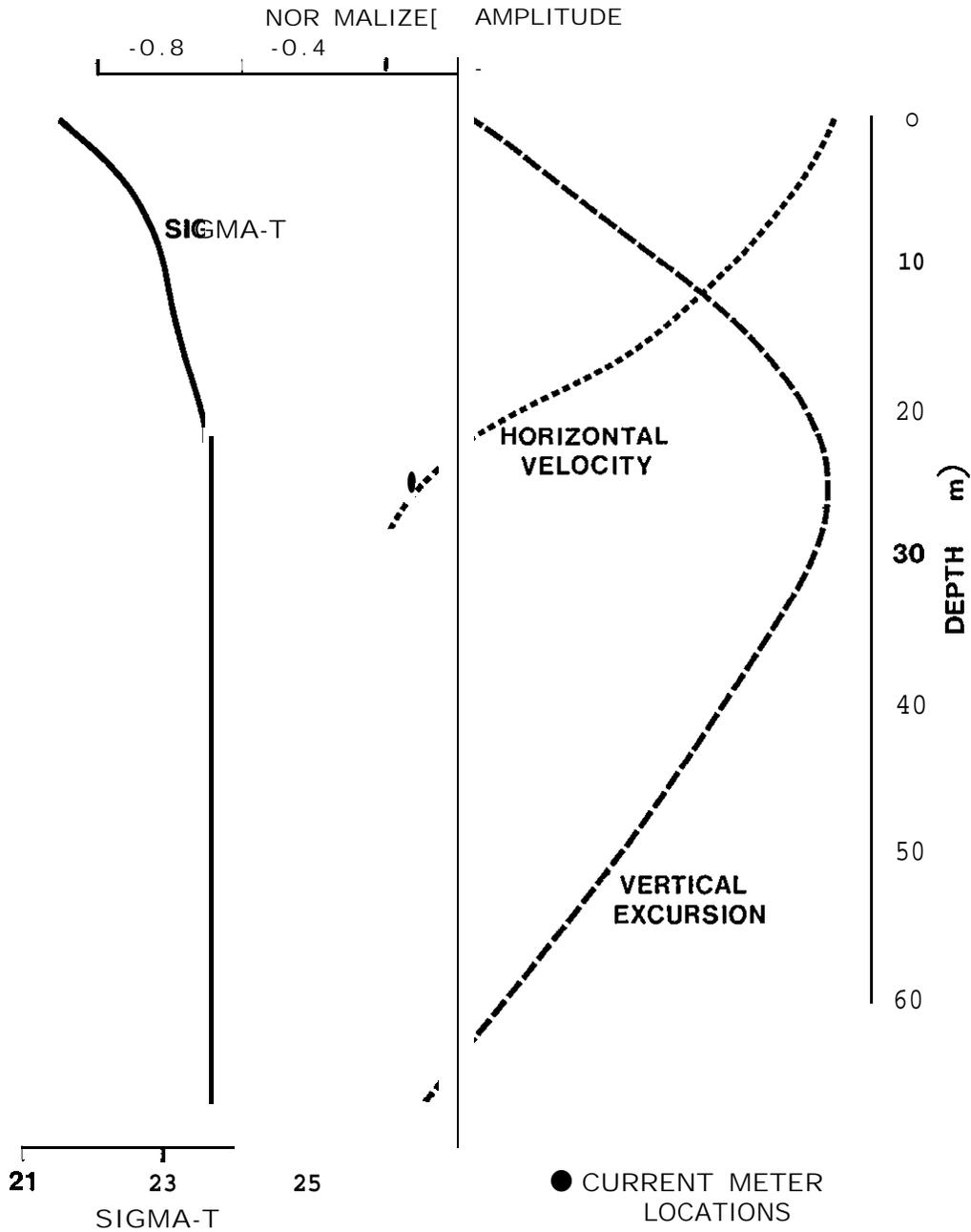


Figure 3.5 Lowest Internal Mode Structure for the M_2 Constituent in Cook Inlet

$$\tan \alpha = \frac{m_1 A_2 \sin \varphi}{\sqrt{1 - A_2^2 \cos^2 \varphi}} \quad (\text{barotropic phase}) \quad (3-9)$$

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

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

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 $0.4^\circ/00$, respectively. Using the temperature and salinity gradients measured in June and August we can estimate the height of the internal tide

$$H \sim \frac{AT}{\partial T / \partial z} \sim \frac{AS}{\partial S / \partial z} \quad (3-12)$$

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 **M₂ Tidal**
Constituent (Amplitudes in **cm/s**)

Cook Inlet

$$BT = 96.2 \cos (nt - 2.8^\circ - G_1)$$

$$BC = -58.6 \cos (nt - 12.8^\circ - G_1)$$

Shelikof Strait

$$BT = 14.5 \cos (nt + 1.7^\circ - G_1)$$

$$BC = -1.3 \cos (nt + 30.9^\circ - G_1)$$

Stevenson

$$BT = 28.7 \cos (nt - 3.5^\circ - G_1)$$

$$BC = 17.4 \cos (nt - 47.6^\circ - G_1)$$

Sanak

$$BT = 3.4 \cos (nt - 3.5^\circ - G_1)$$

$$BC = -1.6 \cos (nt - 67.2^\circ - G_1)$$



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

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 45° 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



AUTOSPECTRUM LONGSHORE VELOCITY COMPONENT, SHELIKOF STRAIT

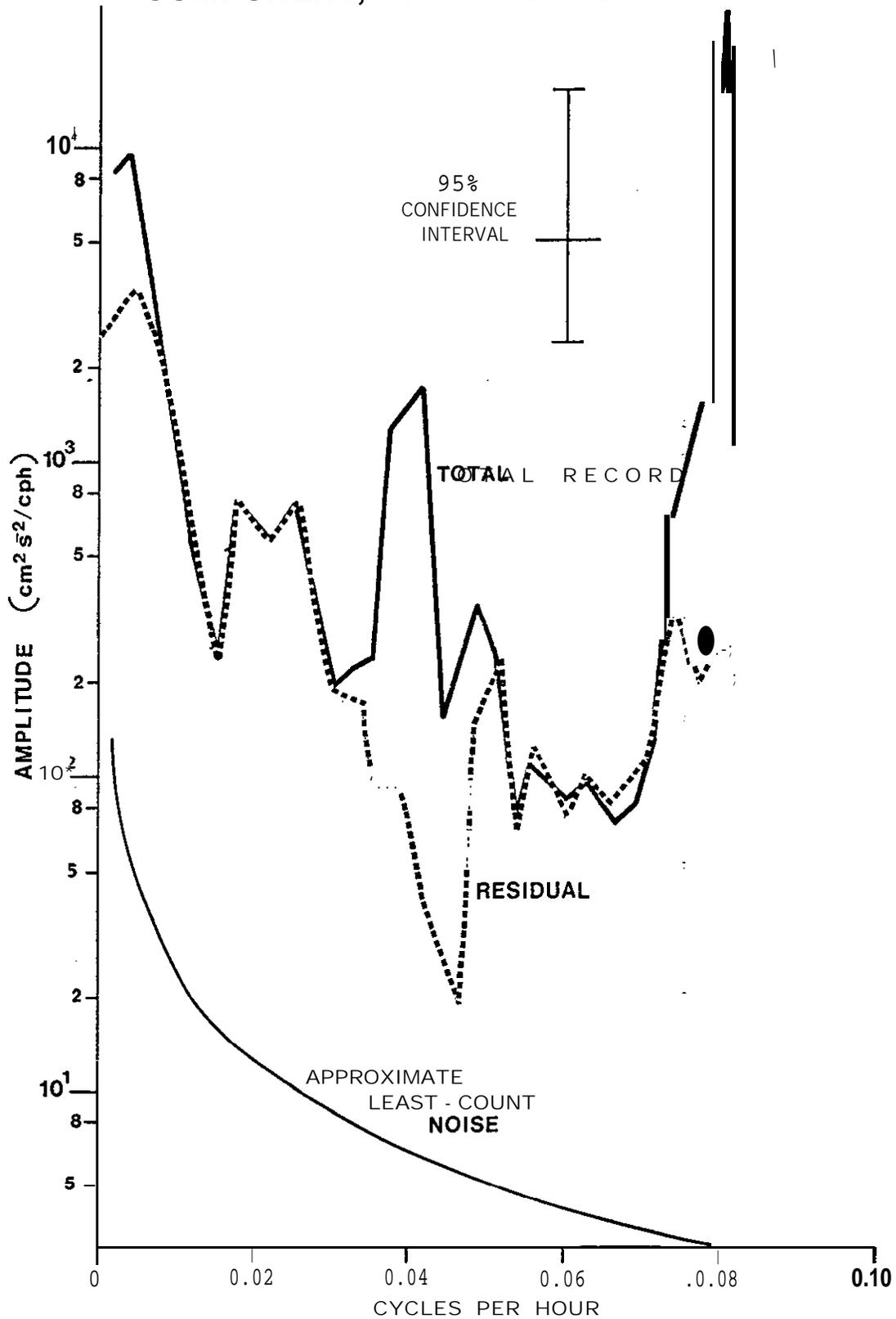


Figure 4.1 Autospectrum alongshore (225°T) component 46 m depth in Shelikof Strait

Table 4.1 Mean Velocities at the **Eight** Current Meters

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 both 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 flow. 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 surface 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 $1 \times 10^6 \text{ m}^3 \text{ s}^{-1}$. 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 the 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

$$\exp(-y/r_i) \quad (4-1)$$

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 $1000 \text{ m}^3 \text{ s}^{-1}$. 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 not permit comparison over the monthly time scales which would be required to investigate such a driving mechanism.



