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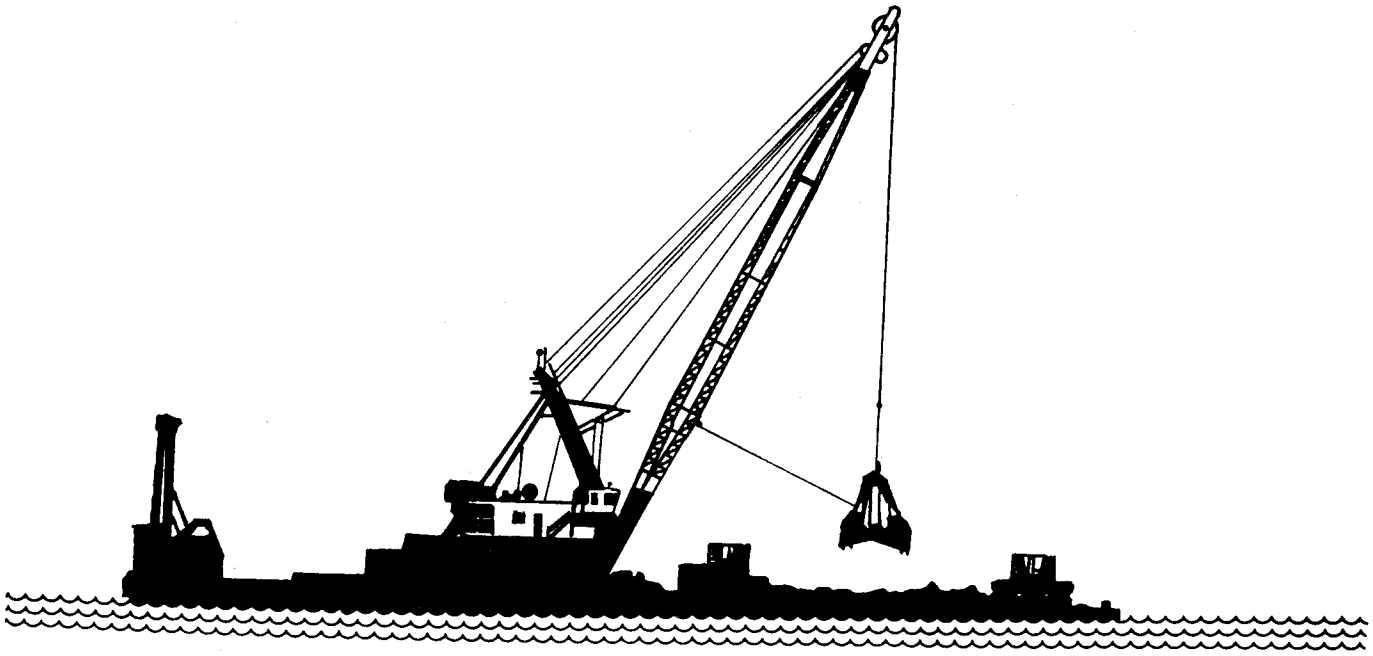
DISPOSAL SITE SELECTION TECHNICAL APPENDIX - PHASE II

(NORTH AND SOUTH PUGET SOUND)



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DISPOSAL SITE SELECTION TECHNICAL APPENDIX
PHASE II

Unconfined Open-Water Disposal Sites for Dredged Material in South and North Puget Sound

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ORGANIZATIONAL PREFACE

This document is a technical appendix to the Puget Sound Dredged Disposal Analysis (PSDDA) Management Plan Report and Final Environmental Impact Statement for the Phase II study area (northern and southern Puget Sound). The appendix was prepared by the Disposal Site Work Group (DSWG), assigned the responsibility for identifying potential unconfined, open-water dredged material disposal sites.

Part I of the Disposal Site Selection Technical Appendix contains introductory and conceptional information for the remaining parts of the document. Part II contains the detailed presentation of the site selection process employed by DSWG.

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EXECUTIVE SUMMARY

This document is a technical appendix to both the Proposed Management Plan Report and the Environmental Impact Statement (EIS) for the Puget Sound Dredged Disposal Analysis (PSDDA) Phase II study covering north and south Puget Sound. Phase I (central Puget Sound) was completed in 1988. This technical appendix was produced by the Disposal Site Work Group (DSWG), which includes the U.S. Army Corps of Engineers as lead agency, supported by the U.S. Environmental Protection Agency (EPA), and the Washington Department of Natural Resources as the state lead agency supported by the Department of Ecology.

Results of disposal site selection studies for Phase II of PSDDA, are summarized herein. Phase II includes the southern portion of Puget Sound south of the Tacoma Narrows and the northern portion of Puget Sound north of Admiralty Inlet to the U.S./Canadian border and west to Port Angeles. DSWG's task in Phase II was to identify suitable unconfined, open-water disposal sites. This technical appendix summarizes the process by which DSWG carried out its task.

Preferred nondispersive, unconfined, open-water disposal sites have been selected in the Nisqually Delta region and in Bellingham Bay. Preferred dispersive sites have been identified in the Rosario Strait, Port Townsend, and Port Angeles areas. A site, considered at Point Roberts, was dropped due to potential conflicts with the commercial trawl fishery in that area. The nondispersive sites, while varying in size primarily due to bathymetry, average about 318 acres in potential bottom impact area. Each site includes a 900-foot radius, 58-acre surface disposal zone within which all dredged material must be released. The dispersive sites range in size from 650 acres at Rosario Strait to 884 acres at Port Angeles and Port Townsend. Each of the dispersive sites includes a 1,500-foot radius, 162-acre surface disposal zone within which all dredged material must be released.

The preferred disposal sites were located, to the maximum extent practicable, in areas with few important biological resources and human use activities. In Rosario Strait, the center of the preferred disposal zone is located about 2 nautical miles south of Reef Point on Cypress Island in water 230 feet deep. The center of the Port Townsend preferred disposal zone is located approximately 10-1/2 nautical miles northwest of Port Townsend in water about 360 feet deep. The center of the Port Angeles preferred disposal site is located about 4-1/2 nautical miles north of Port Angeles in about 430 feet of water. In south Sound, the center of the preferred disposal zone is located midway between Anderson and Ketron Islands in water about 440 feet deep. The preferred site in Bellingham Bay is located about 5-3/4 nautical miles southwest of Bellingham in water about 100 feet deep.

The site selection process used by PSDDA utilized existing information in combination with field studies to identify preferred and alternative disposal sites. Steps of the site selection process were as follows:

(1) Define general siting philosophy. This step addresses disposal philosophy (i.e., whether sites should be dispersive or nondispersive), general siting locations (i.e., ocean, strait, or sound), and the number of disposal sites.

(2) Identify selection factors to delineate Zones of Siting Feasibility (ZSFs). This step uses existing information on biological resources and human use activities to identify general areas where disposal sites might be appropriately located.

(3) Conduct field studies on the ZSFs. Field studies were conducted to fill key data gaps and gather information on the physical and biological conditions of the ZSFs. Since these studies were conducted to check the general condition of the ZSFs, they are referred to as "checking studies."

(4) Identify preliminary sites within the ZSFs. Information from the ZSF studies is used to identify preliminary locations for disposal sites within the ZSFs.

(5) Identify preferred sites. Information from the ZSF studies is used to identify preferred and alternative sites.

Existing DNR disposal sites were considered in the disposal site selection process if they met certain site selection factors. All cooperating agencies in PSDDA agreed early on that no special a priori consideration would be given to the existing sites. An objective site selection process was used to minimize environmental and human usage conflicts as much as possible, and existing sites adequately meeting the site selection factors and constraints were given equal consideration with other potential sites.

The key steps in the site selection process were as follows. First, Zones of Siting Feasibility (ZSFs) were found by overlaying many maps of human-use and biological resources. The map overlays yielded ZSFs large enough to embrace potential disposal sites in the vicinity of major dredging activity near Port Angeles, Port Townsend, Bellingham and Fidalgo Bays, Swinomish Channel, Blaine, and Olympia areas.

Second, more detailed maps were constructed of the ZSFs describing three basic characteristics: 1) current strength; 2) sediment character; and 3) biological resources. From maps of current strength and results from earlier dredging activities it was determined that dredged materials would be resuspended at current speeds faster than half a knot. Because a nondispersive philosophy was originally adopted, areas were sought where dredged material would not be significantly transported or where current speeds were less than half a knot. These areas also coincided with characteristics indicating that these areas were depositional, i.e., where sediments tended to naturally accumulate. Only Bellingham Bay and south Puget Sound were found to have depositional areas. Accordingly, disposal sites for the other dredging areas in north Puget Sound were reassessed based on a

dispersive philosophy. The capacities of the nondispersive disposal sites in the Phase II area are estimated to be several times the probable volume of dredged material projected for disposal through the year 2000. The capabilities of the dispersive sites are essentially unlimited.

PUGET SOUND DREDGED DISPOSAL ANALYSIS
DISPOSAL SITE SELECTION TECHNICAL APPENDIX
PHASE II

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PART I. INTRODUCTION

1. STUDY GOALS, DESCRIPTION AND ORGANIZATION

This technical appendix to the Phase II Management Plan Report (MPR) and EIS addresses the identification of disposal sites for unconfined, open-water disposal of dredged material in north and south Puget Sound (Fig. I.1-1) as specified pursuant to the Clean Water Act (Public Law 92-500) as amended. The site selection process for the Phase II areas (north and south Puget Sound) of the Puget Sound Dredged Disposal Analysis (PSDDA) is presented and discussed. The site selection process for the Phase I area (central Puget Sound) is described in the final Phase I documents (PSDDA, June, 1988). A review and synthesis of studies conducted, information gathered, and analysis performed during the Phase II disposal site selection process are provided herein.

Since the 1970's relatively high concentrations of chemicals of concern have been found in some sediments of a number of bays in Puget Sound. These chemicals have also been identified in fish, shellfish, and other organisms. While research is continuing about the ways in which exposure to sediments containing these chemicals affects marine life or human health, recent field studies have noted some adverse biological effects in areas of elevated sediment chemicals.

The waterways and marinas of Puget Sound require periodic dredging to continue the important economic and social benefits of deep and shallow draft water borne commerce and recreational boating. Dredging has become very expensive due to the limited practical options for disposal of dredged material as well as the extended regulatory process that a dredger must go through to obtain the necessary permits for disposal.

Five basic disposal options are available. These include unconfined open-water, unconfined nearshore/upland, confined aquatic disposal, confined nearshore, and confined upland areas. The three confined options result from the need to address sediment contamination levels that are unacceptable for unconfined or conventional disposal. See the Phase I Evaluation Procedures Technical Appendix (EPTA, June, 1988) for a detailed discussion of disposal options. Open-water sites are located offshore in deep-water areas. Unconfined open-water disposal occurs through free fall of released material to the bottom with no subsequent handling. Confined aquatic disposal involves follow-up capping with material suitable for unconfined open-water disposal. Nearshore disposal sites are typically diked aquatic areas, but the final surface of the site is usually above the waterline. Upland disposal sites are areas created on land entirely above the waterline, and are often diked. PSDDA has generally been limited to unconfined open-water disposal (siting, dredged material evaluation procedures, and site management). The State of Washington Department of Ecology is addressing in a separate, ongoing study, the confined disposal options.

Cost effective evaluation, disposal, and management of dredged material is essential to the economic interests of the Puget Sound region which serves as a major deep water port for the nation. More than 200 small boat harbors meet the needs of commercial fishing vessels and pleasure craft in the Puget Sound region. Periodic dredging is necessary in most of these harbors as well as in the major ports. For uncontaminated dredged material, disposal at unconfined, open-water sites is generally the least costly alternative. As upland and intertidal areas become more difficult to secure, the demand for this type of disposal will increase.

1.1 Puget Sound Dredged Disposal Analysis

The Puget Sound Dredged Disposal Analysis (PSDDA) is an interagency study by the U.S. Army Corps of Engineers (Corps) as lead agency, supported by the U.S. Environmental Protection Agency (EPA) and the Washington Department of Natural Resources (DNR) as state lead supported by the Department of Ecology (Ecology). The goal of PSDDA is to provide the basis for publicly acceptable guidelines governing environmentally safe unconfined, open-water disposal of dredged material, and to provide Puget Sound-wide consistency and predictability. The objectives of PSDDA are as follows:

- Identify acceptable unconfined, open-water disposal sites.
- Define acceptable evaluation procedures for dredged material to be discharged at those sites.
- Develop site use management plans.

The work of PSDDA is divided into two phases that differ geographically and temporally. Phase I of the study began in April 1985 and was completed in October 1988. It covered a smaller geographic areas than Phase II (Fig. I.1-1). The Phase I study area included Puget Sound from Everett south to Tacoma, and Port Susan north of Everett. The Phase II study area includes Puget Sound northward from the Phase I area to the Canadian border and west to Port Angeles. It also includes Puget Sound southward from the Phase I area to Olympia and Shelton and also includes Hood Canal. The Phase II study began in 1986 and is scheduled to be completed in 1989.

Three work groups have been formed to address these objectives with each group staffed by the four agencies conducting PSDDA. Many others including representatives from Puget Sound ports, environmental groups, Indian tribes, dredging industry, local governments, and other state and Federal agencies are also participating in work group activities. The work groups under the general guidance of the PSDDA Study Director, have conducted a number of technical studies. Each work group produced a technical appendix which summarizes these studies. These work groups include:

- Disposal Site Work Group (DSWG)

- Evaluation Procedures Work Group (EPWG)

- Management Plan Work Group (MPWG)

DSWG was assigned the responsibilities for selecting unconfined, open-water disposal sites in the Phase I and Phase II areas (north and south Puget Sound). DSWG produced this Disposal Site Selection Technical Appendix (DSSTA) which addresses the identification of disposal sites for unconfined, open-water disposal of dredged material in north and south Puget Sound, as specified pursuant to the Clean Water Act (CWA) and related authorities.

EPWG was assigned the responsibility for developing a decision making framework and technical specifications for assessing the quality of dredged material and delineating material which is suitable for unconfined, open-water disposal at nondispersive sites and at dispersive sites. EPWG produced the Phase I Evaluation Procedures Technical Appendix (EPTA) which addresses the development of evaluation procedures (testing and disposal guidelines for nondispersive sites) for determining when dredged material is suitable for unconfined, open-water disposal pursuant to the CWA. Additional studies and the development of disposal guidelines for the Phase II dispersive sites are described in Exhibit A to the MPR.

MPWG was assigned the responsibility for developing the management plan for each of the unconfined, open-water disposal sites. MPWG produced the Phase I Management Plans Technical Appendix (MPTA) which addresses the management of sites to be used for unconfined, open-water disposal of dredged material in central Puget Sound, pursuant to implementation of the CWA and related authorities. Management plans for the Phase II sites are discussed in the MPR and detailed in Exhibit B of the MPR.

In addition to PSDDA there are other ongoing programs in Puget Sound. In particular, the work conducted by PSDDA required detailed coordination with the Puget Sound Estuary Program (PSEP) and the Puget Sound Water Quality Authority (PSWQA). The charter of the PSWQA also includes dredging issues. The December 1986 Comprehensive plan of PSWQA was developed in close coordination with PSDDA.

The regulatory basis of the PSDDA study is Section 404 of the Clean Water Act of 1977 (Public Law 92-500), which establishes a Federal permit system for the disposal of dredged and fill material, and Section 401, which requires a water quality certification from the state prior to issuance of a Federal permit. The Coastal Zone Management Act (Public Law 92-583) requires that Federal and non-Federal projects in a particular state be consistent to the maximum extent practicable with the state's coastal zone management program. The appeal process differs between Federal and non-Federal projects not in compliance. In addition, Section 10 of the 1899 Rivers and Harbors Act also applies to disposal activities in navigable waters.

1.2 Disposal Site Work Group

The goal of the Disposal Site Work Group was to develop and implement site selection criteria for choosing unconfined, open-water disposal sites that are environmentally acceptable, practicable, and economically feasible. The site selection process has identified sites that are acceptable for dredged material in full compliance with 404(b)(1) guidelines. The DSWG's charter also included developing guidelines for site use and establishing parameters for the environmental baseline and subsequent monitoring studies at nondispersive and dispersive sites.

1.3 Management of the Disposal Site Work Group

1.3.1 Participants and Coordination of Work--

Four agencies are the principal participants in DSWG. The chair is the U.S. Army Corps of Engineers (Corps). The U.S. Environmental Protection Agency (EPA) and the Washington State Departments of Natural Resources (DNR) (state lead) and Ecology (Ecology) are supporting agencies. Representatives of these agencies meet as necessary to coordinate the work. In addition to the four primary agencies; Indian tribes, port, city, county, other state and Federal agencies, and other interests were also involved in the activities of the DSWG (Table I.1-1).

For all meetings (see Table I.1-2 for Phase II meetings), minutes were recorded that summarized the conclusions of the work group discussion. Meetings were frequent enough to enable many discussions of the relevant issues. The ultimate resolution of the issues appears in this technical appendix.

Another function of the DSWG meetings was general monitoring of the work as it proceeded. This monitoring included contract oversight and review of technical documents submitted by the various agencies and contractors.

1.3.2 Public Involvement--

The public was also involved in the DSWG decision-making process through a series of meetings held at a number of locations. These meetings were publicized through news media coverage, informational brochures, newsletters, and by encouraging involvement of various organizations.

TABLE I.1-1 PSDDA-DSWG PARTICIPATING AGENCIES & ORGANIZATIONS.

- State of Washington

  Department of Fisheries (WDF)
  Department of Wildlife (WDW)
  Department of Social and Health Services (DSHS)
  Puget Sound Water Quality Authority (PSWQA)
  University of Washington Fisheries Department (UW Fish)

- Federal

  National Oceanic and Atmospheric Administration (NOAA)
  U.S. Fish and Wildlife Service (USFWS)
  U.S. Coast Guard (USCG)

- Local Governments/Agencies/Port Districts

  Mason County
  Thurston County
  Island County
  Jefferson County
  Kitsap County
  Snohomish County
  King County
  Pierce County
  City of Everett
  City of Seattle
  City of Tacoma
  Municipality of Metropolitan Seattle (Metro)
  Puget Sound Council of Governments (PSCOG)
  Port of Bellingham
  Port of Everett
  Port of Seattle
  Port of Port Townsend
  Port of Tacoma
  Port of Anacortes
  Port of Edmonds
  Port of Olympia
  Port of Port Angeles
  Port of Skagit County

- Indian Tribes

  Lummi
  Muckelshoot
  Nisqually
  Puyallup
  Skagit
  Squaxin Island
  Suquamish
  Tulalip

- Environmental Groups/Organizations

  Puget Sound Alliance
  League of Women Voters
  Greenpeace
  Washington Environmental Council
  Friends of the Earth

- Private Citizen

  Bonnie Orme

- Other

  Tetra Tech, Inc.
  Cooper and Associates (Cooper)
  Evans-Hamilton, Inc. (EHI)
  Shapiro and Associates (Shapiro)
  Envirosphere, a division of Ebasco, Inc.
  Institute for Marine Studies, University of Washington
  Washington Association of General Contractors
  Washington Association of Cities
  Washington Public Port Association
  Battelle Memorial Institute (Battelle)
  Magnolia Bluff Homeowners Association
  Northwest Indian Fisheries Commission

TABLE I.1-2 MEETING DATES OF THE DISPOSAL SITE WORKING GROUP (DSWG) FOR PHASE II STUDIES.

Meeting No.	Date
1	22 April 1986
2	3 June 1986
3	9 July 1986
4 (Joint DSWG/EPWG MTG)	17 July 1986
5	26 August 1986
6	15 September 1986
7	29 September 1986
8	17 October 1986
9	21 January 1987
10	18 June 1987
11	9 December 1987

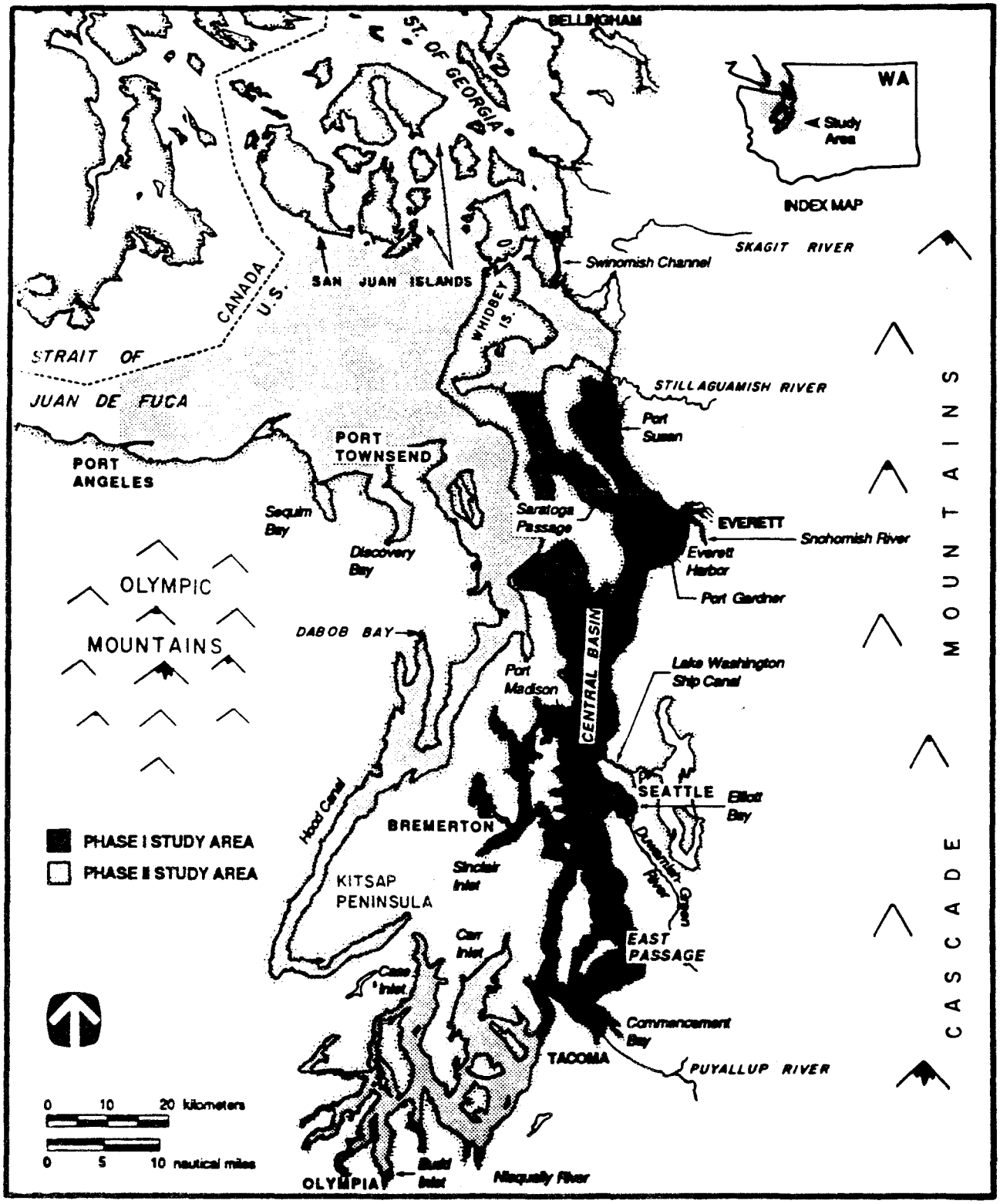

Figure I.1-1 PSDDA study area (Source: Tetra Tech, Inc.).

2. DISPOSAL SITE SELECTION BACKGROUND

2.1 Definition of Dredged Material

The scope of the PSDDA study is limited to the disposal of dredged material. Upland construction material, waste, and debris are not considered. In open water areas, dredged material is defined as sediment and bottom materials that are removed during dredging operations (e.g., clay, silt, sand, and rocks). The definition of dredged material is more complex when dredging operations occur along the shoreline. The reader should consult the Phase I Evaluation Procedures Technical Appendix for a discussion of dredging along the shoreline. This discussion includes material classed as excavation material which is not considered for disposal in marine waters. Historically in Puget Sound, some of this excavation material has been informally considered as dredged material, and will continue to be included as dredged material only if there would be an ecological benefit at the disposal site.

2.2 Existing Unconfined, Open Water Disposal Sites in the Phase II Area

Currently, there are deep water disposal sites in Bellingham Bay, Bellingham Channel, Padilla Bay, Skagit Bay, near Port Angeles, Admiralty Inlet, near Steilacoom, and in Dana Passage (Fig. I.2-1). The procedures utilized to select these existing sites are discussed in this section.

The DNR used guidelines for selecting and managing the original open-water disposal sites (WAC 332-30-166). These guidelines are fairly general and contained the following key points:

- Open-water sites shall be used almost exclusively for material obtained from marine or fresh waters.

- The material must meet the approval of Federal and state agencies.

- In selecting disposal areas, consideration must be given for the sites' natural characteristics, probable dispersal patterns, substrate type, proximity to dredge sites, and living resources (including aquaculture).

- Special consideration must be given to discharges by pipeline.

- The department may require investigations of biological and physical systems, and may perform subtidal surveys.

The existing open-water disposal sites were selected, reviewed, and operated by DNR in conjunction with the Inter-Agency Open-Water Disposal Committee. This committee consisted of representatives from the DNR, Corps, National Marine Fisheries Service (NMFS), EPA, U.S. Fish and Wildlife Service (USFWS), and Washington State Departments of Wildlife, Fisheries, and

Ecology. Site selection by the committee followed the guidelines described above. The establishment of open-water disposal sites is subject to DNR obtaining a shoreline master use permit from the city or county having jurisdiction over the area.

Pursuant to the requirements of the Shorelines Management Act (SMA) of 1971 [Revised Code of Washington 90.58], cities and counties with shorelines on Puget Sound have developed Shoreline Master Programs (SMPs) and corresponding land use permitting processes, including regulation of uses on state-owned submerged lands. Very general guidelines have been established for open-water disposal sites [WAC 173-16-060(16)].

Disposal site shoreline permits issued by the appropriate local shoreline jurisdiction (county or city) fall into one of the following categories: Substantial Development Permit; Conditional Use Permit; or Variance Use Permit. Conditional Use and Variance Use permits require approval by the Washington Department of Ecology.

Shoreline Master Programs generally divide the shoreline area into segments of different environmental classifications in which permissible and prohibited land use activities are defined (e.g., Urban Residential, Conservancy, etc.). In addition to the land use permit requirements of the SMA, DNR must also fulfill the requirements of the State Environmental Policy Act (SEPA) when applying for a site permit for open-water disposal. The Environmental Impact Statement (EIS) requirements for SEPA are analogous to those of the National Environmental Policy Act (NEPA).

In summary, the DNR's permit application requirements for an open-water disposal site are:

- Shoreline Substantial Development Permit
- Conditional Use Permit (where needed)
- Environmental Checklist
- Preparation of an EIS, if environmental impacts are expected to be significant.

2.3 Reevaluation of Unconfined, Open-Water Sites

As described above, the state guidelines are very general and while adequate in the past they may not be effective today for determining if a given disposal site is environmentally and publicly acceptable, given the increase in information available to make the decisions. No field studies were conducted to determine the existing sites' biological and/or physical characteristics. It should be noted that most if not all of the existing sites were established in the early 1970's. Although, the best available published information and the best judgment of site selection committee members had been used to select sites.

Disposal decisions previously had been made primarily on the basis of water quality criteria. Tests used in checking for impacts on water quality gave no indication of impacts on the benthos and other resources from chemicals in dredged material. No other standards were available to interpret these data.

In response to increasing concerns regarding potential environmental and human health impacts associated with open-water disposal of contaminated dredged material, the EPA and Washington Department of Ecology at the request of the City of Seattle and DNR, formulated disposal criteria for the open-water disposal site in Elliott Bay (Fourmile Rock). The Fourmile Rock Interim Criteria (FRIC) were based on reference conditions found at or near the site (a "nondegradation" policy), not a determination of what might constitute an adverse environmental effect. These were interim sediment criteria intended for use only until regional guidelines were developed.

A similar decisionmaking process and interim criteria was also developed for the remainder of Puget Sound in much the same way as they were developed for the Fourmile Rock site. The Puget Sound Interim Criteria (PSIC) which currently apply to the Phase II area, are based on the premise that dredged material should not have higher chemical levels than central Puget Sound sediments, and must not exhibit a statistically significant increase in toxic biological effects. Although not formally promulgated, the Puget Sound Interim Criteria were the basis for disposal at all existing Phase II sites. The PSDDA evaluation procedures now govern use of the Phase I sites.

2.3.1 Need for Unconfined Open-Water Disposal Sites--

2.3.1.1 Dredging in the Phase II Area

Phase II of PSDDA focuses on dredging activities in the northern and southern areas of Puget Sound, including maintenance navigation dredging and dredging for new port facilities. During 1970-1985 approximately eight million cubic yards were disposed in open water in the Phase II area (Table I.2-2). There are a number of Federal navigation projects in the Phase II area of Puget Sound that require periodic maintenance dredging by the Corps. It is expected that the total dredging volume over the period 1985-2000 will be about 90 percent of that generated over the previous 15 years, based on information for currently planned projects.

Most dredging activity is highly dependent on the availability of nearby disposal sites because of economic considerations. Alternative disposal sites are generally not available without considerable increases in transportation, construction and operational costs (e.g., upland sites). Disposal at confined in-water or upland sites, while dependent on the specific project, is estimated to cost from three to ten times more per cubic yard than present open-water disposal. These cost differences affect the feasibility of many dredging projects. See Phase I EPTA (June, 1988) for a full discussion of cost implications of PSDDA requirements on testing and monitoring, and for a discussion and analysis of environmental alternatives and cost implications to dredging and open-water disposal.

2.3.1.2 Dredging Areas

PSDDA has subdivided the Phase II area in to dredging areas which are related in Table I.2-1 to the preferred disposal sites near Port Angeles, Port Townsend, Anacortes (Rosario Strait), Bellingham (Bellingham Bay), and Steilacoom (Anderson/Ketron Islands). The largest quantities of dredged material are generated near these areas. The remainder of the dredging projects in north and south Puget Sound are sporadic in nature and generally consist of lesser quantities. Table I.2-1 identifies the major areas where dredged material is generated. Table I.2-2 identifies the disposal sites where dredged material was deposited in the period 1970-1985. Tables I.2-3 through I.2-7 contain the 15 year projections of material to be dredged in each area. Tables I.2-8 and I.2-9 provide information on haul distances to the various Phase II disposal sites.

Dredging activities in the Phase II area have been reviewed and summarized in the Puget Sound Dredged Material Inventory System (Envirosphere, 1986). The Dredged Material Inventory was developed from Corps permit applications, EPA summary records, and other sources. Its purpose is to inventory the sources of dredged material and to characterize these dredged sediments with regard to location, volume, chemical composition, and known biological effects. The computerized database has been used to summarize historic and current dredging activities, and to project the volume and nature of sediments that may be dredged in the future.

2.3.1.3 Historic Dredging

Dredging operations in the Phase II area of Puget Sound involve removal and disposal of large volumes of material. From the Dredged Material Inventory it has been estimated that a total of 7.9 million cubic yards was dredged during the 15-year period from 1970 to 1985 (Table I.2-2). Approximately 36 percent of this total was deposited at DNR designated unconfined open-water disposal sites. Thus, an average of about 200,000 cubic yards of dredged sediment was deposited at designated DNR sites each year during this period. The remainder of dredged material was deposited at other open-water locations or nearshore or upland disposal sites.

2.3.1.4 Dredging Forecasts

The Dredged Material Inventory database has been used in conjunction with information on currently planned projects to project the total volume of sediment to be dredged in the Phase II area during the 15-year period from 1985 to 2000. A fifteen year planning horizon was used as it encompasses all known major navigation projects and is the maximum forecasting period that PSDDA felt could be established with reasonable certainty. The PSDDA disposal sites can accommodate dredged material well beyond the planning horizon as will be shown in Section II.10.3. The projected total volume to be dredged

is 7,187,000 cubic yards, a volume 9 percent lower than the total dredged during the previous 15-year period. Of this total, most of the projected dredging activities will occur in five areas: Budd Inlet; Swinomish Channel; Bellingham Bay; Fidalgo Bay; and Lummi Bay (Tables I.2-4 - I.2-6). Much of this dredging will be done by the Corps for navigation channel maintenance, and most of these projects have historically used open-water disposal sites. Permit applications also indicate that there will be a great demand for open-water disposal sites for other projects. Without the availability of the relatively less expensive open-water sites, some of these projects may not be economically feasible.

2.3.2 Concerns with Previous DNR Sites--

Concerns were raised about using DNR's previous disposal sites for a variety of reasons. Several gillnet fishermen reported gear losses and fouling from debris such as logs, cable, and other harbor refuse while fishing over the existing disposal site in Bellingham Bay. In Mason County a decision by the Shorelines Hearing Board closed the Dana Passage disposal site. The shoreline permit for the Admiralty Inlet disposal site in Island County stated that measurement of sediment movement must be taken. Due to the cost associated with this condition this site received minimal use.

2.3.3 Site Selection Philosophy--

Previous DNR disposal sites were considered in the disposal site selection process if they met certain site selection factors. All cooperating agencies in PSDDA agreed at the beginning of the study that no special consideration would be given to the existing sites because of human use conflicts and environmental concerns with past dredging and disposal protocols. An objective site selection process was used to minimize environmental and human usage conflicts as much as possible; existing sites adequately meeting the site selection factors and constraints were given equal consideration with other potential sites.

2.3.4 Existing Information--

Earlier studies concerning the movement of dredged material mounds were made in Elliott Bay. One occurred in inner Elliott Bay under the Dredged Material Research Program (DMRP) and the other in the Fourmile Rock disposal site (Schell et al., 1976). These studies span a range of current speeds and provide the basis for the determination of the threshold speed for the movement of dredged material.

The studies indicated little or no change in the disposal area between 1976 and 1979. The data indicated that the currents were weak, moved primarily in response to tidal fluctuations, and apparently did not move much

of the sediment; therefore, the area could be characterized as depositional rather than erosional. For a more detailed description of the study see the Phase I report (DSSTA, 1988).

TABLE I.2-1 MAJOR DREDGING AREAS AND SUBAREAS LOCATED IN THE PHASE II REGION.

Location of Disposal Site	Major Dredging Area Likely to Be Served
Nondispersive ZSFs	
Bellingham Bay	Bellingham Bay Fidalgo Bay Lummi Bay San Juan Islands
Anderson/Ketron Islands	Olympia/Budd Inlet Shelton/Oakland Bay Pickering Pass Tacoma Narrows Steilacoom
Dispersive ZSFs	
Port Angeles	Port Angeles
Port Townsend	Port Townsend San Juan Islands Admiralty Inlet Hood Canal
Rosario Strait	San Juan Islands Swinomish Channel Whidbey Island Blaine

TABLE I.2-2 PUGET SOUND DREDGED MATERIAL INVENTORY FOR THE PHASE II AREA (NORTH AND SOUTH PUGET SOUND) 1970-1985. ALL VOLUMES ARE EXPRESSED IN CUBIC YARDS.

A. Totals

Total Volume Dredged	7,900,000 cubic yards (c.y.)
Total Volume Disposed to Unconfined Open-water	3,253,000 c.y.
Total Volume Disposed at:	
•DNR Sites-North Sound	
Admiralty Inlet	165,000 c.y.
Bellingham Bay	766,000 c.y.
Bellingham Channel	1,147,000 c.y.
Padilla Bay	133,000 c.y.
Port Angeles	168,000 c y.
Skagit Bay	173,000 c.y.
	2,552,000 c.y.
•DNR Sites-South Sound	
Dana Passage	141,000 c.y.
Steilacoom	235,000 c.y.
	376,000 c.y.
•Other Open-Water Locations	325,000 c.y.

B. Project Type

	Corps of Engineers Projects	Port Projects	Other Projects
Total volume dredged (c.y.)	2,100,000	3,167,000	2,633,000
Total volume disposed to open water (c.y.)	615,000	901,000	1,737,000
Total volume disposed upland or nearshore (c.y.)	1,485,000	2,266,000	896,000

TABLE I.2-3. 15-YEAR PROJECTIONS (1985-2000) OF TOTAL DREDGING VOLUMES (CY) TO PSDDA PHASE II DISPOSAL SITES (1)

	AREA		
Project Sponsor	South Sound	North Sound	Total
Proposed by Corps (2)	500,000	2,370,000	2,870,000
Proposed by Ports (3)	225,000	1,459,000	1,684,000
Estimated Other (Private, Municipal, DOT) (4)	612,000	2,021,000	2,633,000
TOTAL	1,337,000	5,850,000	7,187,000

(1) Total dredging volume--not total volumes going to unconfined, open-water disposal.
(2) Forecast by Bob Parker (Corps) for existing and proposed federal navigation projects.
(3) Forecasts by Port Districts.
(4) Assumed to be equal to permitted dredging volumes over period 1970-1985.

TABLE I.2-4. 15-YEAR PROJECTIONS (1985-2000) OF TOTAL DREDGING VOLUMES (CY) BY SPECIFIC DREDGING AREAS WITHIN THE SOUTH SOUND STUDY AREA (1)

Dredging Site	Corps	Projected Port	Volumes Other	Total
Olympia/Budd Inlet	500,000	225,000	312,000	1,037,000
Tacoma Narrows (2)			86,000	86,000
Shelton/Oakland Bay			67,000	67,000
Pickering Pass (3)			104,000	104,000
Steilacoom (4)			43,000	43,000
TOTAL	500,000	225,000	612,000	1,337,000

(1) South Sound study area includes all Puget Sound waters and shoreline south of the Tacoma Narrows Bridge.
(2) Tacoma Narrows dredging area includes The Narrows south of the bridge, Hale Passage, Henderson Bay, and Carr Inlet.
(3) Pickering Pass dredging area includes Pickering Pass, Peale Pass, Case Inlet, and Henderson Inlet.
(4) Steilacoom dredging area includes Steilacoom and Nisqually Reach.

TABLE I.2-5. 15-YEAR PROJECTIONS (1985-2000) OF TOTAL DREDGING VOLUMES (CY) BY SPECIFIC DREDGING AREAS WITHIN THE NORTH SOUND STUDY AREA (1)

Dredging Site	Projected Volumes Corps	Port	Other	Total
Swinomish Channel (2)	400,000	123,000	656,000	1,179,000
Bellingham Bay	360,000	365,000	31,000	756,000
Blaine		350,000		350,000
Fidalgo Bay (3)	60,000	140,000	568,000	768,000
Lummi Bay (4)	1,550,000		3,000	1,553,000
San Juan Islands (5)			165,000	165,000
Port Angeles (6)		104,000	181,000	285,000
Port Townsend		377,000	45,000	422,000
Admiralty Inlet (7)			121,000	121,000
Whidbey Island (8)			107,000	107,000
Hood Canal (9)			144,000	144,000
TOTAL	2,370,000	1,459,000	2,021,000	5,850,000

(1) North Sound study area includes all Puget Sound area waters and shoreline north and west of the Phase I study area to Port Angeles. Waters involved in the PSDDA study do not extend west of Port Angeles.
(2) Swinomish Channel dredging area includes the Swinomish Channel and Skagit Bay.
(3) Fidalgo Bay dredging area includes Fidalgo Bay, Anacortes, and Padilla Bay.
(4) Lummi Bay dredging area includes Lummi Bay and Lummi Island.
(5) San Juan Islands dredging area includes Orcas, Shaw, Lopez and San Juan Island.
(6) Port Angeles dredging area includes Port Angeles and Sequim Bay.
(7) Admiralty Inlet dredging area includes Keystone Harbor and other dredging areas along Admiralty Inlet.
(8) Whidbey Island dredging area includes Cresent Harbor, Oak Harbor, and other eastern sides of Whidbey Island north of the Phase I study area.
(9) Hood Canal dredging area includes all of Hood Canal and Port Gamble.

TABLE I.2-6 PROJECTED DREDGING VOLUMES (CY) FOR FEDERAL NAVIGATION MAINTENANCE AND PROPOSED NEW FEDERAL NAVIGATION PROJECTS (1985-2000).

Project Location	Projected Dredging Volume
North Sound	
Fidalgo Bay (1)	60,000
Bellingham Bay (2)	360,000
Lummi Bay (3)	1,550,000
Swinomish Channel (4)	400,000
	2,370,000
South Sound	
Olympia/Budd Inlet	500,000
	500,000

(1) Fidalgo Bay dredging includes:

Cap Sante Waterway Maintenance	60,000

(2) Bellingham Bay dredging includes:

Whatcom Creek Maintenance	100,000
Squalicum Waterway Maintenance	200,000
I&J Street Waterway Maintenance	60,000

(3) Lummi Bay includes:

Lummi Bay Marina Construction	1,470,000
Lummi Bay Maintenance	80,000

(4) Swinomish Channel includes:

Swinomish Channel Maintenance	400,000

(5) Olympia/Budd Inlet includes:

West Bay Turning Basin and Channel Improvement	500,000

TABLE I.2-7. PROJECTED DREDGING VOLUMES (CY) BY PORT DISTRICTS IN PHASE II AREAS (1985-2000).

Project Location	Projected Dredging Volume
North Sound	
Port of Anacortes (1)	
Fidalgo Bay	140,000
Port of Bellingham (2)	
Blaine	350,000
Bellingham Bay	365,000
Port of Skagit (3)	
Swinomish Channel	123,000
Port of Port Angeles (4)	104,000
Port of Port Townsend (5)	377,000
South Sound	
Port of Olympia (6)	
Olympia/Budd Inlet	225,000

(1) Port of Anacortes includes:

Dakota Creek	60,000
Cap Sante Boat Haven	40,000
Pier I	20,000
Pier II	20,000

(2) Port of Bellingham includes:

Blaine	350,000
I&J Waterway	330,000
Squalicum Creek	30,000
Whatcom Waterway	5,000

(3) Port of Skagit includes:

Swinomish Channel Development	107,000
Swinomish Channel Seaplane Development	4,000
South Perimeter Basin Maintenance	12,000

(4) Port of Port Angeles includes:

Tumwater Creek	50,500
Ediz Hook Launch Ramp	3,000
Port Angeles Boat Haven	500
Dungeness Bay Launch Ramp	30,000
Port Angeles Marine Terminal	15,000
Sequim Bay Marinas	5,000

(5) Port of Port Townsend includes:

Port Townsend Boat Basin	373,000
Point Hudson	3,000
Quilcene Boat Basin	1,000

(6) Port of Olympia includes:

West Bay Terminal	200,000
East Bay Moorage	5,000
Berth 3 and 4	15,000
Berth 2	5,000

TABLE I.2-8. HAUL DISTANCES TO DISPOSAL SITES FROM PHASE II NORTH SOUND DREDGING AREAS (1).

	DISPOSAL SITES				
	DISPERSIVE			* NONDISPERSIVE	
Dredging Areas	Port Angeles(2)	Port Townsend(3)	Rosario Strait(4)	*Bellingham *Bay(5)	Port Gardner(6)
Swinomish Channel	-	26.0	15.1	19.2	-
Bellingham Bay	-	35.7	15.1	2.7	-
Blaine	-	60.3	30.2	32.9	-
Fidalgo Bay	-	18.7	5.5	11.9	-
Lummi Bay	-	28.1	20.2	11.3	-
San Juan Is.(7)	-	15.5	15.5	26.8	-
Port Angeles	4.1	20.6	-	-	60.0
Port Townsend	35.0	14.4	-	-	35.0
Admiralty Inlet(8)	39.1	18.5	-	-	17.7
Whidbey Island(9)	-	31.5	27.4	-	22.6
Hood Canal(10)	57.6	37.0	-	-	37.2

(1) The haul distances represent the approximate average distance nautical miles to the two closest dispersive sites and the closest nondispersive site. The sites considered in determining haul distances include:

Dispersive Sites:
- Port Angeles Site
- Port Townsend Site
- Rosario Strait Site

Nondispersive Sites:
- Bellingham Bay
- Port Gardner

(2) The Port Angeles dispersive site is located in the Strait of Juan de Fuca north of Port Angeles and near the U.S.-Canada border.

(3) The Port Townsend dispersive site is located west of Point Partridge (Whidbey Island) and north of McCurdy Point in the Strait of Juan de Fuca.

(4) The Rosario Strait dispersive site is located southwest of Guemes Island in Rosario Strait, near Anacortes.

(5) The Bellingham Bay nondispersive site is located within Bellingham Bay.
(6) The Port Gardner nondispersive site is the previously described Phase I nondispersive site (see June 1988 Phase I documents).
(7) The hauling distances reported for the San Juan Islands is an average distance based on calculations from Friday Harbor and Orcas Island to the disposal sites.
(8) The hauling distances reported for the Admiralty Inlet area are based on the distances from the disposal sites to the Port Ludlow area.
(9) The hauling distance for Whidbey Island is based on the distance to the disposal sites from the Crescent Bay/Oak Harbor area.
(10) The hauling distance from Hood Canal is an average distance based on calculations from Dabob Bay and Bangor.

TABLE I.2-8. HAUL DISTANCES TO DISPOSAL SITES FROM PHASE II SOUTH SOUND DREDGING AREAS (1).

	NONDISPERSIVE DISPOSAL SITES	
Dredging Areas	Anderson Island /Devils Head (2)	Anderson/Ketron Island (3)
Olympia/Budd Inlet	12.3	17.5
Tacoma Narrows	14.4	9.2
Shelton/Oakland Bay	16.3	21.5
Pickering Pass (5)	5.6	10.8
Steilacoom (6)	9.9	4.7

(1) The haul distances represent the approximate average distance (nm) to the South Area proposed nondispersive sites.
(2) The Anderson Island/Devils Head nondispersive site is located northwest of Treble Point in Drayton Passage.
(3) The Anderson/Ketron Island nondispersive site is located in the Nisqually Reach north of the eastern edge of the Nisqually Flats.
(4) Tacoma Narrows dredging area includes the Narrows south of the bridge, Hale Passage, Henderson Bay, and Carr Inlet.
(5) Pickering Pass dredging area includes Pickering Pass, Peale Pass, Case Inlet, and Henderson Inlet.
(6) Steilacoom dredging area includes Steilacoom and Nisqually Reach.

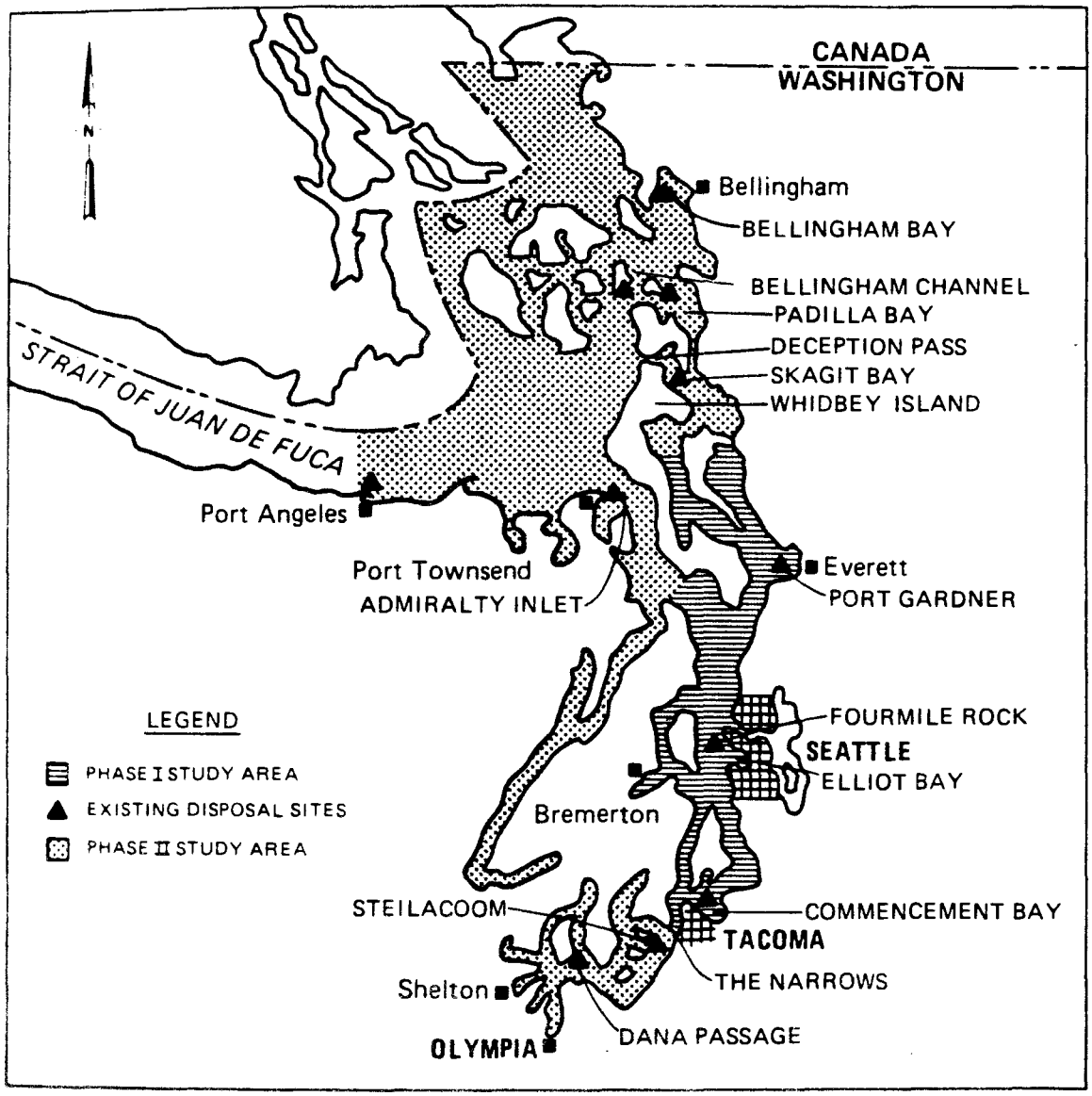

Figure I.2-1 Puget Sound dredge disposal study area (Source: Schmalz, 1986).

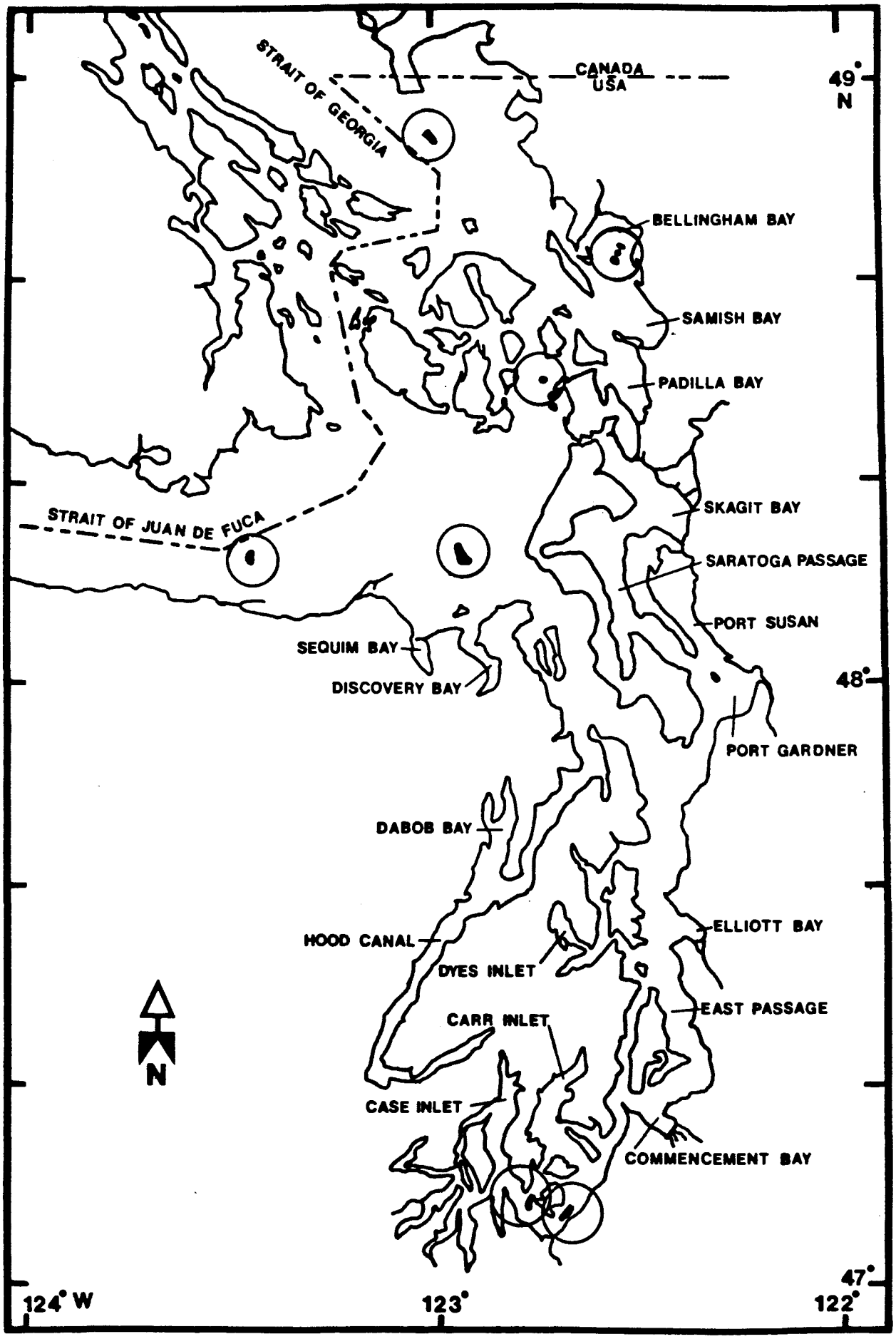

Figure I.2-2 PSDDA Phase II Zones of Siting Feasibility (ZSFs).

PART II IDENTIFICATION OF UNCONFINED OPEN-WATER DISPOSAL SITES

1. OVERVIEW OF DISPOSAL SITE SELECTION PROCESS

The site selection process used by PSDDA utilized existing information in combination with field studies to identify preferred and alternative disposal sites. The approach used is similar to that described in the EPA and Corps workbook entitled "General Approach to Designation Studies for Ocean Dredged Material Disposal Sites" (EPA/Corps, 1984). Steps of the site selection process were as follows:

(1) Define general siting philosophy. This step addresses disposal philosophy (i.e., whether sites should be dispersive or nondispersive), general siting locations (i.e., ocean, strait, or sound), and the number of disposal sites.

(2) Identify selection factors to delineate Zones of Siting Feasibility (ZSFs). This step uses existing information on biological resources and human use activities to identify general areas where disposal sites might be appropriately located.

(3) Conduct field studies on the ZSFs. Field studies were conducted to fill key data gaps and gather information on the physical and biological conditions of the ZSFs.

(4) Identify preliminary sites within the ZSFs. Information from the ZSF studies is used to identify preliminary locations for disposal sites within the ZSFs.

(5) Identify preferred sites. Information from the ZSF studies is used to identify preferred and alternative sites.

Existing DNR disposal sites were considered in the disposal site selection process if they met certain site selection factors. All cooperating agencies in PSDDA agreed at the beginning of the study that no special consideration would be given to the existing sites, because of human use conflicts and environmental concerns with past dredging and disposal protocols. An objective site selection process was used to minimize environmental and human usage conflicts as much as possible, and existing sites adequately meeting the site selection factors and constraints were given equal consideration with other potential sites.

1.1 Disposal Philosophy

Early in the disposal site selection process for the Phase I area, discussions were held on the relative merits of dispersive versus non-dispersive sites (see Phase I Disposal Site Selection Technical Appendix: Kendall et al., 1988). A decision was made for the Phase I areas in favor of nondispersive sites. Placing dredged material in nondispersive sites gives site managers the ability to better maintain control and accountability over

site conditions as the sites can be readily monitored. Dispersive sites require different site management considerations due to the spread of material over a potential greater impact area. Impact monitoring becomes vastly more difficult to accomplish in dispersive, high energy environments. However, highly dispersive sites promote dilution of chemicals and lesser concentrated physical impacts.

Phase I nondispersive sites were located in highly urbanized, low energy embayments. Phase II site selection began with the understanding that Phase II areas are much more hydrodynamically complex areas than the Phase I areas. Consideration was given to locating sites in non-dispersive areas if possible, and dispersive sites were only considered as an alternative disposal siting philosophy in the absence of viable non-dispersive sites. In highly dispersive resource rich environments such as in the Strait of Juan de Fuca, and the Strait of Georgia, it was recognized that acceptable nondispersive areas for siting consideration might be difficult if not impossible to find, and that dispersive areas might be the only possibility.

The general philosophy formulated by PSDDA for the Phase I sites was also used for the Phase II sites with one addition to encompass dispersive sites:

- Full compliance with 404(b)(1) guidelines.
- Only material suitable for unconfined open-water disposal should be allowed at the sites.
- Nondispersive sites should be located in a highly nondispersive environment.
- When site use is discontinued, eventual recovery to ambient conditions should occur.
- Site should have no unacceptable adverse impacts on fish, shellfish, and marine mammals.
- Minimize interference with human uses. (Shipping lanes and anchorages may have Coast Guard restrictions).
- Dispersive sites should be located in a highly dispersive environment.

The ability to monitor disposal site operations, to modify disposal practices, and to conduct any necessary site remedial actions, are all advantages of the nondispersive siting philosophy. If dispersive sites are functioning correctly, monitoring and assessment of impacts is extremely difficult. At nondispersive sites it is expected that any unacceptable adverse impacts can be identified and controlled, thereby providing accountability and greater public acceptance than with dispersive siting. The inability to effectively monitor and assess impacts of disposal operations at dispersive sites require more conservative disposal guidelines and site management, in order to provide a measure of protection to natural resources and human activities potentially affected.

1.1.1 Nondispersive Sites--

Zones of Siting Feasibility (ZSFs) for the Phase II areas were initially selected using a mapping/overlay process (i.e., Puget Sound Environmental Atlas; Evans-Hamilton,Inc. and D.R. Systems, Inc., 1987) which identified critical natural resources, human use, and other factors critical to the siting process such as currents and bathymetry. Minimum resource and human use conflict areas that met other siting factors of depth (i.e., below 120 ft) and buffer distance (2,500 ft from critical resources and from shorelines) were assessed as potential nondispersive sites through a literature review of existing current speeds and sediment quality (Evans-Hamilton, Inc., 1986). The initial evaluation of ZSFs through literature review and Disposal Site Work Group (DSWG) meetings, eliminated all potential nondispersive ZSFs except those in South Puget Sound (Nisqually Delta area). Subsequent DSWG evaluations, reflecting input by the Washington Department of Fisheries (WDF), resulted in the selection of an alternative nondispersive ZSF in Bellingham Bay, which required relaxing the minimum depth criteria, as well as the minimum distance buffer from natural resources.

1.1.1.1 Assumptions

The following assumptions were made by DSWG during Phase I and Phase II in selecting nondispersive areas suitable for disposal sites. These assumptions are discussed later in this Appendix, and are listed here for conciseness. The major assumptions were:

(1) Dredged material will be dumped from bottom dump barges.

(2) The dredged material will be acceptable for unconfined open-water disposal.

(3) The dredged material will remain within the chosen disposal site, i.e., a nondispersive site.

(4) An area is considered nondispersive if the peak 1% current speed is less than 25 centimeters per second, and if the sediments have small grain sizes and statistically elevated (i.e., >1.96 SND*) volatile solids, biochemical oxygen demand, and water content at stations collected for that depth.

1.1.1.2 Criteria

(1) A minimum buffer of 2,500 feet will separate the disposal sites from critical natural resources, shorelines and human use areas.

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* SND = Standard Normal Deviate

(2) Sites will be located in water having a minimum depth of 120 feet (to avoid sensitive biological resources in nearshore shallow waters).

(3) Nondispersive disposal sites will be reasonably accessible to major dredging activity areas.

1.1.2 Dispersive Sites--

DSWG was unable to locate acceptable nondispersive sites in the highly dispersive environments of the Strait of Juan de Fuca, the Strait of Georgia, and Rosario Strait and was therefore forced to select tentative dispersive sites in these areas for further evaluation and consideration. To evaluate the dispersive potential of the sites being tentatively considered a thorough technical review of existing information on tidal currents was conducted, including an evaluation of numerical and physical models covering each area to assess the probable fate and dispersive characteristics at each site. The dispersive characteristics of each dispersive site will be discussed later in this Appendix.

1.1.2.1 Assumptions

The general assumptions and siting considerations made by DSWG in selecting areas suitable for dispersive disposal sites are discussed later in this Appendix, but are listed here for conciseness. The major assumptions were:

(1) Dredged material will be dumped from bottom dump barges.

(2) The dredged material will be acceptable for unconfined open-water disposal.

(3) The dredged material will generally not remain on site over the long term, but be widely dispersed in the environment.

(4) An area is considered dispersive if the average current speed is greater than 25 centimeters per second, and the existing sediments at the site are coarse sand, gravel, cobble, or rock.

1.1.2.2 Criteria

(1) A minimum buffer of 1 nautical mile will be provided from shorelines and human use areas as measured from the edge of "disposal zone" (Fig. II 4-1 for description).

(2) Sites will be located in water having a minimum depth of 180 feet (to avoid sensitive biological resources in nearshore shallow waters).

(3) The ultimate fate of dispersed material will not have a significant adverse impact on amenities downcurrent.

(4) Dispersive disposal sites will be reasonably accessible to major dredging activity areas.

1.2 General Siting Locations

General areas available for unconfined, open-water disposal include the Pacific Ocean, the Strait of Juan de Fuca, and Puget Sound. A discussion of each of these areas follows.

1.2.1 Ocean Disposal--

The Clean Water Act and Section 404(b)(1) guidelines govern the disposal of dredged material within the waters inside the baseline from which the territorial sea is measured. Disposal beyond the baseline, in the open ocean, is regulated by guidelines developed under the Marine Protection, Research and Sanctuaries Act (Public Law 92-532, as amended). The ocean dumping regulations require application of specific criteria to evaluate dredged material and the use of formally designated disposal sites. At the present time, there are no designated ocean disposal sites in the Pacific Ocean west of Cape Flattery.

The costs associated with barge transport of dredged material to the ocean are extremely high. Estimated unit costs of barge transport per cubic yard ($/c.y. $0.03-$0.10/c.y./nm) to potential ocean disposal sites 10 nautical miles off Cape Flattery (the Cape is approximately 124 nautical miles from Elliott Bay) range as follows: Port Angeles, $1.60-5.00/c.y.; Bellingham Bay, $2.93-10.00/c.y.; Olympia, $4.80-16.00/c.y. These costs are in addition to dredging costs.

Prior to any disposal, permitting and Environmental Impact Statement (EIS) procedures similar in nature to PSDDA would be required for site designation and use. Additionally, dredged material evaluation procedures for ocean disposal are similar to those which are being developed by PSDDA. Therefore, it is highly unlikely that disposal of greater quantities of dredged material at unconfined, open-water ocean disposal sites would be considered acceptable, and environmental benefits or savings to offset transportation costs would not be realized. Additionally, nondispersive sites could likely not be found, necessitating use of dispersive sites only.

Another problem with conducting disposal operations in the open ocean environment results from high winds/waves and storm activity, which occur during the fall, winter, and early spring seasons. Therefore, ocean disposal

is a method that is not currently available within the cost effective distance from any of the Phase II areas. This method is therefore not considered to be a reasonable option because of decreased safety, increased costs, and lack of offsetting environmental benefits. Evaluation Procedures Technical Appendix (EPTA), Part II, Section 10.4 contains an additional discussion and cost analysis for the ocean disposal method.

1.2.2. Disposal in the Outer Strait of Juan de Fuca--

Though disposal of dredged material in the Strait of Juan de Fuca is regulated under Section 404 of the Clean Water Act, the concerns for this option are similar to the ocean disposal option. Dredged material evaluation procedures would be similar. Additionally, disposal in this area, especially if located adjacent to the U.S.-Canadian border, may require added coordination with the Canadian authorities.

The transport costs for this option are also very high. Estimated unit costs ($$ 0.03-0.10/c.y./nm) of barge transport from the Phase II areas to a potential disposal site at the mouth of Cape Flattery within the Strait of Juan de Fuca are for example: Port Angeles, $1.35-4.50/c.y.; Bellingham, $2.70-$9.00/c.y.; Olympia, $4.60-15.30/c.y. Frequent winter storms would cause disposal operations to be more hazardous than within the more sheltered areas of Puget Sound.

Therefore, disposal in the outer Strait is a method that is not currently available within a cost effective distance from the Phase II areas and is not considered to be a reasonable option because of decreased safety and lack of offsetting environmental benefits. Phase I EPTA, Part II, Section 10.4 contains an additional discussion and cost analysis for the Straits disposal method.

1.2.3 Puget Sound--

The remaining potential open-water disposal sites are located within the PSDDA Phase I and II study areas (Fig. I.1-2). The general similarity of physical and biological conditions in the various parts of Puget Sound argues against the need to transport dredged material from either the northern or southern portions of the Sound (Phase II areas) to Central Puget Sound (Phase I areas). No discernible gain in environmental benefits that offsets increased costs justifies transport from Phase II area to Phase I. PSDDA was undertaken to provide disposal sites throughout Puget Sound that were relatively convenient to major areas of dredging activity. For the purposes of this appendix dredging and open-water disposal sites within the confines of the PSDDA Phase II areas are addressed in detail.

1.3 Number of Sites

To determine the number of sites needed, the major areas of dredging were identified for the Phase II area. Review of dredging records compiled for PSDDA indicates that the largest quantities of future Phase II area dredged material will be generated from navigation projects located at Port Angeles, Port Townsend, Bellingham, Anacortes, Blaine, Swinomish Channel, and Olympia. Dredging projects at other Phase II areas are expected to generate substantially less volume of material.

PSDDA initially defined thirteen potential nondispersive ZSFs (ten in North Sound and three in South Sound) for the Phase II area. Eight of the ten were eliminated from the North Sound due to high current speeds (>25 cm/s) and coarse sediment types. A site east of Protection Island exhibited low currents but its proximity to a US Fish and Wildlife Service (USFWS) wildlife refuge and concerns over natural resource conflicts reduced the acceptability of this site. Therefore it too was deleted from further consideration by the work group. One of the three South Sound sites was eliminated due to bottom sediments and because it is a known sport fishing area.

With no candidate North Sound nondispersive ZSFs remaining, the work group decided on a dispersive philosophy for the North Sound. As a result, five dispersive ZSFs were chosen for the North Sound area. One near Lopez Island was eventually deleted due to its proximity to nearby bald eagle and peregrine falcon nesting sites. The Rosario Strait ZSF was moved from a site near Guemes Island to one of the original ten ZSFs because the latter was found to be more dispersive. The eastern half of the Port Angeles ZSF was eliminated from further consideration because of concerns raised by commercial fishermen. An alternative to the Point Roberts ZSF was located approximately 6 nautical miles to the southwest. This site was eventually eliminated after coordination with WDF/Marine Fish Division because the site was in a rocky bottom area which also is a popular recreational/sport fishing area. Finally, the Port Roberts ZSF was eliminated as a potential disposal site because it was located in one of the most heavily trawled areas of Puget Sound.

In addition to the remaining three dispersive sites, a nondispersive site was chosen for Bellingham Bay. The original preferred ZSF was in conflict with established trawl fisheries. Two alternative sites in Bellingham Bay were suggested by the Bellingham Groundfish Trawlers Association. One site located approximately 1 nautical mile northwest of the original ZSF was eliminated. WDF/Marine Shellfish Division rejected the northwest site because of concerns for crab resources. The second alternative site located 0.8 nautical mile northeast of the original ZSF was also rejected as a preferred location because of concerns for crab and shrimp resources. After reviewing the natural resource data for Bellingham Bay, the WDF recommended that the preferred site be relocated midway between the two alternative sites being considered by the Disposal Site Work Group. This move would minimize potential conflicts with groundfish trawlers in Bellingham Bay. Additionally, natural resources were comparable to those found in the preferred site.

2. ZONES OF SITING FEASIBILITY (ZSFs) IN PHASE II AREA

2.1 Identification of the ZSFs

Zones of Siting Feasibility (ZSFs) are those areas which may have the potential to accommodate open-water disposal activities based on existing information derived from a literature review. In general, ZSFs are areas which have the least conflict with the siting factors of concern. The process utilized to identify Phase II ZSFs involved three discrete steps:

Step 1. Define general ZSF selection factors.

Step 2. Define and map specific ZSF selection factors.

Step 3. Apply constraints to the identified ZSFs.

These steps are further described below, and are addressed in detail in Section II.3 of this Appendix.

2.1.1 General ZSF Selection Factors--

Four general ZSF selection factors were identified for the PSDDA Phase II study area. It was determined that ZSFs should, to the maximum extent possible be located:

- For nondispersive sites, in relatively low energy areas that would contain dredged material as much as possible within the disposal site area.
- For dispersive sites, in relatively high energy areas that would disperse dredged material significantly beyond the disposal site area.
- To avoid unacceptable adverse impacts on foodfish, shellfish, marine mammals, and marine birds.
- To minimize interference with human uses to the lowest practicable level.

2.1.2 Specific ZSF Selection Factors--

The general ZSF selection factors were further defined by specific selection factors. Most of these factors are identified in Federal and state regulations relating to dredged material disposal sites located in water. The specific factors were mapped and overlayed to display areas where siting might occur with a minimum of conflict (Table II.2-1). See Exhibit A for a description of site selection factors and maps.

2.1.3 Apply Constraints to Identified ZSFs--

Additionally, the following guidelines were applied in selecting ZSF boundaries:

Nondispersive ZSFs

- The ZSF should be located a minimum water surface distance of 2,500 feet from adjacent shorelines to provide a buffer from noise during disposal and adverse environmental effects to the shore.

- The ZSFs should be buffered by a minimum distance of 2,500 feet as measured along the water surface from vulnerable biological resources.

- The ZSFs should be located in water depths greater than 120 feet. Water depths of less than 120 feet are generally more biologically productive and of major importance to many of Puget Sound's important commercial fish and shellfish species.

- The ZSFs should be located in water depths of less than 600 feet. Based on model results, water depths greater than 600 feet could result in substantially more dispersion of the dredged material during descent through the water column.

- The ZSFs should be located in relatively low energy areas where the peak 1% current speeds < 25 cm/sec, and the sediment has small grain sizes and statistically elevated characteristics.

Dispersive ZSFs

- Maximum dispersion of the material is desired, therefore the ZSF should be in an area of high current (i.e., average current speed > 25 cm/sec).

- The ZSF should be buffered by a minimum of 1 nautical mile from shorelines and human use areas as measured from the edge of the disposal zone.

- The ZSF should be located at a minimum depth of 180 feet to avoid sensitive biological resources. It was advisable to increase the depth to provide additional protection for natural resources concentrated near shore at shallower depths.

- The ZSF should be located so that the ultimate fate of dispersed material will not have a significant adverse impact on natural resources.

It is important to note that the selection factors and constraints were not considered or applied as inviolate standards. This is primarily because they were being used with existing and available information. As studies gathered new information about the ZSFs, adjustments to boundaries, and later to site locations, were made as necessary.

2.2 Description of the Non-Dispersive ZSFs

The presence of sandy-mud (10% sand and 90% mud) or finer grained material (mud) was considered indicative of potential low energy areas by the work group. ZSFs identified from this process are located in the Nisqually delta region of South Puget Sound and Bellingham Bay (Fig II.2-1 a-c).

The final preferred and alternative sites were chosen following the field studies and meetings with agencies and interest groups. Table II.2-2a gives these disposal site location coordinates for each ZSF. These sites are shown on figures throughout this report as a convenience to the reader, so that the final sites can be seen with the data. Each ZSF is described in the following paragraphs.

2.2.1 McNeil Island ZSF 1--

The McNeil Island ZSF was located in the center of the channel between McNeil Island and Steilacoom. This site was eliminated following the literature review (Evans-Hamilton, Inc., 1986) due to the muddy-sand bottom sediments and because the site is a known sport fishing area.

2.2.2 Anderson/Ketron Island ZSF 2--

The Anderson/Ketron Island ZSF is located midway between these two islands in 442 feet of water (Fig. II.2-1a). The boundary configuration was drawn so that the disposal site (i.e., impact area) follows the naturally confining bathymetric features of the bottom. This will ensure the confinement of dredged material on site. This is the preferred ZSF for South Puget Sound.

2.2.3 Anderson Island/Devils Head ZSF 3--

The ZSF boundary is located at the south end of Drayton Passage, between Devils Head and Treble Point, and extends into Nisqually Reach (Fig. II.2-1b). This is the alternate ZSF for South Puget Sound. The 2,500 ft buffer zone was relaxed with the understanding that potential conflicts with herring and groundfish resources could be minimized by site use management (i.e., restrict site use during time of year when herring are using the site). The disposal zone is located at a depth of 238 feet.

2.2.4 Bellingham Bay--

The south ZSF (Alternative Site A-1) is located between Portage Island and the mainland (Fig. II.2-1c). The boundaries of this ZSF were determined by navigation lanes, utilities, marine fish resources, and shellfish

resources. This is the primary alternative ZSF site. It was the original preferred ZSF site but was found to be in conflict with established bottomfish trawl fishery areas. The depth of the Bellingham Bay ZSFs are shallower than 120 ft, approximately 100 feet deep. The 120-foot minimum depth criteria was relaxed to allow consideration of a ZSF in Bellingham Bay.

The northeastern ZSF (Alternative Site A-2) in Bellingham Bay is located off South Bellingham. The boundaries of this ZSF were determined using the same factors as the southern ZSF. This is the secondary alternative ZSF site (A-2). The Bellingham Groundfish Trawlers Association suggested this site due to trawling conflicts with the original ZSF. It was ultimately rejected by DSWG as the preferred location because of higher concerns for crab and shrimp resources relative to the south ZSF site.

The preferred site is located about midway between the two alternative sites approximately 0.9 nautical miles west of Post Point. This location places the disposal site closer to more dense populations of Dungeness crab than the southern site. However, WDF proposed site restrictions prohibiting disposal from November 1 through February 28 each year will greatly alleviate concerns over Dungeness crab during critical spawning periods. The site move was recommended by WDF as a compromise after carefully considering Dungeness crab resource concerns to alleviate potential conflicts with bottomfish trawlers in the vicinity of the southern alternative site (A-1).

2.2.5 Lummi/Sinclair Island--

The Lummi/Sinclair Island ZSF was selected using the constraints of political boundaries, navigation lanes, utility corridors, and marine fish and shellfish resources. This ZSF was proposed as a depositional site although it was only marginally adequate in terms of the depositional criteria, due to current speeds of 25.3 cm/sec and sandy-mud bottom sediments. The results of the field Depositional Analysis (DA) sampling indicated that the eastern portion of the ZSF was covered by a hard rock bottom and or cobble/shell bottom (Evans-Hamilton, Inc., 1987a). The northern portion of the ZSF contained high densities of scallops (i.e., 2-3 scallops/0.1 sq. mi.). It appeared that this ZSF was seasonally highly erosive (winter) and would not be acceptable for further consideration as a nondispersive site.

2.3 Description of Dispersive ZSFs

Four potential dispersive sites were initially proposed based on considerations for marine shellfish and fisheries resources and human use concerns (Fig. II.2-1d-f). The dispersive ZSFs tentatively considered are located in the Strait of Juan de Fuca, Rosario Strait, and southern Strait of Georgia. Following field studies and reviews of existing data alternative

sites within each ZSF were selected. Alternative disposal sites were prioritized within each ZSF after reviewing the natural and human resource concerns, and after minimizing conflicts where possible. One dispersive ZSF (Point Roberts) was ultimately rejected due to human use conflicts. Table II.2-2b gives the disposal site location coordinates for each of the tentative alternative sites within each dispersive ZSF. The following paragraphs describe each ZSF.

2.3.1 Point Roberts--

The northern border of the Point Roberts ZSF was located approximately 5 nautical miles SE of Point Roberts at a depth of 720 feet. The Bellingham Groundfish Trawlers Association proposed an alternative ZSF located approximately 6 nautical miles to the southwest. After coordination with WDF/Marine Fish Division this site was rejected because the site was in a rocky bottom area that is a popular recreational/sport fishing area. The original ZSF was ultimately rejected late in the disposal siting process because it was located in a bottomfish trawling area.

2.3.2 Rosario Strait--

The northern border of the Rosario Strait ZSF is located about 1 nautical mile south of Cypress Island (Fig. II.2-1d). This location was adjusted slightly to the north and east of the original site to move it out of a cable crossing area. The preferred site is located in the center of the ZSF, whereas the alternative site is located approximately 0.5 nautical miles to the east. Both sites are located in about 230 feet of water.

2.3.3 Lopez Island--

The northern border of the ZSF is located about 3 nautical miles south of Lopez Island in water depths of approximately 300 feet. This site was deleted from further consideration due to WDF and USFWS concerns for both pelagic fish and birds.

2.3.4 Port Townsend--

The bathymetry at this site is highly variable. The depth of the site is approximately 420 feet at the center of the ZSF (Fig. II.2-1e). The preferred disposal zone is located along the southwest border of the ZSF at about 361 feet of water. The alternative disposal zone is located along the eastern ZSF border in approximately 360 feet of water.

2.3.5 Port Angeles--

The southern border of the ZSF is located about 4 nautical miles north of Port Angeles (Fig. II.2-1f). The eastern half of the original site was eliminated due to trawl fishery. The preferred disposal zone is at the southern tip of the ZSF in about 435 feet of water. The alternative disposal zone is closer to the center at a depth of 445 feet.

2.4 Literature Review

2.4.1 Bibliography--

Parallel to the preparation of the overlays, an intensive literature search was made to compile the information which was used to construct the maps. Due to the large number of citations, they have not been included in this technical appendix; however, they can be found in the report entitled, "Bibliography and Maps Pertinent to the Selection of Open Water Dredged Disposal Sites in the Greater Puget Sound Region" (Evans-Hamilton, Inc., 1985), which is on file at the Corps Seattle District library. The literature survey resulted in a bibliography of references to existing maps containing information relevant to the selection of ZSFs. The geographic area covered included Puget Sound, the Strait of Juan de Fuca east of Port Angeles, and the Strait of Georgia south of the Canadian border.

2.5 ZSF Field Studies

Though initial overlay mapping identified locations of ZSFs, this mapping and literature review revealed several key information gaps for these areas. In order to define characteristics of potential disposal sites within those ZSFs, PSDDA undertook a series of field studies. The sediment in the candidate nondispersive sites in southern Puget Sound and Bellingham Bay were sampled in order to identify and locate depositional zones. Nondispersive ZSFs were sampled to locate, identify, and quantify biological resources (bottomfish, crabs, shrimp, seaurchins, seacucumbers, etc.) on a seasonal basis. Beam and otter trawl equipment was used. Benthic resources were also quantified in the nondispersive study areas, and bottomfish feeding habitat assessments were made using the Benthic Resources Assessment Technique (BRAT). Resource investigations of a more limited scope were also performed at the four dispersive ZSFs during two seasons.

Data collection activities were focused on those areas where information was lacking. Overlay maps attempted to locate sites in areas where little or no conflict with human, shoreline and shallow water uses and values would

occur. Natural resource data identified on resource maps was generally dated or incomplete and pointed out the need for additional site specific studies. Subsequent field studies focused on two critical issues:

First, what is the depositional/erosional (nondispersive/dispersive) nature of areas within each ZSF? Can acceptable nondispersive sites be identified?

And second, what is the value of the ZSFs to biological resources of concern (i.e., crab, bottomfish and shrimp). The focus was placed on species which would be in direct contact with the dredged material on the sea floor.

(1) Depositional Analysis of the Sediments. The objective of the depositional analysis was to locate areas within the ZSF where sediments tend to deposit rather than erode. Previous work by Word et al. (1984a) indicated that sediments within Puget Sound tend to accumulate where existing sediments meet the following four conditions when compared to sediments at similar depths: (1) small grain size; (2) statistically elevated volatile solids; (3) statistically elevated water content; and (4) statistically elevated biochemical oxygen demand. A total of 251 stations were occupied to collect sediment samples for this technique. Study results were used to identify areas that were most nondispersive within each proposed nondispersive ZSF, and Section II.5 of this Appendix describes the methods and results of this study for each of these ZSFs. Based on results for the Phase I ZSFs it was not considered necessary to survey Phase II ZSFs with side scan sonar and a vertical sediment profile camera.

(2) Current Velocity Studies. Current strengths at each ZSF were determined by a combination of historical and numerical model field data. Based on these data, predicted current velocities were identified and mapped. Results indicate that the Bellingham Bay ZSFs lay in relatively low current velocity areas. Currents are higher in the South Sound nondispersive ZSFs compared to the Phase I areas, due to bathymetry. The South Sound ZSF boundaries were adjusted to encompass the entire impact area of a disposal site located in the ZSF. The disposal site (i.e., impact area) was drawn to follow the naturally confining bathymetric features of the bottom ensuring that the material will remain on site. Material deposited at sites in these ZSFs is not expected to significantly move offsite. All of the North Sound dispersive ZSFs are located in areas where currents are strong and fine sediments are expected to erode to surrounding areas.

TABLE II.2-1 MAPPED OVERLAY EVALUATION/SELECTION CRITERIA/FACTORS FOR PHASE II AREAS

Human Uses:

(1) Political Boundaries
(2) Navigation Lanes
(3) Utility Corridors
(4) Former Dredged Disposal Areas

Marine Fish Resources:

(1) Smelt Spawning
(2) Pacific Herring Spawning
(3) Pacific Herring Holding Area
(4) Ground Fish (Major Resource/Fishery Area)
(5) Aquaculture Sites (Commercial and Public)

Shellfish Resources:

(1) Dungeness Crab
(2) Shrimp
(3) Clams and Oysters
(4) Subtidal Clams
(5) Geoducks (Commercial/Major)

Salmon Resources (Commercial and Sportfishing Areas):

Nesting Seabird Sites:

Marine Mammals:

Bathymetry:

TABLE II.2-2a PSDDA DISPOSAL SITE LOCATION COORDINATES
FOR NON-DISPERSIVE ZSFS
PHASE II
1989

Location	Preferred		Alternate	
	Latitude	Longitude	Latitude	Longitude
Anderson/Ketron Is.	47°N 09.43'	122°W 39.40'		
Devils Head			47°N 09.06'	122°W 45.61'
Bellingham Bay	48°N 42.83'	122°W 33.03'		
Alt 1			48°N 41.83'	122°W 33.60'[1]
Alt 2			48°N 43.82'	122°W 32.50'[2]

TABLE II.2-2b PSDDA DISPOSAL SITE LOCATION COORDINATES
FOR DISPERSIVE ZSFS
PHASE II
1989

Location	Preferred		Alternate	
	Latitude	Longitude	Latitude	Longitude
Rosario Strait	48°N 30.88'	122°W 43.48'	48°N 30.70'	122°W 42.73'
Port Townsend	48°N 13.62'	122°W 58.95'	48°N 15.28'	122°W 55.60'
Port Angeles	48°N 11.68'	123°W 24.86'	48°N 13.20'	123°W 25.65'

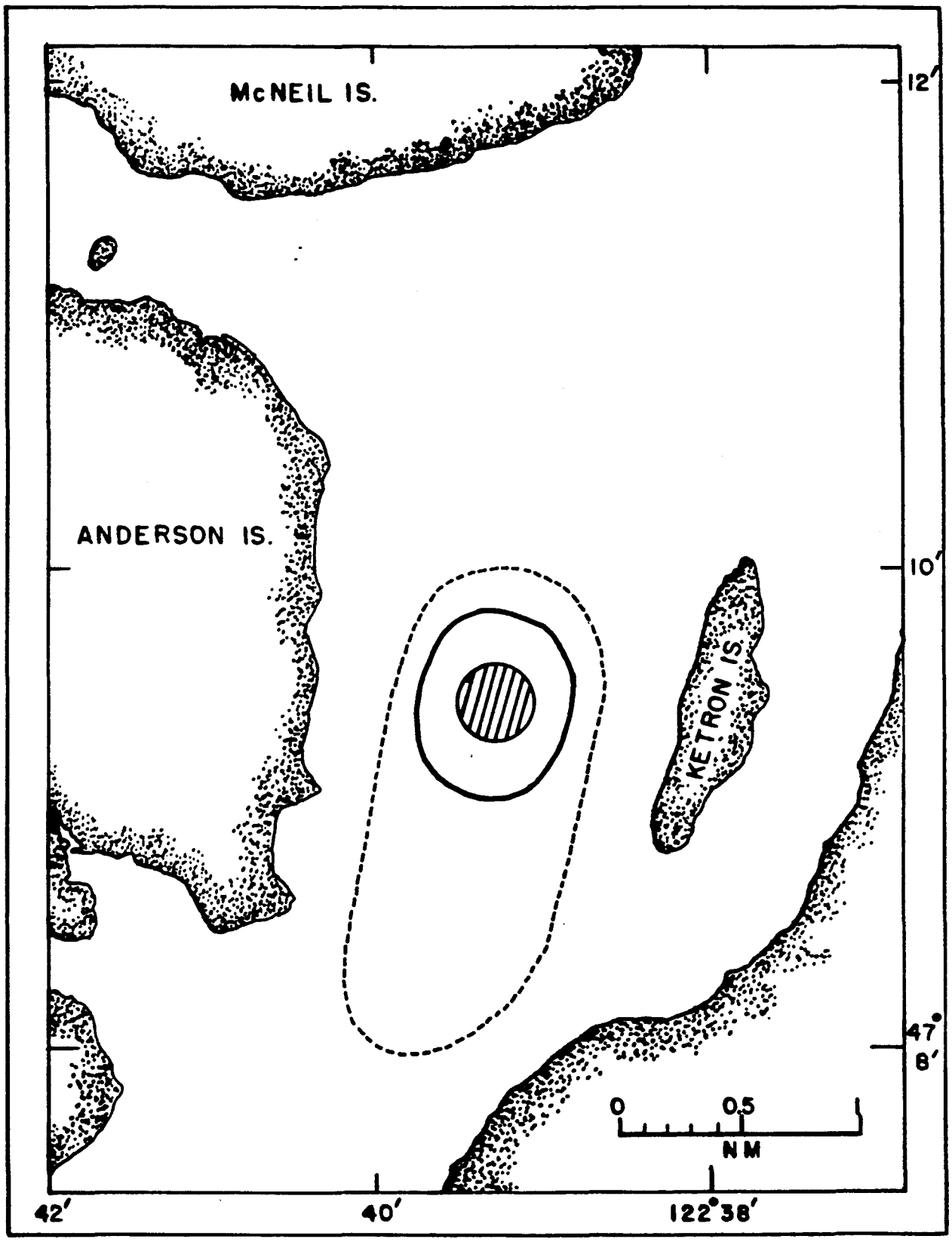


Figure II.2-1a The Anderson/Ketron Island Zone of Siting Feasibility (ZSF; dashed line) depicting the disposal site boundary (heavy line) and disposal zone (hatched area). This is the preferred ZSF for south Puget Sound.

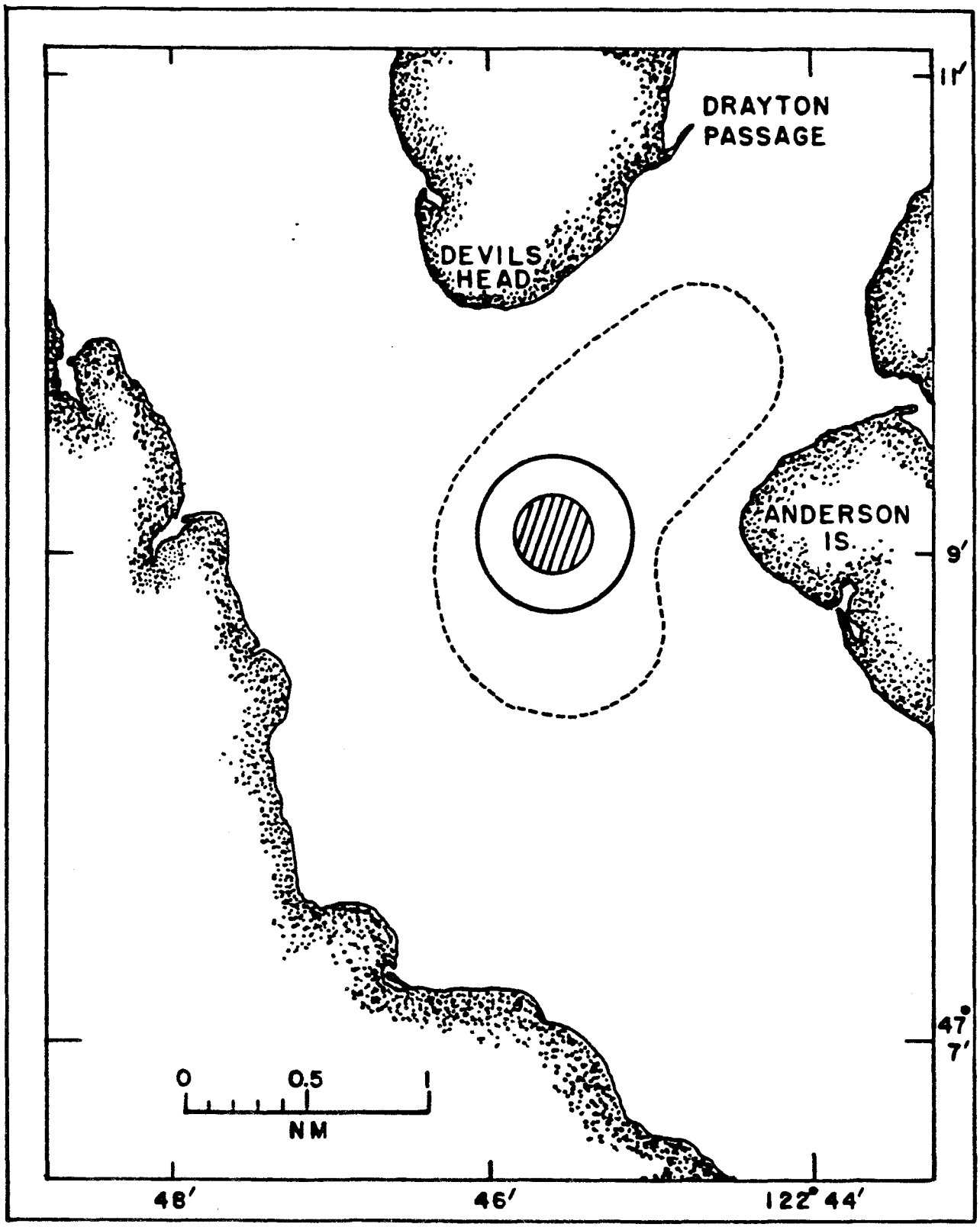


Figure II.2-1b The Anderson Island/Devils Head Zone of Siting Feasibility (ZSF; dashed line) depicting the disposal site boundary (heavy line) and disposal zone (hatched area). This is the alternative ZSF for south Puget Sound.

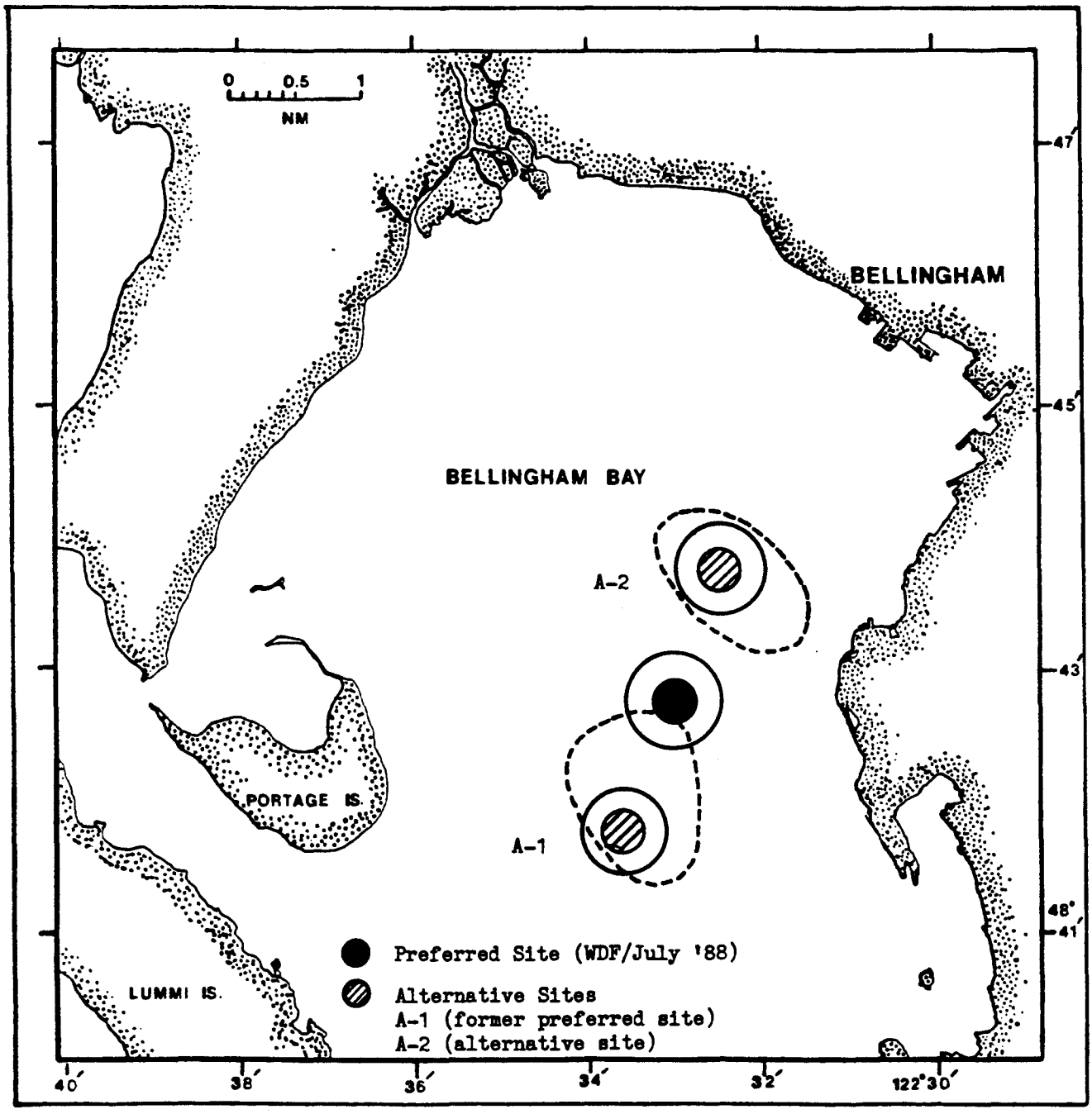


Figure II.2-1c Zones of Siting Feasibility (ZSF; dashed lines) in Bellingham Bay depicting the tentative disposal site boundaries and disposal zones (900 ft radius).

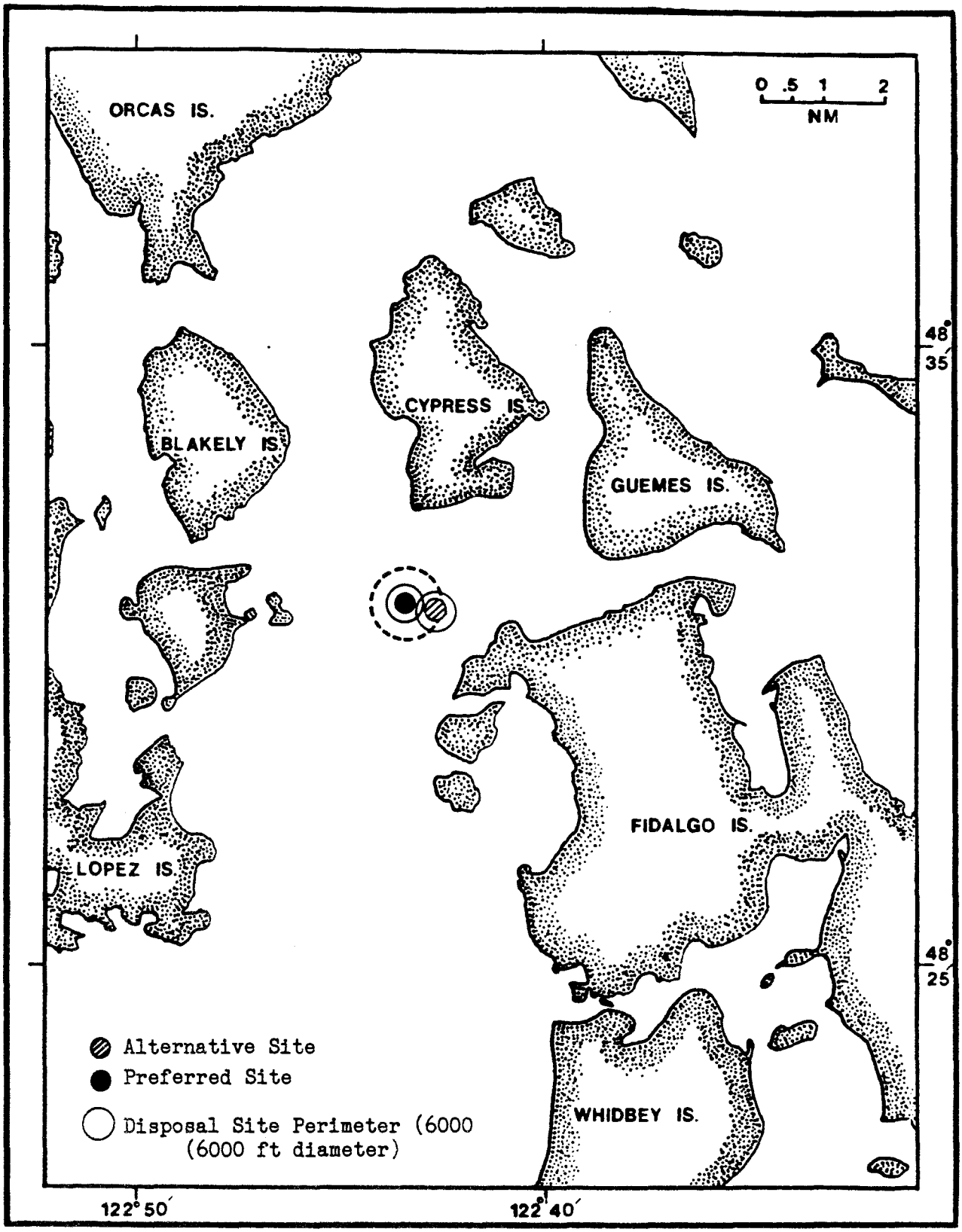


Figure II.2-1d Location of the dispersive Zone of Siting Feasibility (ZSF; dashed line) in Rosario Strait depicting the preferred and alternative disposal site boundaries and disposal zones (1500 ft radius).