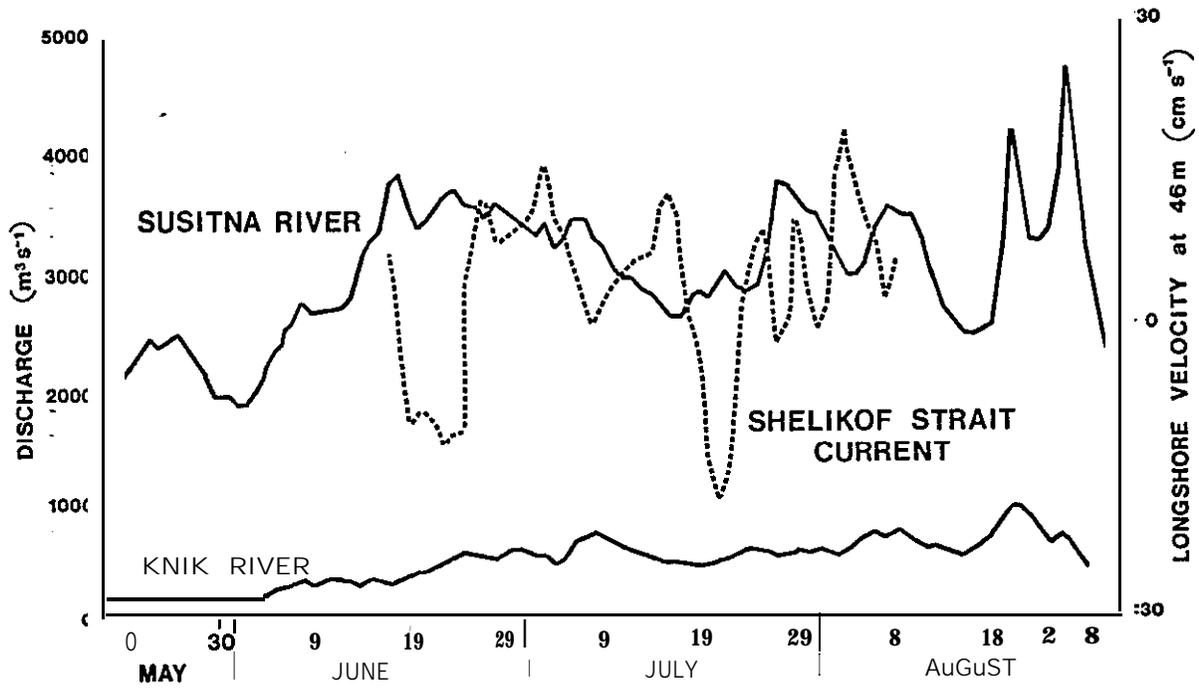


Figure 4.2 Daily discharges of the Knik and Susitna Rivers (solid lines) and the mean daily alongshore component of flow at 46 m depth in Shelikof Strait (broken line) .

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 M_2 (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 M_2 frequency (9% and less than 1% of M_2 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 the spectrum (periods of about 15 to 20 days).

For the lowest frequencies we cannot proceed 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:

$$\vec{\tau} = |\vec{\tau}| \exp(i\gamma) = \rho_a C_D (0.7W)^2 \exp[i(\delta + 20^\circ)] \quad (42)$$

where $\vec{\tau}$ is the surface wind stress vector, ρ_a is the density of air, C_D 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 surface 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 time series yielded no striking correlation. Time series plots of the current velocity components in Shelikof Strait: and the 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 surface 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 oscillations 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 LESS 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 alongshelf (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.

5.1 PROPERTY FIELDS

Between June and August 1984, the surface temperature increased by about 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 the CTD limit the utility of the computed geostrophic currents. In general, however, westerly flows as big 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.

The 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 west 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 M₂ 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

The 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 the 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 were east by northeast nearly across the inlet. The 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 the 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: 151 50 1.8 W
 START : 2300Z 13/ 6/84 END: 1400Z 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	O1	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	OO1	.0,04403054	0.0092	293.79
12	UPSI	.0.04634299	0.0033	270.03
13	EPS2	0.07617730	0.0068	169.58
14	MU2	0.07768947	0.0470	213.74
15	N2	0.07099922	0.3011	297.41
16	M2	0.06081139	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	0.12076712	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	0.20280355	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



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	0.03570635	0.0096	320.29
6	Q1	0.03721850	0.0432	256.19
7	O1	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	0.07617730	0.0077	203.52
14	MU2	0.07765947	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	0.08507365	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	0.24002206	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



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	ZQ 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	EP52	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



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)	I NC	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 N01	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	250.2	13.3
14 MU2	0.07768947	2.474	0.503	67.2	31.9	324.6	98.9
15 N2	0.07899922	5.889	1.478	93.5	50.5	317.0	143.9
16 M2	0.08051139	30.198	0.621	102.1	66.3	324.1	168.4
17 L2	"0.08202356	1.484	-0.096	116.5	37.0	260.5	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 M03	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 ZMK5	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 ZMN6	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 ZMS6	0.24435616	0.720	-0.050	88.9	328.8	269.9	27.7
34 ZSM6	0.24717800	0.525	0.128	134.8	98.0	323.?	232.7
35 ZMK7	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



GULF OF ALASKI?

ANALYSIS RESULTS IN CURRENT ELLIPSE FORM

AMPLITUDES HAVE 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 M03	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 ZMK5	0.20280355	0.679	0.233	40.2	7.4	327.2	47.7
30 ZSK5	0.20844740	0.125	0.079	96.0	171.2	75.2	267.1
31 ZMN6	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 ZMS6	0.24435616	0.474	0.131	41.4	45.7	4.3	87.1
34 ZSM6	0.24717008	0.220	-0.003	105.0	188.3	83.3	293.3
35 ZMK7	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



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: 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)	I NC	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 FILLP1	0.03439657	0.591	-0.411	95.0	26.4	291.4	121.5
5 Q01	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 O1	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 O01	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. 39i	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
1a 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	4 9 a	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



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)	I NC	G	G+	G-
----	-----	-----	-----	---	---	---	---
1 Z0	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 Q01	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 O1	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	0.07758947	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	157.5	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 ZMK5	0.202S0355	0.092	0.064	75.1	344.7	269.7	59.8
30 ZSK5	0.20844740	0.131	0.060	168.8	25S.3	86.5	64.0
31 ZMN6	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 ZMS6	0.24435616	0.323	-0.023	39.2	100.6	61.3	139.8
34 ZSM6	0.24717808	0.127	0.007	179.6	246.0	66.5	65.6
35 ZMK7	0.20331494	0.168	-0.042	57.0	208.8	151.7	265.8
36 MB	0.32204562	0.050	-0.004	76.4	141.7	65.3	218.1



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: 12002 10/ 8/84

NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	INC	G	G+	G-
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1 Z0	0.00000000	3. 839	0.000	59.8	180.0	120.2	239 a
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 ZQ1	0.03570635	0.741	0.473	5.2	39.0	33 a	44.1
6 Q1	0.03721850	0.978	0.273	104.6	299.5	195.0	44.1
7 O1	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	255. 0
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	a s s	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. o	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 ZMK5	0.20280355	0. 386	0.136	170.2	315.9	145.6	126.1
30 ZSK5	0.20844740	0.206	0. 03s	95.1	223.7	128.6	318.8
31 ZMN6	0.24002206	0.141	0.073	123.6	196.4	72 a	320.0
32 M6	0.24153417	0.132	-0.060	104.5	293.9	189.4	38.5
33 ZMS6	0.24435616	0.212	0.11s	177.4	157.8	340.4	335. i
34 ZSM6	0.24717800	0.239	0.158	57.7	252.9	195.2	310.5
35 ZMK7	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



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

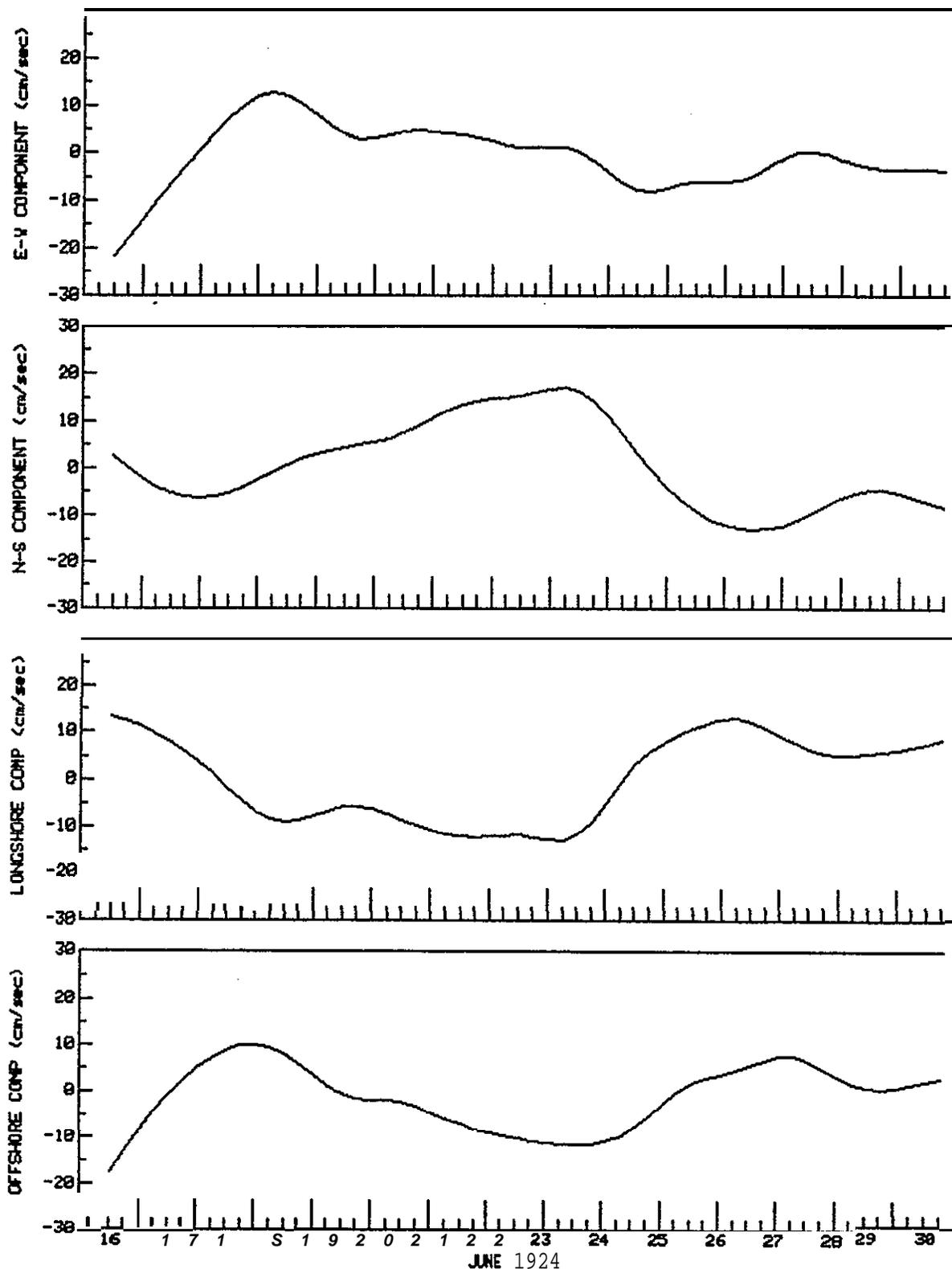
END: 1200Z 10/ 8/84

	NAME	FREQUENCY (CY/HR)	MAJOR (CM/S)	MINOR (CM/S)	I NC	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	ZQ1	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
?	Q1	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
i5	N2	0.07633922	3.111	1.006	4s.s	233.4	97.4	272.2
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	ZMK5	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	ZMN6	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	ZSM6	0.24717808	0.111	0.071	18.5	306.2	287.7	324.7
35	ZMK7	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

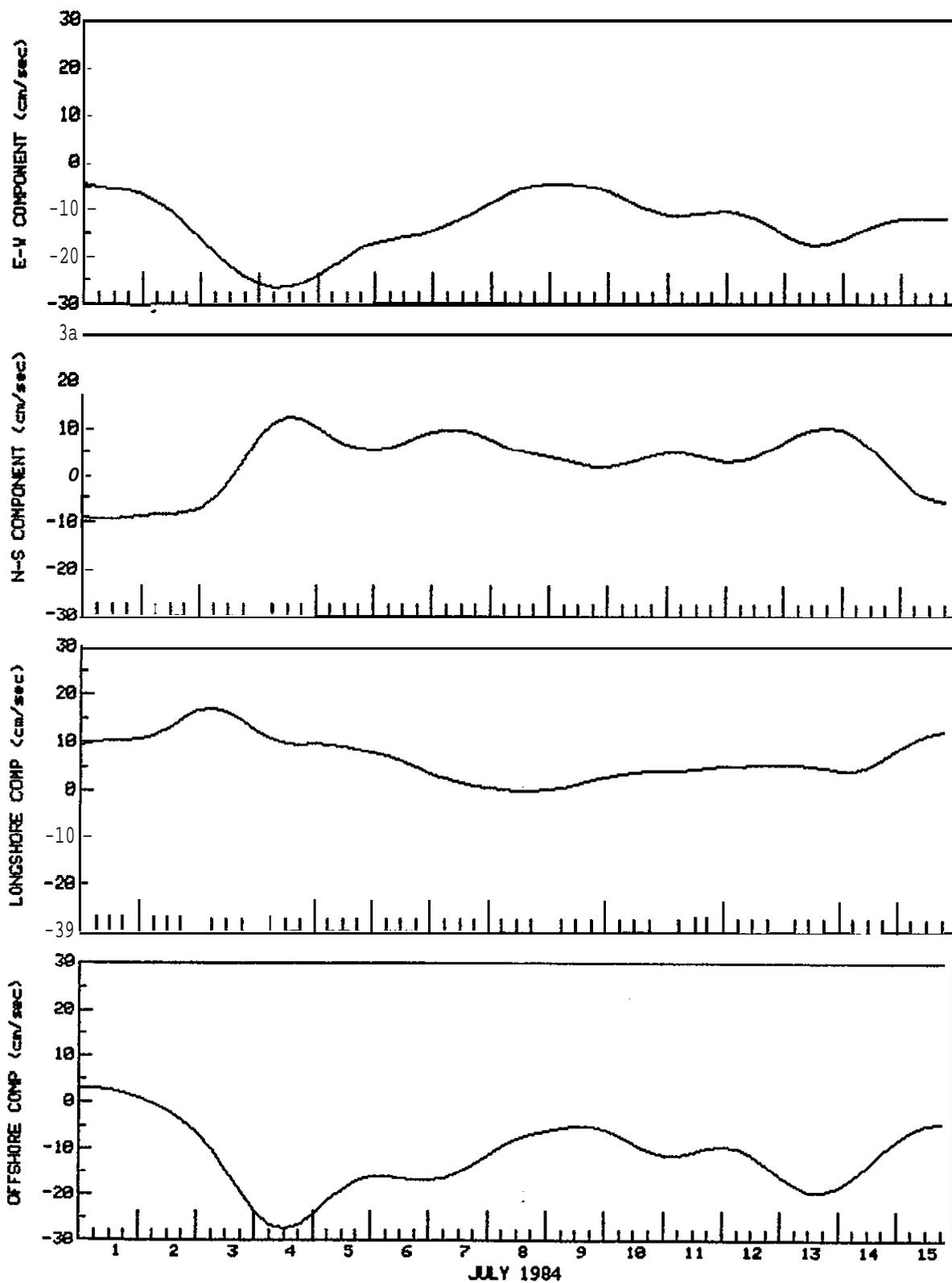


Time series filtered velocity geostrophic
wind, surface wind stress

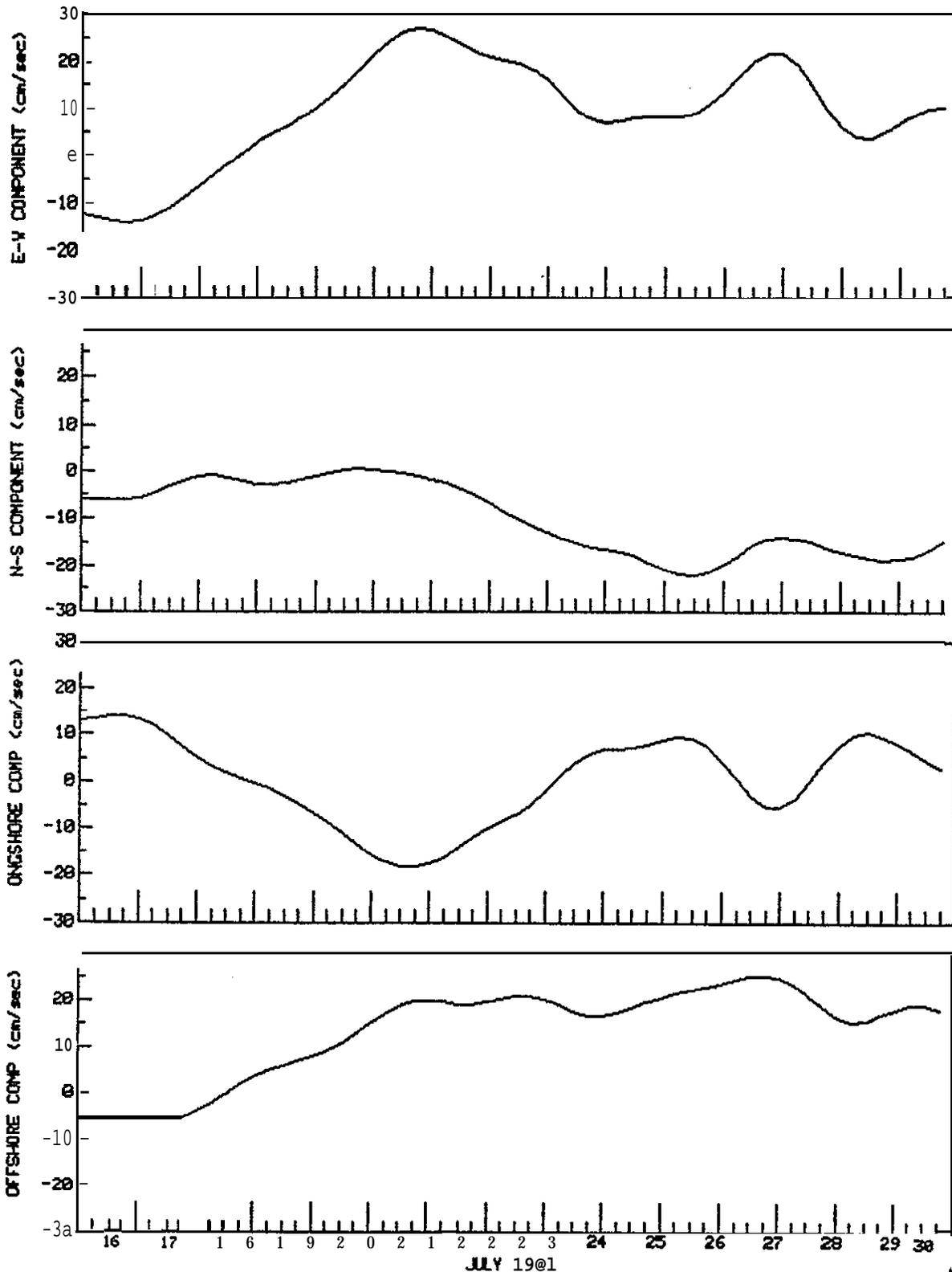
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 57 39' 00"N 155 03' 19. 8"W AANDERAA RCM DT(min) 360