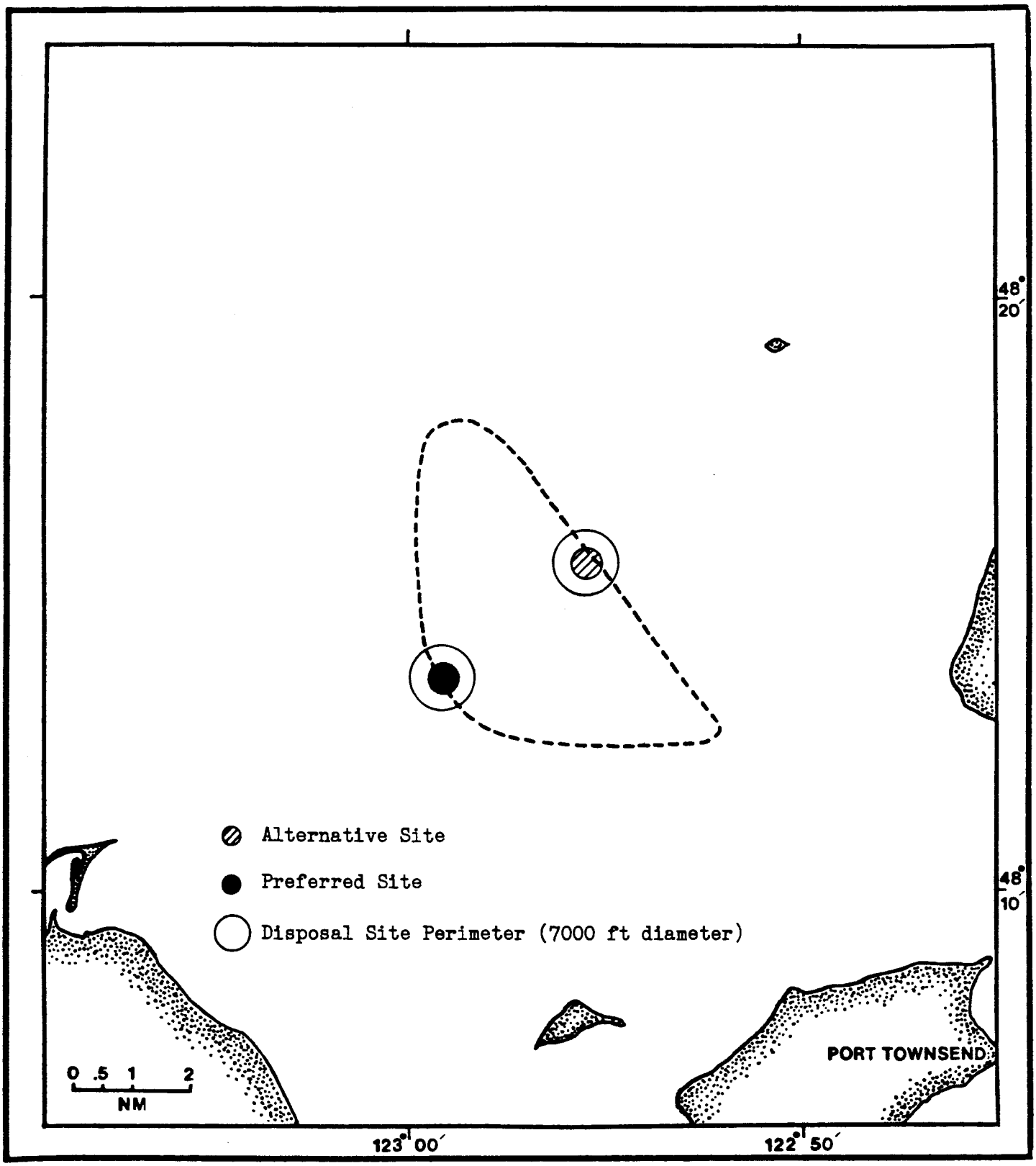


Figure II.2-1e Location of the dispersive Zone of Siting Feasibility (ZSF; dashed line) near Port Townsend depicting the preferred and alternative disposal site boundaries and disposal zones (1500 ft radius).

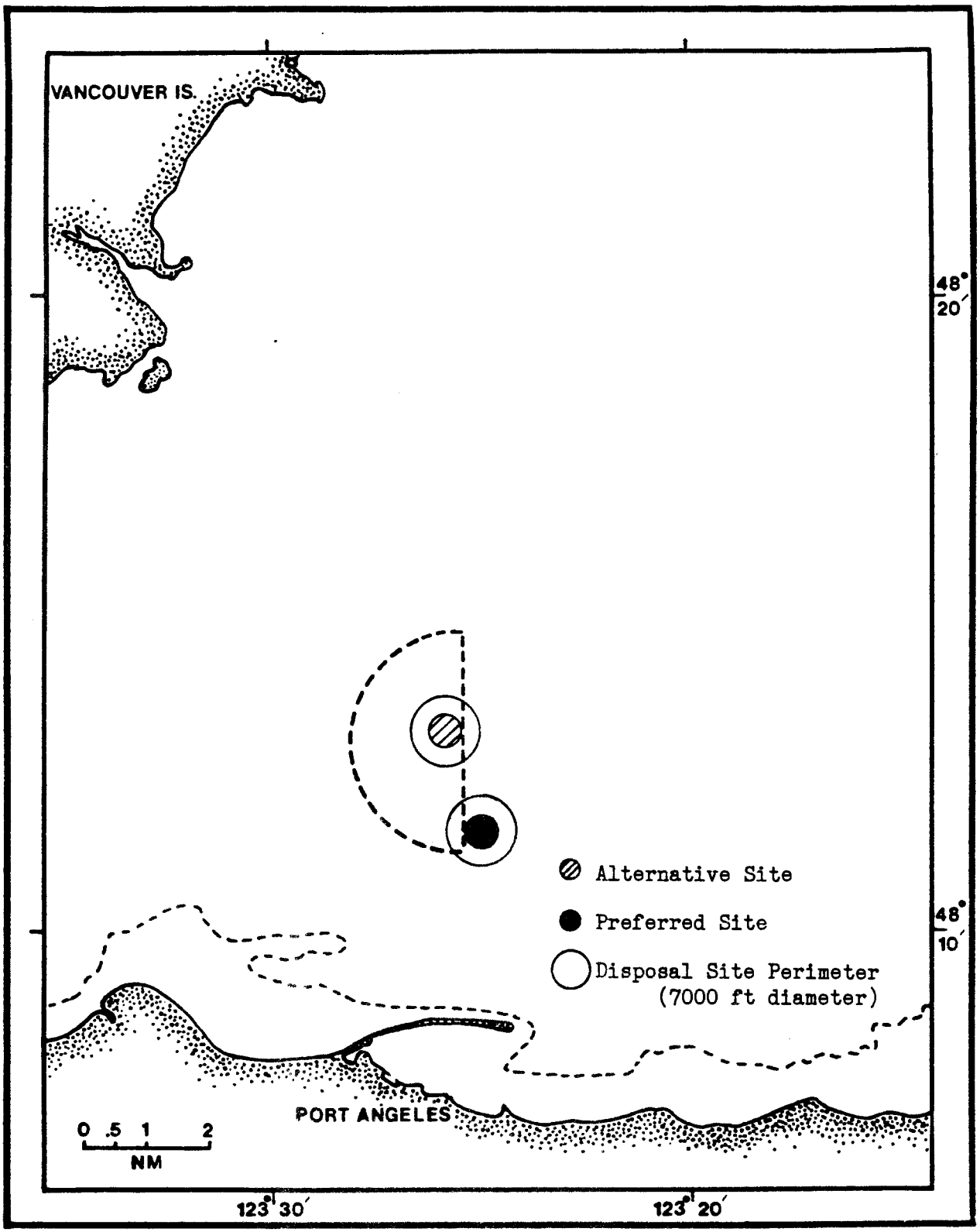


Figure II.2-1f Location of the dispersive Zone of Siting Feasibility (ZSF; dashed semicircle) near Port Angeles depicting the preferred and alternative disposal site boundaries and disposal zones (1500 ft radius).

3. PRELIMINARY DISPOSAL SITE IDENTIFICATION

Using information obtained via ZSF identification and field studies, preliminary disposal site locations within the ZSFs were identified. Two factors were emphasized in locating the nondispersive disposal sites: (1) a low abundance of commercially important animals (i.e., small numbers of crab, shrimp, and bottomfish and other natural resources); and (2) the presence of a relatively nondispersive area (i.e., sediment and current characteristics indicating that sediments would stay at the disposal site).

The lack of nondispersive disposal areas proximal to dredging centers in the Phase II area and issues such as inter-regional transfer (i.e., North Sound to Port Gardner) prompted the DSWG to identify dispersive ZSFs for this region. Two factors were emphasized in locating the dispersive disposal sites: (1) considerations for marine shellfish and fisheries resources and other natural resource and human use concerns (i.e., pelagic bird communities and trawling areas); and (2) the presence of a dispersive area (i.e., sediment and current characteristics indicating that disposed sediments would eventually move off the disposal site).

3.1 Selection Process

To evaluate the prime criteria a selection process was undertaken in the three steps outlined below.

(1) Size of the Disposal Site. The size of the disposal site was related to the bottom physical impact that would result from repeated dumps. An 1,800-foot diameter disposal zone was estimated for a nondispersive site and a 3,000-foot diameter disposal zone for a dispersive site. The impact area was evaluated using a numerical model and field data. Using data pertinent to PSDDA, the Corps Waterways Experiment Station (WES) in Vicksburg, Mississippi, performed a simulation study depicting dredged material disposal in an unconfined open water environment. The model simulated the passage of dredged material through the water column for varying water depths, current speeds, and sediment types to predict the behavior of material during future disposal operations. The simulated conditions were representative of those in Puget Sound - sediment types that are routinely dredged and disposed of were simulated; depths ranged from 100-800 feet; and tidal currents ranged from zero to two knots (3.38 feet per second). See Figures II.4-1a,b for typical site parameters.

(2) Nondispersive versus Dispersive Probability. The likelihood that dredged material would or would not remain within the disposal site was evaluated using a number of approaches.

First, the maximum currents within each ZSF were mapped using historical data. These results were compared with speeds that were observed during special field studies in Dana Passage (Sternberg and

Collias, 1973) to mobilize and transport sediment. At speeds above approximately 0.5-knot dredged material was observed to be resuspended and transported.

Second, four sediment characteristics within the ZSFs were mapped (grain size, sediment biochemical oxygen demand, percent moisture, and percent volatile solids) using a technique called "depositional analysis" (Evans-Hamilton, Inc., 1987a). An area was classified as nondispersive or "depositional" in character if its sediments had the following characteristics: small grain size; high oxygen demand; high percent water; and high volatile solids.

Thirdly, the fate of resuspended materials was evaluated within the ZSFs to avoid impacts downstream on sensitive habitats.

(3) Biological Resources. Specific studies were conducted for the nondispersive sites including trawls documenting the seasonal abundance of critical resources such as crab, shrimp, bottomfish, etc. Also, boxcore sampling was accomplished to quantify and assess the benthic habitat values and estimate bottomfish foraging habitat potential using the Benthic Resources Assessment Technique (BRAT). Use was made of existing data and limited trawling studies during spring and fall 1987 at each of the dispersive sites to assess each of the disposal zones relative to natural resources.

Maps developed from these determinations were overlayed to identify disposal sites that best satisfied the desired site conditions.

3.2 Preliminary Sites

Preliminary sites were identified in all of the ZSFs after all field studies had been completed (c.f., Figs. II.2-1a-f). One preferred site was ultimately selected for each of the two areas in Bellingham and South Sound, with alternative sites also being identified for consideration. Detailed descriptions of the site selection process are described later in this Appendix for each site.

3.3 ZSF Specific Field Studies

Additional studies were conducted within the preliminary ZSFs to define the size of the bottom impact area and to provide information to evaluate site selection locations relative to commercially important invertebrate and vertebrate resources, benthic resources, and benthic food web values within the ZSFs.

(1) Numerical Dump Model. To assist in establishing the size and location of the disposal sites, a numerical model, originally developed for EPA, and later refined by the Corps' Waterways Experiment Station, was used to estimate the depositional pattern caused by the disposal of a

single bargeload of dredged material. The model was run for two types of dredged material at several depths and current speeds (Trawle and Johnson 1986a). Results from this model were combined with an estimate of the surface disposal zone diameter to provide an initial assessment of the sediment deposition pattern that might be caused by repeated disposals within a site. The model results indicate that the impact of any one barge load (1,500 c.y.) of material is confined to a relatively small area. In 400 feet of water the descending cloud is approximately 250 feet in diameter when it hits the bottom, occurring 30 seconds after disposal is initiated. The collapsing cloud then spreads out in all directions. Ten minutes later essentially all of the material is deposited on the bottom within a 1,000-foot radius of the drop point. The thickness of the deposited material varies from about 0.3 inches at the center of the disposal mound to 0.04 inches at the edge. These results assume a worst-case spread of a completely slurried load. Dredged material with cohesive clumps would not spread as far or as thinly. The final size, orientation, and configuration of the disposal sites are not significantly affected by the materials deposited from any single barge disposal, but are governed by the total amount of material being deposited, sediment bulking factors, stable side slope characteristics of the sediments, existing bottom topography and consolidation characteristics of both the bed and dredged material. These model studies were used to define the bottom impact area, described later, for each of the sites.

(2) Crab, Shrimp, and Bottomfish Trawling Studies. The distribution and relative abundance of bottomfish resources and commercially important marine invertebrate resources such as Dungeness crab, shrimp, sea urchin, and sea cucumbers were mapped in and around all nondispersive ZSFs from data obtained during seasonal (February, April-May, July, October) sampling cruises. Dispersive ZSFs were sampled during two seasons (April and October). The objective was to evaluate the relative abundance and distributions of the ZSFs in general to the less mobile marine invertebrate resources and bottomfish resources. Site selection within the ZSFs attempted to avoid commercially important natural resources as much as possible.

Results indicated disposal sites can be located within the ZSF yet avoid significant conflict with each of these resources.

(3) Food Web Study. Benthic resources within and adjacent to each of the preliminary nondispersive disposal sites under consideration were evaluated in terms of their food support potential to bottomfish resources. A procedure called the Benthic Resources Assessment Technique (BRAT) developed by the U.S. Army Waterways Experiment Station (Lunz and Kendall, 1982), was used to quantify the food value of bottom-dwelling organisms within soft-bottom habitats to bottom-feeding fishes. The BRAT estimates which organisms at a given site are both vulnerable and available to selected fish species.

Different species of bottom-feeding fishes can detect, capture, and ingest only a portion of the available benthos. They will consume different prey at different locations and seasons, reflecting the availability of vulnerable prey. In the BRAT, vulnerability is taken to be a function of the size of the benthic food item, and availability of the prey's location below the sediment-water interface. Both factors are estimated from an examination of the diets of target predatory fish, and confirmed by a parallel examination of vulnerable and available prey in the local benthic environment. Food web linkages between benthic organisms, key fish and shellfish, and ultimately humans via commercial and recreational fisheries offers resource managers a way of assigning comparative resource values to alternative disposal sites. Section II.9 of this Appendix contains a complete description of the methods and results of this procedure as applied to the nondispersive ZSFs in south Puget Sound, near the Nisqually Delta and within Bellingham Bay in north Puget Sound.

4. BEGINNING THE SEARCH FOR DISPOSAL ZONES WITHIN THE ZSFs

To assist in establishing the appropriate size and location of a dredged material disposal site within a ZSF, the numerical dredged material disposal model developed by the Corps Waterways Experiment Station (Trawle and Johnson, 1986a) was used to estimate the depositional pattern caused by the disposal of a single barge load of dredged material of varying composition at selected depths and current speeds. These estimates, combined with an estimate of the disposal (drop) zone diameter, provided an initial assessment of the sediment pattern that might be caused by repeated disposal operations within a nondispersive ZSF and the pattern from a single disposal at a dispersive ZSF. The final size, orientation, and configuration of the disposal site were based on the results of the disposal model with those of depositional analysis, current characteristics, and bottom topography. The initial estimates of disposal zone size were also used to determine the regional sampling plans for mapping biological resources.

4.1 Characteristics of Dredged Material

The numerical dredged material disposal model requires as input the characteristics of the material to be dredged. The available Corps records indicate that little or no samples have been characterized pertinent to Phase II dredging areas. As a guide to the characteristics of possible future dredging activities, sediment records from Phase I area past dredging work were reviewed.

Table II.4-1 lists the percentages of nine sediment types according to the Wentworth size classification. Shown are both the range of the percentages as well as the mean percentage for the samples taken in each area. The percentage ranges indicate great variability. Consider, for instance, that the percentage of medium sand varies between 4-63.5% in Everett Harbor, 2-44.6% in the Duwamish Waterway, and 1-30.5% in Hylebos Waterway. The ranges for medium silt and clay percentages vary between 0-28% in Everett Harbor, 3.1-76.5% in Duwamish Waterway, and 19.0-73.0% in Hylebos Waterway. If these values are indicative of other dredged material it appears that future disposal operations will deal with a wide range of sediment types.

4.2 Numerical Dredged Material Disposal Model

4.2.1 Objective--

The objective of the dredged material disposal modeling effort was to predict the short term fate of material which may be dredged and disposed of in the Phase I and II areas. The potential open water sites within the Phase II ZSFs are located in water depths ranging from 95 to 442 feet. A preliminary scan of the data base showed that tidal currents range from still water to speeds as great as two knots (3.4 feet per second) in the ZSFs.

4.2.2 Approach--

The numerical dredged material disposal model known as DIFID (Disposal from an Instantaneous Dump; Trawle and Johnson, 1986) was used to simulate the barge disposal of dredged material. The model predicted the pattern of disposed material on the bottom for each of a number of test conditions. The input data required for DIFID falls into four groups: (1) a description of the ambient environment at the disposal site; (2) characterization of the dredged material; (3) data describing the disposal operation; and (4) model coefficients.

The test conditions included water depth, ambient current, material dumped, and barge bulk density. The conditions used in each of the tests are shown in Table II.4-2. The remainder of the required model input for each series is shown in Table II.4-3. See Trawle and Johnson (1986) for a description of the model coefficients used in this study. The model grid used for all tests represented an area within a square boundary measuring 12,000 by 12,000 feet. Each grid cell represented an area of 400 by 400 feet. To be representative of a typical disposal operation in Puget Sound, the volume used in all simulations was 1,500 cubic yards.

The dumping of two types of material was simulated by the model in these tests. These were chosen to represent the most dispersive materials dumped into Puget Sound. The primary material tested consisted of 25 percent fine sand and 75 percent clay/silt. The clay/silt fraction was modeled both as cohesive and noncohesive material. The second material consisted of 50 percent fine sand and 50 percent medium sand with no clay/silt. For a description of the model and test results see Trawle and Johnson (1986a) and DSSTA Phase I (DSSTA, 1988).

4.3 Preliminary Disposal Site Dimensions

Only the disposal zones of former disposal sites are shown on various NOAA charts (circular areas measuring 1800 feet in diameter). This area circumscribes the DNR prescribed "disposal zone" for a disposal barge, or the area within which the dredged material must be released at the water surface. To evaluate the effects of dredged material on bottom dwelling animals, it was necessary to define a larger impact area within which the material would be deposited, based on a series of dumps, as shown by the results from the numerical dredged material disposal model. To plan the PSDDA field studies, preliminary dimensions were chosen, later modified as a result of the field studies. The final disposal site boundaries are described later in this technical appendix.

A typical PSDDA disposal site consists of three elements (Fig. II.4-1). The target area A and disposal zone B lie within long-term bottom impact area C, defined as the disposal site. The disposal barges should open their hoppers within the target area, but allowing for some error of maneuverability, within an area no larger than the disposal zone.

For a nondispersive site the disposal site circumscribes the horizontal spread over a period of repeated dumps of the dredged material after it is released at different locations within the disposal zone during both flood and ebb tides (assuming a current speed of 0.5 knot or 0.85 feet per second at the time of disposal). The dimensions of the dump site were chosen using results corresponding to typical water depths and currents envisioned for the disposal sites. Based on a model test for 400 feet water depth and a 0.5 knot current (0.85 feet per second) test results indicated a horizontal spread of approximately 1000 feet downstream from the dump spot and 600 feet to either side. As a precaution 600 feet and 1000 feet were added to the short and long (tidal current direction) axes dimensions, respectively, to arrive at the size (3,000 by 3,800 feet) of the rectangle shown in Figure II.4-2 for a typical site located on a flat bottom with single direction (reversible) tidal currents.

For a dispersive site the disposal site circumscribes the horizontal spread of a single dump of dredged material released within the disposal zone. The distance required for a dump is 3,000 feet assuming an average tow speed of 3 knots (5.07 feet per second) during a dump and a time of 10 minutes required for a dump. Based on a water depth of 400 feet and an average current of 1 knot (1.69 feet per second) results indicate a horizontal spread of approximately 2,000 feet downstream from the dump spot and 1,000 feet to either side. The final disposal site rectangle has a size of 5,000 by 7,000 feet as shown in Figure II.4-3. The dimensions of the disposal site vary with the site bathymetry and water depth. Figure II.4-4 shows the site dimensions for the three Phase II preferred dispersive site.

TABLE II.4-1 PERCENTAGES OF SEDIMENT TYPES IN SEDIMENTS FROM EVERETT HARBOR, DUWAMISH WATERWAY, AND HYLEBOS WATERWAY.

Sediment Type	(1) Everett Harbor (5 samples) Range	(mean)	(2) Duwamish Waterway (34 samples) Range	(mean)	(3) Hylebos Waterway (6 samples) Range	(mean)
Gravel						
Sand	0-11.0	(3.3)	0.2- 8.0	(3.2)	0- 3.0	(0.5)
Very coarse	0-16.0	(7.5)	0.3- 4.1	(1.9)	0- 3.0	(0.8)
Coarse	1.0-38.0	(25.2)	0.3-14.0	(4.9)	0-11.0	(3.6)
Medium	4.0-63.5	(37.2)	2.0-44.6	(19.7)	1.0-30.5	(10.8)
Fine	6.0-21.0	(11.1)	4.1-35.9	(16.6)	4.0-34.0	(16.4)
Very fine	0.5-32.5	(7.4)	4.0-22.1	(12.2)	6.5-22.0	(13.5)
Coarse silt	0-13.5	(2.7)	1.5-15.6	(4.9)	5.0-14.0	(11.2)
Medium silt-clay	0-28.0	(5.6)	3.1-76.5	(37.9)	19.0-73.0	(43.3)

Sources: (1) COE Seattle District records designated NPDEN-GS-L, 74-S-590.

(2) Chan et al., 1986.

(3) COE Seattle District records designated NPDEN-GS-L, 78-S-4.

TABLE II.4-2 CONDITIONS USED IN THE 21 TEST RUNS OF THE NUMERICAL DREDEGED MATERIAL DISPOSAL MODEL.

Test No.	Water Depth (feet)	Current speed (fps)	Time (min)	Material Fine Sand %	Type Clay/Silt %	Cohesive Y/N	Deposited Fine Sand %	Clay/Silt %
1	100	0.10	60	25	75	Y	100	100
2	100	1.69	60	25	75	Y	100	100
20	100	1.69	60	100	0	N	100	0
3	100	3.38	60	25	75	Y	100	100
4	200	0.10	60	25	75	Y	100	100
5	200	0.85	60	25	75	Y	100	100
6	200	1.69	60	25	75	Y	100	100
7	400	0.10	60	25	75	Y	100	100
16	400	0.10	60	25	75	N	100	53
8	400	0.85	60	25	75	Y	100	100
17	400	0.85	60	25	75	N	100	18
9	400	1.69	60	25	75	Y	100	100
18	400	1.69	60	25	75	N	100	14
19	400	1.69	60	25	75	N	100	15
10	600	0.10	60	25	75	Y	100	100
11	600	0.85	60	25	75	Y	100	100
12	600	1.69	60	25	75	Y	100	100
13	800	0.10	60	25	75	Y	100	100
14	800	1.69	60	25	75	Y	93	67
21	800	1.69	60	100	0	N	100	0
15	800	3.38	30	25	75	Y	66	55

TABLE II.4-3. ADDITIONAL MODEL INPUT INFORMATION USED IN THE 21 TEST RUNS OF THE NUMERICAL DREDGED DISPOSAL MODEL.

	Tests 1-15	Tests 16-18	Test 19	Tests 20-21
Medium sand concentration by volume (cu ft/cu ft)	--	--	--	0.15
Fine sand concentration by volume (cu ft/cu ft)	0.05	0.05	0.07	0.15
Clay-silt concentration by volume (cu ft/cu ft)	0.16	0.16	0.22	--
Sand density (gm/cc)	2.60	2.60	2.60	2.60
Silt-clay density (gm/cc)	2.60	2.60	2.60	--
Fluid density (gm/cc)	1.018	1.018	1.018	1.018
Medium sand fall velocity (fps)	--	--	--	0.03
Fine sand fall velocity (fps)	0.02	0.02	0.02	0.02
Clay-silt fall velocity (fps)	0.0013	0.0013	0.0013	--
Dredged material bulk density (gm/cc)	1.35	1.35	1.48	1.48
Aggregate voids ratio	4.50	4.50	4.50	4.50
Cohesive Aggregate Option for clay/silt fraction	On	Off	Off	Not Applicable

PRELIMINARY DISPOSAL SITE DIMENSIONS

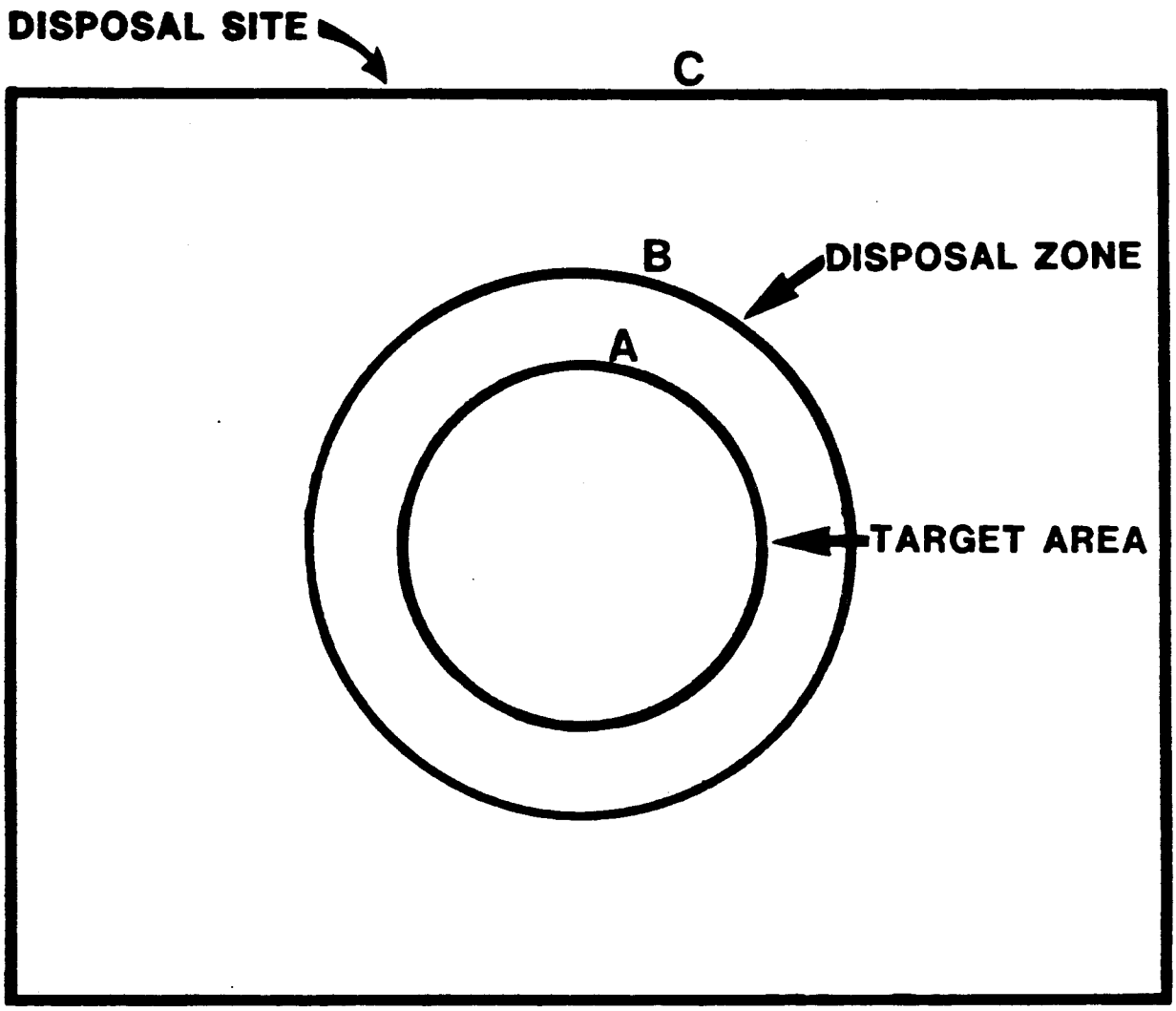
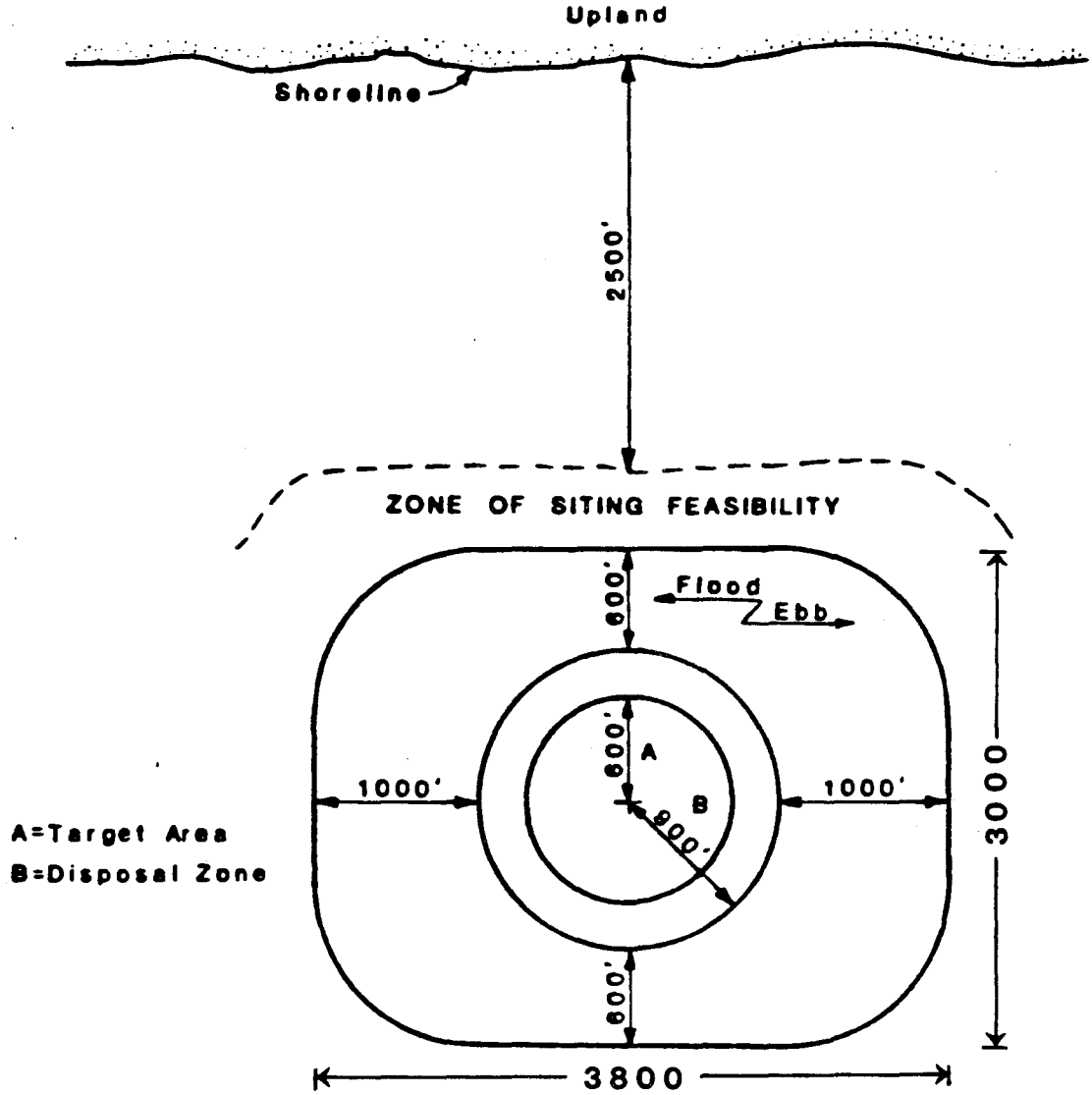
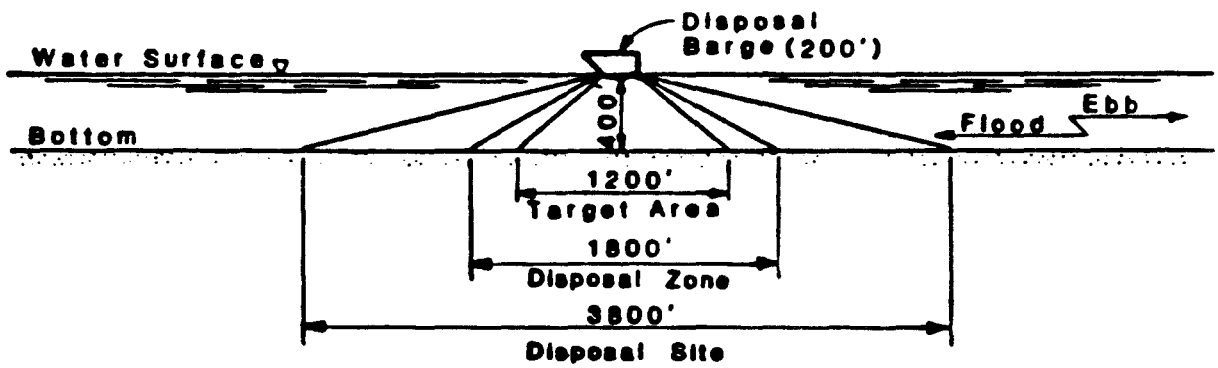


Figure II.4-1 Preliminary PSDDA disposal site (Source: EHI).



PLAN VIEW



ELEVATION VIEW

Figure II.4-2 Typical disposal site dimensions for a nondispersive area (Source: Corps).

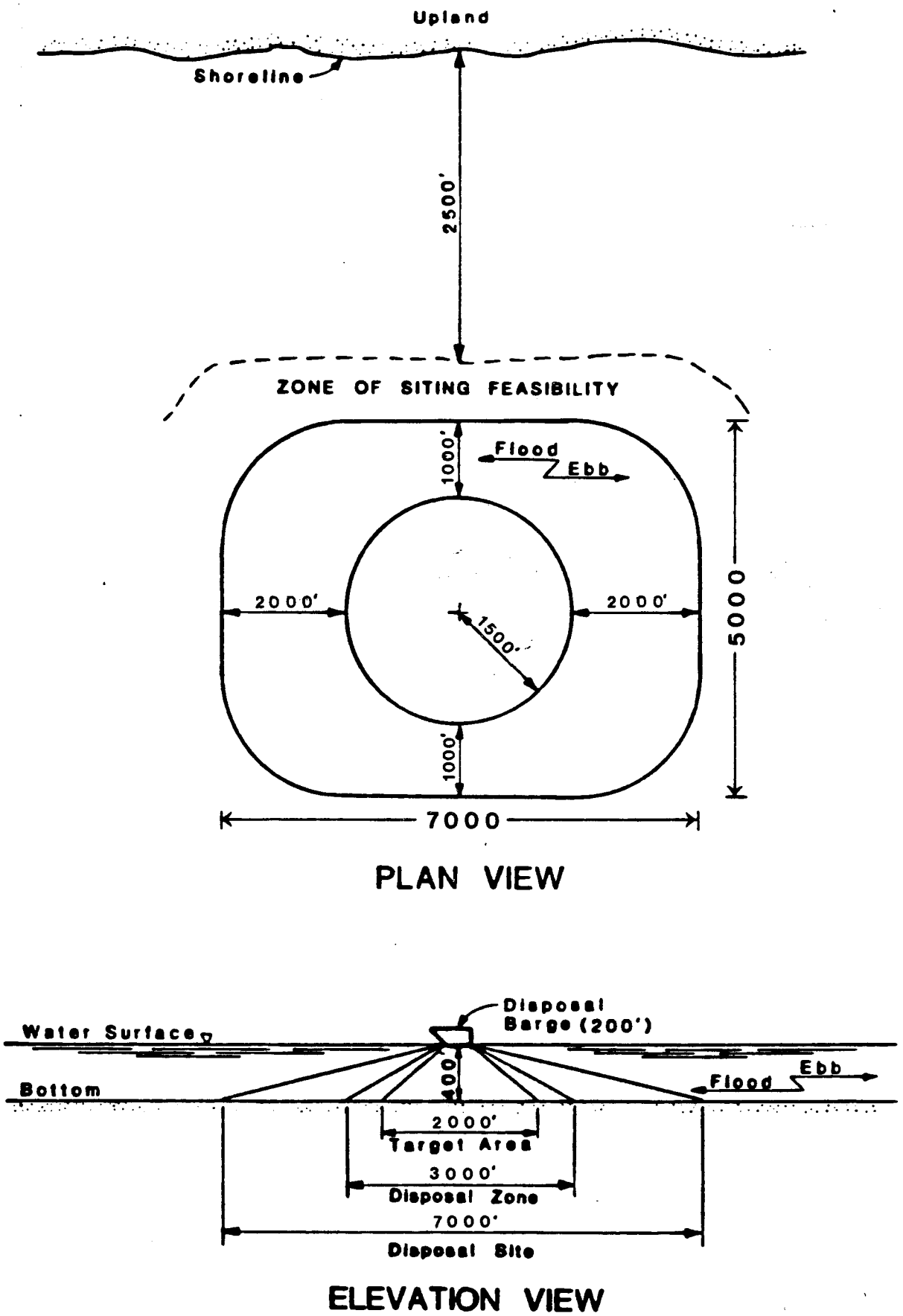


Figure II.4-3 Typical disposal site dimensions for a dispersive area (Source: Corps).

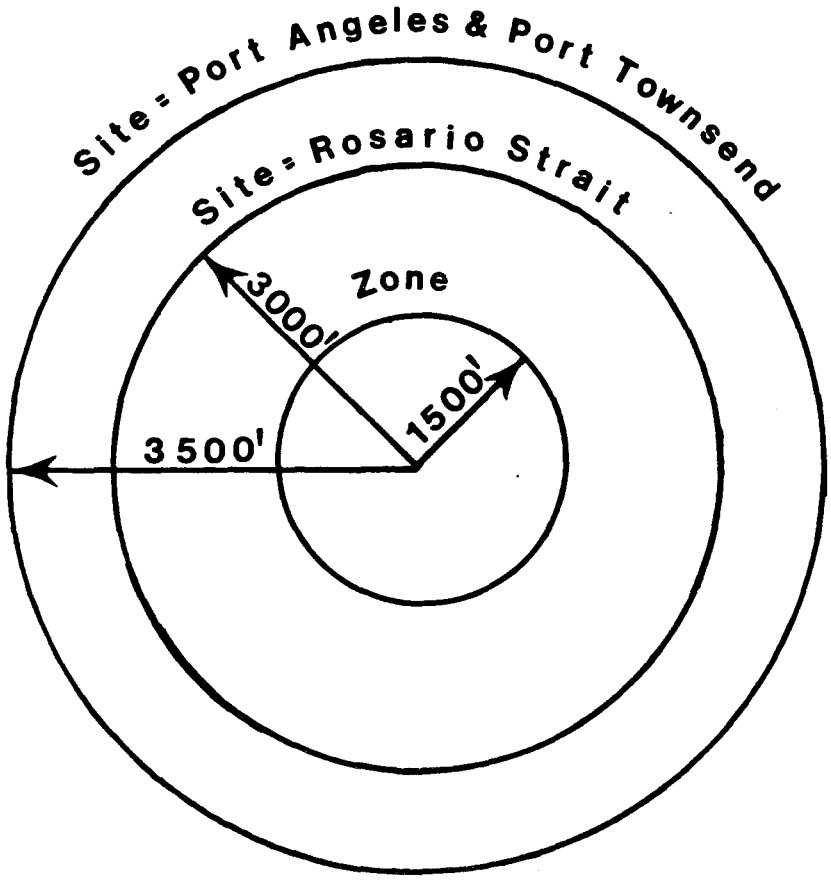


Figure II.4-4 Disposal site dimensions for a dispersive site (Source: Corps).

5. DEPOSITIONAL ANALYSIS/SEDIMENT CHARACTERIZATION IN NONDISPERSIVE ZSFS

5.1 Objective

The objective was to locate areas within the nondispersive ZSFs where sediments tend to deposit rather than erode, and areas that were large enough to encompass preliminary disposal sites. These determinations were made from maps and statistical evaluations of sediment characteristics.

5.2 Background

Previous work by Word et al. (1984a) indicated that sediments in Puget Sound tend to accumulate where existing sediments meet four criteria when compared to sediments at similar depths: 1) small grain size; 2) statistically elevated volatile solids; 3) statistically elevated biochemical oxygen demand; and 4) statistically elevated water content. During PSDDA field studies, measurements were made in the ZSFs to evaluate these criteria.

5.3 Depositional Analysis Technique

The assessment of depositional potential was determined from characteristics of the sediments in the ZSFs. The analysis presented below was adapted from Evans-Hamilton, Inc. (1987a).

The depositional analysis was conducted within the five proposed ZSFs at stations selected along transect lines at specific depth intervals. The ZSFs were sampled with 251 stations as follows: 1) Sinclair/Lummi Island ZSF, 59 stations on 22, 25, and 26 September 1986; 2) Bellingham Bay, 40 stations on 15-16 October 1986; 3) Devils Head ZSF, 41 stations; 4) Anderson/Ketron Island ZSF, 66 stations; and 5) McNeil Island ZSF, 42 stations. Sampling in the South Sound occurred from 20-25 October 1986.

Subtidal sediment samples were collected in a consistent, repeatable manner with a 0.1 square meter modified Van Veen grab sampling device. Upon collection of each sample, the following physical characteristics of the sediment were described and recorded: sediment texture and color; strength and type of odors; sampler penetration depth; degree of leakage and sediment surface disturbance; and obvious abnormalities, e.g., wood debris and biological structures. Samples which showed excessive disturbance of the sediment surface were rejected. In addition, sediment samples were rejected if they did not meet certain minimum penetration depths. Samples were taken from the upper two centimeters of the sediments.

Sediments larger than 62 microns were air dried and analyzed by dry sieving through a series of graded sieves using a Braun mechanical shaker. Sediments finer than 62 microns were analyzed by wet pipetting techniques.

Sediments were then classified into the following size categories: cobble (156-64 millimeters), gravel (64-2 millimeters), coarse sand (2-0.5 millimeters), fine sand (0.5-0.062 millimeters), silt (0.062-0.004 millimeters), and clay (less than 0.004 millimeters). Percent volatile solids (% VS) were determined by combustion at 550°C, once the samples were completely thawed and homogenized. The 5-day biochemical oxygen demand (BOD_5; milligrams of oxygen used per kilogram of sediment, dry weight) was determined following procedures in Standard Methods for the Examination of Water and Wastewater (1985) and in the Puget Sound Estuary Program (PSEP) protocols manual (Tetra Tech, Inc., 1986) with some modifications (see Evans-Hamilton, Inc., 1987a). The percent water was determined by oven drying a weighed aliquot of homogenized sediment, and weighed again for computation of percent water.

A statistical method was employed to determine if individual samples indicated a station to be more depositional in nature than other stations at a similar depth. The mean, standard deviation, 95% confidence interval (95% CI), and 1.96 standard normal deviate (1.96 SND) were calculated for each sediment parameter for each depth contour using data from all 251 stations as described by Word et al. (1984a,b). Values falling beyond the 1.96 SND were considered outliers. They were temporarily removed from the data, and the computations performed again. Removal of the outliers decreased the variance and produced more realistic average values for the data. Once the final mean, 95% CI and 1.96 SND were obtained for each depth contour, the observed values (including outliers) were compared to the values at each depth.

The data from each region were examined to determine which areas exceeded the upper bounds for % VS, BOD_5, and water content. A range of +1.96 standard normal deviate was chosen for the upper bound in addition to the 95% confidence interval to identify those stations which departed substantially from mean values.

A station was considered depositional if the percent volatile solids, BOD_5, or percent water exceeded the 95% confidence limit for the depth contour on which the station was located. In addition, the sediment grain size must have a mean size of 7 (fine silt), 8 (very fine silt), or 9 (clay).

The maps prepared from these conventional techniques were derived from the upper two centimeters of sediment. As sediments deposit naturally at the rate of 0.5-2 centimeters per year (Lavelle et al., 1986), the depth sampled by conventional methods represents approximately two years of accumulated sediment. DSWG relied on conventional sediment chemistry to locate depositional sites because it represented a longer period of sediment accumulation than did the REMOTS data as was shown in the Phase I Disposal Site Selection Technical Appendix.

The grain size numbers contoured in the following maps show the boundaries of the arbitrary numbers which represent the sediment types shown in the legend of each grain size map (Evans-Hamilton, Inc., 1987a). These numbers are not related to phi sizes in any way.

5.4 Distribution in the ZSFs

5.4.1 McNeil Island ZSF--

The field data for the McNeil Island ZSF in south Puget Sound showed it to be unsuitable for use as a nondispersive site for the dredged material. A number of stations contained silty sediments but these sediments contained a large component of sand. The majority of the stations in the central portion of the ZSF consisted of coarse sand with some gravel. For this reason the entire ZSF was removed from consideration.

5.4.2. Anderson/Ketron Island ZSF 2--

The percent volatile solids (% VS) ranged from less than 1% to 4%. The greatest amount of organic material was found at the base of the slopes between the Anderson and Ketron Islands (Fig. II.5-1). The values in the ZSF range from 2% to 4% with the higher values found in the central portion of the ZSF. Elevations in the amount of organic material past the 95% CI occurs at one station within the ZSF and at two additional stations; one along the shore of Anderson Island and the other south of Ketron Island near the mainland.

Low BOD_5 values (< 500 mg/kg dry weight) occur at relatively shallow depths along the margin of the two islands (Fig. II.5-2). Low values also occur at the northern and southern margins of the ZSF. Values of 750 mg/kg dry weight were found at the base of the slopes from both islands and encompass the entire ZSF. The 1000 mg/kg contour abuts the western edge of the ZSF and extends to the north and south for a distance of about one nautical mile. Elevations in BOD_5 beyond the 95% CI are found throughout most of the ZSF and concentrations beyond the 1.96 SND were found along the western edge of the study area and ZSF within the 1000 mg/kg contour.

Trends in percent water are relatively similar to those seen for BOD_5 and % VS. Values range from less than 30% to over 50% water. The 5 sediments with greater than 40% water content occur at the base of the slopes between the two islands and encompass much of the ZSF (Fig. II.5-3). Elevations in percent water beyond the 95% CI occur at four stations in the center of the ZSF and at two stations along the shorelines surrounding the ZSF.

The median grain size at the extreme northern and southern parts of the study area was predominantly medium to very fine sand with percentages of clay ranging from 4% to 8% (Figs. II.5-4 and II.5-5, respectively). The sediment along the margins of Anderson and Ketron Islands consists of fine sand with 6% to 8% clay. Sediments in the central portion of the ZSF were predominantly coarse silt with percentages of clay ranging from 10% to 12%.

Areas containing the higher organic content and smaller grain sizes overlay much of the ZSF. The highest concentrations and elevations of BOD_5 and percent water occur within the ZSF. Elevations of % VS beyond the 95% CI occurs at one station in the central portion of the ZSF at the same station where elevations of BOD_5 and percent water occur. This portion of the ZSF contains the finest sediment and the greatest percentage of clay. This combination is indicative of a low energy area where sediments are being deposited naturally. The suitability of this site for the disposal of dredged material appears to be very good, as long as the dredged material's erodability characteristics are similar to those of the existing bottom sediment. The area that appears to be the most depositional is situated between Anderson Island and southern end of Ketron Island in the center of the basin.

5.4.3 Anderson Island/Devils Head ZSF 3--

Both BOD_5 and % VS show similar trends for this area. Low levels of both parameters occur in the south end of the ZSF and high values occur to the northwest in the direction of Drayton Passage (Figs. II.5-6 and II.5-7). The % VS range from 1% to just under 2%, while concentrations of BOD_5 in the ZSF range from 250 to 500 mg/kg dry weight. The greatest concentrations in BOD_5 occurred between Anderson Island and Devils Head on the Kitsap Peninsula. These values ranged from 500 to over 1000 mg/kg dry weight. The % VS in the same region ran from 1% to 3%. Elevations beyond the 95% CI and 1.96 SND occurred in this area for BOD_5. Elevations in %VS beyond the 95% CI occurred in the central basin and also between Anderson Island and Devils Head.

The percentages of water in the sediments in the study area surrounding the ZSF ranged from 30% to over 50% (Fig. II.5-8). The contour patterns shown by % water are very similar to that seen for the two measures of organic material. Low percent water content (< 30%) occurred at the southern end of the ZSF. Highest concentrations (> 50%) were found in Drayton Passage between Anderson Island and Devils Head and in the northwest corner of the study area similar to the results of BOD_5 and % VS. Elevations beyond the 95% CI for % water occur at the northwest end of the ZSF proper and in the region in Drayton Passage.

The median grain size consists of medium sand southeast of the ZSF grading to very fine sand and fine silt within the ZSF (Fig. II.5-9). Coarse to fine silt predominates in the two areas mentioned as having elevated amounts of organic material and a greater percent water. These two areas are the northwestern corner of the study area and in Drayton Passage. Both areas contain greater amounts of the finer sediments which can be seen in the percent clay content (Fig. II.5-10). The percentage of clay within the study area ranges from less than 5% to over 20%. The areas with the greatest amount of clay overlaps areas with the finest sediment. In the ZSF the percent clay ranges from 5% at the southern end to 20% at one station.

The area of lowest energy in the study area appears to be located at the entrance to Drayton Passage. This area contains the greatest amount of organic material based on elevations beyond the 95% CI for BOD_5, % VS and

percent water. The median sediment grain size in the area is predominantly coarse to medium silt, and while the percent clay is not the highest encountered in the study area, it does range from 10% to 15%.

5.4.4 Bellingham Bay--

The contour intervals showing the levels of organic material in Bellingham Bay are depicted in Figures II.5-11 and II.5-12. Both the % VS and BOD_5 show increasing concentrations from the southwest to the north and from the northeast into the center of the study area. Both measures show a high and uniform concentration throughout the center of the Bay and in the ZSF. These values exceed the 95% CI for both % VS and BOD_5 at all stations. In addition % VS values exceeding the 1.96 SND were found in the northwest, northeast, and southeast corners of the study area. The BOD_5 values exceeding the 1.96 SND were located at the same stations where the % VS also exceeded that limit. The only data point that differs from the % VS is where the BOD_5 exceeds the 1.96 SND at the north edge of the study area.

Percent water shows the same pattern as seen in the BOD_5 and % VS (Fig. II.5-13). Percent water values increase from approximately 30% at the western and northeastern edges to over 60% in the center and southeastern portions of the study area. At the northern edge of the ZSF 70% water content was encountered. Areas of elevated % water presented in Figure II.5-13 show the study area and ZSF to contain sediment with percent water in excess of the 95% CI. The northwest and southeast corners of the ZSF were significantly elevated due to their data points falling beyond the 1.96 SND range.

The median grain size patterns in Bellingham Bay are medium sand grading to very fine sand off the eastern shore and the south end of Portage Island (Fig. II.5-14). Gradually this pattern changes to medium silt in the center of the study areas and ZSF. Two areas containing sediment consisting of fine silt are found in the far north and to the east of the ZSF.

The clay fraction found in this ZSF follows the grain size contour intervals (Fig. II.5-15). The amount of clay increases from the east and west sides of the Bay towards the center of the area, and is roughly constant at 16-18% within the ZSF. Two lobes of 18-20% clay were found northeast and northwest of the ZSF.

In reviewing the measured parameters, it is evident that the sediments in the Bellingham Bay ZSF contain a large amount of enriched organic material. The BOD_5 concentrations range from 2000 to 2500 mg/kg of sediment, % VS are in excess of 8% and percent water ranges around 70%. The entire study area has all the attributes of a very low energy, depositional environment. The area that appears to be the most depositional in the study area is roughly 0.5 nautical miles due north of the existing ZSF. All stations in the Bay contained sediments where the BOD_5, % VS and % water were enhanced beyond the 95% CI for each parameter.

The grain size is predominantly silt in this area and percent clay ranges from 18% to 20%.

5.4.5. Lummi/Sinclair Island--

Field data indicated that there was a large component of sand at all but two stations in the ZSF. The northernmost transects also contained large numbers of scallop shell fragments. In addition there were roughly three to four live scallops in each 0.1 m^2 van Veen grab sample. The obvious lack of clay/silt sediments and the presence of scallops, which are indicative of high current areas, caused this ZSF to be removed from consideration as a potential nondispersive disposal site.

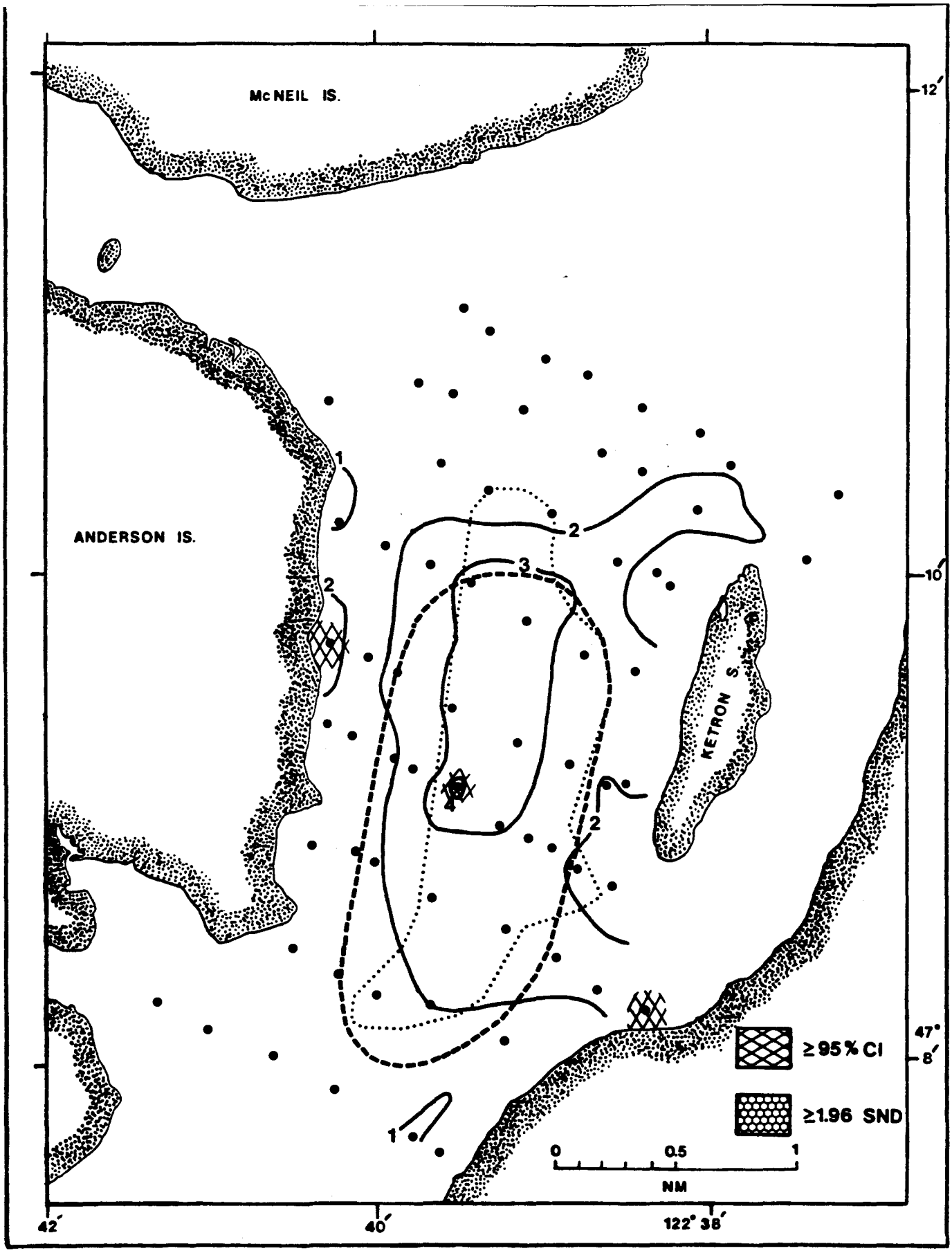


Figure II.5-1 Contours of volatile solids content (percent) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Anderson/Ketron ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

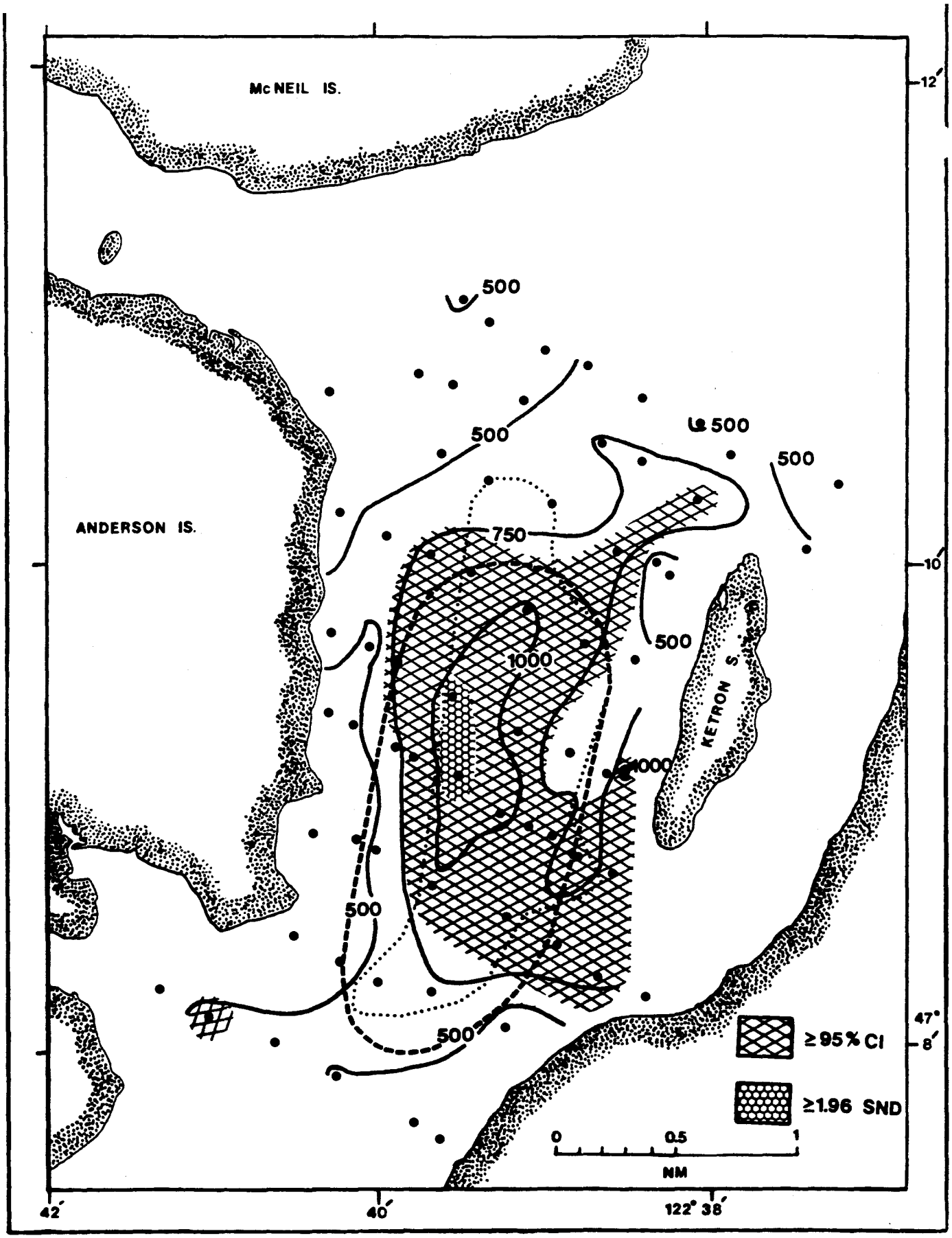


Figure II.5-2 Contours of five-day biological oxygen demand (mg/kg dry weight) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Anderson/ Ketron ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

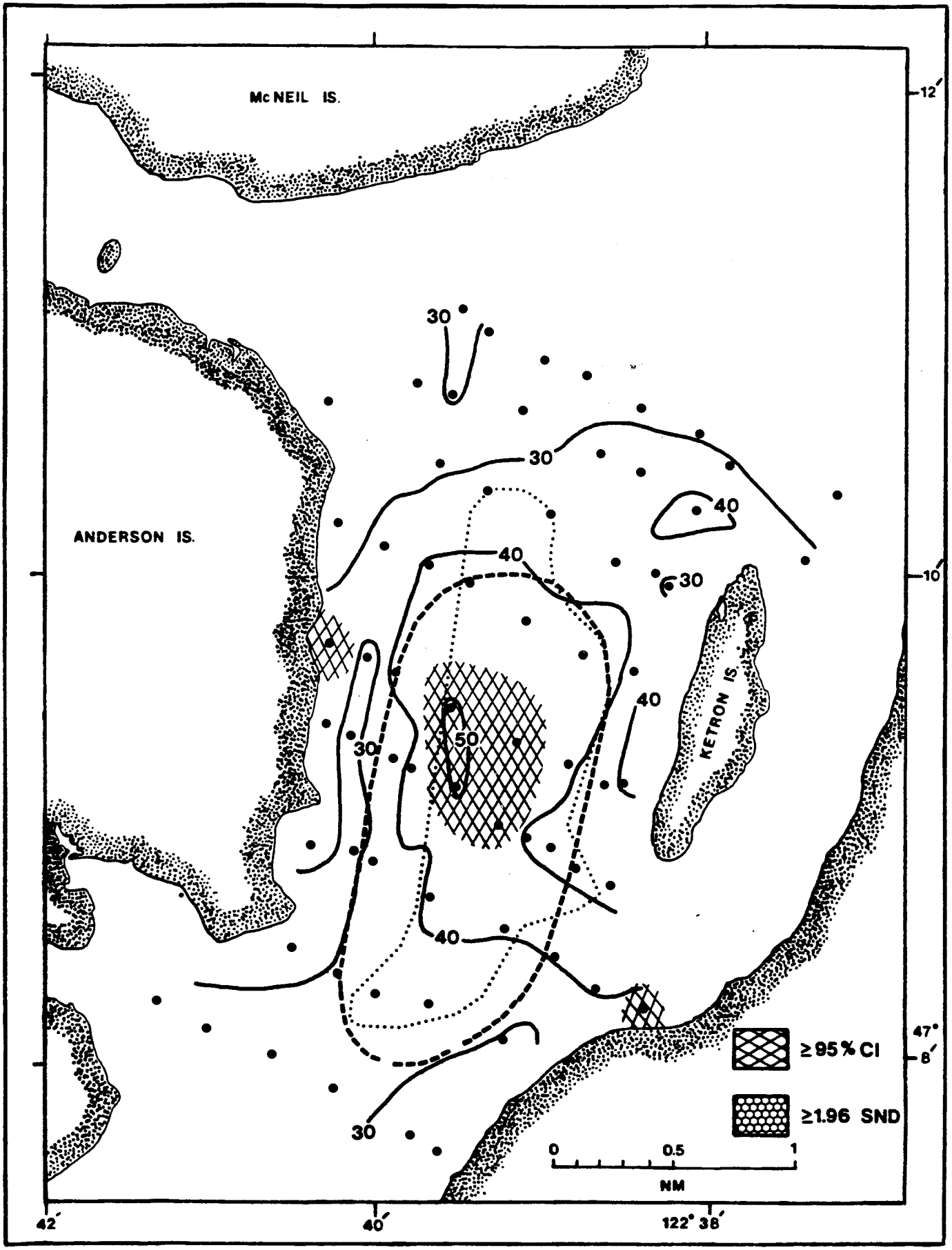


Figure II.5-3 Contours of water content (percent) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Anderson/Ketron ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

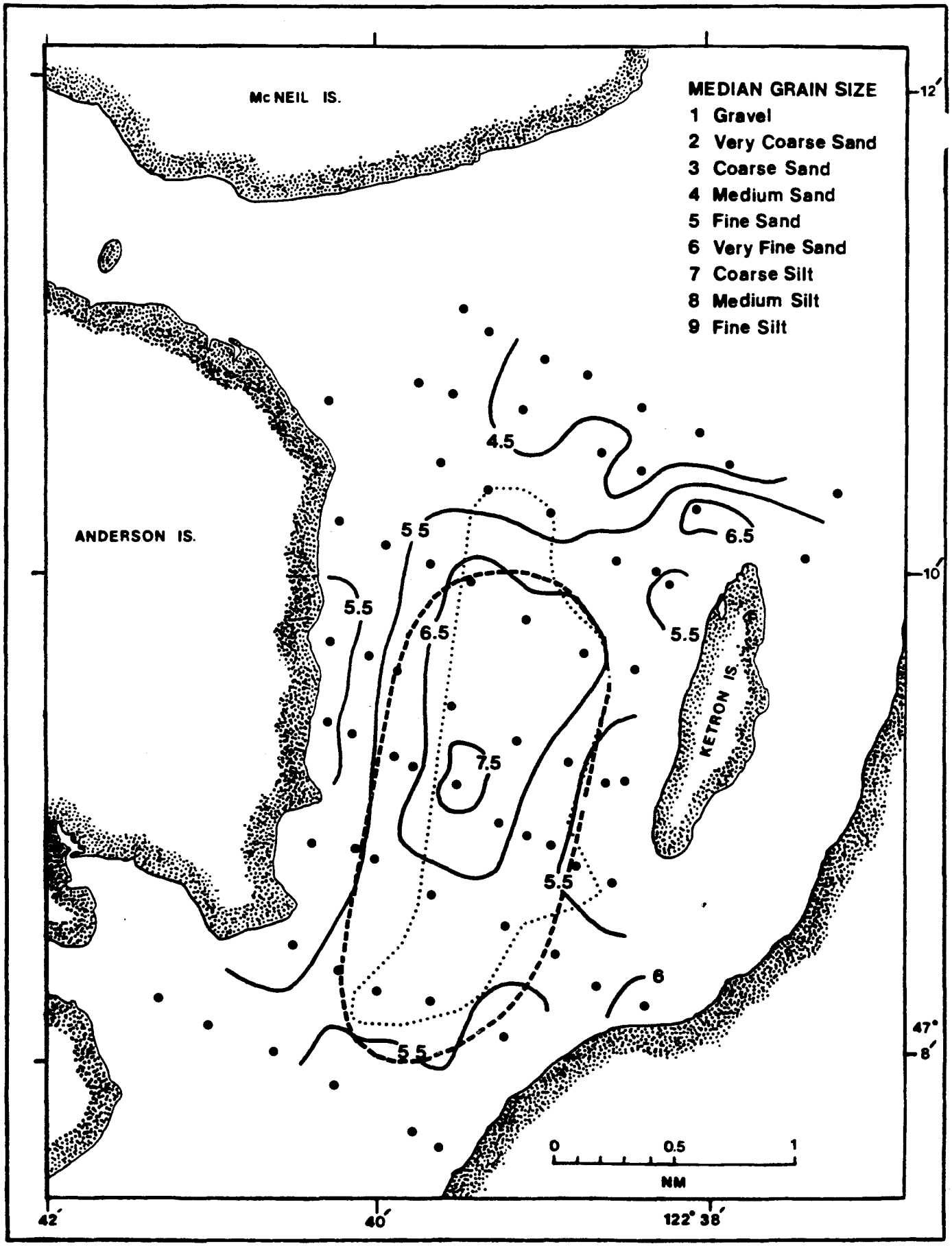


Figure II.5-4 Contours of median grain size in Anderson/Ketron ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

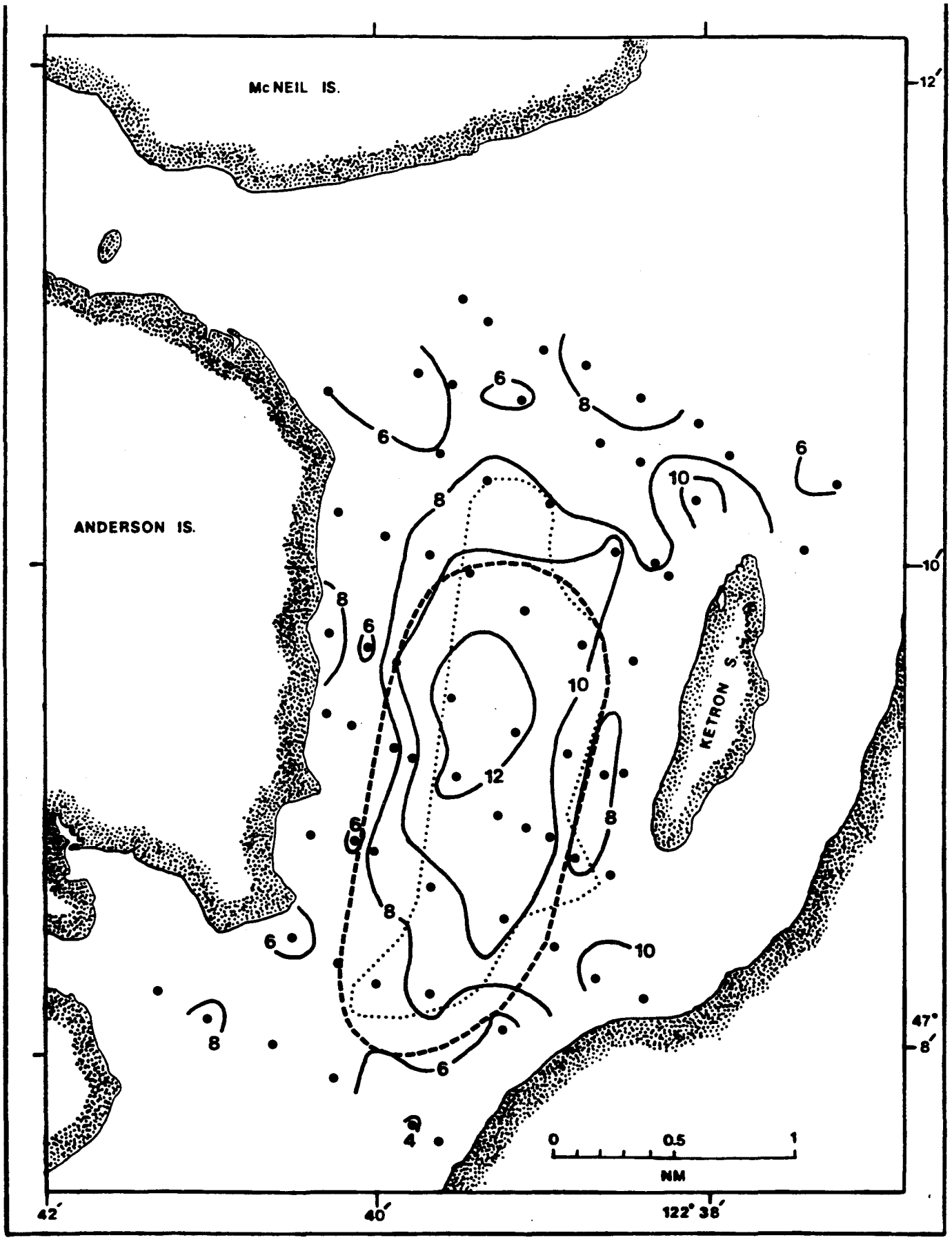


Figure II.5-5 Contours of clay content (percent) in Anderson/Ketron ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

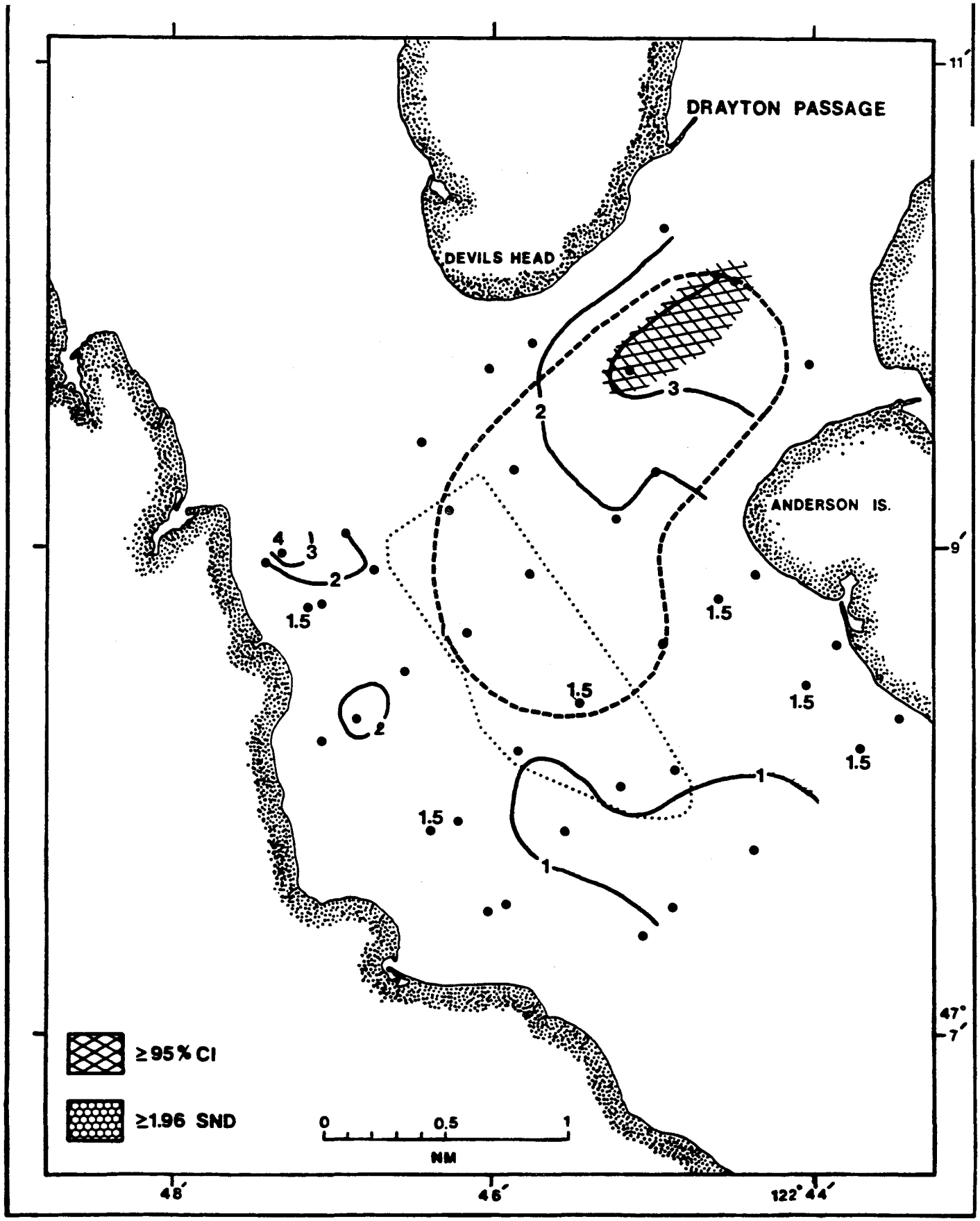


Figure II.5-6 Contours of volatile solids content (percent) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Anderson Is./Devils Head ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

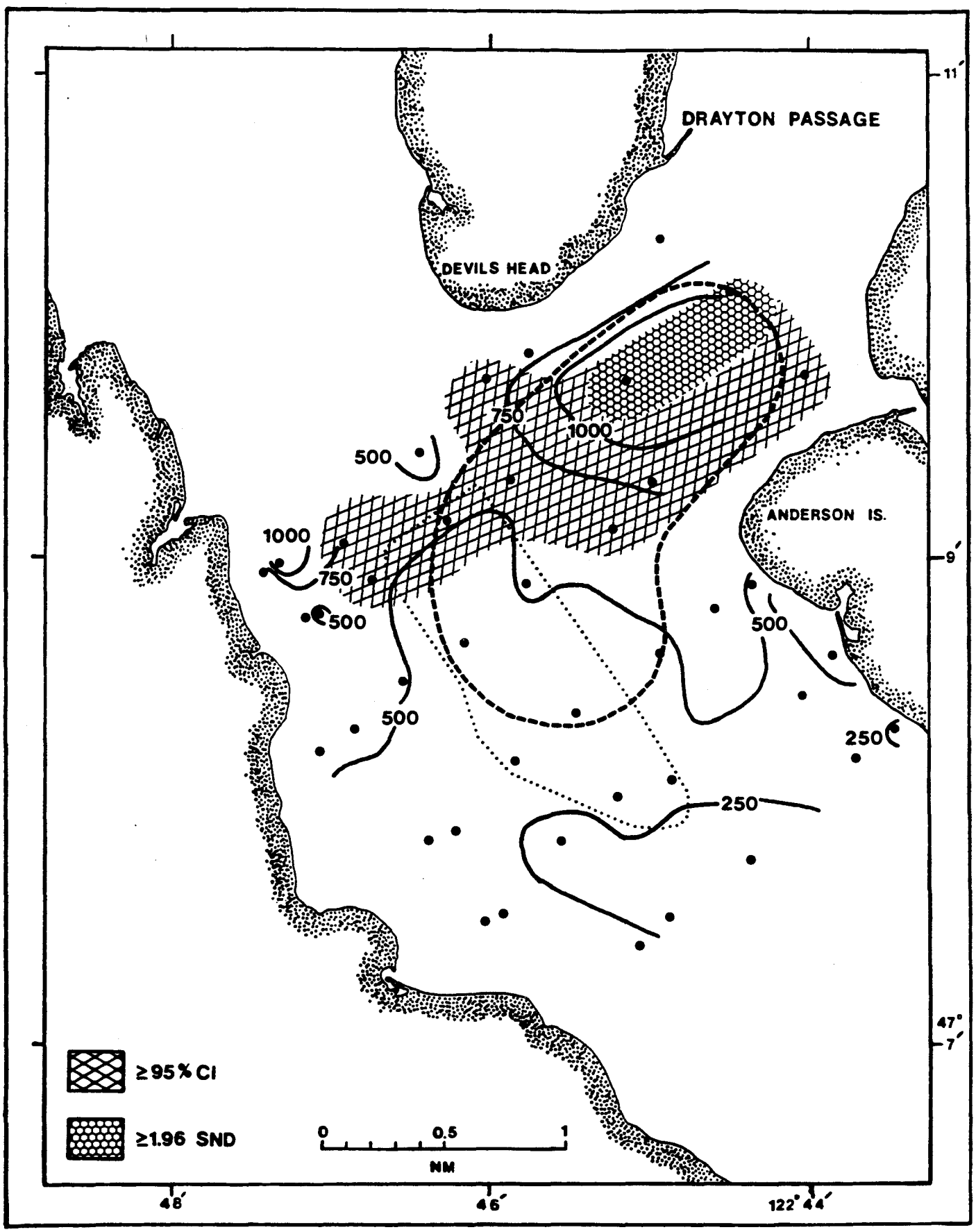


Figure II.5-7 Contours of five-day biological oxygen demand (mg/kg dry weight) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Anderson Is./ Devils Head ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

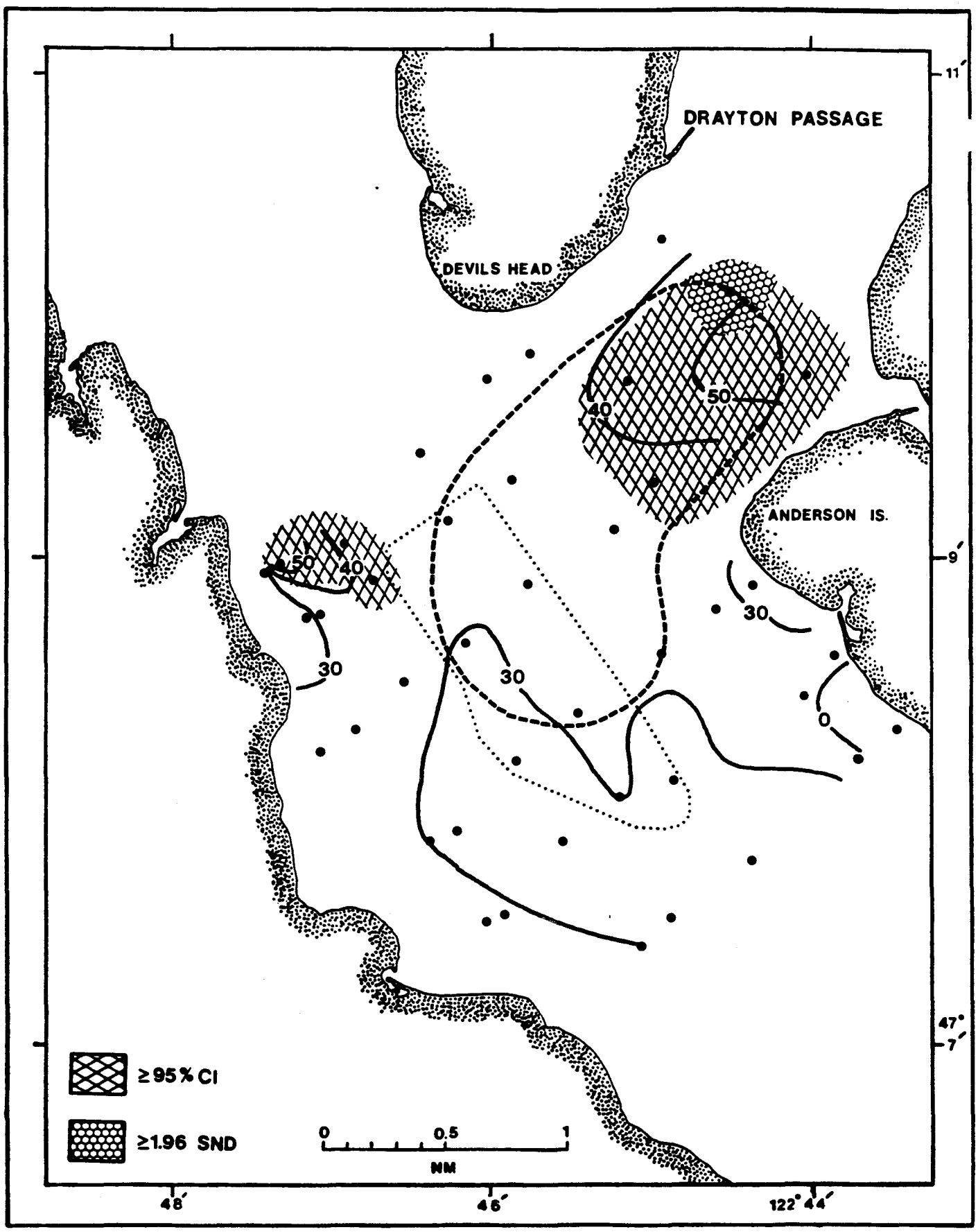


Figure II.5-8 Contours of water content (percent) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Anderson Is./Devils Head ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

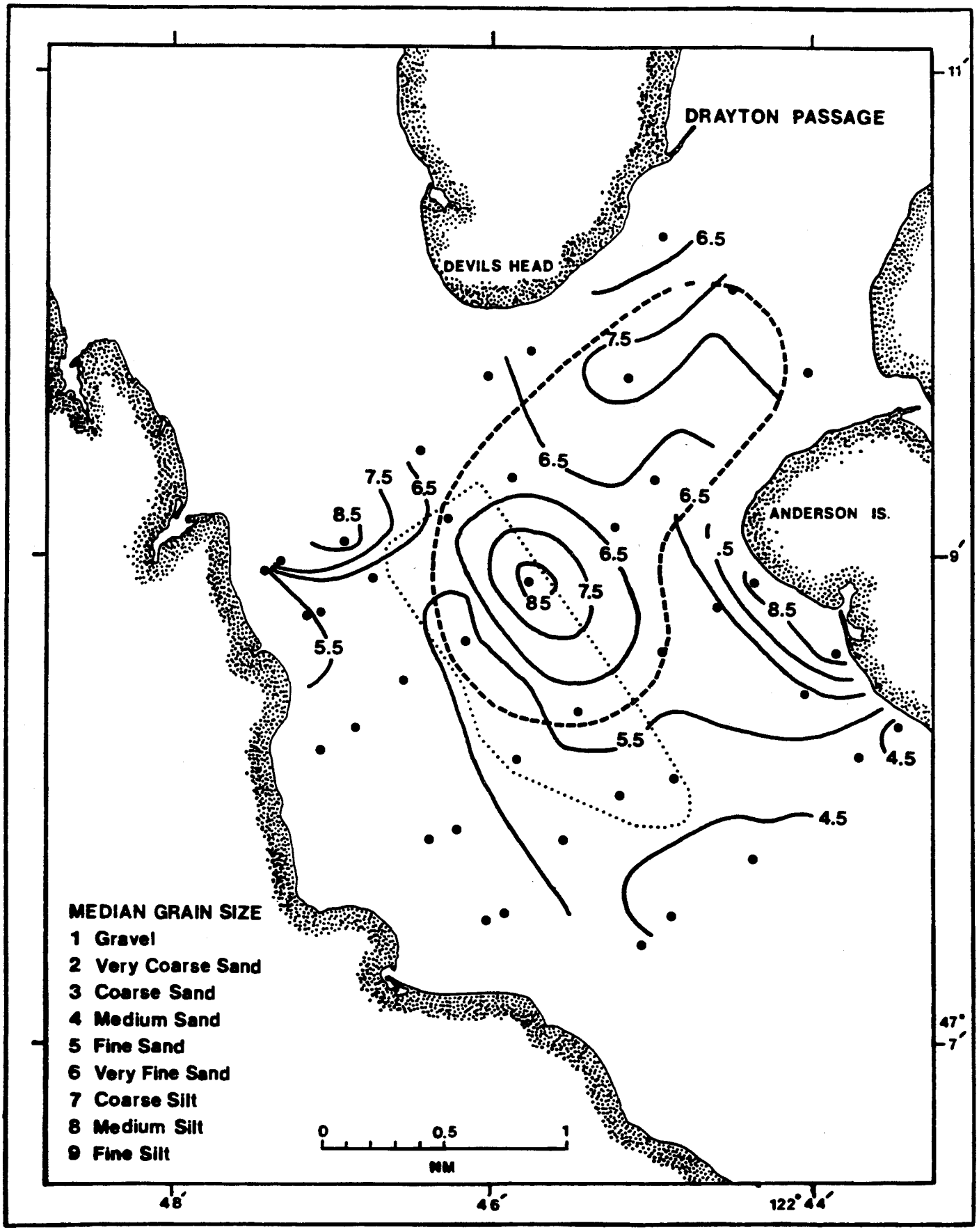


Figure II.5-9 Contours of median grain size in Anderson Is./Devils Head ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

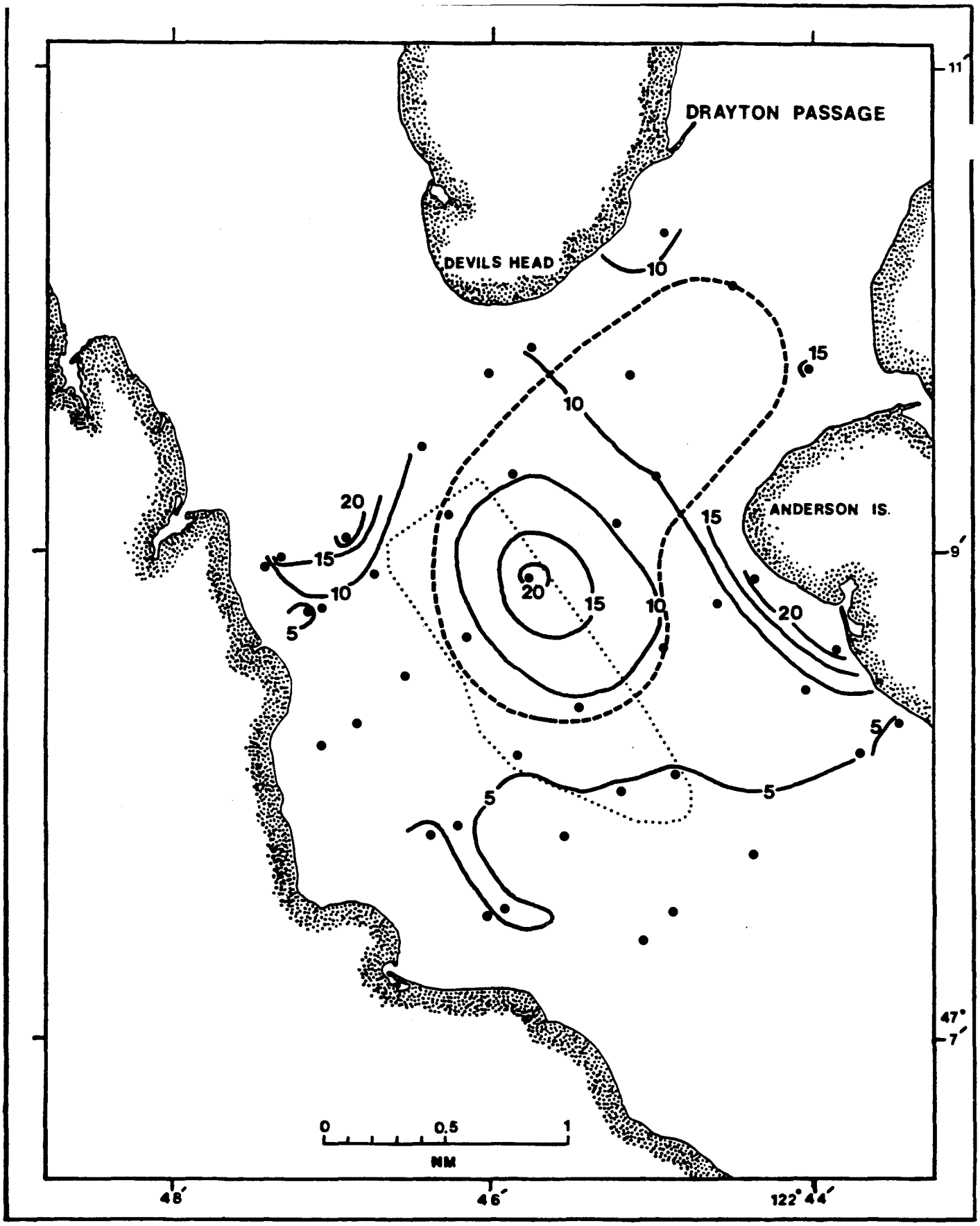


Figure II.5-10 Contours of clay content (percent) in Anderson Is./Devils Head ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

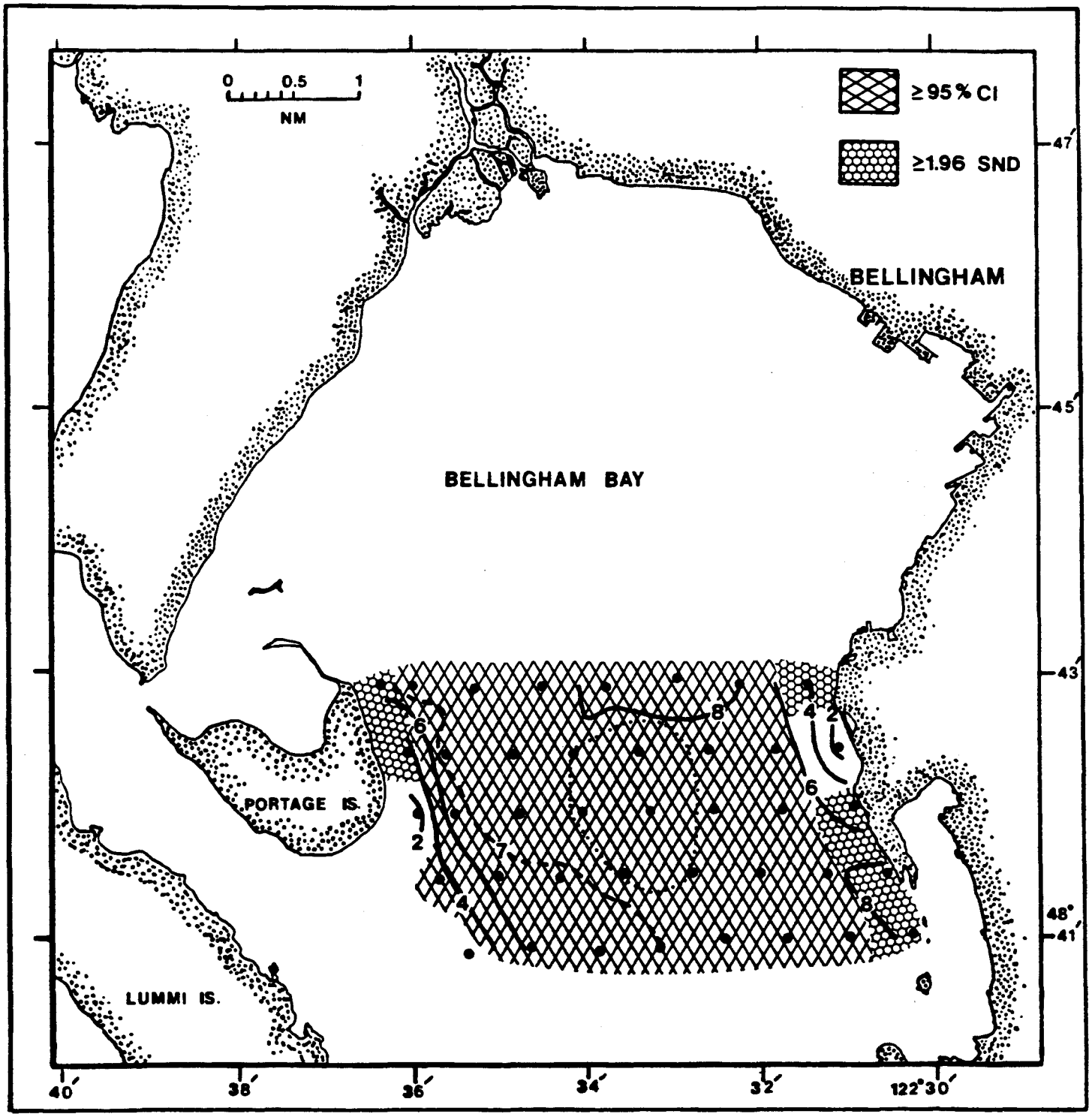


Figure II.5-11 Contours of volatile solids content (percent) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Bellingham Bay. Dotted line represents preliminary ZSF boundary.

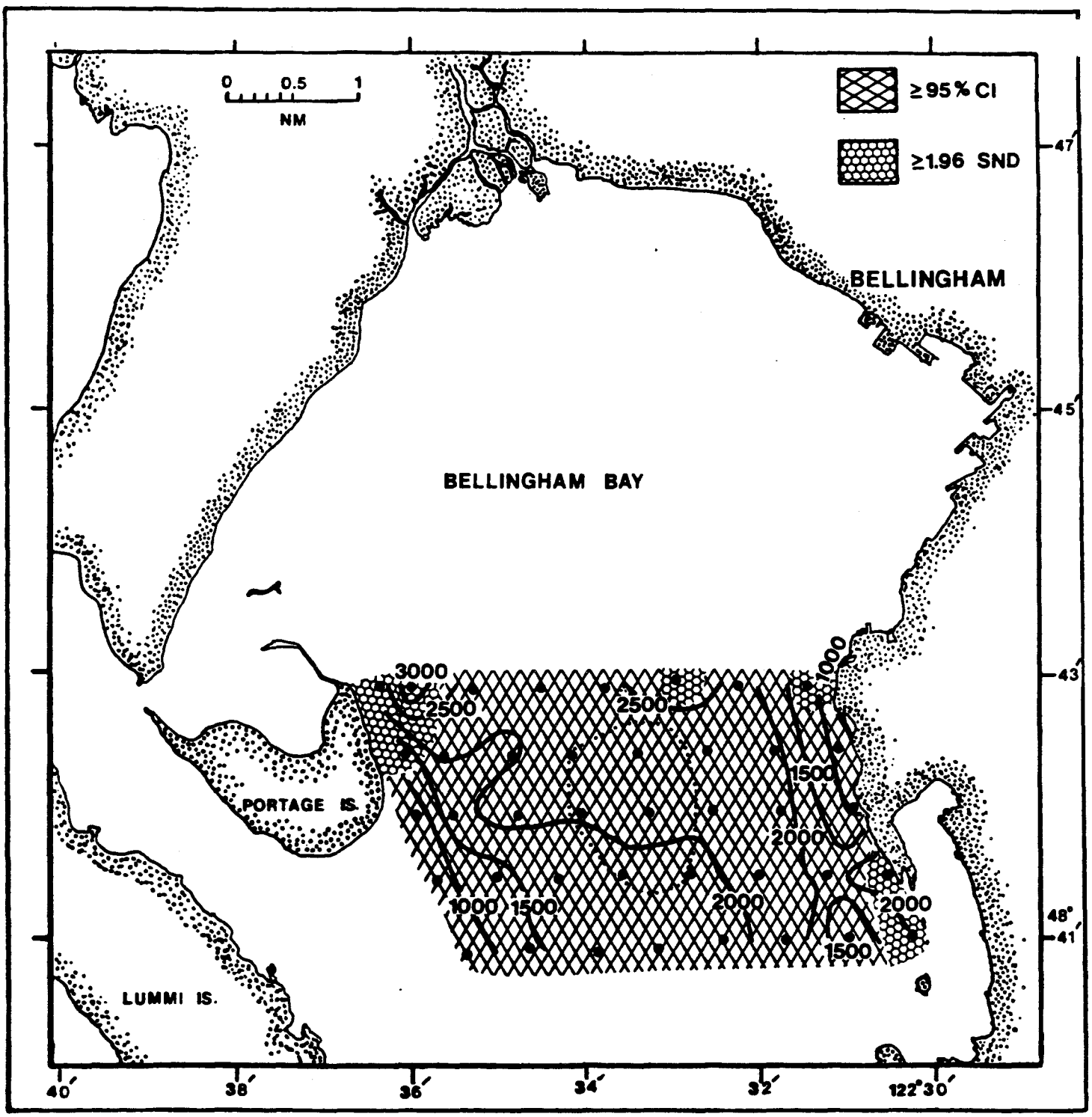


Figure II.5-12 Contours of five-day biological oxygen demand (mg/kg dry weight) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Bellingham Bay. Dotted line represents preliminary ZSF boundary.

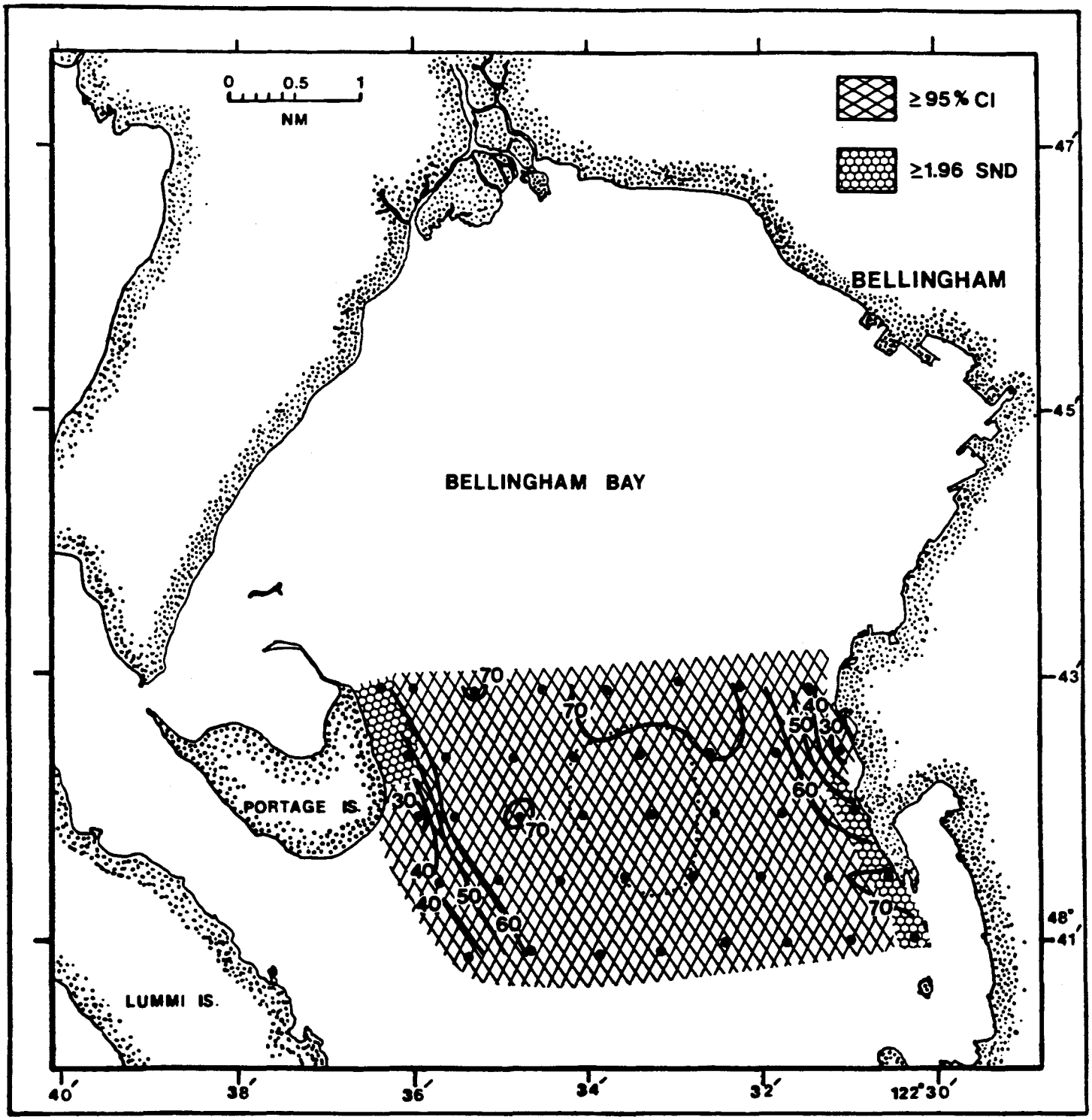


Figure II.5-13 Contours of water content (percent) and areas which exceed the 95% confidence interval (CI) and 1.96 standard normal deviate (SND) values, in Bellingham Bay. Dotted line represents preliminary ZSF boundary.

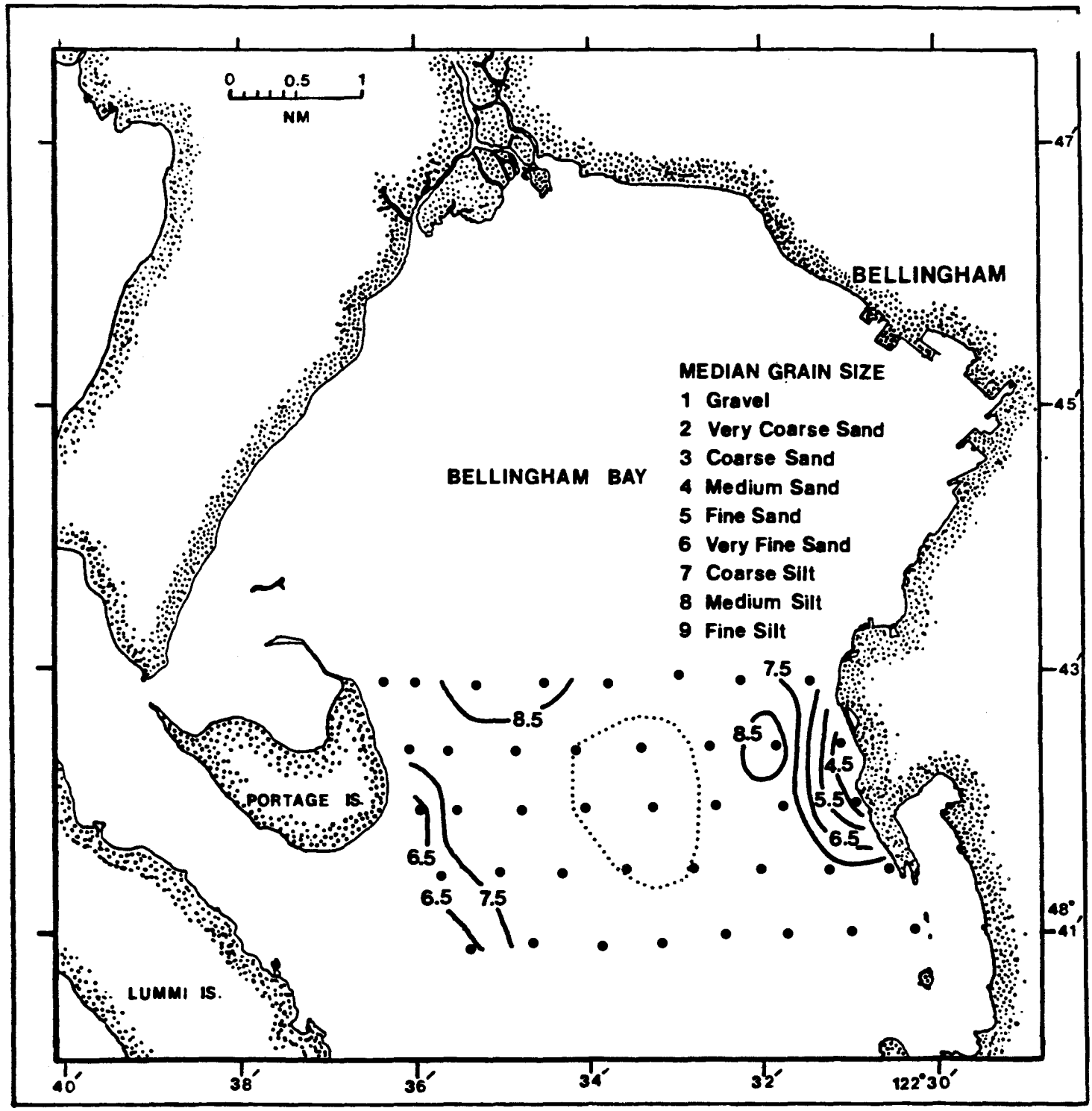


Figure II.5-14 Contours of median grain size in Bellingham Bay. Dotted line represents preliminary ZSF boundary.

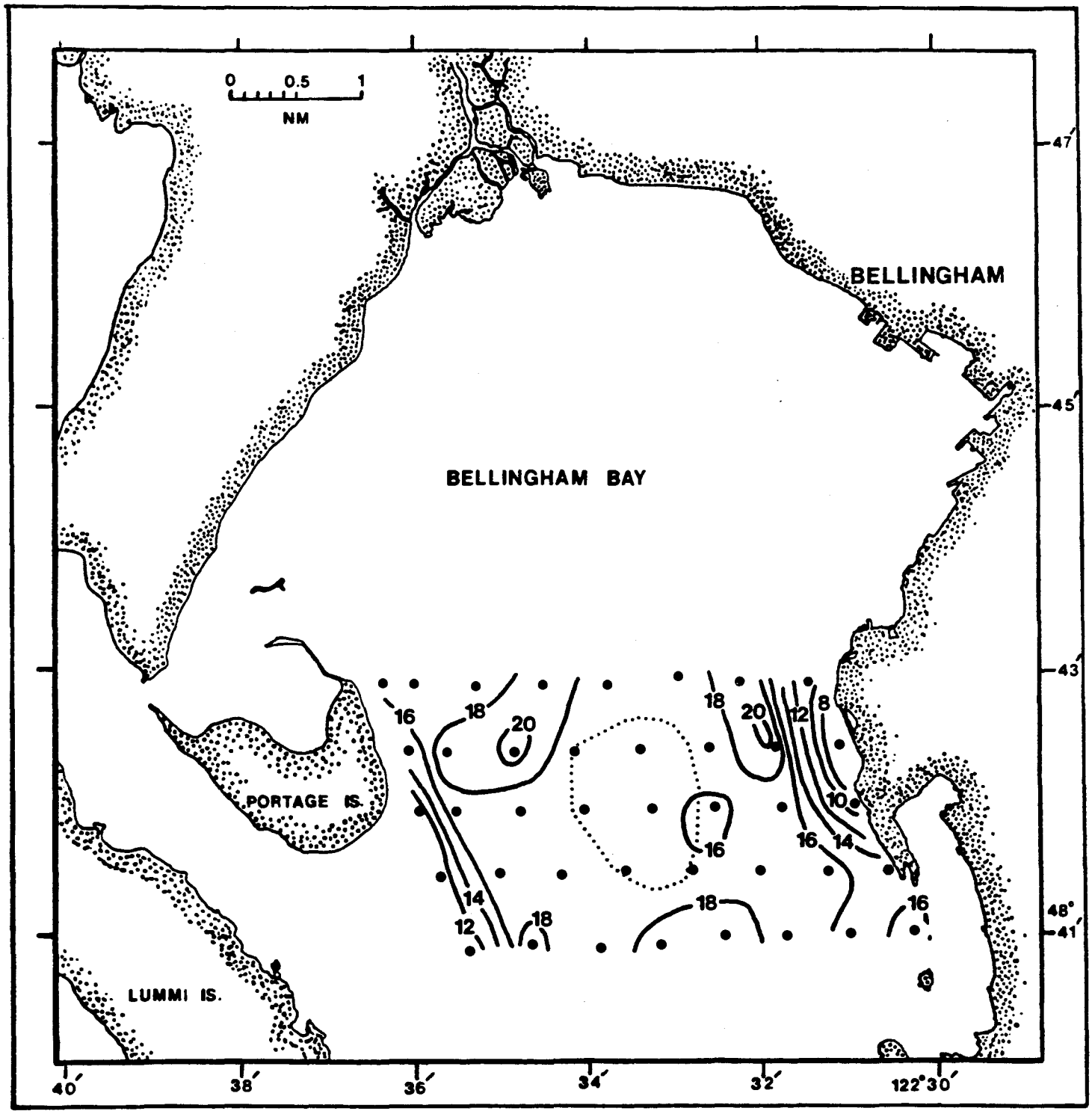


Figure II.5-15 Contours of clay content (percent) in Bellingham Bay. Dotted line represents preliminary ZSF boundary.

6. HYDRAULIC CHARACTERISTICS

6.1 Objective

From the previous two sections it is evident that there are areas where natural sediments tend to deposit or erode. The central question is whether the dredged material will remain when placed in the nondispersive areas and eventually erode from the dispersive areas. Newly deposited dredged material containing substantial amounts of silts and clays begins to erode when the current speed exceeds a threshold of approximately 25 centimeters per second (0.5 knot; 0.85 feet per second). As a result, PSDDA sought areas with these current characteristics for dispersive ZSFs. Maps of current strength and direction were also prepared for the nondispersive ZSFs to verify that extreme speeds were less than 0.85 feet per second so as to ensure that sediments tended to accumulate.

6.2 Methods

Current strength in each of the ZSFs was determined using current meter data. When possible these data were supplemented using data obtained from drifting objects. In addition, estimates were generated with a numeric model for the dispersive ZSFs.

6.2.1 Historical field measurements--

Several hundred current meter records were reviewed. A record is defined as one obtained at a particular depth over a given duration, or the approximate time between installation and retrieval of an individual current meter. Nearly all of the records were obtained using Aanderaa current meters attached to moorings. These were anchored to the bottom and held taut with a subsurface float. Usually several current meters were attached to a mooring at various depths, so that a number of records were often obtained at a given latitude and longitude over the same interval of time.

Statistical computations (described later) were made for those records which met the following criteria: 1) the measurements were taken at fixed locations; 2) both speed and direction were recorded; 3) the speed measurement was consistently above the minimal recording value of the instrument; and 4) the measurements lasted at least one tidal day (24.84 hours). Inspection of the original records revealed a number of obviously spurious data and gaps longer than one hour between data points. Those portions of records containing erroneous data were deleted. Whenever gaps of one hour or greater were found between data points, the records were segmented into subrecords.

6.2.2 Crean's hydrodynamical numerical model--

A computer generated model was used to fill the gaps between insufficient field data. Crean (1983) developed a numerical hydrodynamic model to simulate tides within the Georgia-Juan de Fuca Straits system. A detailed description of the model can be found in Crean (1983).

Some results of the numerical model were published in a tidal current atlas (Canadian Hydrographic Service, 1983). The computed vertically averaged tidal velocity fields are presented at hourly intervals over representative ranges both for spring and neap tides. The tidal current atlas illustrates the current flow due to tides during various tidal phases. The tidal flow agrees reasonably well with the tidal current flow seen in nature. Departures in nature from this tidally induced approximation will occur in near-surface velocities during periods of high winds or in areas where surface flows are dominated by local river discharge. The longer temporal scales of estuarine flow are also not depicted. Since the model depicts coastlines as straight lines, details of the flow near selected shorelines may be less accurate than further offshore.

Tidal vectors were chosen within and surrounding each ZSF during a neap tide from the tidal current atlas. The vectors displayed indicate ranges of speed, therefore the average value for each vector range was used to calculate a mean speed at that grid point. For example, if the velocity range for a vector at a specific location is 38.58-51.44 centimeters per second (0.75-1 knots per hour) at t=1 hour during a tidal cycle, then the average velocity would equal 45.27 cm/sec (0.88 knots per hour). The average velocity may change for that vector throughout the tidal cycle, and the mean speed at that location is the mean of all the average velocities.

6.2.3 Interrelations between current parameters--

The strength of currents in Puget Sound have been estimated in a number of ways. Various investigators have examined mean speed, total variance, and peak speeds (Cox et al., 1984; Ebbesmeyer et al., 1984). These terms are defined as follows. Mean speed is the mean of all speeds in a current meter record regardless of direction and is defined mathematically as follows:

$$\text{Mean Speed} = \frac{1}{n} \sum_{i=1}^{n} s_i \qquad (1)$$

where s_i is the magnitude of the current velocity and the current meter record contains n observations. Total variance is the sum of the variances determined for the two component directions, east-west (u) and north-south (v).

$$\text{Total variance} = \frac{1}{n}\sum_{i=1}^{n} (u_i-u)^2 + (v_i-v)^2, \qquad (2)$$

$$u = \frac{1}{n}\sum_{i=1}^{n} u_i \qquad v = \frac{1}{n}\sum_{i=1}^{n} v_i$$

where n is the number of observations for the current record and u_i, v_i are the east-west and north-south components of the velocity, respectively. The rms (root mean square) speed is defined as the square root of the variance and gives the standard deviation of the current which is another useful measure of current strength. This value is nearly equal to the mean current speed. Peak speeds are estimated in two ways. Some investigators determine the fastest speed in a record. For this study the peak speed is defined as the speed above which there are 1% of the observations. In other words, if there are n observations in a current meter record, the peak speed is the threshold above which there are 0.01 times n observations.

The interrelationship of various current parameters (mean speed, rms speed, and 1% fastest speed) has been previously documented for Puget Sound (PSDDA-DSSTA, 1988). The observations occurred in environments varying from near the heads of bays where currents are weak, to the mid-channel areas where currents are stronger, and over a wide range of depths and durations. Linear regressions were computed for mean versus rms speeds, mean versus 1% speeds, and rms versus 1% speeds. From the correlations amongst the three measures of current strength, the equations of the linear regressions can be used to predict extremes from the mean value and total variance. The equations are as follows where speeds have been expressed in centimeters per second:

1) mean versus rms speeds:
   mean speed = 0.89 + (0.87 x rms speed)

2) mean versus 1% speed:
   1% speed = 1.20 + (2.67 x mean speed)

3) rms versus 1% speed:
   1% speed = 2.97 + (2.40 x rms speed)

For convenience in later intercomparisons the following table gives values of the three parameters at intervals of total variance used elsewhere in this appendix.

Total Variance (cm^2/s^2)	rms speed (cm/s)	Estimated mean speed (cm/s)	Estimated 1% speed (cm/s)
25	5	5	15
50	7	7	20
100	10	10	27
200	14	13	37

6.3 Nondispersive ZSFs

6.3.1 Horizontal Distribution of Mean Currents--

Several current meter records were previously obtained in the vicinity of the ZSFs. These are described below for the two locations in southern Puget Sound.

6.3.1.1 Anderson/Ketron Island ZSF 2

Few current meter records have been obtained in the reach between the Nisqually River delta and the Narrows. Fortunately, two records were obtained within the disposal area, sites 66 and 70 (Fig. II.6-1). Table II.6-1 summarizes these records; briefly, at site 66 two meters were deployed for 15 days at depths of 22 and 119 meters, whereas at site 70 current meters were deployed for approximately 170-200 days at depths of 6 and 34 meters.

The deeper records at each site were used to evaluate rms speeds in the ZSF. In the northern portion of the disposal site the rms speed equaled 13.5 cm/s at a depth of 119 m, whereas in the southern portion of the disposal site the rms speed varied between 9.4 - 12.0 cm/s during six months of measurements at 34 m depth. Using the foregoing regressions then rms speeds correspond to the following 1% fastest speeds: at site 66, 35.4 cm/s; at site 70, 25.5-31.8 cm/s. These results indicate that speeds in this disposal site are near or above the threshold for fine particle transport. However, it should be noted that both of these meters are measuring the mid- to lower-water column and not the bottom current conditions. Depositional analysis is more relevant to bottom conditions and the DA results from the previous chapter show that this area has a nondispersive character.

6.3.1.2 Anderson Island/Devils Head ZSF 3

Three current meter sites embrace this ZSF (Fig. II.6-2). In Drayton Passage a two day long record was obtained at 5 m depth; in the ZSF, but southeast of the disposal site 199 days of record were obtained at 34 m depth; and northwest of the site three days of record were obtained at 4 m depth (Table II.6-2). The rms speeds for these records vary from 7.1 cm/s in Drayton Passage to 15.3-19.1 cm/s southeast of the ZSF, to 16.4 cm/s northwest of the ZSF. Because the disposal site is located in the reach between the Nisqually River delta and Dana Passage, the rms values northwest and southeast of the ZSF were considered more applicable to this disposal site.

The available records at the deepest depths indicate that the rms speeds at the disposal site lie between 15.3-19.1 cm/s. Applying the linear regression yields 1% speeds estimated to be 39.7-48.8 cm/s. These current speeds are at about mid-depth in the water column. As with the

Anderson/Ketron Island ZSF the DA results indicate the areas is non-dispersive. The available records suggest that the tidal speeds at the Devils Head disposal site are higher than those of the Anderson/Ketron Island site, hence it is the alternative site.

6.3.2 Vertical Distribution of Net Currents--

Coklet, Stewart, and Ebbesmeyer (in preparation) utilized these records to estimate net currents. They found that the net directions were aligned with the along channel directions. A mean cross channel direction was chosen and components directed along channel were computed for the two sites closest to these sections. Finally, quadratic functions were fit to the components to obtain estimates of the along channel speed versus depth. The results of these analyses have been reproduced here as Figure II.6-3.

6.3.2.1 Anderson/Ketron Island ZSF 2

The quadratic fit to the records obtained at sites 66 and 70 may be described as follows. Above a depth of approximately 35 meters the net flow is directed northward, whereas at greater depth the net flow is directed southward. Near a depth of 125 m the net inflow reaches a maximum value of approximately 7 cm/s.

6.3.2.2 Anderson Island/Devils Head ZSF 3

The quadratic fit to the records obtained at sites 59 and 60 may be described as follows. Above a depth of approximately 30 m the net flow is directed toward the southeast, whereas at greater depths the net flow is directed toward the northwest. Near a depth of 65 meters the net inflow reaches a maximum value of approximately 10 cm/s.

It should be noted that this ZSF lies near the junction of three channels whereas the quadratic fit was derived for measurements to the northwest of the ZSF. The six months of observations made at a depth of 34 m at site 62 southeast of the disposal site shows a mean direction of 323° True which almost exactly coincides with the along channel direction (322° True). Therefore, it appears that the inflow from site 62 continues past the disposal site and joins the inflow shown by the quadratic fit.

6.3.3 Horizontal Distribution of Net Currents--

In the vicinity of the disposal sites the net flow appears to be directed primarily along channel as shown by the arrows in Figures II.6-4 and II.6-5. Undoubtedly additional measurements would show how these net flows merge with inflow and outflow connecting channels. However, these are too few data to say with any certainty how these flows should be drawn.

6.4 Dispersive ZSFs

The following sections describe the various currents found in and around the four dispersive ZSFs.

6.4.1 Horizontal Distribution of Mean Currents

Mean current speeds were calculated from both field measurements and Crean's (1983) model results. For field data, only a limited number of measurements were obtained for which direct calculations of the mean speed have been previously made from the individual recorded speeds. When actual records were not obtained, mean speeds published by other investigators were used and are noted in the appropriate section. Therefore, mean speeds for field data were calculated using the rms speed-mean speed relationship (c.f. section 6.2.4) based on the rms speed previously calculated by Evans-Hamilton, Inc. (1987b; i.e., rms speed derived from total variance values equals the square root of the total variance).

Mean speeds calculated from Crean's model represent a vertical average of the water column for the model grid points selected for each ZSF. To allow comparison of the mean speed calculated from the model and the field measurements, mean speeds of field measurements at various depths of a measurement site, and sometimes from several meaaurement periods, were averaged to obtain one mean speed per site.

Using the mean speed - 1% fastest speed relationship, mean speeds exceeding 9 cm/s will normally indicate the presence of current speeds in excess of 25 cm/s (sediment movement threshold speed) during at least 1% of the time, therefore at areas with mean speeds exceeding 9 cm/s, sediment resuspension will occur to some extent.

6.4.1.1 Rosario Strait

Mean speeds surrounding the Rosario Strait ZSF range from 36 to 69 centimeters per second (Fig. II.6-6a). The model data for a neap tide also show the highest mean speeds peaking above 60 centimeters per second centering in an area northeast of the ZSF where three channels merge (Fig. II.6-6b).

6.4.1.2 Port Townsend

Figure II.6-7 reveals different patterns of mean speed between the field and model data except for one feature. Both data sets show highest speeds north of Port Townsend at the entrance to Admiralty Inlet which decrease as

they approach the ZSF. Field data indicate mean speeds within the ZSF range from 30-50 centimeters per second whereas model values range from 20-25 centimeters per second. In both cases the mean speed is relatively high.

6.4.1.3 Port Angeles

No field data exist for the area contained within the ZSF so the contours of Figure II.6-8a may be somewhat biased. However, the general trends of the data surrounding the ZSF are also evident in contours of the model data (Fig. II.6-8b). These show slower mean speeds approaching Port Angeles harbor and increasing speeds moving north, east, and west away from the ZSF towards midchannel.

6.4.2 Horizontal Distribution of Maximum Tidal Currents--

Crean's published numerical model results provide an estimate of the maximum ebb and flood tidal currents during spring and neap tidal conditions throughout the northern PSDDA Phase II area. These results are used below to describe the maximum tidal currents expected in the five ZSFs. Actual field measurement data were not used because summaries of these data typically do not describe the peak speeds measured, therefore sufficient field data on peak speeds does not exist to accurately describe the tidal currents within the ZSFs. The time periods within the spring and neap tide cycles for the model results utilized are shown in Figure II.6-9. The actual maximum flood and ebb current speeds published by Crean (1983) that were utilized in the discussion below are shown in Figures II.6-10a-d. Note that these current speeds represent a depth averaged value.

6.4.2.1 Rosario Strait

During all tidal currents the peak speeds near Guemes Island are in the neighborhood of 100 centimeters per second flowing in many directions. The channel to the northeast of the ZSF is deep and narrow, thereby inducing stronger tidal currents. The channel to the east is shallow and has very weak currents.

6.4.2.2 Port Townsend

The spring ebb is the strongest tidal current with a peak speed around 100 cm/s. The neap flood comes next with a peak speed of 75 cm/s. The spring flood has a peak speed of 65 cm/s and the neap ebb has a peak speed of 50 cm/s. The peak speeds are stronger in the northern portion of the ZSF than in the southern portion. The ebb tides flow westerly and the flood tides flow easterly.

6.4.2.3 Port Angeles

The spring ebb and neap flood tidal currents both have peak speeds of about 125 cm/s. The spring flood has a peak speed of about 100 cm/s and the neap ebb has a peak speed of about 65 cm/s. The ebb tides flow westerly and the flood tides flow easterly.

6.4.3 Vertical Distribution of Net Currents--

Vertical profiles of the net current flow were constructed for each ZSF where field data were available. The vector net direction of each record has been grouped into two general directions, seaward or landward. The profiles can be classified within three categories; single layer flow, two layer flow, and unresolved due to a lack of obaervations.

6.4.3.1 Rosario Strait

This area shows a predominantly single layer southern flow (seaward) towards the inner Strait of Juan de Fuca (Fig. II.6-11). Net speeds generally fall between 10-30 centimeters per second throughout the water column.

6.4.3.2 Port Townsend

Five current stations fall within the ZSF boundary (Fig. II.6-12). The profile shows the area covered by the ZSF as having a two layered flow where measurements above about 50 meters show net seaward flow and measurements below this depth show net landward flow. The net speeds are fastest near the surface, reaching approximately 30 centimeters per second. The net speeds decrease with depth, then increase in the opposite direction below 50 meters. The small number of measurements in the lower layer prevent further interpretation of this part of the profile.

6.4.3.3 Port Angeles

Current measurements are nonexistent within the ZSF; however, sites to the east and west of the ZSF have been measured through the water column (Fig. II.6-13). Sites located at midchannel rather than near shore or shallow regions were used to construct the vertical profile to best emulate currents within the ZSF. The profile shows two layered flow, seaward near the surface and landward in the lower depths. The division between these two layers is not as well defined as that seen for the Port Townsend ZSF, but is at approximately 30-50 meters depth.

6.4.4 Horizontal distribution of net currents--

In order to assess circulation patterns near the ZSFs, net current vectors were plotted which present a horizontal view of the flow. The vectors are mapped separately for near surface and near bottom within each ZSF for clearer presentation. Vectors representing all measurements at a site are displayed regardless of the length of the measurements or their seasonal variability. For near surface circulation currents within the upper 21 meters were plotted, a region where the majority of all the measurements were taken. Current records within 22 meters of the bottom were plotted for circulation patterns in the lower layer, an area directly impacting the ZSF after disposal occurs.

6.4.4.1 Rosario Strait

The vertical profile of net currents for this area (c.f. Fig. II.6-11) indicates a predominantly net outflow (seaward) over the water column. Figure II.6-14 illustrates this flow within the main channel (Rosario Strait). What appear to be contradictory flow patterns, especially near the bottom, can be explained when viewing the bathymetry (Fig. II.6-15). The channel is fairly narrow, bounded on the east and west by small islands, and contains several shoals.

6.4.4.2 Port Townsend

A two layer flow is evident for this ZSF. Net surface flow is seaward and near bottom net flow is landward (Fig. II.6-16). Remnants of water from Rosario Strait flowing southward are seen at the entrance to Admiralty Inlet just north of Port Townsend. The bathymetry of this area has several large shoals with fairly deep passages (70-90 fathoms) between them (Fig. II.6-17).

6.4.4.3 Port Angeles

The area surrounding this ZSF also shows a net surface flow seaward and a net bottom flow landward (Figures II.18 and II.19, respectively). The bathymetry of the area shows a gradually sloping bottom from mid-channel to the southern shoreline (Fig. II.6-20). A feature not shown on Figure II.6-20 is the existence of a sill just west of the ZSF stretching from the point west of Port Angeles to Vancouver Island.

TABLE II.6-1. CURRENT METER RECORDS IN THE VICINITY OF THE ANDERSON/KETRON ISLAND ZSF.

SITE	DATE	DAYS OF RECORD	METER DEPTH (M)	MEAN* SPEED (CM/S)	NET DIRECTION (° TRUE)	NET SPEED (CM/S)	RMS SPEED (CM/SEC)
66	3/28-4/13 1978	15	22	10.63	330	2.73	11.2
66		15	119	14.55	152	5.69	15.7
70	6/02-6/26 1977	23	6	13.33	21	7.31	14.3
70	6/26-8/03 1977	37	6	15.68	18	5.89	17.0
70	8/03-9/09 1977	32	6	38.39	14	17.08	43.1
70	9/09-10/11 1977	31	6	12.20	354	4.80	13.0
70	10/11-11/29 1977	47	6	13.68	8	4.33	14.7
70	5/07-6/02 1977	26	34	10.46	252	2.34	11.0
70	6/02-6/26 1977	23	34	10.29	258	1.91	10.8
70	6/26-8/03 1977	37	34	11.24	269	1.36	11.9
70	8/03-9/09 1977	36	34	9.07	298	2.26	9.4
70	9/09-10/11 1977	31	34	9.42	293	2.56	9.8
70	10/11-11/29 1977	47	34	11.33	235	2.88	12.0

*ESTIMATED FROM EQ. (1).

TABLE II.6-2. CURRENT METER RECORDS IN THE VICINITY OF THE ANDERSON ISLAND/DEVILS HEAD ZSF.

SITE	DATE	DAYS OF RECORD	METER DEPTH (M)	MEAN* SPEED (CM/S)	NET DIRECTION (° TRUE)	NET SPEED (CM/S)	RMS SPEED (CM/SEC)
59	3/27-4/12 1978	15	4	16.72	168	16.76	18.2
		15	21	15.33	225	2.72	16.6
		15	71	20.81	343	6.92	22.9
60	1/30-2/04 1945	2	4	15.25	123	12.12	16.5
62	6/02-6/26 1977	23	6	18.46	152	3.12	20.2
62	6/26-9/08 1977	72	6	18.03	156	4.98	19.7
62	9/08-10/13 1977	34	6	17.86	154	4.41	19.5
62	10/13-11/28 1977	45	6	19.51	165	3.22	21.4
62	11/28-2/06 1978	69	6	16.90	161	4.53	18.4
62	5/06-6/02 1978	27	34	15.51	337	8.33	16.8
62	6/26-9/08 1978	72	34	14.20	313	8.41	15.3
62	9/08-10/04 1978	26	34	15.25	310	9.13	16.5
62	10/13-11/28 1978	45	34	15.94	330	3.84	17.3
62	11/28-2/06 1978	69	34	17.51	325	8.98	19.1
291	3/15-3/20 1947	2	5	7.07	27	4.38	7.1

*ESTIMATED FROM EQ. (1).

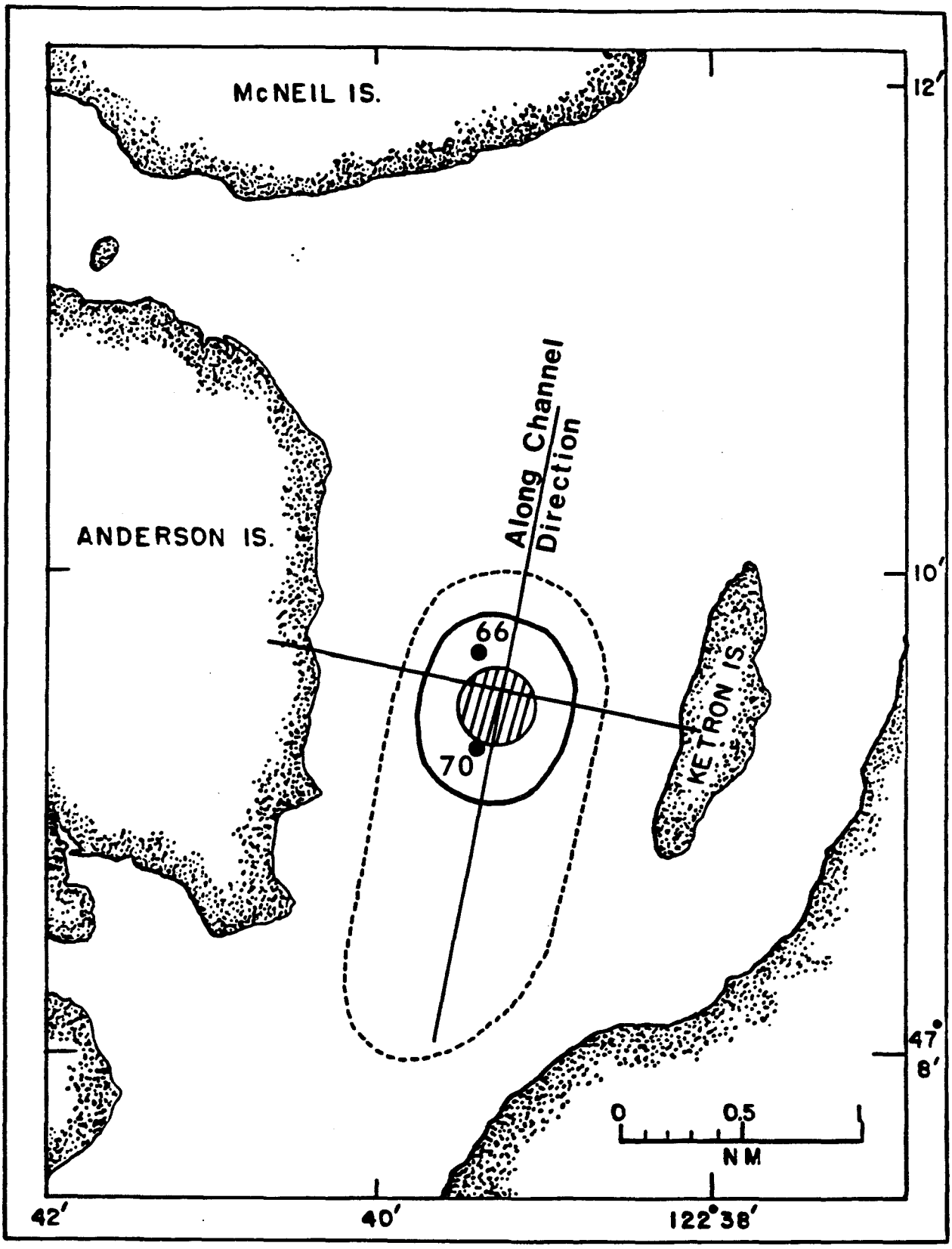


Figure II.6-1 Location of current meter sites and orientation of along channel current direction for the Anderson/Ketron Island ZSF.

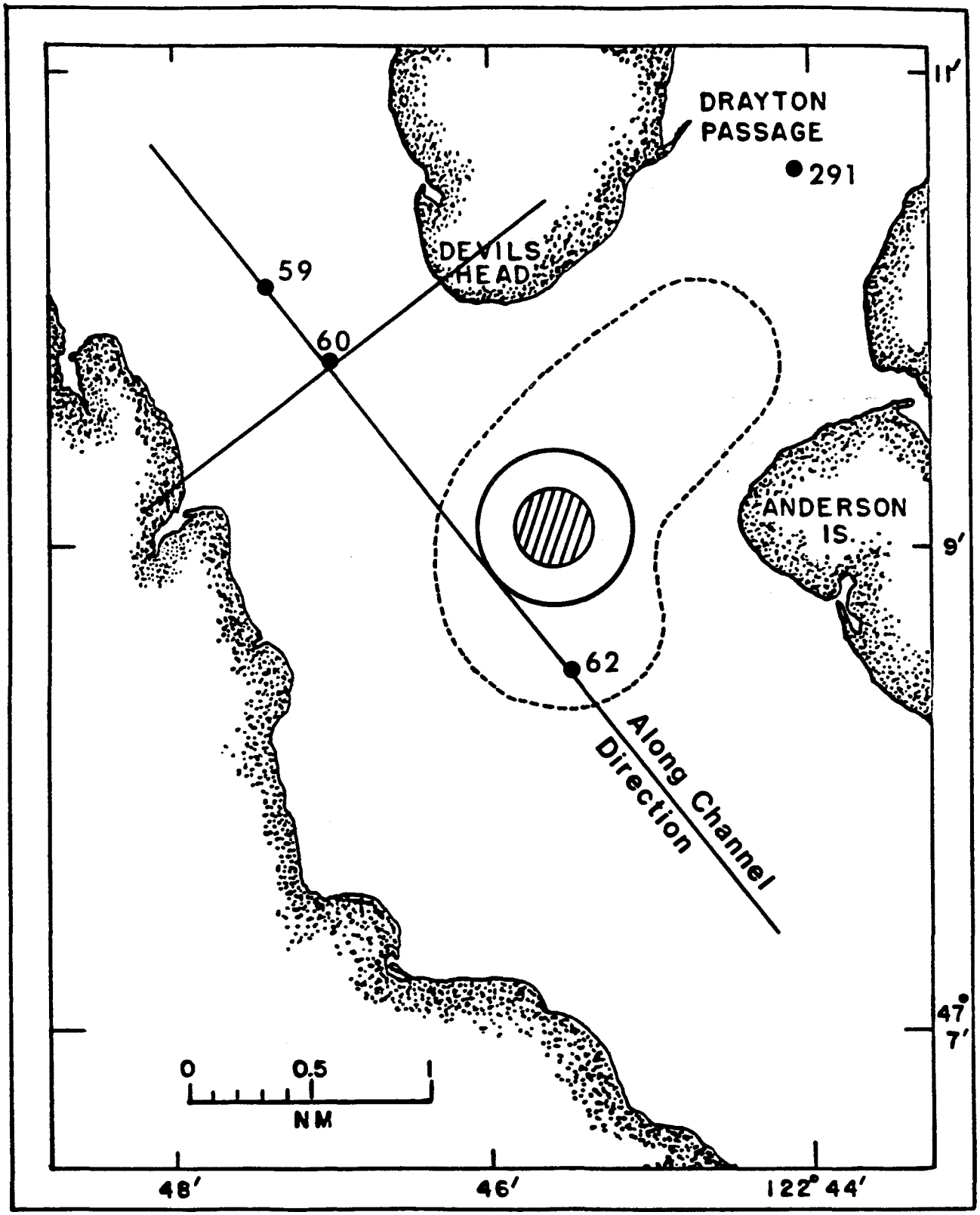


Figure II.6-2 Location of current meter sites and orientation of along channel current direction for the Devils Head ZSF.

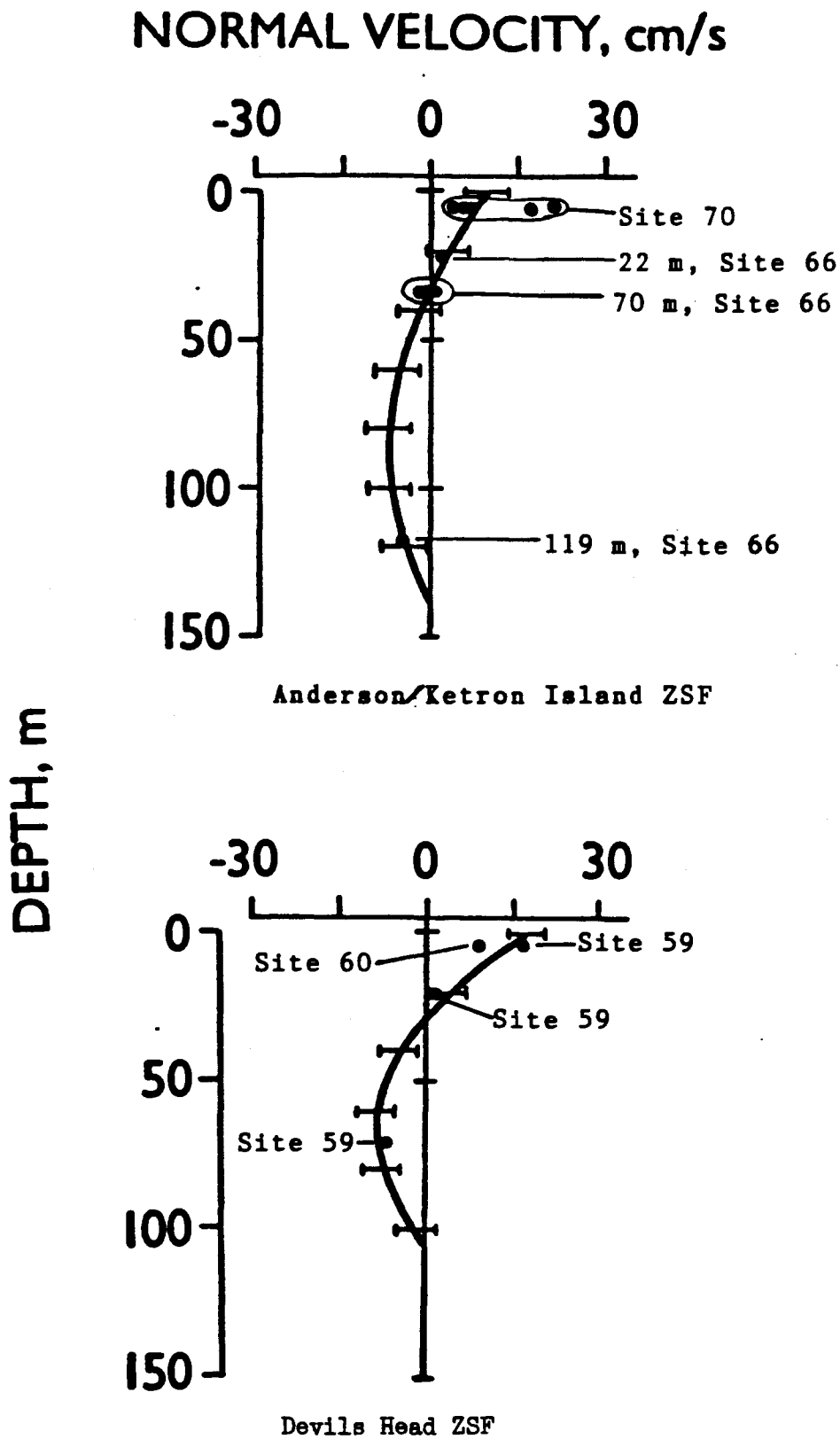


Figure II.6-3 Estimated vertical profiles of along channel net current speed for the two ZSFs in southern Puget Sound. Dots represent individual records, lines represent quadratic fit, and bars represent standard error.

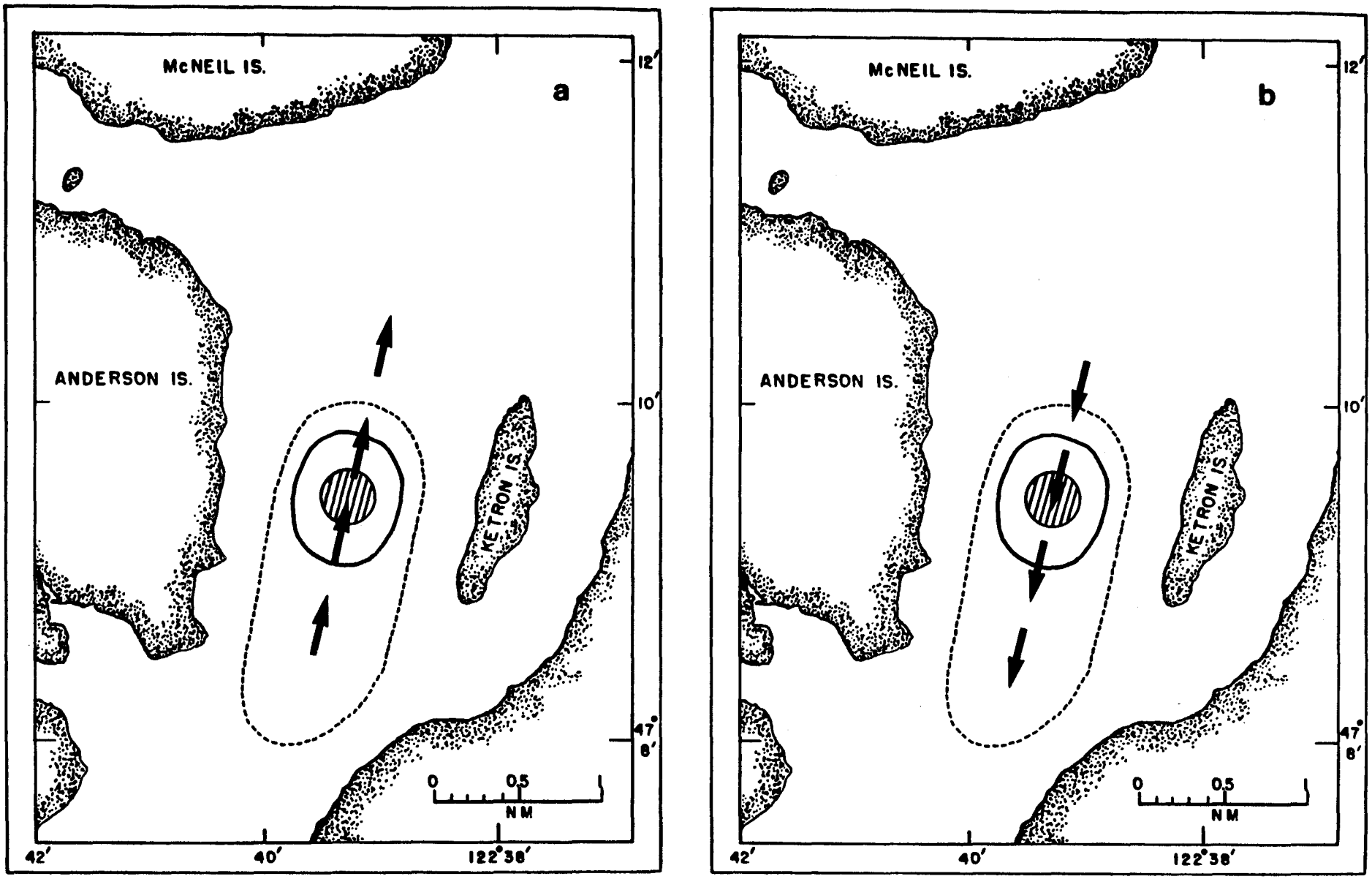


Figure II.6-4 Estimated net flow in the depth range of 0-35 m (a) and 35 m to bottom (b) for the Anderson/Ketron Island ZSF.

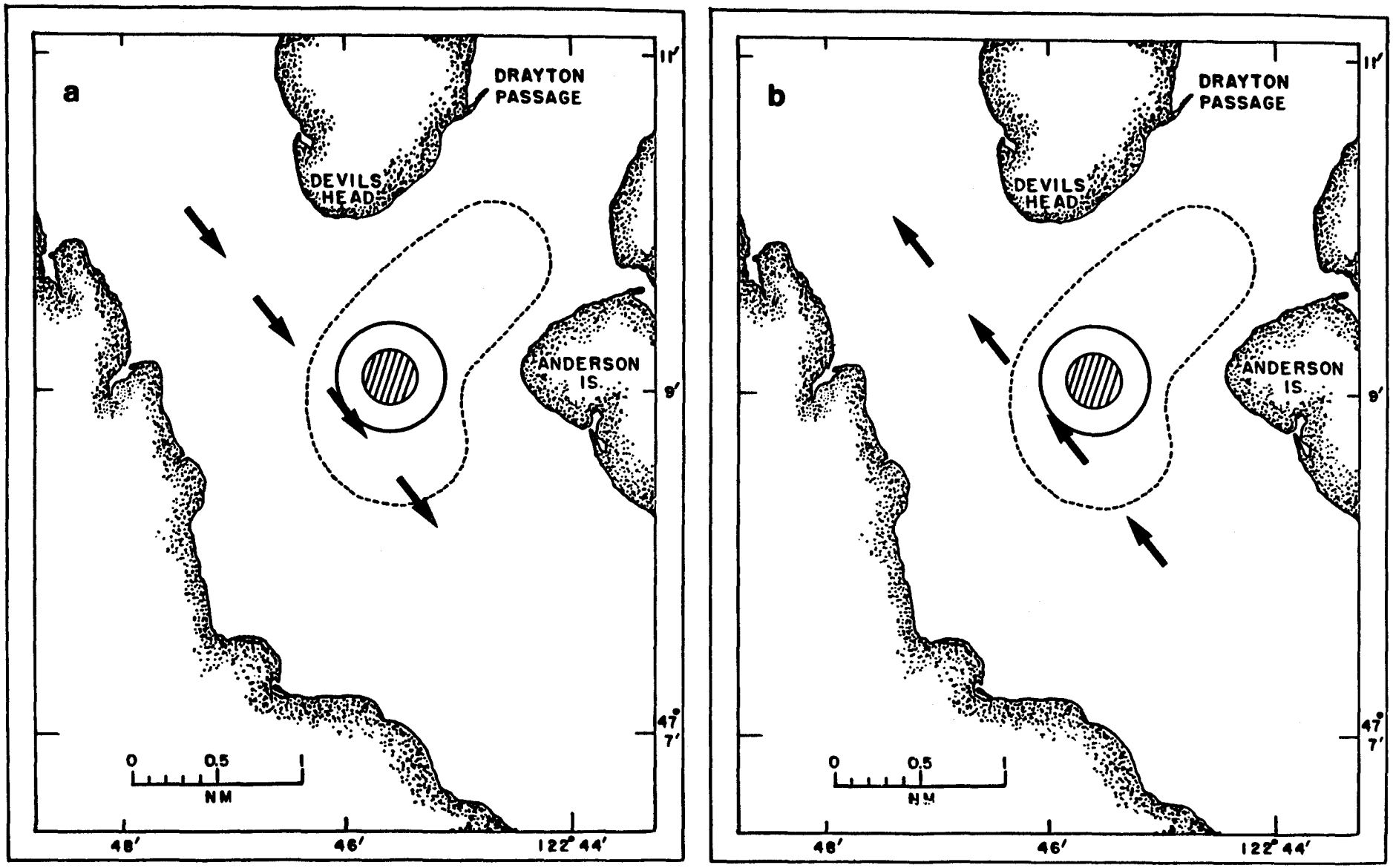


Figure II.6-5 Estimated net flow in the depth range of 0-30 m (a) and 30 m to bottom (b) for the Devils Head ZSF.

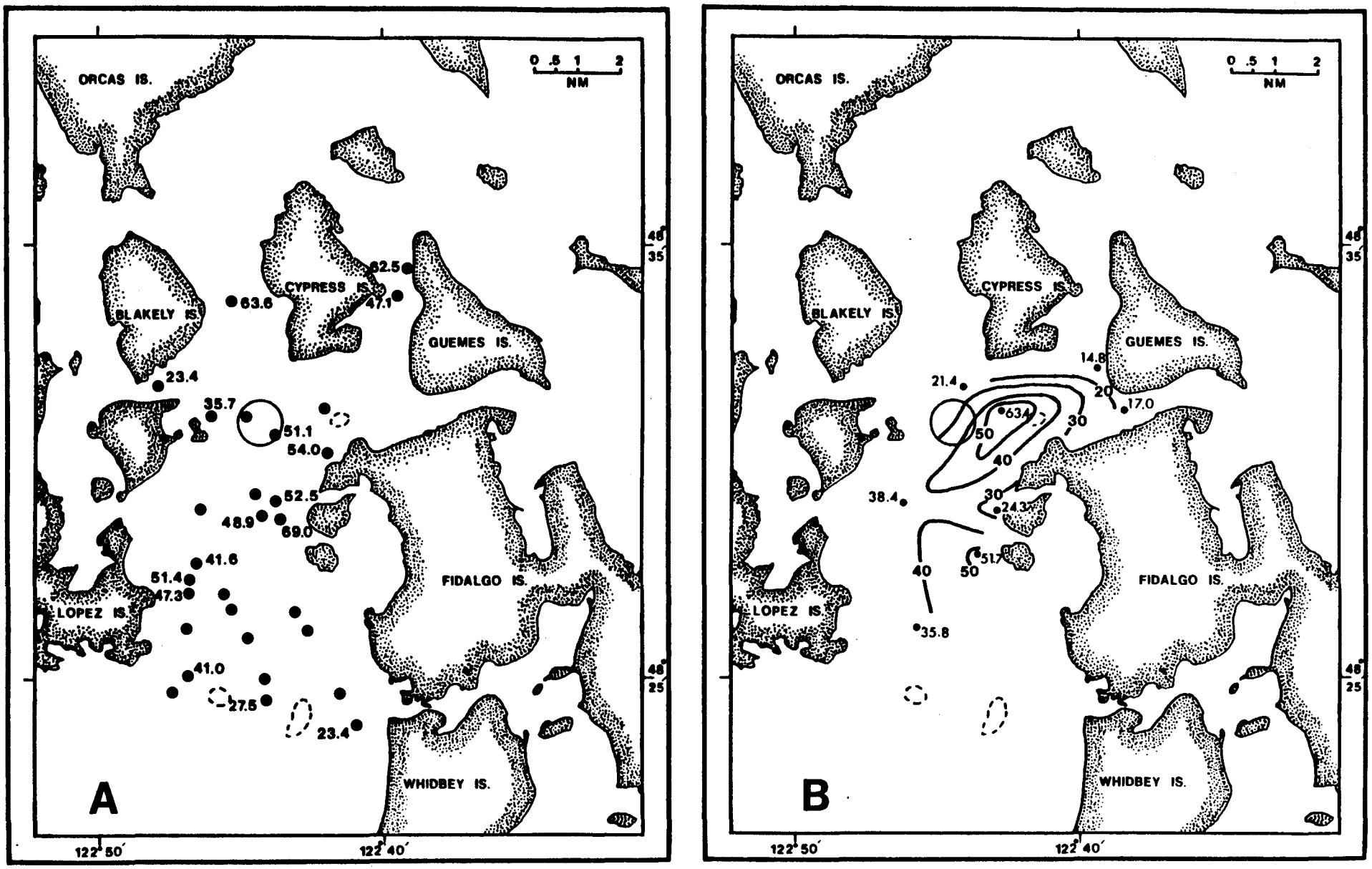


Figure II.6-6 Mean speed (cm/s) near the Rosario Strait ZSF using current meter data (a) and contours of mean speed (cm/s) using model data (b). (Source: EHI)

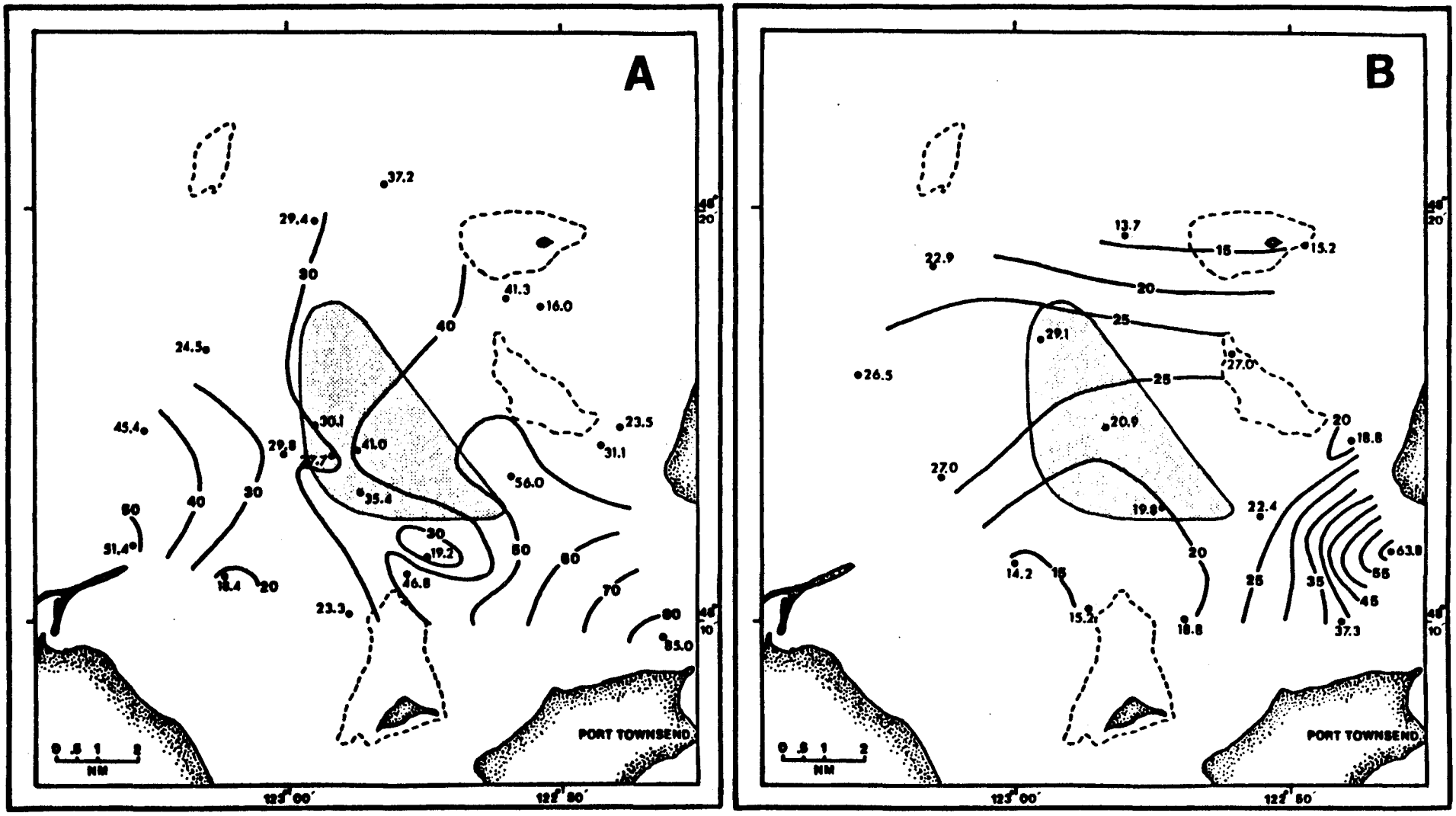


Figure II.6-7 Contours of mean speed (cm/s) near the Port Townsend ZSF. Mean speeds were calculated using current meter data (a) and model data (b). (Source: EHI)

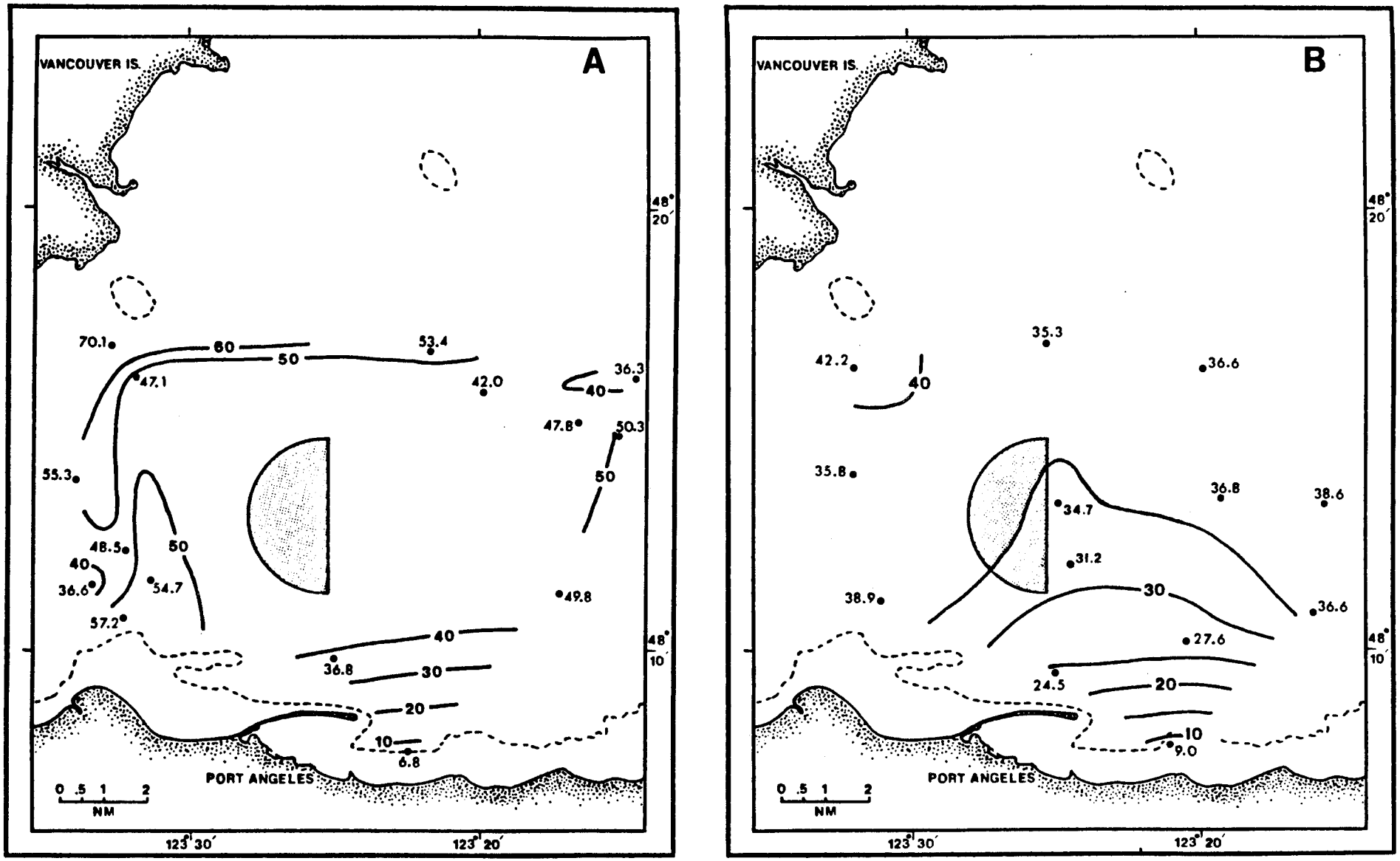


Figure II.6-8 Contours of mean speed (cm/s) near the Port Angeles ZSF. Mean speeds were calculated using current meter data (a) and model data (b). (Source: EHI)

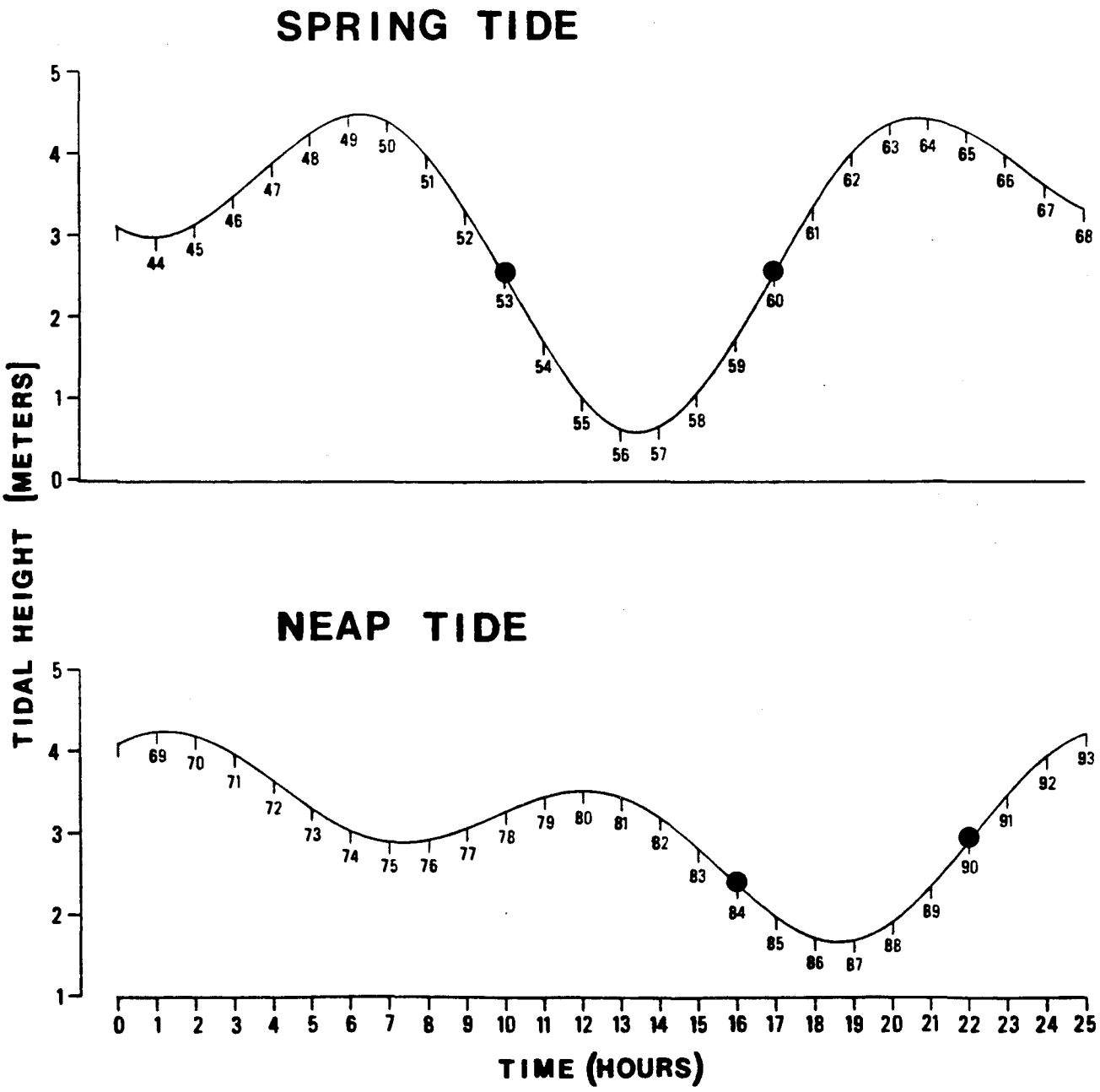


Figure II.6-9 Tidal curves of spring and neap tides. ●'s indicate the tidal stage of Figures II.6-10a-d. (Source: Canadian Hydrographic Service, 1983).

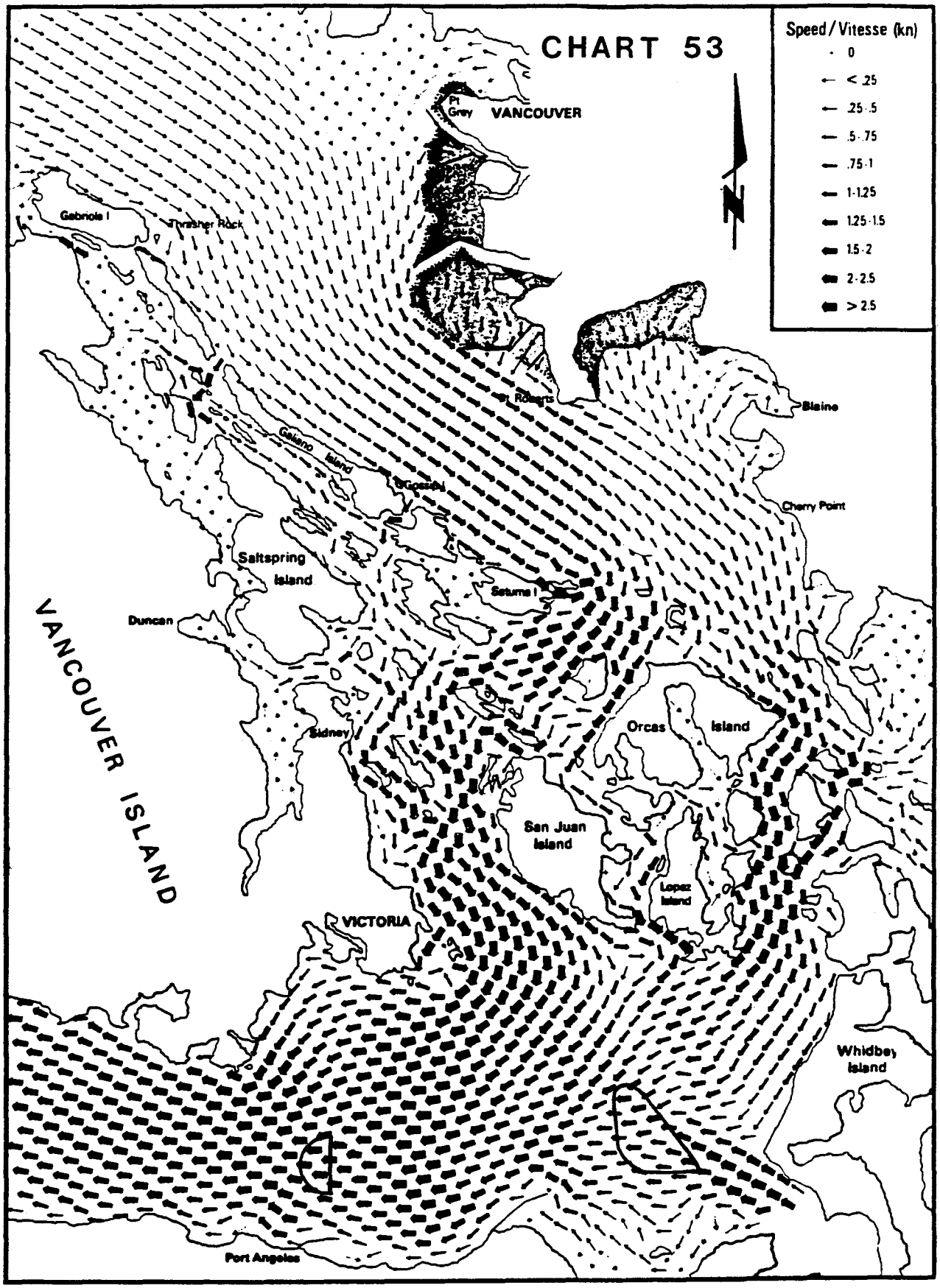


Figure II.6-10a Chart showing current speed and direction for spring ebb tides from Crean's (1983) model. (Source: Canadian Hydrographic Service, 1983).

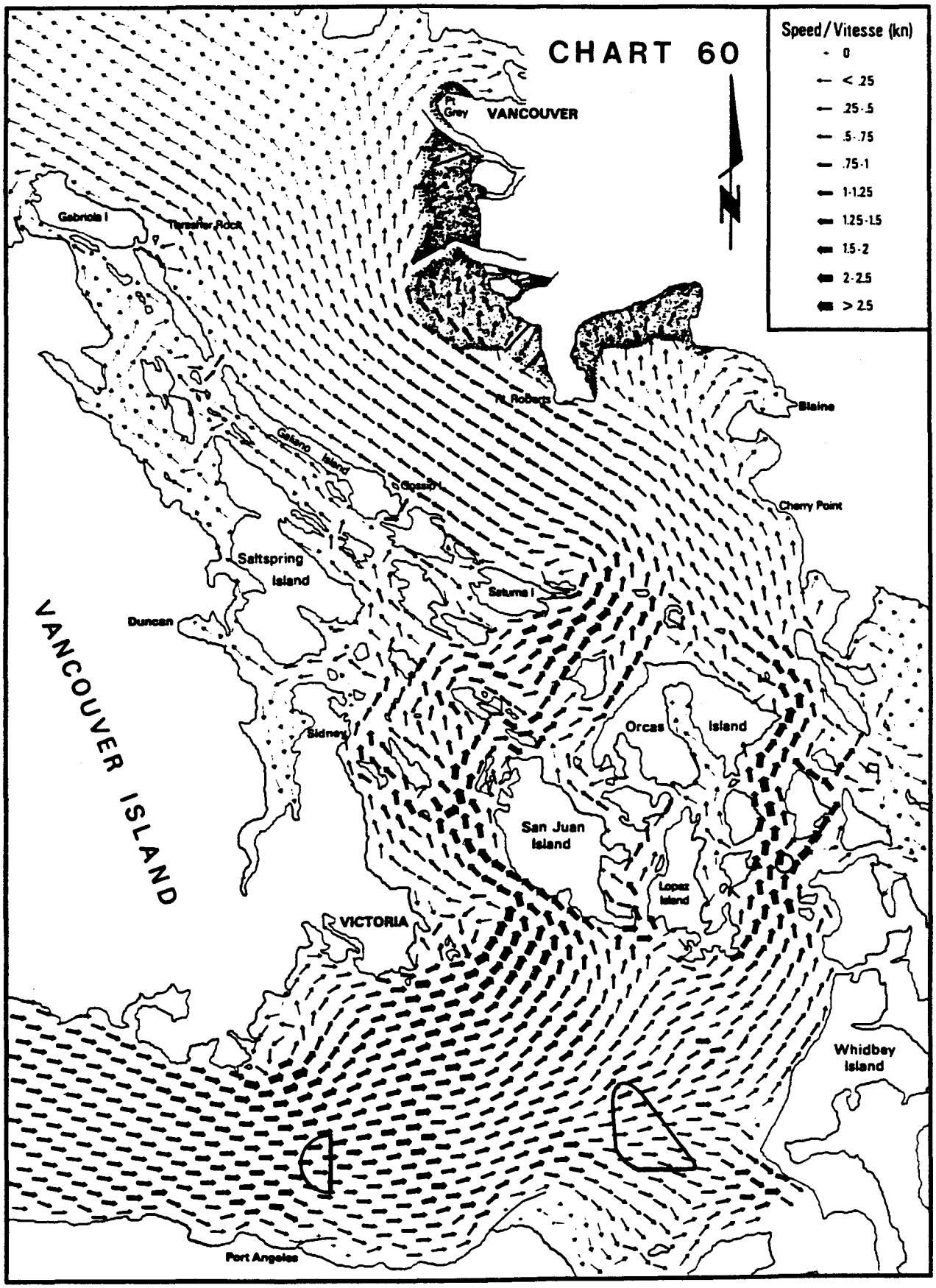


Figure II.6-10b Chart showing current speed and direction for spring flood tides from Crean's (1983) model. (Source: Canadian Hydrographic Service, 1983).

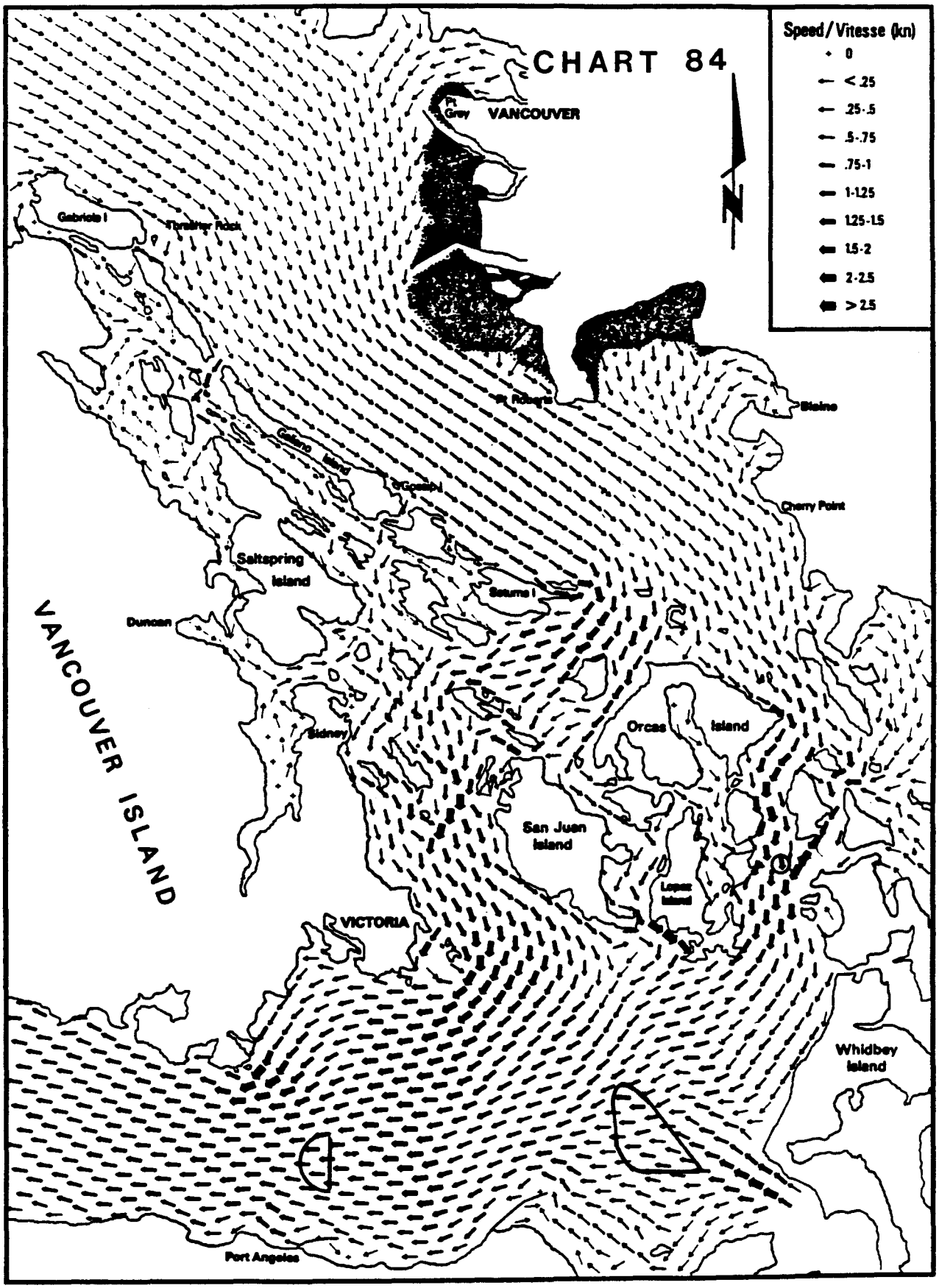


Figure II.6-10c Chart showing current speed and direction for neap ebb tides from Crean's (1983) model. (Source: Canadian Hydrographic Service, 1983).

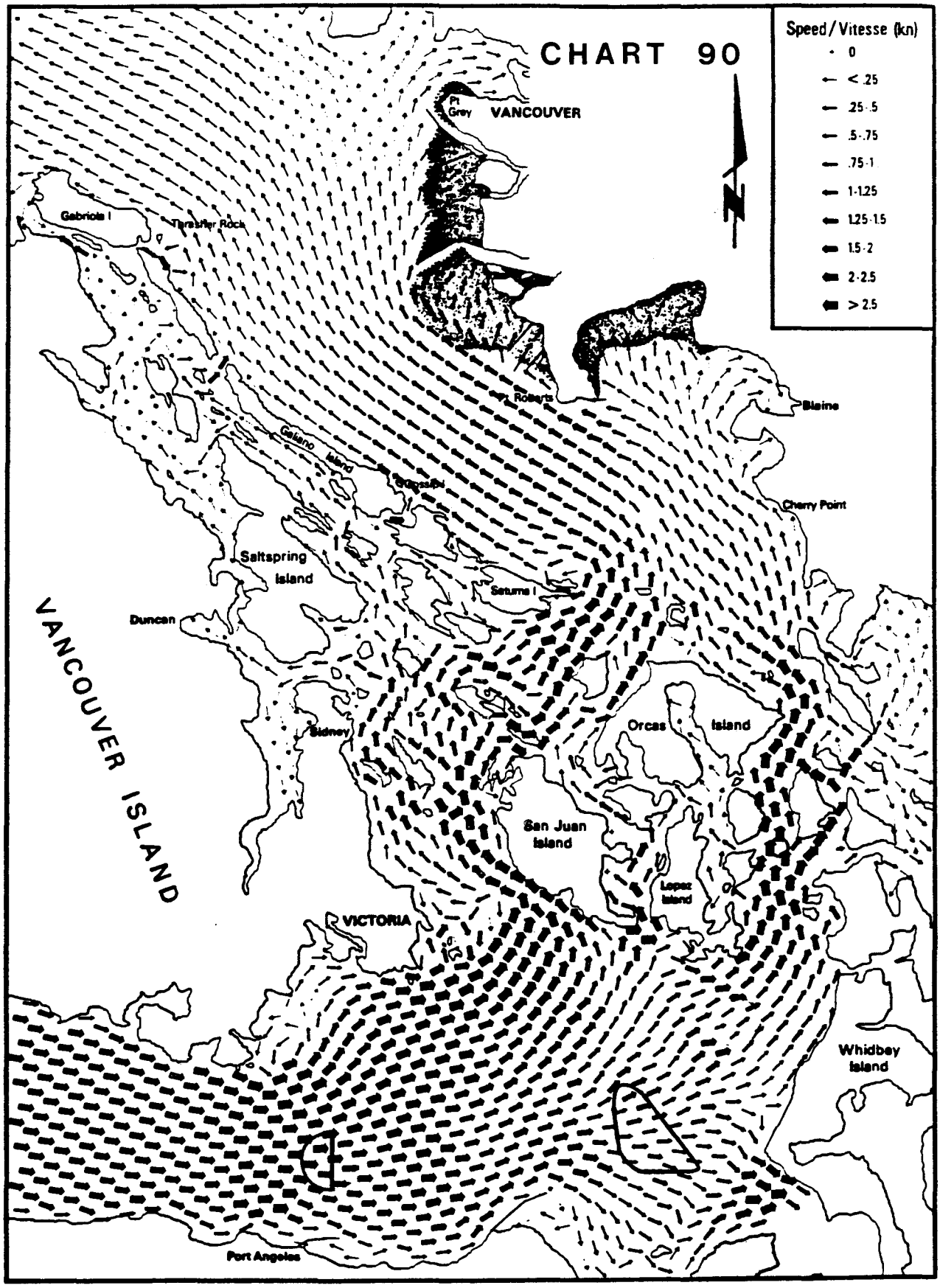
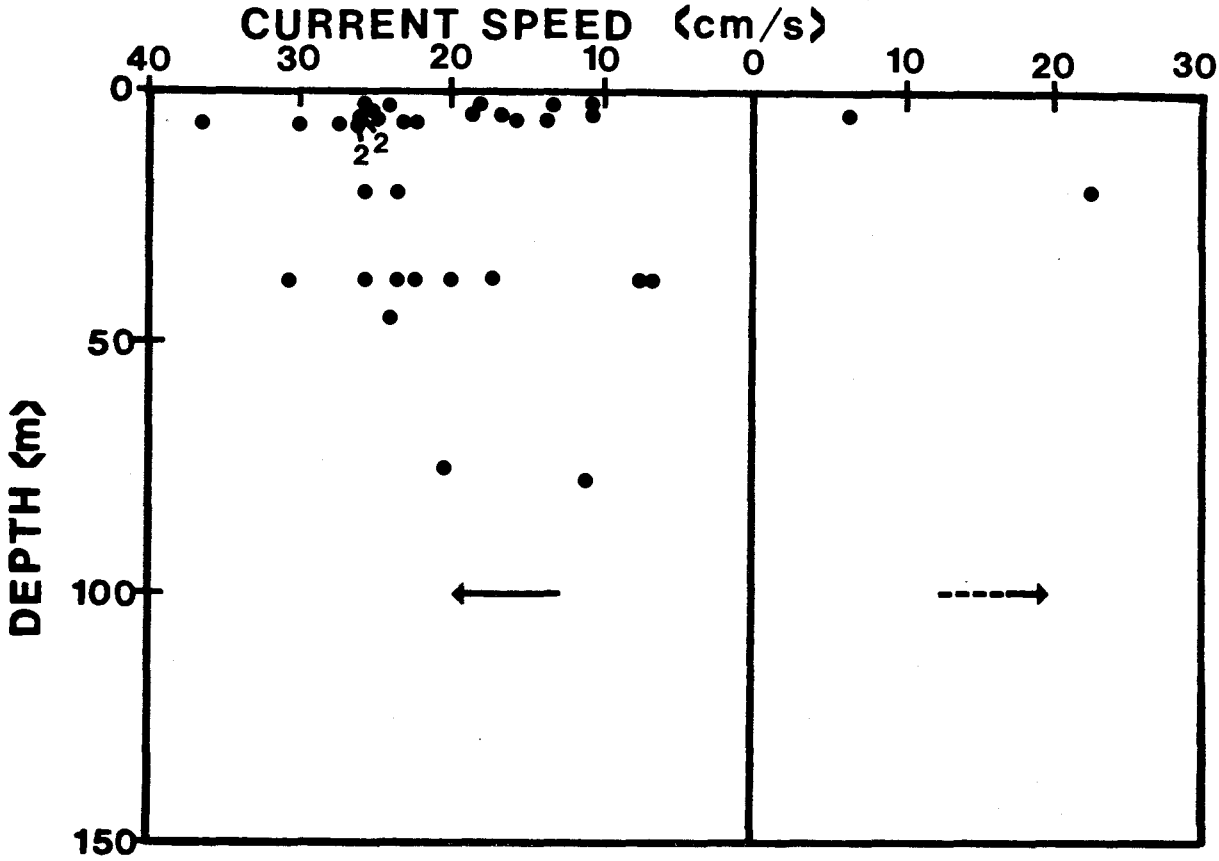


Figure II.6-10d Chart showing current speed and direction for neap flood tides from Crean's (1983) model. (Source: Canadian Hydrographic Service, 1983).