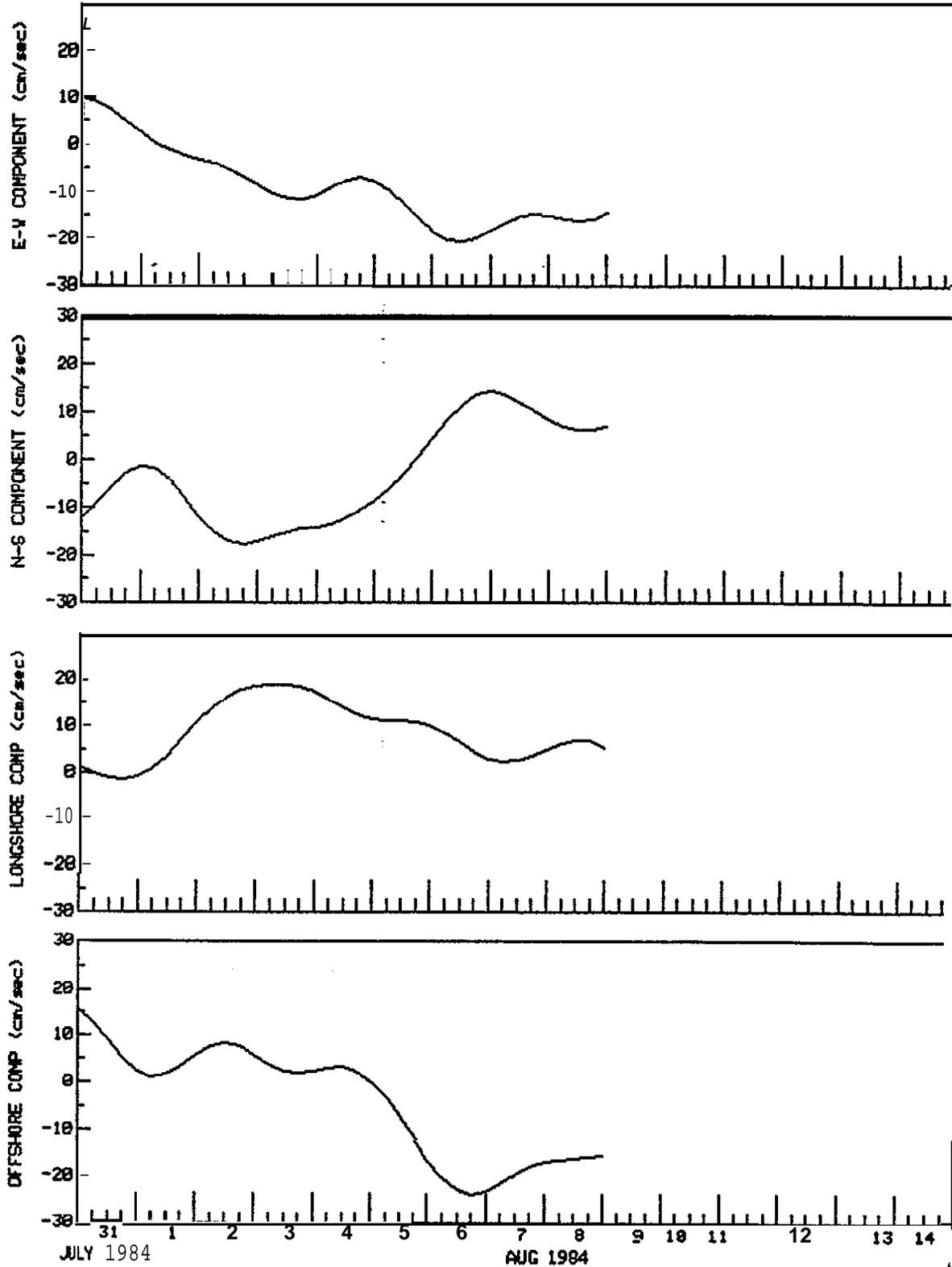
TIME SERIES OF U, V AND LONGSHORE, OFFSHORE COMPONENTS
SHELIKOF STRAIT METER 3127 DEPTH(m) 46 TYPE FILTERED
5739' 00"N 155 03' 19.8"W AANDERAA RCM DT(min) 360



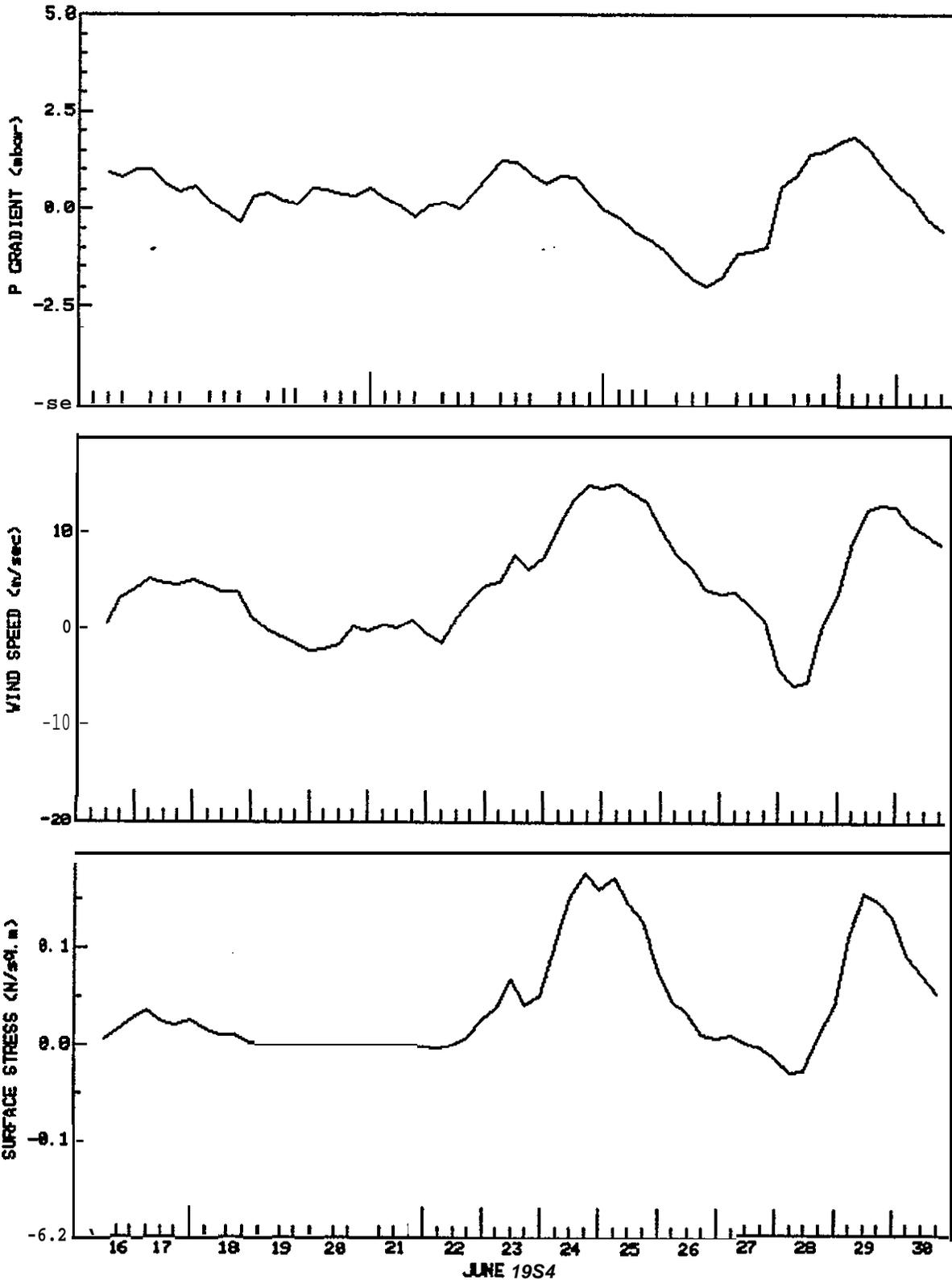
TIME SERIES OF U, V AND LONGSHORE, OFFSHORE COMPONENTS
 SHELIKOF STRAIT METER 3127 DEPTH (m) 46 TYPE FILTERED
 57 39' 00"N 155 03' 19.8"W AANDERAA RCM DT(min) 360