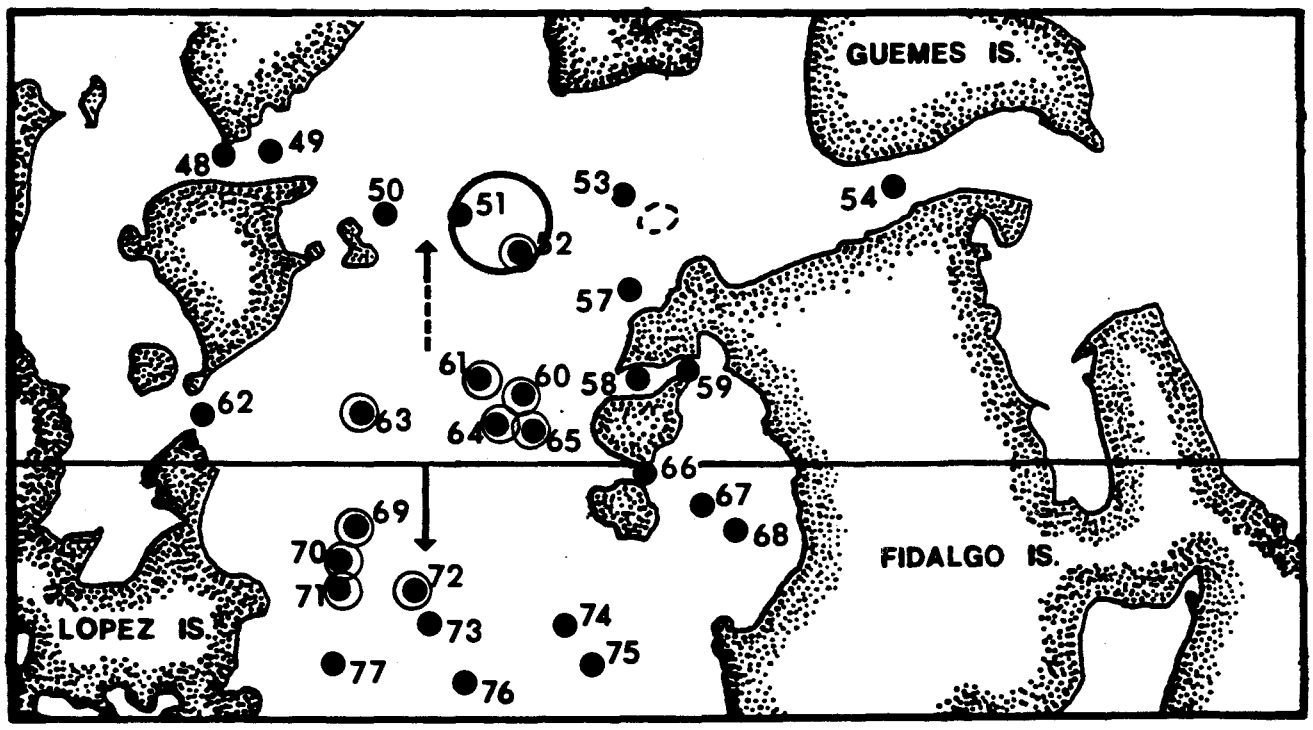
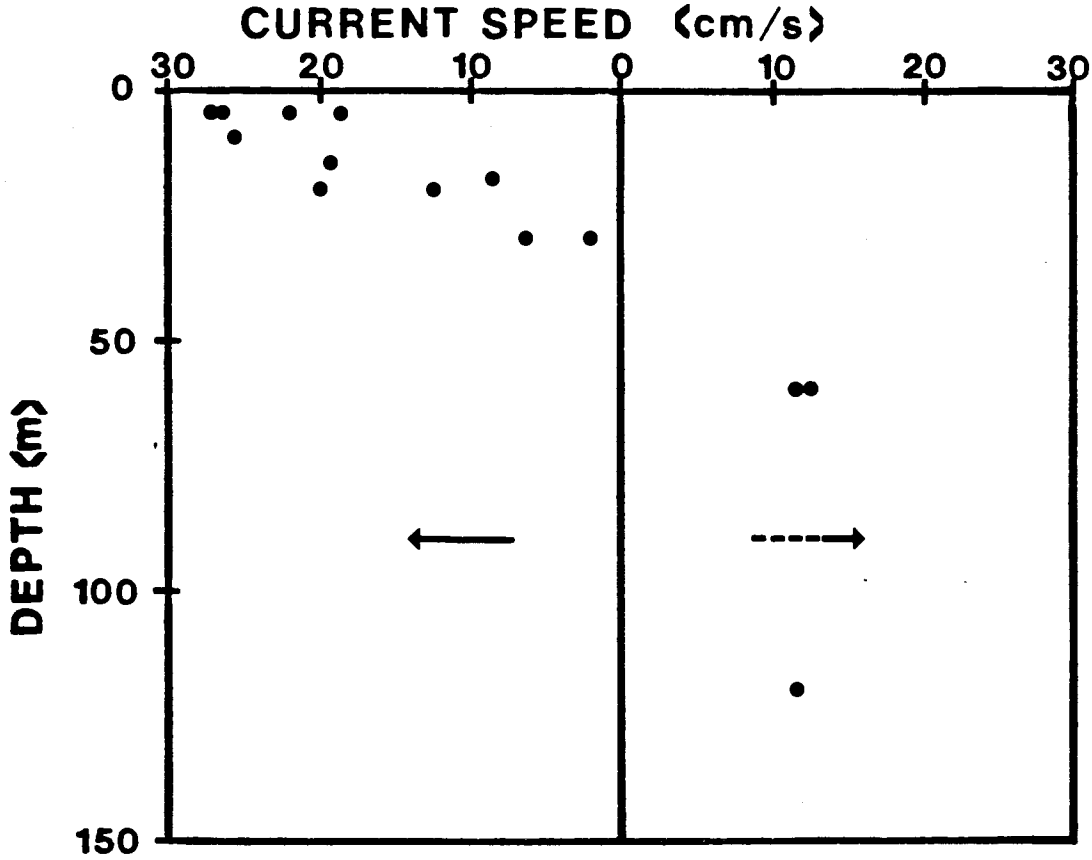


Figure II.6-11 Vertical profile (top) of net current speed reckoned seaward (solid arrow) or landward (dashed arrow). The map (bottom) shows the locations (●) of the current meter measurements used to construct the profile. The transect line differentiates the two divisions of direction, landward and seaward. (Source: EHI)



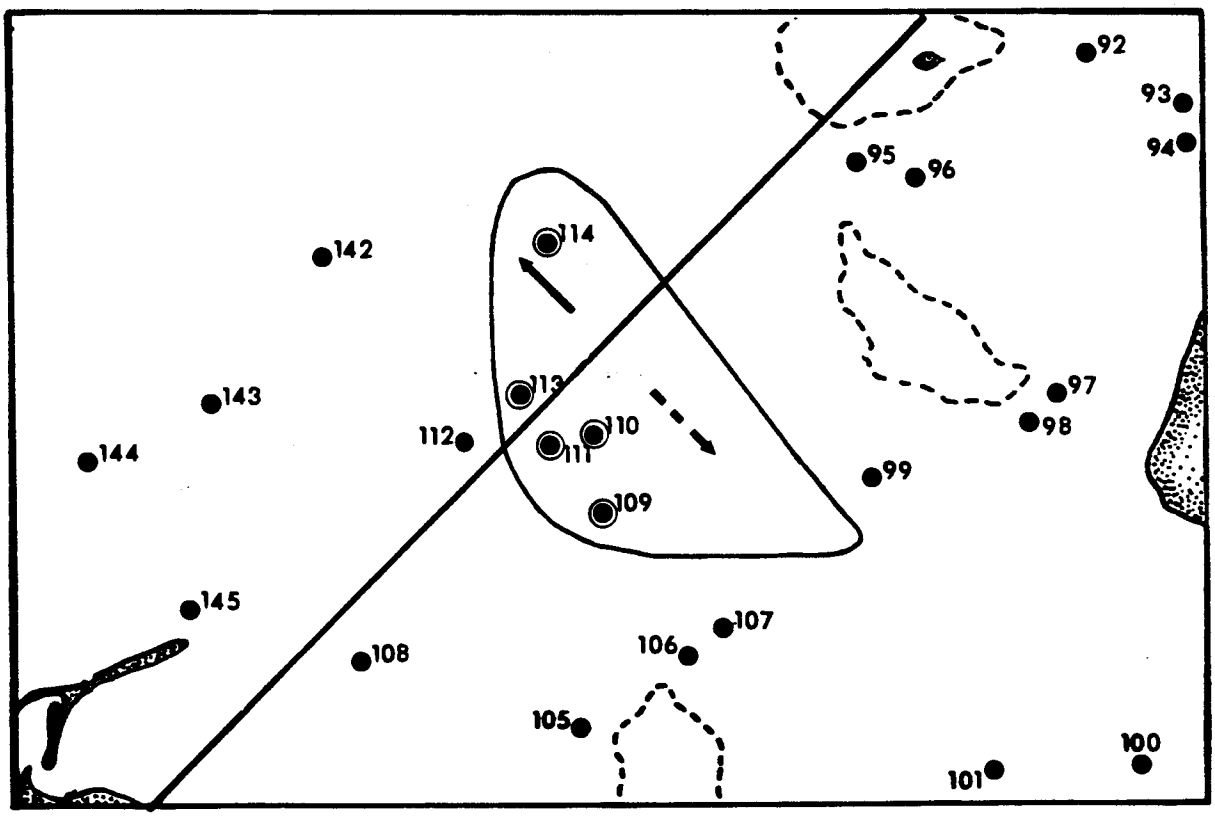


Figure II.6-12 Vertical profile (top) of net current speed reckoned seaward (solid arrow) or landward (dashed arrow). The map (bottom) shows the locations (●) of the current meter measurements used to construct the profile. The transect line differentiates the two divisions of direction, landward and seaward. (Source: EHI)

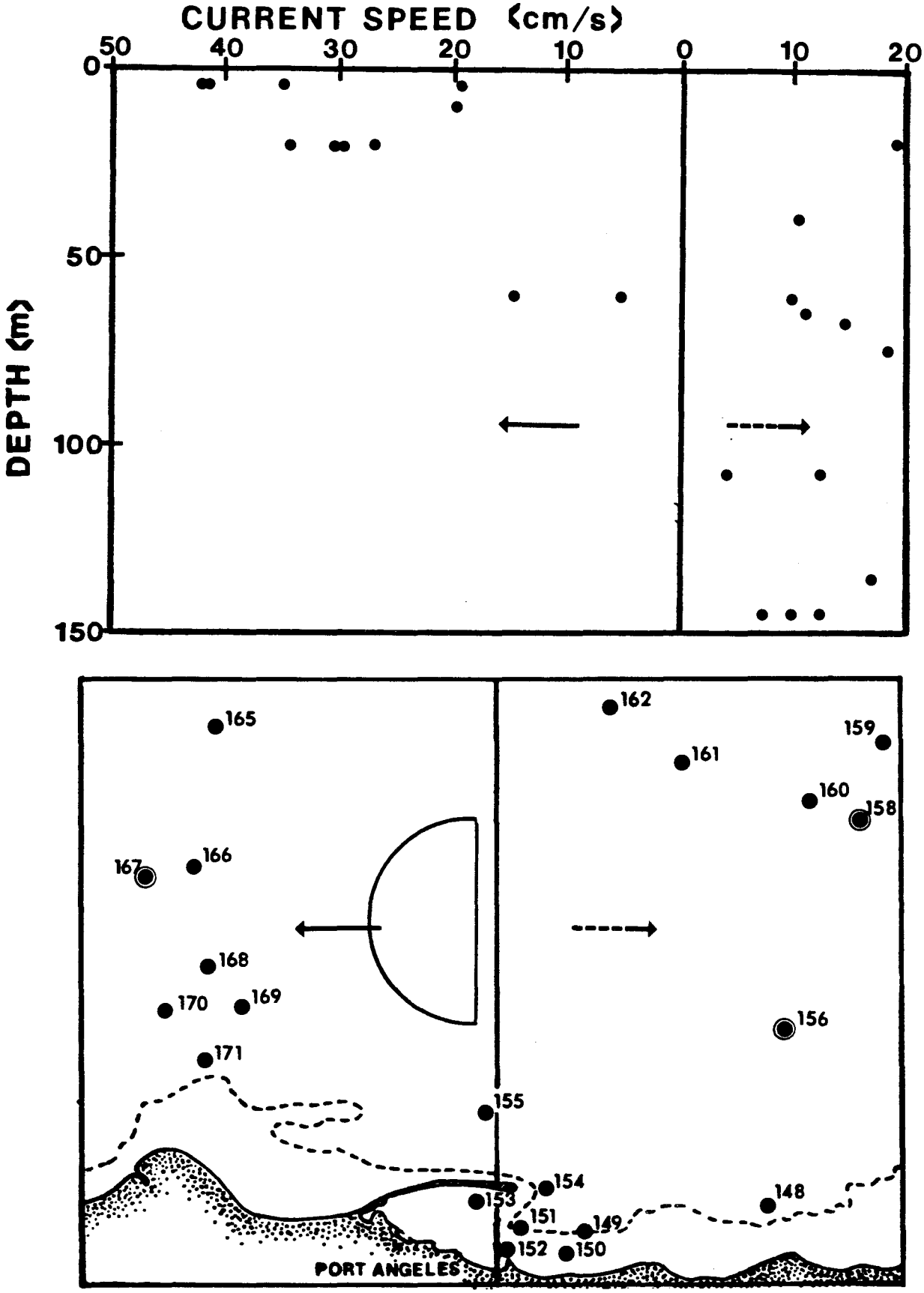


Figure II.6-13 Vertical profile (top) of net current speed reckoned seaward (solid arrow) or landward (dashed arrow). The map (bottom) shows the locations (●) of the current meter measurements used to construct the profile. The transect line differentiates the two divisions of direction, landward and seaward. (Source: EHI)

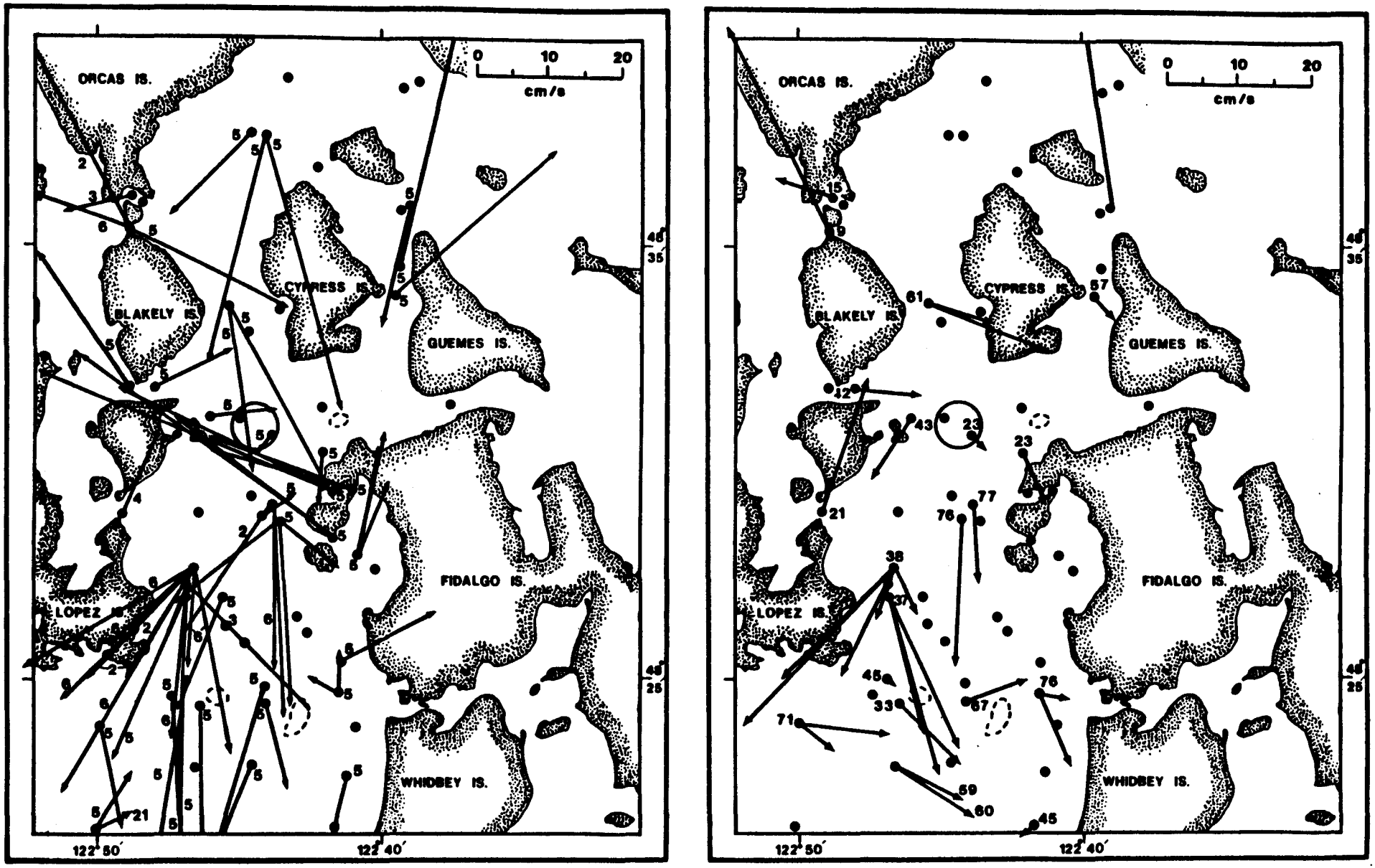


Figure II.6-14 Current vectors near the surface (a) and near bottom (b) computed from historical records. Numbers indicated depth of measurement (m) (Source: EHI)

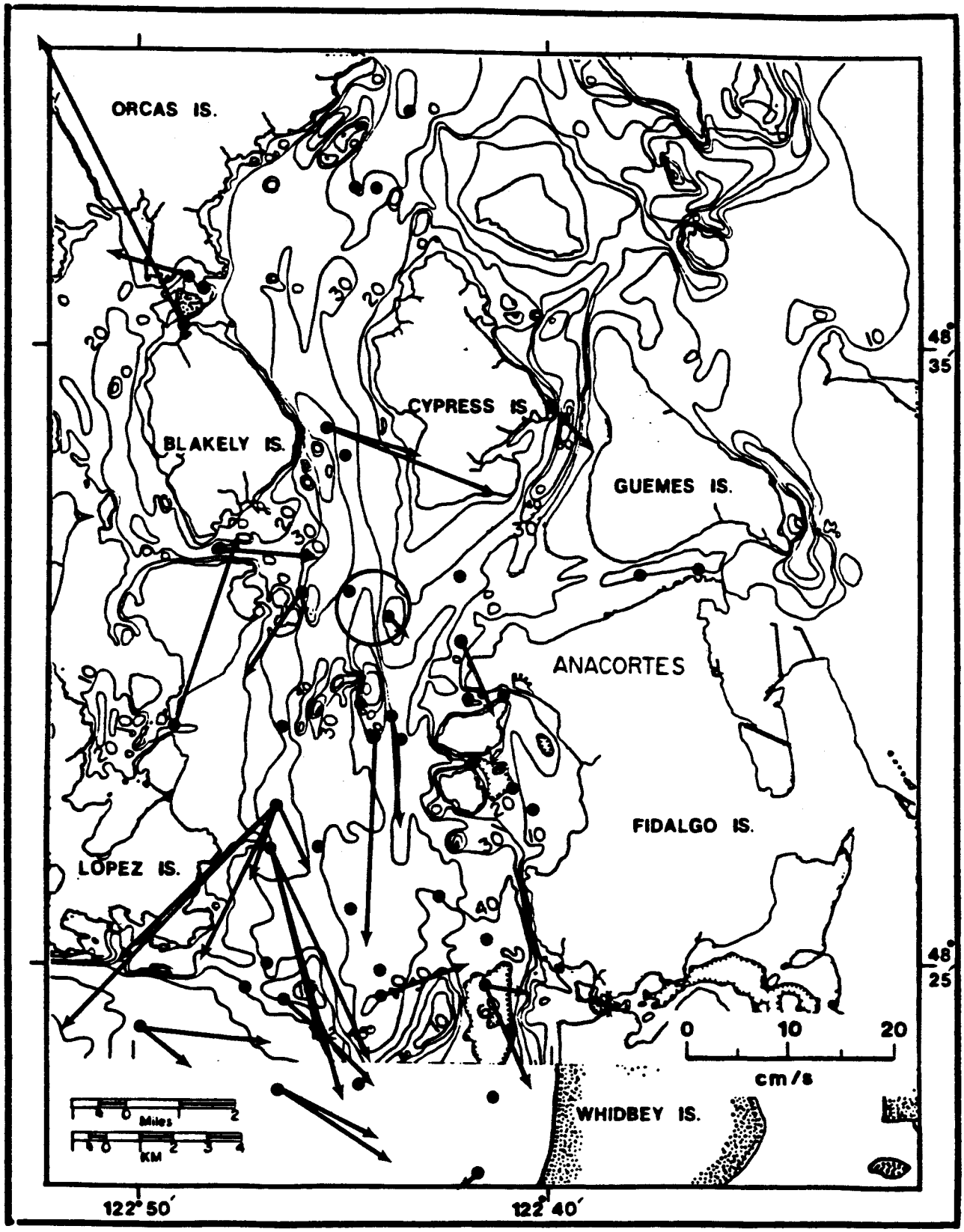


Figure II.6-15 Current vectors near the bottom superimposed on bathymetry chart of the Rosario Strait ZSF area. (Source: EHI)

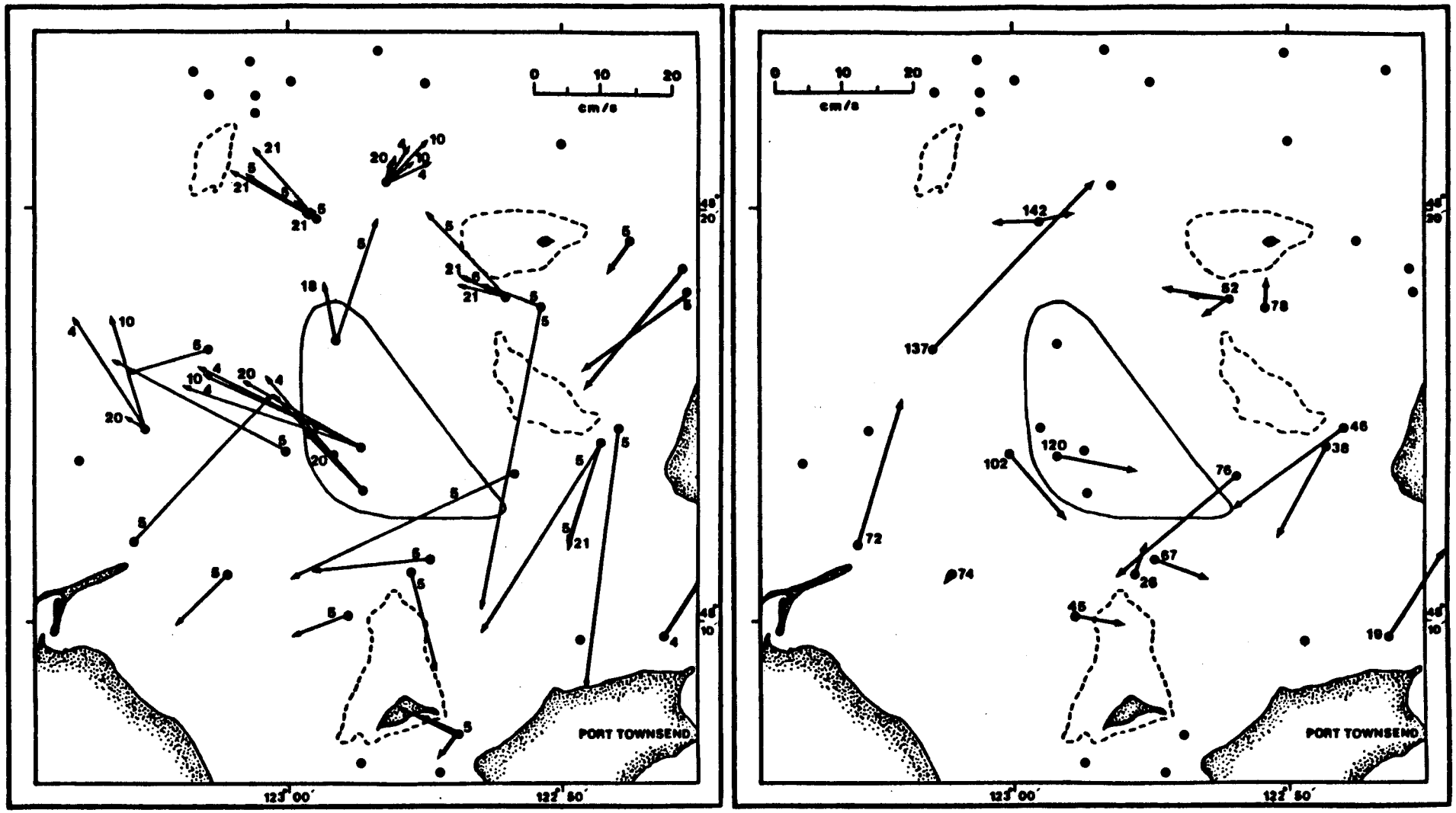


Figure II.6-16 Current vectors near the surface (a) and near bottom (b) computed from historical records. Numbers indicated depth of measurement. (Source: EHI)

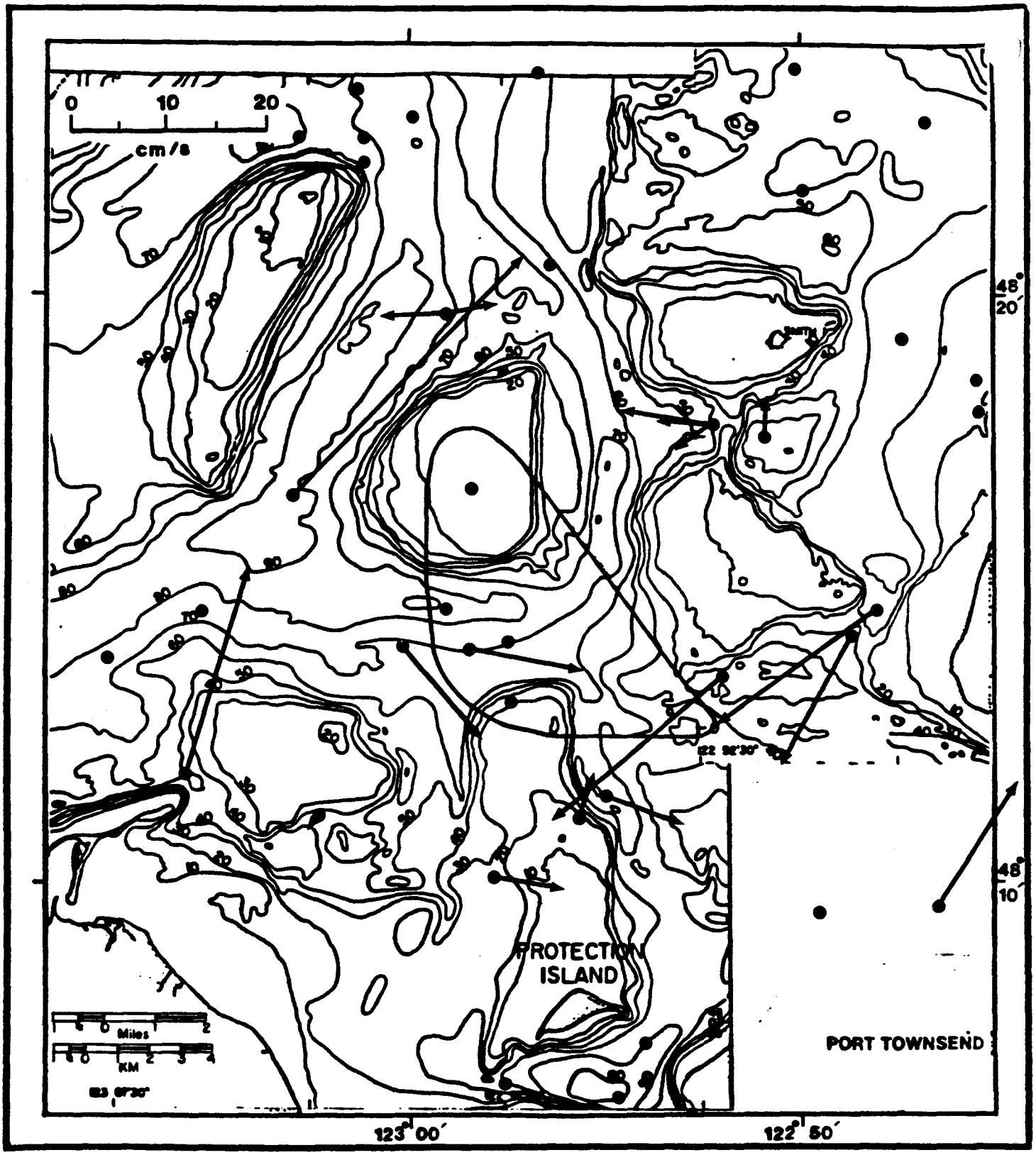


Figure II.6-17 Current vectors near the bottom superimposed on bathymetry chart of the Port Townsend ZSF area. (Source: EHI)

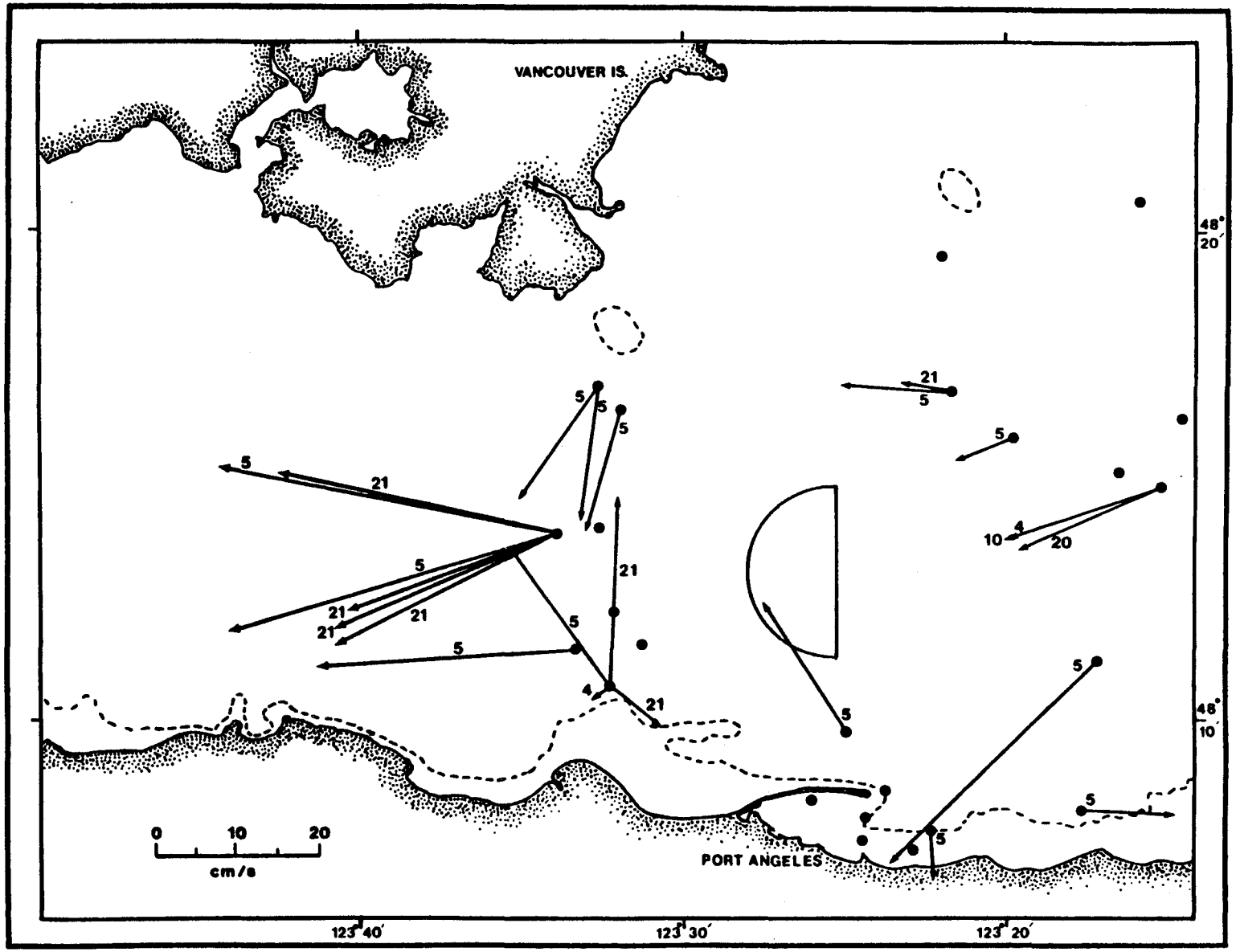


Figure II.6-18 Current vectors near the surface, computed from historical records. Numbers indicated depth of measurement. (Source: EHI)

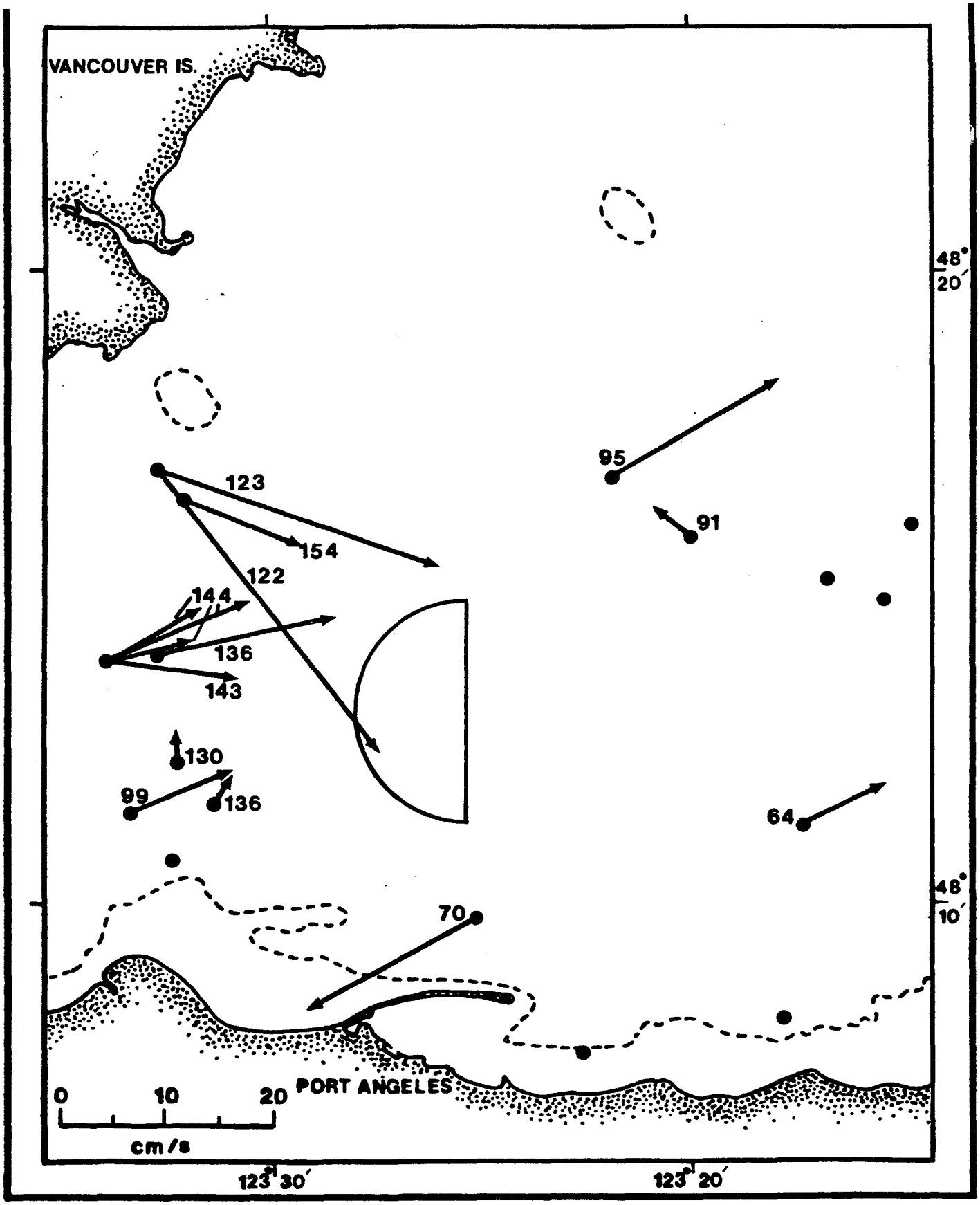


Figure II.6-19 Current vectors near the bottom, computed from historical records. Numbers indicated depth of measurement. (Source: EHI)

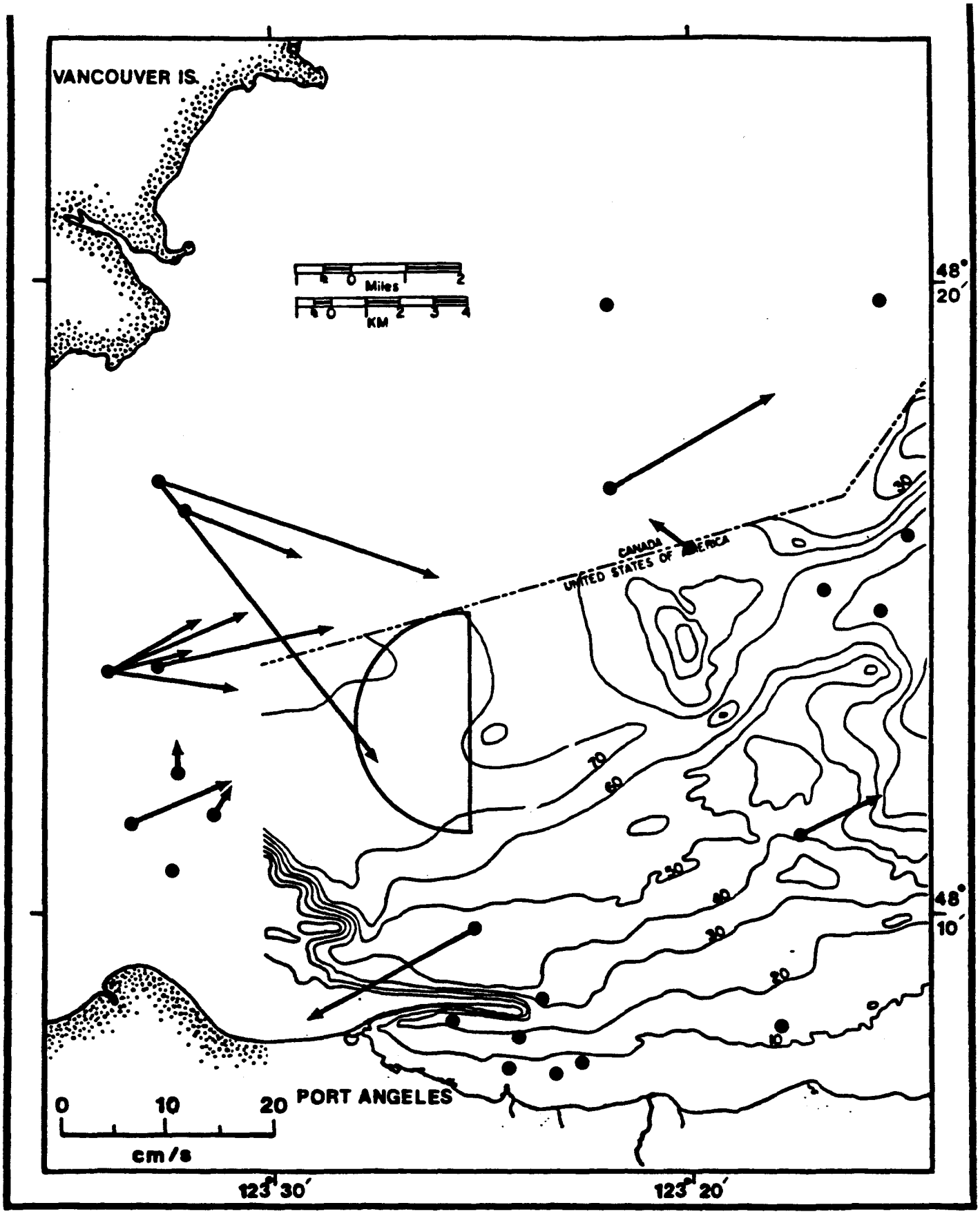


Figure II.6-20 Current vectors near the bottom superimposed on bathymetry chart of the Port Angeles ZSF area. (Source: EHI)

7. FATE OF DREDGED MATERIAL

Although the purpose of locating dispersive sites is to find areas in which the disposal material eventually will be transported away from the site, the fate of that dredged material is also important. Undoubtedly a small fraction of the disposal material deposited in the nondispersive ZSFs will also be transported beyond the disposal site boundaries. Transport offsite can occur through two mechanisms. First, the total amount of disposal material remaining suspended in the water column has been estimated to vary approximately one to five percent, after the main mass of material reaches the bottom as described below in more detail (Phase I DSSTA, Kendall et al., 1988). The prevailing currents may transport the suspended material, with some of it settling beyond the disposal site boundaries. Second, the majority of the mean current speeds through the dispersive ZSF areas are greater than the threshold speed (25 cm/sec) above which sediment becomes transported. Therefore, all of the clay/silt fraction that reaches the bottom will eventually become resuspended and transported with the prevailing current. Unusually strong currents in the nondispersive ZSFs may resuspend a portion of the disposal material, however the frequency of this occurring is only about 1% of the time.

An important factor in determining sediment fate is the composition of the sediment being disposed. During the dredging operation the clamshell dredge can deliver sediments in a near "in situ" condition. The "clumpiness" of the clamshell sediments allows the disposal operations to be more predictable, with sediment fate more easily controlled. Tests have shown that this material, disposed of by bottom dump barge, tends to remain more or less intact and falls to the bottom as a mass at a high rate of speed (Fig. II.7-1). These clumps attain their terminal velocity quickly after release from a barge and do not accelerate further with depth. After impact, the material breaks up and its ultimate dispersion is dependent on ambient currents and bed slope at the point of impact. Field measurements by Gorden (1974), Sustar and Wakeman (1977), Bokuniewicz et al. (1978), and Tavolaro (1982; 1984) indicate that one to five percent of the material is stripped from the descending jet. The rest impacts the bottom and, based on the numerical model study conducted for PSDDA Phase I by Trawle and Johnson (1986a), a large percentage of this material settles on the bottom within a 600-foot radius of the center of the dump within one hour.

The velocity of water currents affects the distribution of sediment particle sizes in unconsolidated soft bottom material. Coarser sediments are associated with higher current environments, while fine-grained sediments are associated with lower energy environments. For example, a current velocity of 0.4 knot (20.6 centimeters per second) will shift ordinary sand along the bottom, while a current of one knot (51.5 centimeters per second) will shift fine gravel. A current of 2.15 knots (111 centimeters per second) will move coarse gravel 2.5 centimeters in diameter, and 3.5 knots (180 centimeters per second) will move angular stones up to 3.8 centimeters in diameter (Moore, 1958). Therefore, to a substantial degree currents determine the grain-size distribution of sediments. Figure II.7-2 illustrates the relation between current velocity and its potential to deposit, transport, and/or erode sediments of various grain sizes.

The historical current data were examined to determine possible pathways by which the suspended sediment may be carried by prevailing currents. For this purpose the current meter records previously examined for current strength were also used to compute the prevailing currents expressed mathematically as vectors having a net speed and direction.

The following sections describe the thickness of disposal sediments based on the WES model and natural deposition rates. Where natural sediment rates were unavailable an approximate computation was made to estimate sediment thickness. In addition the dispersion of suspended and resuspended materials specific to each ZSF are considered herein compared with naturally occurring sediments and transport processes.

7.1 Nondispersive ZSFs

7.1.1 Thickness of Disposal Sediments--

Sediment thickness is discussed below as determined from the WES model (c.f. Section II.4 and Phase I DSSTA) and an approximate computation, since natural deposition rates were generally not available for the nondispersive ZSFs. In areas of low current, a large portion of suspended material will eventually settle in the disposal site. Assuming a worst case scenario in which the suspended material equals 5% and it settles in an area adjacent to the disposal site, the sediment thickness can be calculated as follows:

$$\frac{0.05 \times \text{potential disposal volume} \times \%\ \text{solids} \times \text{density}}{A \times 15\ \text{years}} \text{ in units of } \frac{mg}{cm^2 y^{-1}} \quad (1)$$

where A is the area the sediment will settle in. Disposal volumes are based on 15 year projections (1985-2000), hence the 15-year multiplier.

7.1.1.1 Anderson/Ketron Island ZSF 2

The disposal depth of the ZSF averages 442 feet. The WES model simulating a 400-foot depth disposal site yields mass accumulation rates varying between 0.167 - 0.459 gm/cm^2 (Fig. II.7-3b). Table II.7-1 displays the minimum, maximum, and mean thickness for all of the model runs (test runs = 30 minutes). All three test runs at 400 feet ended before all of the material settled to the bottom. A earby site estimated by Carpenter et al., (1985) averages 0.360 gm/cm^2 and compares favorably with the model estimate (Fig. II.7-4).

Figure II.7-5 shows the area used to calculate the thickness of the 5% suspended sediment after settling to the bottom. Based on equation (1) the sediment accumulation would be approximately .00559 gm/cm^2/year, a value ranging from 3.3%-1.2% of the model yearly estimate and 1.6% of the Carpenter et al. (1985) stuty.

7.1.1.2 Anderson Island/Devils Head ZSF 3

The average water depth at the Devils Head ZSF is 238 feet. The closest depth simulated by the WES model is 200 feet (Table II.7-1, test runs 4-6; Fig. II.7-3a). Mass accumulation rates using the model ranged from 0.458 to 0.995 gm/cm^2. These values are higher when compared to the site studied by Carpenter et al., (1985; Fig. II.7-4). The thickness of the initially 5% suspended sediment is estimated at .00856 based on estimates from equation (1). This value is about 2.5%-1% of the model results and studies by Carpenter et al. (1985).

7.1.1.3 Bellingham Bay

All of the Bellingham Bay ZSFs average 90 feet, the shallowest of all the ZSFs. The closest WES model run is at 200 feet with sediment accumulation rates of 0.458 to 0.995 gm/cm^2 per year for a single barge dump. A site studied by Carpenter et al., (1985) located to the north of the ZSFs averaged 0.650 gm/cm^2 per year, a value well within the model ranges (Fig. II.7-4). This means that a single dump deposits a thickness equivalent to natural deposition in a year.

7.1.2 Anticipated Effect of Dredged Material Disposal--

Assuming that 95 percent of the dredged material settles to the bottom and that particles settle at a slow speed of 0.0017 feet per second, a time of about ten hours is required for the remaining five percent to be deposited on the bottom 61' water depth. In a site that has a radius of approximately 2,000 feet, with the disposal zone at the center, and a bottom current of 0.1 feet per second (3 centimeters per second), a time of about 5.5 hours would be required to transport a sediment particle out of the site. Thus, an additional two to three percent of the dredge material will be deposited within the site, leaving two to three percent that would be transported beyond the site. Note: @ .0017 ft/sec it would take approximately 65 hours for all material to settle in 400' of water, i.e., $\frac{400 \text{ ft}}{.0017 \text{ ft/sec}} = 65$ hrs.

7.2 Dispersive ZSFs

7.2.1 Thickness of Disposal Sediments--

Sediment thickness is discussed below as determined from the WES model and the natural deposition rate. The depositional patterns will vary depending upon the phase and type of tide during which disposal occurs. Slack and major floods represent the extremes. During slack water, the possibility of current reversal could cause larger thicknesses than reported. Table II.7-1 lists resultant thicknesses based on results from the WES model.

7.2.1.1 Rosario Strait

The average water depth of the Rosario Strait ZSF is 180 feet, the shallowest of the dispersive ZSFs under study. The closest depth in the WES model is 200 feet (test runs 4-6). Table II.7-1 displays the minimum, maximum, and mean thickness. All of the material settled to the bottom before the end of the test runs, i.e., in 30 minutes (Fig. II.7-3a).

Sediment accumulation rates from Carpenter et al. (1985) average 0.076 gm/cm^2/year (Figure II.7-4). The WES model yields mass accumulation rates ranging from 0.995 gm/cm^2 to 0.458 gm/cm^2, depending upon speed, yielding thicknesses 6 to 13 times greater than the range of the natural deposition rates.

7.2.1.2 Port Townsend

The average water depth is 420 feet. The closest depth in the WES model is 400 feet (test runs 7-9; Fig. II.7-3b). Table II.7-1 displays the minimum, maximum, and mean thicknesses. All of the material settled to the bottom before the end of the test runs.

Neither Carpenter et al. (1985) nor Lavelle et al. (1986) studied the area around the Port Townsend ZSF. Neither study's data base can be used to estimate the natural deposit on rates in thi area. The WES model yields a range from 0.167 gm/cm^2 to 0.459 gm/cm^2.

7.2.1.3 Port Angeles

The average water depth is 420 feet. The closest depth in the WES model is 400 feet (test runs 7-9; Fig. II.7-3b). Table II.7-1 displays the minimum, maximum, and mean thicknesses. All of the material settled to the bottom before the end of the test runs.

Neither Carpenter et al. (1985) nor Lavelle et al. (1986) examined the area around the Port Angeles ZSF. Neither study's data base can be used to estimate the natural deposition rates in this area. The WES model calculates a mass per unit area ranging from 0.167 gm/cm^2 to 0.459 gm/cm^2.

7.2.2 Anticipated Effect of Dredged Material Disposal--

Because the mean current speeds lie substantially above the threshold speed above which fine sediment becomes eroded, the disposal sediments in the three dispersive ZSFs, where preferred sites have been identified, will become resuspended and move with the prevailing currents. These materials were considered along with the other materials that were initially suspended in the water column in relation to naturally occurring materials.

The seasonal distributions of total suspended solids were determined by Baker et al. (1978) for the area north of Admiralty Inlet, east of Port Angeles, and south of the Fraser River between November 1976 and August 1977. Distributions of suspended particulate matter near the surface and near the bottom for November 1976, March 1977, and August 1977 are shown in Figure II.7-6a-f. Values typically ranged from 0.5 to 2 milligrams per liter throughout most of the area. The highest concentrations were observed near the Fraser River (8 milligrams per liter) and Deception Pass (2-3 milligrams per liter) during November 1976 and August 1977. Vertical distributions of suspended particulate matter showed highest concentrations in the surface and near bottom waters. The high surface concentrations are believed to be due to freshwater runoff and primary production. Seasonal variability was insignificant on a regional basis except for areas directly influenced by river runoff. Diurnal variability was most pronounced near major sediment sources and at stations characterized by large tidal excursions. Elevated levels near the bottom are probably related to resuspension processes.

A considerable amount of sediment is discharged by local rivers. The Fraser and Skagit Rivers discharge approximately 24 million metric tons annually (Baker et al., 1978). If all of this material were to deposit on the bottom at the large bulk density seen in maintenance dredging and disposal operations (1.35 grams per cubic centimeter), this mass of material would be equivalent to 57 million cubic yards of dredged material. Additional sediment is contributed by erosion from local cliffs.

The amount of sediment discharged by the rivers may be compared with estimates of the sediment accumulating on the bottom (Fig. II.7-4). In general the accumulation rates in northern Puget Sound appear to be approximately 200-300 milligrams per square centimeter per year.

A key factor in the selection of the Phase II dispersive ZSF's was to locate the ZSF's where the disposed sediment would be dispersed rapidly over a wide region. The circulation data presented in the previous chapter, when combined with the results of recent numerical modeling studies on the disposal process for dredged material (Trawle and Johnson, 1986a), provide enough information to allow a rough check on the dispersive nature of the Phase II sites and the effects of disposal operations on natural conditions. The following estimates of the short term effects due to the disposal of dredged material assumes that the dredging operations are conducted using a clamshell dredge and bottom dump barge. As discussed in section II.4, when dredged material is released from a barge, it descends through the water column as a dense fluid like jet. When this jet hits the bottom it collapses, and moves radially outward as a density/momentum-driven surge. At a nondispersive site, where peak current speeds are less than about 25 cm/sec, little if any further movement of the material is expected. However, peak current speeds at all the Phase II dispersive sites greatly exceed 25 cm/sec. These currents will erode the mound of deposited material at a rate that is dependent on the mound area, current speed, and material type. In another study Trawle and Johnson (1986b) estimated the erosion potential of dredged material as a function of the current speed. Using this information, estimates can be made of both the suspended particulate concentration immediately after a disposal operation, and the dispersion rate of material that is deposited on the bottom.

7.2.2.1 Effect of Disposal on Suspended Sediment Concentration

With several assumptions, a rough estimate of the increase in suspended sediment concentrations due to the disposal of a barge load of dredged material may be made. The assumptions made in the calculations are:

1) 1,500 cubic yard capacity barge (1.1×10^6 liters),

2) 21 percent of this load, (by volume), is sediment, (2.3×10^5 liters), the rest is water. At a specific gravity of 2.6 for the solids alone, (average density of 2600 grams per liter), the mass of the suspended sediment is 6×10^8 grams,

3) 5 percent of the disposed sediment remains suspended after one hour (3×10^{10} milligrams),

4) The disposal takes place at the beginning of a flood or ebb tide,

5) The average current speed during, and for six hours after the disposal, is 1 ft/sec (30 cm/sec),

6) The disposed material spreads out in a wedge shape, 45 degrees to either side of the current flow,

7) The average water depth is 400 feet,

8) The material is distributed evenly throughout the wedge.

Immediately after the disposal operation elevated concentrations of suspended sediment may be evident at selected depths in the water column. At the end of one hour, only 5 percent of the material is expected to remain in the water column. This material will have traveled 3,600 feet and is assumed to be distributed evenly throughout the volume of a "wedge" downstream from the dump site. The volume of this "wedge" at one hour after the dump is equal to 1/4 of a cylinder that has a radius of 3,600 feet and is 400 feet high, or 4.1×10^9 cubic feet (1.2×10^{11} liters). Dividing the quantity of suspended sediment by the "wedge" volume gives a concentration of 0.25 milligrams per liter which is approximately one quarter of background concentrations (see Fig. II.7-6).

After 6 hours, (one flood or ebb tide), the material will have traveled a distance of 21,600 feet, (6 hrs x 3600 sec/hr x 1 ft/sec). The volume of the "wedge" is equal to the volume of 1/4 of a c linder that has a radius 21,600 feet and is 400 feet high, or 1.5×10^{11} cubic feet, (4.2×10^{12} liters), and the concentration of suspended sediment in the "wedge" will be 0.0007 milligram/liter, (3×10^{10} milligrams/4.2×10^{12} liters). Thus, within one tide cycle the average suspended sediment concentration due to the disposal of dredged material will drop to less than 1/100 of the background concentration levels found throughout most of Puget Sound if the material disperses evenly within this volume.

It is evident from circulatory information that after several days the material should be widely dispersed. For purposes of comparing the combined impact of a year's worth of disposal operations at the three northern ZSF's within the inner Strait of Juan de Fuca to background suspended sediment concentration in the inner Strait, calculations were made which assumed all the suspended particulate material remaining in the water column after each dump (5%) stayed suspended for a year and did not exit the inner Strait of Juan de Fuca. This calculation is highly conservative as currents would most likely remove a great deal of the suspended material from the inner Strait. The calculations were made based on the following assumptions:

1) 20,000 cubic yards of material were dumped at each ZSF annually for a total of 60,000 cubic yards (4.6×10^7 liters),

2) 21 percent of the disposed amount by volume is sediment (1.3×10^4 cubic yards; 9.6×10^6 liters),

3) Five percent of the disposed sediments (6.5×10^2 cubic yards; 4.8×10^5 liters) become dispersed over the area of the inner Strait of Juan de Fuca,

4) The specific gravity of the suspended material is 2.6 for solids alone (2600 grams per liter).

Using these assumptions, 1.2×10^9 grams of material would remain suspended. Assuming further that the material is evenly distributed through the volume of the inner Strait (1.4×10^{14} liters), then the concentration would be approximately 0.009 milligrams per liter. At that time the natural concentrations would exceed that from disposal operations by approximately two orders of magnitude.

7.2.2.2 Effect of Disposal on Dispersion and Accumulation of Bottom Sediments

As stated earlier, a numerical model study conducted for PSDDA Phase I (Trawle and Johnson, 1986a) indicated that a large percentage of the material disposed by a bottom dump barge will be deposited within a relatively small area. For depths less than 600 feet and current speeds less than one foot per second, assuming the material is a slurry with no clumps the mound that results from one 1500 cubic yard disposal will have a radius of approximately 600 feet and a height of less than one inch, (see Table II.7-1 and Figs. II.7-3a,b).

Trawle and Johnson (1986b) investigated the erosion potential of dredged material as a function of current speed. By utilizing the erosion rates for unconsolidated material presented in Figure II.7-7, a calculation can be made of the time required to erode one barge load of dredged material from each ZSF for median (measured), and peak (calculated) tidal current conditions. Assuming 95 percent of the material from a 1,500 cubic yard dump reaches the bottom, and 90 percent of the material that reaches the bottom is deposited

within a 600-foot radius of the disposal location, the initial disposal mound contains 1,280 cubic yards. At a bulk density in the barge of 1.15 tons/cubic yard (1.35 gm/cc), this quantity of dredged material has a mass of 1,500 tons, or 3 x 10^6 pounds. The erosion time is determined by dividing the mass of the moun by the product of the erosion rate times the area of the mound (1.1 x 10^6 square feet), i.e., t = mound mass/(erosion rate x mound area). The erosion times presented in Table II.7-2 indicate that complete erosion probably would occur over a single flood or ebb at the Rosario Strait, Port Townsend, and Port Angeles sites.

These time estimates assume that the disposed material is a slurry composed of clay/silt and fine sand, (<0.2 mm), with no clumps, and that the material does not remain undisturbed on the bottom long enough to consolidate. Experience at the Alcatraz disposal site in San Francisco Bay indicates that dredged material composed of clumps of coarse sand is very resistant to erosion. Material that does not erode within one or two tidal cycles appears to become "hardened" and can resist erosion by currents as high as 150 cm/sec. To avoid accumulating material, disposal methods which maximize dispersion may be required.

Over the period of a year, material that is eroded will be spread throughout each ZSF, and probably far beyond. An estimate of the effect the disposed material will have on the accumulation of bottom sediments can be made for the anticipated annual disposal of 20,000 cubic yards at each ZSF. If, as stated prev6ously, 21 percent of the dredged material, or 4,200 cubic yards (3.2 x 10^6 liters) is solids, and the rest is water, and at a specific gravity of 2.6 for the solids (2600 gm/1), approximately 8.6 x 10^9 grams (8.6 x 10^{12} milligrams) of sediment would be placed in the ZSF. If the material is spread evenly over the average area of the ZSFs (approximately ten square miles, or 2.6 x 10^{11} square centimeters), the accumulation rate of the sediment would amount to 33 milligrams per square centimeter per year. This is about 1/100 of the natural accumulation rate that now takes place throughout most of northern Puget Sound (see Fig. II.7-4).

The impact of far field dispersion can also be assessed by reviewing the movement of materials released in or near each ZSF (Evans-Hamilton, Inc., 1987b). Lagrangian drifter observations have been made since the early 1970's. These field studies have been used to examine possible far field dispersion of suspended material. In addition, Crean's (1983) model was used to trace the movement of a particle released at the center of each ZSF during both a neap and spring tide. Since PSDDA is seeking erosional areas in Phase II, the particle release time was chosen as the slack at the higher low of a tidal cycle. This condition occurs prior to the lowest tidal energy regime and simulates a worst-case condition.

Particle movement following release was traced over a 25 hour period, the approximate length of a tidal day.

7.2.3 Site Specific Transport--

7.2.3.1 Rosario Strait ZSF

Perhaps the dominant characteristic of the Rosario Strait ZSF is that the prevailing net flows are directed southward throughout the water column. These strong currents are able to transport suspended material on average at the rate of ten miles per day.

A study by Schumacher and Reynolds (1975) traces drogue trajectories released near the ZSF at the entrance to Guemes Channel and at the north end of the channel (Figs. II.7-8). The three initial releases were at the beginning of a major ebb. All three drogues moved south and had reached midchannel of Rosario Strait within 2 1/2 - 3 hours. The drogues were redeployed at the entrance to Guemes Channel at slack tide prior to a flood. It is interesting to note that Drogue 105 (Fig. II.7-8a) drifted in a northeast direction whereas Drogue 106 (Fig. II.7-8b), released seven minutes later, drifted in a northwest direction.

During both neap and spring tide conditions using Crean's model, the particles moved into Guemes Channel and then headed south towards Rosario Strait (Fig. II.7-9a,b). Particles released during a spring tide reached farther north into the channel between Cypress and Guemes Islands before heading south. After entering Rosario Strait particle movement was north-south. The net movement of the particle during the neap tide was southward approximately 1.5 nautical miles, whereas during the spring tide it moved southward nearly four nautical miles.

On 25 April 1971 an oil spill occurred in Fidalgo Bay near the end of a major flood during a spring tide (Fig. II.7-10). As it spread the oil was tracked over the following 41.5 hours. The pattern of oil movement in the area of the Guemes Island ZSF follows a similar pattern as that seen for a particle release in the model during a spring tide (Fig. II.7-9a). The oil continued to move south in Rosario Strait and into the Strait of Juan de Fuca. From here the oil travelled west within the Strait and northward through the San Juan Islands.

Local winds may have aided in the dispersal of the oil. Although the winds at the time of the oil spill are not known, except through local newspaper reports (Evans-Hamilton, Inc., 1987b), the pattern of movement shown on that occasion probably represents the movement expected through the water column. Given the high mean and net current speeds, it is reasonable to expect that a substantial amount of the disposal material will be quickly transported throughout the area covered by the oil spill.

7.2.3.2 Port Townsend ZSF

The bathymetry of this ZSF contains a deep channel traversing the center between two shallow subsurface banks. This ZSF lies approximately ten miles to the northwest of Admiralty Inlet. Vigorous tidal mixing in proximity to Admiralty Inlet significantly affects the dispersion of materials.

At the assumed disposal site in the deepest portion of the channel, the net currents are directed toward Admiralty Inlet in the lower half of the water column, and toward Vancouver Island in the upper portion of the water column (c.f. Figs. II.6-12 and II.6-16). In both parts of the water column the net speeds reach values of approximately ten miles per day. At these speeds the prevailing currents can carry resuspended material to the mouth of Admiralty Inlet in approximately one day. Resuspended materials mixed into the upper layer within this sill zone can reach Vancouver Island in approximately two days.

Undoubtedly some of the resuspended material will be carried inland into the central basin of Puget Sound. An example of this bottom transport was provided by the movement of a sea bed drifter which was initially released on the Washington/Oregon Coast (C. A. Barnes, personal communication). That drifter was carried northward along the Pacific Coast until it entered the mouth of the Strait of Juan de Fuca. Subsequently, it traversed the Strait of Juan de Fuca, moving inland with the bottom current, and most likely passing through the Port Townsend ZSF. The drifter passed through Admiralty Inlet and eventually was found south of the Hood Canal Bridge.

Some of the very fine resuspended material from the disposal site will be mixed into the upper layer by tidal currents in Admiralty Inlet and transported seaward. This material and suspended material may then settle out as it is carried by the prevailing currents. The wide dispersion of surface materials originating within or near this ZSF is illustrated by the recovery positions of drift cards released there (Fig. II.7-11). The recoveries of these cards show that the cards reached nearly all beaches within the inner Strait of Juan de Fuca. Dredged materials residing in the surface microlayer can be expected to do the same.

Drift sheets released near or within the ZSF also show the dispersive nature of the surface layer (Cox et al., 1978). An example of this is illustrated in Figures II.7-12 and II.7-13. Although released only about two miles apart, the two drift sheets headed in very different directions. Drift sheet No. X7 (Fig. II.7-12) moved primarily east-west and after 25 hours was located northwest of Dungeness Spit. Drift sheet No. X8 (Fig. II.7-13) moved in a zigzag pattern to the north ending near the southern tip of San Juan Island after about 28 hours.

A particle trajectory during a neap tide using the model oscillates in an east-west direction and never leaves the ZSF during the first 25 hours (Fig. II.7-14a). The net movement over 25 hours was 1.0 nautical mile westward. A particle released during a spring tide exited the ZSF after only nine hours (Fig. II.7-14b). The particle eventually reentered the ZSF and its net movement was 1.5 nautical miles westward, similar to that for the neap tide.

7.2.3.3 Port Angeles ZSF

Like the Port Townsend ZSF, the Port Angeles ZSF also lies in a hydrographic region in which there are two flow layers. The lower layer of this ZSF lies immediately upstream, approximately ten miles, from the sill zone that stretches from the vicinity of Dungeness Spit to Victoria.

The material that is resuspended will be carried via the prevailing currents in the lower layer to this sill zone. Although the turbulence over this sill is not as intense as in Admiralty Inlet, observed surface patterns suggest that on occasion tidal currents mixed bottom water up to the surface. Thus, some of the resuspended material may be mixed into the upper layer and be carried westward by the prevailing outflow from the inner Strait of Juan de Fuca.

The resuspended material that remains in the lower landward flowing circulatory layer will be carried inland to some extent, over time likely entering the Strait of Georgia via Haro Strait and Puget Sound via Admiralty Inlet. This process is the same as that occurring at the Port Townsend site.

Recovery positions of drift cards released in this ZSF vicinity indicate surface borne materials are spread over a wide portion of the Strait of Juan de Fuca and up into the San Juan Islands (Figs. II.7- 15a,b). The study by Ebbesmeyer et al. (1978) in April 1978 took into account tidal and wind influences. The majority of the cards were released at high slack tide or on a small ebb tide, the one exception was on April 25th at the beginning of a large flood tide. Winds during April 24-30 were primarily from the west to northwest at from 2-20 knots on various days. Under these conditions all but a few of the recovered cards were found east of Port Angeles, with a large percentage landing on Dungeness Spit.

In 1980 drift cards were released at the beginning of a flood and ebb tide on July 1 and 2, respectively (Cox et al., 1980. Once again Dungeness Spit received a large percentage of the cards. More cards were found west of Port Angeles in 1980 than in 1978. In general, for cards released during the flood tide, more were found on beaches to the east of Port Angeles than to the west. The reverse was true for cards released during the ebb tide as would be expected. This did not hold true for those cards released near the enclosed end of Port Angeles Harbor; these cards did the opposite of the other releases.

Movements of drift sheets released in April 1978 in the vicinity of the ZSF indicates that any material remaining at the surface may move out of the ZSF region within a few hours (Ebbesmeyer et al., 1978). Several of these drift sheets traversed the area of the ZSF in less than three hours. These trajectories were observed primarily during a major spring flood tide; however, two of the drift sheets observed during a weak ebb tide show significant movement although at slower speeds. Results of a release during a weak ebb tide (the sheets were allowed to drift for nearly two days before their final observation) showed that the probable paths of the drift sheets before their recovery were in an east-west oscillation towards the south (Cox et al., 1978).

Particle trajectories during a neap tide from Crean's model indicate the tidal circulation is entirely east-west in this region and that over a twenty five hour period the particle returned to its original release position (Fig. II.7-16a). Within nine hours the particle had moved outside of the ZSF; however, the particle was outside the ZSF for only nine of the twenty five hours of the trajectory. Particles released during a spring tide move much faster, exiting the ZSF in four hours (Fig. II.7- 16b). The particle's movement was also east-west, and the net movement placed the particle slightly northwest of its release position. This east-west movement was the same suspected for drift sheet releases.

7.2.4 Collection Zones--

Throughout Puget Sound and the Straits of Juan de Fuca areas exist where surface borne materials tend to collect. Tide rips containing flotsam are excellent examples of this. Previous studies (Ebbesmeyer et al., 1979; Cox et al., 1978) have identified at least one such surface collection area located midway between the Port Angeles and Port Townsend ZSFs. Drift sheets released over an approximately 20 kilometer area tended to move together to form a patch of 10-20 drift sheets north of Dungeness Spit (Fig. II.7-17). This patch oscillated east-west for a number of days, collecting additional drift sheets each day. A number of tide rips containing flotsam were found in this area.

TABLE II.7-1. RESULTS OF WES MODEL WITH ALL CLAY/SILT SETTLING AT AGGREGATED SETTLING VELOCITY (EVANS-HAMILTON, (INC., 1987b).

TEST NO.	WATER DEPTH (FT)	CURRENT SPEED (FPS)	MINIMUM THICKNESS (FT)	MAXIMUM THICKNESS (FT)	MEAN THICKNESS (FT)	MEAN THICKNESS (G/CM)	ALL MATERIAL DEPOSITED	FINE SAND/ CLAY-SILT PERCENTAGES
4	200	0.1	0.022	0.053	0.027	0.458	Y/98%	25/75%
5	200	0.85	0.028	0.071	0.035	0.596	Y/99%	25/75%
6	200	1.69	0.02	0.071	0.058	0.995	Y/95%	25/75%
7	400	0.1	0.003	0.027	0.01	0.167	Y/99%	25/75%
8	400	0.85	0.005	0.053	0.027	0.459	Y/98%	25/75%
9	400	1.69	0.002	0.024	0.013	0.225	Y/96%	25/75%
10	600	0.1	0.001	0.013	0.008	0.134	Y/96%	25/75%
11	600	0.85	0.001	0.024	0.013	0.227	Y/97%	25/75%
12	600	1.69	0.001	0.019	0.007	0.123	Y/96%	25/75%
13	800	0.1	0.009	0.014	0.011	0.194	N/92%	25/75%
14	800	1.69	0.001	0.007	0.003	0.048	N/69%	25/75%
15	800	3.38	0.001	0.005	0.002	0.034	N/59%	25/75%

TABLE II.7-2. The time estimated to erode the clay/silt fraction of a disposal assuming mean or 1% fastest current speeds. (Source: Evans-Hamilton, Inc., 1987b).

ZSF	Mean Area (ft^2)	Mean Speed (cm/sec)	1% Fastest Speed (cm/s)	ER* @ Mean Speed ($lb/ft^2/min$)	ER* 1% Speed ($lb/ft^2/min$)	ET** @ Mean Speed (hour) minutes	ET** @ 1% Fastest Speed (hours) minutes
Rosario St.	1.10×10^6	50	134.7	.03	.40	90	7
Pt. Townsend	1.10×10^6	40	108.0	.015	.24	180	11
Pt. Angeles	1.10×10^6	45	121.4	.025	.31	110	9

*ER - Erosional Rate from Figure II.7-7
**ET - Erosion Time

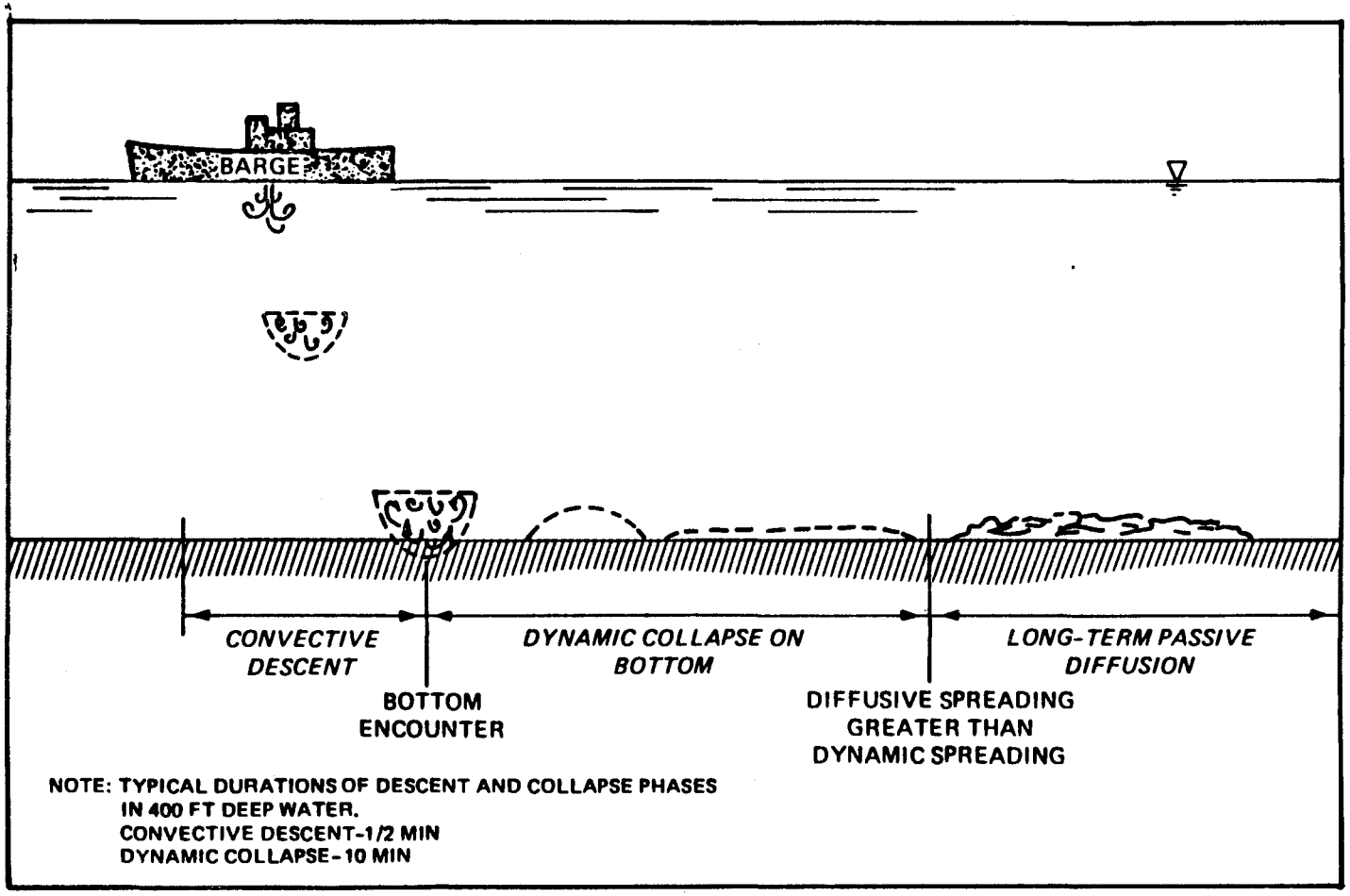


Figure II.7-1 Illustration of idealized bottom encounter after instantaneous dump of dredged material

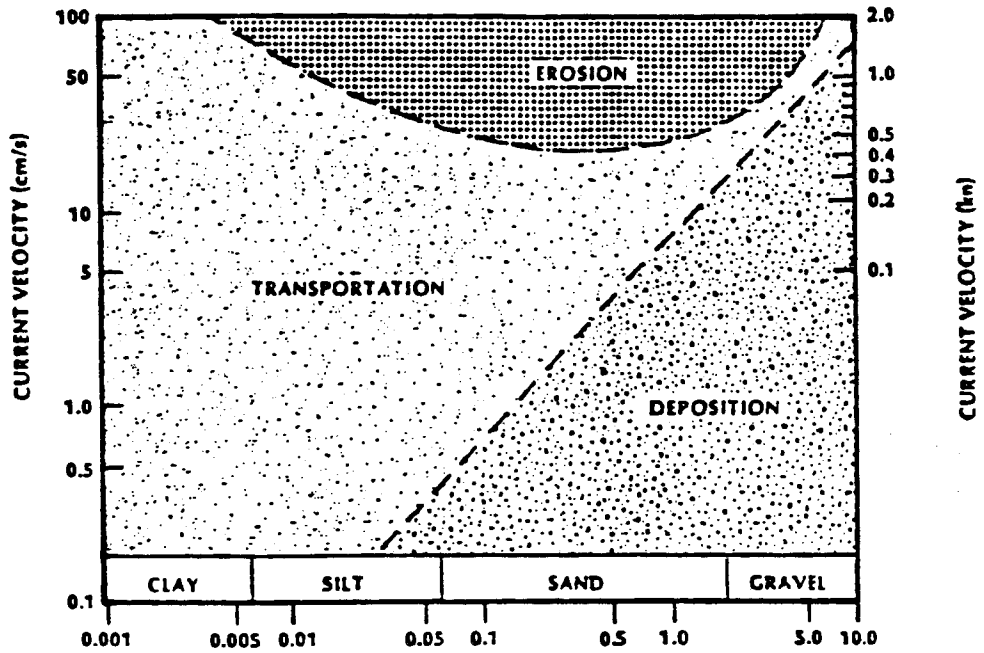


Figure II.7-2 The relationship between current velocity and its potential to deposit, transport, or erode sediments of various grain sizes. (Source: after Moherek, 1978)

MEAN THICKNESS (feet)

0.027 0.035 0.058

MASS PER UNIT AREA (grams/square cm)

0.449 0.596 0.995

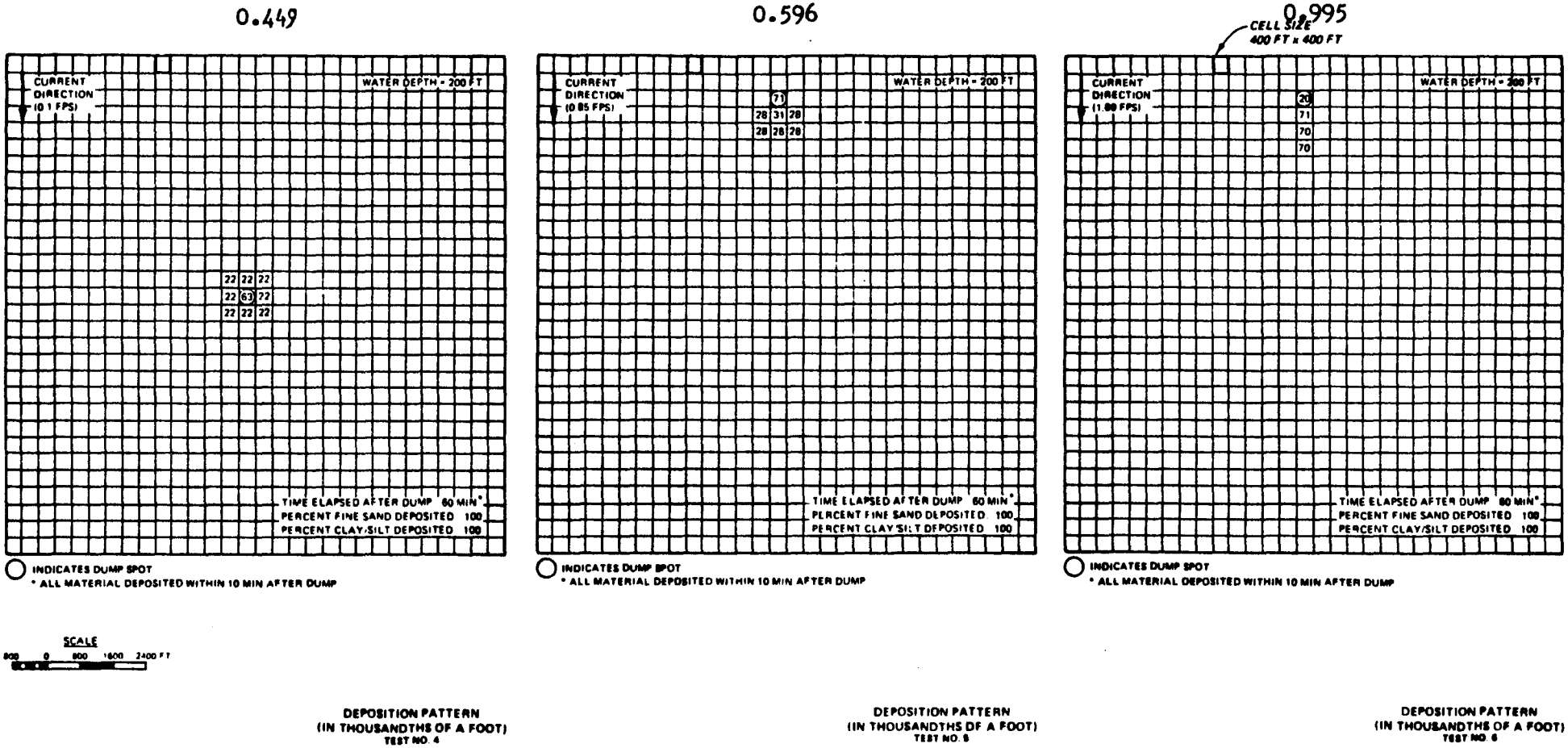


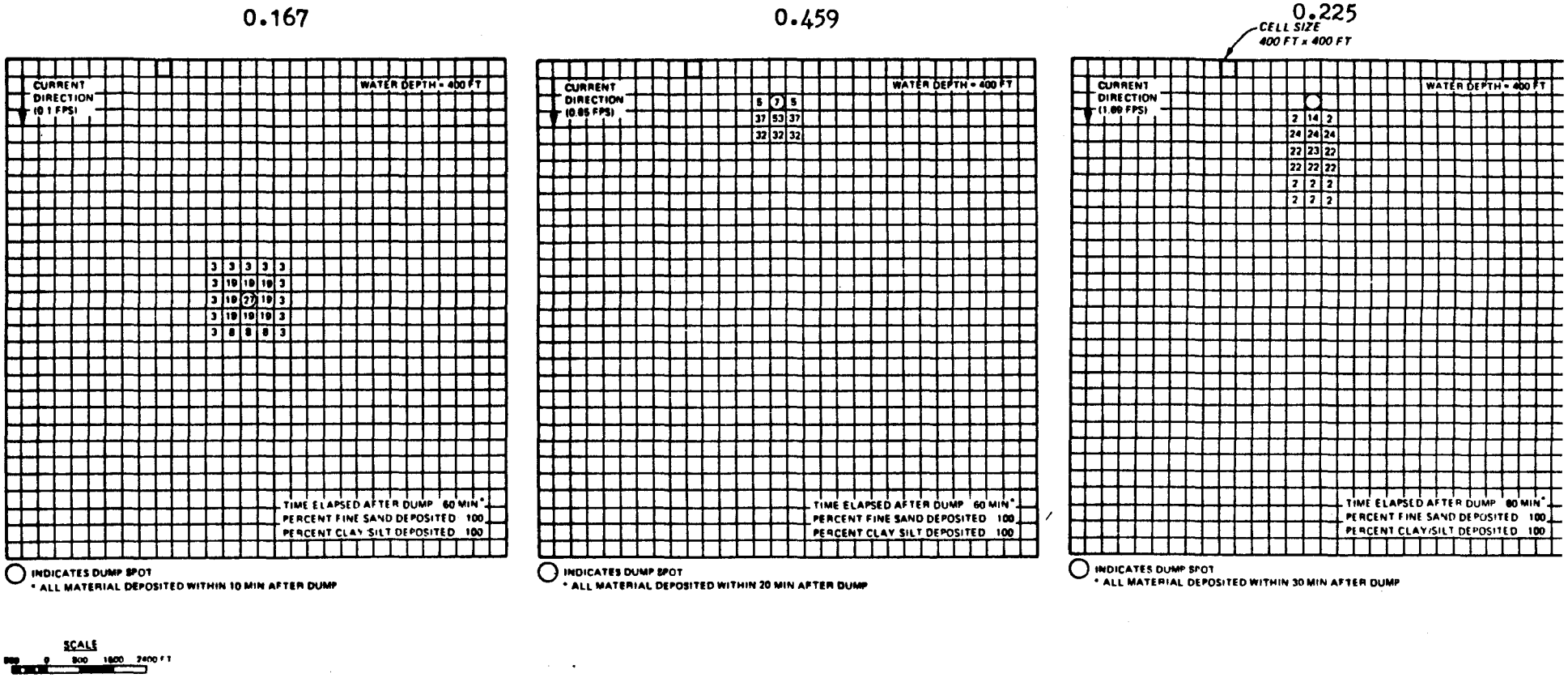
Figure II.7-3a WES Model test runs 4-6 (200 feet) showing depositional patterns on the models grid, mean thickness and mass per unit area. (Source: Trawle & Johnson, 1986a)

MEAN THICKNESS (feet)

0.010 0.027 0.013

MASS PER UNIT AREA (grams/square cm)

0.167 0.459 0.225



DEPOSITION PATTERN (IN THOUSANDTHS OF A FOOT) TEST NO. 7

DEPOSITION PATTERN (IN THOUSANDTHS OF A FOOT) TEST NO. 8

DEPOSITION PATTERN (IN THOUSANDTHS OF A FOOT) TEST NO. 9

Figure II.7-3b WES Model test runs 7-9 (400 feet) showing depositional patterns on the models grid, mean thickness and mass per unit area. (Source: Trawle & Johnson, 1986a)

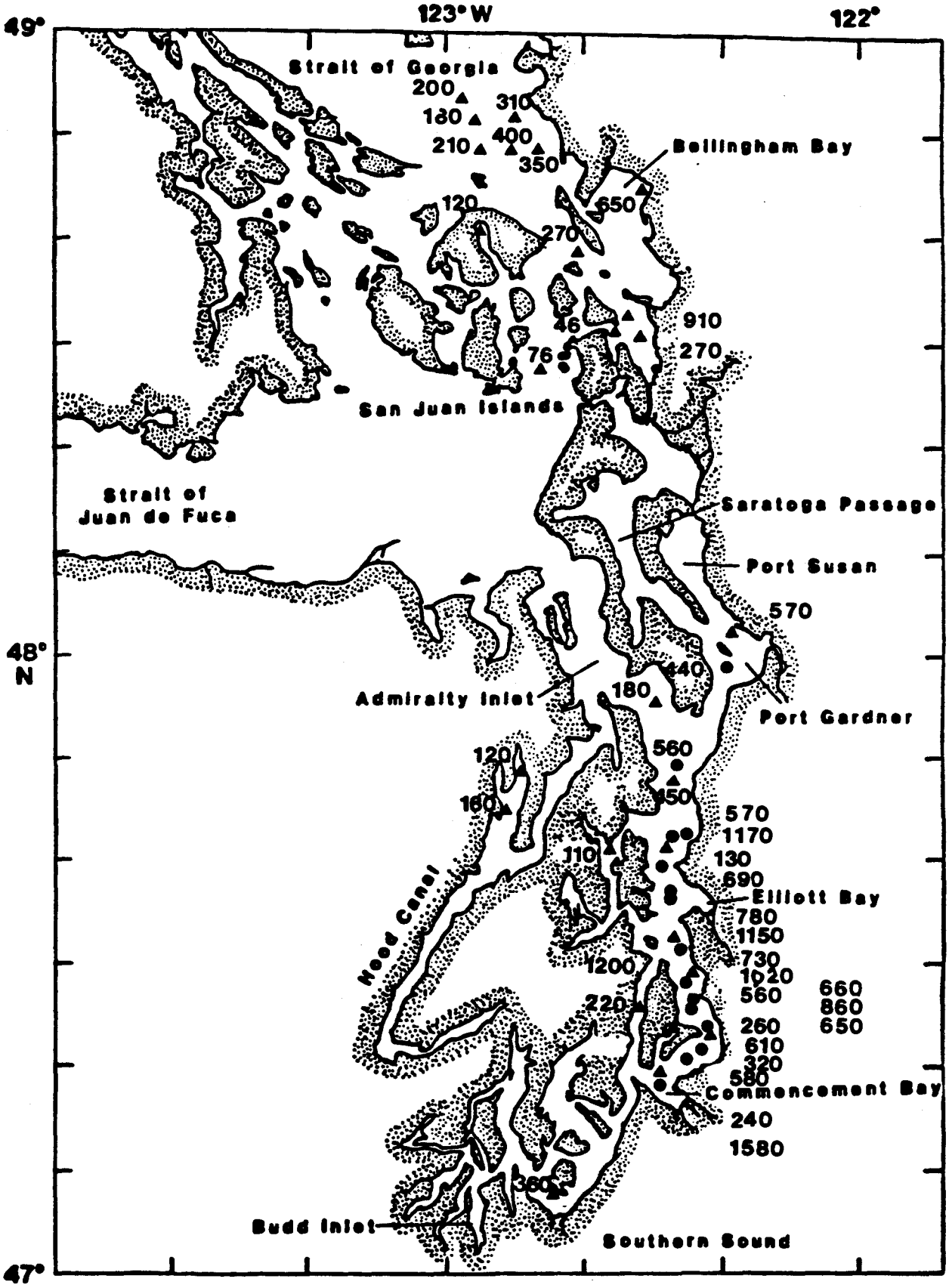


Figure II.7-4 Locations and mass accumulation rates of sediment (in mg cm^2/year) in Puget Sound. (Source: adapted from Carpenter et al., 1985, and Lavelle et al., 1986)

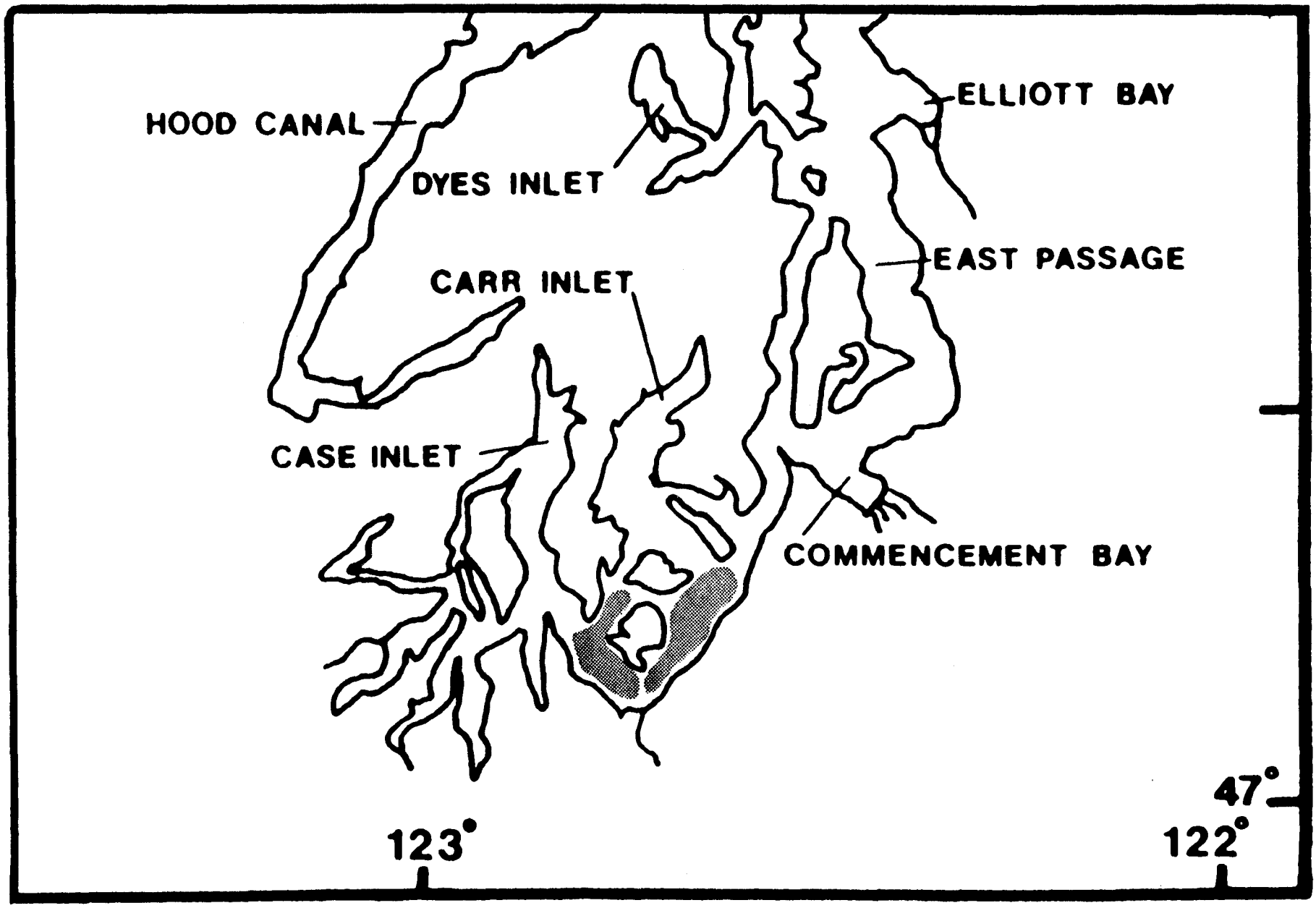


Figure II.7-5 Areas (shaded) used to calculate 5% sediment accumulation.

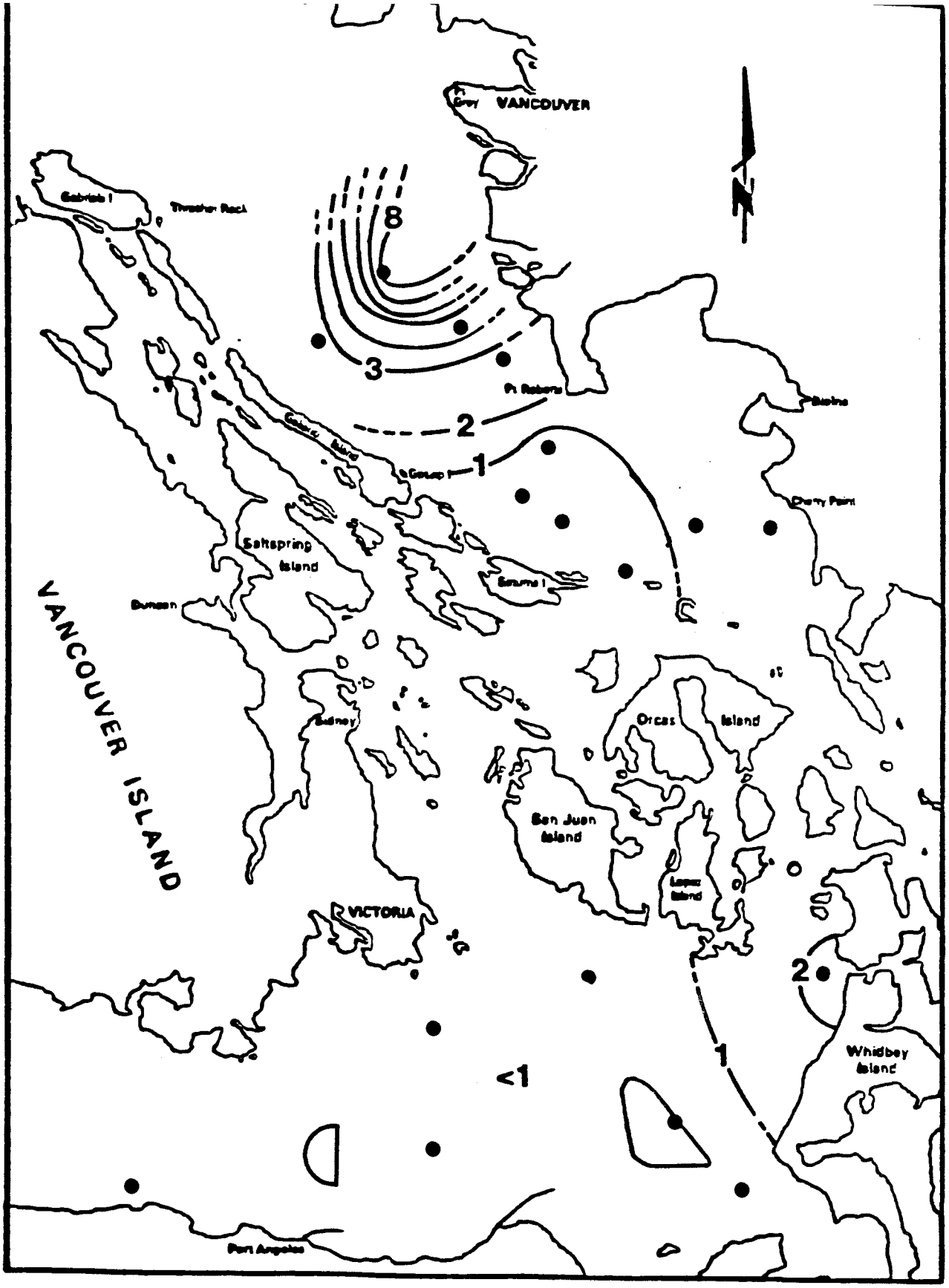


Figure II.7-6a Concentration contours (mg/l) of suspended particulate matter for surface samples from MESA I, November 1976. (Source: Baker et al., 1978)

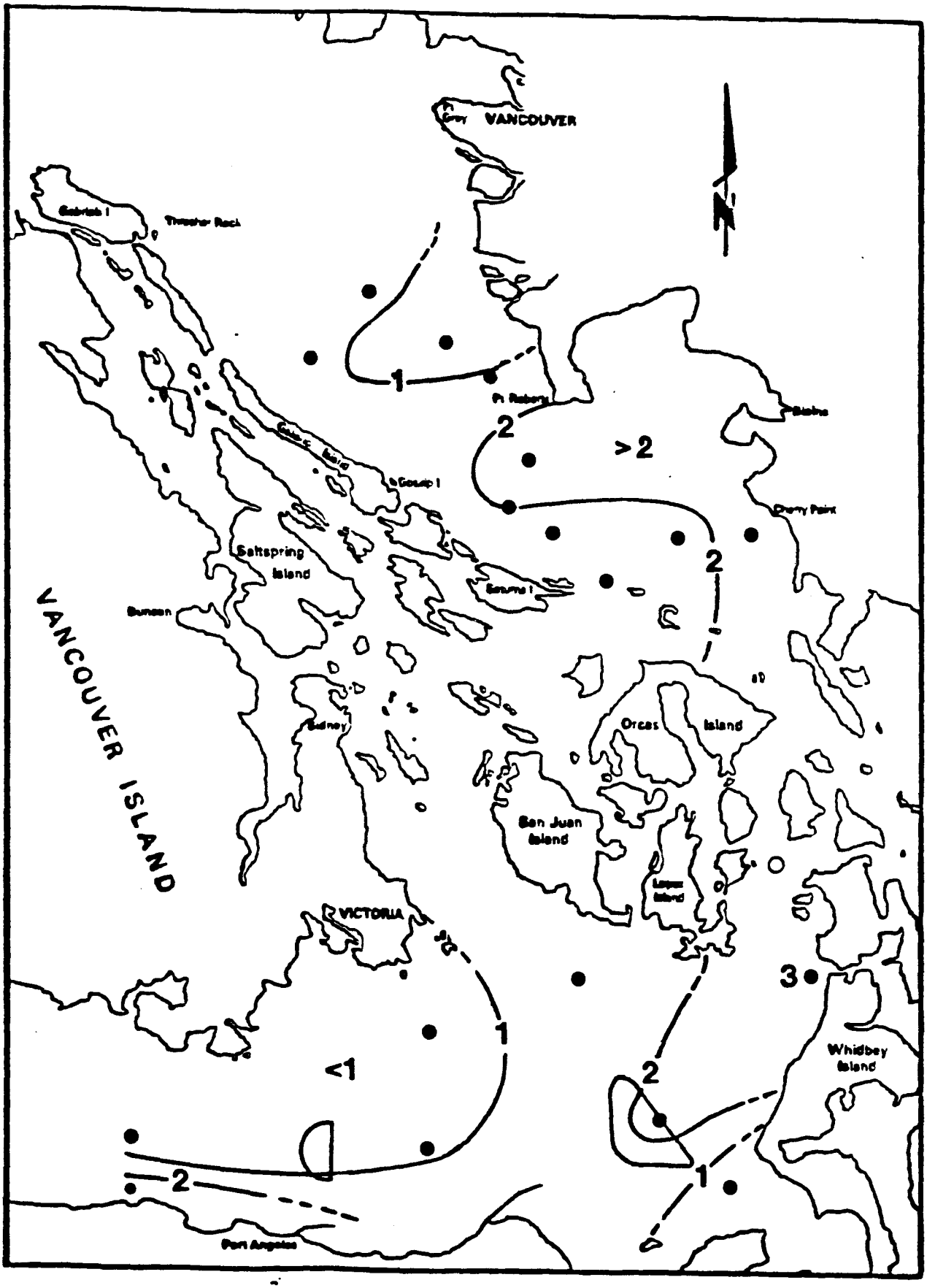


Figure II.7-6b Concentration contours (mg/l) of suspended particulate matter for near bottom samples from MESA I, November 1976. (Source: Baker et al., 1978)

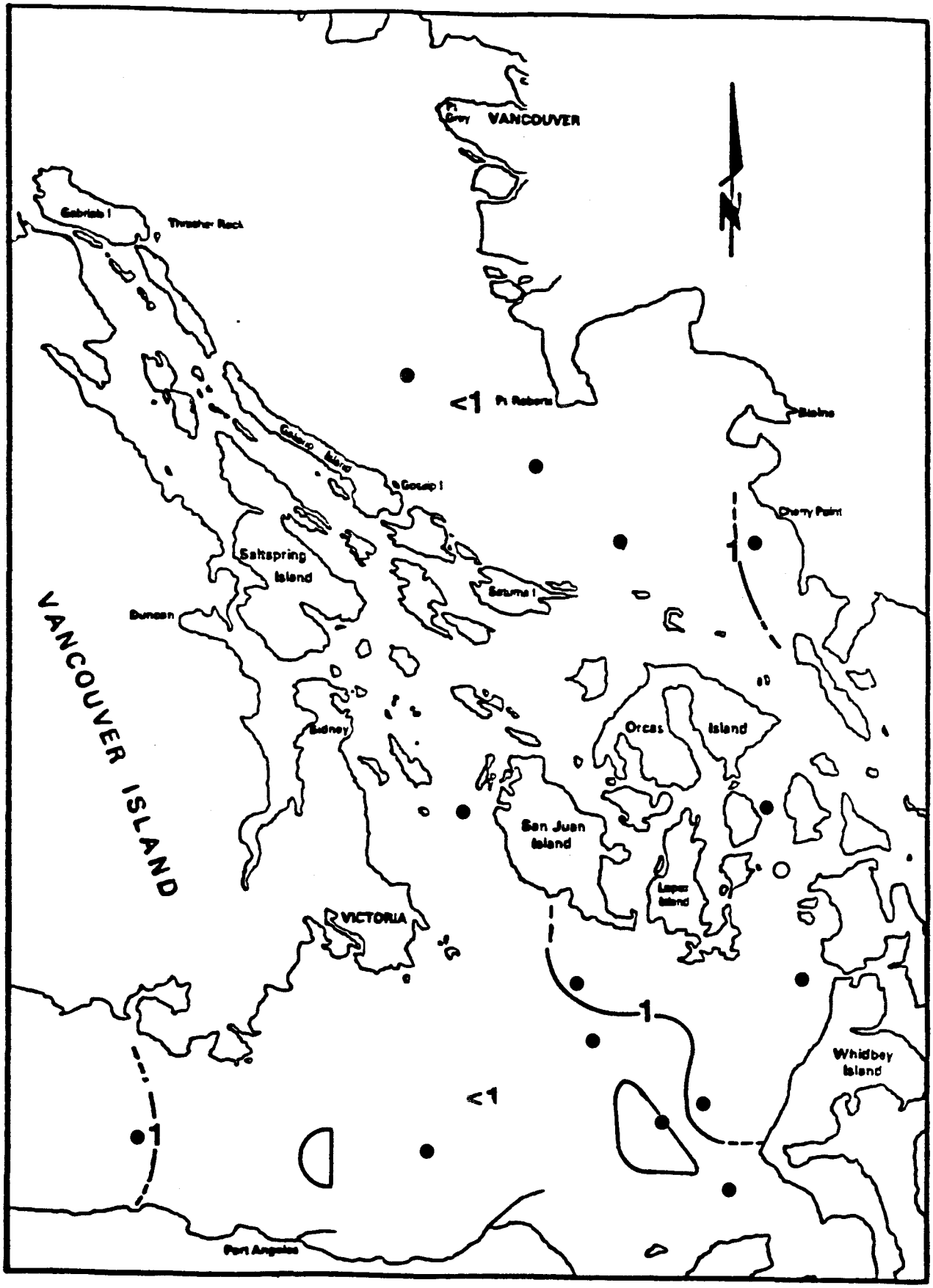


Figure II.7-6c Concentration contours (mg/l) of suspended particulate matter for surface samples from MESA II, March 1977. (Source Baker et al., 1978)

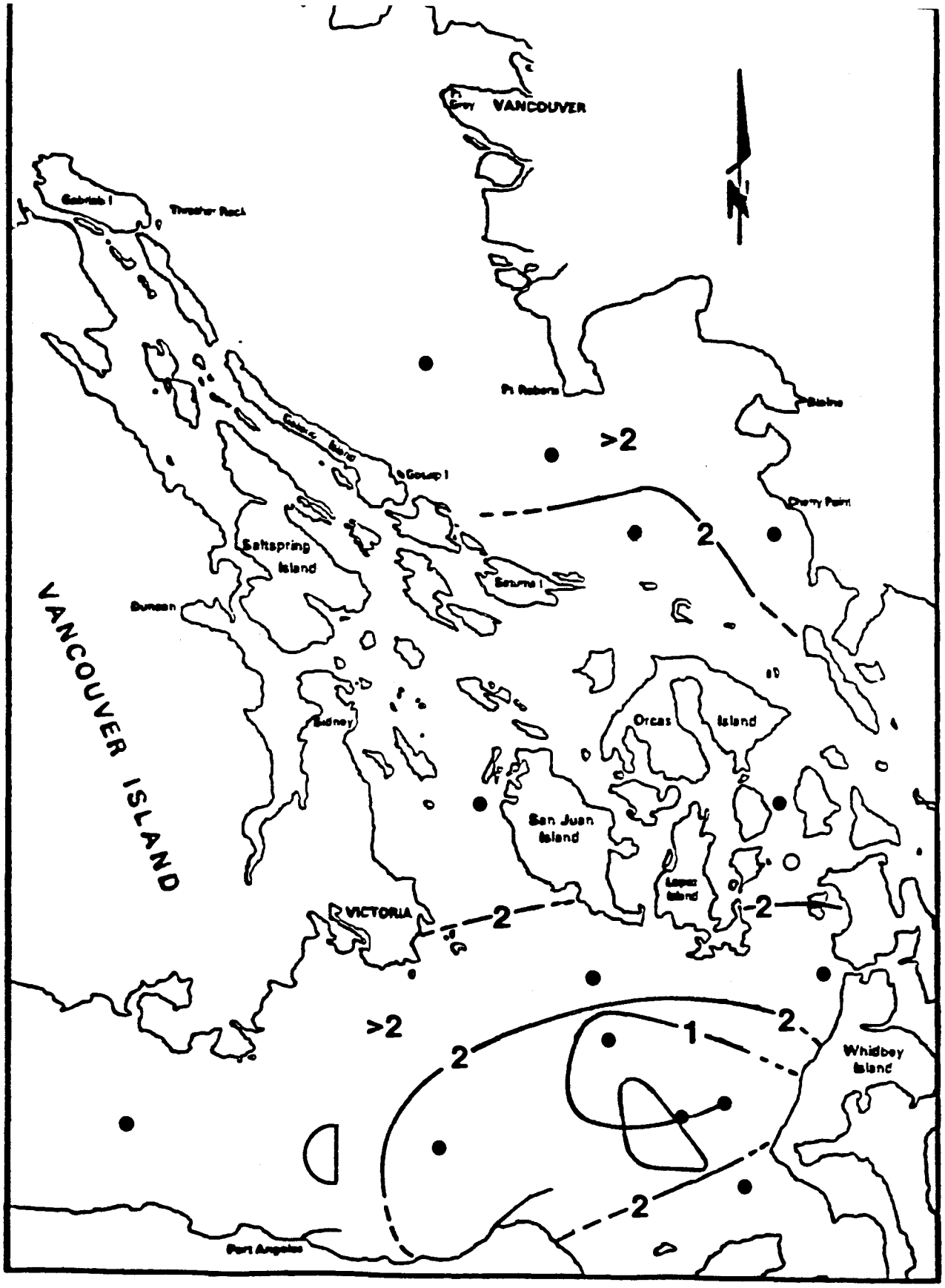


Figure II.7-6d Concentration contours (mg/l) of suspended particulate matter for near bottom samples from MESA II, March 1977. (Source: Baker et al., 1978)

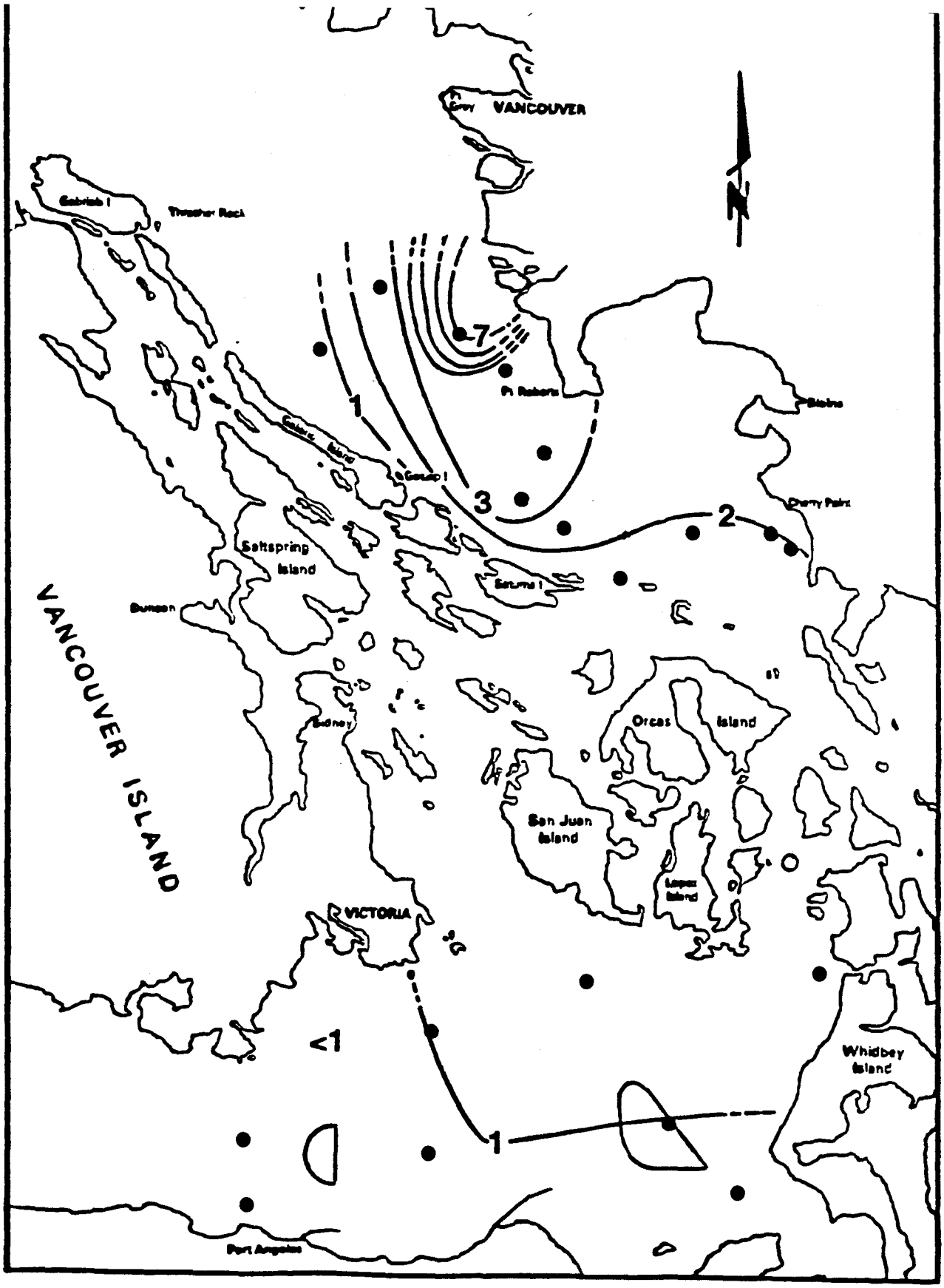


Figure II.7-6e Concentration contours (mg/l) of suspended particulate matter for surface samples from MESA III, August 1977. (Source: Baker et al., 1978)

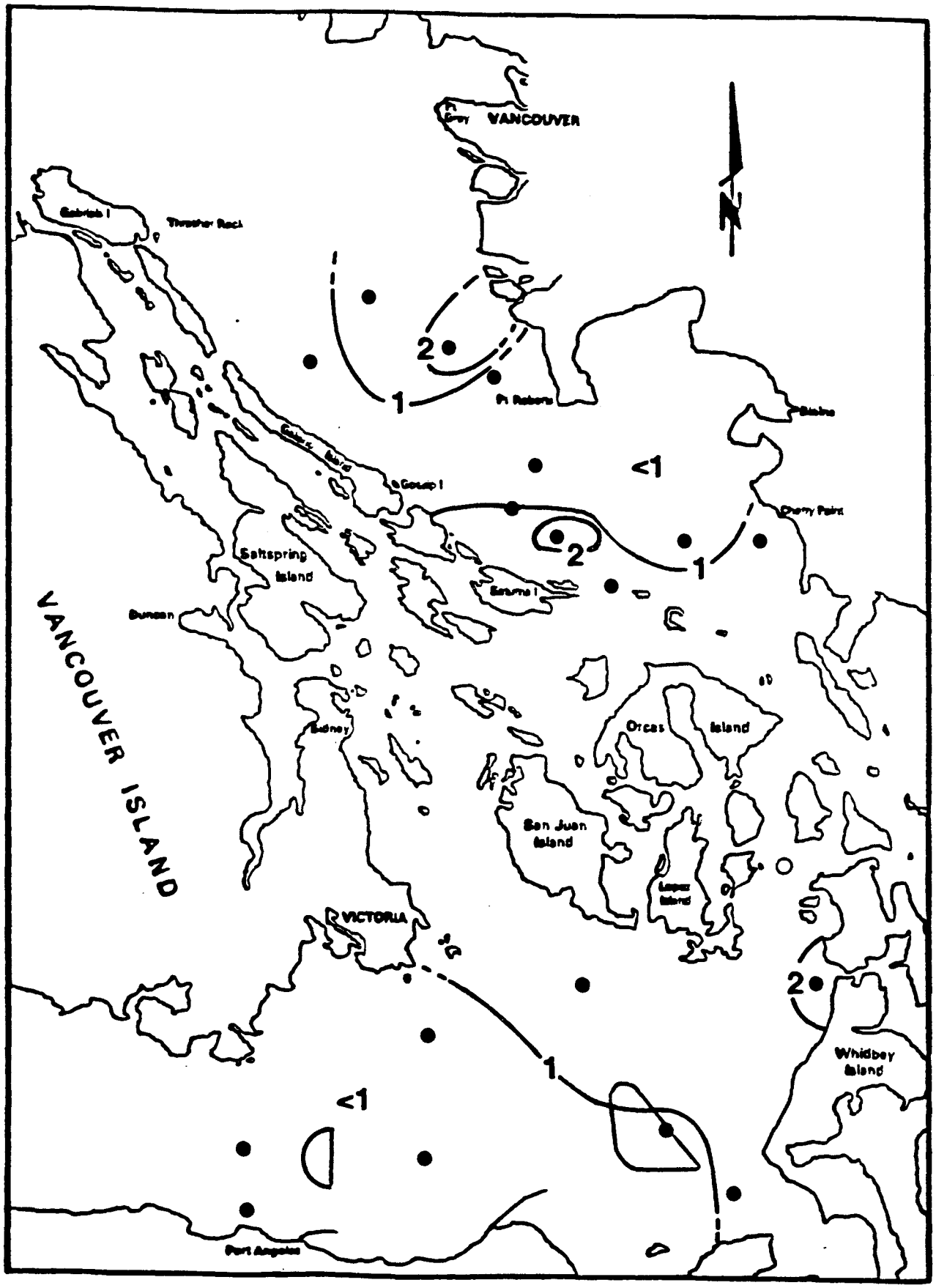


Figure II.7-6f Concentration contours (mg/l) of suspended particulate matter for near bottom samples from MESA III, August 1977. (Source: Baker et al., 1978)

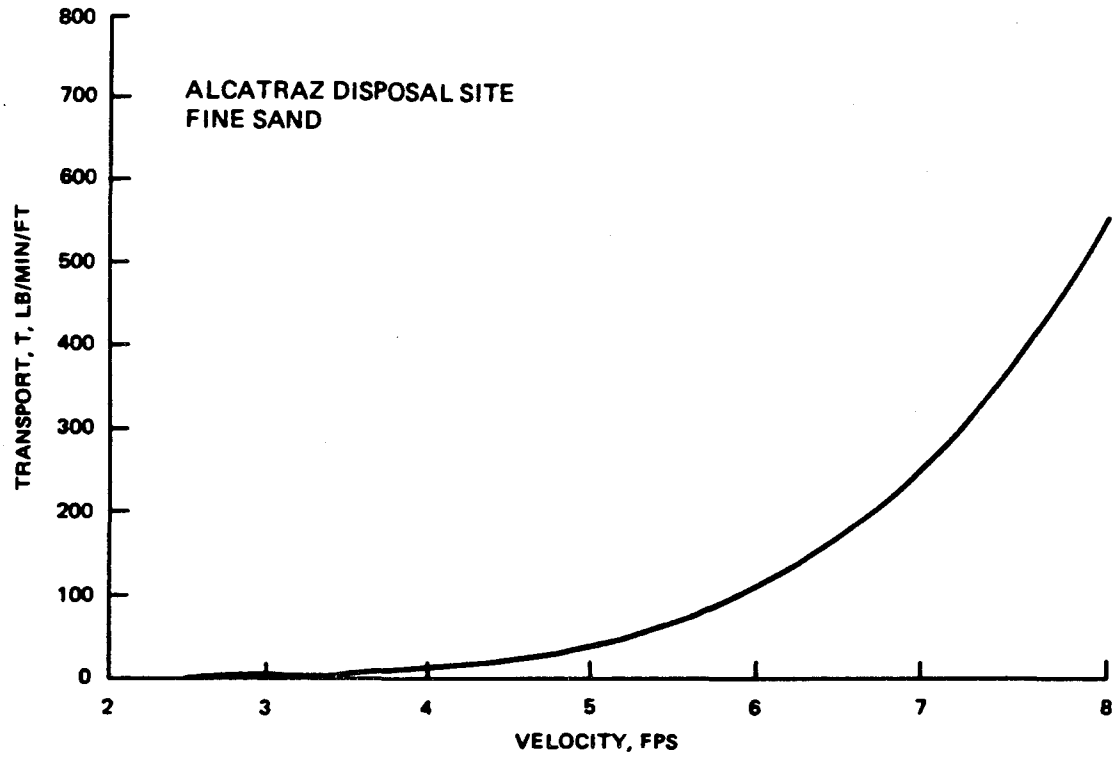


Figure II.7-7 Erosion potential of clay/silt at mound (both consolidated and unconsolidated) as a function of current speed based on modified Parthenaides equation. (Source: Trawle and Johnson, 1986b)

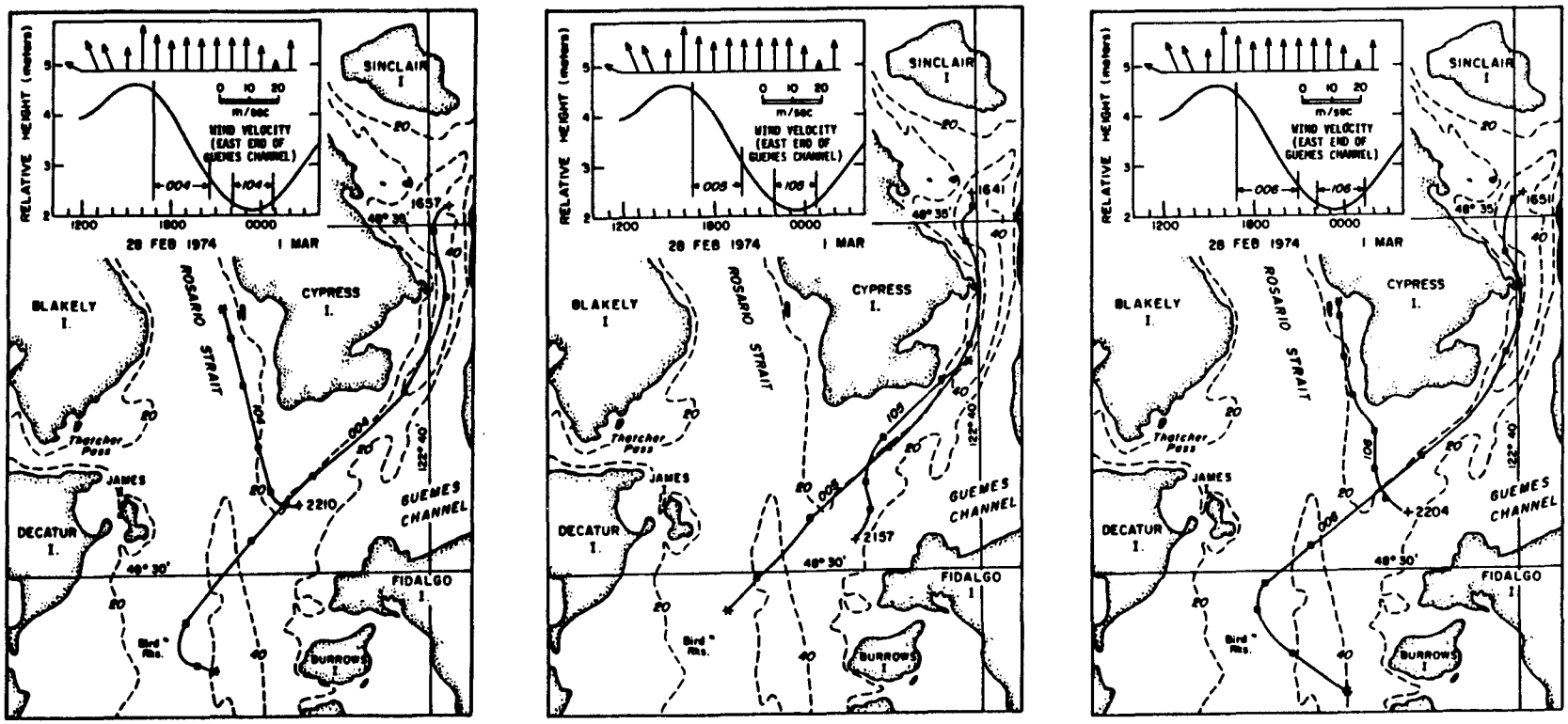


Figure II.7-8 Drogue trajectories on 28 February 1974 from the Drogue Series II Cyprus Island. Initial time of release (+) and recovery (*) are noted and trajectory is marked at half-hour intervals (■). (Source: Schumacher and Reynolds, 1975)

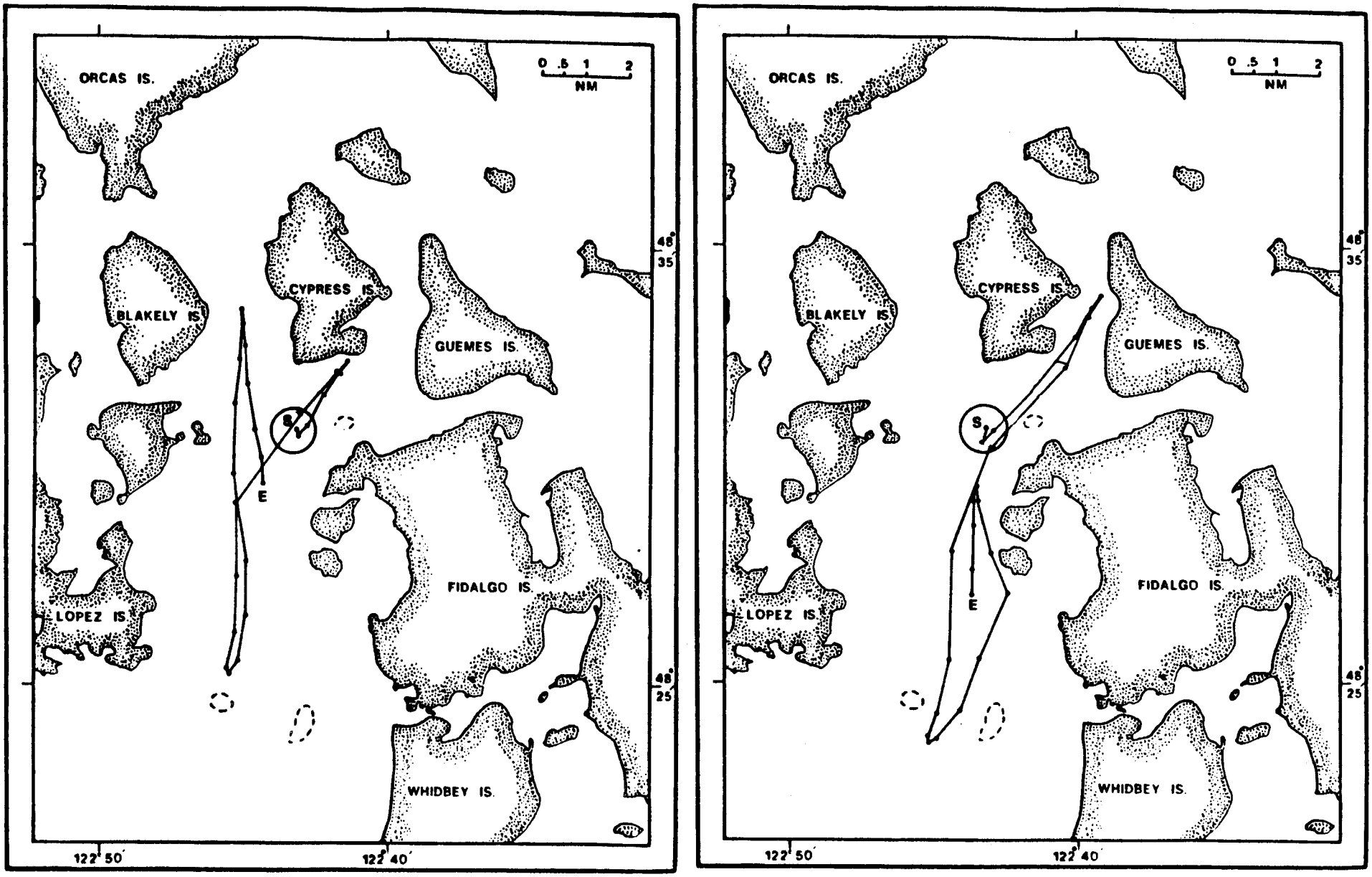


Figure II.7-9 Trajectory of a parcel of water for twenty-five hours starting during slack tide. Dots indicate hourly increments, S = starting position, and E = ending position. Data obtained from Crean's (1983) tidal stream charts. (Source: EHI)

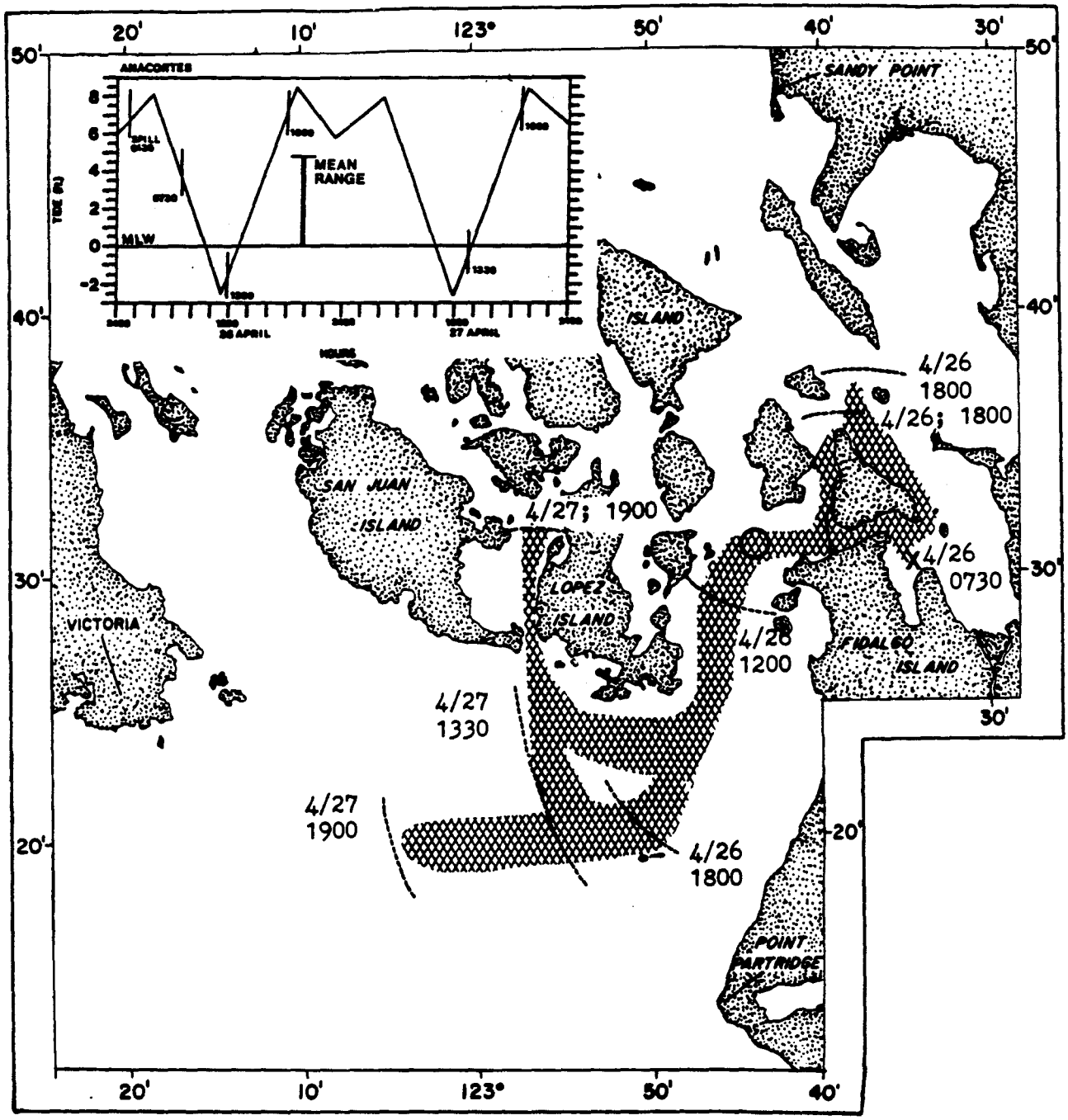


Figure II.7-10 Spread of oil spill at Anacortes April 26, 1971, X indicates origin of the spill, Rosario Strait ZSF is indicated by circled area. (Source: Vagnars and Mar, 1972)

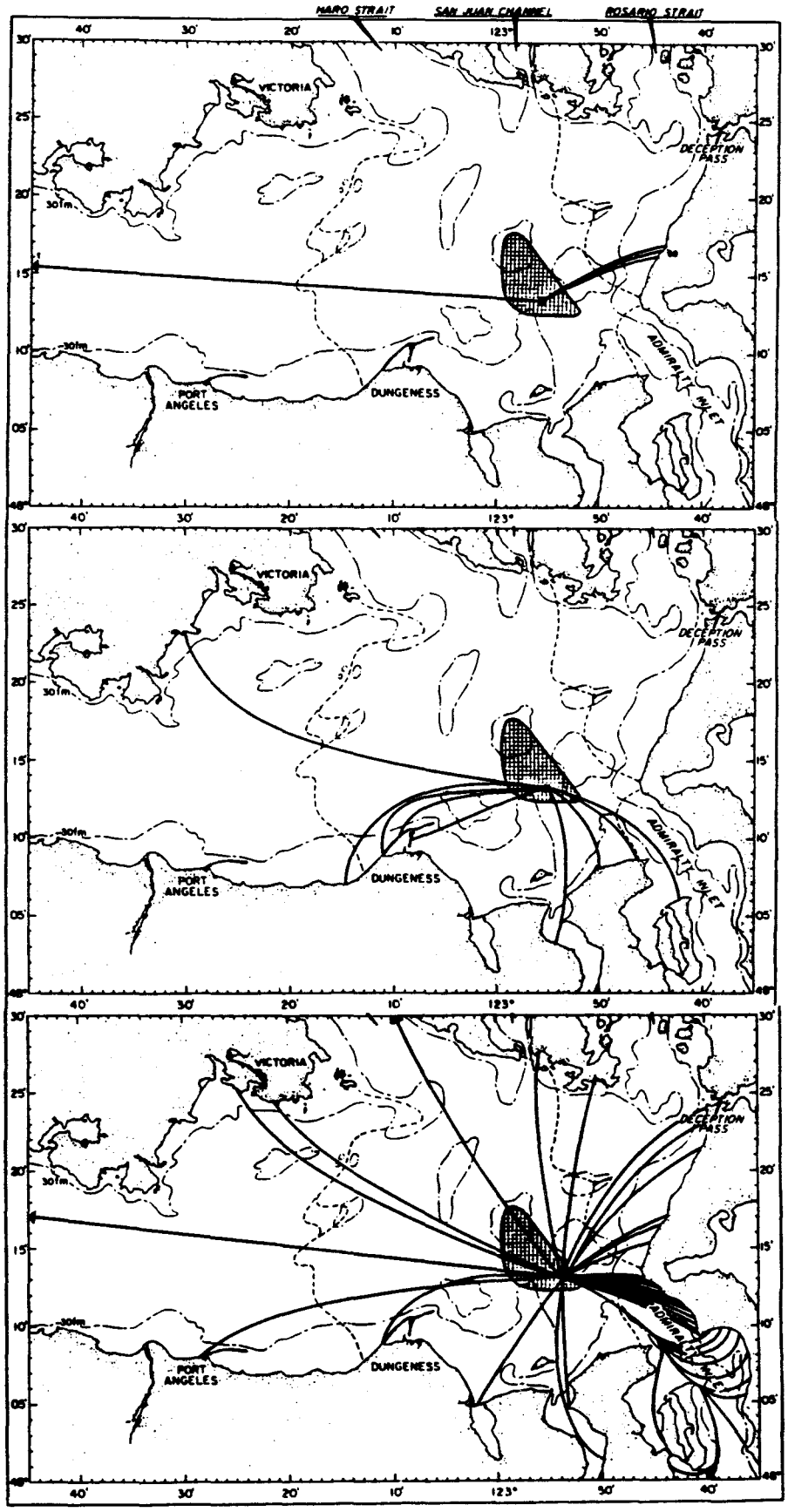


Figure II.7-11 Recovery positions of drift cards released on a) 14 April 1976 (94% returned); b) 17 May 1976 (66% returned); and c) 22 July 1976 (53% returned). Arrows indicate direction of off map recoveries. ZSF is shown as cross hatched area. (Source: Pashinski and Charnel, 1979).

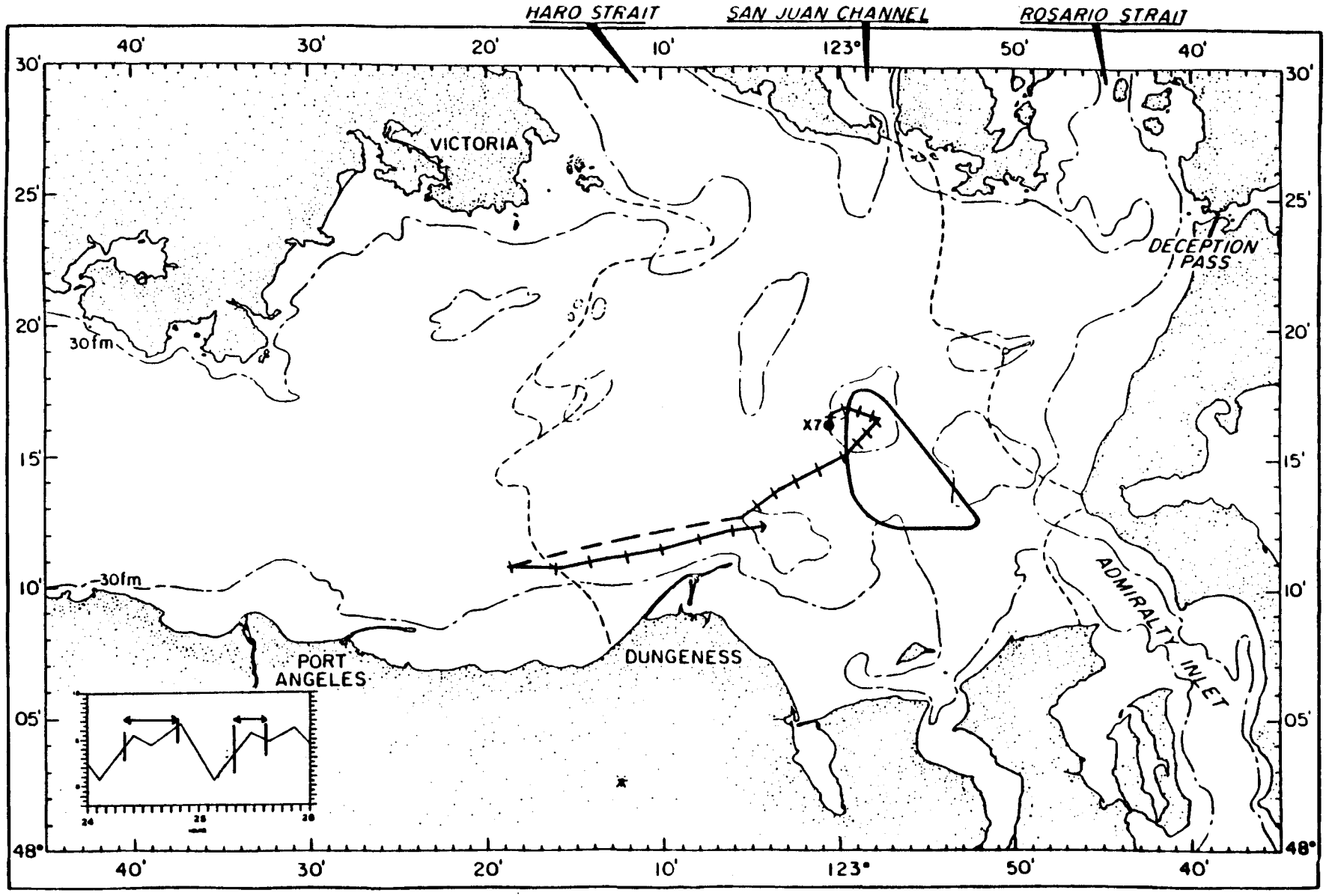


Figure II.7-12 Drift sheet movement observed off Dungeness Spit, 25-26 August 1978. (●) indicates initial sighting; tick marks at hourly intervals; arrows indicate direction at last sighting; broken line indicates movement when drift sheets not observed; tick marks on tide curve shows period drift sheet under observation. (Source: Cox et al., 1978)

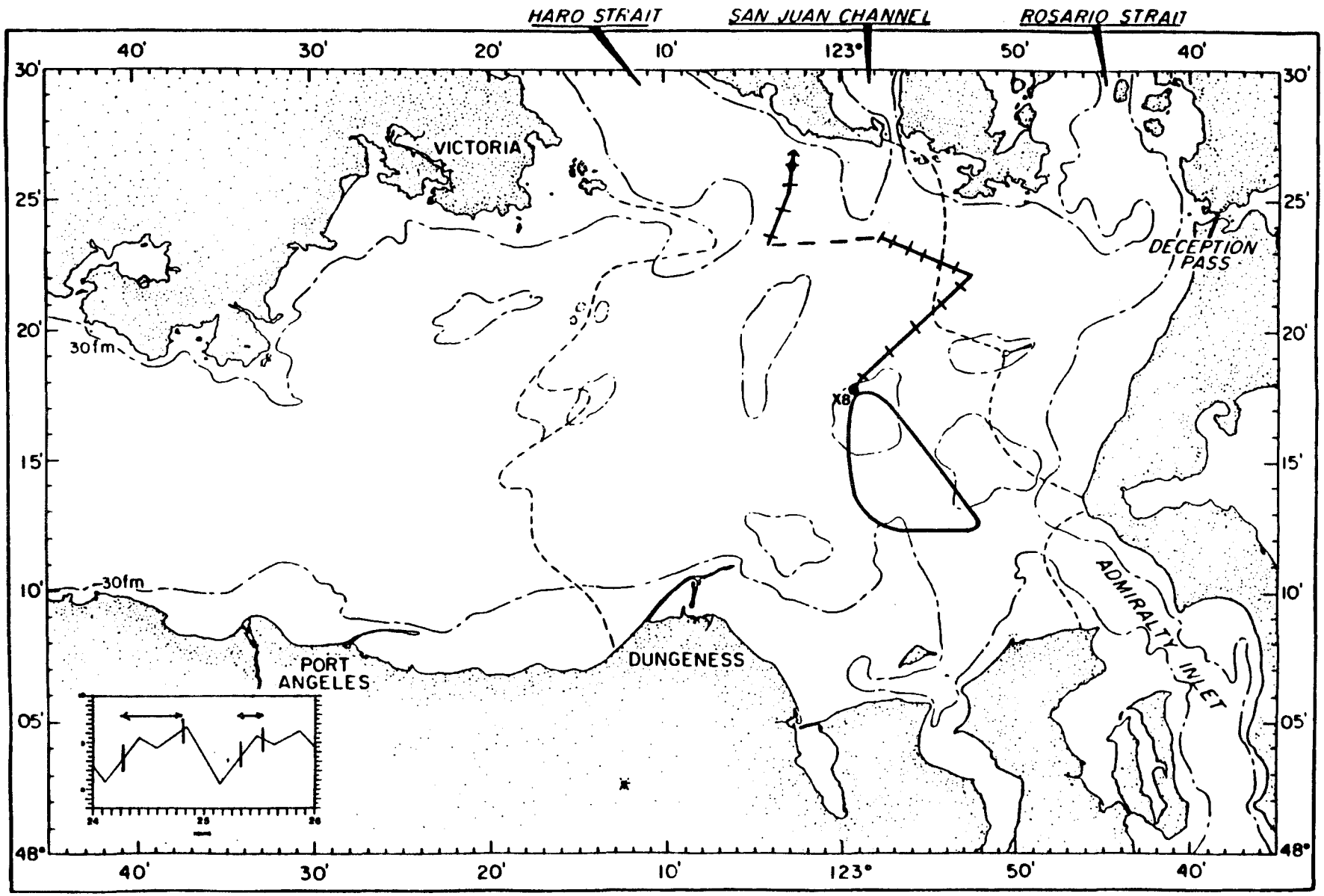


Figure II.7-13 Drift sheet movement observed off Smith Island, 25-26 August 1978. (●) indicates initial sighting; tick marks at hourly intervals; arrows indicate direction at last sighting; broken line indicates movement when drift sheets not observed; tick marks on tide curve shows period drift sheet was under observation. (Source: Cox et al., 1978).

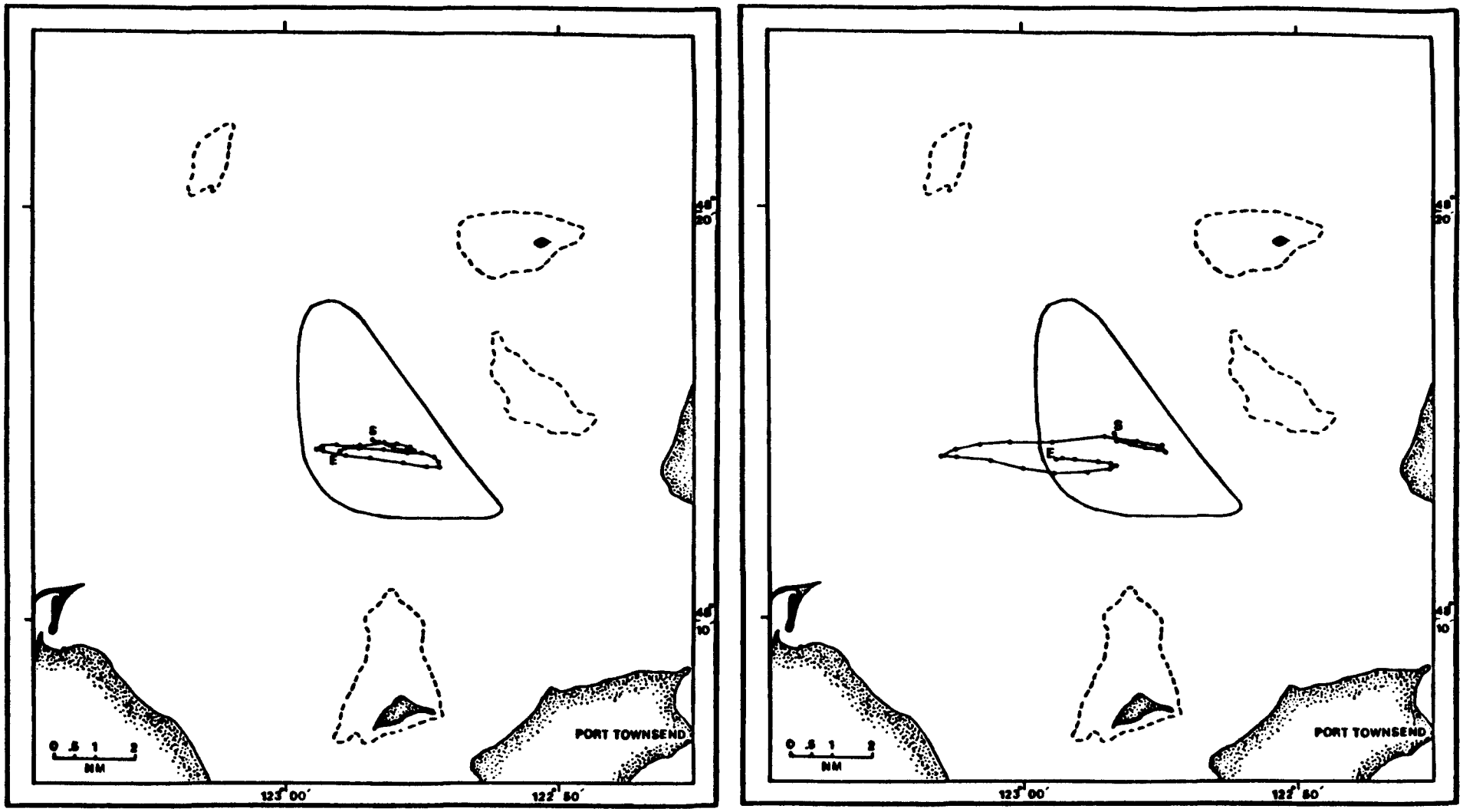


Figure II.7-14 Trajectory of a parcel of water for twenty-five hours, starting during slack tide. Dots indicate hourly increments, S = starting position, and E = ending position. Data obtained from Crean's (1983) tidal stream charts. (Source: EHI).

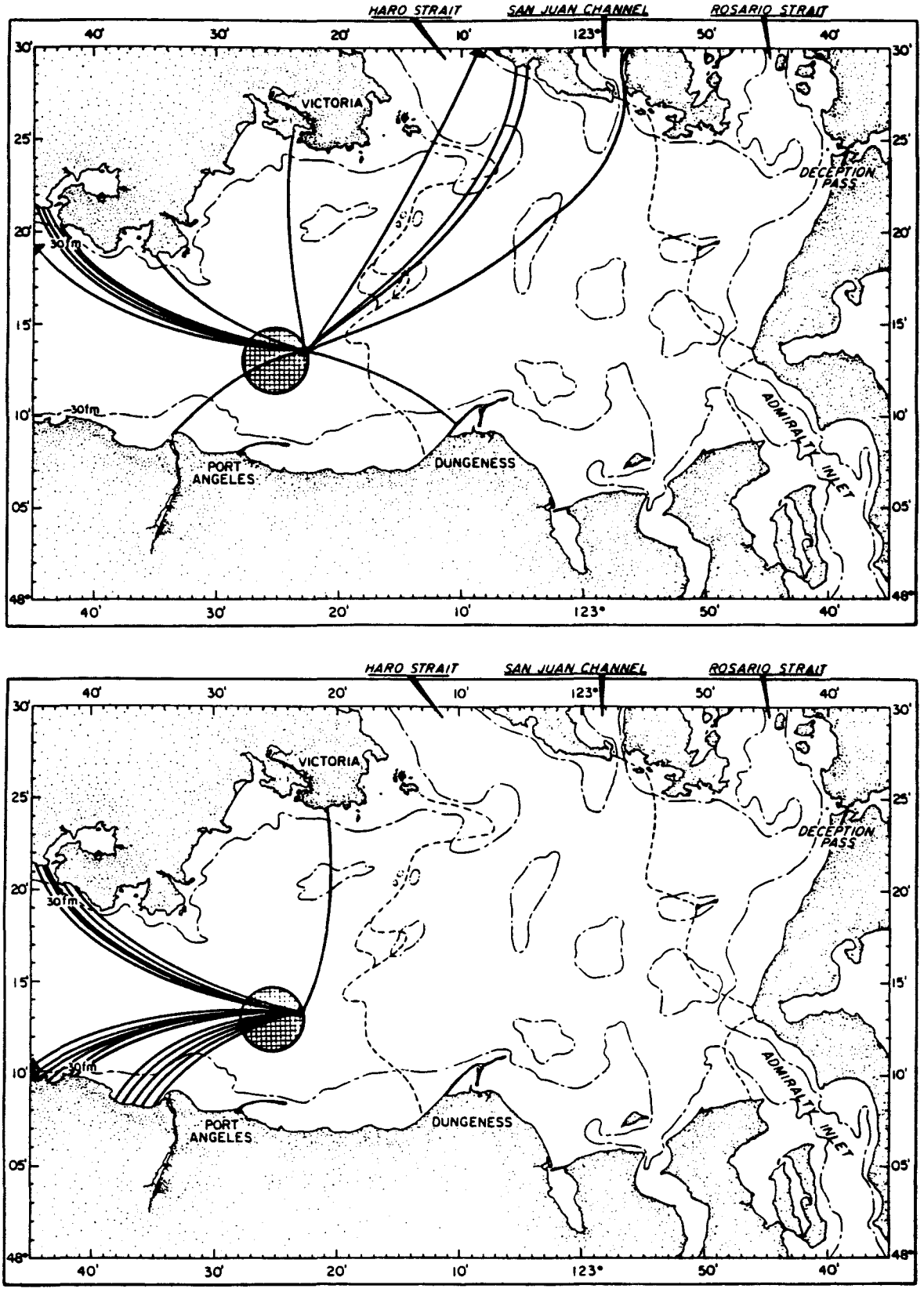


Figure II.7-15 Recovery positions of drift cards released on a) 6 April 1976 (42% returned) and b) 20 July 1976 (13% returned). Arrows indicate direction of off map recoveries. ZSF is shown as cross hatched area. (Source: Pashinski and Charnel, 1979).

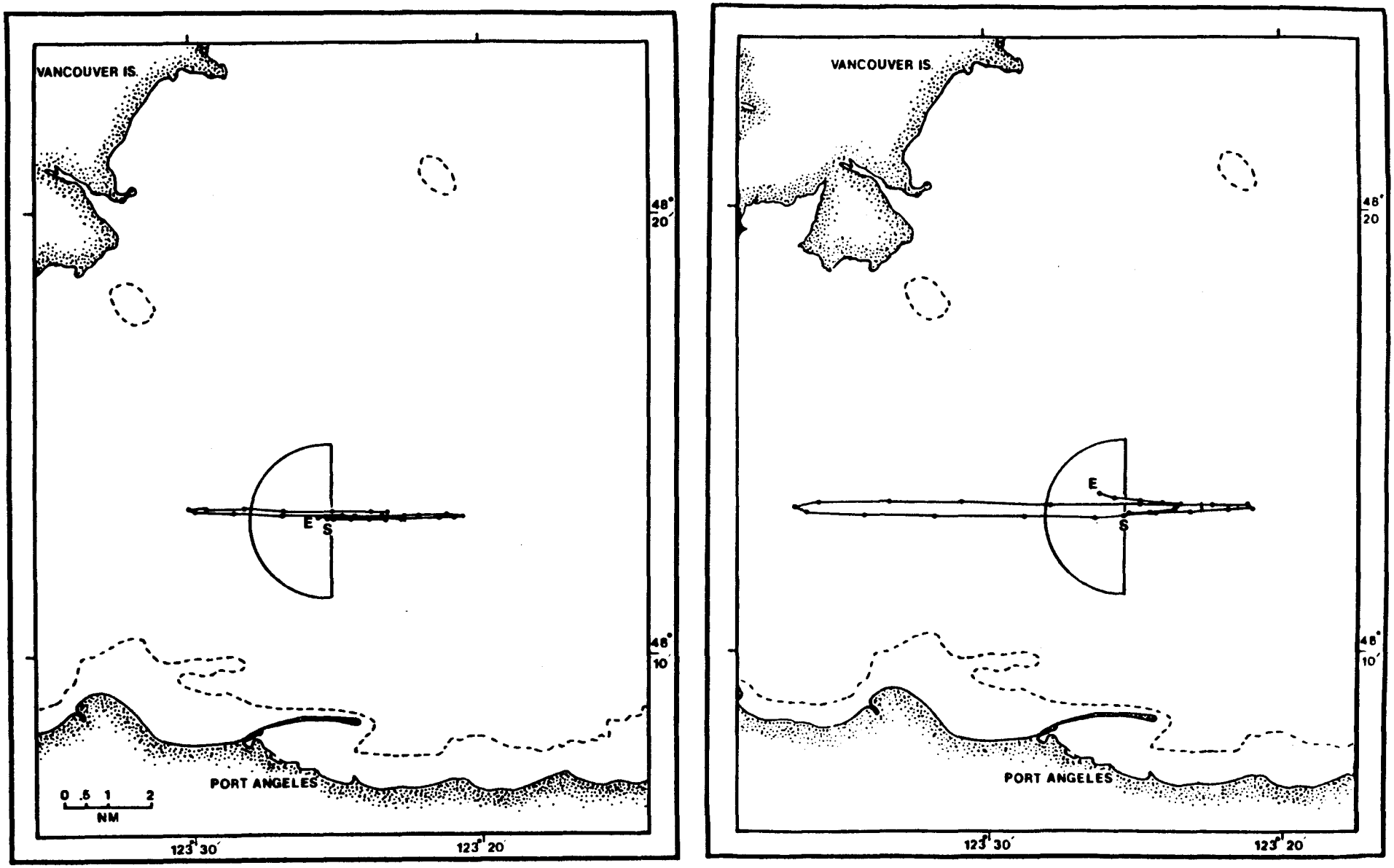


Figure II.7-16 Trajectory of a parcel of water for twenty-five hours, starting during slack tide. Dots indicate hourly increments, S = starting position, and E = ending position. Data obtained from Crean's (1983) tidal stream charts. (Source: EHI).

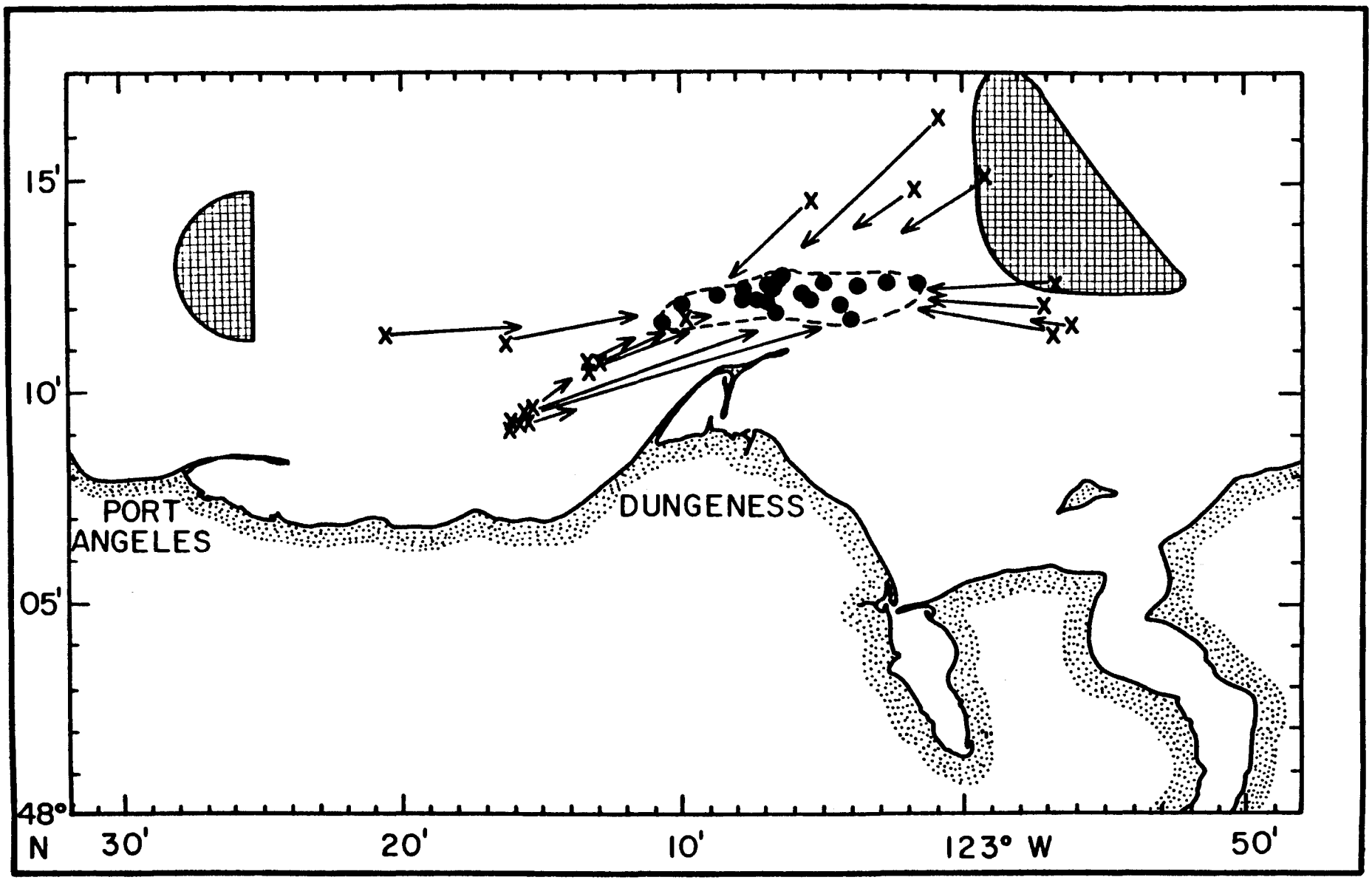


Figure II.7-17 Convergence of 20 drift sheets into a patch off Dungeness Spit. Data from Cox et al. (1978). Notation: X, launch positions; arrows, net direction of movement; and dots, positions of drift sheets at 1200-1500 on 26 August 1978. (Source: Ebbesmeyer et al., 1979).

8. BIOLOGICAL RESOURCES: BENTHIC HABITAT/CHARACTERISTICS MAPPED WITH CRAB, SHRIMP, AND BOTTOMFISH ASSESSMENTS

8.1 Objective

The distributions of Dungeness crab, shrimp, and bottomfish were mapped in the ZSFs from data obtained during cruises in February, April-May, July, and October, 1987. The objective was to select disposal sites in areas having a minimal impact on populations of these animals. Based on the data available, disposal in an area with a Dungeness crab density of 100 crab per hectare (or less) is considered a minimum impact area (Cahill, 1986). The following sections are based on Dinnel et al. (1988) and Donnelly et al. (1988).

8.2 Background

A key factor in locating PSDDA's disposal sites was an assessment of important fisheries resources including Dungeness crab, shrimp, and bottomfish. Each of these groups is known to use Puget Sound for feeding, growing, and reproducing.

Dungeness crab have been the object of commercial and sports fisheries on the west coast of the United States since 1848 (Dahlstrom and Wild, 1983). With the exception of a few early studies in the 1940's and 1950's, most of the studies specifically designed to understand Dungeness crab have been conducted in the last twenty years. Of these studies, only Mayer (1973) and English (1976) have addressed the locally important crab resources of the inland waters of Puget Sound. Ironically, it is these areas that have experienced some of the greatest increases of urbanization, industrial development, pollution, and fishing pressure.

The dramatic and sustained depression of crab resources in the San Francisco Bay area from the early 1960's to the present is a reminder that fishery stocks can be fragile. Although the decline in San Francisco Bay crab stocks may be partially attributable to changing natural oceanographic conditions (Wild et al., 1983), other impacts have been identified which were related to loss of nursery habitats and pollution (Wild and Tasto, 1983; Armstrong, 1983).

Though Dungeness crab are widely distributed in Puget Sound and constitute a commercial fishery of 1.3 to 2.0 million pounds annually (PMFC, 1982), little is known concerning their distribution and habitat preference. Studies of northern Puget Sound have shown that several life stages also utilize marine areas to depths of 400 feet (Dinnel et al., 1985a). These life stages include growing and molting young and mature adults, females with and without eggs, and possibly mating pairs. The northern Puget Sound data also suggest that certain habitats attract aggregations of crab for unknown reasons, although studies of coastal estuaries indicate a strong dependence of small juveniles on habitat (Armstrong and Gunderson, 1985). Therefore, an assessment of the disposal sites was necessary to determine if these areas are used by crab.

A critical concern during PSDDA was the level at which animal populations become important. This concern is difficult to address; it is a complex issue and there is a general lack of baseline information needed to interpret the available data.

After a review of available data, D. Armstrong and P. Dinnel (personal communications) determined that the average background concentration of crab populations was approximately 10 crab per 1,000 square meters in the northern Puget Sound area. They found that there probably will not be a time or place where there will be no crab. Therefore, future dredge disposal operations will inevitably have some impact on crab populations. However, on a tentative basis, average crab densities of ten or less per 1,000 square meters is considered minimal. Since there are 10,000 square meters per hectare, areas having less than 100 crab per hectare were considered to have minimal populations as indicated by Cahill (1986). On a sound wide basis, however, crab densitites decreased from north to south, and south Sound densities would average less than 10 crab per 1,000 square meters (Dick Baumgarner (WDF) personal communication, 1989).

Prior to PSDDA the extent of commercial or recreational shrimp resources in the ZSFs was unknown, although no commercial shrimp fishing occurs in or near the ZSFs. Table II.8-1 provides an estimate of average shrimp catches from otter trawls in selected areas of Hood Canal and Puget Sound in and near historical commercial shrimp activity areas. Also, see Exhibit B for more recent WDF estimates of shrimp catches from selected areas in Puget Sound (Dick Baumgarner (WDF) personal communication, 1989).

A variety of bottomfish species of commercial and recreational importance are known to inhabit Puget Sound (English, 1976; Miller and Borton, 1980), and a commercial trawl fishery for bottomfish is known to exist in Bellingham Bay and the Strait of Georgia. A recent study has shown that fish species diversity can be large between depths of 150 to 300 feet in Puget Sound (Donnelly et al., 1984).

8.3 Rationale

The reasons for evaluating these biological resources relative to dredged material disposal are two-fold: 1) a favored substrate type may be altered; and 2) food resources may be affected (see also section II.9). It is also important to document the presence and/or absence of crab, shrimp, and bottomfish and their relative abundance compared to other areas. Dungeness crab, for instance, have been shown to aggregate in certain areas relative to size, molting, and egg-bearing (Armstrong et al., 1986), some of these areas being deep-water habitats (Dinnel et al., 1985a). Selection of these habitats may be partially dependent on substrate type for food or for burial to avoid predation, especially during molting or egg-carrying. Changes in sediment quality may reduce the suitability for these purposes. There is some concern about depositing mud on a sandy bottom and less concern about depositing mud on a muddy bottom. In general for nondispersive ZSFs the preferred approach was to deposit dredged materials on the bottom where there was comparable sediment.

8.4 Methods

This section describes the methods and materials used in the field sampling for crab, shrimp, and bottomfish. The beam trawl and rock dredge surveys primarily focused on demersal invertebrate resources and the otter trawl primarily targeted bottomfish resources. Descriptions of the beam trawl, rock dredge, and otter trawl follow below. In addition to trawling, surface and bottom water samples were collected by Niskin Sampler and measured for temperature, salinity and dissolved oxygen. Trawl cruises were conducted on the following dates: 9 February-1 March (nondispersive sites only); 6-20 April (dispersive sites only); 6-13 May (nondispersive sites); 8-24 July (nondispersive sites); and 12-31 October (all sites).

8.4.1 Dungeness Crab Sampling--

Dungeness crab were sampled with a three meter beam trawl described by Gunderson and Ellis (1986) and used elsewhere in Puget Sound (Dinnel et al., 1985a, 1985b, 1986a, 1986b, 1987, 1988; Weitkamp et al., 1986). The beam trawl was towed approximately 232 meters (1/8 nautical mile) at a target ground speed of 2.5 km/hr (1.4 knots) which yielded an area swept by the net (opening = 2.3 m) of 534 m^2. All crabs caught in the trawls were measured, sexed, and assessed for molt condition (degree of shell softness) and reproductive condition (females with or without eggs) and returned to the water. Catches of shrimp and fish from the beam trawls were preserved for later processing in the laboratory. Other demersal resources such as scallops, sea cucumbers, sea urchins, mussels, and starfish were counted and returned to the water.

A rock dredge (86 cm wide x 38 cm high) was used to sample Rosario Strait and a few stations in the Strait of Georgia due to the presence of rock and/or cobble on the bottom. The dredge was towed approximately 185 m (0.1 nm) unless obstacles necessitated a shorter distance. The large mesh of the rock dredge bag was lined with a beam trawl cod-end liner (5 mm mesh). The catches made with the rock dredge must be viewed qualitatively since its sampling efficiency is unknown and probably quite variable depending on bottom type. All animals caught in the rock dredge were processed as noted above for the beam trawl.

8.4.2 Bottomfish Sampling--

Bottomfish were sampled with a 7.6-meter otter trawl described by Mearns and Allen (1978). The otter trawl stations were subsets of the beam trawl stations. The otter trawl was towed approximately 370 meters at a ground speed of 2.5 to 3.0 knots, yielding an area swept by the net of square meters based on an opening of 3.8 meters. Bottomfish were frozen for later processing ashore, which included identification of species, measurement of length and biomass, and checks for external lesions and parasites. Crab caught by the otter trawl were processed aboard the vessel as described above and returned to the water.

8.4.3 Shrimp Sampling--

Shrimp were collected as incidental catches from both the beam trawls for crab and the otter trawls for bottomfish. Specific stations for shrimp sampling were not established. Shrimp were preserved for later processing ashore which included identification of commercially important species, measurement of carapace length, and state of reproduction (females with or without eggs).

8.4.4 Trawl Gear Efficiency--

All trawl catches were converted to estimated densities based on our best guess of the actual area swept by the trawl. Our "best guess" is based on previous underwater measurements of net opening, observations of net behavior, and measurements of actual "net on bottom" times using sonic transducers on the net (unpublished data).

Regardless of the accuracy in calculating "area swept" for the bottom trawl, no trawl is 100% efficient at catching the animals in its path, which means that the faunal densities are almost always underestimated, the degree of underestimation being dependent on animal species and bottom type. The term "density" or "estimated density" (e.g., crab/ha) as used in this report has been used with the assumption of a net capture efficiency of 100%. Therefore, "densities" reported herein specifically refer to an <u>index</u> of estimated densities which should provide the best <u>relative</u> measures of demersal resources present and trends in abundances between areas, between seasons, and between years.

8.4.5 Sample Sites--

Sampling was conducted in the vicinity of preliminary disposal sites in the two nondispersive ZSFs in South Sound and four dispersive ZSFs in North Sound. Bellingham Bay sampling stations were selected to give general coverage to the entire Bay since the selected ZSFs in this location were tentative. See Dinnel et al. (1988) and Donnelly et al. (1988) for a detailed description of the sampling locations.

8.5 Distribution of Crab in the Nondispersive ZSFs

Maps of crab abundance were prepared for each ZSF based on sampling done during the winter, spring, summer, and fall of 1987 which are described below.

8.5.1 Anderson/Ketron Island ZSF 2--

Six stations each were sampled by beam and otter trawl in each of the two South Sound ZSFs during each season. Dungeness crab (C. magister) were absent from all trawls at this ZSF during all seasons (Fig. II.8-1). Dungeness crab were caught in small numbers outside the ZSF boundary. The average estimated density for all seasons and stations combined (n = 214 beam trawl tows) was 3 crab/ha, decreasing from 5 crab/ha in February to 1 crab/ha in October (Fig. II.8-2). Analyses of the basic biological data for this species shows that all individuals caught were large, mature individuals over 120 mm carapace width (CW). Females slightly outnumbered males in the catches except in October when only several males were caught. Possibly, females were not caught in October because they had extruded new egg masses and were buried in the substrate (thus unavailable to the trawl gear).

Rock crabs (Cancer productus and C. gracilis) were much more plentiful (average for all beam trawls = 156 crab/ha) in the Nisqually region than were Dungeness crab (average = 3 crab/ha). In general, C. gracilis outnumbered C. productus by roughly 10-fold in the catches.

Generally, for C. productus females were more abundant in the catches than males except for October. Gravid females were most prevalent in the February samples and the age of the egg masses varied from new to spent. Recruitment of juveniles started in about July. The Young-of-the-Year (YOY) dominated the catches in October and had grown to a size range of about 10 to 30 mm. Both male and female C. productus occurred to depths greater than 100 m with little clear indication that a specific depth interval was favored.

For C. gracilis males and females were caught in essentially equal numbers in February and May while the catches were dominated by males in July and October. Gravid females and juvenile crabs were caught during each season. The age of the egg masses were also of varied ages during each season. Hence, the spawning and settlement times for this species are distinctly less seasonal than for C. magister or C. productus. C. gracilis was found down to depths of 100 m but generally favored depths less than 60 m.

The area was also very rich in other invertebrate fauna including starfish (a wide variety of species), sessil tunicates, anemones, brachiopods, and gastropods. An occasional pink scallop was also caught along the west side of Ketron Island.

8.5.2 Anderson Island/Devils Head ZSF 3--

The overall (all seasons and stations combined, n = 24 beam trawl tows for each ZSF) average estimated densities for the various resources show that Dungeness crab were absent from both ZSFs, sea cucumbers were almost absent from both ZSFs, and that the faunal densities of rock crab, shrimp

and starfish were substantially less in ZSF 2 as compared to ZSF 3 or the average abundances for the Nisqually area in general. Comparisons of the average catches between the two ZSFs are graphically represented for the beam trawl and the otter trawl (Figs. II.8-3 and II.8-4, respectively). These figures emphasize the density differences between these two sites, especially for rock crab, shrimp, and starfish. ZSF 3 is a distinctly richer area than the deeper ZSF 2. Comparison of the catches for these two ZSFs by type of trawl gear shows that the beam trawl was a much better sampling gear for crab and starfish while the otter trawl was as efficient at sampling shrimp and, perhaps, sea cucumbers.

The primary invertebrate species of actual or potential commercial concern caught in the Nisqually region in 1987 were Dungeness and rock crab, pandalid shrimp and sea cucumbers. Dungeness crab were sparse yet of concern for two reasons: 1) crabs were caught near the south boundaries of both ZSFs and 2) this population of crab supports a small sport fishery in the Nisqually Delta region (Ron Westley, personal communication). The recruitment dynamics for Dungeness crab in this area are unknown. Larvae may come from the few local resident females or recruitment might be dependent on larvae transported southward through the Tacoma Narrows from the Main Basin of Puget Sound. The larger sizes of Dungeness crab from the Nisqually (esp. the females) together with a general appearance of good health suggests that the Nisqually area could support more Dungeness crab if settlement (and/or juvenile survival?) were more successful.

Other Cancer crabs present in the Nisqually region were the rock crabs C. productus and C. Cracilis. C. productus is utilized for food by some sport crabbers and divers while the more plentiful C. Rracilis is generally not fished (with the possible exception of members of certain ethnic groups) because of its smaller size. Rock crabs tend to be relatively more important in the sport catches when Dungeness crab are unavailable. C. productus is also a potential commercial species, since the large claws of this species now appear in California fish markets.

8.5.3 Bellingham Bay--

Bellingham Bay proved to be a rich area for several biological resources. Dungeness crab were generally abundant in most areas of Bellingham Bay (Fig. II.8-5) and averaged (all seasons and stations combined, n = 155 beam trawl tows) an estimated density of 83 crab/ha (range of 56 crab/ha in February to 108/ha in May; see Fig. II.8-2). The highest catches of Dungeness crab were consistently made at 10 to 20 m depths near Post Point (north of Chuckanut Bay) and Portage Island. The lowest crab catches were generally at the mid-bay stations, especially in the general area of the south ZSF site A-1. Dungeness crab outnumbered both species of rock crab in the Bellingham Bay beam trawl catches by about 3-4:1 (except October when a relatively large number of YOY C. gracilis were caught).

Females dominated the catches in all seasons by a factor of about 2-4 times the catch of males and relatively few juveniles were caught. Gravid females were caught in February with egg masses. Male crab showed some

molting activity (i.e., soft shells) February through May while the females showed only slight signs of molting in July. Very few juvenile Dungeness crab were caught. Those caught in February were 1986 YOY which averaged about 15 mm CW. The 1987 settlement took place between the July and October sampling with the average YOY CW being about 10 - 12 mm. Conspicuously absent from all samples were 1-2 year old crabs in the size range of 20 to 90 mm.

Dungeness crab inhabited all depths in Bellingham Bay but the females favored the deeper area during February and the shallower areas (15-20 m, especially off Post Point) in October. Thus, the Post Point area appears to be a favored area for the females during the egg incubation period. Males were caught only in shallow areas near shore in May but at all depths during the other three seasons.

Rock crab (C. productus and C. gracilis) were roughly one-half as plentiful (overall average of 40 crab/ha, n = 155 beam trawl tows) in Bellingham Bay as Dungeness crab (see Fig. II.8-2). Relatively few C. productus were caught in Bellingham Bay, especially in February and May. Sexes were fairly even for this species. The only gravid female in the species was caught in May and had a spent egg mass. Several 1986 YOY crabs caught in February were 10-20 mm CW. Settlement of the 1987 YOY occurred between July and October when they again averaged 10-20 mm CW. The bulk of C. productus were caught at shallow (10-15 m) depths near shore.

The majority of the rock crabs caught in Bellingham Bay were C. gracilis. The sexes were equally abundant with gravid females being found only in February with new eggs. Settlement of YOY in 1987 began in July while the previous years settlement had grown to about 40-50 mm CW by this season. Relatively few C. gracilis over 60 mm were found in Bellingham Bay in contrast to a relatively healthy population over 60 mm in the Nisqually area. The reason(s) for the different age structure between the two areas is presently unknown. The distribution of C. gracilis was limited primarily to shallow areas in February and May, but covered all depths in July and October, in large part due to the wide distribution of the newly settled YOY.

Tanner crab (Chionoecetes bairdi - also commercially known as snow crab) were found in small numbers in the Bellingham Bay samples but would have to be considered more of an "incidental observation" since this species does not support any fishery in the inland waters. The individuals caught in Bellingham Bay were mostly juveniles which probably settled from November-January and grew to an average size of about 50 mm CW by October. Except for February, males slightly outnumbered the females and their overall distribution was deep (25-30 m) and restricted to the mid-bay area.

Five stations each were sampled each season by beam trawl in or close to the proposed ZSFs in Bellingham Bay. Table II.8-2 shows the average seasonal and annual estimated densities (all seasons and stations combined, n = 20 beam trawl tows for each ZSF) for each of the invertebrate "resources". Dungeness crab and Tritonia (a large nudibranch) were least plentiful in the south ZSF site A-1, and shrimp and starfish (essentially all Luidia) in greater abundance in the south ZSF. Figures II.8-6 and II.8-7 provide graphical breakdowns of the average densities of invertebrate resources caught by beam

and otter trawls in each ZSF for each season. Comparison of these two figures again shows the relative efficiency of the beam trawl for sampling invertebrate resources with the single exception that estimates of shrimp densities were generally higher for the otter trawl.

8.6 Distribution of Crab in Dispersive ZSFs

Maps of crab abundance were prepared for each ZSF based on sampling done during spring and fall of 1987 which are described below.

8.6.1 Rosario Strait--

Eleven stations in Rosario Strait were sampled by rock dredge during April and October. Each tow with the rock dredge was roughly 0.1 nautical mile. No attempts were made to estimate resource densities from the rock dredge tows since the sampling efficiency of a rock dredge bouncing on a rocky bottom must be very poor.

Dungeness and rock crabs (except for small and plentiful *Cancer oregonensis*) were completely absent from the rock dredge samples during both seasons.

8.6.2 Port Townsend--

Six stations were sampled in and around the ZSF with both beam and otter trawls (except that three stations were not sampled by beam trawl in April due to high winds and rough seas). The station depths ranged from 70 to 150 m. The bottom was probably a mixture of sand, small gravel and shell. No Dungeness, rock, or tanner crabs were caught in this area during either sample season.

8.6.3 Port Angeles--

Six stations were sampled in and around the ZSF. The station depths ranged from 110 to 136 m and the bottom type was apparently a sand/gravel mix with some shell. As was true for the Port Townsend site, no crabs were caught in the Port Angeles ZSF.

8.7 Distribution of Shrimp in the Nondispersive ZSFs

8.7.1 Anderson/Ketron Island ZSF 2--

Small numbers of pandalid shrimp were caught throughout the Nisqually region in all seasons (average of all 214 beam trawl tows = 75 shrimp/ha). The highest shrimp catches were in July and October with the bulk of these shrimp being young Pandalus danae caught in shallow areas away from the deeper disposal ZSFs (Fig. II.8-8). The pink shrimps, P. jordani and P. borealis, were caught in small numbers with only an occasional individual of the other species being caught. The size distributions for the most plentiful species showed that P. danae YOY settled between May and July and grew to a size range of about 9 to 15 mm carapace length (CL) by October. Settlement of P. jordani YOY was evident in the July trawls and the age group present in the February trawls had grown from about 7-8 mm in February to about 17-18 mm in October. P. borealis settlement appeared slightly later than P. jordani with 1-year old individuals growing from about 9-10 mm in February to 15-17 mm by October. For the other species, settlement times (although sparse in numbers caught) appeared to be the following: Pandalopsis dispar = June-July and P. hypsinotus = April-May. Gravid females of P. danae and P. borealis were found only in the February trawls.

Historically, the south Puget Sound re ion was identified by Smith (1937) as important for smooth pink shrimp (P. jordani) production, although little information was provided which identified specific shrimp producing areas within this region. Most of the past shrimping efforts appear to be focused in the Carr and Case Inlet areas prior to 1976 and not in the Nisqually region. Since 1976, low abundances of shrimp have resulted in a closure of the shrimp fishery in these areas, and in the time period 1985-7, no shrimp harvests were reported from South Sound (D. Ward, W.D.F., personal communication).

8.7.2 Anderson Island/Devils Head ZSF 3--

Shrimp densities were higher for this ZSF compared to ZSF 2. Figures II.8-3 (beam trawl) and II.8-4 (otter trawl) present side-by-side comparisons of average estimated densities of invertebrate resources in both of the Nisqually ZSFs. These figures strongly suggeat that invertebrate resources would be more impacted by location of a disposal site in the shallower ZSF 3 near Devils Head.

8.7.3 Bellingham Bay--

Bellingham Bay proved to be relatively rich in commercial shrimp resources compared to many other areas of Puget Sound. All seven species of pandalid shrimp which were recorded in this study occurred in Bellingham Bay, although the spot prawn P. platyceros, and the pink shrimp, P. jordani, were scarce. The Bay was especially rich in P. hypsinotus, P. danae, and P. borealis. The overall average (all seasons, stations, and species combined, n = 155 beam trawl tows) estimated density was 600 shrimp/ha with a seasonal range of 413 shrimp/ha (May) to 942 shrimp/ha (February).

Shrimp were caught at most stations in Bellingham Bay with the highest densities generally being caught in the deeper (25-30 m) mid-portions of the bay (Fig. II.8-9). The one exception to this was substantial catches of juvenile P. danae in July and October at some of the shallow areas (10-20 m), especially in the Post Point area. Only in the case of shrimp (in south ZSF) and the large pink nudibranch Tritonia (south ZSF) did "resource" densities in the ZSFs exceed the bay-wide averages.

Relatively few P. platyceros and P. jordani were caught; hence little information is available regarding timing of egg extrusion and juvenile recruitment. For the other shrimp species, egg-bearing females were only caught in the February trawls except that a few gravid P. danae were also found in the May trawls. No gravid P. dispar were caught. Recruitment of juvenile YOY shrimp was first noted for most species in the July trawls, except that P. hypsinotus YOYs were not caught until October.

Besides providing estimates of shrimp densities, the trawl sampling also produced information on the age structure of shrimp populations in Bellingham Bay. For some species (P. platyceros, P. dispar, and P. jordani), only one year class of shrimp were evident in the trawls at any one time. For several other species (P. borealis, P. goniurus, and P. hypsinotus), two year classes were generally present while three year classes were evident for P. danae. From these size-frequency plots, growth and relative abundances of each of the year classes can be traced.

Pandalid shrimp were abundant in Bellingham Bay as compared to the Nisqually region. Three species, P. danae, P. hypsinotus, and P. borealis, were abundant enough to be considered resources with future harvest potential. Past surveys in Bellingham Bay have also noted large numbers of shrimp in the catches. Webber (1975), sampling nine stations in Bellingham Bay with a 3-m try net, found that approximately 50% of all invertebrates caught were pandalid shrimp. Similar surveys by CH_2M Hill (1984) using an otter trawl identical to that used in this study found that shrimp also dominated their catches (77% of all invertebrates caught were shrimp).

Selection of a disposal site in Bellingham Bay is more difficult than for the Nisqually because of two factors: 1) Dungeness crab and shrimp are generally much more plentiful; and 2) there is no clear cut biological basis for selecting one ZSF over the other. Comparisons of the beam and otter trawl catches between the two ZSFs (Fig. II.8-6 and II.8-7) suggest that Dungeness crab may be more plentiful in the north ZSF but that shrimp are more abundant in the south ZSF. Tritonia catches were patchy but roughly equal between the two ZSFs. One possible deciding factor may be the relative densities of the starfish Luidia foliolata, which is considered a serious nuisance by-catch of commercial fish trawls in some areas of Bellingham and Samish Bays. While ubiquitous throughout Bellingham Bay, the highest beam trawl catches were in the south-central portion of the bay and the estimated densities of this animal in the two ZSFs showed its preference for the south ZSF in each of the four seasons. Hence, selection of the south ZSF as the first alternative might be preferable relative to the trawl industry.

8.8 Distribution of Shrimp in Dispersive ZSFs

8.8.1 Rosario Strait--

A relatively large number of small, non-pandalid shrimp were caught in the rock dredge but only small numbers of pandalid shrimp (mostly small P. danae) were caught at all stations except the most northerly station (Fig. II.8-10). These findings suggest that the best location for a disposal site would be at the north end of Rosario Strait where the ZSF is located.

8.8.2 Port Townsend--

The Port Townsend ZSF was fairly rich in shrimp (esp. juvenile P. danae and P. borealis), pink scallops and sea urchins. A modest average density of 236 shrimp/ha (all stations combined, n = 6 otter trawl tows) was estimated for this area in April (Fig. II.8-11). The average density of shrimp estimated from the October otter trawl catches jumped dramatically to 6,802 shrimp/ha primarily due to an influx of young P. danae and P. borealis. The distributions of shrimp in the Port Townsend area were similar for each of the two seasons sampled with the highest catches being made at Stations 4 and 6 (stations closest to Port Townsend). In each case these catches were dominated by P. danae. Fewer shrimp were consistently caught at Stations 1 and 5. Pandalus platyceros, P. jordani, and P. hypsinotus were not caught in this area and relatively few P. dispar and P. goniurus were in the catches. The few P. dispar that were caught were mature shrimp averaging about 25-30 mm carapace length (CL) except that a few juveniles were caught in October. The few P. goniurus caught only in October, were all juveniles averaging 10 mm CL. P. borealis caught in the April sampling were of two size groups averaging about 10-12 mm and 16-17 mm CL while the October samples were dominated by YOYs averaging 9-10 mm. The size-frequency plot for P. danae caught in April also suggests 2 size groups for this species with average sizes of 10-12 mm and 17-20 mm CL. The number of P. danae caught in October also increased roughly two orders of magnitude, but, unlike P. borealis, the increase in numbers appeared to be due to an influx of 1-2 year old animals rather than due to settlement of YOY.

Not enough samples were collected in this area to be able to discern any preferable areas for locating a disposal site.

8.8.3 Port Angeles--

Few shrimp (average density, n = 6 beam trawls, was 53 shrimp/ha) were caught in the trawls in April, the majority (~ 90%) of those that were caught being P. borealis (Fig. II.8-12). However, catches of shrimp in October jumped more than two orders of magnitude (average estimated density = ~ 6,775 shrimp/ha) due entirely to settlement of YOY P. borealis averaging about 8-9 mm CL. Unlike Port Townsend, no P. danae were caugnt in the Port Angeles area. The balance of the shrimp catch at Port Angeles consisted of a few P. dispar and P. goniurus.

The distribution of the April shrimp catches was uniformly low at all stations with the largest catch (206 shrimp/ha) at Station 5. However, the very high catches in October were not evenly distributed with about 94% of the total shrimp caught coming from only 3 stations (Stations 1, 2, 3) with catches equal to 26,462 to 68,927 shrimp/ha, although this pattern is not readily evident due to the scale.

As was the case with Port Townsend, not enough stations were sampled to provide enough information to fine-tune the selection of a preferred disposal site within or around the Port Angeles ZSF.

8.9 Distribution of Bottomfish in Nondispersive ZSFs

8.9.1 Anderson/Ketron Island ZSF 2--

Fifty-one species of fish were caught in the eastern Nisqually region during all four seasons. Twenty-seven of these species were captured in ZSF 2 during the study. Almost one-half of the species occurred during either three or four of the sampling periods. ZSF 2 had the highest abundance values and biomass values during May and October (Figs. II.8-13 and II.8-14, respectively). Abundance catch per unit effort (CPUE) for the eastern Nisqually region ranged from 12 to 775 fish, and biomass CPUE ranged from 7 kg to 61 kg. In general, abundance and biomass CPUE values showed similar fluctuations throughout the study period (Fig. II.8-15).

Pacific hake was found in all seasons except winter while the following fish were found throughout the year; blacktip poacher, brown rockfish, Dover sole, English sole, longnose skate, Pacific tomcod, plainfin midshipman, quillback rockfish, ratfish, rex sole, and slender sole. English sole and slender sole were the dominant species; together they accounted for 35 to 80 percent of the relative abundance during each season.

The abundance of English sole varied by season and depth (Fig. II.8-16). The largest catches occurred at ZSF 2 during autumn followed by ZSF 2 in spring, and the 60 m depth stratum (transect 2) during winter and spring. The 20 m depth stratum (transect 2) consistently had the lowest abundance of English sole.

Length frequency plots of English sole indicated the presence of at least seven year classes within the study area (Fig. II.8-17). Length-frequency plots were only made for those depth strata that showed high abundance or had some other attribute such as a concentration of juveniles. English sole larger than 300 mm (males) and 380 mm (females) may represent fiah older than 7 years. Female English sole size distributions indicated a larger average size compared to male English sole. No ripe females were found during this study. In general the largest English sole were found at the greatest depth. The largest females and males occurred in ZSF 2 where the female size distribution was decidedly larger than the male size distribution.

English sole seemed to undergo migrations between shallow to deep strata. Generally the younger fish were found in the shallow strata, while the older ones were found at greater depths. This suggests that English sole moved into deeper water as they aged. Ketchen (1956) and English (1976) indicated that English sole moved from shallow to deep water as they grew. Ketchen (1956) further found a pronounced shift of abundance into shallow water during spring; however, this same phenomenon was not detected in the ZSFs. Since English sole are known to undergo migrations between different areas (Ketchen, 1950), the decline in abundance at all strata during summer may indicate migration out of the area. In Puget Sound, English sole spawn from January through April (Smith, 1936), therefore, the low abundance in winter and the lack of ripe females suggests that the ZSF was not being used as a spawning area. Cluster analysis found that English sole were usually caught with slender sole and ratfish at ZSF 2 (> 110 m deep). All three species are usually found as adults at depths of 40 m or more in other parts of Puget Sound (Lauth et al., 1988; Donnelly et al., 1984a and 1984b).

Species diversity varied by season and stratum (Fig. II.8-18). ZSF 2 had the highest diversity compared with surrounding stations during winter and the lowest diversity during spring. The species diversities found in the ZSF 2 site showed different seasonal patterns and values compared to other studies at similar depths (Lauth et al., 1988; Donnelly et al., 1984a and 1984b). These same studies also found abundance and biomass to be generally high at depths of 40 m to 50 m. Species richness varied by depth and season. Generally the 20 and 110 m depths had the lowest values in each season during autumn when the 20, 40, and 110 m depths had similar values and were all low. ZSF 2 had intermediate to high values throughout the year.

Dover sole, English sole, flathead sole, rex sole, and rock sole all showed indications of blood worm infestations. The incidence of Philometra sp. varied between species, seasons, and strata, but did not show a discernible pattern. One liver tumor was found by gross examination in a rex sole during spring in the ZSF. There was zero incidence of fin erosion and skin tumors.

8.9.2 Anderson Island/Devils Head ZSF 3--

Forty-four species of fish were caught in the western Nisqually region. Thirty-five of these species were captured in ZSF 3 during the study. Over one-half of the species occurred during either three or four of the sampling periods. ZSF 3 had the highest abundance and biomass values during October (Figs. II.8-13 and II.8-14, respectively). Abundance for the western Nisqually region ranged from 31 to 516 fish, and biomass CPUE ranged from 3 kg to 23 kg. Abundance and biomass CPUE values did not show similar fluctuations from season to season (Fig. II.8-19).

Based on previous studies the ZSF 3 site appeared to be typical of other locations in Puget Sound at their respective depths (Lauth et al., 1988; Donnelly et al., 1984a and 1984b). The previous studies found abundance and biomass to be generally low at depths of 100 m or more.

Blackbelly eelpout, blacktip poacher, English sole, longnose skate, Pacific herring, Pacific tomcod, plainfin midshipman, ratfish, rex sole, rock sole, roughback sculpin, shiner perch, and slender sole were all found throughout the year. Six other species (flathead sole, Pacific hake, sand sole, snake prickleback, speckled sanddab, and spiny dogfish) were captured during three seasons. The dominant species varied from season to season. Blackbelly eelpout, Pacific tomcod, and shiner perch had the highest combined relative abundance during the winter. Blackbelly eelpout and English sole dominated spring and with the addition of Pacific tomcod also dominated the rest of the year.

The abundance of English sole in ZSF 3 was generally intermediate in value except during autumn when the ZSF 3 abundance was second only to 40M depth stratum (transect 5) during the same month (Fig. II.8-20).

The length frequency plots of English sole at the 40M depth stratum (transect 5) indicated the presence of only one or two year classes consisting of fairly small fish (Fig. II.8-21). The 60M and ZSF 3 depth strata contained older fish in which the females were generally larger than the males.

The depth of ZSF 3 is generally shallow (60 m or less) and the species associated with English sole were those species usually found at similar depths in other parts of Puget Sound (Donnelly et al., 1984). English sole dominate the commercial catches in the whole area (Pattie, 1985). While the English sole are a commercially exploited species, they also play a vital role in the overall ecology of the marine community.

Species diversity varied by season and depth (Fig. II.8-22). Winter and spring values showed only minor fluctuations between depths while values between seasons decreased for all depths except 20 m. The highest species diversity was found at 20 m during summer and the lowest at 20 m during autumn, variation at the other three strata during summer and autumn was low. In general summer values at all depths except 20 m were lower than other seasons of the year.

Species richness showed similar patterns for each season except for summer when the 20 m depth value increased. In general the 20 m depth was the lowest except summer and ZSF 3 values were the highest for all seasons.

Blood worm infestation was found in English sole, rex sole, rock sole, and sand sole. The incidence of Philometra sp varied between species, seasons, and strata, and did not show a discernible pattern. There was zero incidence of fin erosion and liver tumors.

8.9.3 Bellingham Bay--

Fifty-seven species of fish were caught in Bellingham Bay during the course of this study. Alternative site A-2 had the highest abundance and biomass values and the preferred site and the lowest values, due in part to the lack of stations (Fig. II.8-23 and II.8-24). Abundance CPUE for the entire area ranged from 16 during autumn to 1592 in the summer, and biomass CPUE ranged from less than 1 kg in winter to 66 kg during the same period. Abundance and biomass CPUE values varied considerably and showed few similarities during the study period (Fig. II.8-25).

Abundance, species richness, and species diversity results indicated that ZSF A-1, ZSF A-2, and samples taken at > 20 m depth were similar to each other. However, biomass results show that ZSF A-1 and depths > 20 m were similar while ZSF A-2 always had higher values. The shallowest depths sampled (15 m to 20 m in depth) generally had the lowest values in the ecological measures. The similarities in the ecological measures of the two ZSFs and depths > 20 m may be due to the fact that these strata were all within 5 m depth of each other. Most of Bellingham Bay included in the study area was approximately 30 m in depth. Previous studies in Puget Sound have generally shown that similar fish assemblages occur at similar depths within geographically limited areas (Lauth et al., 1988; Donnelly et al., 1984a; Donnelly et al., 1984b; Donnelly et al., 1986; Wingert and Miller, 1979; and Moulton et al., 1974).

Temporal differences also occurred in measures of the fish community. The peaks in abundance and biomass that occurred during the year were due in large measure to relatively high concentrations of longfin smelt; however, other species such as blackbelly eelpout, English sole, Pacific tomcod, and shiner perch showed occasional peaks in abundance. Temporally, abundance and biomass were generally lowest during the spring. The dominant species and relative abundances were also similar between the two ZSFs and samples from > 20 m depth both spatially and temporally.

Forty-three species were captured in the ZSF A-2 stratum during the study. Blackbelly eelpout, butter sole, daubed shanny, English sole, flathead sole, longfin smelt, Pacific herring, Pacific tomcod, shiner perch, spiny dogfish, and starry flounder were all found throughout the year. Six other species (pile perch, plainfin midshipman, sand sole, shortfin eelpout, snail prickleback, and staghorn sculpin) were captured during three seasons. The dominant species throughout the year was longfin smelt with blackbelly eelpout and English sole making a substantial contribution to the catch during spring.

Thirty-two species were found within ZSF A-1 during the study. Over one-half (18) of the species occurred during either three or four of the sampling periods. Nine species (blackbelly eelpout, butter sole, English sole, flathead sole, longfin smelt, Pacific herring, Pacific tomcod, slim sculpin, and spinyhead sculpin) were all found throughout the year. Another nine species (daubed shanny, plainfin midshipman, sand sole, shiner perch, shortfin eelpout, snail prickleback, spiny dogfish, staghorn sculpin and starry flounder) were captured during three seasons. The dominating species throughout the year was longfin smelt. Two other species that contributed substantially were shiner perch (winter) and blackbelly eelpout (spring).

Butter sole appeared to undergo migrations within the study area. Results suggested that butter sole in Bellingham Bay move offshore during autumn and winter possibly for spawning purposes. Butter sole in Bellingham Bay are known to move into shallow water during summer and then into deep water, and spawn from February through late April (Hart, 1973; Levings, 1986; Manzer, 1949). Field observations were in agreement with the literature since gravid female butter sole were found during the winter sampling period. Length frequency plots of butter sole at ZSF A-1, ZSF A-2, and depths > 20 m show the presence of several year classes within the study area. Ages older than 4 may have been represented by larger fish (greater than 255 mm). The size distributions of the two sexes showed that females were only slightly larger than the males. Field sampling during the winter indicated the presence of gravid females.

Relatively high concentrations of English sole were found at ZSF A-2 during winter and spring. Abundance levels at other times of the year were relatively low suggesting little or no migration within the study area, but possibly migration into and out of the area. English sole are known to undergo migrations between different areas (Ketchen, 1950), the decline in abundance at all depths during summer and autumn may indicate migration out of the area. In Puget Sound, English sole spawn from January through April (Smith, 1936), therefore, the high abundance in winter and the presence of gravid females found during field sampling suggests that ZSF A-1, ZSF A-2, and depths > 20 m may be used as spawning areas. Length frequency plots of English sole indicate the presence of several year classes within the study area. The two ZSFs had an even distribution of all sizes within the size ranges exhibited.

Flathead sole were found in the greatest abundance during spring through autumn in the two ZSFs and depths > 20 m. The individuals captured at these depths included small, YOY, apparently mixed in with the larger adults. Miller (1969) indicated that flathead sole spawn from March to late April in some parts of Puget Sound. There was a single relatively large peak of abundance of flathead sole in ZSF A-2 during winter, and also at the same time gravid females were found. These results suggested a concentration of individuals for spawning. However, the number of individuals involved was not large (approximately 30) and therefore additional observations would be needed to confirm the suggestion of spawning. In addition, the shifts in abundance from area to area within Bellingham Bay was small and not suggestive of migratory behavior. The length-frequency distributions contain many year

classes from YOY to individuals exceeding five years of age. Young of the year were located primarily in ZSF A-1 and samples > 20 m. In all, ZSF A-1, ZSF A-2, and > 20 m depth had size distributions that showed females were larger than males. Field observations indicated the presence of gravid females scattered throughout the study area during the winter.

Relatively high concentrations of starry flounder were found in ZSF A-1 and ZSF A-2 during winter. Abundance levels at other times of the year were low suggesting little or no migration within the study area, but possibly migration into and out of the area. Starry flounder are known to spawn in shallow water in Puget Sound during the winter months (Smith, 1936). The relatively large concentration of starry flounder during the winter may suggest a spawning aggregation since individuals were captured containing eggs that were nearly ripe. The movement and spawning aggregation speculations are based on a small sample size, and similar to the flathead sole, would need to be confirmed with additional sampling. Length-frequency histograms of fish from ZSF A-2 indicated the presence of several year classes. All of the largest starry flounder found in ZSF A-2 were females. No gravid females were located during the course of this study.

Longfin smelt were the dominant species in terms of abundance in Bellingham Bay. High numbers occurred in the two ZSFs during most seasons. Longfin smelt in Puget Sound are known to be anadromous, and are thought to spawn and die at the end of 2 years (Hart, 1973). Length-frequency histograms of the sampled individuals support the hypothesis of only two year classes. ZSF A-1, ZSF A-2, and samples from > 20 m all contained what appeared to be two year olds, while ZSF A-1 and > 20 m depth also contained YOY. The occurrence of both juveniles and adults together, and in high numbers, suggests the bay is being used as a nursery area for the young and a forage area for adults. Longfin smelt appear to prefer the deeper portions of Bellingham Bay.

Butter sole, English sole, flathead sole, and starry flounder are caught by commercial and sport fisheries in Bellingham Bay and other locationa in Puget Sound. Cluster analysis showed that these four species usually clustered in the same or closely related species groups. Longfin smelt are captured by a fishery in the Nooksak River. Starry flounder dominate the catches of flatfish in Bellingham Bay (Pattie, 1986). The order of importance, based on catches, of the other flatfish is English sole, butter sole, and flathead sole. While all five species may be exploited, it is important to bear in mind that they also play a vital role in the overall ecology of the marine community.

Other species such as larger skates, ratfish, and other flatfish are also exploited in Bellingham Bay. The skates and flatfish are taken as incidental catch when fishing for the species mentioned above. Ratfish have also been actively fished in the past, but only occasionally. The ratfish were exploited for oil used for specific lubricant applications.

Species richness showed irregular changes from season, while fluctuations in species diversities were similar from season to season (Fig. II.8-26). In general, spring, summer, and autumn species diversities showed similar

patterns by depth or season. The lowest species diversity value occurred during summer at ZSF A-1 and the highest during autumn at stratum 1 (15-20 m). Summer values were low except for stratum 1. The species diversities at the ZSFs were generally intermediate in value. ZSF A-1 showed almost no variation in species richness. Stratum 2 (> 20 m) had the highest values for all seasons except summer when ZSF A-2 was slightly higher. With the exception of summer, the two ZSFs were intermediate in value throughout the year.

Results of other studies (Palmisano, 1984, Webber, 1975) generally agreed with the findings of the present study except for the species composition found by Palmisano (1984) and the dominant species found by Webber (1975). The reason for the differences may be due to different sampling designs and locations of sample stations. Most of the work of the two previous studies concentrated in the inner part of the bay near the City of Bellingham and near Post Point. The present study was spread over a larger area and most sampling was done away from the shoreline. Bellingham Bay is biologically rich and has numerous species of fish. Many of these fish appear to use Bellingham Bay as both a spawning and a nursery area. The large, relatively shallow area, appears to be very productive and would seem to be a good location for demersal fish. The overwhelming impression is one of similarity at all stations and strata below 20 m in depth.

Butter sole, English sole, flathead sole, rock sole, and starry flounder all showed indications of blood worm infestation. The incidence of Philometra sp. varied between species, seasons, and area, and did not show a discernible pattern. Four skin tumors were noted, 3 on. English sole caught at stations outside the ZSFs at > 20 m depth during winter (2) and spring (1), and 1 skin tumor on a flathead sole found in ZSF A-1 during summer. There was zero incidence of fin erosion and liver tumors.

8.10 Distribution of Bottomfish in Dispersive ZSFs

The dispersive sites were sampled during spring (April 1987) and autumn (October 1987). The specific location of the sampling stations was determined by the location of the ZSF and tidal currents in each location.

8.10.1 Rosario Strait--

Few species or individuals were captured at any of the Rosario Strait sampling stations. One large catch of 66 ringtail snailfish was collected at a station about 0.4 nautical mile north of the ZSF with a beam trawl. The catches from the rock dredge were small and contained few species of commercial interest. The comparison of catches by rock dredge and the research otter trawl are unknown; however, it was presumed that the rock dredge was a much less efficient sampler of fish. Based on the finding of this study the proposed ZSF in Rosario Strait does not contain any fish resources that would be of concern to the disposal of clean dredge materials.

8.10.2 Port Townsend--

Twenty-seven species were found in the Port Townsend area. Eight species and a total of 12 specimens were captured during spring while 23 species and 382 individuals were caught during autumn. The number of species and abundance of each increased in the ZSF and adjacent stations from spring to autumn. Walleye pollock dominated the catches during autumn. In contrast, only one walleye pollock was captured in the spring.

The area from Port Townsend to Port Angeles is an important sport fishery area. There is a limited commercial trawl fishery in the Strait of Juan de Fuca that targets true cod with incidental catches of English sole and rockfish. Several species of interest to sport and commercial fisheries were captured during this study (e.g., English sole, Dover sole, quillback rockfish, walleye pollock, etc.). All of the exploited species, except walleye pollock, were in low abundance. Walleye pollock subadults were encountered in substantial numbers during the autumn sampling period, while in spring they were represented by a single individual. These results are interesting since young walleye pollock were captured during the spring months by surface trawl in the Strait of Georgia (Barraclough, 1967). The presence of walleye pollock in substantial numbers during autumn in the Strait of Juan de Fuca might imply migration from one area to the other during the summer.

8.10.3 Port Angeles--

Twelve species were caught during each sampling period, resulting in a combined total of 21 species for the entire study. Nine of the twelve species were unique to each season. Forty individuals were caught in the spring while 991 fish were captured during autumn. Subadult walleye pollock dominated the catches during autumn (936 were caught). Walleye pollock were caught in substantial numbers at all stations except at a station about 5 nautical miles east of the ZSF. Few species or number of individuals were found within the ZSF during either season except for walleye pollock. The total catch of walleye pollock was 936 for the autumn sampling, of which 871 were caught within the ZSF. Dredged materials that are anticipated to be disposed of in the Strait of Juan de Fuca ZSFs will be rapidly dispersed by the tidal currents (Coomes et al., 1987) and are not expected to have much impact on bottomfish.

TABLE II.8-1 ESTIMATED AVERAGE SHRIMP CATCHES PER HECTARE FROM OTTER TRAWLS CONDUCTED IN SELECTED AREAS OF HOOD CANAL AND PUGET SOUND FROM 1967 TO 1979. THESE ESTIMATES ARE DERIVED FROM UNPUBLISHED DATA COLLECTED AND SUMMARIZED BY DR. KENNETH CHEW, SCHOOL OF FISHERIES, UNIVERSITY OF WASHINGTON.

Location/Depth (m)	Number of trawls	Catch (kg)/Ha
HOOD CANAL		
Dabob Bay		
20 - 45	33	2.9
45 - 70	26	2.7
70 - 125	24	3.5
Pleasant Harbor		
35 - 65	5	2.9
65 - 90	8	10.0
Seabeck		
45 - 80	3	0.8
Potlatch		
70 - 90	4	6.8
PUGET SOUND		
Port Susan		
25 - 70	9	12.8
80 - 120	7	5.7
Tulalip		
50 - 80	3	13.5
80 - 120	4	11.8
Carr Inlet		
45 - 80	4	15.1
80 - 135	3	2.4

TABLE II.8-2 BELLINGHAM BAY MARINE INVERTEBRATE RESOURCES*
(AVERAGE NUMBER/HECTARE)

	Crabs			Shrimp			Tritonia			Starfish		
Season	P	A-1	A-2	P	A-1	A-2	P	A-1	A-2	P	A-1	A-2
February	8	12	19	1554	175	1251	41	44	26	52	225	41
Apr/May	37	31	79	1064	556	506	19	6	11	26	393	41
July	19	6	68	75	1423	318	23	6	15	195	300	161
October	19	19	19	67	737	45	4	0	19	131	294	154
Average	21	17	46	690	723	530	22	14	18	101	303	99

*Legend P = Perferred Site
A-1 = South Alternative Site
A-2 = North Alternative Site

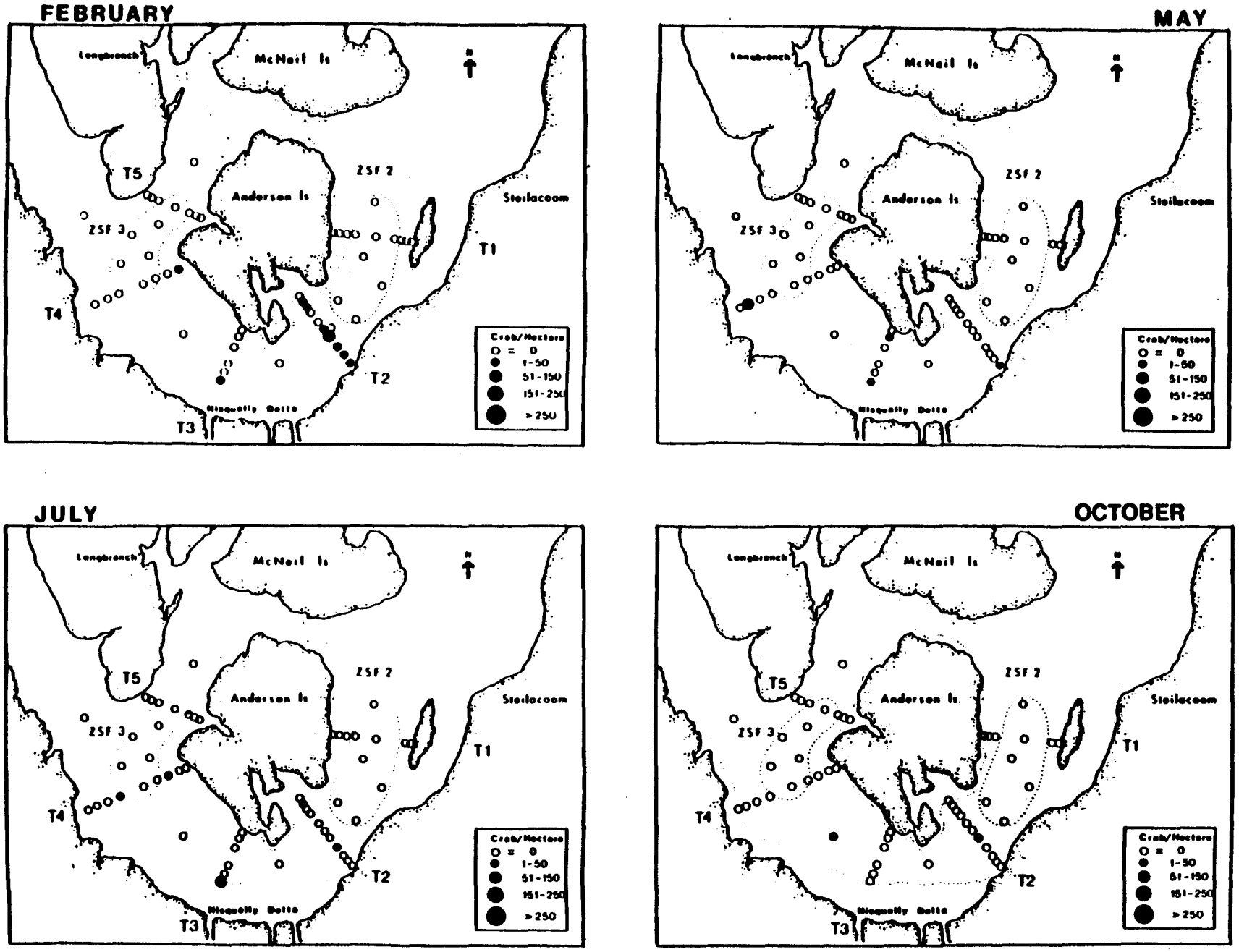


Figure II.8-1 Maps of the Nisqually region showing the densities of Dungeness crab as estimated from beam trawl catches in February, May, July and October 1987.