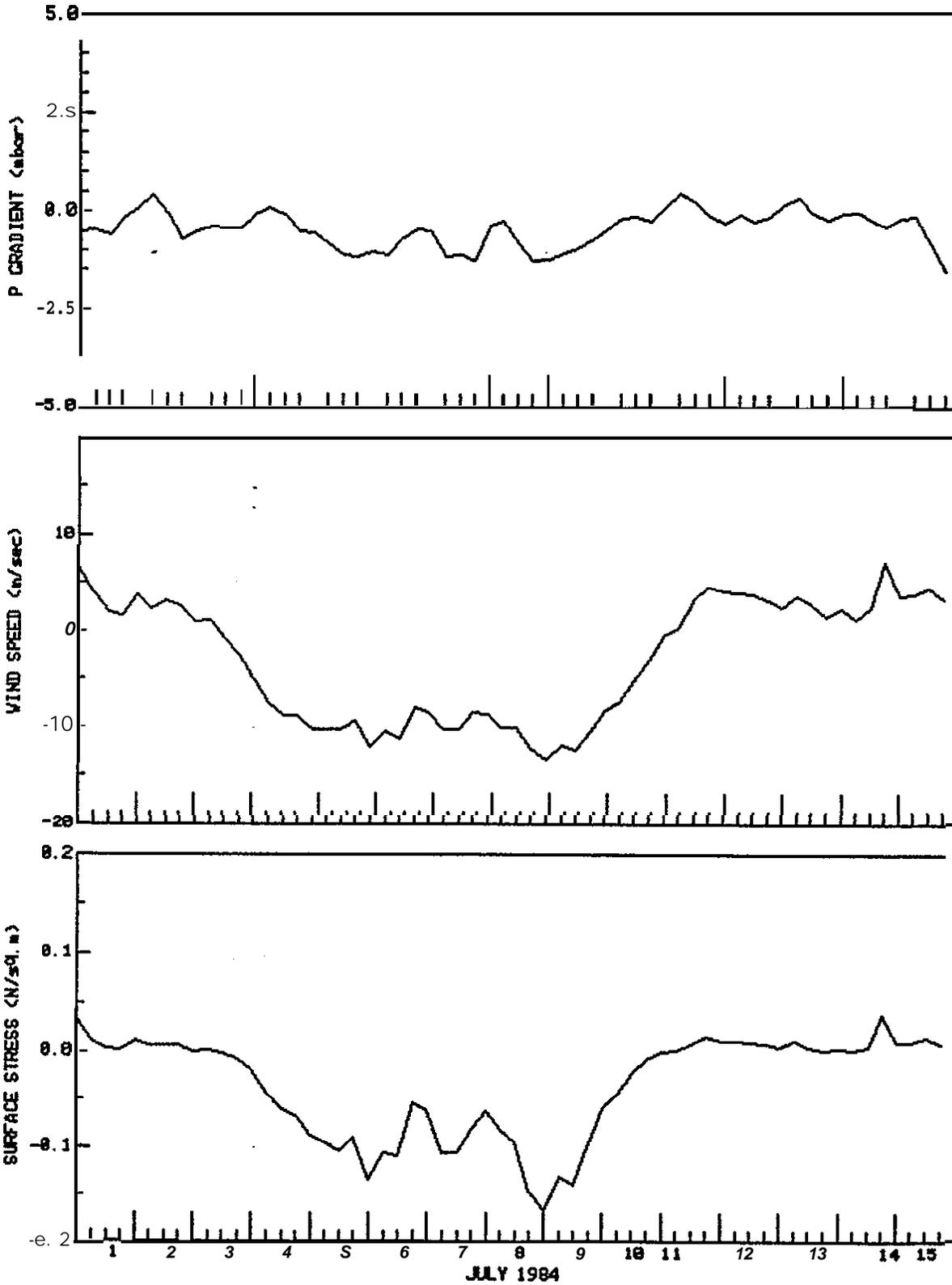
TIME SERIES OF U, V AND LONGSHORE > OFFSHORE COMPONENTS
 SHELIKOF STRAIT METER 3127 DEPTH(m) 46 TYPE FILTERED
 57 39' 00"N 155 03' 19.8"W AANDERAA RCM DT(min) 360



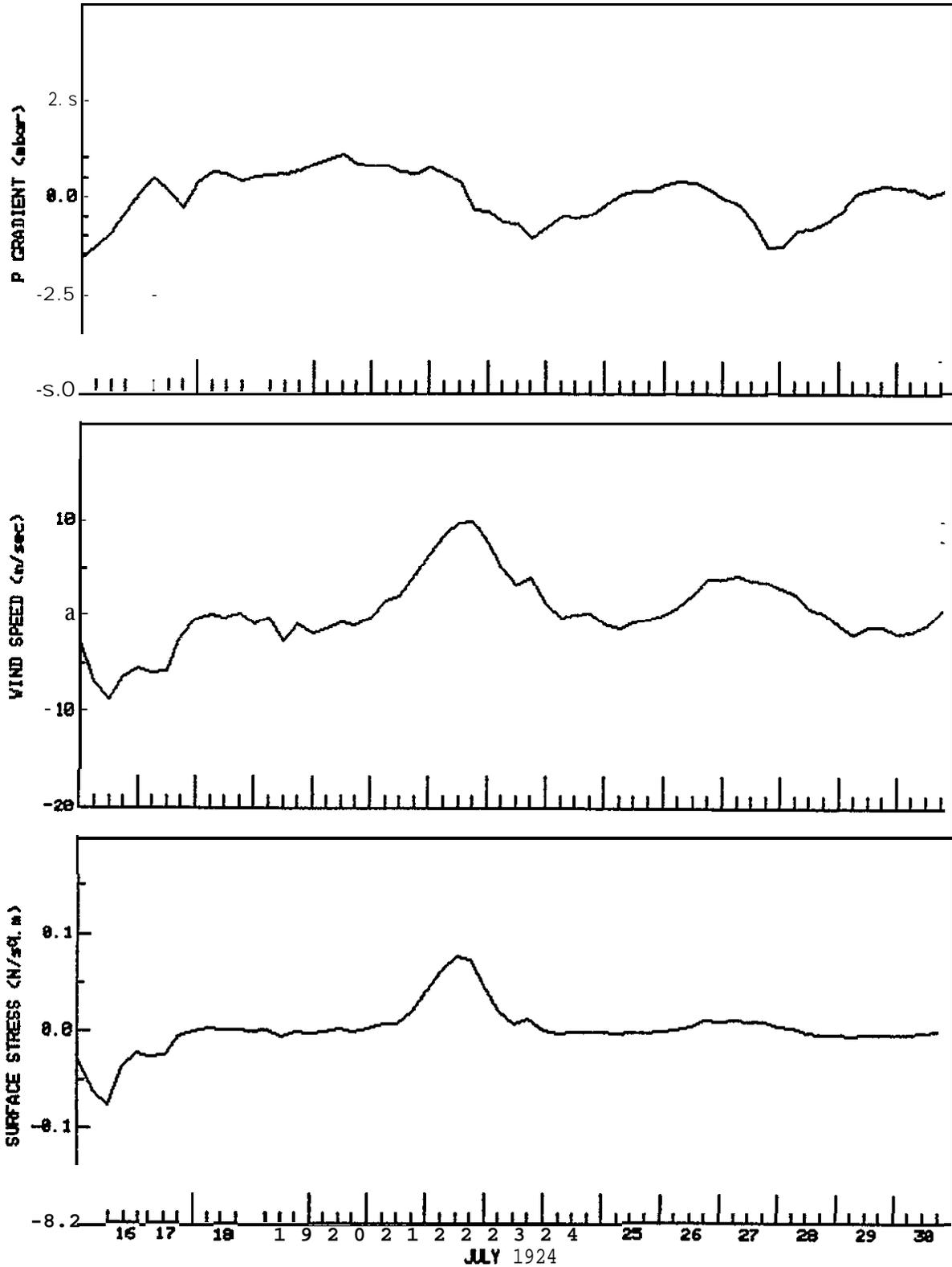
TIME SERIES OF OFFSHORE COMPONENT OF
 PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
 SHELIKOF STRAIT DT(min) 3613



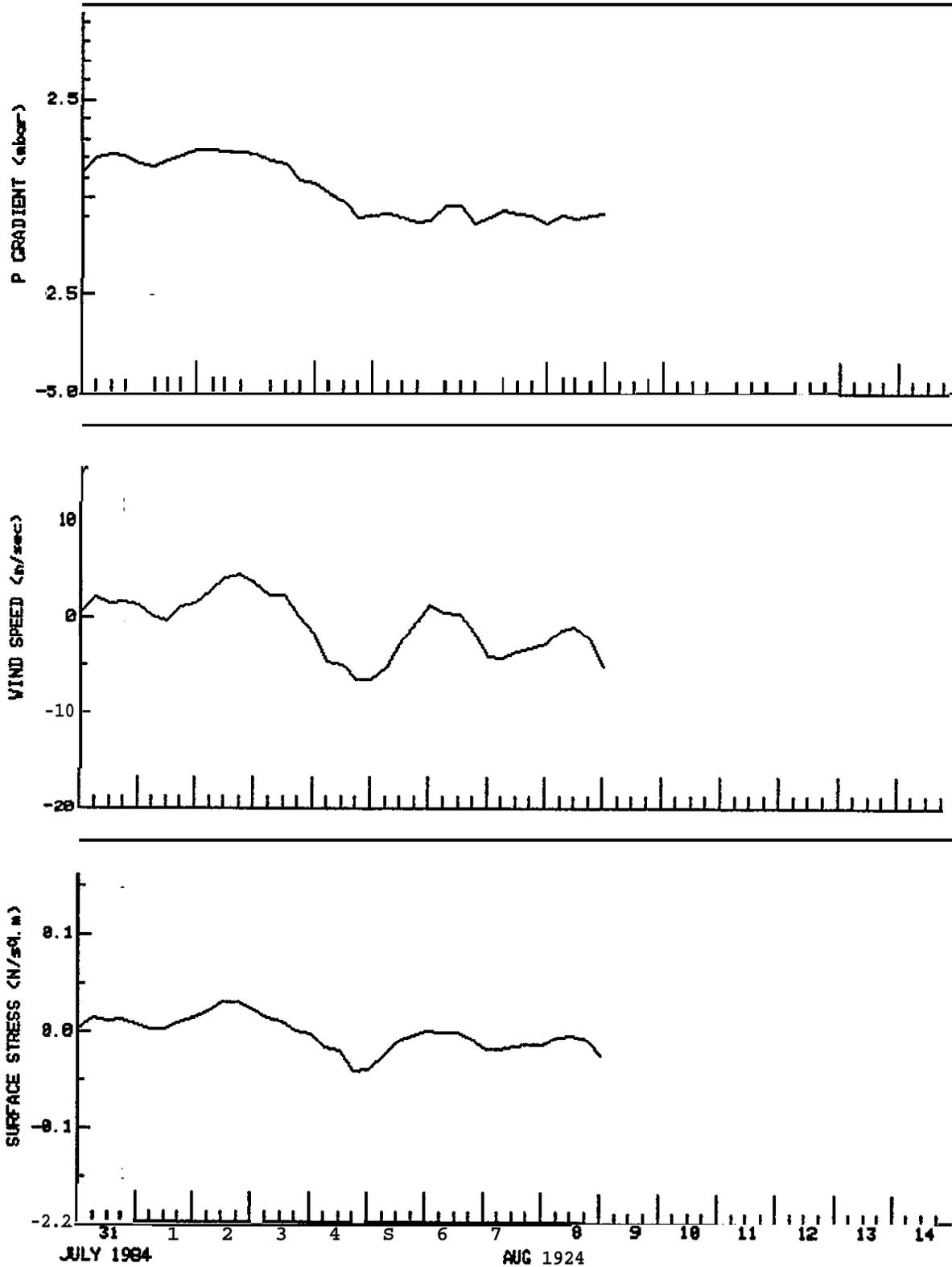
TIME SERIES OF OFFSHORE COMPONENT OF
PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
SHELIKOF STRAIT DT(min) 360