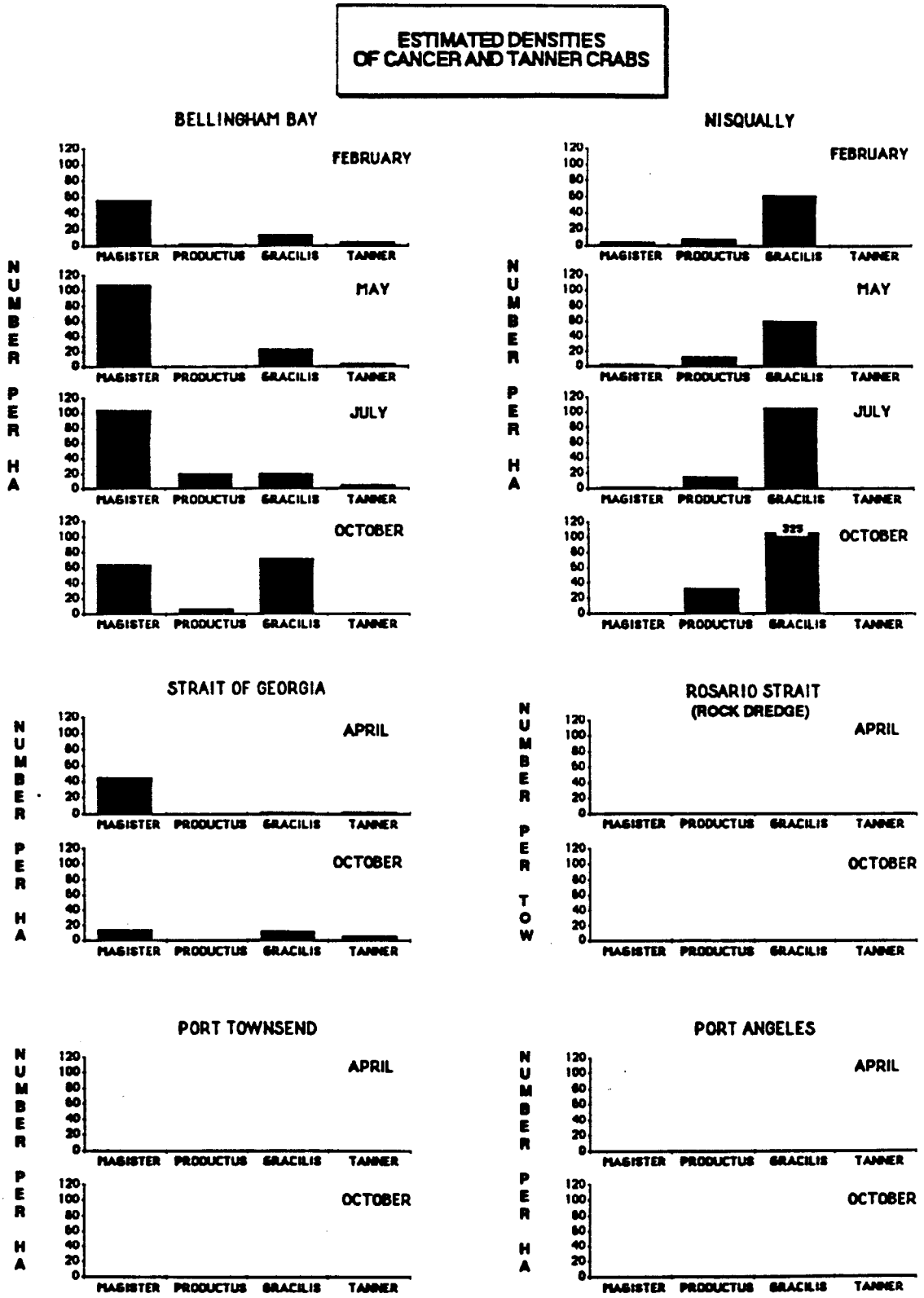


Figure II.8-2 Summary of the estimated average densities (#/ha) of Cancer and tanner crabs by area, by season and by species based on the beam trawl catches (except #/tow for the rock dredge in Rosario Strait).

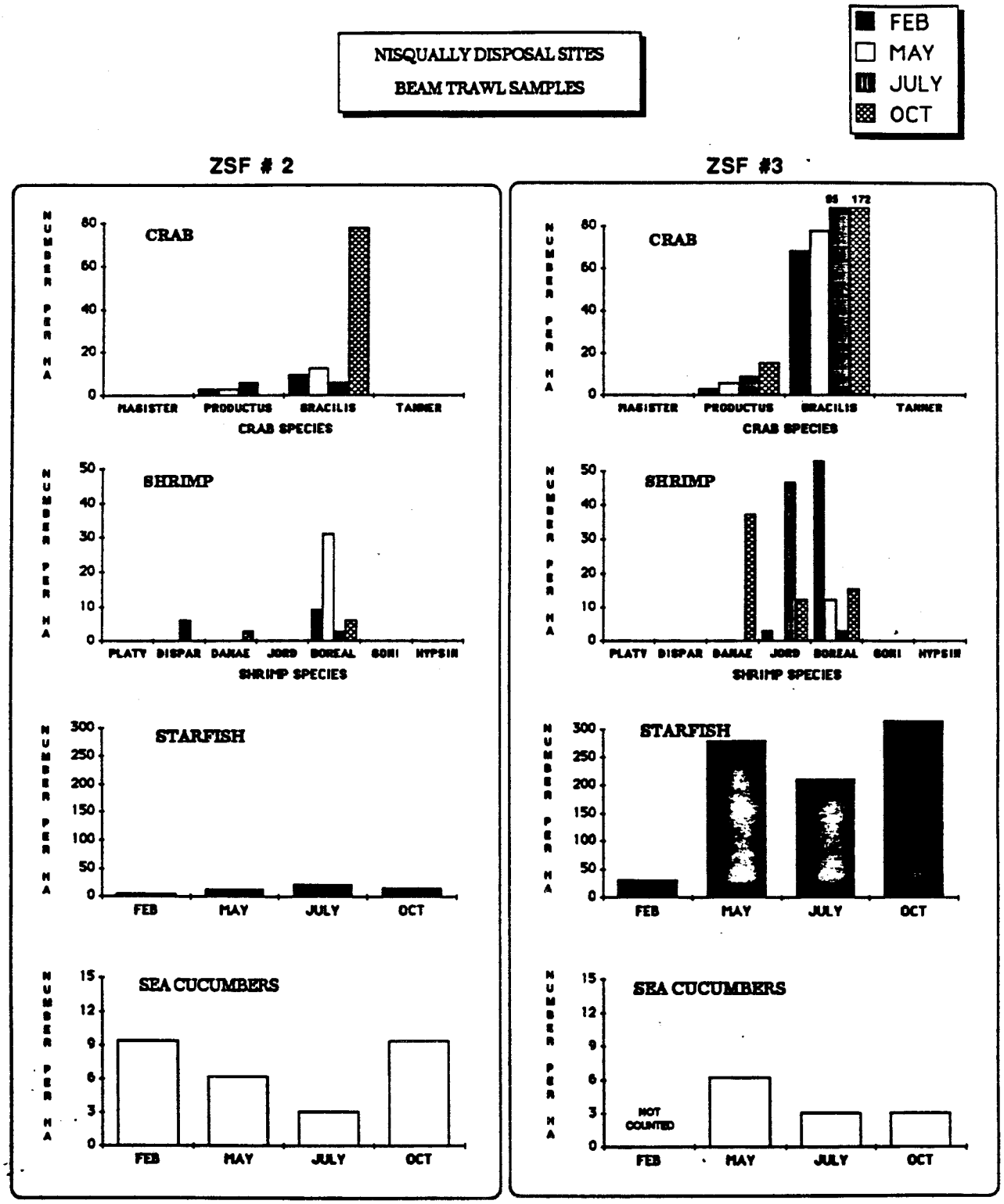


Figure II.8-3 Comparison of average beam trawl catches (estimated #/ha) by species and by season between Nisqually ZSF 2 and ZSF 3.

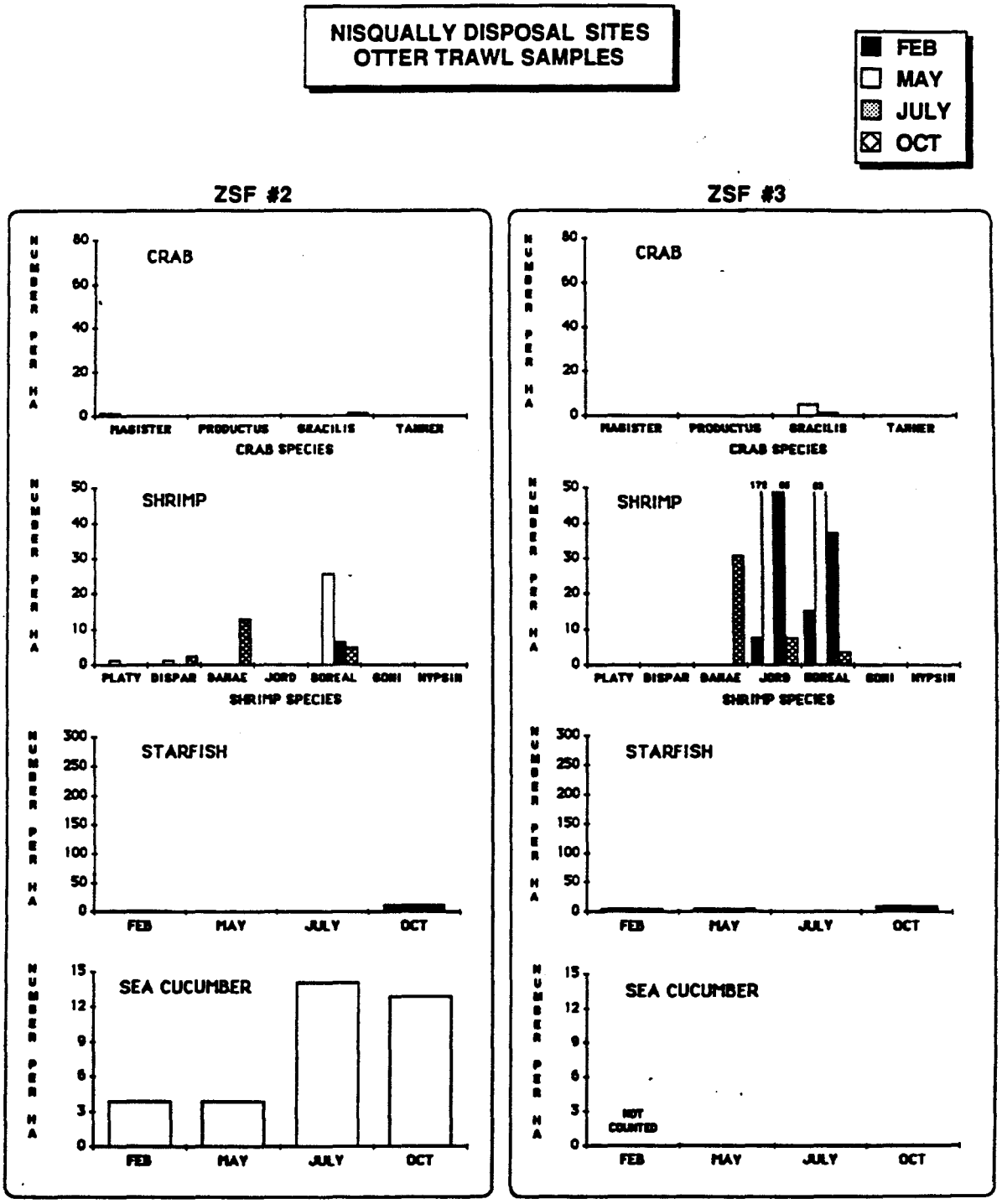


Figure II.8.4 Comparison of average otter trawl catches (estimated #/ha) by species and by season between Nisqually ZSF 2 and ZSF 3.

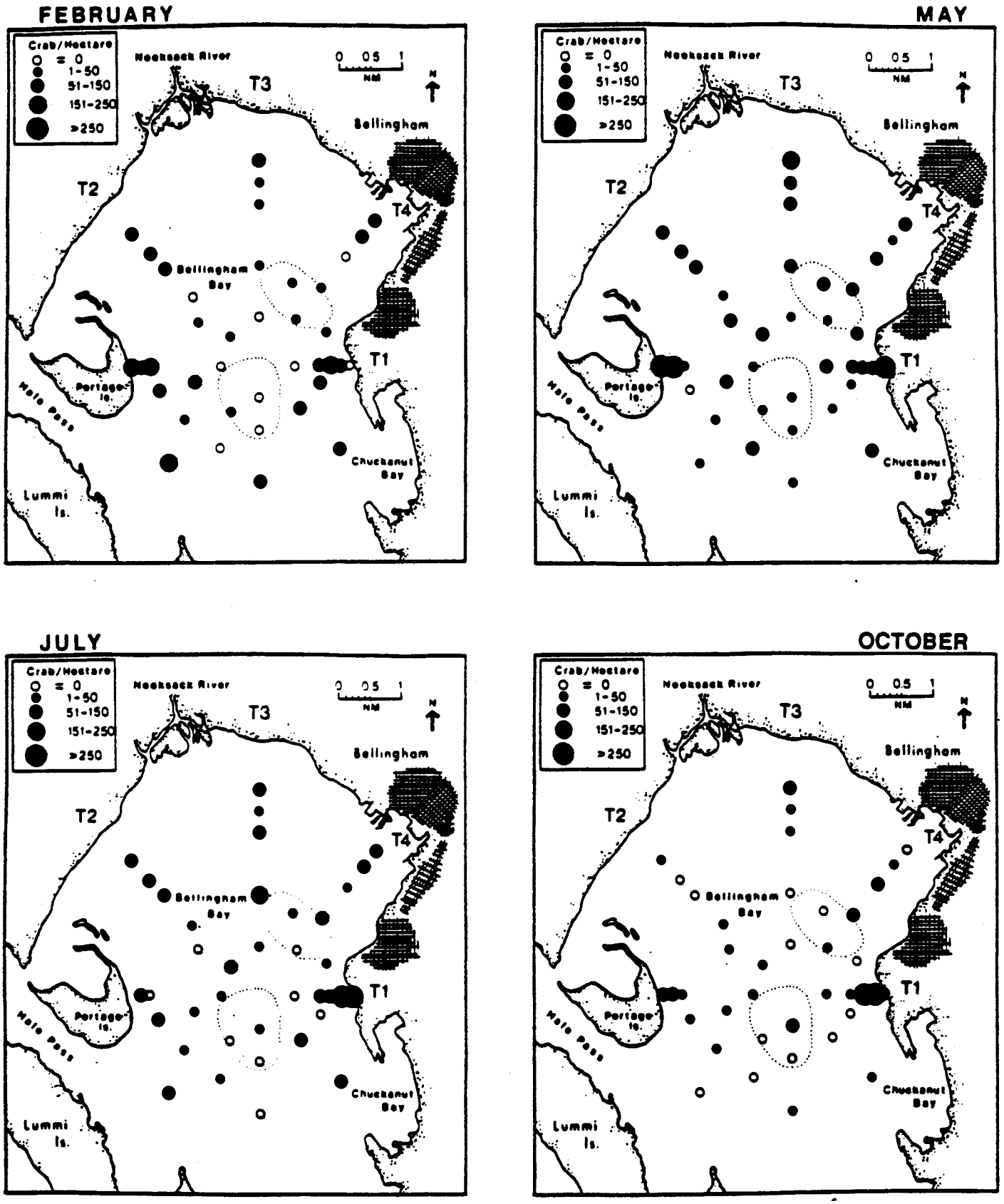


Figure II.8-5 Maps of Bellingham Bay showing Dungeness crab densities as estimated from beam trawl catches in February, May, July and October 1987.

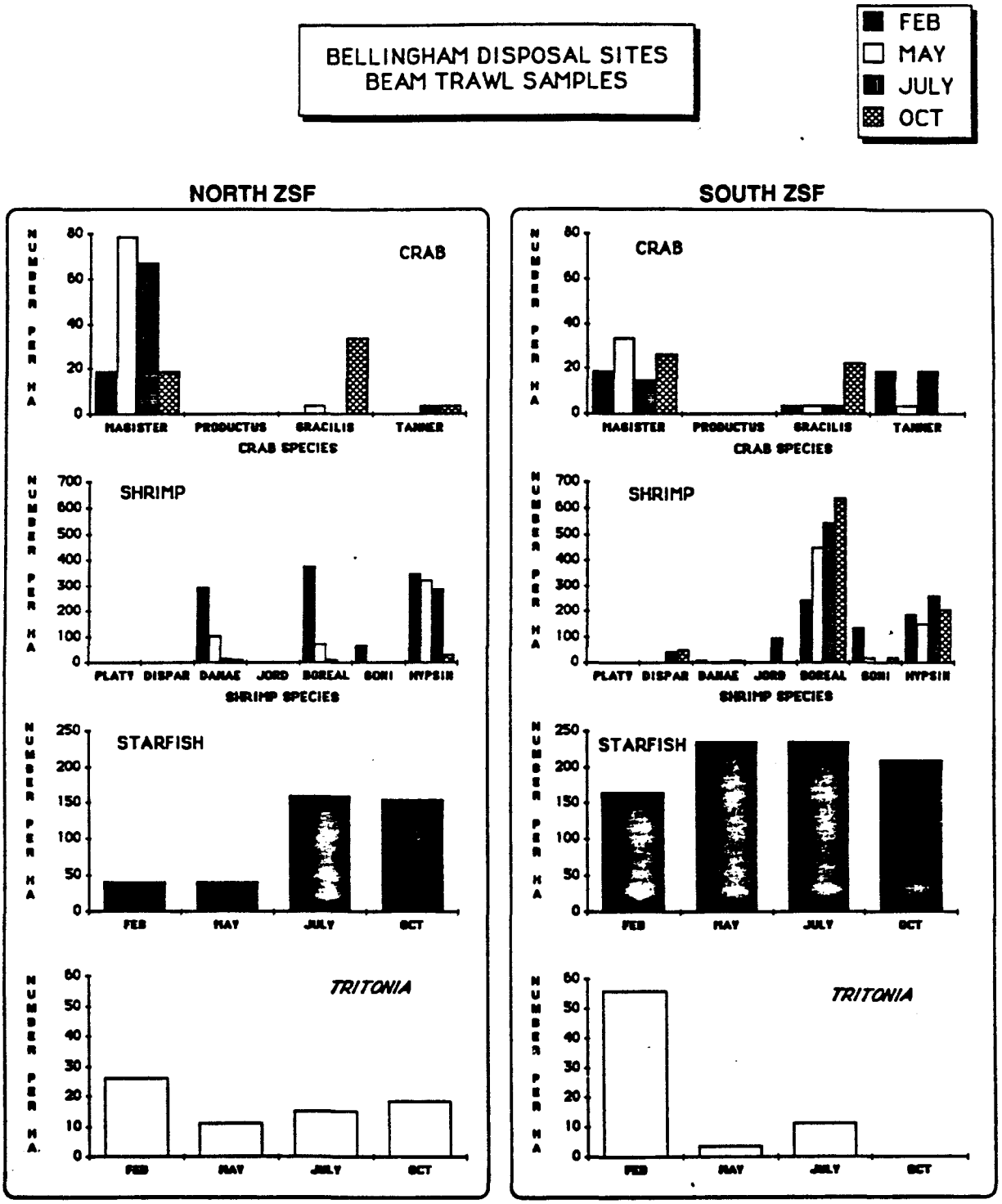


Figure II.8-6 Comparison of average beam trawl catches (estimated #/ha) by species and by season in the North and South ZSFs in Bellingham Bay.

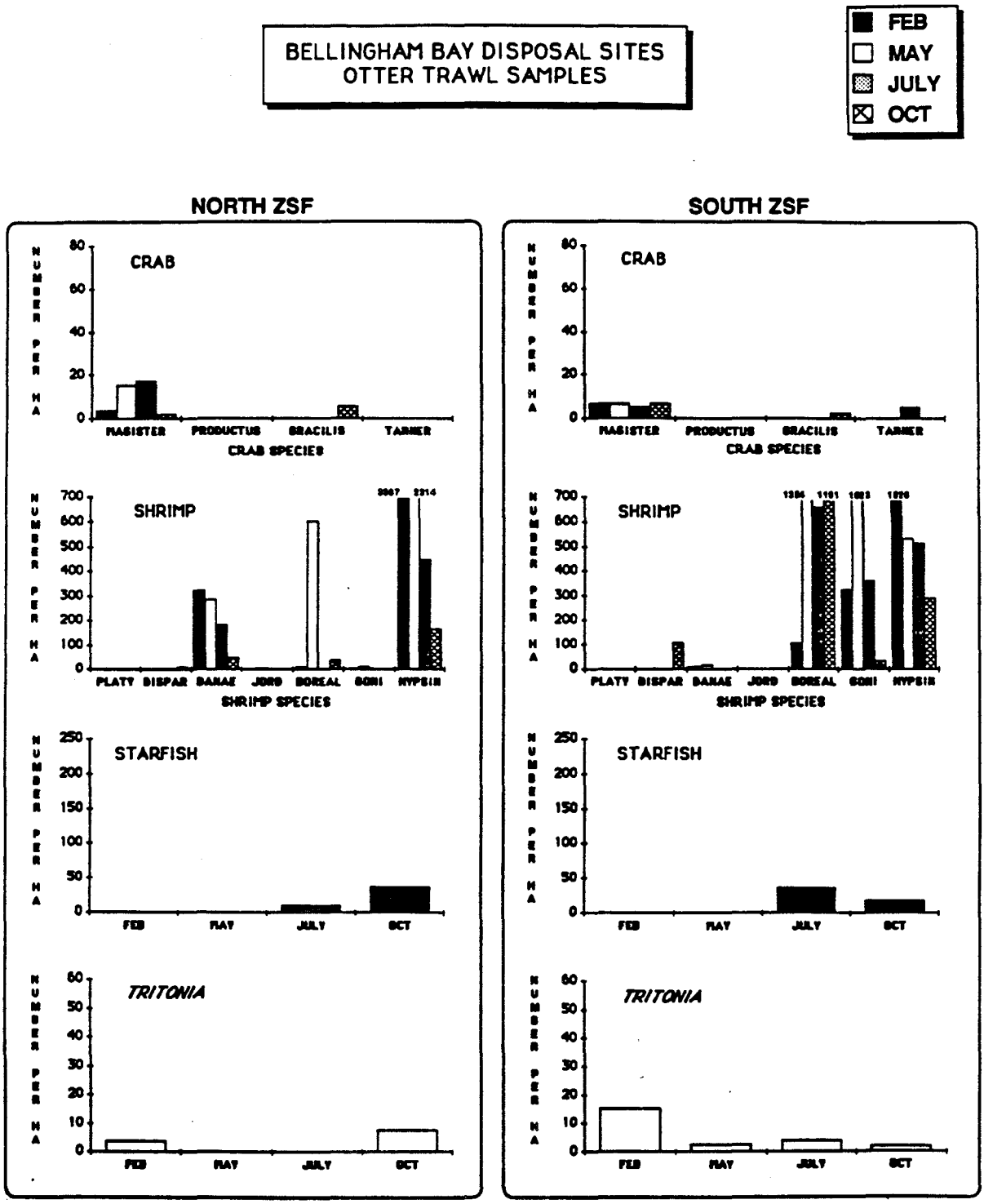


Figure II.8-7 Comparison of average otter trawl catches (estimated #/ha) by species and by season between the North and South ZSFs in Bellingham Bay.

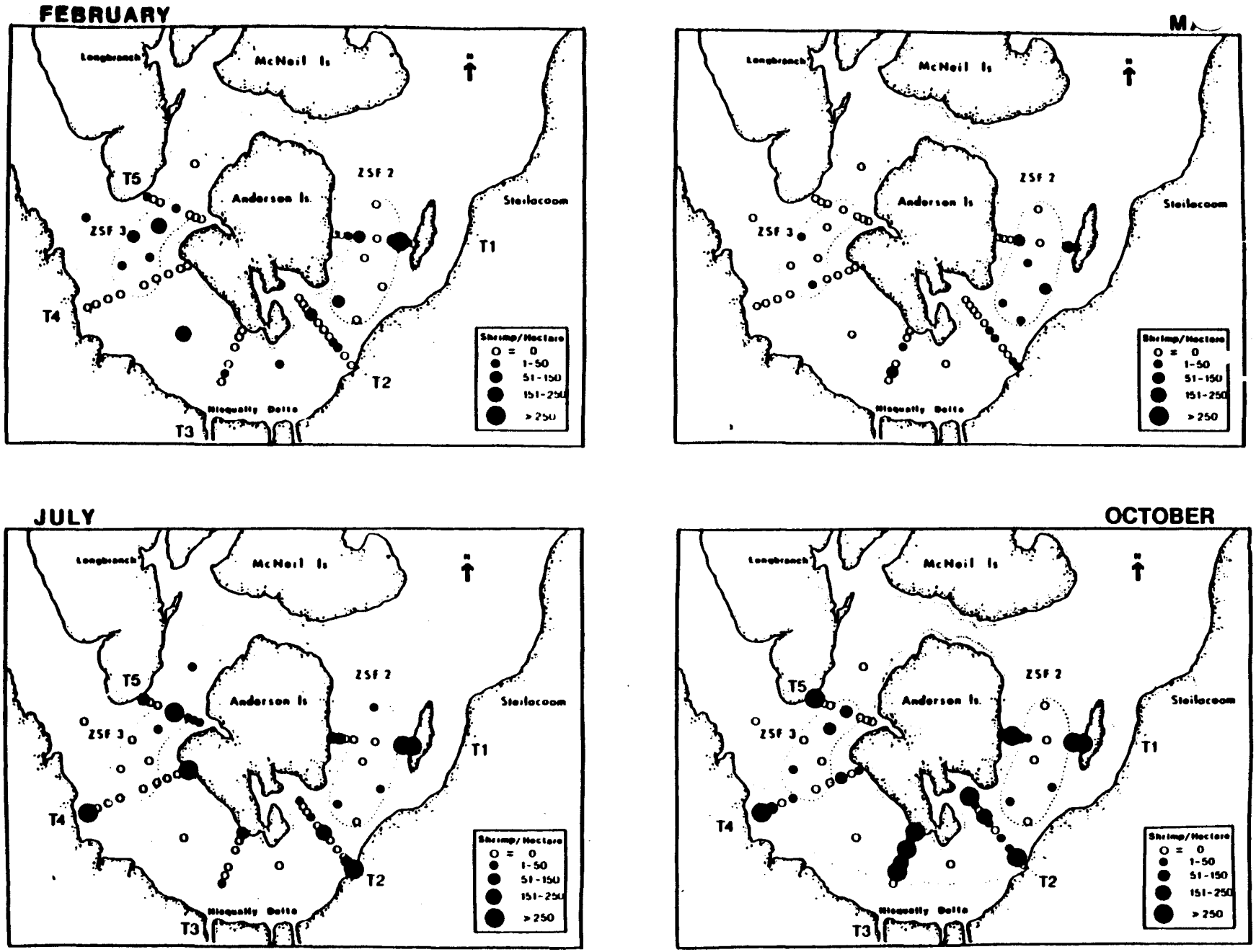


Figure II.8-8 Maps of the Nisqually region showing the densities of commercial pandalid shrimp as estimated from beam trawl catches in February, May, July and October 1987.

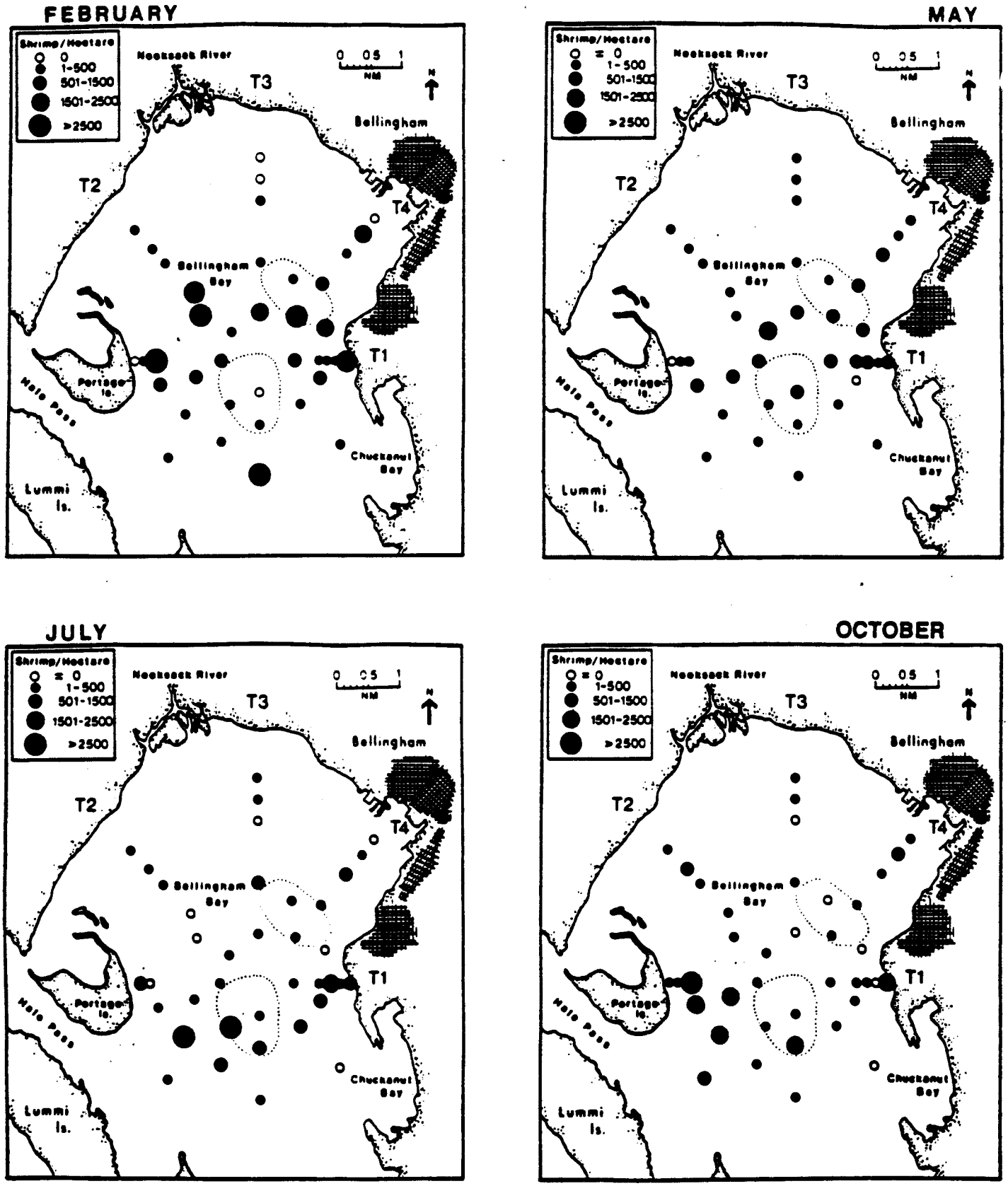


Figure II.8-9 Maps of Bellingham Bay showing the densities of commercial pandalid shrimp as estimated from beam trawl catches in February, May, July and October 1987.

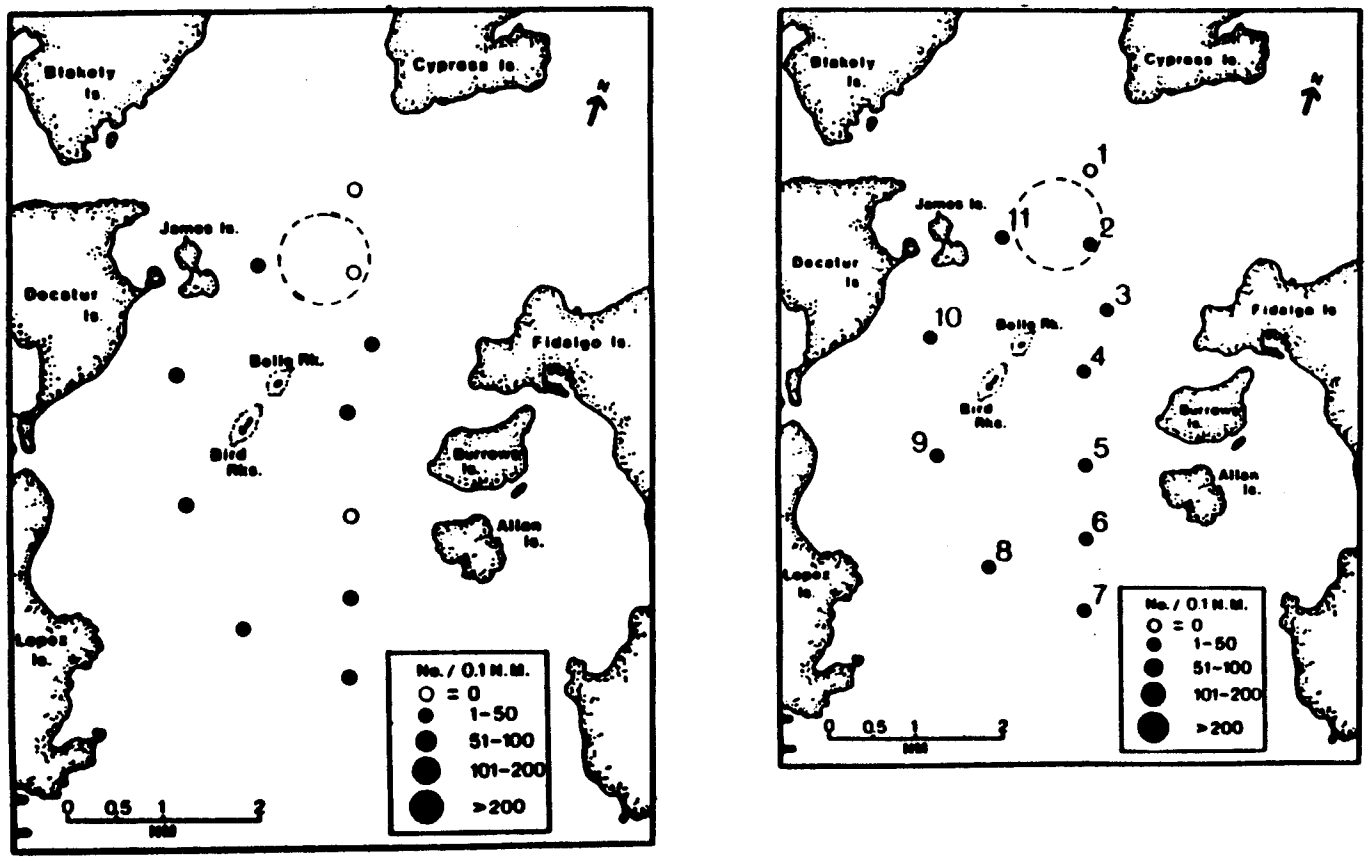


Figure II.8-10 Maps of Rosario Strait showing the number of commercial pandalid shrimp caught per 0.1 nautical mile (NM) by the rock dredge in April 1987 (left) and October 1987 (right).

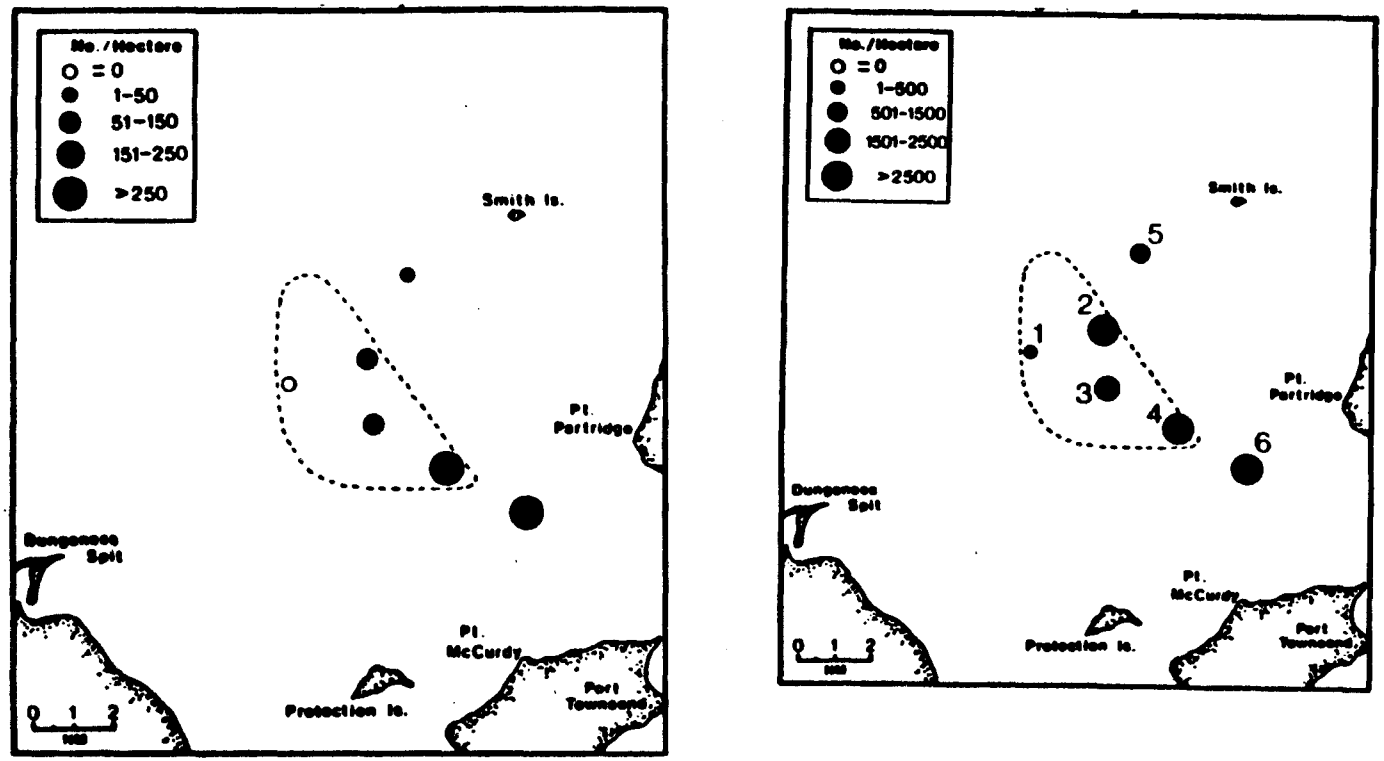


Figure II.8-11 Maps of the Port Townsend region showing the densities of commercial pandalid shrimp caught per 0.1 nautical mile (NM) by the rock dredge in April 1987 (left) and October 1987 (right).

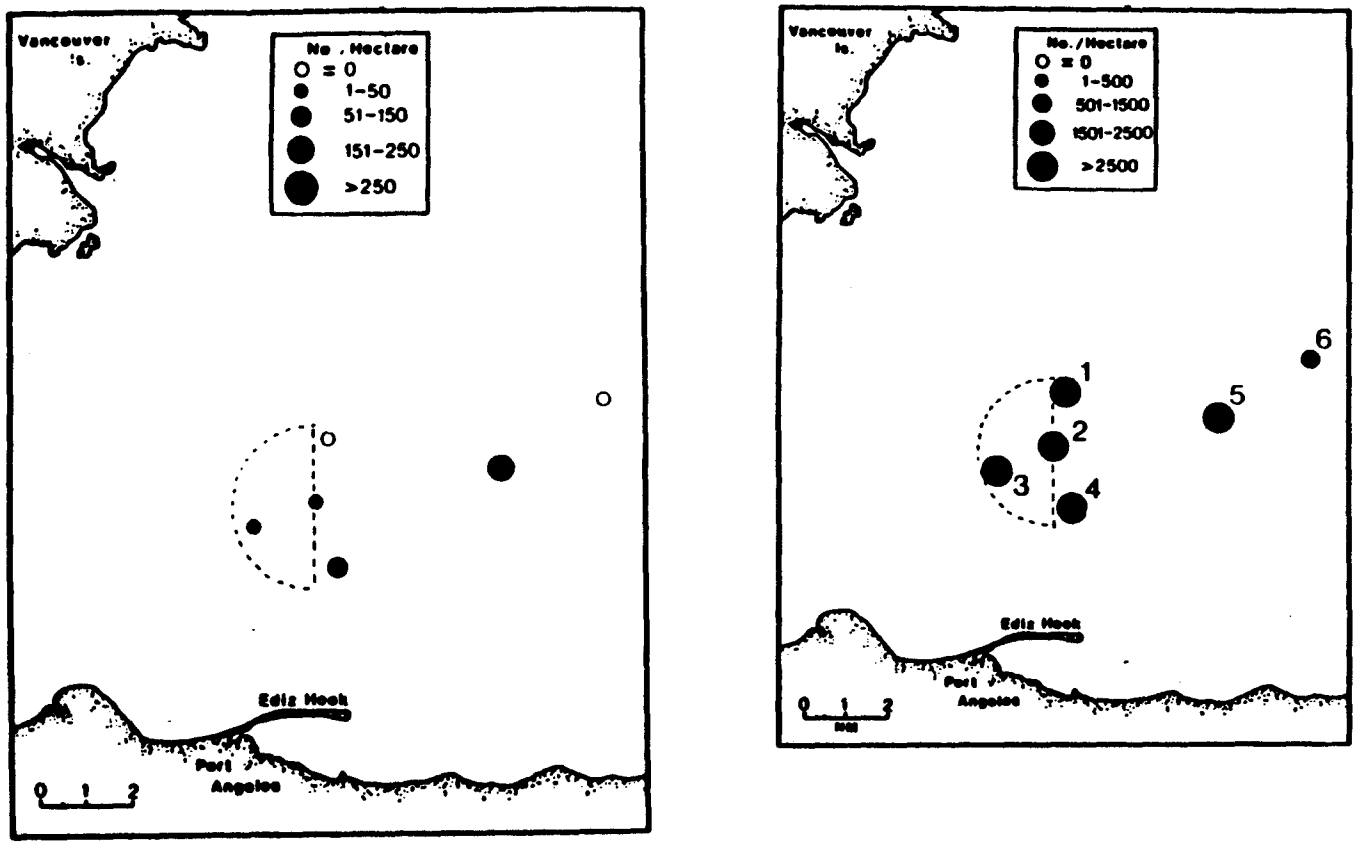


Figure II.8-12 Maps of the Port Angeles region showing the densities of commercial pandalid shrimp caught per 0.1 nautical mile (NM) by the rock dredge in April 1987 (left) and October 1987 (right).

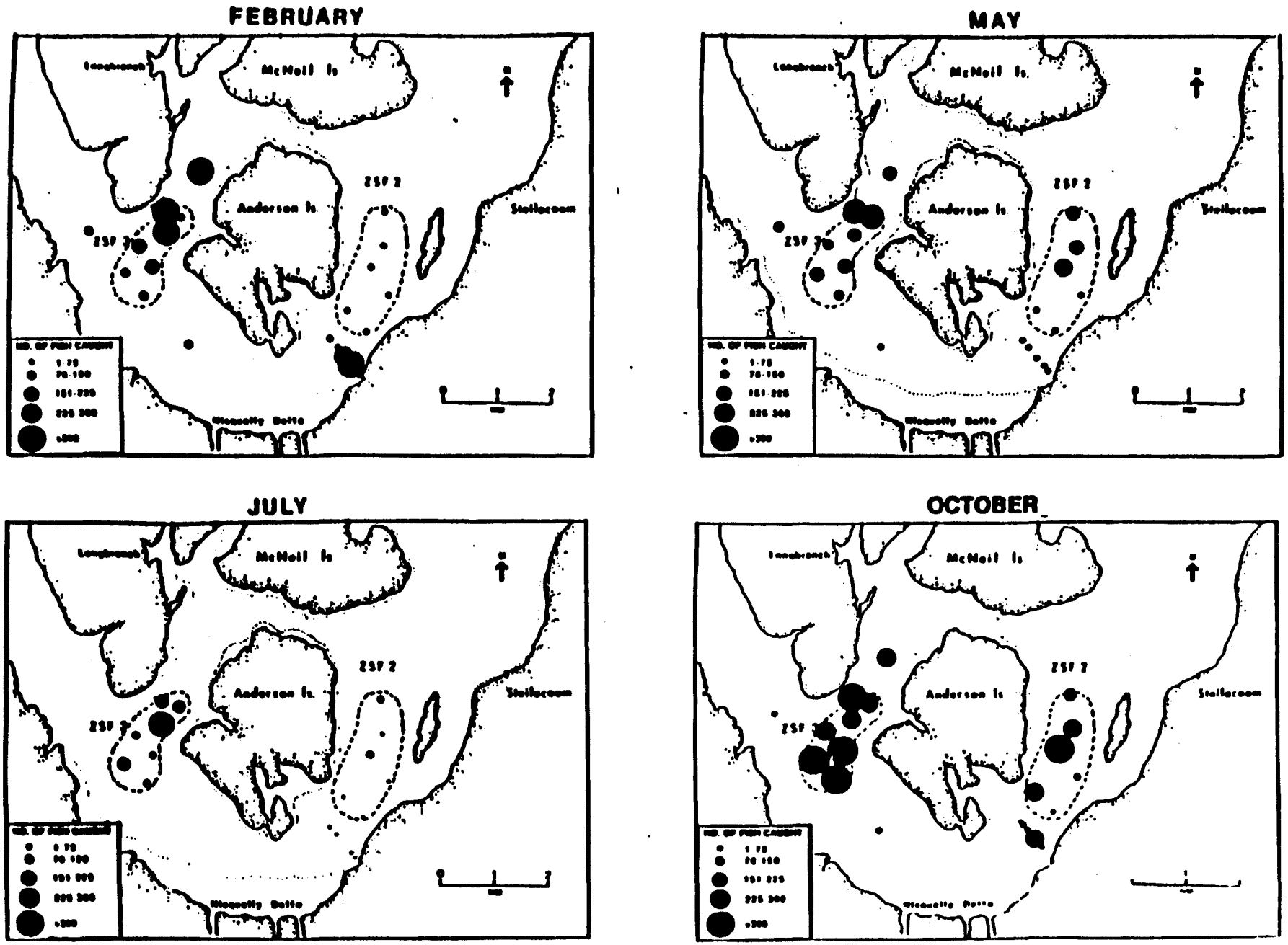


Figure II.8-13 Maps showing the total number of fish caught per otter trawl sample stations in the Nisqually region during February, May, July, and October 1987.

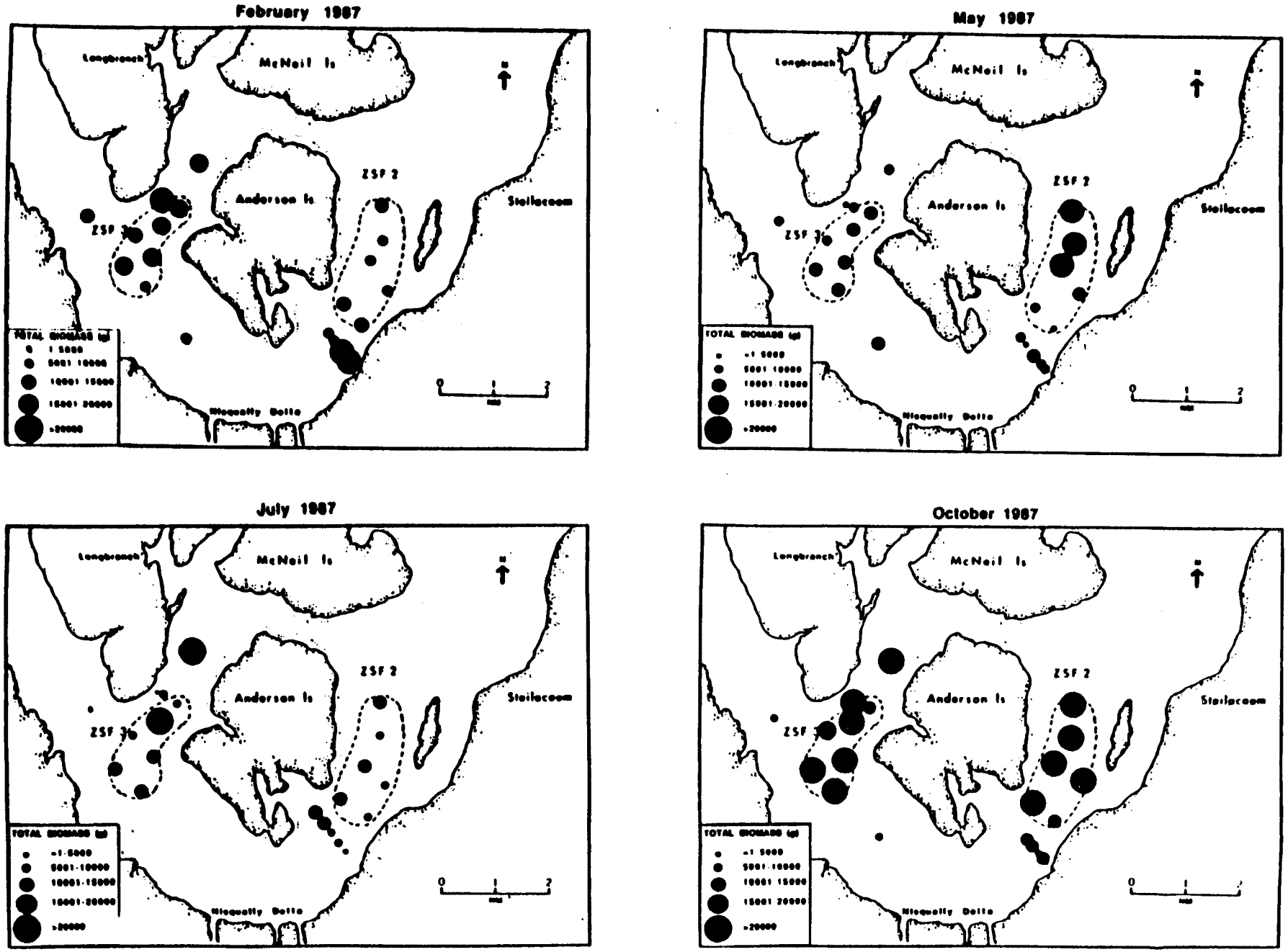
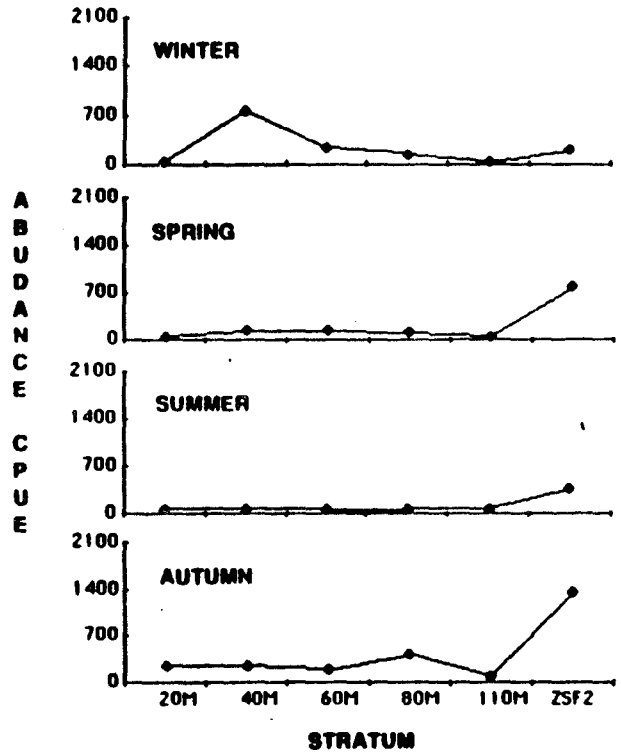
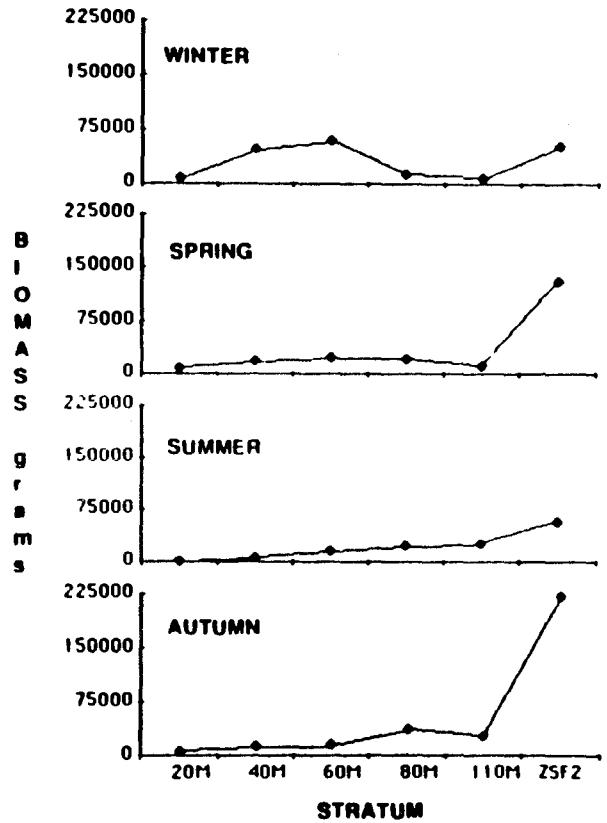


Figure II.8-14 Maps showing the total biomass (grams) of fish caught per otter trawl sample at stations in the Nisqually region.



(Transect 2)



(Transect 2)

Figure II.8-15 Nisqually East abundance (CPUE) and biomass (grams) by stratum and season.

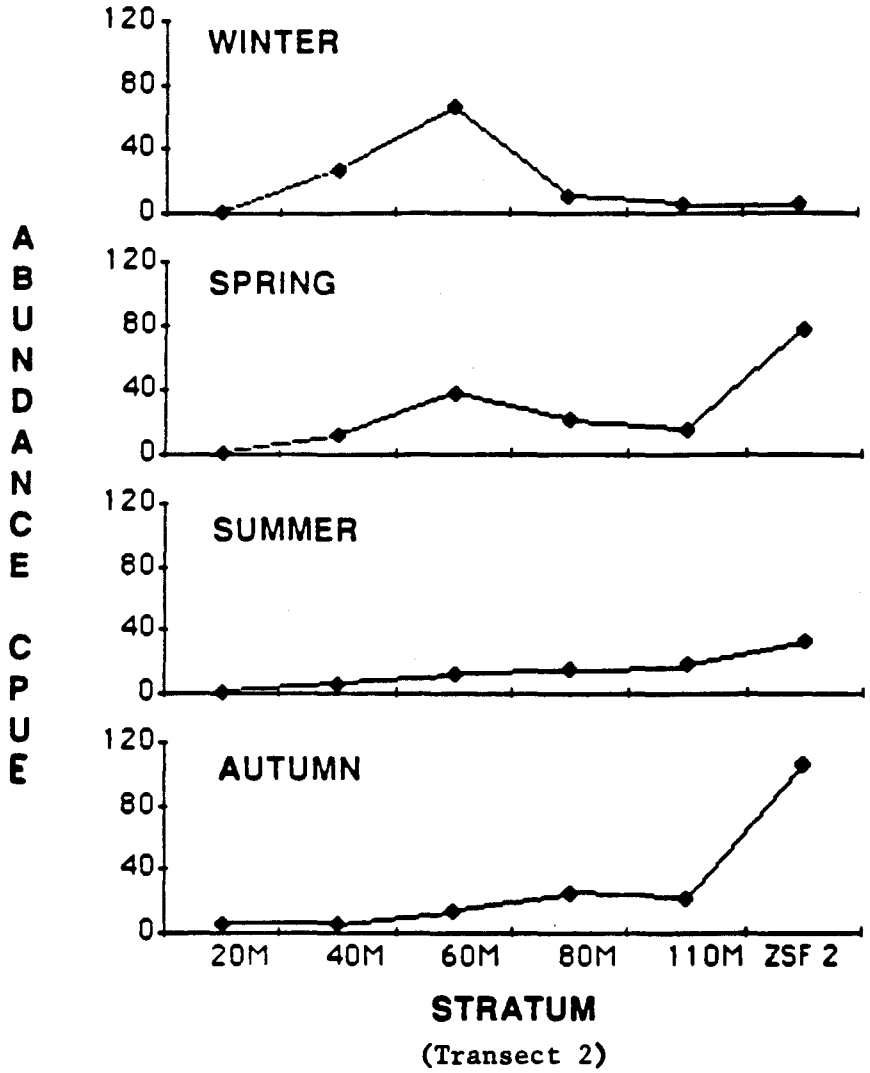


Figure II.8-16 Nisqually East English sole abundances (CPUE) by strata and season.

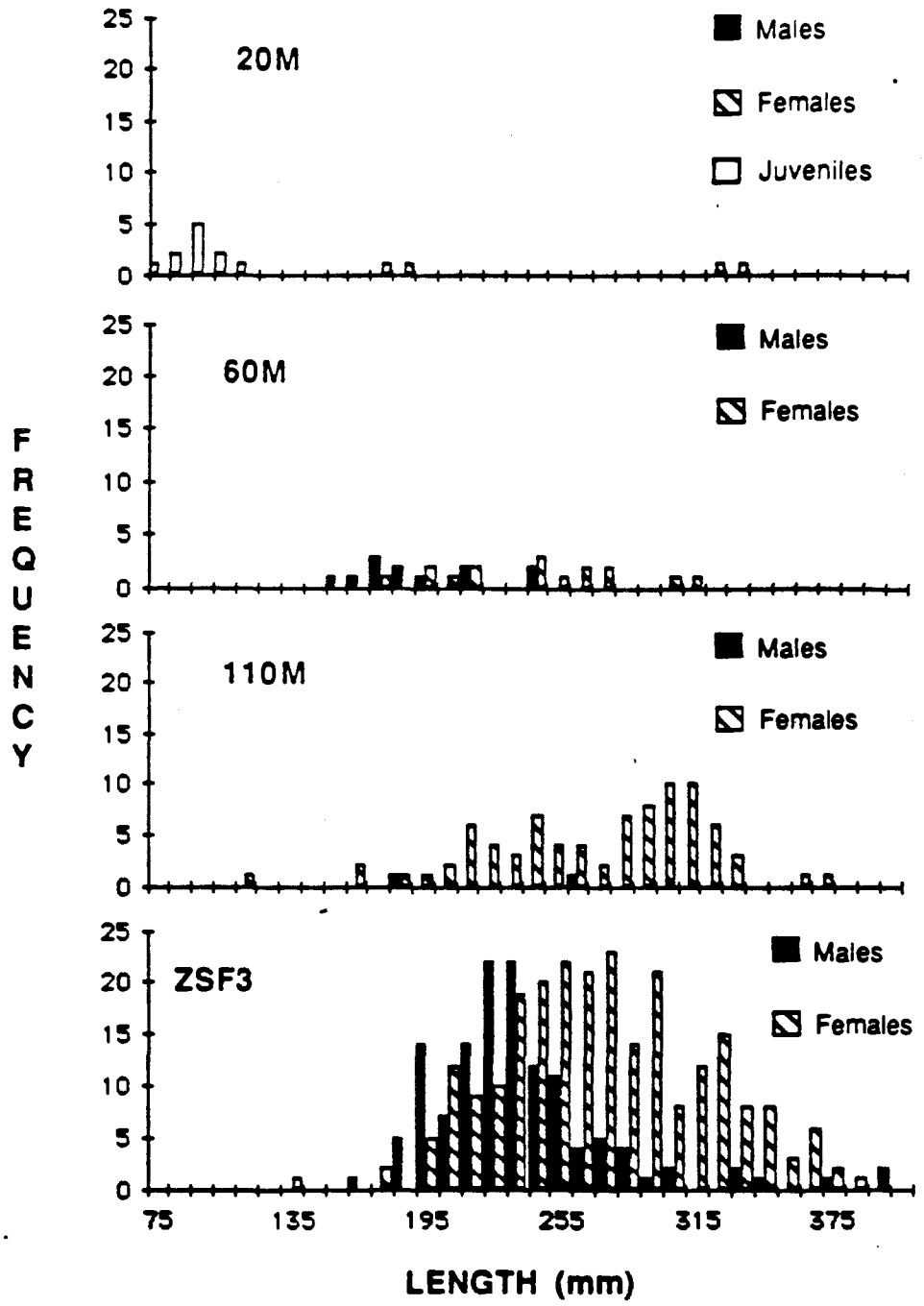
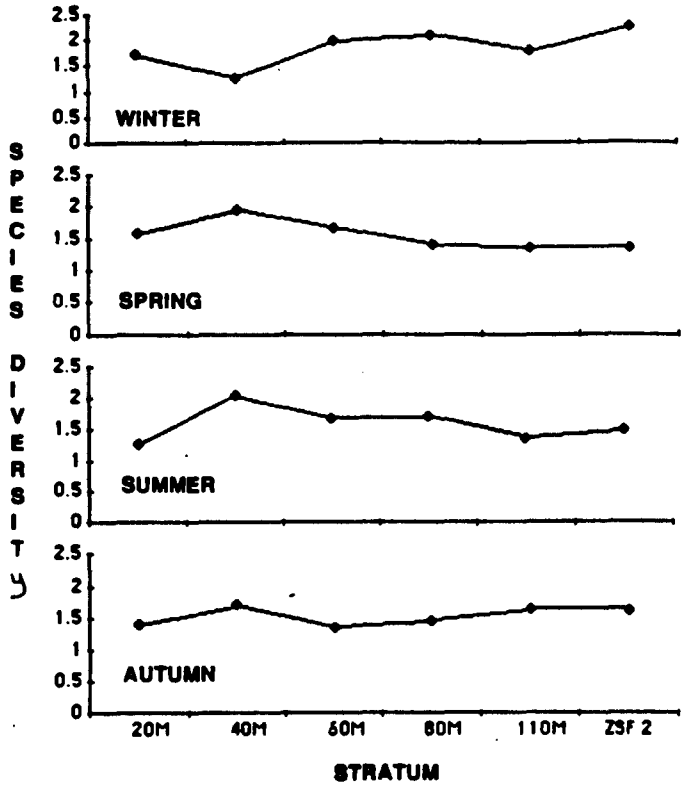


Figure II.8-17 Nisqually East English sole length-frequencies.



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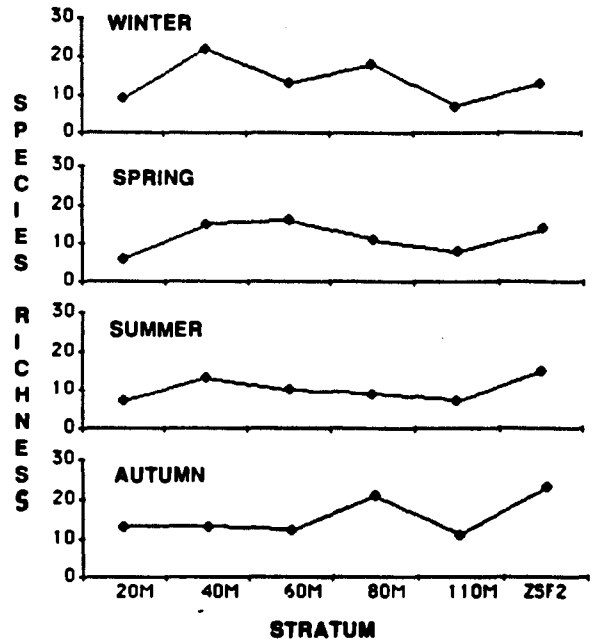


(Transect 2)

Figure II.8-18 Nisqually East species diversity by stratum and season.

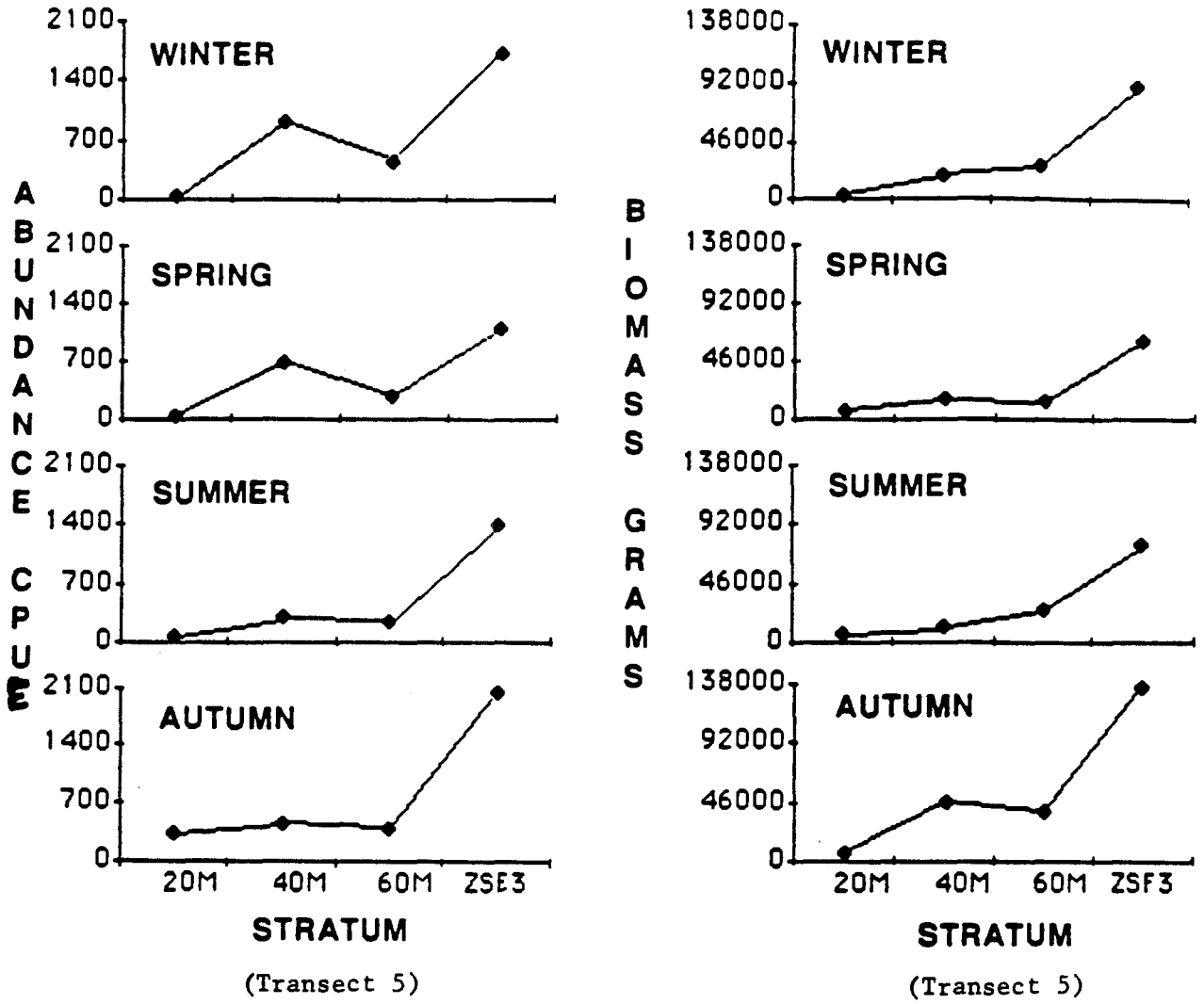


Figure II.8-19 Nisqually West abundance and biomass by stratum and season.

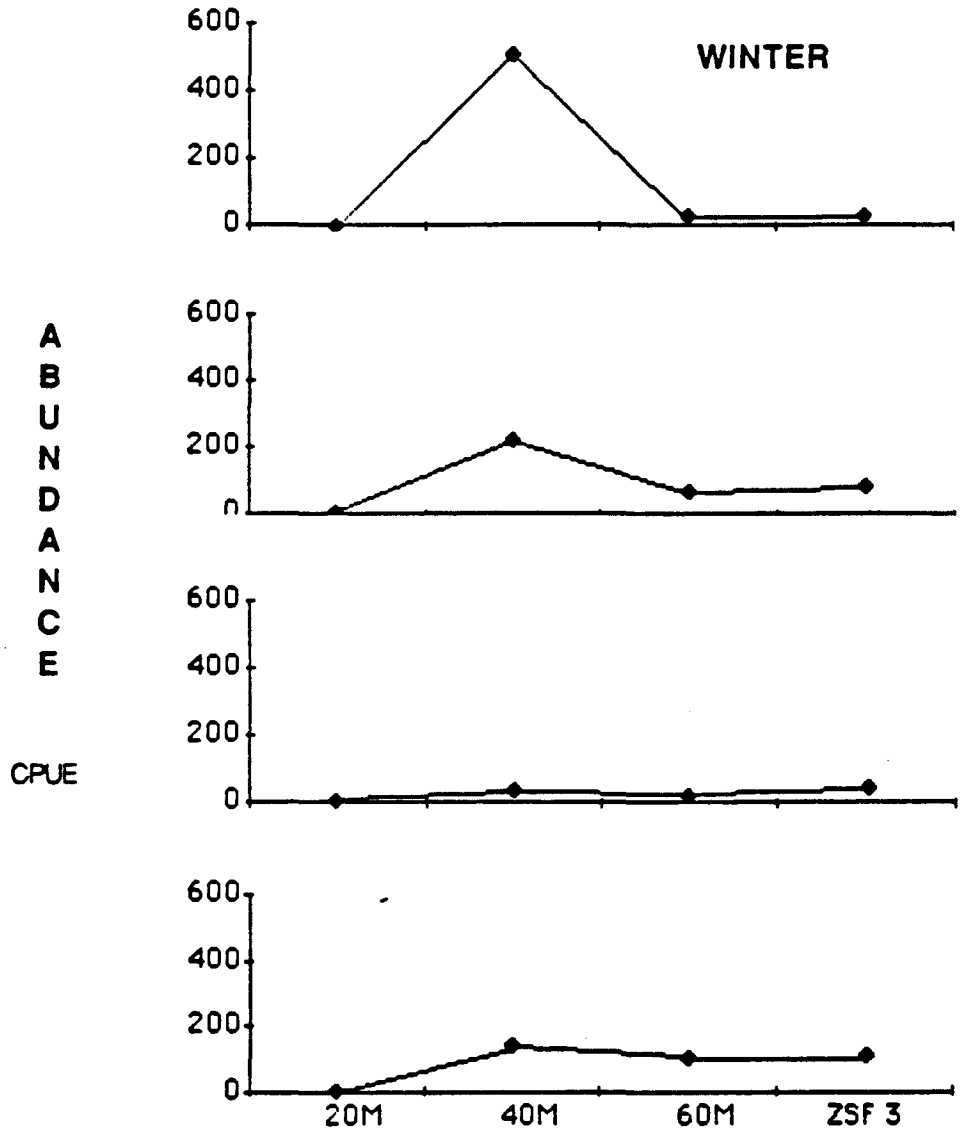


Figure II.8-20 Nisqually West English sole abundances (CPUE) by strata and season.

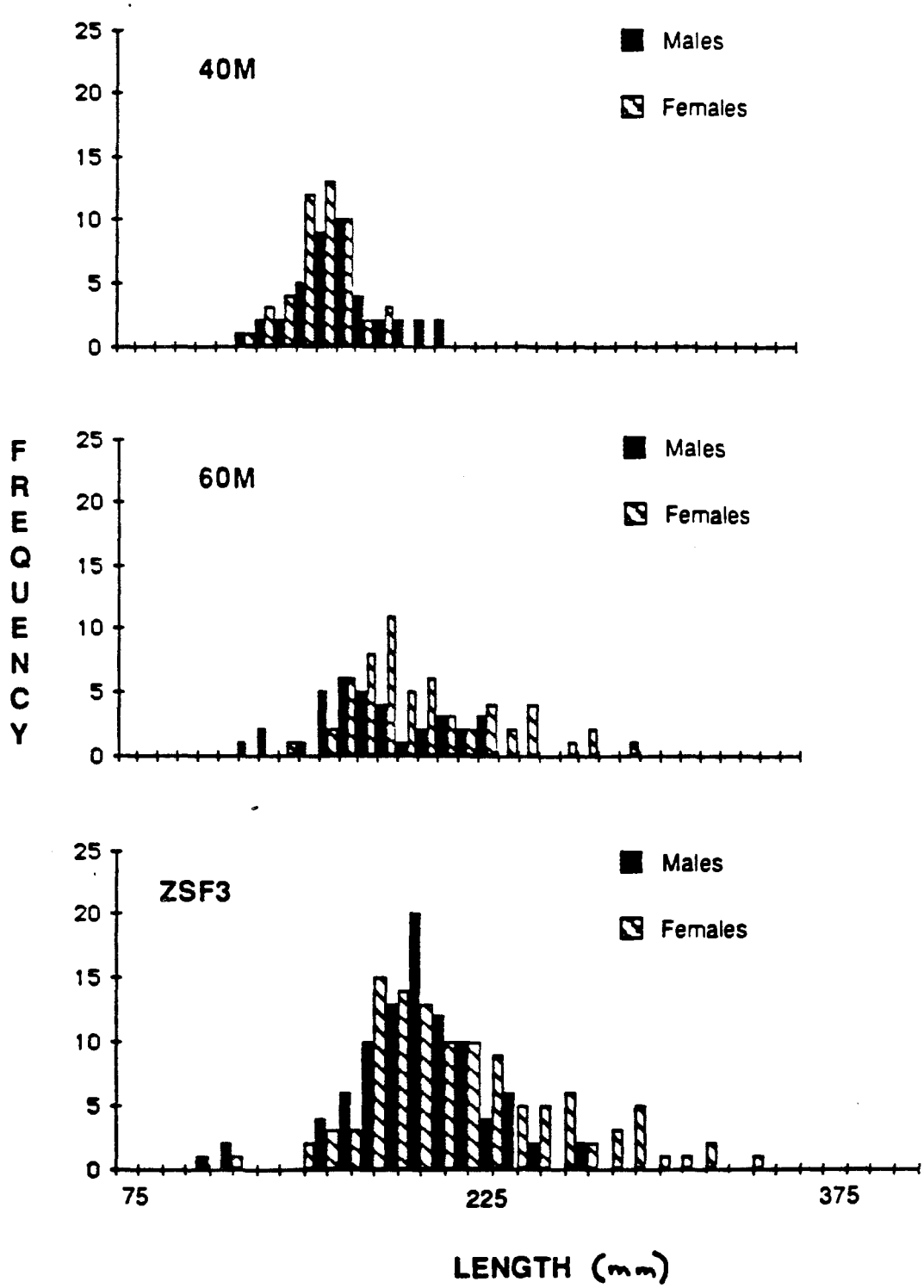


Figure II.8-21 Nisqually West English sole length-frequencies.

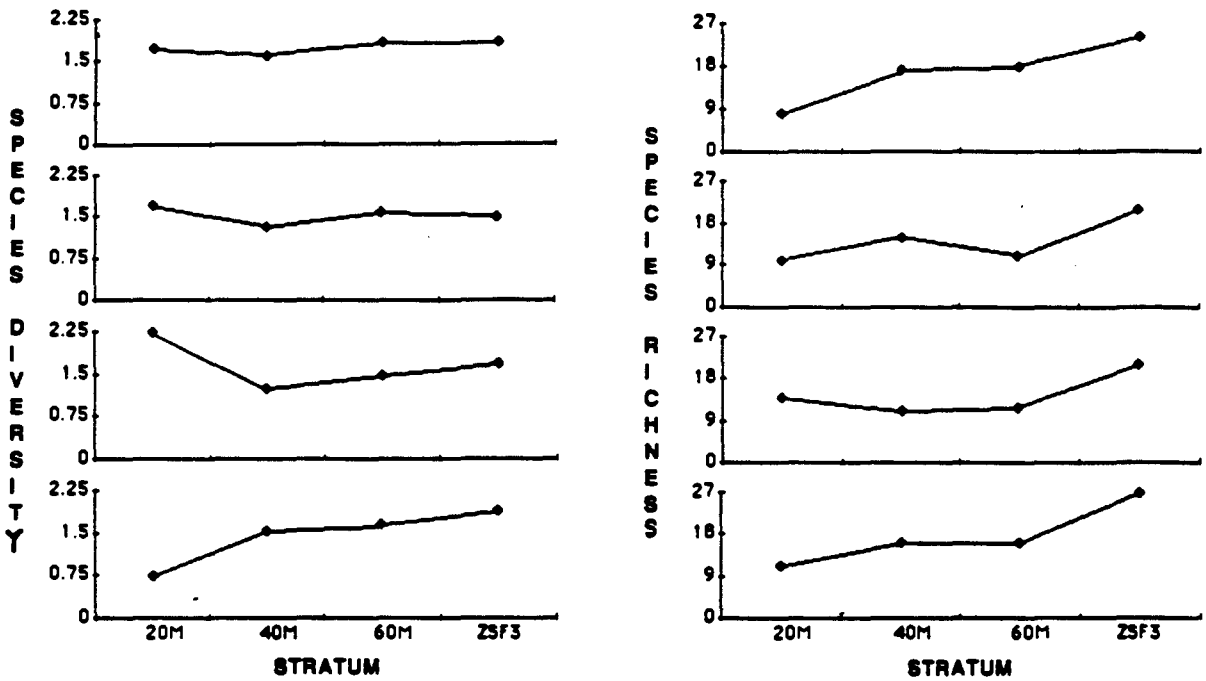


Figure II.8-22 Nisqually West species diversity by stratum and season.

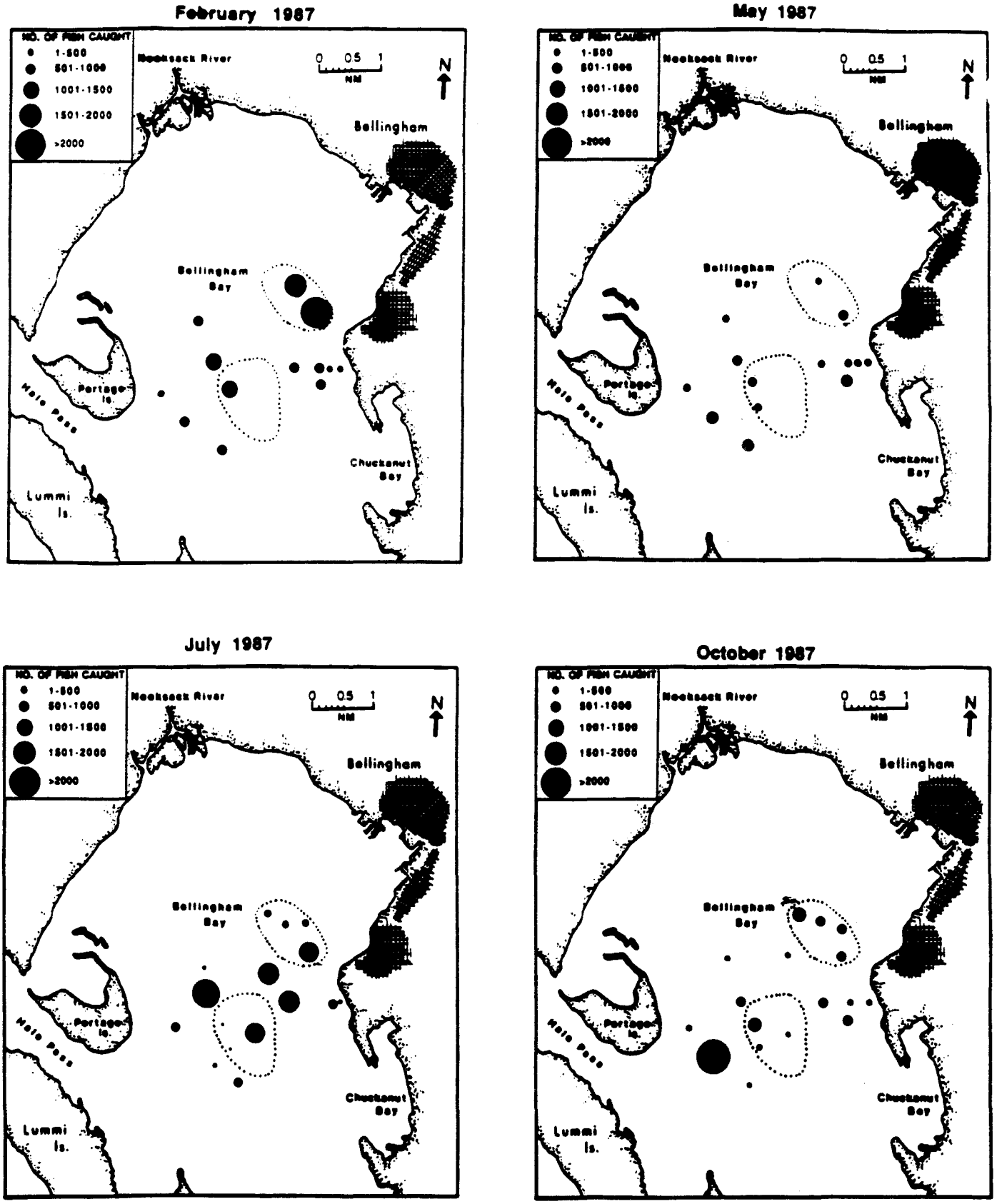


Figure II.8-23 Maps showing the total number of fish caught per otter trawl sample at stations in Bellingham Bay during February, May, July, and October 1987.

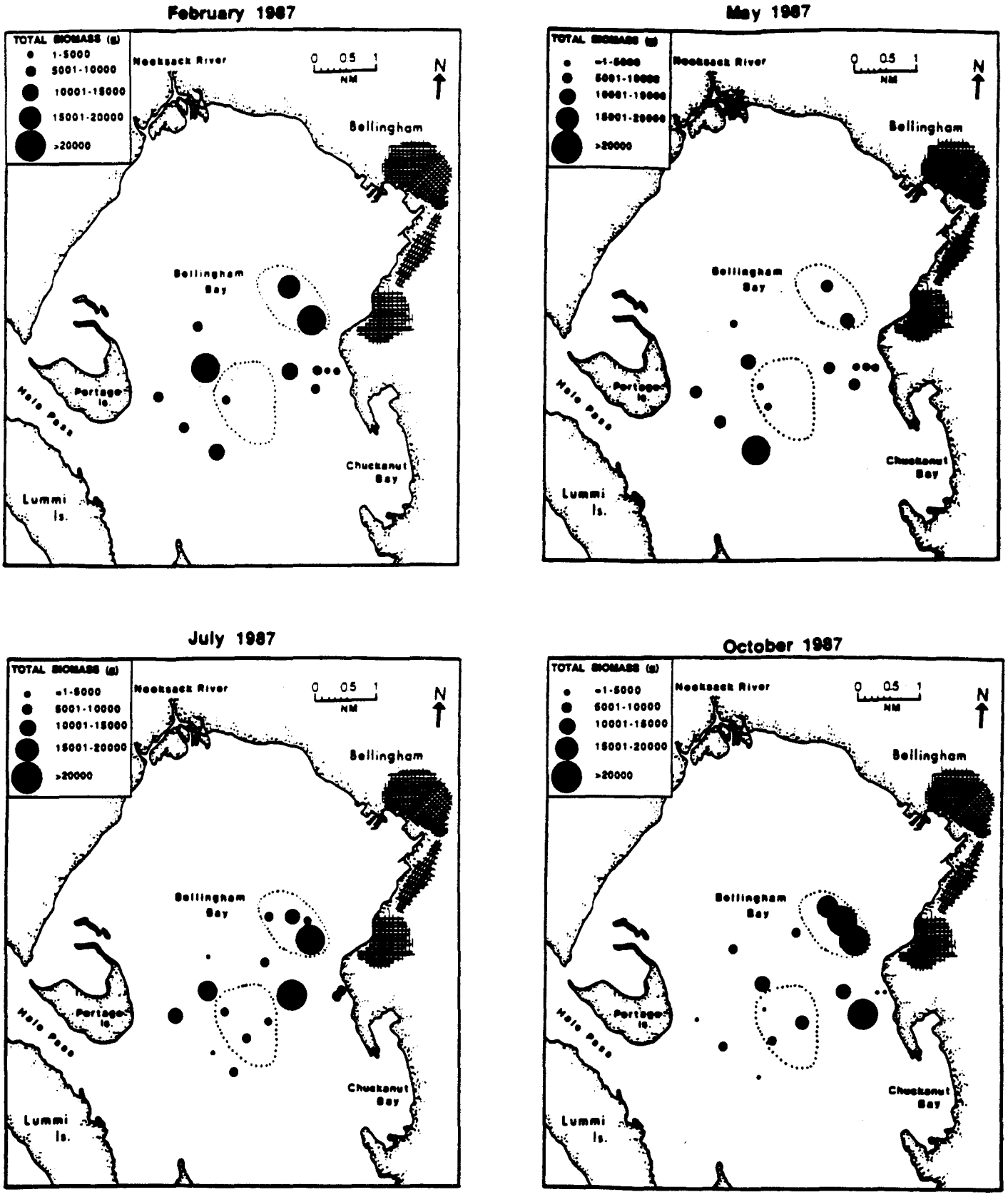


Figure II.8-24 Maps showing the total biomass (grams) of fish caught per otter trawl sample in Bellingham Bay.

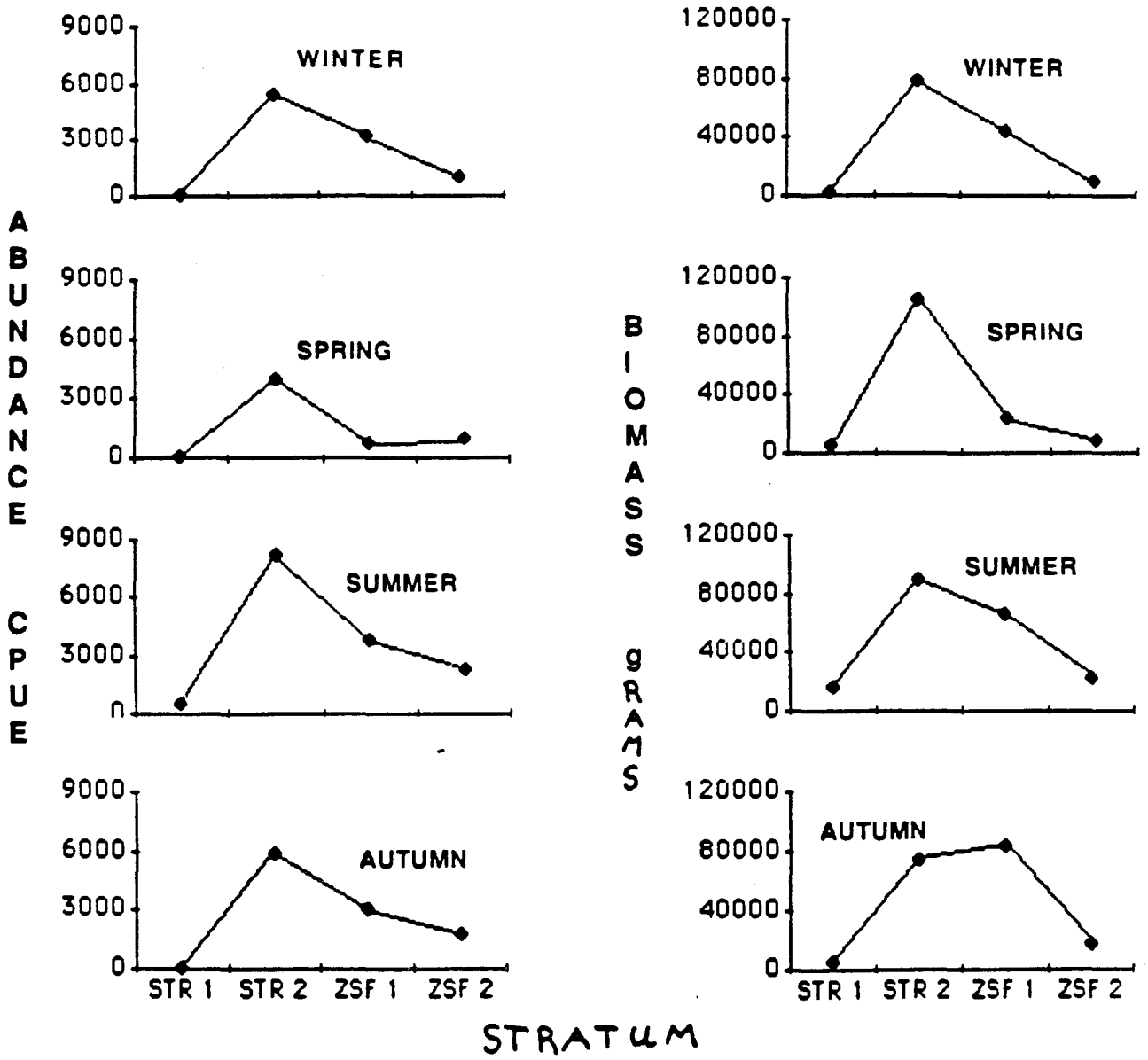


Figure II.8-25 Bellingham Bay abundance (CPUE) and biomass (grams) by stratum and season.

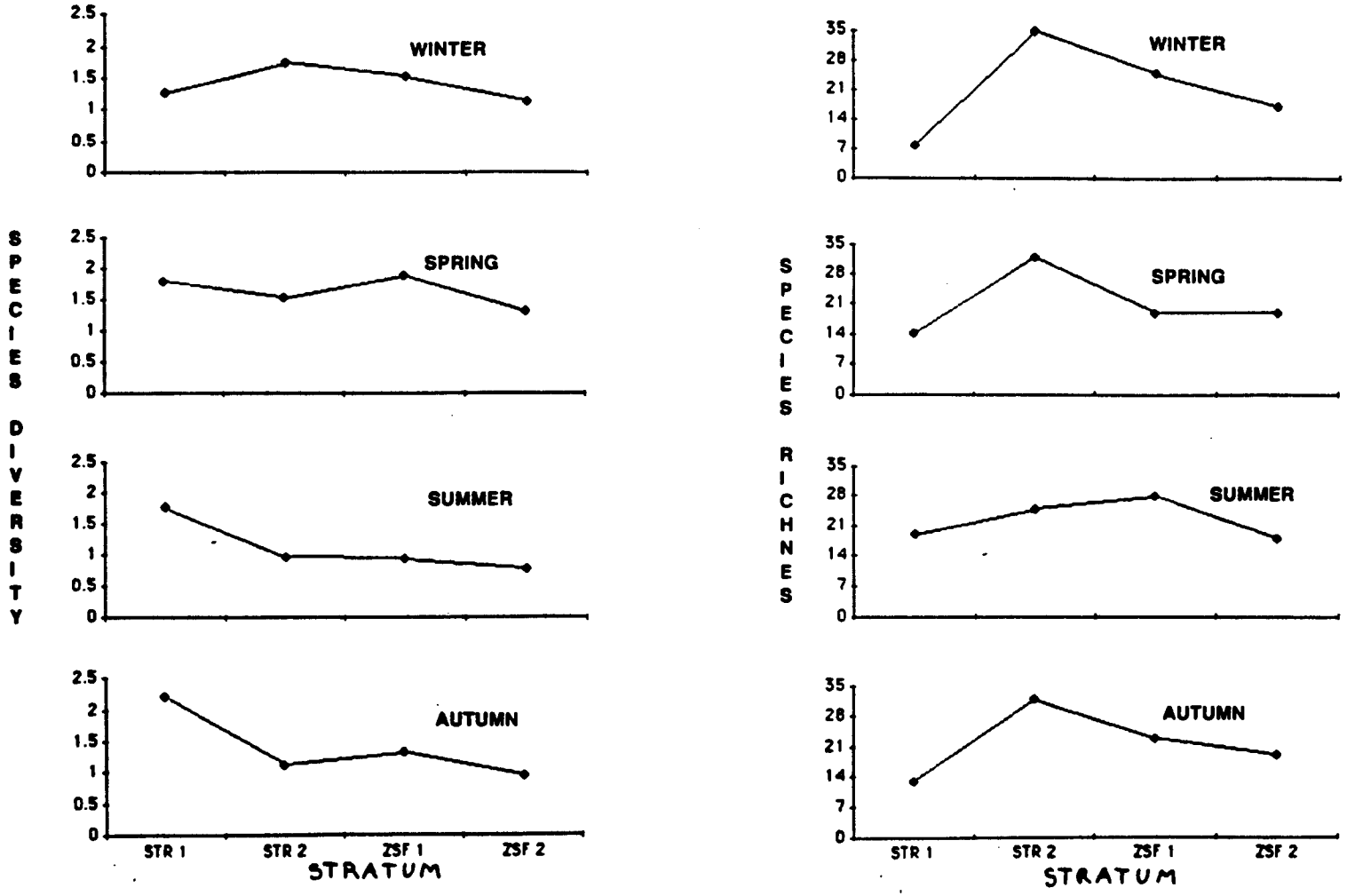


Figure II.8-26 Bellingham Bay species (H') by stratum and season.

9. BIOLOGICAL RESOURCES: BENTHIC HABITAT/CHARACTERISTICS MAPPED USING THE BENTHIC RESOUHOES ANALYSIS TECHNIQUE (BRAT).

9.1 Objective

To characterize the food value of benthic organisms to bottom-feeding fish.

9.2 Background

Coastal engineering projects often cause disturbances of soft (muddy or sandy) bottom habitats in estuarine systems, e.g., dredged material disposal operations. An environmental question that often arises is: Will this project result in unacceptable changes to the habitat involved? Presuming that the potential habitat loss concerns physical disturbance rather than chemical contamination, the resource manager has few tools with which to judge the biological response to the disturbance.

One aspect of benthic habitat quality is the relative amount of trophic support that a given benthic habitat provides demersal bottom-feeding fishes. Analytical procedures have been developed at the U.S. Army Engineer Waterways Experiment Station (WES) with funding from the Corps of Engineer's Environmental Impact Research Program to estimate this aspect of benthic habitat quality. These procedures are collectively called the Benthic Resources Assessment Technique, or BRAT (Lunz and Kendall, 1982; Clarke and Lunz, 1985). The BRAT analysis involves the collection of two data sets; one which describes benthic biomass in terms of size and vertical distribution in sediments at selected sites, and a second which describes the foraging depth and prey size exploitation pattern of demersal fishes at those sites. The BRAT then estimates that portion of the total benthic infaunal biomass that is both available and vulnerable to predation by target fishes. For a detailed description of the technique see Lunz and Kendall (1982) and Clarke and Kendall (1987).

During the period of 14-23 July 1987, benthic box-corer and otter trawl samples were collected at three areas identified as zones of siting feasibility (ZSF) for unconfined open-water disposal sites in Puget Sound. This report presents the results of a BRAT analysis of these samples.

9.3 Methods

Field sampling was performed at three locations: Anderson Island/ Devils Head (ZSF 3), Anderson/Ketron Island (ZSF 2), and Bellingham Bay. Specific boundary coordinates for each sampling site were provided by the U.S. Army Engineer District, Seattle. Specific locations of benthic stations and trawl transects were determined based on best available information on site boundaries, benthic and physical characterization data, and previous fisheries

resource surveys. In particular, an attempt was made to coordinate trawl stations with those occupied by the fisheries surveys (c.f., Section II.9 of this appendix). For a detailed map of station locations see Clarke and Kendall (1987). Due to limits on the total sampling effort imposed by funding constraints, a decision was made to allocate sampling unequally among the three areas. This approach allowed a more detailed evaluation of selected sites on a prioritized basis.

9.3.1 Benthic Sampling and Processing--

A total of 41 benthic samples were taken among 39 stations at the three sites with sample allocation as follows: Anderson Island/Devils Head (ZSF 3) - 11 stations; Anderson/Ketron Island (ZSF 2) - 11 stations; and Bellingham Bay - 17 stations. At one station within ZSF 2 three replicate samples were taken to examine heterogeneity of the benthos at that site. Due to coarse sediments at preselected stations in the southern portions of both ZSF 2 and ZSF 3, box corer penetration was inadequate to obtain samples of the required depth for a BRAT analysis. These stations were reallocated elsewhere in the respective ZSF.

Cores were collected by means of a 0.062 sq m Gray O'Hara stainless steel box-corer fitted with a plexiglass liner. As soon as the corer was retrieved and on deck, the liner containing the undisturbed sample was removed from the corer and processed as follows. Beginning at the sediment-water interface the core was divided into 0-2, 2-5, 5-10, and 10-15 cm vertical sections. The 0-2 cm section was washed into a 0.25 mm mesh seive bucket. The remaining vertical sections were individually washed into a 0.5 mm mesh sieve bucket. Each sediment sample was sieved by immersion of the buckets in a 30 gallon upright container filled with ambient seawater, and gently shaken and swirled to suspend the larger material and to allow fine sands, silts and clays to pass through the screens. Residual material was placed in cloth bags that were prelabelled internally and externally with an indelible marker, tied, and preserved in 10% seawater-buffered formalin. The storage container and location of each bag was recorded on a field data sheet. All four vertically sectioned samples were then moved to the laboratory for analysis.

Organisms were removed from each of the four vertical depth fractions (0-2, 2-5, 5-10, and 10-15 cm) from each box core, sorted to major taxa and individually separated into discrete size class intervals by a wet sieving procedure as described by Carr and Adams (1973) and Sheridan (1979). Nested, graded 3-inch standard sieves used in the benthic analysis were; 6.35, 3.35, 2.0, 1.0, and 0.5 mm. The sieve series for processing the 0-2 cm depth fraction had one additional sieve with a 0.25 mm mesh size. Each sample was processed as follows: the sample was carefully washed through the nested sieve series using a gentle water rinse, taking care not to damage soft-bodied benthic organisms. Each sieved sample starting with the 6.35 mm sieve and working down to the appropriate smallest mesh sieve was then vacuum filtered onto 0.45 micron cellulose acetate filters (millipore filter type HA), and next quantitatively transferred to weighing bottles. Taxa sorted from the

0.25 mm sieved sample for the 0-2 cm depth fraction were weighed directly after filtering, as explained below. Wet-weight biomasses were initially recorded to 0.01 g and the sample returned to a properly labelled vial containing 70% alcohol. In some isolated cases, when the available biomass was small, a higher level of accuracy was required (0.1 mg).

For the 0-2 cm vertical depth fraction all individuals of each major taxon were enumerated. Approximately 150 individuals of each major taxon were divided into 5 subsamples of 30 individuals each. Each subsample was weighed on an analytical balance to the nearest 0.001 mg. Average individual weight for all five subsamples were then calculated as well as the standard deviation and coefficient of variation. The average individual weight was then used to estimate the total weight of that taxon in the sample by multiplying by the total number of individuals enumerated.

Biomass data were converted to g/sq m (wet weights) and incorporated into the overall BRAT evaluation. All samples have been archived.

9.3.2 Fish Sampling and Processing--

A total of 27 otter trawl samples were obtained. Fish collections were conducted using a 25-foot otter trawl at each of the study sites concurrently with the benthic sampling. Sampling was allocated as follows: Anderson Island/Devils Head (ZSF 3) - 8 trawls, Anderson/Ketron Island (ZSF 2) - 7 trawls, and Bellingham Bay - 12 trawls. The catch at each study was divided as follow: trawls (1-3) in the northern section of ZSF 2, trawls (4-6) in the southern section of ZSF 2, trawls in the ZSF 2 reference area, trawls (1-2) in the northern section of ZSF 3, trawls (3-4 in the middle zone of ZSF 3, trawls (5-6) in the southern section of ZSF 3, trawls in the ZSF 3 reference areas (A,B), trawls in the southern section of Bellingham Bay, and trawls in the northern section of Bellingham Bay.

Trawls were of relatively short duration in order to minimize deterioration and regurgitation of the gut contents. Target benthic feeding fish species representative of demersal fishes utilizing each site included the English sole (*Parophrys vetulus*), Dover sole (*Microstomus pacificus*), rex sole (*Glyptocephalus zachirus*), starry flounder (*Platichthys stellatus*), butter sole (*Isopsetta isolepis*), rock sole (*Lepidopsetta bilineata*), and snake prickleback (*Lumpenus sagitta*). Fish collection efforts were directed by the number and composition of the catch at each study site. Fishes collected along each transect were processed as follows: (a) demersal bottom-feeding fishes were separated from pelagic fishes, which do not have value in the analysis, (b) the demersal fish catch was sorted by species and each species was divided into Standard Length (SL) size classes of 5-9.9, 10-14.9, 15-19.9, 20-24.9, 25-29.9, and greater than 30 cm, (c) all individuals of the same species and size class captured at the same location were processed for food habits analysis according to the procedures described by Borgeson (1963). In brief, contents of multiple stomachs are dispersed into the same container with buffered 10% formalin. This procedure pools the

variability between diets of individuals of the same species and size to yield a sample representative of the diet of an average individual feeding at a particular site. The procedure also preserves the integrity of individual food items that commonly become entangled and difficult to separate and identify when they are fixed within a fish's stomach as per more traditional techniques.

Stomach contents representing individual species size class samples were picked and sorted to major taxonomic categories (e.g., Mollusca, Annelida, Crustacea, etc.). Fish prey items were placed under the general category Nekton. Sorted-by-taxon samples were individually separated into discrete size class categories by a wet-sieving procedure described by Carr and Adams (1973) and Sheridan (1979). Wet-sieving was accomplished using a 3-inch diameter set of nested sieves from top to bottom in the following sequence: 6.35, 3.35, 2.0, 1.0, 0.5, 0.25, and 0.063 mm. In a manner similar to the treatment of the benthic samples, the stomach contents from each sieve were vacuum-filtered onto pre-weighed 0.45 micron cellulose acetate filters. This step stabilized the sample by removing free water. Wet-weights were recorded to the nearest 0.01g and the sample returned to a labelled container with 70% alcohol. Weights were tabulated by site, predator species, major taxon, and sieve size category. All samples have been preserved in 10% buffered formalin and archived.

9.4 Data Analysis

The data sets created by the field and laboratory efforts described above form the input to the BRAT evaluation. Based on examination of the fish food habits data, that component of the total benthic biomass that is both available and vulnerable to predation by the target fish species is estimated. This determination involves assignment of each fish size class sample to groups based upon their particular prey-size exploitation pattern. Percent biomass data were subjected to cluster analysis (numerical classification: Bray-Curtis similarity coefficient, group averaging sorting strategy) to objectively assign food habits samples, each representing a fish species-size class-location combination, to a feeding strategy group based on similarities in prey-size exploitation behavior. From the prey-size exploitation data, an estimate of the size range of prey utilized by, or vulnerable to given target predators is obtained. The stomach contents data are also used to estimate the foraging depth of each species size class sample. This is done by examination of the taxonomic composition of benthic prey in each food habits sample as compared to observations of the vertical distribution of prey taxa in the box-corer collections.

An examination of the raw benthic data indicated that several large patches of biomass, particularly in the deeper sediment fractions, were contributed by large bivalve molluscs. These large bivalves, as evidenced by the stomach contents data, were not utilized as prey items by any of the target fishes. Therefore, because their large biomaases would otherwise mask the importance of contributions made by the remaining benthic taxa, these large bivalves were selectively deleted from the benthic data set. All deletions represented biomass in the 10-15 cm sediment depth interval.

For each cumulative (0-2, 0-5, 0-10, 0-15 cm) sediment depth fraction, size-partitioned biomass data for all non-deleted taxa were subjected to cluster analysis (Bray-Curtis similarity coefficient, square root transformation, group averaging sorting strategy) to assign benthic samples to groups or "strata" on the basis of their similarities in benthos-size distribution and relative biomass contribution. Patterns of high or low benthic biomass and size distribution can then be discerned when these data are superimposed on the spatial array of sampling stations.

Each benthic biomass stratum is then evaluated in terms of the potential trophic support afforded to each predator group. This step involves summation of the vulnerable (ie. appropriate size range) prey biomass from the sediment surface down to the lowest zone of prey availability (ie. foraging depth). Thus each benthic stratum is given a value in cumulative prey biomass (g/sq m) for each predator group. These values represent the potential prey biomass for target predator species, and allow comparative estimates of the trophic support afforded by different sampling sites to be made.

9.5 Results

As stated earlier, a total of forty-one box-core samples was collected. Stations at ZSF 3 ranged in water depth from 48 to 80m; at ZSF 2 from 113 to 136m; at Bellingham Bay from 22 to 31m. Visual inspection of box-corer samples indicated that sediments at most sampling sites were composed of relatively homogeneous silty-clays typical of depositional environments. Difficulties in obtaining box corer samples were encountered at both South Sound study areas. Penetration problems reflected a gradient of increasingly coarse sediments running roughly from north to south in each area.

In the BRAT analysis benthic samples are sorted only to major taxonomic categories. Therefore a precise description of taxonomic composition at the family-species level cannot be given (see Clarke and Kendall, 1987, for a more complete description on benthic community structure within each study area). Examination of the changes in percent composition of major taxa among the study areas, however, does reveal some trends in the data (Fig. II.9-1). Polychaetes represent a major component of the benthos at each study area. Bivalve molluscs form a substantially larger proportion of the benthos in Bellingham Bay than in either Anderson Island study area (note, however, that large bivalve mollusc biomass has been removed from four stations as described earlier). Ostracods were present in appreciable amounts at the Anderson Island study areas, but were essentially absent from Bellingham Bay. Ophiuroids were collected in notable quantities in all areas with the exception of Anderson/Ketron Island. In terms of biomass, polychaetes generally dominate the benthos at the Anderson Island/Devils Head station groups. Visual inspection of the benthic samples indicated that polychaetes of the families Ophiliidae, Spionidae, and Maldanidae were important members of the infauna. Molluscs, primarily bivalves of the genera Axinopsida and

Macoma, were found at all study areas, but were dominant at the Bellingham Bay South stations. The biomass depicted as Other Taxa in Figure II.9-1 is predominantly comprised of Anthozoan or sand anemones.

Highest mean biomass (0-15 cm sediment depth) per station was found at the Commencement Bay Alternative Disposal Site. The lowest value occurred at the Anderson/Ketron Island (ZSF 2) study area. The lowest value occurred at the Anderson Island/Devils Head reference stations (located both to the north and to the southeast of the actual ZSF 3 areas). The northern and southern Bellingham Bay study areas have mean total biomass values (80.84 and 84.04 g/sq m, respectively) that are intermediate to those at Ketron Island and Devils Head.

All five study areas have approximately equivalent amounts of benthic biomass in the 10-15 cm sediment depth level. Most biomass at this depth, with the exception of that portion represented by fauna that vertically migrate, is beyond the foraging depth of most demersal fish predators. The upper two cm of the sediment column, however, which is probably the most important from a trophic support standpoint, shows some substantial differences among the study areas. The pattern is consistent with that for total biomass, i.e., Devils Head showing lowest overall values, Bellingham Bay sites intermediate, and Ketron Island showing the highest value. In the 2-5 cm sediment depth interval, the Bellingham Bay sites, particularly the northern area, show substantially greater amounts of benthic biomass. The Ketron Island reference stations contained the least biomass (6.52 g/sq m) in this sediment depth interval. In the 5-10 cm sediment depth interval, the Devils Head and Bellingham Bay samples revealed approximately equivalent mean total benthic biomass values, generally in the 17-27 g/sq m range. A large concentration of biomass (approximately 47 g/sq m) is found at this sediment depth in the Ketron Island samples.

Benthic biomass data were clustered using size-partitioned and total biomasses as attributes for each station. Thus stations from different study areas could, based on their similarity in biomass distribution, occur in the same cluster or stratum. Importantly, it should be noted that strata are formed independent of taxonomic composition. In data sets in which there are no remarkable differences among most stations in their size-partitioned biomass distribution, total benthic biomass will drive the groupings of stations into strata. In this data set size differences among stations was sufficient to jointly act with total benthic biomass to determine station cluster composition. Spatial displays of the stations within a stratum can therefore reflect both quantity and size characteristics of the benthos present at each sediment depth level.

A total of 41 species-size class samples (meeting an arbitrary criterion of at least two stomachs containing identifiable material per sample) were used in the analysis. Additional species were represented in the trawl catch, but not in sufficient numbers in a given size class to justify inclusion. Among these 41 species-size classes a total of 502 individual stomachs was distributed (Table II.9-1). Sample size was unequal among species and study areas, generally reflecting the composition of the catch at the respective study areas. English sole made up the majority of the total catch, and was

the most abundant target species at both Anderson Island study areas. At Bellingham Bay, snake prickleback were taken in high numbers, in addition to English sole, butter sole, and starry flounder. Rock sole were taken in sufficient numbers to form an adequate sample at Anderson Island/Devils Head only. Dover sole and rex sole were taken only at Anderson/Ketron Island. The catch differs substantially from that taken in a previous investigation of proposed Puget Sound disposal sites in Commencement Bay, Elliott Bay, Port Gardner, and Saratoga Passage (Clarke, 1986). At these sites the catch was more evenly distributed among slender sole (Lyopsetta exilis) Dover sole (Microstomus pacificus), and English sole (Parophrys vetulus), and smaller numbers of flathead sole (Hippoglossoides elassodon) and rex sole (Glyptocephalus zachirus). The size distributions of English sole in the present study differed somewhat among study areas. For example, the size mode of English sole at Anderson/Ketron Island fell into the 20-24.9 cm SL category, whereas at Anderson Island/Devils Head the majority of individuals were in the 15-19.9 cm SL size category. English sole larger than 30 cm SL were taken only at the Anderson Island study areas, whereas individuals smaller than 15 cm SL were taken only in Bellingham Bay. These observations generally support the concept that juvenile English sole prefer shallower habitats than adults, and that Bellingham Bay may serve as an important nursery area for this species.

Despite the fairly deep water depths along some of the trawl transects, the general condition of the stomach contents was excellent, as indicated by the low biomass percentages (never exceeding 16.7%) of unidentifiable food items.

The food habits data for each target predator species are discussed below. Recognition should be given to the fact that sample size for several target species is limited, and to the single season coverage of the samples. Thus the results reflect a "snapshot" of the feeding behavior of these species, and not a comprehensive picture of their biology. Figure II.9-1 displays the taxonomic composition of the diets on a percent biomass basis. Morphological features, particularly of the mouth and dentition, are important considerations in the selection of target species for the ensuing analysis. Detailed descriptions of the morphology of target species treated below are given in Hart (1973).

(a) English Sole (Parophrys vetulus) - This species displays the classic morphological features of an infaunal-feeding flatfish. The terminally placed mouth is asymmetrical, facilitating downward orientation during feeding, and has a small gape. Composition of the diet of juvenile English sole varied among sites and habitats sampled by Simenstad et al. (1979). Important prey items in mud/eelgrass and sand/eelgrass habitats included cumaceans, gammarid amphipods, polychaetes, tanaids, crabs, and bivalves. A number of additional studies have reported the food habits of this flatfish (Kravitz et al., 1976; Hulberg and Oliver, 1979; Becker, 1984a,b; Cross et al., 1985; Becker and Chew, 1987). Notable food items include bivalve siphons, polychaetes, small crabs and shrimps, and brittle stars. Samples collected by Becker (1984a) in central Puget Sound had diets consisting mainly of polychaetes (over 70 percent by abundance), molluscs (about 18 percent), and crustaceans (about 10

percent). Becker's (1984b) samples from the Commencement Bay area had eaten primarily polychaetes (84.4 percent relative abundance) and molluscs (14.0 percent). English sole in the Commencement Bay area were shown to selectively prey on Capitella spp. in bottom habitats disturbed by releases of municipal sewage effluent (Becker and Chew, 1987). Abundance of English sole was demonstrated by Cross et al. (1985) to be correlated positively with increasing polychaete density along a pollution gradient on the continental shelf off Los Angeles, California. Overall these fishes had a diet consisting of polychaetes, nematodes, bivalves, gastropods, and small crustacea. For English sole collected in Commencement Bay and Port Gardner, Clarke (1986) reported that the diet consisted largely of polychaetes and bivalves. In the present study samples of English sole fed primarily on some combination of polychaetes, bivalve molluscs, euphausiids (note that mysids were pooled with this taxon), amphipods, decapods (generally small crabs and shrimp), and ophiuroids, with other taxa such as ostracods and cumaceans contributing significantly to several food habits samples. Euphausiids/mysids were an important food item at the Anderson Island/Devils Head study area in particular. Their contribution diminished somewhat at Anderson/Ketron Island, and became negligible at Bellingham Bay. This corresponds dramatically with the abundances of euphausiids/mysids in the trawl catches at these sites. Cumaceans represented a notable percentage of the diet of English sole samples from Anderson/Ketron Island only. In contrast, ophiuroids were essentially absent from English sole taken from Anderson/Ketron Island. This pattern is reversed for Anderson Island/Devils Head English sole samples.

(b) Dover Sole (Microstomus pacificus) - Dover sole are also an excellent example of an infaunal-feeding flatfish. In a study by Pearcy and Hancock (1978), Dover sole fed predominantly on annelids (64.4 percent by weight) and secondarily on molluscs (18.3 percent) and crustaceans (11.2 percent). They reported that Dover sole were opportunistic feeders, as the diet varied with sediment type. Their catch of Dover sole on the Oregon coast was positively correlated with the abundance of polychaetes in grab samples. In a study of resource partitioning among a guild of flatfishes in central Puget Sound, Becker (1984a) observed that Dover sole preferred deeper (32 m), muddy nearshore habitats, and were primarily diurnal feeders. Polychaetes were a major food item (approximately 58 percent by abundance), followed by crustaceans and molluscs (approximately 30 and 13 percent respectively). In a separate study of flatfishes taken from the delta of the Puyallup River in lower Commencement Bay, Becker (1984b) reported that Dover sole diets consisted of 63.1 percent (relative abundance) annelids, 22.5 percent crustaceans, and 14.4 percent molluscs. Although less selective than English sole or rex sole, Dover sole were found to be capable of effective predation on Capitella spp. by Becker and Chew (1987). The abundance of Dover sole increased along a pollution gradient created by effects of municipal wastewater effluent near Los Angeles, California (Cross et al., 1985). In a manner similar to that reported by Pearcy and Hancock (1978), the abundance of Dover sole paralleled the increasing abundance of polychaetes in the sediments along the gradient. This was reflected in their diets as polychaetes became more important prey components. Crustacea showed an opposite trend of decreasing abundance along the gradient, both in the grab samples and in the stomach contents samples. Gabriel (1981) investigated factors determining feeding selectivity by Dover sole on the Oregon continental shelf. She noted

that polychaetes and ophiuroids were more important prey items in terms of weight, numbers, and frequency of occurrence than molluscs or crustaceans. Clarke (1986) reported that Dover sole fed largely on annelids. Bivalves were also important, particularly for larger size classes (25-29.9 and 30-34.9 cm SL) at the Port Gardner Alternative Disposal Site. A single size class sample (25-29.9 cm SL) at the Commencement Bay Alternative Disposal Site had eaten decapods almost exclusively. Dover sole taken from the Elliott Bay Alternative Disposal Site exhibited comparatively high diversity of stomach contents, including mysids, amphipods, cumaceans, isopods, and ostracods in appreciable amounts. In the present study, the single Dover sole size class sample, collected at Anderson/Ketron Island, fed on polychaetes and anemones, with additional minor prey contributions of amphipods, decapods, and euphausiids/mysids.

(c) Rex Sole (Glyptocephalus zachirus) - The rex sole is another small-mouthed flatfish. Pearcy and Hancock (1978) reported that rex sole smaller than 15 cm SL fed primarily on amphipods and other crustaceans, whereas larger rex sole shifted their diets to mainly polychaetes. In the Gulf of Alaska rex sole (12-26 cm) were found by Smith et al. (1978) to eat mainly polychaetes (54.6 percent by weight), followed by pandalid shrimp, small crabs, euphausiids, and pelecypods. Rex sole collected in central Puget Sound by Becker (1984a) had stomach contents consisting almost entirely of polychaetes. His samples contained fish in the 21-29 cm Total Length (TL) size range. At Commencement Bay, Becker (1984b) determined that rex sole had also eaten primarily polychaetes (over 96 percent relative abundance). Rex sole (5-9.9 cm SL) taken from Elliott Bay had eaten decapods, copepods, and amphipods (Clarke, 1986). In the present study, rex sole were taken only at the Anderson/Ketron Island study site. Three rex sole captured in trawls in the northern section of ZSF 2 had eaten primarily bivalves and decapods, whereas the diet of eight fish from the southern portion of the ZSF consisted largely of polychaetes.

(d) Rock sole (Lepidopsetta bilineata) - Rock sole fit the general morphological pattern of a bottom-feeding flatfish. The mouth is small, terminal in position, and has a small gape. The asymmetrical jaws have a slight upward orientation. As summarized by Hart (1973) and Livingston and Goiney (1983), the diet of this species as documented in past studies consists of mollusc siphons, small clams, polychaetes, shrimps, small crabs, amphipods, brittle stars, and sand lance. On the basis of sixty-six rock sole stomachs taken in northern Puget Sound Simenstad et al. (1979) reported that polychaetes, tanaids, gammarid amphipods, bivalves, and caridean shrimp were important food items. The single species size class sample taken in the present study (from Anderson Island/Devils Head) had eaten primarily cerianthid anemones, with smaller biomass contributions of bivalves and polychaetes.

(e) Butter sole (Isopsetta isolepis) - This species also possesses a small, asymmetrical, terminal mouth with a narrow gape. Descriptions of the diet of this flatfish from the literature (Livingston and Goiney, 1983) note that polychaetes, small bivalves (Macoma sp.) ophiuroids, shrimps, crabs, and fishes as prey items. Forrester and Thomson (1969) reported polychaetes, clams, small crabs, and sand lance in butter sole from British Columbian

waters. In the present study this target species was captured in sufficient numbers only in Bellingham Bay. These butter sole had eaten predominantly a mix of polychaetes and small bivalves, with amphipods and ophiuroids present in smaller quantities.

(f) Starry flounder (Platichthys stellatus) - This flatfish is similarly characterized by a small, terminal mouth with a narrow gape. The mouth is asymmetrical, facilitating feeding on and in the bottom. The diet of starry flounder in northern Puget Sound shallow sublittoral habitats has been described by Simenstad et al. (1979) as consisting mainly of polychaetes, amphipods, tanaids, bivalves, cumaceans, and mysidaceans. Orcutt (1950), Miller (1967), and Jewett and Feder (1980) have also reported on the diet of starry flounder. This species appears to modify its diet in accordance with the relative abundances of epifaunal and infaunal prey. Major prey items in the northern extent of its geographical range include brittle stars and rotobranch clams (Jewett and Feder, 1980). Orcutt (1950) and Miller (1967) also reported that small bivalves were important food items of starry flounder from Monterey Bay, California, and the San Juan Archipelago, Washington, respectively. This is consistent with the results of the present study. Three separate species size class samples taken at Bellingham Bay and representing eighteen fish had essentially identical stomach contents. Bivalves contributed ninety percent or greater of the dietary biomass in each sample.

(g) Snake prickleback (Lumpenus sagitta) - This is the only non-pleuronectid target species used in the present study. Although pricklebacks are demersal fishes, little is known of their food habits. As cited by Livingston and Goiney (1983), a study of forty-nine snake pricklebacks from Alaskan waters revealed a diet of polychaetes, gammarid amphipods, fish eggs, decapods, and small molluscs. Simenstad et al. (1979) reported that this species was primarily a benthic feeder in northern Puget Sound. Bivalves, tanaids, polychaetes, and gammarid amphipods were found to be important food items in terms of abundance and weight. A decision to sample this species in the present study was based on visual examination of their stomach contents form trawl catches in Bellingham Bay. The eighty-nine fish sampled had predominantly eaten polychaetes, bivalves, and amphipods, supplemented by smaller quantities of ophiuroids, ostracods, cumaceans, and decapods.

These data indicate that for the purposes of the BRAT analysis, all of the samples of target species described above are suitable for use in the overall evaluation due to their demonstrated reliance on infaunal prey items.

The results of cluster analysis and graphical treatment of the food habits biomass data were used to classify species and size classes into prey size feeding strategy groups that are described in Table II.9-2. Table II.9-3 lists the fish species and size classes assigned to each group. Note that in a number of instances the same size class of the same fish species exhibits a different feeding strategy. For example, English sole representing the 15-19.9 cm SL size class from the various study areas fall into Groups IIA, IIB, IID, and IIIA. Likewise, at least one English sole 20-24.9 cm SL size class sample is found in every feeding group. Given the caveat that sample

sizes are fairly small, this may be an indication that qualitative differences in the prey available to these bottom feeders exist at the various sites. Composition of several groups show a substantial degree of species integrity. For example, snake prickleback samples occur only in Group IIA, and starry flounder samples occur only in Group IIB. Although sample sizes are small, an ontogenetic shift in diet is apparent among butter sole samples. Butter sole in the 5-9.9 cm SL size category fall into Group IIB, which has a relatively small prey size mode. Group IID, with a somewhat larger prey size mode, contains 10-14.9 cm SL butter sole. Finally, the largest butter sole, in the 15-19.9 cm SL size category, show a Group IIIB feeding strategy, in which very large prey items are utilized.

Observed differences in prey size exploitation patterns by the same species and size class captured from two locations, however slight, lead to questions regarding feeding efficiency. Data on the weight of each fish food habits sample and the number of stomachs that comprised each pooled sample were used to calculate the mean weight of food in each sample (Table II.9-4). These calculations indicate that although feeding efficiency was on the whole low (ie., small amounts of biomass per stomach), substantial differences in feeding efficiencies among the study areas are not apparent. Not surprisingly, a slight trend is shown for increasing mean biomass of stomach contents with increasing Standard Length. No striking differences are noted among study areas for English sole samples of the same size category.

For each fish group a determination of that portion of the total benthic biomass that is both vulnerable and available to predation is made. Those portions of the total biomass determined to be either too small or too large to fit a predator group's feeding strategy (not vulnerable) or beyond that predator group's foraging depth (not available) are deleted from the appropriate cluster's total biomass. Recall that parcels of large bivalve biomass, which do not represent prey items, have already been removed from the data set.

Comparison of the taxonomic composition of the diets of fish size class samples in each predator feeding strategy group reveals that in several cases a group consists partially or mainly of epibenthic rather than infaunal feeders. Groups which contain no evidence of infaunal feeding are logically of little importance in assigning a value to the benthos as trophic support. For example, several samples of demersal fishes in Puget Sound were reported by Clarke (1986) to have fed predominantly on epifaunal organisms and were not considered in a trophic resource analysis. In the present data set, however, all samples of demersal fishes were demonstrated to have preyed heavily on infaunal prey items and are treated below.

First, an estimate is made of the size range of prey showing significant (i.e., for the purposes of the analysis a ten percent dietary contribution within a single prey size category has arbitrarily been defined as significant) exploitation by a given predator group (c.f., Table II.9-2). Second, a determination is made of the foraging depth of the selected predator groups. This is the most subjective step in the overall analysis, and requires extensive investigation of the data sets. For example, if polychaetes are the major prey taxon of a particular predator group,

examination of the vertical distribution of polychaete biomass in the sediments at stations adjacent to the trawl transects from which the fish samples were captured can provide insight into the probable foraging depth of those fishes. If the major concentration of polychaete biomass lies between 2 and 5 cm, then a conclusion can be reached that the fishes are exploiting the 0-5 cm sediment depth fraction. If the polychaete biomass accumulates in a linear fashion with sediment depth down to 15 cm, then best available information on the feeding behavior of a given species must be relied upon. For example, Gabriel (1981) reported that only large size classes of Dover sole foraged deeper than 2 cm into the sediment. This approach, however, must consider the behavior of the specific prey items. Many species of polychaetes which build tubes deep into the sediment are surface deposit-feeders. Although fish are able to crop the exposed portions of the annelids at the sediment surface, the biomass for these polychaetes may actually be found quite deep in the box-corer samples. During sampling these and other annelids might be expected to retract downward into their tubes. Specific taxa may act as labels of distinct foraging depths. Based on considerations such as these, an estimated foraging depth for each predator group is reached.

The results of the benthic resource computations for each ZSF are listed in Table II.9-5 and presented in Figures II.9-3 through II.9-5. For Group IIA and IIB predators a 5 cm foraging depth was used. From the total available biomass in the 0-5 cm sediment depth zone, as depicted in Figure II.9-6, that portion determined to be outside of the vulnerable range is removed. This operation is repeated for each 0-5 cm benthic stratum. The biomass remaining in each stratum is then a measure of the potential biomass that can be utilized by Group IIA and IIB predators at stations in that respective stratum. In establishing biomass criteria for the benthic strata, a progression from very low biomass in Stratum A1 to very high biomass in Stratum D1 was created. However, the resource analysis for Group IIA predators indicates that, for this group of predators, Stratum B1 (26.1 g/sq m) contained a greater potential food resource than Stratum D1 (12.0 g/sq m). An overall pattern of rough equivalence of potential food value among strata existed, with the exception of the peak biomass in Stratum C1. The total potential food biomass available to predators selecting mainly small prey items is, however, shown to be relatively low in comparison with that available to predators feeding on larger infaunal prey items. In each ZSF the potential feeding habitat was higher for Group IIB predators than for Group IIA. For Groups IID and IIIA predators a 0-10 cm foraging depth was used (Fig. II.9-7).

An initial statement of the limits of the data is required. Because the data represent a single summer sampling effort, extrapolation of the results to a complete seasonal cycle is impossible. However, the data do adequately describe conditions at the project sites during a period when benthos are actively being exploited by resident fish populations. A second limitation of the data is that sampling effort was unequal among study areas such that not all target species were sampled at each site. This reflects in part variation in the habitat preferences of the selected target species. The ichthyofauna inhabiting the southern versus the northern Puget Sound study areas were not surprisingly quite different. Sufficient data were obtained to reach conclusions regarding key target species, particularly English sole.

The most remarkable difference between study areas observed in the data is the contrast in abundance of small bivalve molluscs. The dense standing crop of bivalves at Bellingham Bay provides an important food resource for several of the demersal fish species present. Starry flounder were found to be feeding almost exclusively on these small bivalves. Seasonal sampling would be necessary to determine whether other components of the benthos became more important as bivalve abundances varied, or whether bivalve production was sufficiently high to accommodate high levels of predation throughout the year.

The overall patterns of biomass distribution among size categories and vertical sediment depth fractions were essentially similar among study areas with the possible exception of the northern Bellingham Bay study area. Each site shows a predominance of large benthos found deep in the sediment column. This general condition is indicative of stable benthic communities in which larger, deeper-dwelling fauna have become established. The northern Bellingham Bay study areas shows the largest departure from this pattern, although deep-dwelling fauna were indeed present. This may represent a north-south gradient in terms of benthic "quality" in response to altered conditions of physical stress (e.g., susceptibility to storm-induced disturbance) or perhaps anthropogenic perturbation (e.g., trawling induced disturbance or organic enrichment due to proximity to urban center). Other more subtle differences in the benthic assemblages at each study area relate to differences in potential trophic support. For example, the relatively higher biomasses of benthos in the upper sediment column at Anderson/Ketron Island as compared to Anderson Island/Devils Head accounts for higher calculated food resource values for benthic strata found primarily at the former site.

In summary, although major differences in benthic habitat quality were not demonstrated among the various study sites, observed patterns of potential trophic resources available to demersal bottom-feeding fishes would support certain management decisions. At Anderson Island/Devils Head study area low benthic biomasses were found in the upper sediment depth fractions to the north of the existing ZSF 3 boundaries. Location of the operational disposal site in the northern portion of ZSF 3, or shifting the disposal site boundaries northward of their present location may have the effect of minimizing detrimental impacts to the foraging base. The lower benthic biomass also correspond with higher densities of demersal fishes at this location during the same period, which may reflect higher foraging pressure on the benthic community. Concerns for herring resource concentration areas north of the ZSF near Anderson Island/Devils Head precluded moving the alternative sites further to the north. At Anderson/Ketron Island stations characterized by low food resource value were generally located along the eastern edge of the ZSF 2 boundary. Placement of the operational disposal site in the eastern portion of ZSF 2 would appear to offer minimal risk to the existing trophic resource. At Bellingham Bay the northern ZSF appears to have somewhat higher trophic support value than the southern ZSF. In the southern Bellingham Bay study area an east-west gradient of increasing trophic resource

value is indicated. Shifting the operational disposal site location slightly to the west would appear to be the best available option to minimize risk to the forage base. Accordingly, the DSWG adjusted the disposal site in the south ZSF into the lower benthic resource value area as recommended (see Figure II.2-1c alternative site A-1).

Table II.9-1. Distribution of fish food habits samples among proposed dredqed material disposal sites in Puget Sound. Fish size classes listed as Standard Length (SL). ZSF = Zone of Siting Feasibility, BB = Bellingham Bay. n = number of individual stomachs containing identifiable prey.

DISPOSAL AREA	ZSF 2		ZSF 3		BB	
	SL(cm)	n	SL(cm)	n	SL(cm)	n
SPECIES						
English Sole					10-14.9	2
	15-19.9	27	15-19.9	103	15-19.9	21
	20-24.9	81	20-24.9	64	20-24.9	11
	25-29.9	21	25-29.9	15	25-29.9	4
	30-34.9	3	30-34.9	3		
Rex Sole	15-19.9	3				
	20-29.9	8				
Dover Sole	15-24.9	7				
Rock Sole			20-29.9	4		
Butter Sole					5-9.9	3
					10-14.9	13
					15-24.9	2
Starry Flounder					20-24.9	4
					25-29.9	14
Snake Prickleback					20-29.9	89

TOTALS

DISPOSAL AREA	ZSF 2	ZSF 3	BB
	150	189	163

SPECIES	English Sole	Rex Sole	Dover Sole	Rock Sole	Butter Sole	Starry Flounder	Snake Prickleback
	355	11	7	4	18	18	89

Table II.9-2. Description of prey size feeding strategy groups.

Group I - Fishes feeding on prey less than or equal to 1.0 mm or smaller with a modal prey size around 0.25 mm. No representatives of this group were found in this data set.

Group 11 - Fishes that exploit a range of prey sizes and that are not clearly small prey or large prey exploiters. Group 11 contains five subgroups in this data set.

- Group IIA - Fishes that exploit prey between 0.5 and 3.35 mm. A prey size mode of 1.0 mm is indicated for benthic prey items.
- Group IIB - Fishes that exploit prey between 1.0 and 3.35 mm. A prey size mode of 2.0 mm is indicated.
- Group 11C - Fishes that exploit prey between 1.0 and 6.35 mm. Prey size distribution is bimodal, having separate peaks of 1.0 and 3.35 mm.
- Group 11D - Fishes that exploit prey between 1.0 and 3.35 mm, with a size mode of 3.35 mm.
- Group 11E - Fishes that exploit prey between 1.0 and 6.35 mm, with a prey size mode of 3.35 mm.

Group 111 - Fishes that do not exploit small sized prey. Exploitation is predominantly among prey that are greater than 3.35 mm. Two subgroups occur in this data set.

- Group IIIA - Fishes that exploit prey in the intermediate size range (1.0-3.35 mm), as well as the larger sizes with a prey size mode of 6.35 mm.
- Group IIIB - Fishes that predominantly exploit prey in the 3.35 and 6.35 mm size range, with a distinct 6.35 mm prey size mode.

Table II.9-3. Composition of feeding strategy groups based on prey size exploitation patterns.

GROUP	SPECIES	SIZE CLASS (cm, SL)	NUMBER OF INDIVIDUALS	SITE
IIA	English Sole	15-20	15	Ketron Island (1-3)
	English Sole	15-20	12	Ketron Island (4-6)
	English Sole	15-20	2	Bellingham Bay (South)
	Snake Prickleback	15-20	53	Bellingham Bay (South)
	Snake Prickleback	20-25	36	Bellingham Bay (North)
	Snake Prickleback	20-25	53	Bellingham Bay (South)
IIB	English Sole	15-20	32	Devils Head (1-2)
	English Sole	15-29	10	Devils Head (RB)
	Starry Flounder	20-25	4	Bellingham Bay (North)
	Starry Flounder	25-30	6	Bellingham Bay (South)
	Starry Flounder	25-30	8	Bellingham Bay (North)
	Butter Sole	5-10	3	Bellingham Bay (North)
11C	English Sole	20-25	46	Ketron Island (1-3)
	English Sole	20-25	23	Ketron Island (4-6)
11D	Rex Sole	15-20	3	Ketron Island (4-6)
	English Sole	10-15	2	Bellingham Bay (North)
	English Sole	15-20	6	Bellingham Bay (South)
	English Sole	15-20	35	Devils Head (5-6)
	English Sole	15-20	13	Devils Head (RA)
	English Sole	20-25	22	Devils Head (1-2)
	English Sole	20-25	10	Devils Head (RA)
	English Sole	20-25	4	Devils Head (3-4)
	English Sole	20-25	13	Devils Head (5-6)
	English Sole	20-25	15	Devils Head (RB)
	English Sole	25-30	6	Devils Head (1-2)
	English Sole	25-30	9	Devils Head (RB)
	Butter Sole	10-15	13	Bellingham Bay (North)
IIE	English Sole	20-25	12	Ketron Island (R)
	English Sole	30-35	3	Ketron Island (4-6)
	Dover Sole	15-20	7	Ketron Island (1-3)
	Rex Sole	20-25	8	Ketron Island (1-3)
IIIA	Rock Sole	20-25	4	Devils Head (1-2)
	English Sole	15-20	13	Devils Head (3-4)
	English Sole	15-20	13	Bellingham Bay (North)
	English Sole	20-25	8	Bellingham Bay (North)
	English Sole	20-25	4	Bellingham Bay (South)
	English Sole	25-30	3	Devils Head (5-6)
	English Sole	25-30	6	Ketron Island (4-6)

(continued)

GROUP	SPECIES	SIZE CLASS (SL, cm)	NUMBER OF INDIVIDUALS	SITE
IIIB	English Sole	20-25	4	Bellingham Bay (South)
	English Sole	25-30	7	Ketron Island (1-3)
	English Sole	25-30	8	Ketron Island (RA)
	Butter Sole	15-20	2	Bellingham Bay (South)

Table II.9-4. Feedinq efficiency of fishes sampled at three disposal areas in Puget Sound, as indicated by mean weight of food items per stomach. SL = Standard Length category in cm (1 = 5-9.9, 2 = 10-14.9, 3 = 15-19.9, 4 = 20-24.9, 5 = 25-29.9, 6 = >30). DH = Anderson Island/Devils Head (ZSF 3), KI = Anderson Island/Ketron 1sland (ZSF 2), BB = Bellingham Bay. Trawl designations given for each study area (R = reference, S = South, N = North)

SPECIES	SL	Mean Weight of Food Per Stomach (g)									
		DH					KI			BB	
		1-2	3-4	5-6	RA	RB	1-3	4-6	R	S	N
English Sole	2										0.375
	3	0.092	0.138	0.081	0.139	0.113	0.066	0.060		0.317	0.330
										0.188	
	4	0.332	0.199	0.213	0.116	0.438	0.150	0.231	0.183	1.791	0.380
	5	0.590				0.955	0.497	0.702	1.122	0.351	
	6			0.288				0.670			
Rock Sole	4	1.078									
Rex Sole	3							0.233			
	4						0.292				
Dover Sole	3						0.219				
Starry Flounder	4										0.986
	5									1.149	0.685
Butter Sole	1										0.127
	2										0.272
	3									0.365	
Snake Prickle-back	4									0.036	0.064

Table II.9-5. Comparative bottomfish feeding habitat values at Phase II nondispersive disposal site alternatives.*

Site	Predator Feeding Groups** IIA	IIB	IID	IIIA
Bellingham Bay				
Preferred	29	41	67	65
Alternative 1	5	13	23	46
Alternative 2	22	32	51	51
South Sound				
Preferred (Ketron Island)	14	24	31	73
Alternative 8 15 23 52 (Devils Head)				

* Benthic habitat values expressed in g/m2 (wet)

** Predator IIA: Available zone (foraging depth): 0-5cm
Vulnerable sizes: 1-2mm

Predator IIB: Available zone: 0-5cm
Vulnerable sizes: 1-3.35mm

Predator IID: Available zone: 0-10cm
Vulnerable sizes: 1-3.35mm

Predator IIIA: Available zone: 0-10cm
Vulnerable sizes: 2-6.35mm

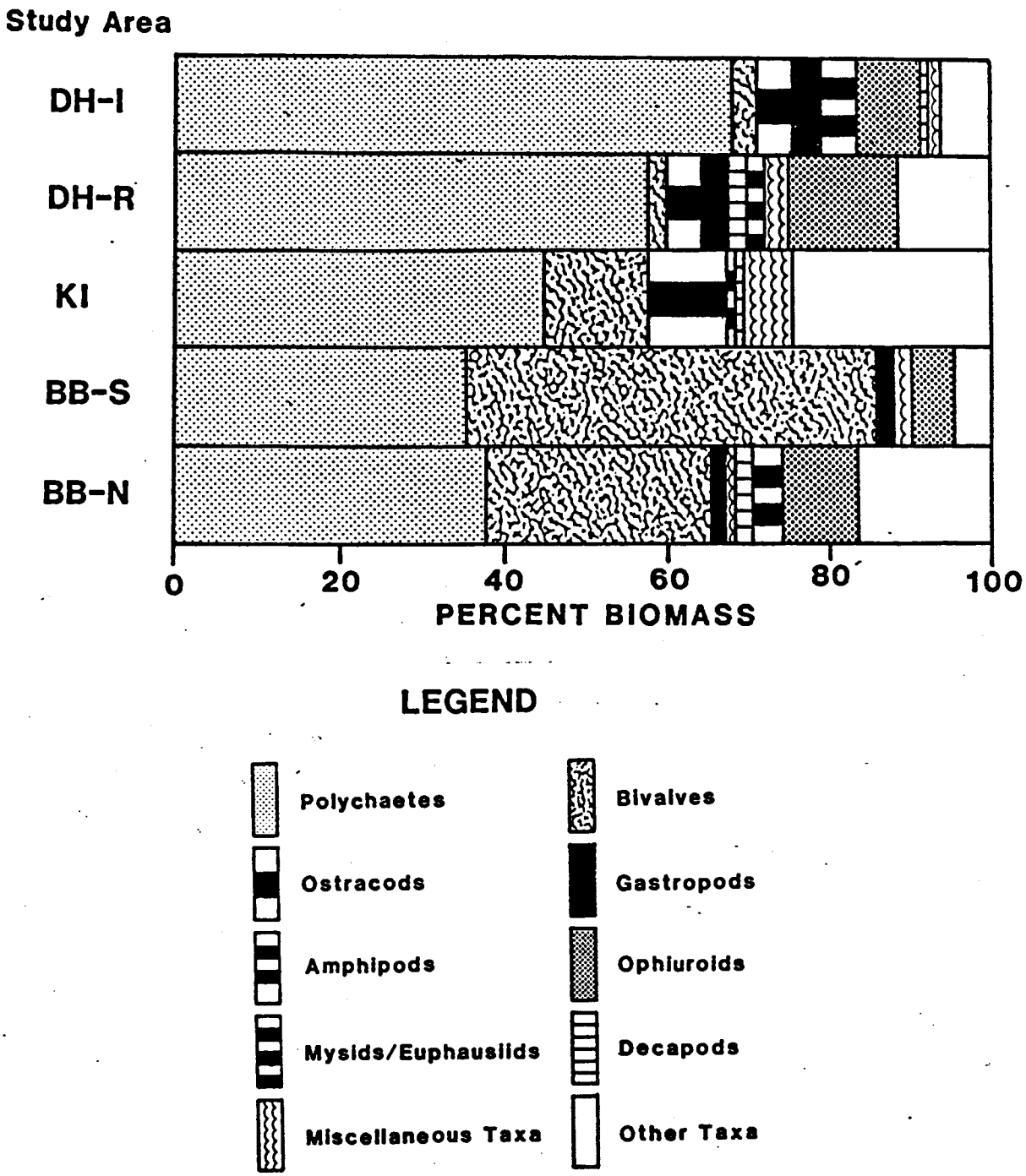


Figure II.9-1. Taxonomic composition of benthos (large bivalves excluded) among the Puget Sound study areas. DH = Anderson Island/ Devils Head, KI = Anderson Island/Ketron Island, BB = Bellingham Bay, I = Impact Area, R = Reference Area, S = South, N = North.

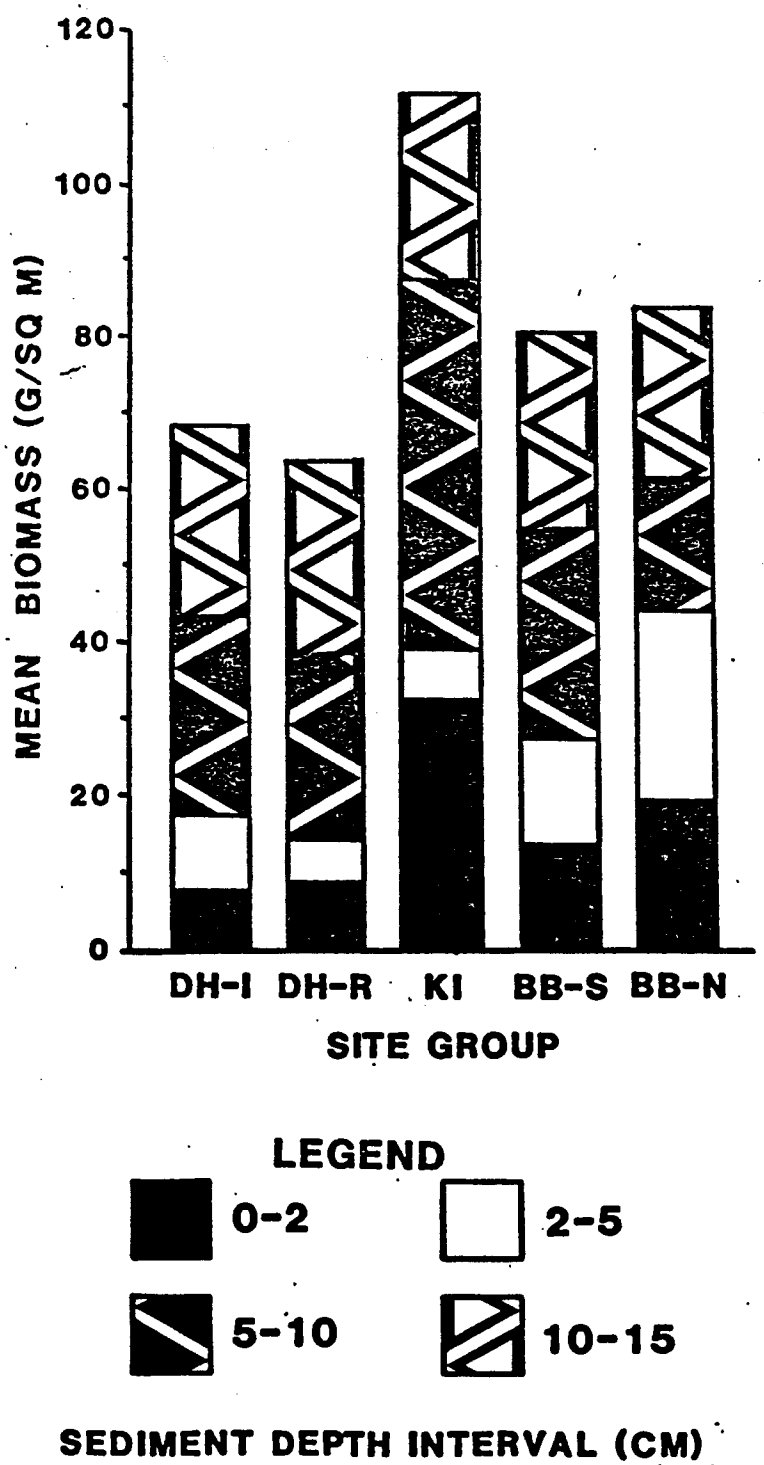


Figure II.9-2. Distribution of mean benthic biomass among stations at each Puget Sound study area. DH = Anderson Island/Devils Head, KI = Anderson Island/Ketron Island, BB = Bellingham Bay, I = Impact Area, R = Reference Area, S = South Area, N = North Area.

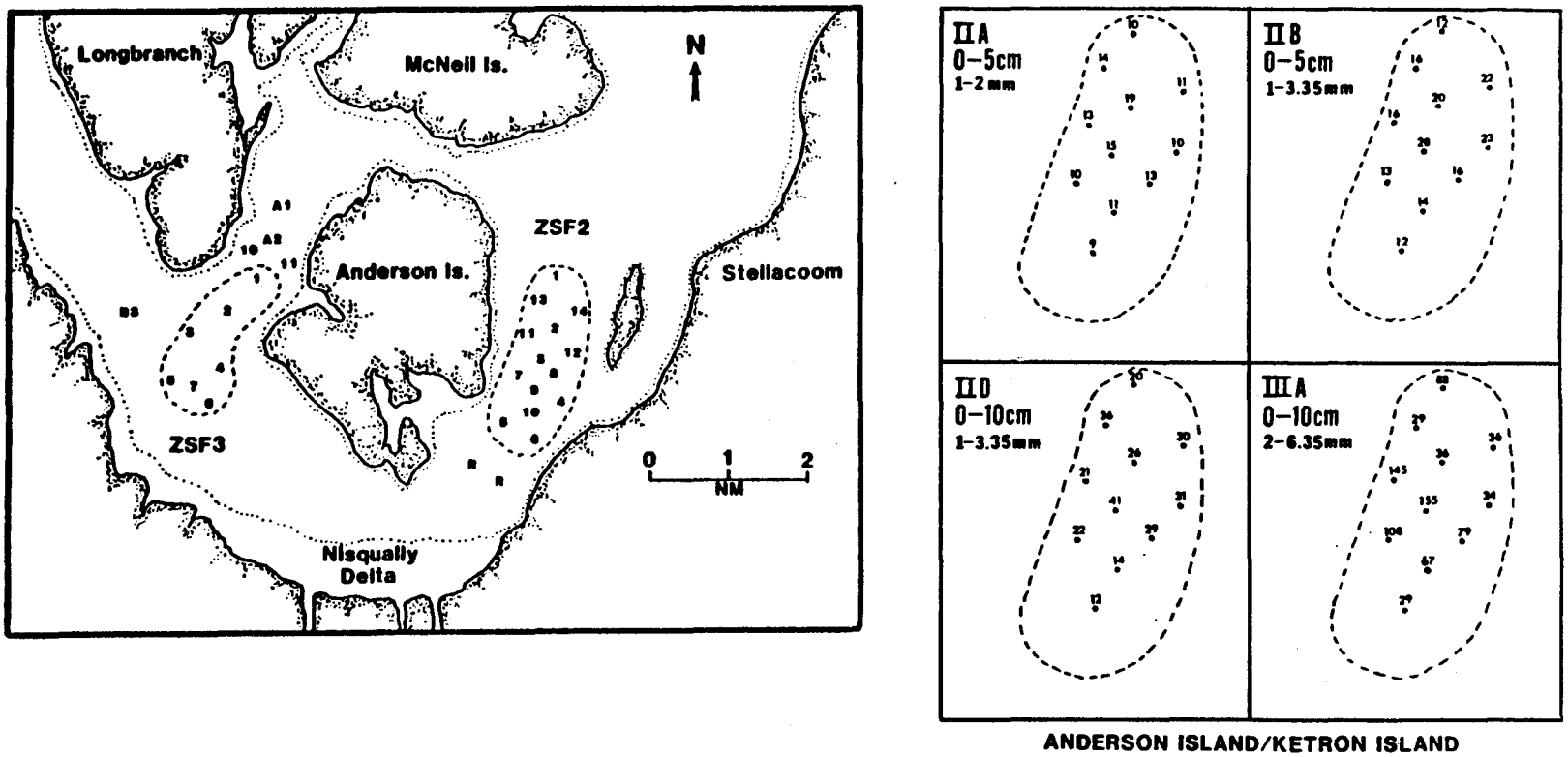
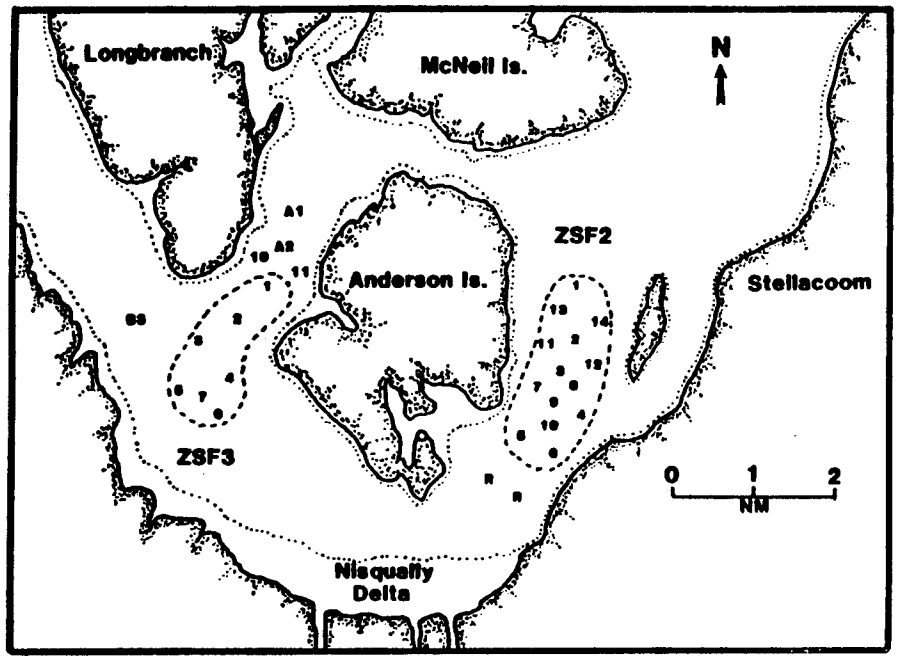
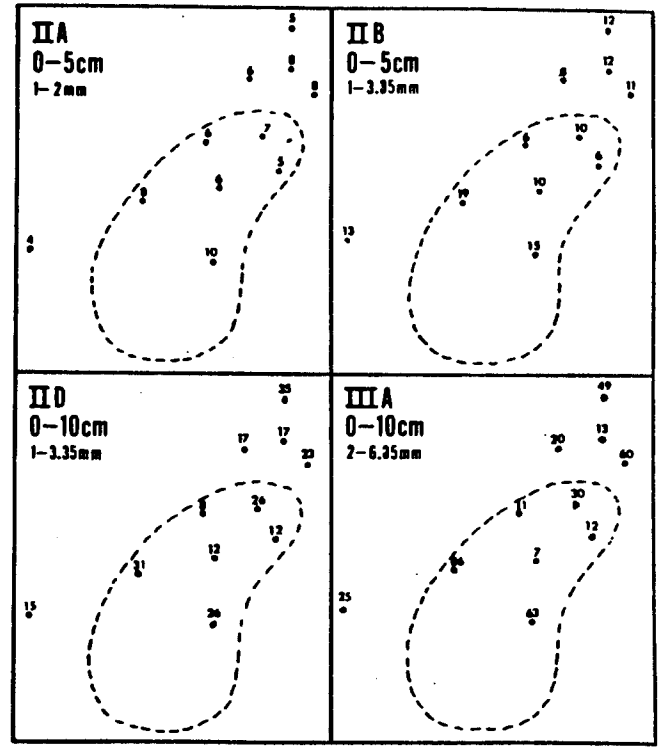


Figure II.9-3 Vicinity map (left) depicts the box core stations sampled within the Anderson/ Ketron Island ZSF. Figure on right depicts spatial arrays of benthic feeding habitat potential for four of the identified predator feeding groups. Values are expressed in grams/square meter (wet weight).

Legend: Predator Feeding Groups: IIA, IIB, IID, IIIA
Available Zone (foraging depth): 0-5cm, 0-10cm
Vulnerable Sizes: 1-2mm, 1-3.35mm, 2-6.35mm

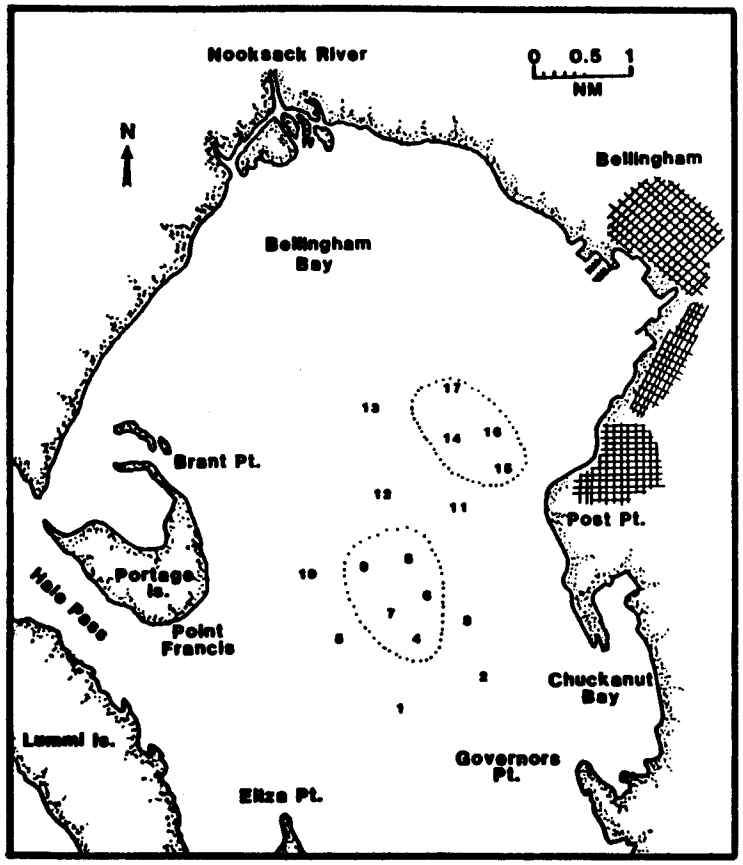




ANDERSON ISLAND/DEVILS HEAD

Figure II.9-4 Vicinity map (left) depicts the box core stations sampled within the Anderson Island/Devils Head ZSF. Figure on right depicts spatial arrays of benthic feeding habitat potential for four of the identified predator feeding groups. Values are expressed in grams/square meter (wet weight).

Legend: Predator Feeding Groups: IIA, IIB, IID, IIIA
Available Zone (foraging depth): 0-5cm, 0-10cm
Vulnerable Sizes: 1-2mm, 1-3.35mm, 2-6.35mm



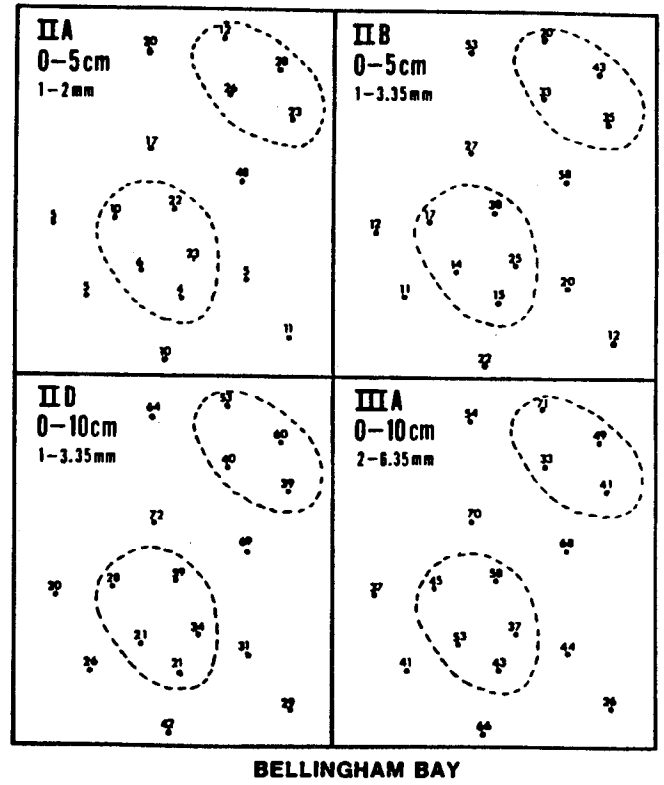


Figure II.9-5 Vicinity map (left) depicts the box core stations sampled within the Bellingham Bay ZSFs. Figure on right depicts spatial arrays of benthic feeding habitat potential for four of the identified predator feeding groups. Values are expressed in grams/square meter (wet weight).

Legend: Predator Feeding Groups: IIA, IIB, IID, IIIA
Available Zone (foraging depth): 0-5cm, 0-10cm
Vulnerable Sizes: 1-2mm, 1-3.35mm, 2-6.35mm

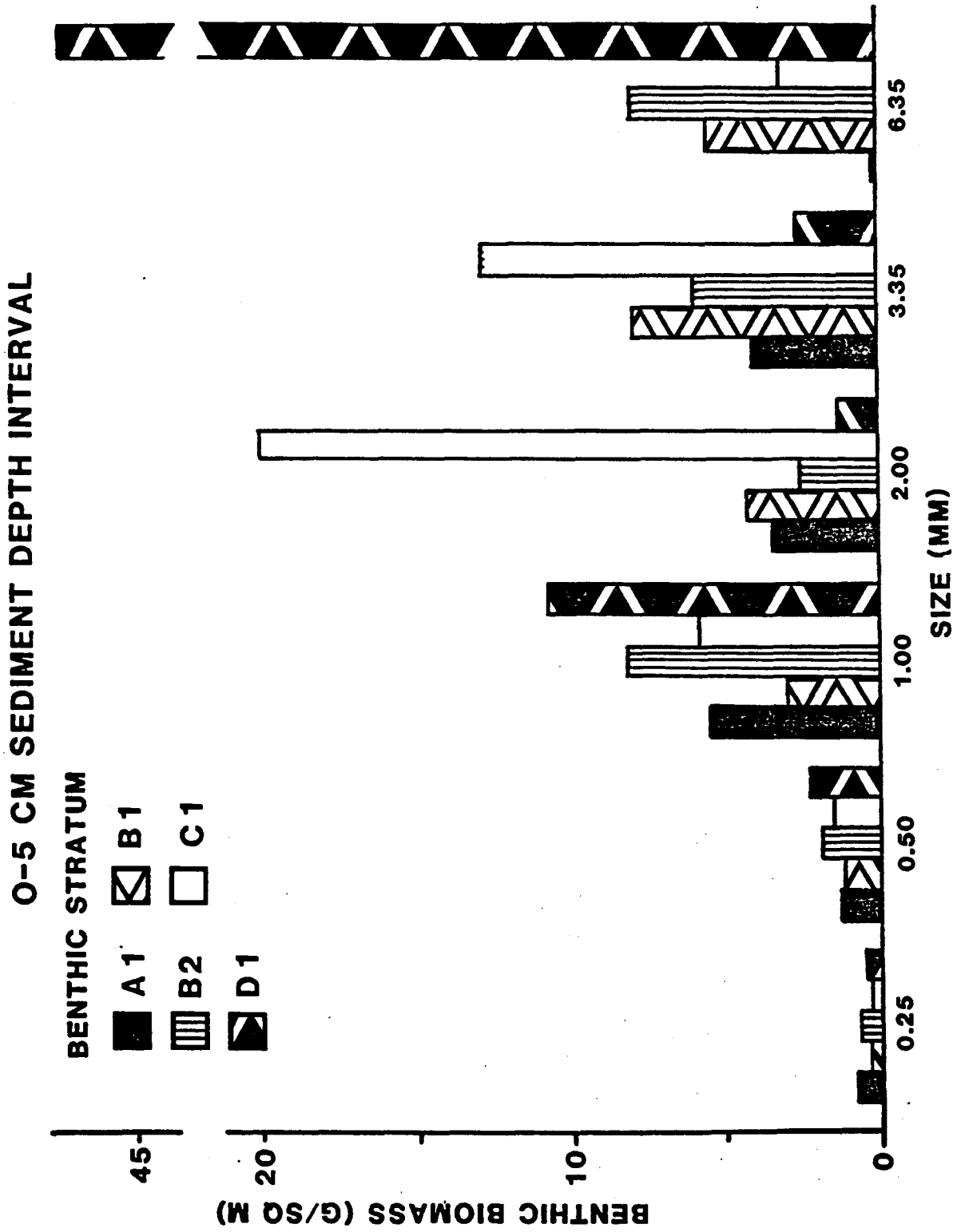


Figure II.9-6. Size distribution of benthic biomass among benthic strata in the 0-5 cm sediment depth interval for the Puget Sound study areas.

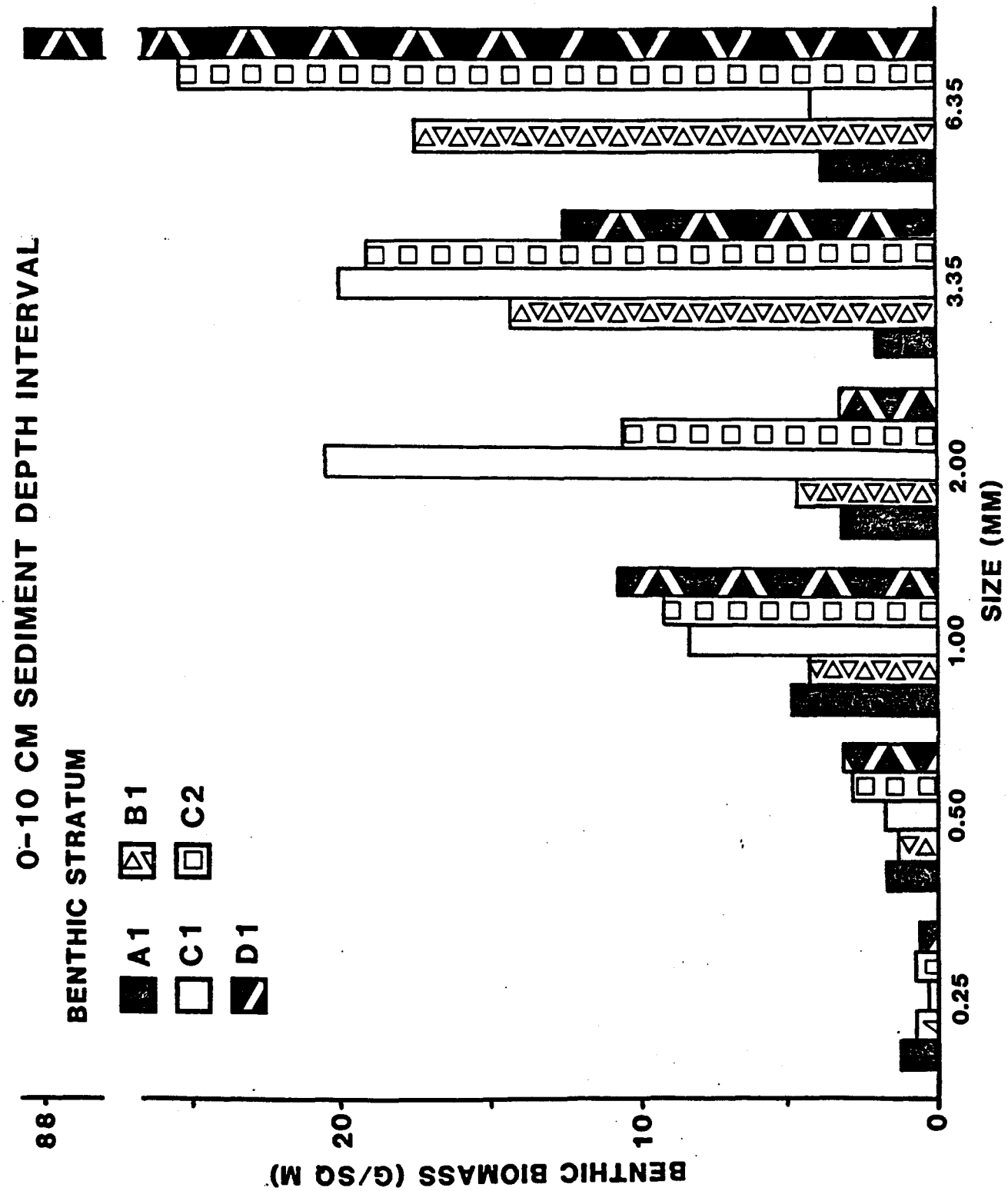


Figure II.9-7. Size distribution of benthic biomass among benthic strata in the 0-10 cm sediment depth interval for the Puget Sound study areas.

10. SELECTION OF RECOMMENDED DISPOSAL SITES

The final locations recommended for the disposal sites were determined in two stages. First, the final size and shape of the disposal site was chosen; and second, the chosen size was overlaid on the various maps of hydraulic characteristics, sediments, and biological resources. For each service area, a preferred and an alternate disposal site was chosen.

10.1 Objective

The objective of this chapter is to discuss the size, shape, and locations of the recommended disposal sites. These choices are summarized by overlaying the preferred and alternate disposal sites on the ZSF maps.

10.2 Disposal Site Delineation

The estimated size, orientation, and configuration of the non-dispersive disposal sites were determined by combining results of and estimations based on the numerical dredged material disposal model, sediment depositional analysis, and bathymetric and tidal current data. The disposal model provided estimates of the area over which the material might spread for a single disposal from a barge for varying water depths and current speeds. Using bathymetry and tidal current conditions the appropriate set of dump model results were selected to predict the representative depositional patterns; however, the results represented only the effects of a single barge load of dredge material for both nondispersive and dispersive sites. An estimate of the deposition pattern that will evolve over a long period of time for the nondispersive sites was calculated by assuming that a large number of barge loads of dredged material will be disposed of randomly throughout an 1,800-foot diameter disposal zone. For nondispersive areas with low tidal currents (< 25 cm/s 99% of the time), the resulting disposal pattern is a circle, concentric with the 1,800-foot diameter disposal zone. This circle has a diameter of approximately 4,000 feet for depths ranging between 200 and 600 feet. See Figure II.4-2 for a plan and elevation view of the disposal site parameters. For dispersive areas with high tidal currents (> 25 cm/s 50% of the time), the resulting disposal pattern is a circle, concentric with the 3,000-foot diameter disposal zone. This circle has a diameter of approximately 6,000 feet for depths of 200 feet and a 7,000-foot diameter for depths of 400 feet. See Figures II.4-3 and II.4-4 for plan and elevation views of the disposal site parameters.

The final orientation and configuration of a nondispersive disposal site was estimated by considering the depositional analysis and the effects of bottom slope. For a dispersive disposal site the final orientation and configuration were estimated considering the disposal depth and average current speed. Table II.10-1 provides the locations of the center of each disposal site; its area, depth and dimensions. Table II.10-2 compares the parameters that were examined in the site specific studies, for the preferred and alternate disposal sites.

10.2.1 Anderson/Ketron Island ZSF 2--

The Anderson/Ketron Island ZSF is the preferred disposal site for South Sound. It is situated in a depth of 442 feet on a comparatively flat plane. The boundary configuration was drawn so that the disposal site follows the naturally confining bathymetric features of the bottom. Tidal current and depositional analysis data indicate that the site is subject to weak currents. The ZSF boundary was revised based on depositional analysis results. Mean speeds near the bottom averaged 0.48 feet per second (14.55 cm/s) near the center of the proposed disposal site. Benthic resource values were generally low, typical for the sediments and water depths of the site. In general all commercially important marine invertebrate resources were scarce or absent within the ZSF and were usually concentrated upslope in shallower nearshore areas (Dinnel et al., 1988). No Dungeness crab were found in the ZSF site and pandalid shrimp abundances were all found to be relatively low. Because tidal currents should not significantly alter the disposal site configuration and the bottom slopes may help confine the disposal material, the delineated site forms an ellipse 4,400 feet by 3,600 feet in diameter with the long axis of the ellipse orientated with the current. The 1,800-foot diameter dump zone is centered within the site.

10.2.2 Anderson Island/Devils Head ZSF 3--

The Anderson Island/Devil's Head site is the alternative disposal site for South Puget Sound. It is located at a depth of 238 feet in a relatively flat area. The mean current speed near bottom exceeded 20 centimeters per second, indicating a more energetic area than the Anderson/Ketron Island area. Depositional analysis and small grain size support this as a depositional area. In general all commercially important marine invertebrate resources documented during ZSF studies were either scarce or absent within the ZSF and were generally found in shallower areas upslope or in the region of the Nisqually delta. Dungeness crab were not found in the site and shrimp abundances were relatively low.

10.2.3 Bellingham Bay--

The Bellingham Bay preferred site is located at a depth of about 96 feet and is subject to sluggish tidal currents (Fig. II.2-1c). Benthic resource values were generally low throughout the study area encompassing the preferred and alternative sites, although they were somewhat lower to the south at the south alternative site (A-1). Although Dungeness crab densities are slightly higher (21 crab/ha versus 17 crab/ha) at this location compared with the south alternative disposal site (A-1). Average shrimp resources were found to be slightly less abundant at the preferred site (690/ha versus 723/ha) than at the south Alternative site. Site restrictions proposed by WDF to protect Dungeness crab resources and flatfish spawning activity would prohibit disposal from 1 November through 28 February each year. Additionally, the

fisheries closure period between March 15 and June 15 each year would effectively limit disposal of dredged material between 16 June and 31 October each year. Crab and shrimp resource abundances were found to be lowest between July and October (i.e., 10 crabs/ha and 71 shrimp/ha) when dredging and disposal would be allowed. The preferred site was found to be an acceptable compromise between natural resource concerns and potential bottomfish trawling conflicts at the south alternative site. Average Dungeness crab densities of 21 crabs/ha are will below the WDF criteria of 100 crabs/ha signifying concern.

The Bellingham Bay primary alternative site is located south of the preferred disposal zone (Fig. II.2-1c). This site lies in 98 feet of water. The currents in this site are also sluggish. The depositional analysis and grain size show the site to be depositional. Crab were found in low abundance at the preferred site and shrimp in relatively high abundance. However, because of concerns over conflicts with disposal operations and the established trawl fishery this area was considered only as an alternative.

10.2.4 Rosario Strait--

The Rosario Strait ZSF is located in the most energetic area of the proposed disposal sites. Both disposal zones are located in water 230 feet deep. The expected deposition pattern is approximately 3,000 feet wide and 3,500 feet long. When the varying current speeds and directions are considered throughout the 3,000-foot diameter drop zone, the resulting disposal site has a diameter of 6,000 feet. The preferred site lies at the center of the ZSF. The alternative site lies to the east and the the disposal site perimeter overlaps with that of the preferred site.

Current measurements in or near this site indicate that currents are well above the threshold speed. Natural resource investigations on and around the ZSF showed only low abundances of shrimp and scallops and other marine invertebrates during two seasons (spring and fall). No Dungeness crab were found.

10.2.5 Port Townsend--

Both sites in Port Townsend extend slightly outside of the original ZSF boundaries. However, it should be remembered that the selection factors and constraints used to identify the ZSFs, were not considered or applied as inviolate standards. This was because they were being used with existing and available information. As checking studies and site specific studies gathered new information about the ZSFs, adjustments to the boundaries, and later to site locations, were made as necessary.

Both sites lie at a depth of 361 feet. The preferred site is in an area that is on the average less energetic than the alternative site. However, shrimp and scallop densities are lower or nonexistent at the preferred site.

Because of the depth and currents in the area the disposal site pattern for one barge dump is expected to be 3,000 feet wide and 3,500 feet long. To ensure that each dump falls within the same area the final disposal site has a diameter of 7,000 feet with a 3,000-foot disposal zone at the center.

10.2.6 Port Angeles--

The preferred disposal site lies at a depth of about 435 feet and the alternative site at 445 feet. Because of the depth and currents in the area the disposal site pattern for one barge dump is expected to be 3,000 feet wide and 3,500 feet long. To ensure that each dump falls within the same area the final disposal site has a diameter of 7,000 feet with a 3,000-foot disposal zone at the center. Because of high densities of scallops and seasonally abundant pandalid shrimp resources, it is recognized that site management may require specialized disposal including seasonal restrictions to minimize resource conflicts as much as practicable.

10.3 Site Capacity

The size of the disposal site is not affected significantly by the material deposited from any single barge load of material. However, it is governed by the cumulative effect of many disposals at nondispersive sites and the disposal depth and current speed and direction at dispersive sites. Disposal model data indicate that the vast majority of the material from each disposal will be deposited in an area measuring approximately 1,000 feet in diameter (about 20 acres) for nondispersive sites and 3,000 feet in diameter for dispersive sites. The overall size of the disposal site is governed by the amount of material being deposited, sediment bulking factors, material characteristics that govern stable side slopes of the disposal mound, effects of bottom slopes, and settlement characteristics. Water depth affects only the initial area of deposition from an individual dump. This area would increase with an increase in water depth for dispersive site.

Investigations of existing disposal sites and an evaluation of the dredged material sediment characteristics indicated that mound side slopes of approximately 1:30 were likely (refer to "Technical Supplement to Evaluation of Dredged Material Disposal Alternatives U.S. Navy Homeport at Everett, Washington").

PSDDA estimates of site capacity for nondispersive sites assume that the shape can be approximated by a truncated cone with a base diameter of 4,000 feet and a diameter at the top of the cone equal to 2,000 feet. A truncated cone with this geometry has a volume equal to approximately nine million cubic yards. It was assumed that bulking effects which take place during dredging and disposal operations will be offset by the long term consolidation of the disposal mound. This assumption equates to a one-to-one ratio of dredged material volume to site capacity volume. Therefore the capacity of a site

with a 2,000-foot radius is estimated to be approximately nine million cubic yards. Since all of the Phase II sites have a minimum diameter of approximately 4,000 feet, each site can accommodate at least nine million cubic yards within the designated site boundaries. This volume is larger than the volume projected for all sites combined for 1985-2000.

10.4 Overlays of the Recommended Disposal Sites with Hydraulic, Sediment, and Biological Characteristics

To complete the description, the disposal sites were overlayed on maps presented earlier describing the ZSFs hydraulic, sediment, and biological characteristics.

10.4.1 Anderson/Ketron Island--

Field data collected near the center of the preferred disposal site showed that the peak (1%) speed near the bottom lay above the threshold for the movement of newly deposited material (25.5-35.4 cm/s). Maps of sediment characteristic show that the site is located in an area of high clay content (relative to other south Sound areas at comparable depths studied by depositional analyses) and where the 95% confidence limits are exceeded for biological oxygen demand and water content (Fig. II.10-1). The site also contains the finest sediment in the ZSF. These characteristics are indicative of a depositional area. With respect to biological resources, the site is located in an area where no crab were found and the population of shrimp has not exceeded 250 shrimp per hectare (Figs. II.10-2 and II.10-3). The fish resources for this site showed fewer numbers of fish and larger in size compared to the Devils Head ZSF.

For the approximately 1% of the dredged material that remains suspended for some time in the water column the prevailing currents indicate that this sediment will be transported northward or southward (Fig. II.10-4).

10.4.2 Anderson Island/Devils Head--

Available records of the current strength near the alternative disposal site indicate stronger tidal currents than the preferred site. The 1% fastest speeds were estimated at 39.7-48.8 centimeters per second (rms speeds of 15.3-19.1 cm/s). These results suggest that the alternative site is sufficiently energetic that dredged material could be eroded.

The disposal site area of the ZSF has lower volatile solids, biological oxygen demand, and percent water than in the remainder of the ZSF (Fig. II.10-5). However, it contains the finest sediments and highest percent clay of the entire ZSF.

No crab were found within the disposal site during the four cruises (Fig. II.10-2). Highest abundance of shrimp observed was <150 per hectare in February (Fig. II.10-3). These quantities indicate that crab and shrimp are not found in commercial quantities within the proposed disposal site.

The prevailing currents, as indicated by net current speed and direction, are directed toward the northwest near the bottom in the recommended disposal site (Fig. II.10-6). Because of the low animal populations, the suspended sediment carried by the prevailing currents is expected to have minimal impact on the biological resources (Figs. II.10-2 and II.10-3)..

10.4.3 Bellingham Bay--

There are no direct current measurements in the vicinity of the disposal sites. For these reasons the choice of a disposal site location was guided primarily by the depositional analysis results, the patterns of sediment characteristics, and natural resources.

The preferred disposal site lies in an area where the sediment properties are anomalous, suggesting that here the sediments tend to deposit rather than erode. In this area the percentage clay is elevated above 18%, the water content exceeds 50%, the volatile solids exceed 8%, and the biochemical oxygen demand exceeds 2000, and all exceed the 95% confidence limits (Fig. II.10-7). The small grain size also suggests that the area is very depositional. With respect to biological resources no stations were sampled for crab and shrimp near this disposal site, and stations near the site boundaries were used to estimate resource abundances below WDF criteria of 100 crab/ha; whereas average shrimp abundances were estimated at 690 shrimp/ha. This site was chosen as the preferred site because of 1) an established trawl fishery near alternative site 1, and 2) higher abundances of Dungeness crab at alternative site 2, and recommendations by WDF (Blum, 1988) to move site midway between alternative sites A-1 and A-2 to minimize concerns for 1 and 2 above.

10.5 Conclusions

In conclusion, the two preferred nondispersive disposal sites located in south Sound (i.e., Anderson Island/Ketron Island) and north Sound (i.e., Bellingham Bay) are judged to lie in depositional areas because: 1) the sediment characteristics show fine grained material and statistically elevated water content, biochemical oxygen demand, and volatile solids, and 2) the quantities of crab and shrimp are generally low. The maximum densities of crab and shrimp observed thus far in PSDDA are estimated at 496 crab per hectare (in Port Gardner; September, 1986) and 68,927 shrimp per hectare (in Port Angeles outside the disposal zones; October, 1987). In contrast, 0 crab and 51-150 shrimp per hectare were found in the south Sound preferred disposal site. Corresponding average resource estimates for the Bellingham Bay preferred site are 21 crabs/ha and 690 shrimp/ha. The number of crab for each site lie well below the 100 per hectare threshold below which the crab populations are considered minimal. These data suggest that there are small populations of crab and small to moderate populations of shrimp in the proposed disposal sites.

TABLE II.10-1 INFORMATION ON THE PREFERRED AND ALTERNATIVE DISPOSAL SITES.

	Latitude	Longitude	Area (acre)	Depth (ft)	Dimensions (ft)
Anderson/Ketron Island					
Preferred	47° 09.43'	122° 39.40'	318	442	4400 x 3600
Anderson Island/Devils Head					
Alternate	47° 09.06'	122° 45.61'	318	238	4200 x 4200
Bellingham Bay					
Preferred	48° 42.83'	122° 33.03'	260	96	3800 x 3800
Alternate 1	48° 41.83'	122° 33.60'	260	98	3800 x 3800
Alternate 2	48° 43.82'	122° 32.50'	260	95	3800 x 3800
Rosario Strait					
Preferred	48° 30.88'	122° 43.48'	650	230	6000 x 6000
Alternate	48° 30.70'	122° 42.73'	650	230	6000 x 6000
Port Townsend					
Preferred	48° 13.62'	122° 58.95'	884	361	7000 x 7000
Alternate	48° 15.28'	122° 55.60'	884	361	7000 x 7000
Port Angeles					
Preferred	48° 11.68'	123° 24.86'	884	435	7000 x 7000
Alternate	48° 13.20'	123° 25.65'	884	435	7000 x 7000

TABLE II.10-2 COMPARISON OF SITE SELECTION FACTORS FOR PREFERRED AND ALTERNATE DISPOSAL SITES.

	STATISTICALLY ELEVATED					CURRENTS				
	VOLATILE SOLIDS	BIOCHEMICAL OXYGEN DEMAND	WATER CONTENT	GRAIN SIZE	PERCENT CLAY	MEAN SPEED (cm/s)	1% FASTEST SPEED (cm/s)	CRAB* (#/Hectare)		SHRIMP* (#/Hectare)
Anderson/Ketron Island										
Preferred	No	Yes	Yes	Coarse Silt	10-12%	15	26-35	0		30
Anderson Island/Devils Head										
Alternate	No	Yes	No	Coarse Silt	10-20%	21	40-49	0		50
Bellingham Bay										
Preferred	Yes	Yes	Yes	Medium Silt	16%	-	-	21**		690**
Alternate 1	Yes	Yes	Yes	Medium Silt	18%	-	-	17		723
Rosario Strait										
Preferred	-	-	-	-	-	51	100	0	0	0
Alternate	-	-	-	-	-	51	100	0	0	>50
Port Townsend										
Preferred	-	-	-	-	-	30	50-100	0	0	0
	-	-	-	-	-	50	50-100	0	0	>2500
Port Angeles										
Preferred	-	-	-	-	-	30[a]	65-125	0	0	>2500
Alternate	-	-	-	-	-	35[a]	65-125	0	0	>2500

* These numbers are the highest average beam trawl catches within and surrounding the site for all sample periods.
a These numbers are from model results.
** The resource abundances reflect average beam trawl catches at closest stations surrounding the site.
no data are available for resources within the site boundary.

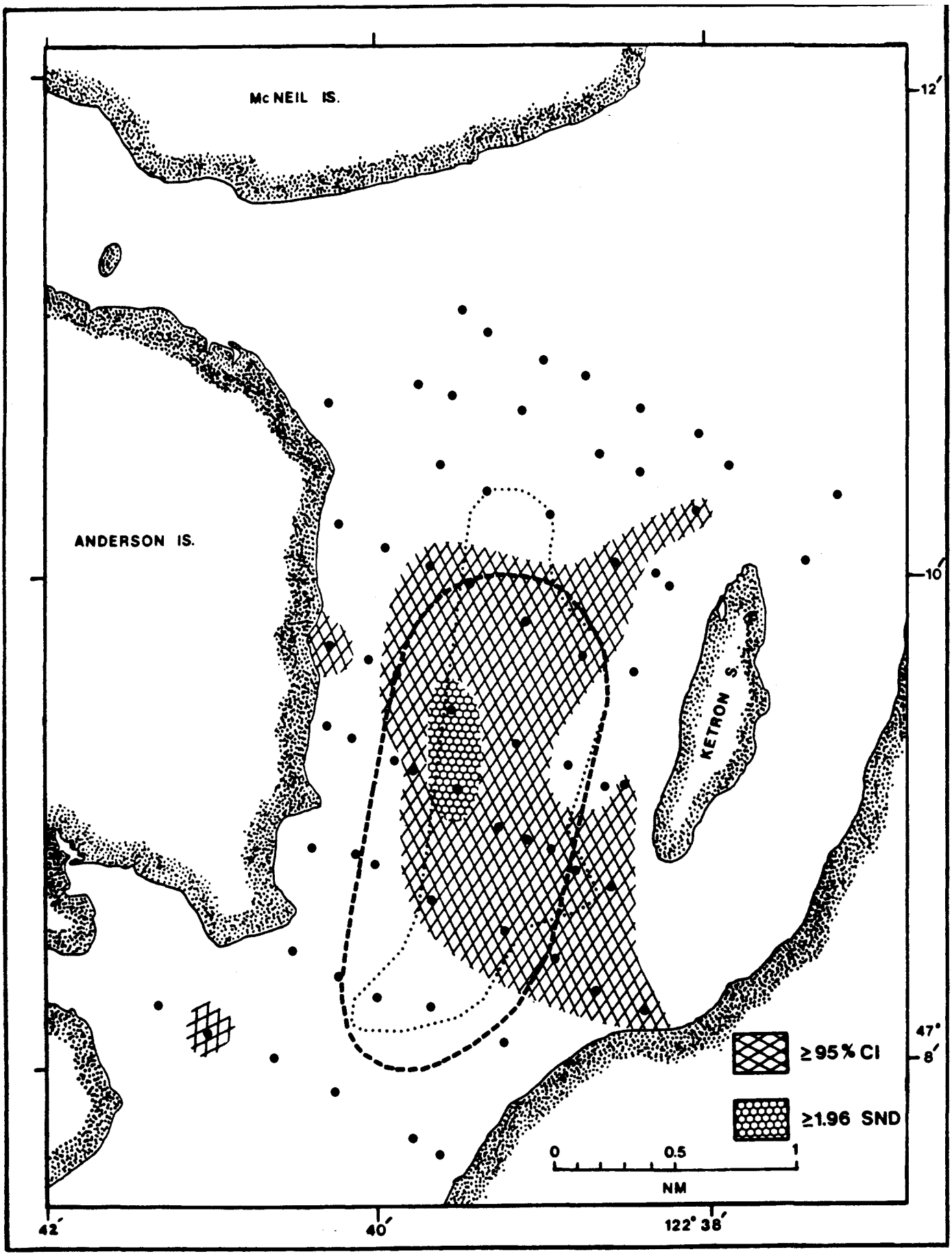


Figure II.10-1 Areas where at least one parameter (biochemical oxygen demand, volatile solids, or percent water) exceeded the 95% confidence interval or the 1.96 standard normal deviate for Anderson/ Ketron Island ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

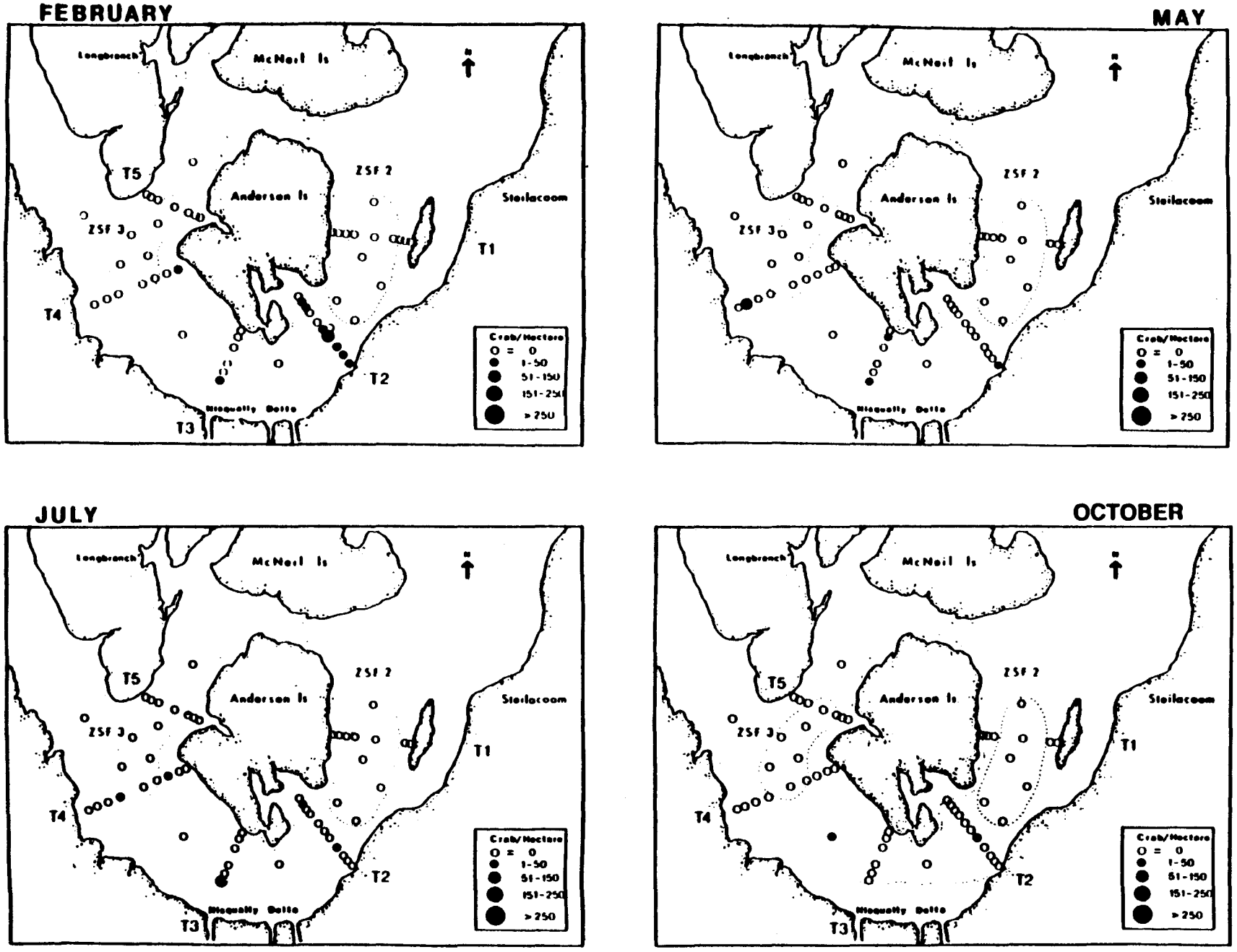


Figure II.10-2 Maps of Nisqually region showing the densities of Dungeness crab as estimated from beam trawl catches in February, May, July, and October 1987.

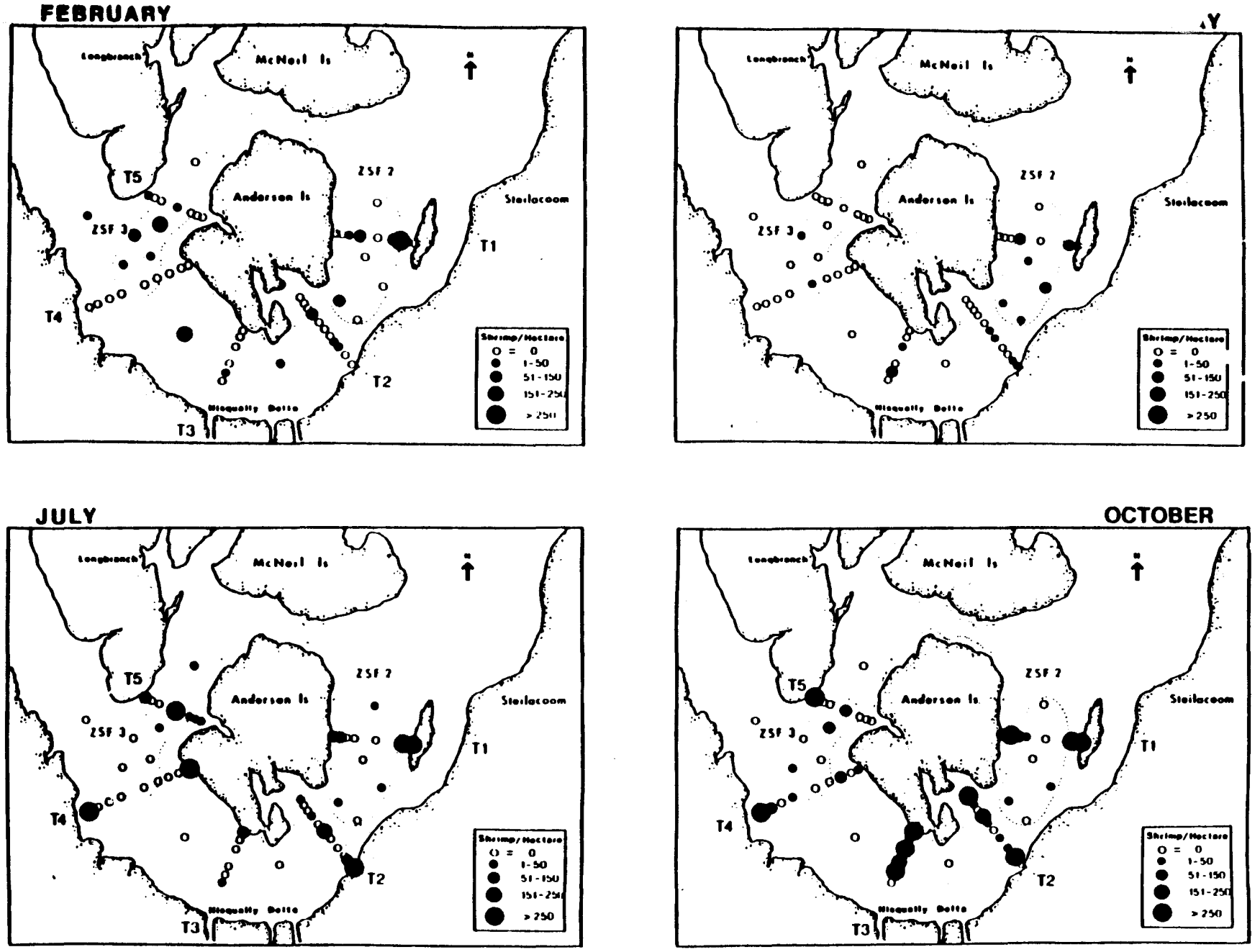


Figure II.10-3 Maps of Nisqually region showing the densities of commercial pandalid shrimp as estimated from beam trawl catches in February, May, July, and October 1987.

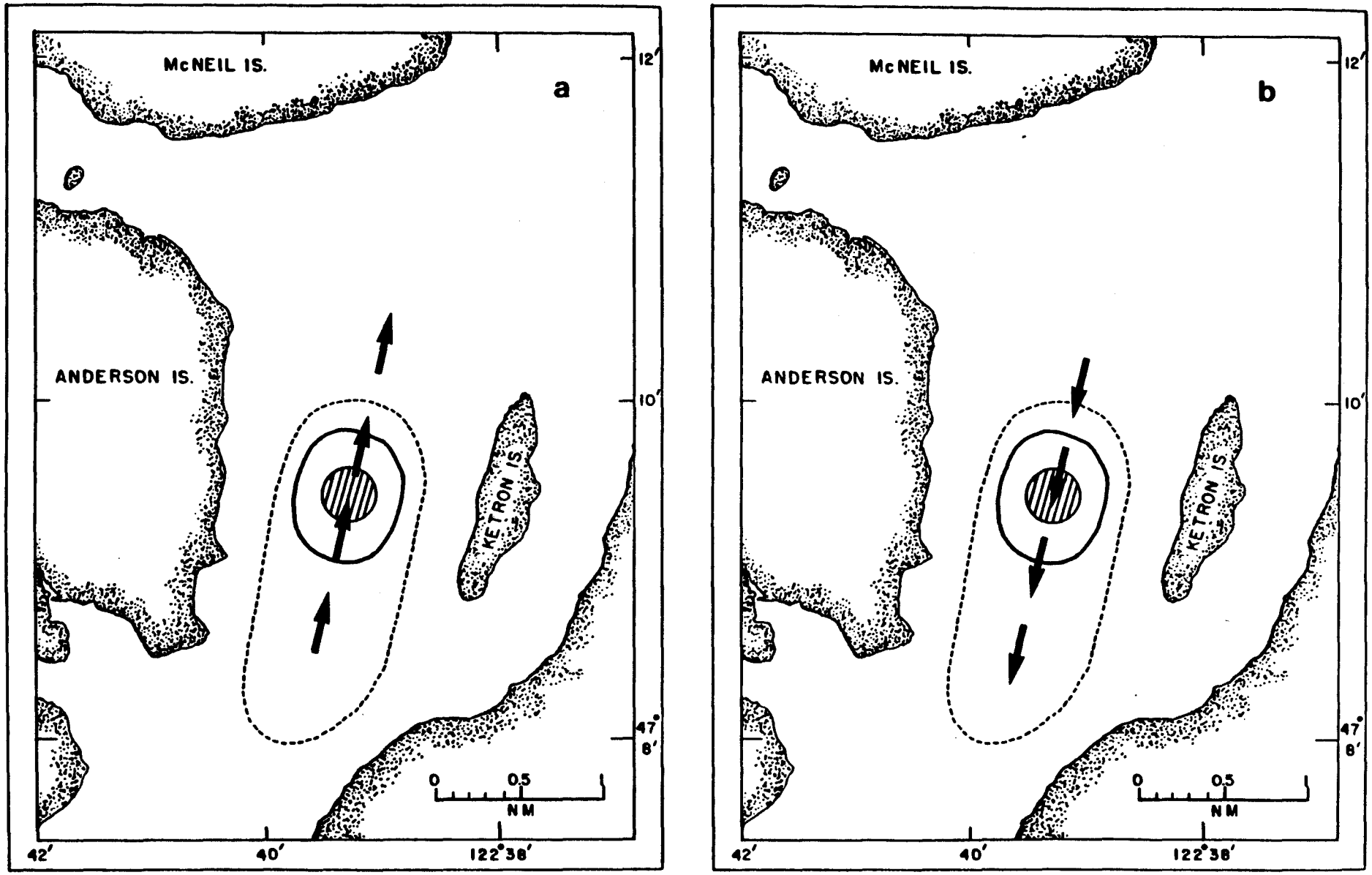


Figure II.10-4 Estimated net flow in the depth range of 0-35 m (a) and 35 m to bottom (b) for the Anderson/Ketron Island ZSF.

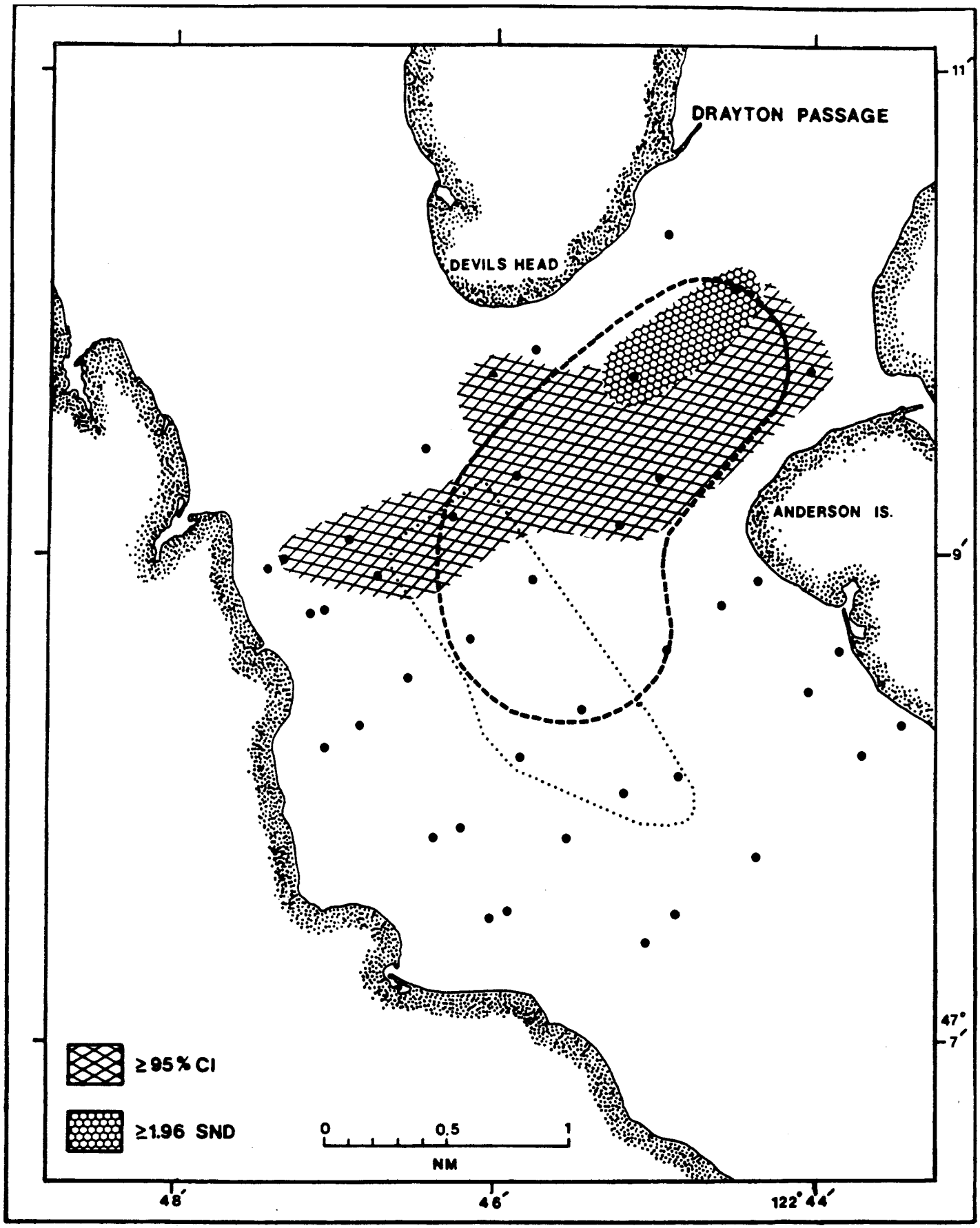


Figure II.10-5 Areas where at least one parameter (biochemical oxygen demand, volatile solids, or percent water) exceeded the 95% confidence interval or the 1.96 standard normal deviate for Anderson Island/Devils Head ZSF. Dotted line represents preliminary ZSF boundary. Dashed line indicates revised boundary based on deposition analysis results.