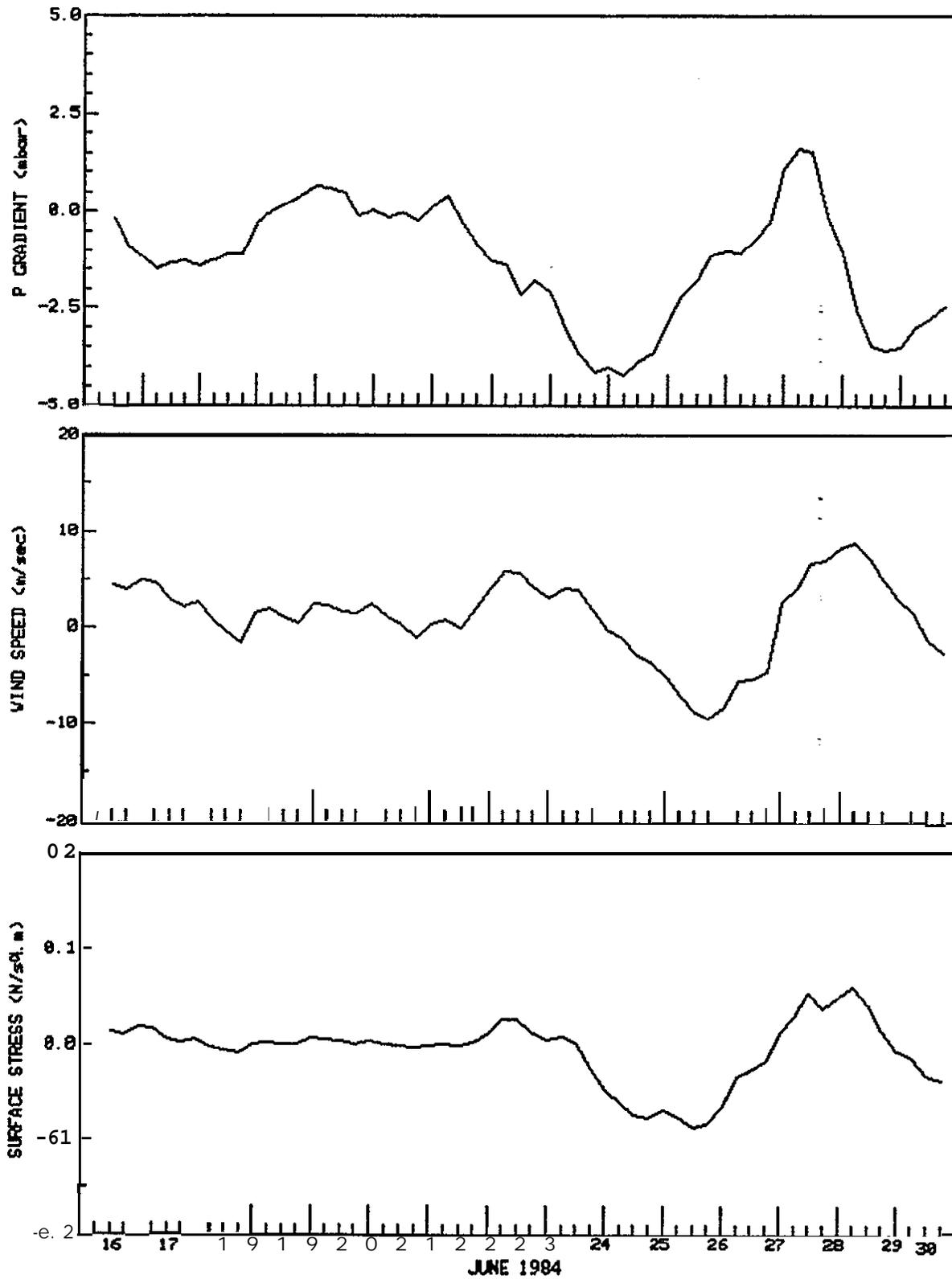
TIME SERIES OF OFFSHORE COMPONENT OF
 PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
 SHELIKOF STRAIT
 DT(min) 360



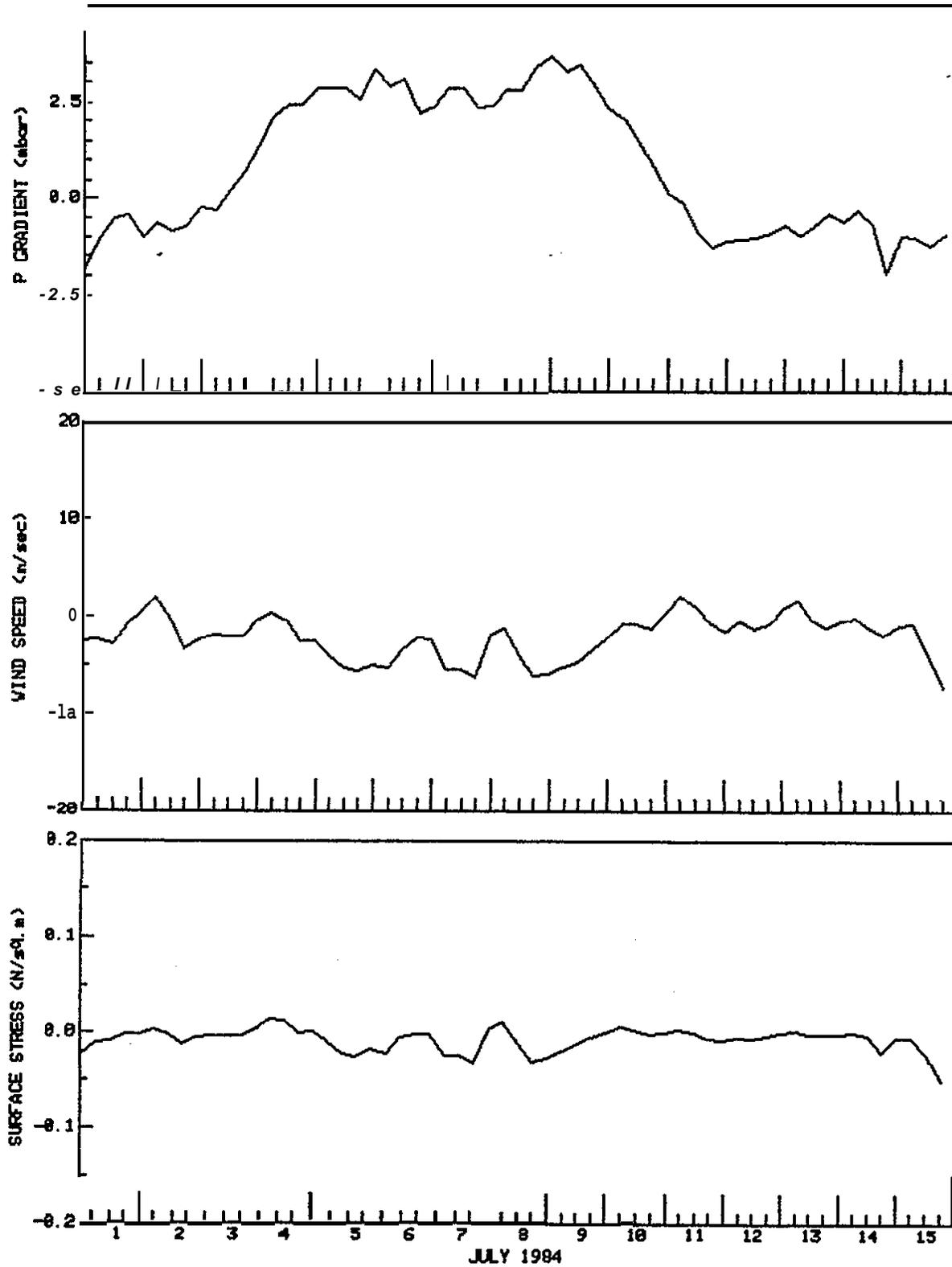
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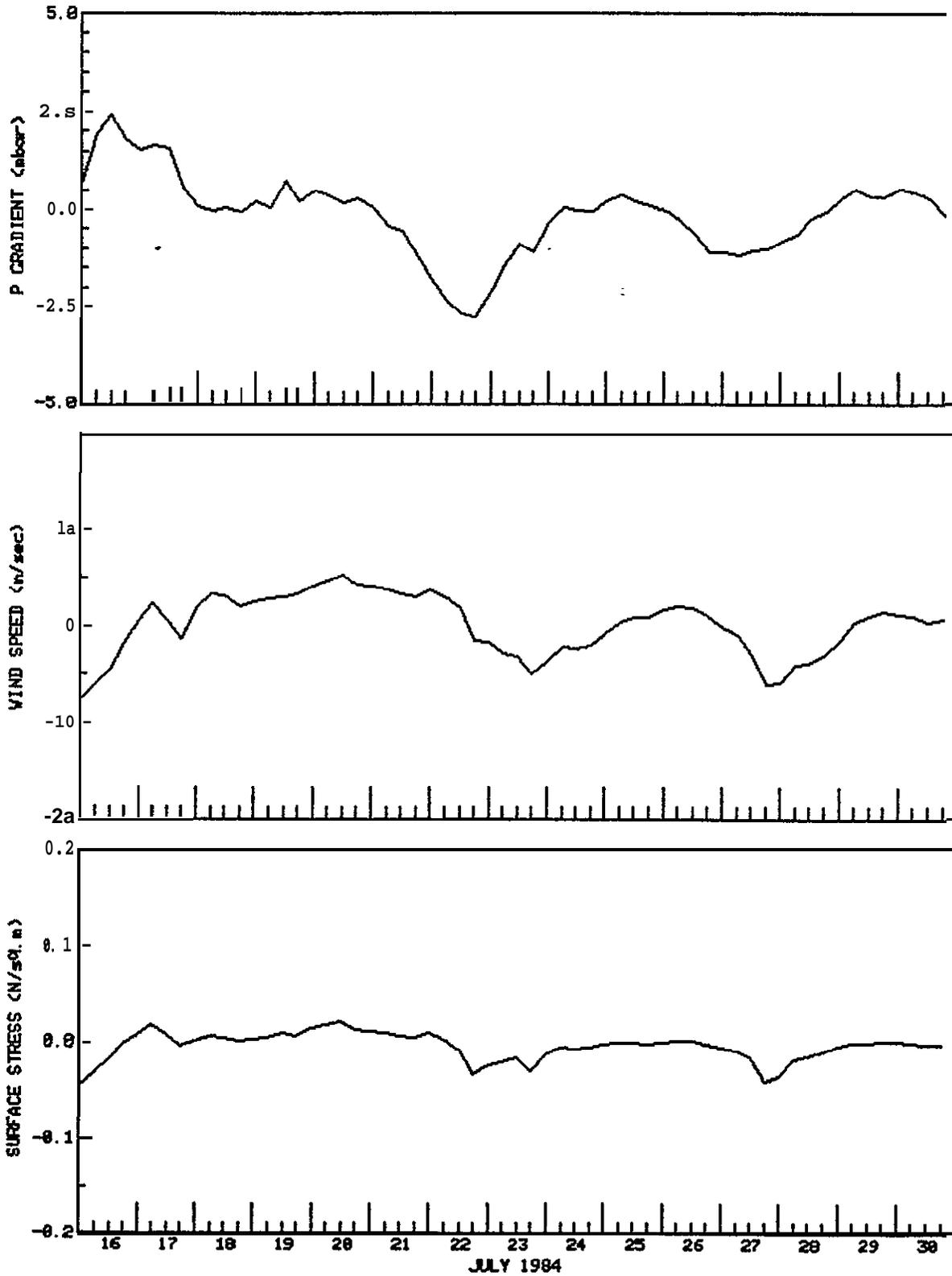
TIME SERIES OF LONGSHORE COMPONENT OF
 PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
 SHELIKOF STRAIT DT(min) 360



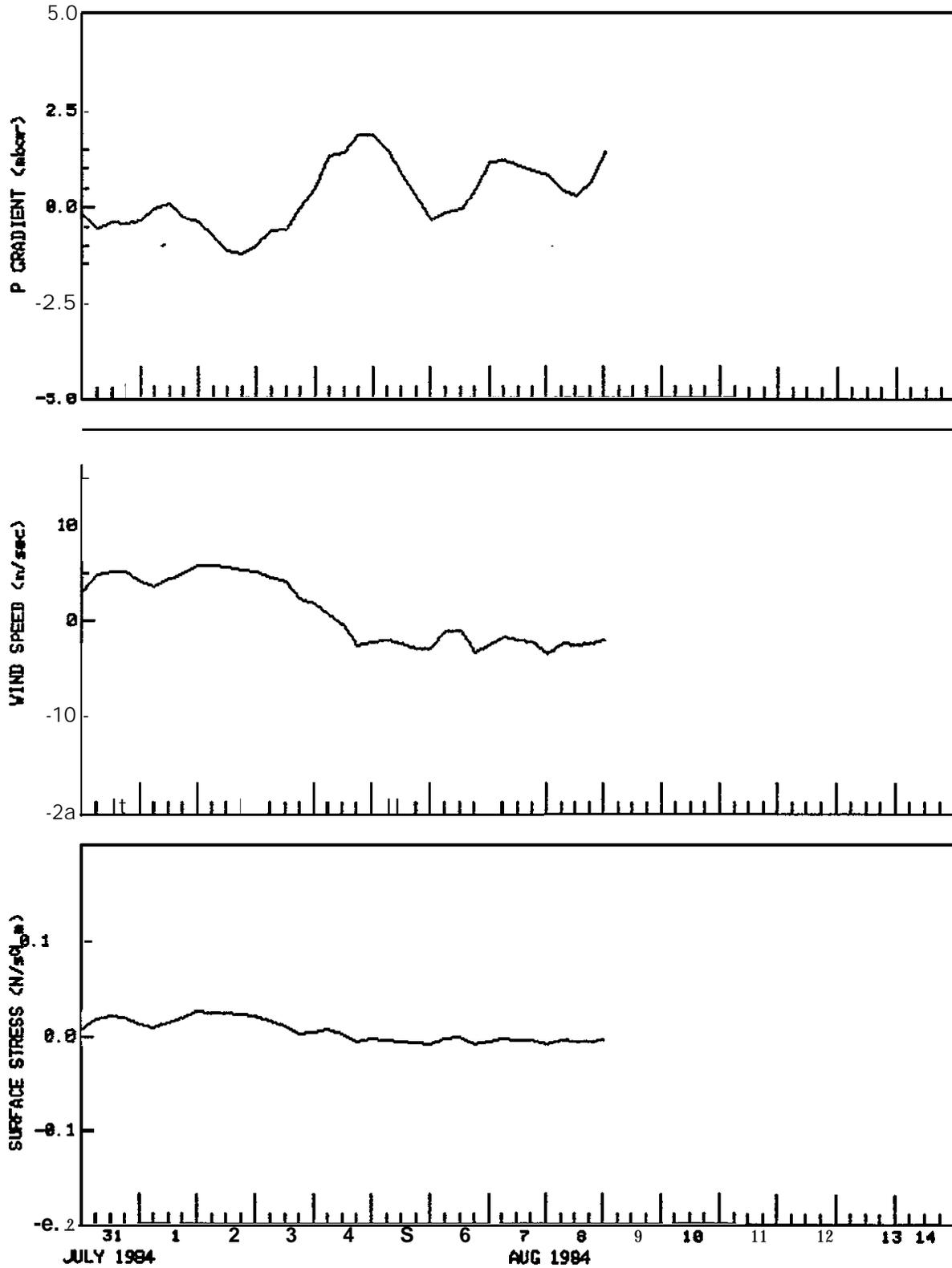
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DT(min) 360



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



TIME SERIES OF LONGSHORE COMPONENT OF
 PRESSURE GRADIENT, GEOSTROPHIC WIND AND SURFACE WIND STRESS
 SHELIKOF STRAIT
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R0603

REMOTE SENSING DATA ACQUISITION,
ANALYSIS AND ARCHIVAL

by

William J. Stringer



AK -
OCSEAP

REMOTE
SENSING

FOURTH QUARTERLY REPORT

October 1 - December 31, 1986

OCSEAP Research Unit 267 663

AK 1/4/88

July

Submitted to

National Oceanic & Atmospheric Administration
Ocean Assessments Division
Alaska Office
PO Box 56
Anchorage, Alaska 99511-3

February 1987

Geophysical Institute
University of Alaska
Fairbanks, Alaska 99775-0500

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 used 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 be 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 1983 were added to existing files and new files were created **for** data for January 1986.
2. The Bering Sea ice edge for 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 **Brueggeman** at the end of this quarter consisted of:

- 1) Magnetic tape capturing 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 polynya**. 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 the 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 **polynyas**. 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 from 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 the 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 for 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 do not essentially 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 from the data set is statistically unsound. On the other hand, so is adding an **arbitrarily** 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 some 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 listed 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 polynyas compiled in order to give an idea of the total polynya areas in the study area. "St. Lawrence" is the sum of St. Lawrence, North (E) and St. Lawrence, South (D) . (However, usually only one is open at a time.) 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 polynya 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 daily 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.)

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 is a great quantity of these prints as they represent at least one copy of

✓
NOAA
AVHRR
Positive
transparency
format
← 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 well 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.

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 Appendix II). Normally we only monitor the acquisition of this data because of its limited value and not so limited expense.

ice charts
drifting buoy

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, all 3000 of Brueggeman's whale/no whale data will 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 satellite 1 ice 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.

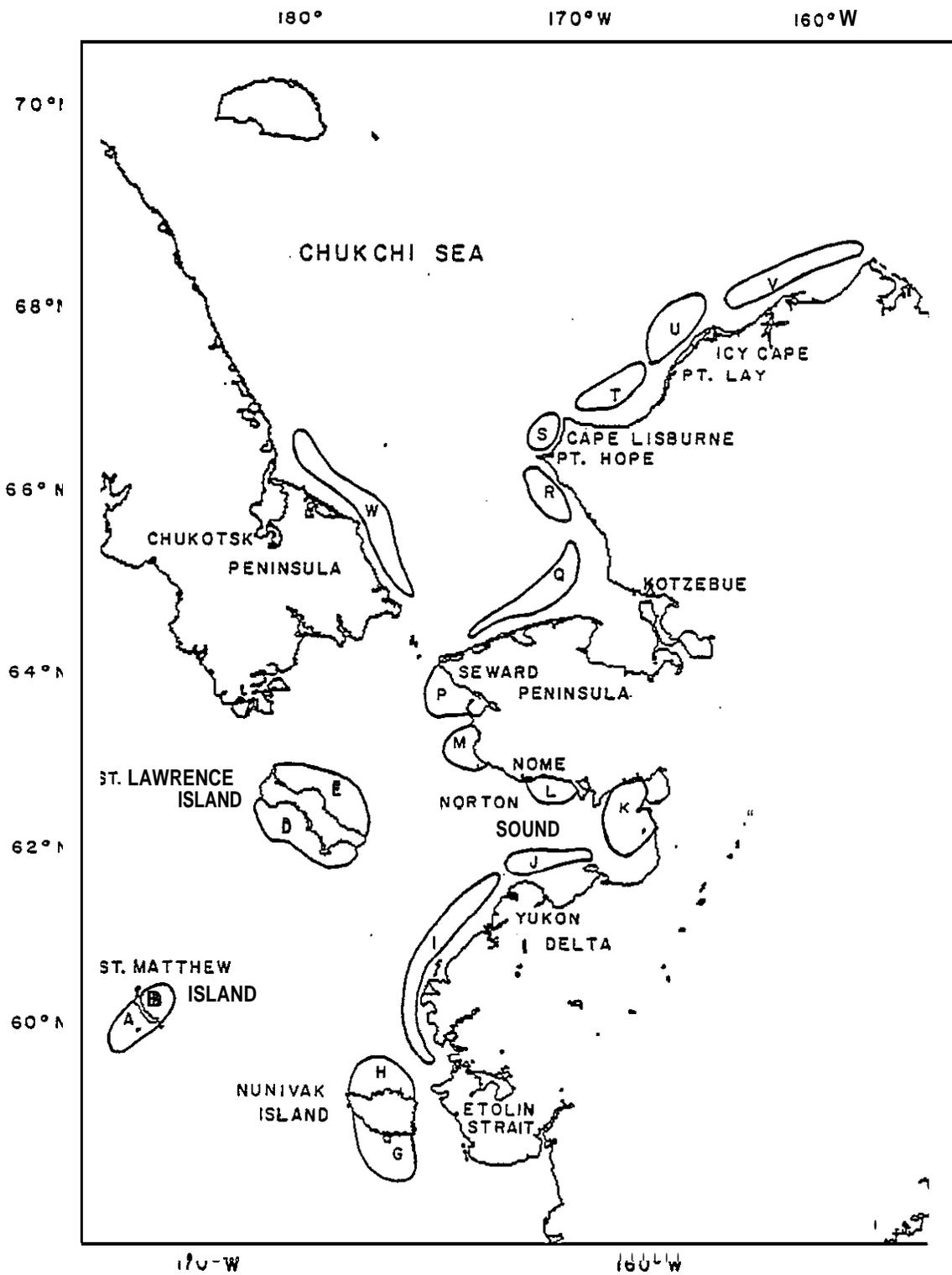


Figure 1. Map showing approximate location of persistent polynyas in the Bering Sea/ Chukchi Sea study area.

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

JANUARY

Polynya	Median Area*	1975	Maximum Area	Median Area*	1977	Maximum Area
		Median Area**			Median Area**	
	km ²					
St. Lawrence	3120	3120	27100	2260	2260	3140
Norton Sound	218	1610	2590	0	1400	3420
Kotzebue	360	3940	11100	4520	5820	7860
Chukchi	0	0	1650	283	2500	18200

Polynya	Median Area*	1979	Maximum W-es Area	Median Area*	1983	Maximum Area
		Median Area**			Median W-es**	
	km	km	km	km	km	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	Median Area*	1986	Maximum Area
		Median W-es***	
	km	km	km
St. Lawrence	2000	2000	10500
Norton Sound	1380	1380	4230
Kotzebue	452	620	1780
Chukchi	1050	1050	7410

FEBRUARY

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

Pol ynya	1977			1979		
	Medi an Area* km	Medi an Area** km	Maximum Area km	Medi an Area* km	Medi an Area** km	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

Pol ynya	1983		
	Medi an Area* km	Medi an Area** km	Maximum Area km
St. Lawrence	2060	2060	3360
Norton Sound	1260	1260	1720
Kotzebue	0	4500	4500
Chukchi	0	2640	4340

MARCH

Polynya	1974			1975		
	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	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			1977		
	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	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			1983		
	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	Maximum Area km
St. Lawrence	2200	2200	8180	2600	2600	11500
Norton Sound	5780	5780	15500	9260	9260	16500
Kotzebue	314	3350	9600	0	238	305
Chukchi	1260	1680	4410	1020	2100	3900

APRIL

Polynya	1974			1975		
	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	Maximum Area km
St. Lawrence	5650	5680	90100	2770	3260	10900
Norton Sound	10300	10300	13200	1080	2390	5920
Kotzebue	0	0	0	1170	3000	3910
Chukchi	0	331	4170	1290	5350	28200

Polynya	1976			1977		
	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	Maximum Area km
St. Lawrence	5180	5500	12000	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			1983		
	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	Maximum Area km
St. Lawrence	13600	5650	Open	4890	2230	Open
Norton Sound	16500	13000	Open	16300	10300	Open
Kotzebue	722	786	Open	221	960	1490
Chukchi	1360	1700	7200	1180	1310	9570

JUNE

		1974			1975	
Pol ynya	Median Area* km	Median Area** k m	Maximum Area km	Median Area* km	Median Area** km	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

		1 976			1977	
Pol ynya	Median Area* km	Median &-es** km	Maximum Area km	Median Area* km	Median Area** km	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

		1979			1983	
Pol ynya	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	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

JULY

	1974			1975		
Polynya	Median Area* km	Median Area** km	Maximum Area km	Median Area* (%es*) km	Median Area** km	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

	1975			1977		
Polynya	Median Area* km	Median Area** km	Maximum Area km	Median Area* km	Median Area** km	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	10900	10900	Open	23100	23100	Open

	1983		
Polynya	Median Area* km	Median Area** km	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
St. 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, 1982)

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 have 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 2 (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 with 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 think 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-

I should also let you know 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 more than happy to do 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 an 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 date 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.

Letter to E. Oxturgut
December 5, 1986
Page 2

The other two sets of images have me puzzled for the moment. It is possible that they were accidentally 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

30 AHEAD FOR NEW CALL

FTT GA 00533761/77

GEOPH INST FBK

ZZ 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 K1A 0H3

TELEX: 053-3761 DOE AES ICE OTT

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 005.7 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. PLAS CDN PLUS COURIER CHARGES. A LISTING OF ALL
FLIGHTS CAN BE MAILED IF SO DESIRED.

GEDDES

ICE CLIMATOLOGY OTTAWA
161840X

GEOPH INST FBK

DOE AESICE OTT

TOD DEC 17 86

CONVERS

18/86

3761
18-86 1543 02748
FR INST FBK

REJECT OF

FR INST FBK

Q 27 FAIRBANKS ALASKA USA 18 DEC 1986
MR GEDDES
CEMOTOLOGY OTTAWA
EX 70533761 DGE/RESICE OTT

YOUR TELEX 12/17/86

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

THANK YOU
STRINGER
EX 35414 GEOPH INST FBK
RESICE OTT
HE 0017 HINS

But what shall I do with this?
Thank you for this
Paul



Environment
Canada

Environnement
Canada

Atmospheric
Environment
Service

Service
de l'environnement
atmosphérique

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

Your file / Votre référence

Our file / Notre référence
8280 -6(ACIC)

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

12 September, 1985

Dear Mr. Stringer:

AS 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
Senior Ice
Climatological Technician

Enclosure

ICEC086STRINGER

07-01-22-12786

06 DEC 1966

RECEIVED

07-03-22-12786

GEOPH INST FBK
EXTN STRENGER

06-10
15-1966

FOLLOWING IS A LIST OF DATES FOR FLIGHTS OVER YOUR AREA OF INTEREST

1965

SEPT 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

OCT 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

NOV 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

1966

JAN 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

FEB 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

MAR 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

APR 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

MAY 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

JUNE 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

JULY 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

AUG 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

SEPT 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

OCT 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

REGARDS
GEODES
SEGE CLIMATOLOGY
294055EST
GEOPH INST FBK
DOE AESTSE GTT
06 DEC 1966

Rept
 Ref your telex of 12/19/66
 Please send copies of radar
 wind prof from Sept 29 and Oct 27
 1966. I have have generated a
 purchase order for \$240 for maps
 and plus \$60 for course cards payable
 to 50 Central, Canada, P.O. number 66
 54225-4610, Geophysical Institute, University
 of Alaska. Payment will be by check unless you
 prefer otherwise. Thank you. Bill Strong
 54225-4610

CONVERSATION

08-35 12/22/86

DEC 22 08 1022 1031
GPOH INST PHC

DOE RESIDE OTT

UNABLE TO TRANSMIT FOLLOWING MESSAGE TO YOU ON 12/15/86. YOUR
TELEX KEPT RECASTERING A NT OF INT. LOOKS OK NOW.

ZCZS 032 FAIRBANKS ALASKA USA 19 DEC 1986

ATTN: GEDDES
ICE CLIMATOLOGY
TELEX 051-3761

REF: YOUR TELEY OF 12/15/86

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
54273-4610, GEOPHYSICAL INSTITUTE, UNIVERSITY OF ALASKA. PAYMENT
WILL BE BY CHECK UNLESS YOU SPECIFY OTHERWISE. THANK YOU.

BRIE STINGER
TELEX 95414 GPOH INST PHC

DOE RESIDE OTT

TIME 002 7 11 MS

*Bill
Geddes
12/22/86*