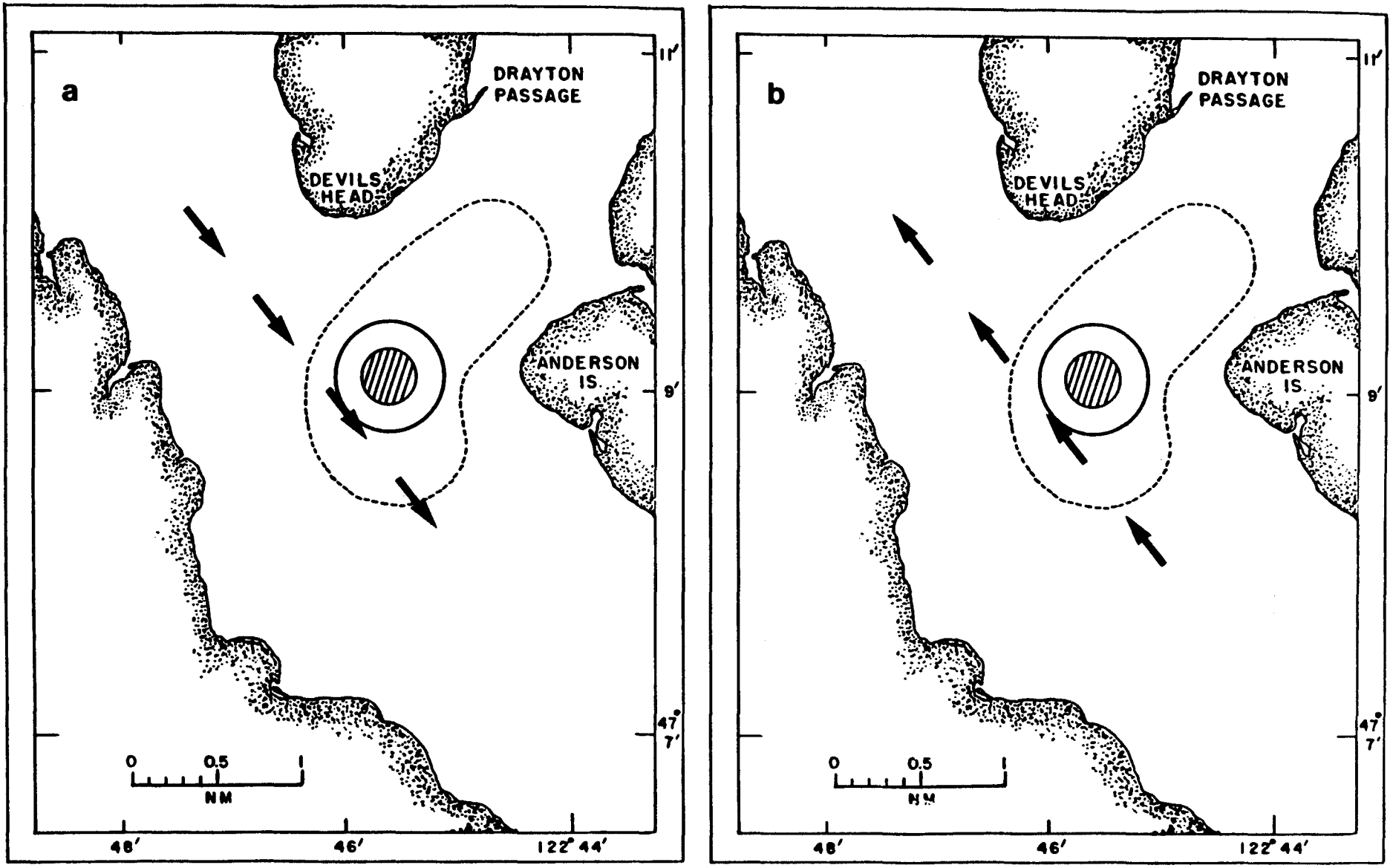


Figure II.10-6 Estimated net flow in the depth range of 0-35 m (a) and 35 m to bottom (b) for the Anderson Island/Devils Head ZSF.

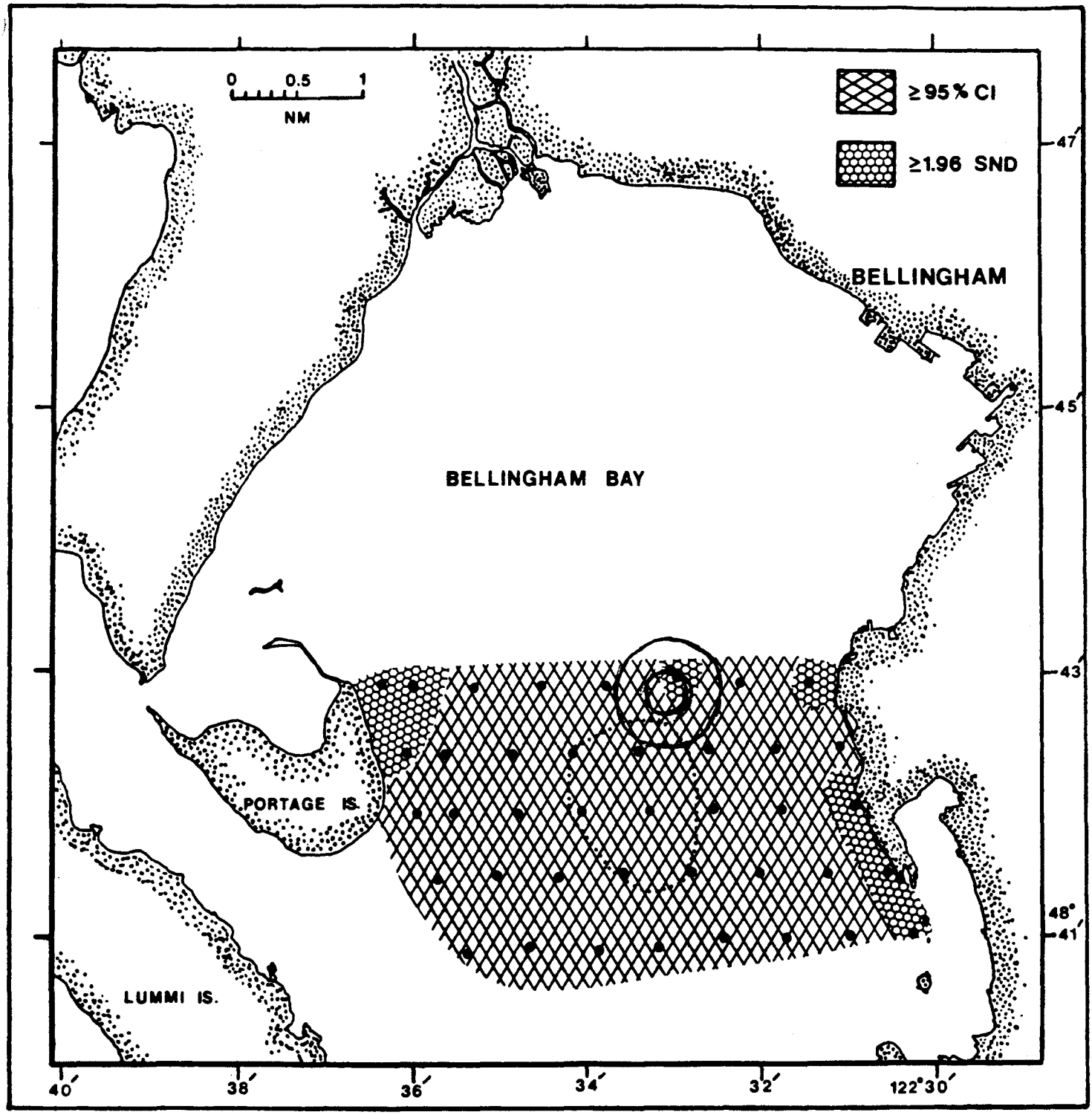


Figure II.10-7 Areas where at least one parameter (biochemical oxygen demand, volatile solids, or percent water) exceeded the 95% confidence interval or the 1.96 standard normal deviate for Bellingham Bay. Dotted line represents preliminary ZSF boundary. The preferred site outline is also shown.

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PUGET SOUND DREDGED DISPOSAL ANALYSIS (PSDDA)
GLOSSARY OF TERMS

Amphipods. Small, shrimp-like crustaceans (for example, sand fleas). Many live on the bottom, feed on algae and detritus, and serve as food for many marine species. Amphipods are used in laboratory bioassays to test the toxicity of sediments.

Apparent Effects Threshold. The sediment concentration of a contaminant above which statistically significant biological effects would always be expected.

Area Ranking. The designation of a dredging area relative to its potential for having sediment chemicals of concern. Rankings range from "low" potential to "high" potential, and are used to determine the intensity of dredged material evaluation and testing that might be required.

Baseline Study. A study designed to document existing environmental conditions at a given site. The results of a baseline study may be used to document temporal changes at a site or document background conditions for comparison with another site.

Bathymetry. Shape of the bottom of Puget Sound expressed as the spatial pattern of water depths. Bathymetric maps are essentially topographic maps of the bottom of Puget Sound.

Benthic Organisms. Organisms that live in or on the bottom of a body of water.

Bioaccumulation. The accumulation of contaminants in the tissues of an organism. For example, certain chemicals in food eaten by a fish tend to accumulate in its liver and other tissues.

Bioassay. A laboratory test used to evaluate the toxicity of a material (commonly sediments or wastewater) by measuring behavioral, physiological, or lethal responses of organisms.

Biota. The animals and plants that live in a particular area or habitat.

Bottom-Dump Barge. A barge that disposes of dredged material by opening along a center seam.

Bottomfish. Fish that live on or near the bottom of a body of water, for example, English sole.

Bulk Chemical Analyses. Chemical analyses performed on an entire sediment sample, without separating water from the solid material in a sample.

Capping. See confined aquatic disposal.

Carcinogenic. Capable of causing cancer.

Clamshell Dredging. Scooping of the bottom sediments using a mechanical clamshell bucket of varying size. Commonly used in fine grain sediments and calm water, the sediment is dumped onto a separate barge and towed to a disposal site when disposing in open water.

Code of Federal Regulations. The compilation of Federal regulations adopted by Federal agencies through a rule-making process.

Compositing. Mixing sediments from different samples to produce a composite sample for chemical and/or biological testing.

Confined Disposal. A disposal method that isolates the dredged material from the environment. Confined disposal may be in aquatic, nearshore, or upland environments.

Confined Aquatic Disposal (CAD). Confined disposal in a water environment. Usually accomplished by placing a layer of sediment over material that has been placed on the bottom of a water body (i.e., capping).

Contaminant. A chemical or biological substance in a form or in a quantity that can harm aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment.

Contaminated Sediment.

Technical Definition: A sediment that contains measurable levels of contaminants.

Management or Common Definition: A sediment that contains sufficient quantities of contaminants to result in adverse environmental effects and thus require restriction(s) for dredging and/or disposal of dredged material (e.g., is unacceptable for unconfined, open water disposal or conventional land/shore disposal, requiring confinement).

Conventional Nearshore Disposal. Disposal at a site where dredged material is placed behind a dike in water along the shoreline, with the final elevation of the fill being above water. "Conventional" disposal additionally means that special contaminant controls or restrictions are not needed.

Conventional Pollutants. Sediment parameters and characteristics that have been routinely measured in assessing sediment quality. These include sulfides, organic carbon, etc.

Conventional Upland Disposal. Disposal at a site created on land (away from tidal waters) in which the dredged material eventually dries. Upland sites are usually diked to confine solids and to allow surface water from the disposal operation to be released. "Conventional" disposal additionally means that special contaminant controls or restrictions are not needed.

Depositional Analysis. A scientific inspection of the bottom sediments that identifies where natural sediments tend to accumulate.

Depositional Area. An underwater region of Puget Sound where material sediments tend to accumulate.

Disposal. See confined disposal, conventional nearshore disposal, conventional upland disposal, and unconfined, open-water disposal.

Disposal Site. The bottom area that receives discharged dredged material; encompassing, and larger than, the target area and the disposal zone.

Disposal Site Work Group. The PSDDA work group that is designating locations for open-water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible.

Disposal Zone. The area that is within the disposal site that designates where surface release of dredged material will occur. It encompasses the smaller target area. (See also "target area" and "disposal site".)

Dredged Material. Sediments excavated from the bottom of a waterway or water body.

Dredged Material Management Unit. The maximum volume of dredged material for which a decision on suitability for unconfined open-water disposal can be made. Management units are typically represented by a single set of chemical and biological test information obtained from a composite sample. Management units are smaller in areas of higher chemical contamination concern (see "area ranking").

Dredger. A private or public agency conducting dredging (ports, Corps of Engineers, etc.). (Compare to "local sponsor".)

Dredging. Any physical digging into the bottom of a water body. Dredging can be done with mechanical or hydraulic machines and is performed in many parts of Puget Sound for the maintenance of navigation channels that would otherwise fill with sediment and block ship passage.

Disposal Site Work Group. The PSDDA work group that is designating locations for open-water unconfined dredged material disposal sites that are environmentally acceptable and economically feasible.

Ecosystem. A group of completely interrelated living organisms that interact with one another and with their physical environment. Examples of ecosystems are a rain forest, pond, and estuary. An ecosystem, such as Puget Sound, can be thought of as a single complex system. Damage to any part may affect the whole. A system such as Puget Sound can also be thought of as the sum of many interconnected ecosystems such as the rivers, wetlands, and bays. Ecosystem is thus a concept applied to various scales of living communities and signifying the interrelationships that must be considered.

Effluent. Effluent is the water flowing out of a contained disposal facility. To distinguish from "runoff" (see below) due to rainfall, effluent usually refers to water discharged during the disposal operation.

Elutriate. The extract resulting from mixing water and dredged material in a laboratory test. The resulting elutriate can be used for chemical and biological testing to assess potential water column effects of dredged material disposal.

Entrainment. The addition of water to dredged material during disposal, as it descends through the water column.

Environmental Impact Statement. A document that discusses the likely significant environmental impacts of a proposed project, ways to lessen the impacts, and alternatives to the proposed project. EIS's are required by the National and State Environmental Policy Acts.

Erosion. Wearing away of rock or soil via gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical and chemical forces.

Estuary. A confined coastal water body where ocean water is diluted by inflowing fresh water, and tidal mixing occurs.

Evaluation Procedures Work Group. The PSDDA work group that is developing chemical and biological testing and test evaluation procedures for dredged material assessment.

Gravid. Having eggs, such as female crabs carrying eggs.

Ground Water. Underground water body, also called an aquifer. Aquifers are created by rain which soaks into the ground and flows down until it collects at a point where the ground is not permeable.

Habitat. The specific area or environment in which a particular type of plant or animal lives. An organism's habitat provides all of the basic requirements for life. Typical Puget Sound habitats include beaches, marshes, rocky shores, bottom sediments, mudflats, and the water itself.

Hazardous Waste. Any solid, liquid, or gaseous substance which, because of its source or measurable characteristics, is classified under state or Federal law as hazardous, and is subject to special handling, shipping, storage, and disposal requirements. Washington State law identifies two categories of hazardous waste: dangerous and extremely hazardous. The latter category is more hazardous and requires greater precautions.

Hopper Dredge. A hydraulic suction dredge that is used to pick up coarser grain sediments (such as sand), particularly in less protected areas with sea swell. Dredged materials are deposited in a large holding tank or "hopper" on the same vessel, and then transported to a disposal site. The hopper dredge is rarely used in Puget Sound.

Hydraulic Dredging. Dredging accomplished by the erosive force of a water suction and slurry process, requiring a pump to move the water-suspended sediments. Pipeline and hopper dredges are hydraulic dredges.

Hydraulics Project Approval. RCW 75.20.100 Approval from the Washington Department of Fisheries and Washington Department of Game for the use, diversion, obstruction or change in the natural flow or bed of any river or stream, or that will use any salt or fresh waters of the state.

Hydraulically Dredged Material. Material, usually sand or coarser grain, that is brought up by a pipeline or hopper dredge. This material usually includes slurry water.

Hydrocarbon. An organic compound composed of carbon and hydrogen. Petroleum and its derived compounds are hydrocarbons.

Infauna. Animals living in the sediment.

Intertidal Area. The area between high and low tide levels. The alternate wetting and drying of this area makes it a transition between land and water organisms and creates special environmental conditions.

Leachate. Water or other liquid that may have dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. Rainwater that percolates through a sanitary landfill and picks up contaminants is called the leachate from the landfill.

Local Sponsor. A public entity (e.g., port district) that sponsors Federal navigation projects. The sponsor seeks to acquire or hold permits and approvals for disposal of dredged material at a disposal site.

Loran C. An electronic system to facilitate navigation positioning and course plotting/tracking.

Management Plan Work Group. The PSDDA work group is developing a management plan for each of the open-water dredged material disposal sites. The plan will define the roles of local, State, and Federal agencies. Issues being addressed include: permit reviews, monitoring of permit compliance, treatment of permit violations, monitoring of environmental impacts, responding to unforeseen effects of disposal, plan updating, and data management.

Material Release Screen. A laboratory test proposed by PSDDA to assess the potential for loss of fine-grained particles carrying chemicals of concern from the disposal site during disposal operations.

Mechanical Dredging. Dredging by digging or scraping to collect dredged materials. A clamshell dredge is a mechanical dredge. (See "hydraulic dredging.")

Metals. Metals are naturally occurring elements. Certain metals, such as mercury, lead, nickel, zinc, and cadmium, can be of environmental concern when they are released to the environment in unnatural amounts by man's activities.

Microlayer, Sea Surface Microlayer. The extremely thin top layer of water that can contain high concentrations of natural and other organic substances. Contaminants such as oil and grease, many lipophylic (fat or oil associated) toxicants, and pathogens may be present at much higher concentrations in the microlayer than they are in the water column. Also the microlayer is biologically important as a rearing area for marine organisms.

Microtox. A laboratory test using luminescent bacteria and measuring light production, used to assess toxicity of sediment extracts.

Molt. A complex series of events that results in the periodic shedding of the skeleton, or carapace by crustaceans (all arthropods for that matter). Molting is the only time that many crustaceans can grow and mate (particularly crabs).

Monitor. To systematically and repeatedly measure something in order to detect changes or trends.

Nutrients. Essential chemicals needed by plants or animals for growth. Excessive amounts of nutrients can lead to accelerated growth of algae and subsequent degradation of water quality due to oxygen depletion. Some nutrients can be toxic at high concentrations.

Overdepth Material. Dredged material removed from below the dredging depth needed for safe navigation. Although overdepth is incidentally removed due to dredging equipment precision, its excavation is usually planned as part of the dredging project to ensure proper final water depths. Common overdepth is 2 feet below the needed dredging line.

Oxygen Demanding Materials. Materials such as food waste and dead plant or animal tissue that use up dissolved oxygen in the water when they are degraded through chemical or biological processes. Chemical and biological oxygen demand (COD and BOD, respectively) are different measures of how much oxygen demand a substance has.

Parameter. A quantifiable or measurable characteristic of something. For example, height, weight, sex, and hair color are all parameters that can be determined for humans. Water quality parameters include temperature, pH, salinity, dissolved oxygen concentration, and many others.

Pathogen. A disease-causing agent, especially a virus, bacteria, or fungi. Pathogens can be present in municipal, industrial, and nonpoint source discharges to the Sound.

Permit. A written warrant or license, granted by an authority, allowing a particular activity to take place. Permits required for dredging and disposal of dredged material include the U.S. Army Corps of Engineers Section 404 permit, the Washington State Department of Fisheries Hydraulics Permit, the city or county Shoreline Development Permit, and the Washington Department of Natural Resources Site Use Disposal Permit.

Persistent. Compounds that are not readily degraded by natural physical, chemical, or biological processes.

Pesticide. A general term used to describe any substance, usually chemical, used to destroy or control organisms (pests). Pesticides include herbicides, insecticides, algicides, and fungicides. Many of these substances are manufactured and are not naturally found in the environment. Others, such as pyrethrum, are natural toxins which are extracted from plants and animals.

pH. The degree of alkalinity or acidity of a solution. Water has a pH of 7.0. A pH of less than 7.0 indicates an acidic solution, and a pH greater than 7.0 indicates a basic solution. The pH of water influences many of the types of chemical reactions that occur in it. Puget Sound waters, like most marine waters, are typically pH neutral.

Phase I. The PSDDA study is divided into two, 2-year long, overlapping phases. Phase I covers the central area of Puget Sound including Seattle, Everett, and Tacoma. Phase I began in April 1985.

Phase II. The PSDDA study is divided into two, 2-year long, overlapping phases. Phase II covers the North and South Sound (including Olympia, Bellingham, and Port Angeles) - the areas not covered by Phase I. Hood Canal is not being considered for location of a disposal site. Phase II began in April 1986.

Pipeline Dredge. A hydraulic dredge that transports slurried dredged material by pumping it via a pipe. (See "hydraulic dredge".)

Point Source. Locations where pollution comes out of a pipe into Puget Sound.

Polychaete. A marine worm.

Polychlorinated Biphenyls. A group of manmade organic chemicals, including about 70 different but closely related compounds made up of carbon, hydrogen, and chlorine. If released to the environment, they persist for long periods of time and can concentrate in food chains. PCB's are not water soluble and are suspected to cause cancer in humans. PCB's are an example of an organic toxicant.

Polycyclic (Polynuclear) Aromatic Hydrocarbon. A class of complex organic compounds, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAH's are commonly formed by forest fires and by the combustion of fossil fuels. PAH's often reach the environment through atmospheric fallout, highway runoff, and oil discharge.

Priority Pollutants. Substances listed by EPA under the Clean Water Act as toxic and having priority for regulatory controls. The list includes toxic metals, inorganic contaminants such as cyanide and arsenic, and a broad range of both natural and artificial organic compounds. The list of priority pollutants includes substances that are not of concern in Puget Sound, and also does not include all known harmful compounds.

Puget Sound Water Quality Authority. An agency created by the Washington State legislature in 1985 and tasked with developing a comprehensive plan to protect and enhance the water quality of Puget Sound. The Authority adopted its first plan in January 1987.

Range Markers. Pairs of markers which, when aligned, provide a known bearing to a boat operator. Two pairs of range markers can be used to fix position at a point.

Regional Administrative Decisions. A term used in PSDDA to describe decisions that are a mixture of scientific knowledge and administrative judgment. These region-wide policies are collectively made by all regulatory agencies with authority over dredged material disposal to obtain Sound-wide consistency.

Regulatory Agencies. Federal and State agencies that regulate dredging and dredged material disposal in Puget Sound, along with pertinent laws/permits, include:

U.S. Army Corps of Engineers

- River and Harbor Act of 1899 (Section 10 permits)
- Clean Water Act (Section 404 permits)

U.S. Environmental Protection Agency

- Clean Water Act (Section 404 permits)

Washington Department of Natural Resources

- Shoreline Management Act (site use permits)

Washington Department of Ecology

- Clean Water Act (Section 401 certifications)
- Shoreline Management Act (CZMA consistency determinations)

Washington Department of Fisheries

- Hydraulics Project Approval

Washington Department of Game

- Hydraulics Project Approval

Local shoreline jurisdiction e.g., City of Seattle, City of Everett, Pierce County

- Shoreline permit to non-Federal dredger/DNR

U.S. Fish and Wildlife Service (Key reviewing agency)

National Marine Fisheries Service (Key reviewing agency)

The Resource Conservation and Recovery Act. The Federal law that regulates solid and hazardous waste.

Respiration. The metabolic processes by which an organism takes in and uses oxygen and releases carbon dioxide and other waste products.

Revised Code of Washington. The compilation of the laws of the State of Washington published by the Statute Law Committee.

Runoff. Runoff is the liquid fraction of dredged materials or the flow/seepage caused by precipitation landing on and filtering through upland or nearshore dredged material disposal sites.

Salmonid. A fish of the family Salmoniidae. Fish in this family include salmon and trout. Many Puget Sound salmonids are anadromous, spending part of their life cycles in fresh water and part in marine waters.

Sediment. Material suspended in or settling to the bottom of a liquid, such as the sand and mud that make up much of the shorelines and bottom of Puget Sound. Sediment input to Puget Sound comes from natural sources, such as erosion of soils and weathering of rock, or anthropogenic sources, such as forest or agricultural practices or construction activities. Certain contaminants tend to collect on and adhere to sediment particlès. The sediments of some areas around Puget Sound contain elevated levels of contaminants.

Spot Checking. Inspections on a random basis to verify compliance with permit requirements.

State Environmental Policy Act. A State law intended to minimize environmental damage. SEPA requires that State agencies and local governments consider environmental factors when making decisions on activities, such as development proposals over a certain size. As part of this process, environmental documents such as EIS's are prepared and opportunities for public comment are provided.

Statistically Significant. A quantitative determination of the statistical degree to which two measurements of the same parameter can be shown to be different, given the variability of the measurements.

Subtidal. Refers to the marine environment below low tide.

Suspended Solids. Organic or inorganic particles that are suspended in water. The term includes sand, mud, and clay particles as well as other solids suspended in the water column.

Target Area. The specified area on the surface of Puget Sound for the disposal of dredged material. The target area is within the disposal zone and within the disposal site.

Toxic. Poisonous, carcinogenic, or otherwise directly harmful to life.

Toxic Substances and Toxicants. Chemical substances, such as pesticides, plastics, detergents, chlorine, and industrial wastes that are poisonous, carcinogenic, or otherwise harmful to life if found in sufficient concentrations.

Treatment. Chemical, biological, or mechanical procedures applied to an industrial or municipal discharge or to other sources of contamination to remove, reduce, or neutralize contaminants.

Turbidity. A measure of the amount of material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. Very high levels of turbidity can be harmful to aquatic life.

Unconfined, Open-Water Disposal. Discharge of dredged material into an aquatic environment, usually by discharge at the surface, without restrictions or confinement of the material once it is released.

Variable Range Radar. Radar equipped with markers which allow measurement of bearings and distances to known targets.

Vessel Traffic Service (VTS). A network of radar coverage for ports of Puget Sound operated by the Coast Guard to control ship traffic. Most commercial vessels are required to check in, comply with VTS rules, and report any change in movement.

Volatile Solids. The material in a sediment sample that evaporates at a given high temperature.

Washington Administrative Code. Contains all State regulations adopted by State agencies through a rule-making process. For example, Chapter 173-201 WAC contains water quality standards.

Water Quality Certification. Approval given by Washington State Department of Ecology which acknowledges the compliance of a discharge with Section 401 of the Clean Water Act.

Waterways Experiment Station (WES). Corps of Engineers (Corps) research facility located in Vicksburg, Mississippi, that performs research and support projects for the various Corps districts.

Wetlands. Habitats where the influence of surface or ground water has resulted in development of plant or animal communities adapted to such aquatic or intermittently wet conditions. Wetlands include tidal flats, shallow subtidal areas, swamps, marshes, wet meadows, bogs, and similar areas.

Zoning. To designate, by ordinances, areas of land reserved and regulated for specific land uses.

ABBREVIATIONS

Battelle	Battelle Memorial Institute
BOD	Biochemical Oxygen Demand
BOD_5	Five-day Biological Oxygen Demand
BRAT	Benthic Resources Assessment Technique
^oC	degrees Celcius
cc	cubic centimeter
CI	Confidence Interval
CL	carapace length
cm	centimeters
cm/s	centimeters per second
COE	U.S. Army Corps of Engineers
Cooper	Cooper Consultants Inc.
Corps	U.S. Army Corps of Engineers
CPUE	catch per unit effort
cu	cubic
CW	carapace width
CWA	The Federal Clean Water Act, previously known as the Federal Pollution Control Act
cy	cubic yard
DA	Deposisional Analysis
DCLU	Department of Construction and Land Use
DIFID	Disposal From an Instantaneous
DMRP	Dredged Material Research Program
DNR	Washington Department of Natural Resources
DOT	Department of Transportation
DSHS	Department of Social and Health Services
DSSTA	Disposal Site Selection Technical Appendix
DSWG	Disposal Site Work Group
Ecology	Washington Department of Ecology
EHI	Evans-Hamilton, Inc.
EIS	Environmental Impact Statement
ENVIROSPHERE	Envirosphere, a division of Ebasco, Inc.
EPA	U.S. Environmental Protection Agency, Region 10
EPTA	Evaluation Procedures Technical Appendix
EPWG	Evaluation Procedures Work Group
fps	feet per second
ft	feet
FRIC	Fourmile Rock Interim Criteria
gm	gram
ha	hectare
hr	hour
kg	kilogram
l	liter
lb/ft^2	pounds per foot squared
m	meter
Metro	Municipality of Metropolitan Seattle
mg/kg	milligram per kilogram
mg/l	milligram per liter
mi	mile
min	minute
mm	millimeter

MPTA	Management Plans Technical Appendix
MPWG	Management Plan Work Group
MTG	meeting
°N	degrees North
NEPA	National Environmental Policy Act
nm	nautical mile
NMFS	National Marine Fisheries Service
NOAA	U.S. National Oceanic and Atmospheric Administration
PHI	Grain size classification
PSCOG	Puget Sound Council of Governments
PSDDA	Puget Sound Dredge Disposal Analysis
PSEP	Puget Sound Estuary Program
PSIC	Puget Sound Interim Criteria
PSWQA	Puget Sound Water Quality Authority
REMOTS	Remote Environmental Monitoring of the Sea Floor
rms	root mean square
s	second
sec	second
SEPA	Washington State Environmental Policy Act
Shapiro	Shapiro and Associates
SL	Standard Length
SMA	Shoreline Management Act
SMP	Shoreline Master Program
SND	Standard Normal Deviates
sq	squared
TPM	Total Particulate Matter
TVS	Total Volatile Solids
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
UW FISH	University of Washington Fisheries Department
%VS	percent volatile solids
°W	degrees West
WAC	Washington Administrative Code
WDF	Washington State Department of Fisheries
WDG	Washington State Department of Game
WDNR	Washington State Department of Natural Resources
WDOE	Washington State Department of Ecology
WES	Waterways Experiment Station
WPPA	Washington Public Ports Association
YOY	Young-of-the-Year
ZSF or ZSFs	Zone(s) of Siting Feasibility
401	Section 401 of the Clean Water Act
404	Section 404 of the Clean Water Act

CONVERSION FACTORS FOR UNITS OF MEASUREMENT

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic feet per second	0.02831685	cubic meters per second
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet per second	0.3048	meters per second
feet per second (fps)	0.5921	knots
fathoms	6.00	feet
square meters	0.0001	hectare
hectare	2.47	acres

EXHIBIT A

MAPPING AND OVERLAY PROCESS: SITE SELECTION FACTORS

1. PRELIMINARY MAPS

Zones of Siting Feasibility were selected through a mapping approach which involved superimposing overlays to locate areas of few or no conflicts. The selected areas had minimal conflicts with the site selection factors. The DSWG examined a series of preliminary maps as an aid to decide which key factors should be shown on the final maps which were used for ZSF selections. The following factors were mapped:

a. Human Uses:	Maps Prepared:
1. Designated navigation lanes/ channels/anchorage areas, approaches and high density vessel traffic areas.	Navigation lanes and areas of high density traffic
2. Recreational uses (fishing, sailing courses, diving sites, anchorage areas, artificial reefs, shoreline parks).	Underwater recreation areas/state parks/ artificial reefs
3. Cultural/historical sites (wrecks and historical areas).	Shipwrecks
4. Aquaculture facilities and disignated aquaculture areas.	DNR aquaculture sites
5. Utilities (pipelines and cables).	Utility corridors
6. Areas of special scientific importance (natural preserves, sanctuaries).	No map
7. Point pollution sources (outfalls and designated zones of initial dilution including municipal and industrial outfalls).	Major outfalls
8. Water supply (salt water intakes).	Major intakes
9. Compatibility of dredged disposal with local shoreline master programs, aesthetics, noise.	Shoreline designations
10. Political boundaries (counties, cities, Indian reservations, international border).	Political boundaries

11. Costs of transportation to disposal sites.	Dredge disposal transportation costs from Everett/Seattle/ Tacoma
12. Beneficial effects of long-term disposal (beach replenishment, habitat creation, etc.).	No map

b. Biological Resources:

13. Food fish/shellfish harvest areas(commercial and recreational - using WDF and tribal description).	Shellfish harvesting areas, salmon fishing areas and non-salmonoid harvesting areas
14. Threatened and endangered species.	Bald eagle nest sites
15. Food fish and shellfish habitat (critical breeding, rearing, nursery and migration).	Shellfish critical habitats, non-ground-fish critical habitats and groundfish critical habitats
16. Wetlands, mudflats, vegetated shallows.	Vegetated shallows and nearshore wetlands

c. Physical Parameters:

17. Bathymetry.	Bathymetry at one fathom contours
18. Substrata (physical, chemical and benthic sediment characteristics).	Long-term monitoring stations, sediment sampling stations, surface sediments, areas of elevated sediment chemistry
19. Current patterns and water circulation.	Current meter stations, maximum and net surface currents, maximum and net currents near bottom.

1.1 Final Maps

Of the above maps, five which displayed key factors were selected and subsequently used to identify the ZSFs. The key maps selected were:

(1) Political boundaries
(2) Navigation lanes
(3) Utilities
(4) Marine fish resources and aquaculture sites
(5) Shellfish harvesting areas

1.2 Additional Maps Used to Adjust ZSF Boundaries

The key maps were verified by the participating agencies. They were then overlayed and the ZSFs defined after applying the constraints noted in Section II.1.3. Further refinement of the ZSF boundaries was made by placing additional overlay maps successively over the ZSF base map. These maps were:

(1) Bathymetry
(2) Net surface currents
(3) Net near bottom currents
(4) Marine mammals
(5) Nesting seabird sites
(6) Salmon (commercial and recreational fishing)

The DSWG first defined the ZSFs by avoiding vulnerable resources and areas of human uses, and second by considering transportation haul costs. There was no weighting of the factors.

Further adjustment of the ZSFs was made by the DSWG as a result of the Depositional Analysis and input from: Federal; state and local agencies; Indian tribes; interest groups; scientists; and citizens. This input was received at DSWG meetings.

2. DESCRIPTION OF OVERLAY MAPS

The maps used to locate the ZSFs have been reproduced for this appendix. Several of the preliminary parameters were mapped together for ease of use.

2.1 Map No. 1 (Figs. A-1 to A-3)

Political Boundaries, Navigation, and Utilities, in the north Puget Sound region (Fig. A-1), Strait of Juan de Fuca (Fig. A-2), and south Puget Sound (Fig. A-3). Categories mapped are described below.

Boundaries for: (1) U.S./Canada; (2) cities; (3) counties; (4) outer harbors; (5) Lummi Indians; (6) Swinomish Indians; (7) Squaxin Indians. These areas were defined from master plans obtained from each city or county.

Navigation Lanes, Areas of High Density Traffic, Utilities. Categories mapped include: (1) navigation lanes; (2) ferry routes; (3) tug routes; (4) pipe lines; (5) cables; (6) potential marinas; (7) ports; (8) dredge disposal areas. These were compiled from NOAA nautical charts, the Washington Marine Atlas, and information from COE.

2.2 Map No. 2 (Figs. A-4 to A-6)

Marine Fish Resources and Aquaculture Sites (commercial and public). Categories mapped include: (1) smelt spawning beaches; (2) Pacific herring spawning grounds; (3) Pacific herring holding areas; (4) major resource and fishery areas for groundfish; (5) on bottom culture sites; (6) suspended culture sites; (7) existing pen culture sites; (8) proposed pen culture sites. The first four items were from WDF Technical Report No. 79, and aquaculture sites were mapped from data supplied by DNR.

2.3 Map No. 3 (Figs. A-7 to A-9)

Shellfish Resources. Subjects mapped include: (1) geoducks; (2) other clams; (3) oysters; (4) shrimp; (5) Dungeness crab. All data were taken from WDF Technical Report No. 79.

2.4 Map No. 4 (Figs. A-10 to A-12)

Bathymetry. The original maps produced for PSDDA were done at a one fathom contour interval (one fathom equals six feet). The maps shown in Figures A-10 to A-12 have been redrawn at a ten fathom interval for clarity. The DSWG in its selection of the ZSFs used the finely contoured charts (one fathom interval).

These bathymetry charts were compiled by the U.S. Navy during the 1940's using data collected prior to World War II.

2.5 Map No. 5 (Figs. A-13 to A-15)

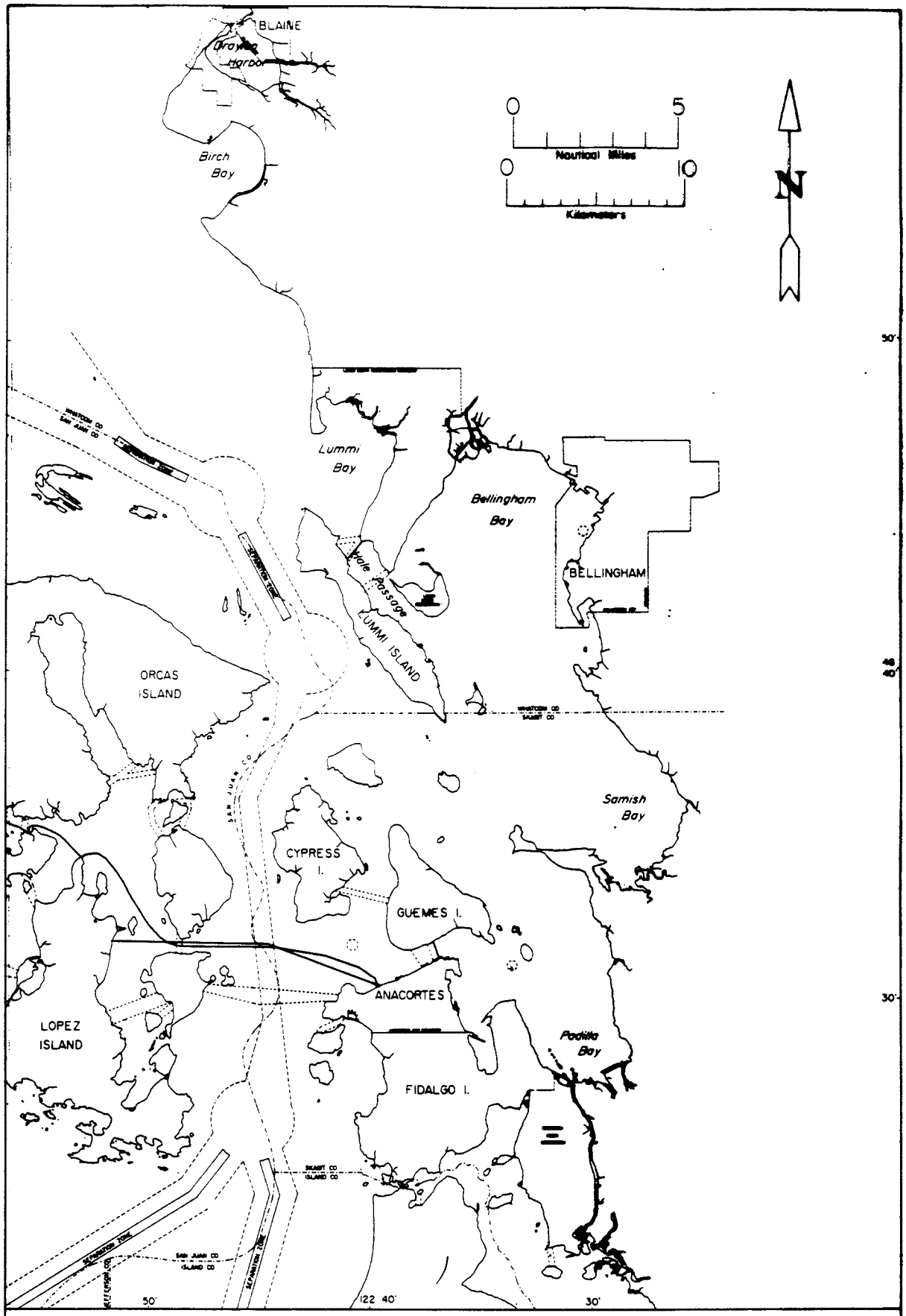
Marine Mammals. Subjects mapped include: (1) river otter habitat; (2) seal haul out sites; (3) sitings of Doll's Porpoise, Harbor Porpoise, and Minke Whales.

2.6 Map No. 6 (Figs. A-16 to A-18)

Nesting Seabird Sites. Subjects mapped include: (1) Glaucous-winged gull; (2) Double-crested cormorant; (3) Pelagic cormorant; (4) Pigeon guillemot; (5) Tufted puffin; (6) Rhinoceros auklet; (7) Black oystercatcher; and (8) Arctic tern.

2.7 Map No. 7 (Figs. A-19 to A-21)

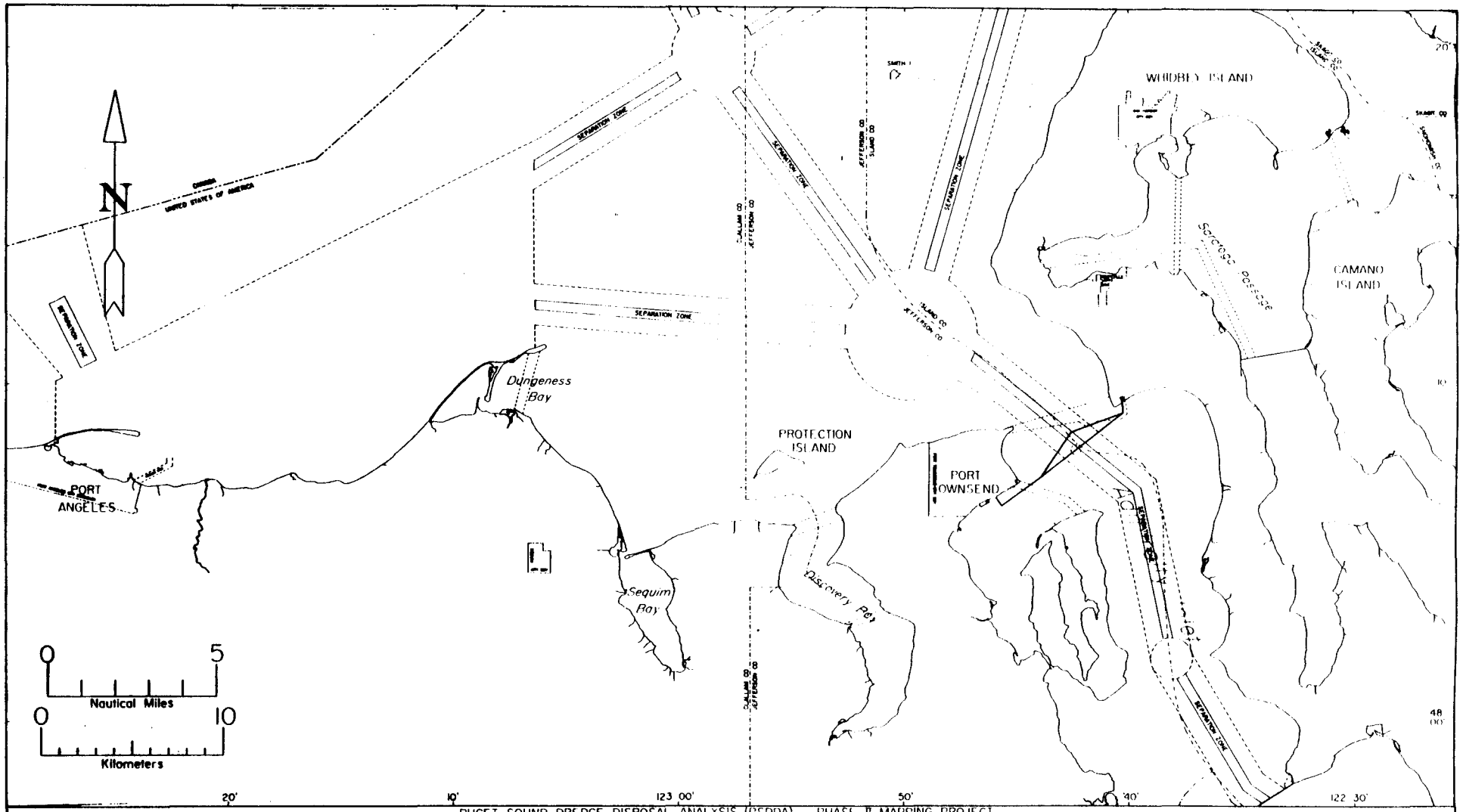
Salmon Resources. Subjects mapped include: (1) commercial fishing areas; and (2) recreational fishing areas. These maps were adapted from data contained in Technical Report No. 79.



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

POLITICAL BOUNDARIES
NAVIGATION
UTILITIES
Dredge Disposal Area

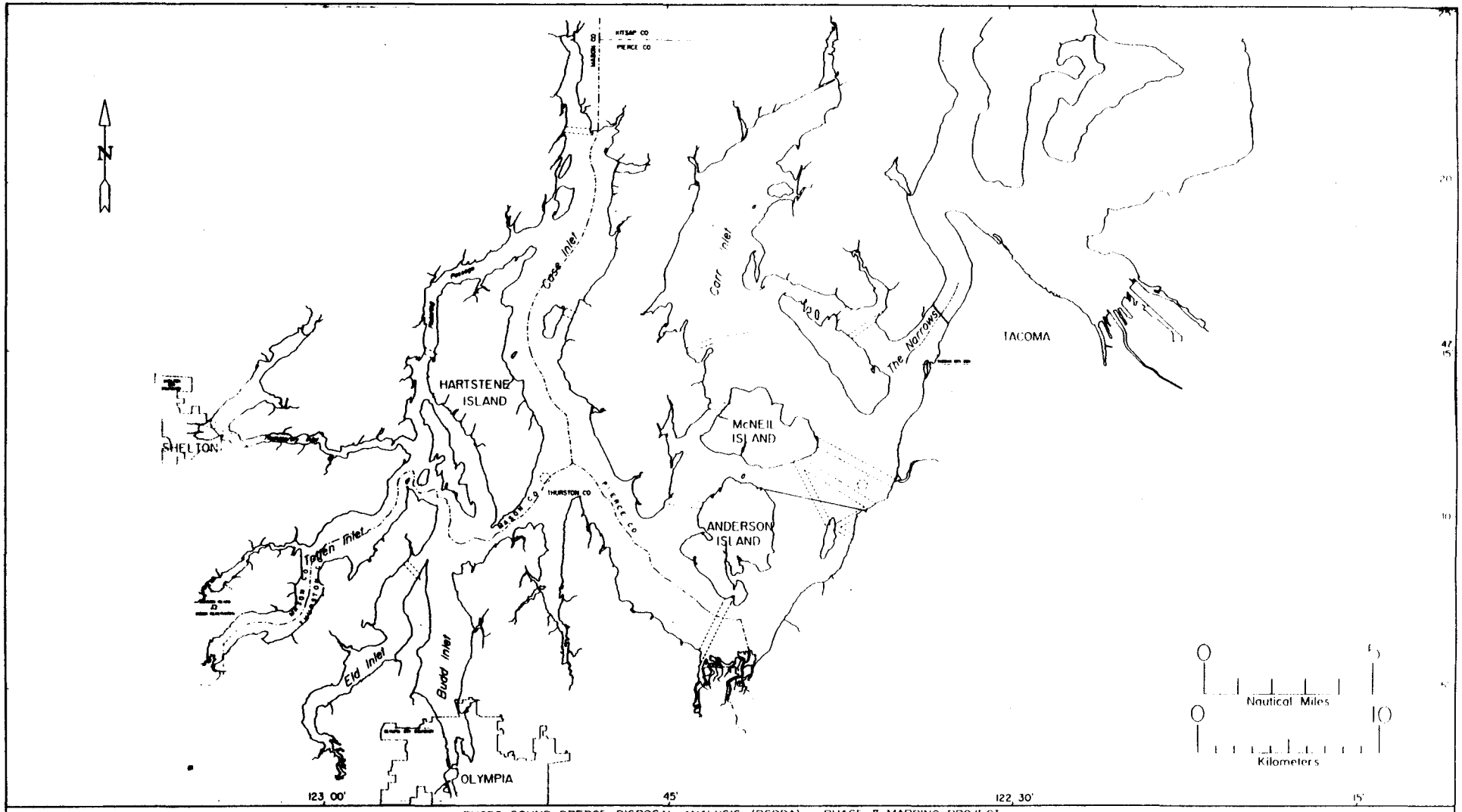
Figure A-1



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) PHASE II MAPPING PROJECT

POLITICAL BOUNDARIES
International
County
City
Indian Reservation
NAVIGATION
Traffic Lane
Ferry Route
UTILITIES
Cable Area
Pipeline Area
Dredge Disposal Area

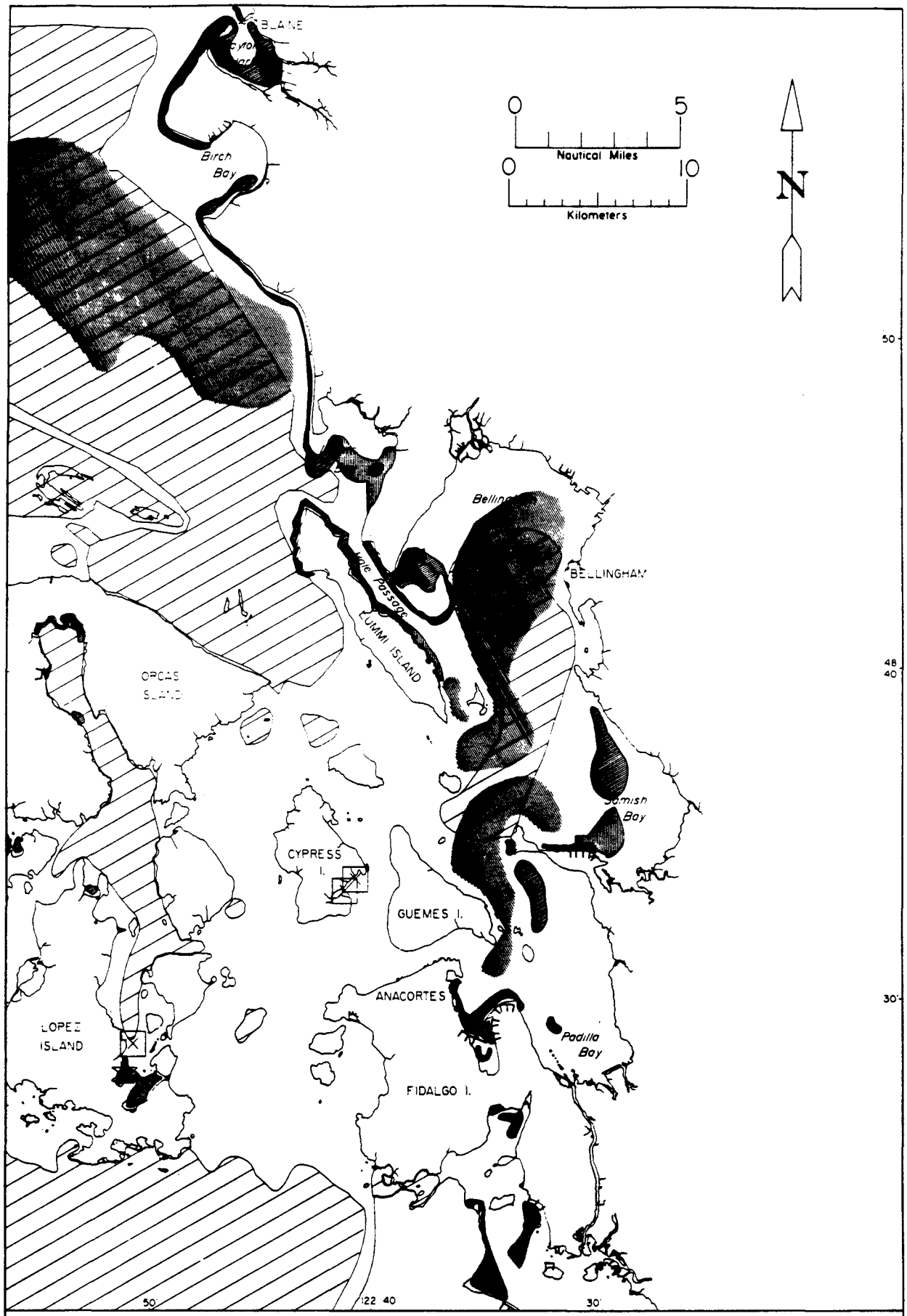
Figure A-2



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) PHASE II MAPPING PROJECT

POLITICAL BOUNDARIES
NAVIGATION
UTILITIES
Dredge Disposal Area

Figure A-3

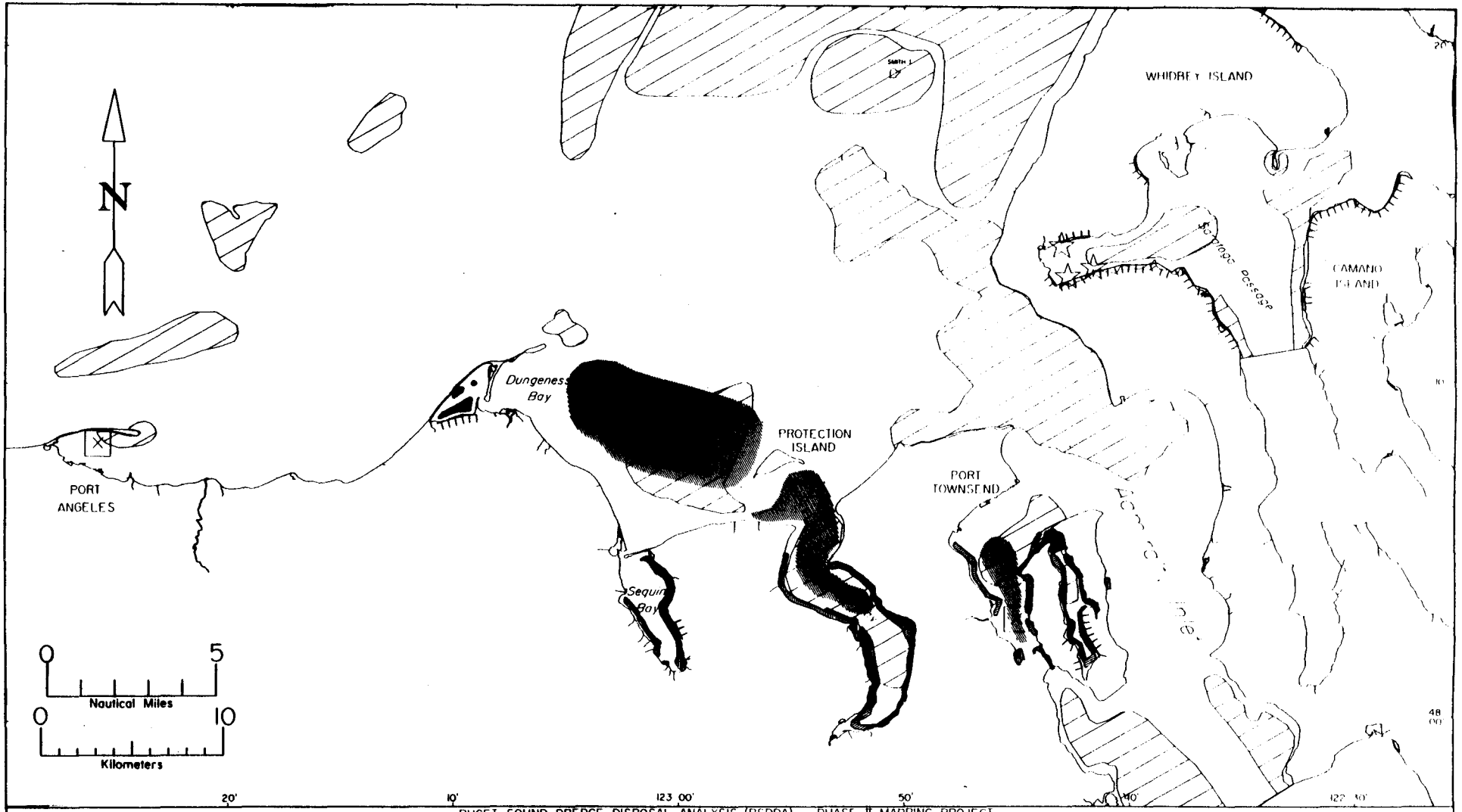


PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

MARINE FISH RESOURCES

AQUACULTURE SITES

Figure A-4



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) PHASE II MAPPING PROJECT

MARINE FISH RESOURCES

AQUACULTURE SITES

Figure A-5

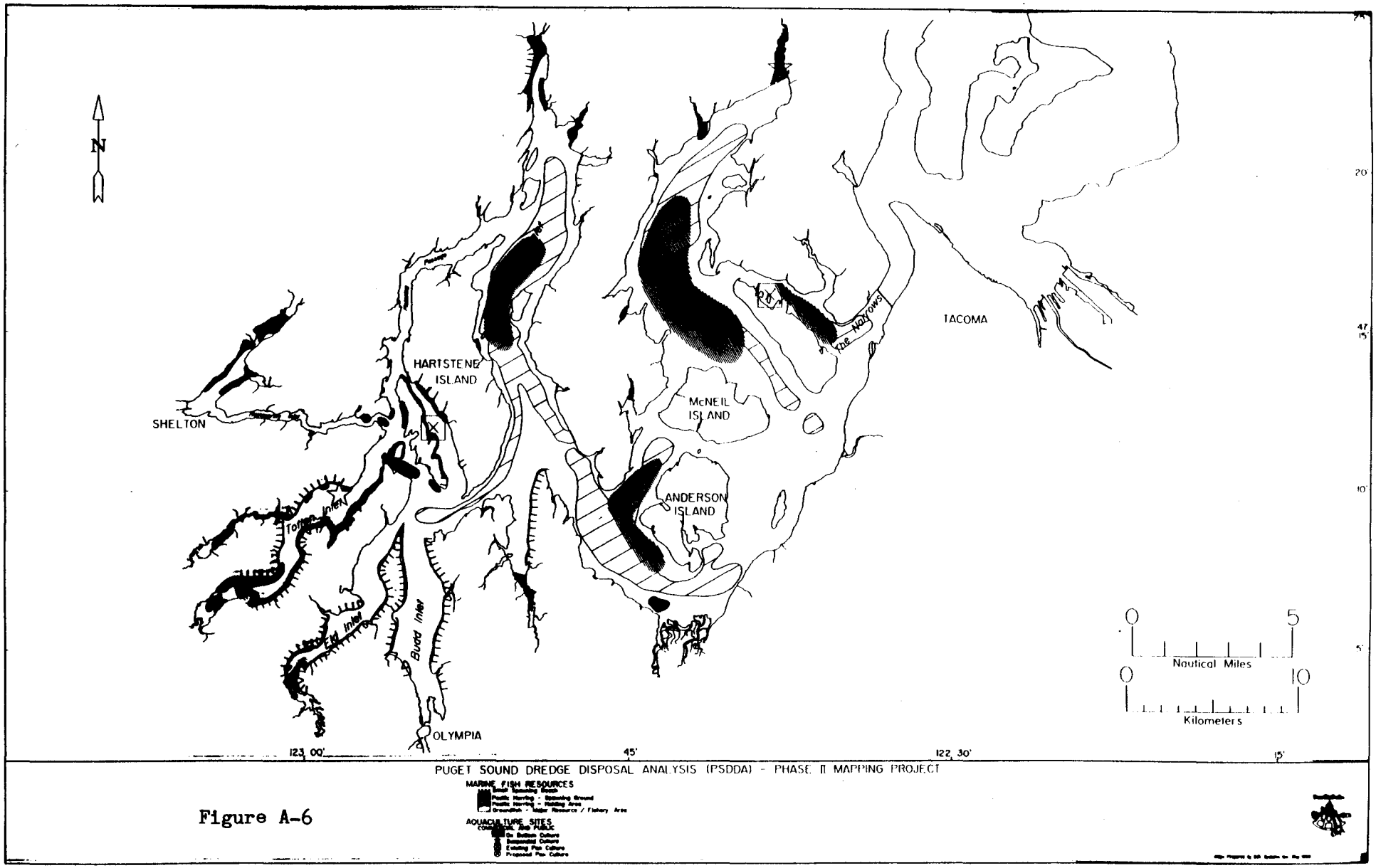
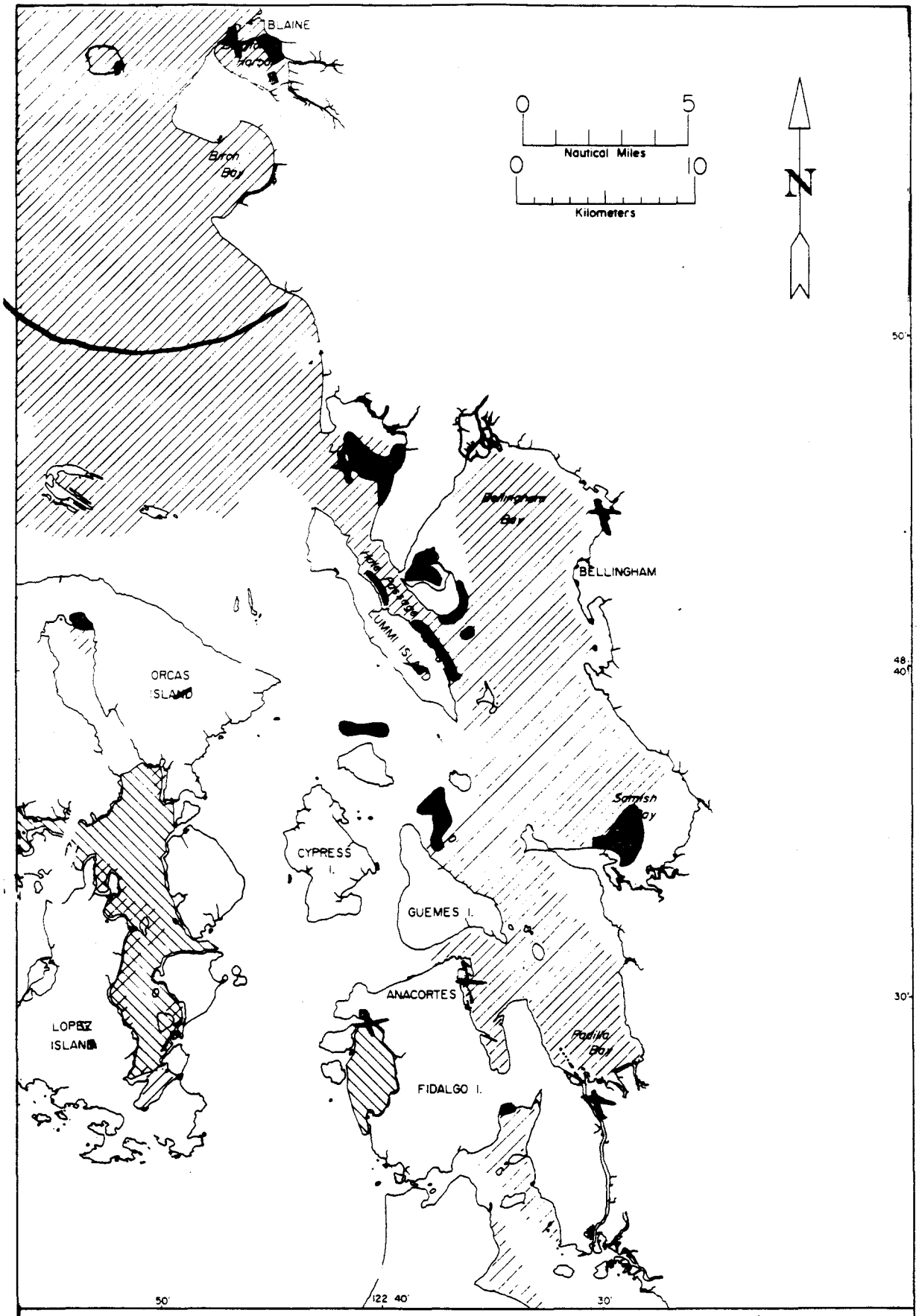

N
SHELTON
HARTSTENE ISLAND
McNEIL ISLAND
ANDERSON ISLAND
TACOMA
the NARROWS
Totten Inlet
Eld Inlet
Budd Inlet
OLYMPIA
0 5
Nautical Miles
0 10
Kilometers
123 00'
45'
122 30'
15'
20'
47 15'
10'
5'
PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT
MARINE FISH RESOURCES
AQUACULTURE SITES
COMMERCIAL AND PUBLIC

Figure A-6



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

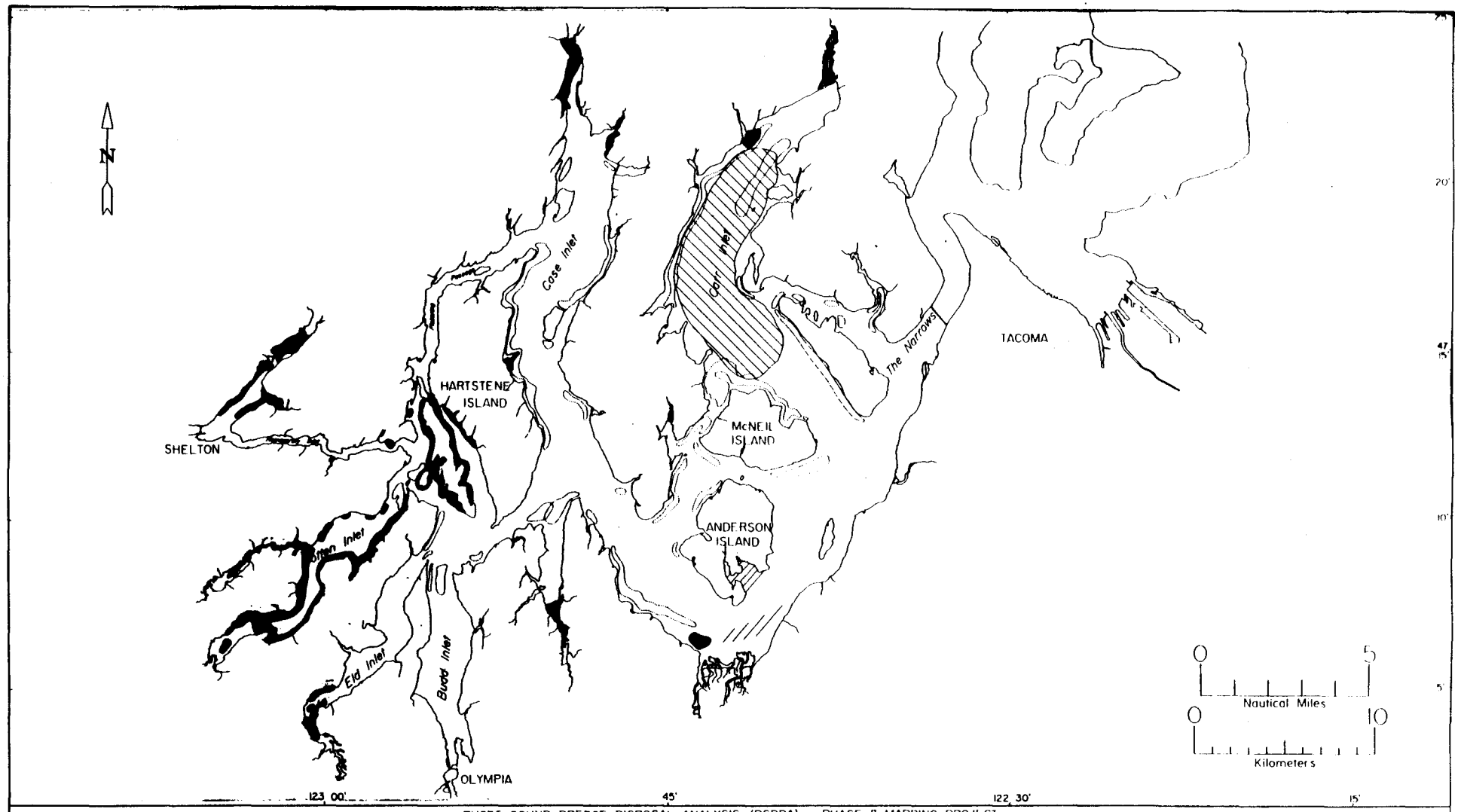
SHELLFISH RESOURCES

Figure A-7

PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

Figure A-8

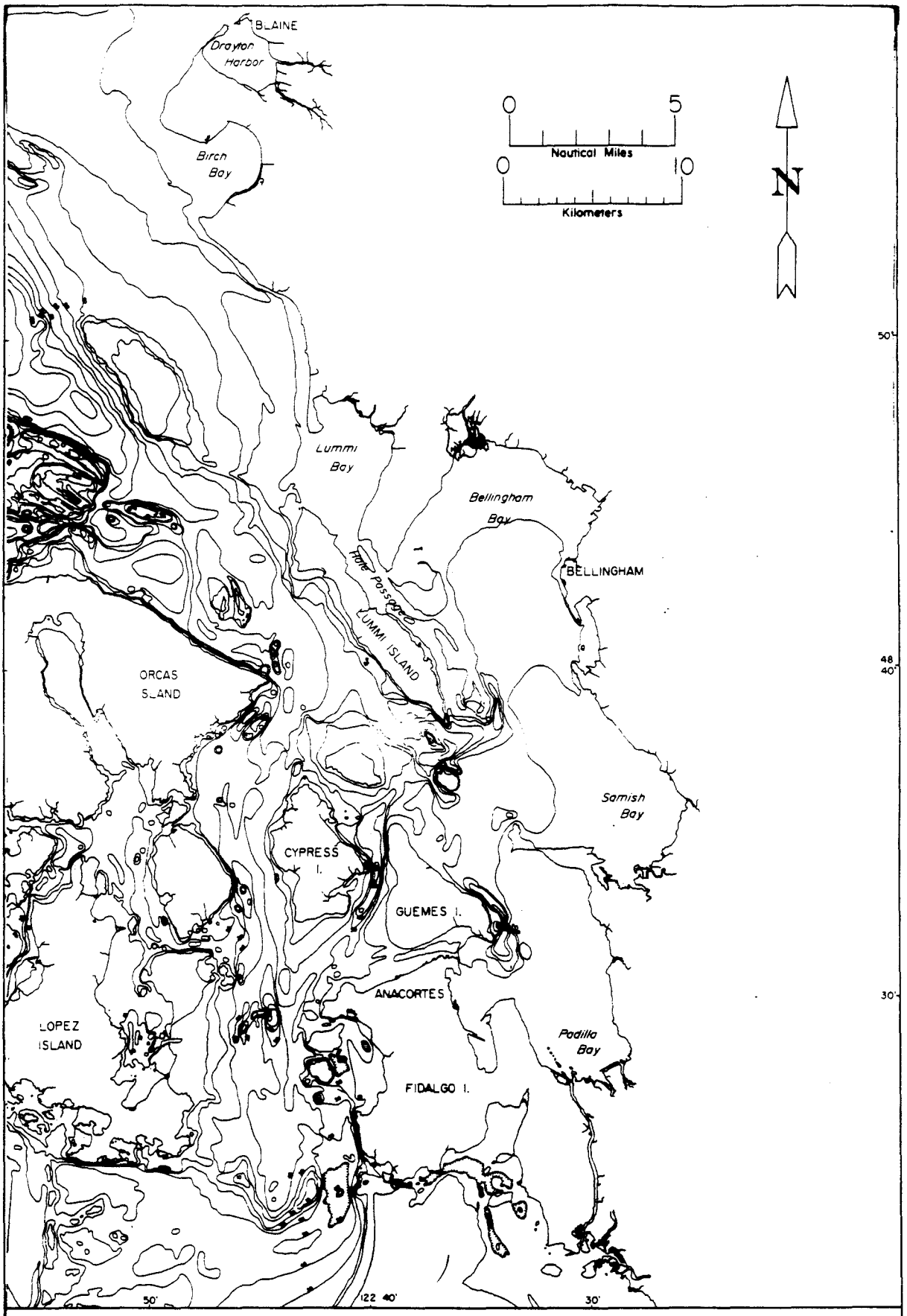
SHELLFISH RESOURCES



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

SHELLFISH RESOURCES

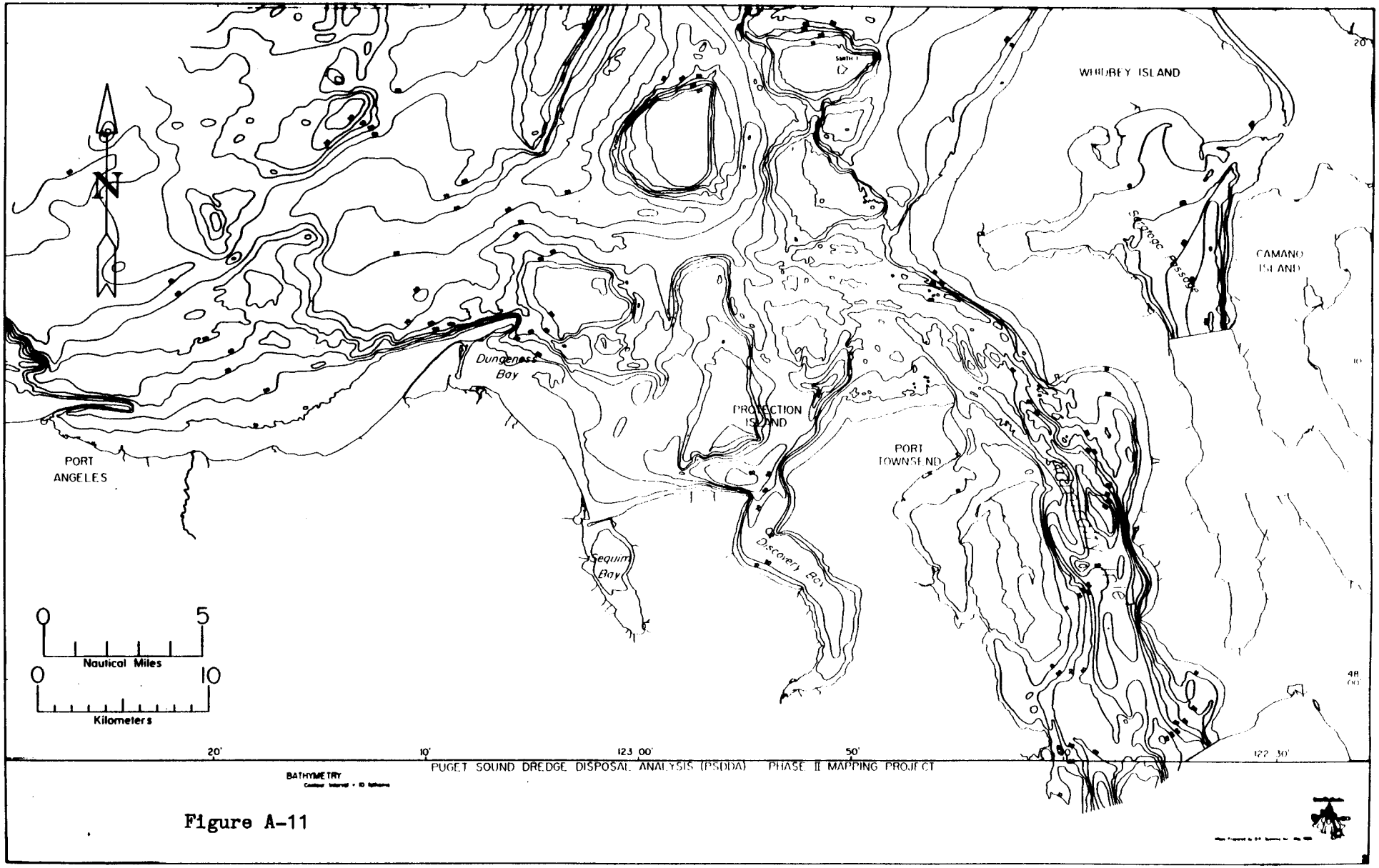
Figure A-9



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

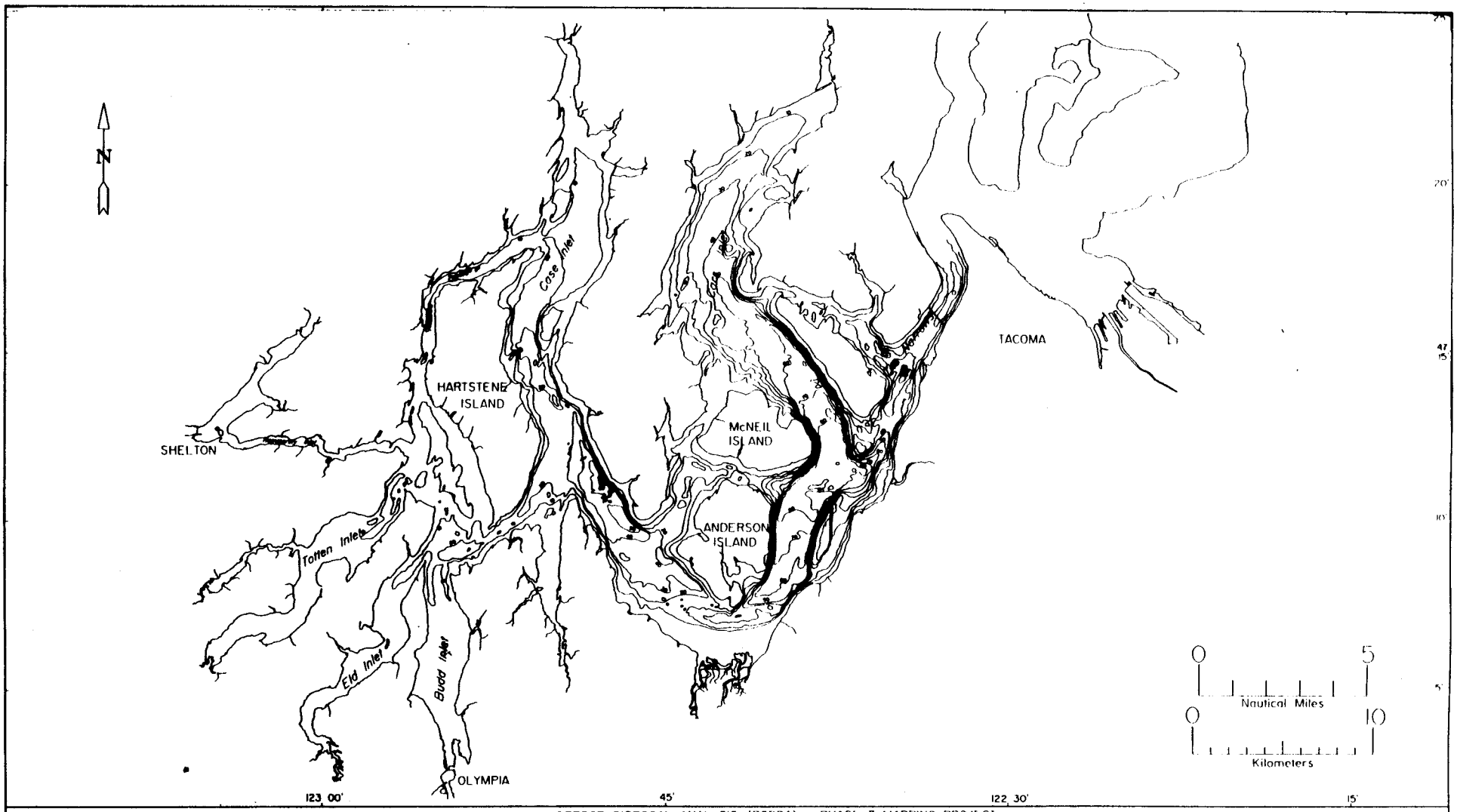
BATHYMETRY

Figure A-10



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) PHASE II MAPPING PROJECT

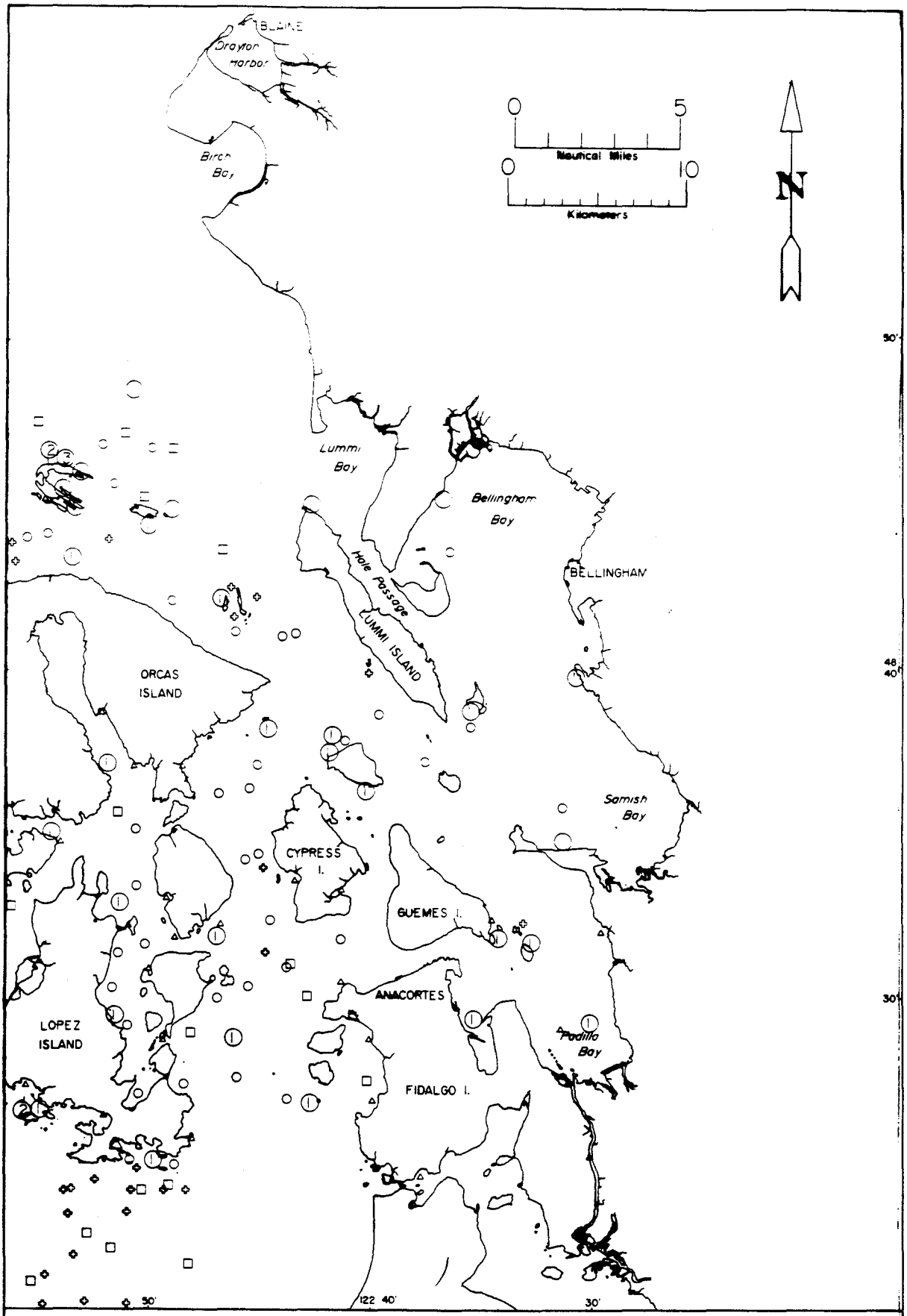
Figure A-11



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

BATHYMETRY

Figure A-12



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

Figure A-13

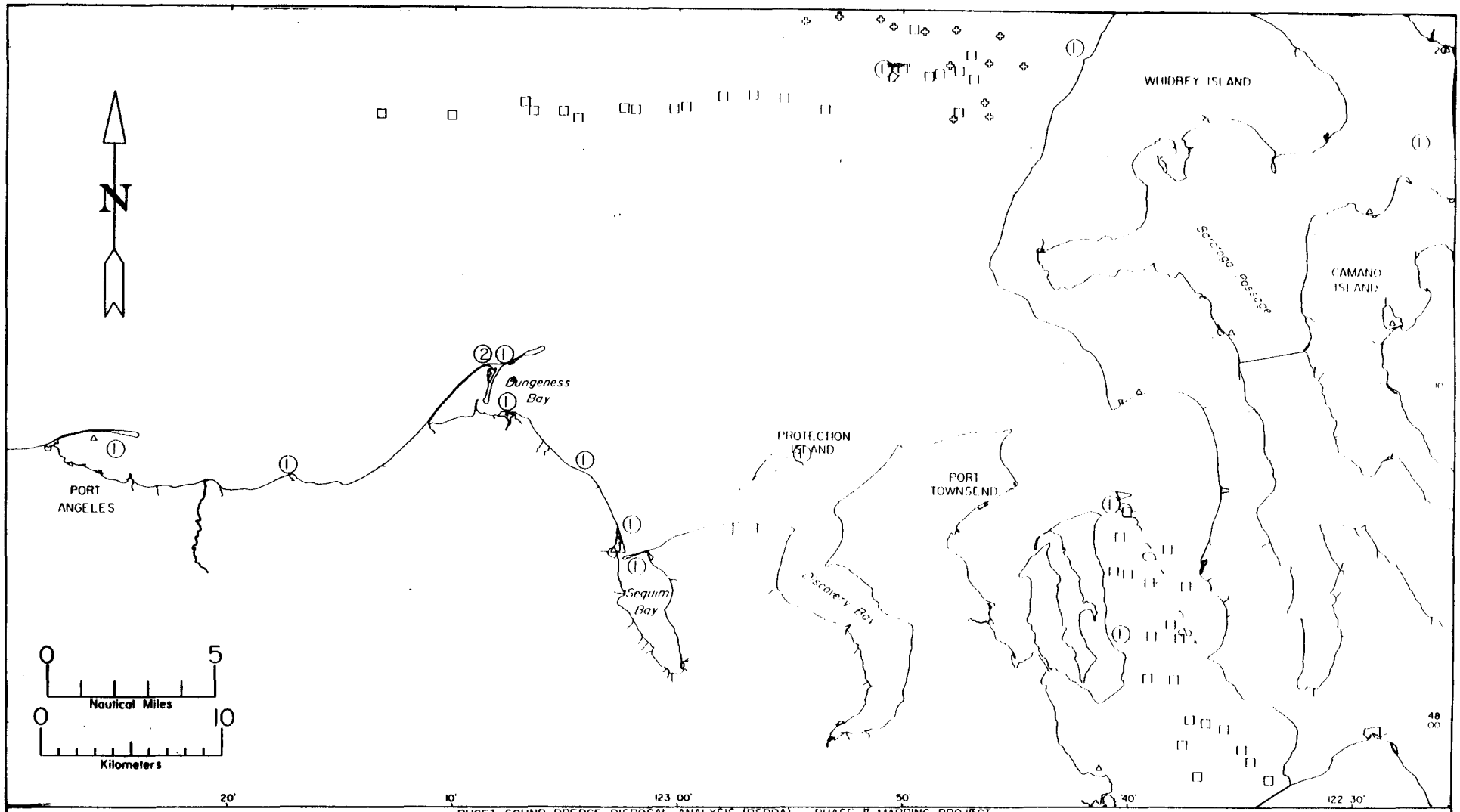
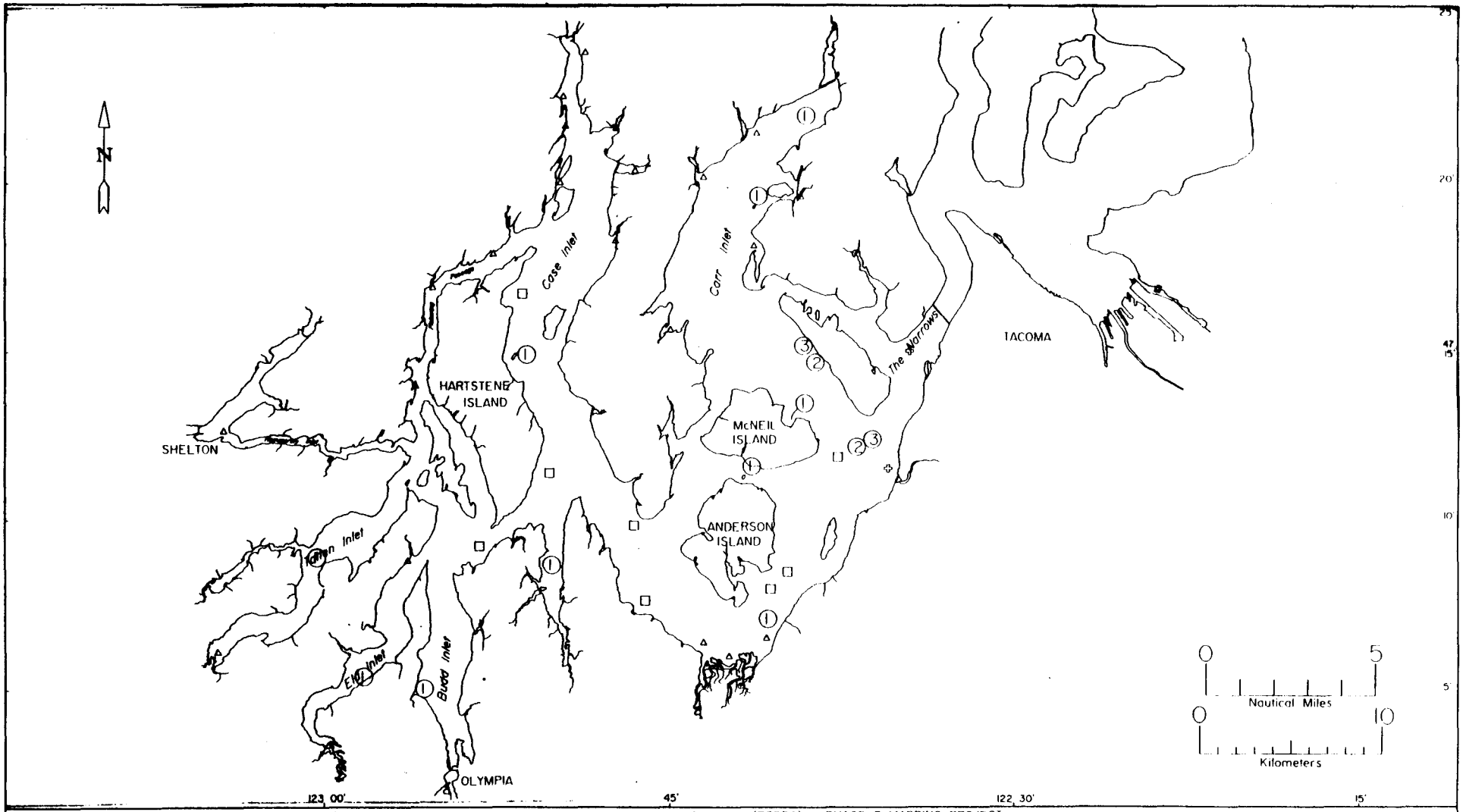

N
PORT ANGELES
Dungeness Bay
Sequim Bay
PROTECTION ISLAND
Discovery Bay
PORT TOWNSEND
WHIDBEY ISLAND
Saratoga Passage
CAMANO ISLAND
0 5
Nautical Miles
0 10
Kilometers
20'
10'
123 00'
50'
40'
122 30'
48 00
PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) PHASE II MAPPING PROJECT
MARINE MAMMALS
RIVER OTTER HABITAT
HAUL OUT SITE
Harbor Seal
Northern Sea Lion
California Sea Lion
SIGHTINGS
Dall's Porpoise
Harbor Porpoise

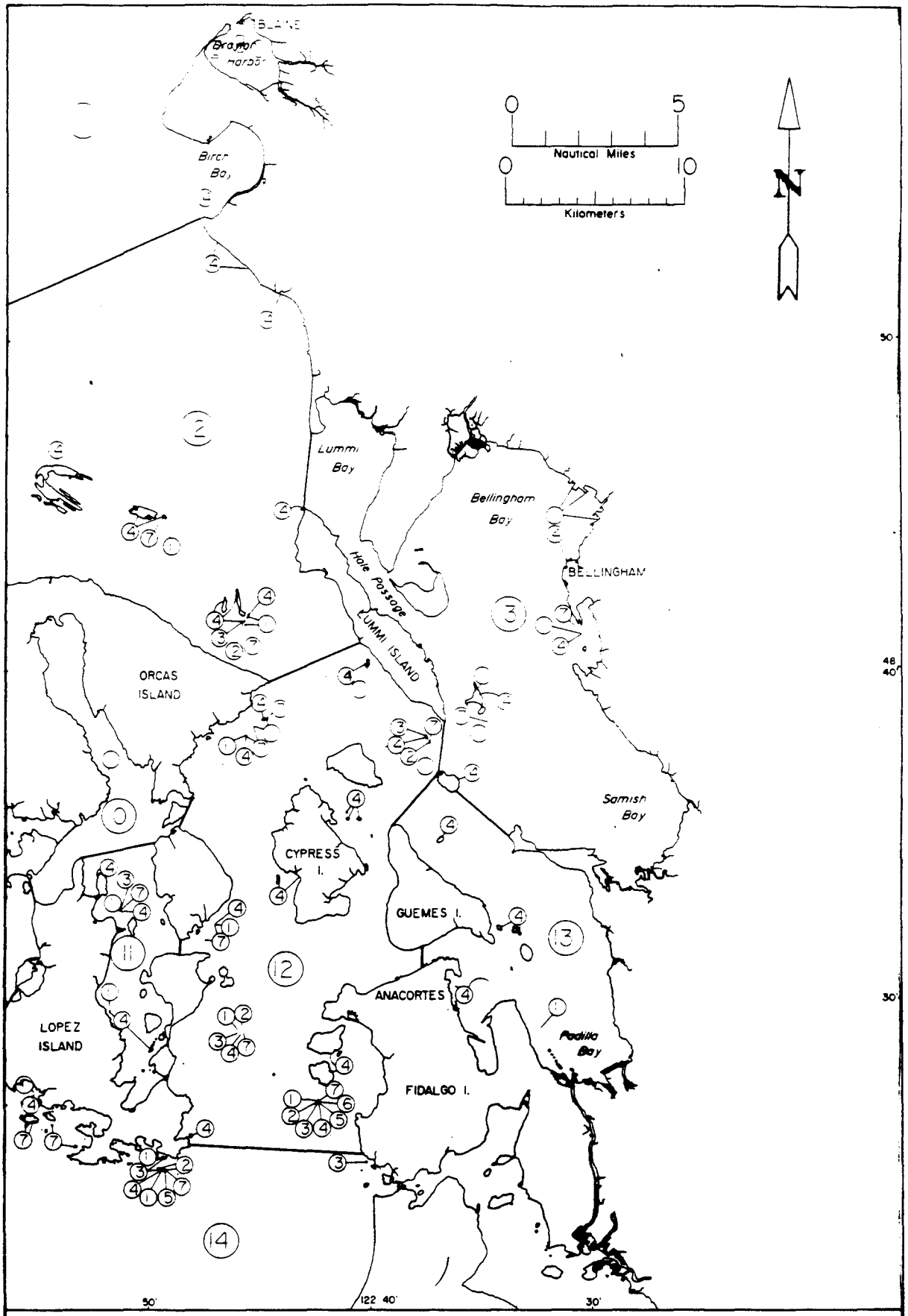
Figure A-14



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

MARINE MAMMALS
△ RIVER OTTER HABITAT
HAUL OUT SITE
● Harbor Seal
● Northern Sea Lion
● California Sea Lion
SKYHIPHOS
□ Dall's Porpoise
○ Harbor Porpoise
● Minke Whale

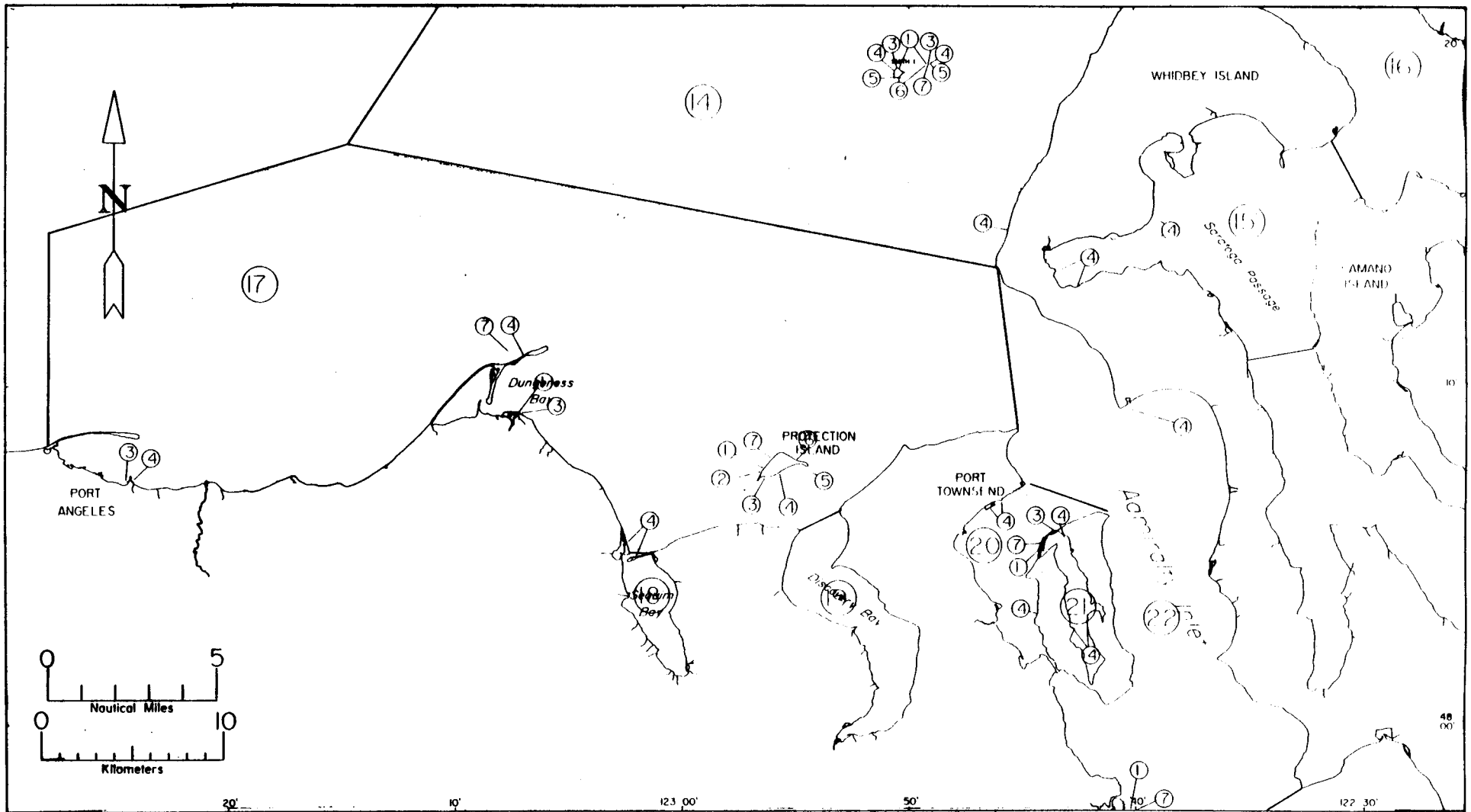
Figure A-15



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

NESTING SEABIRD SITES

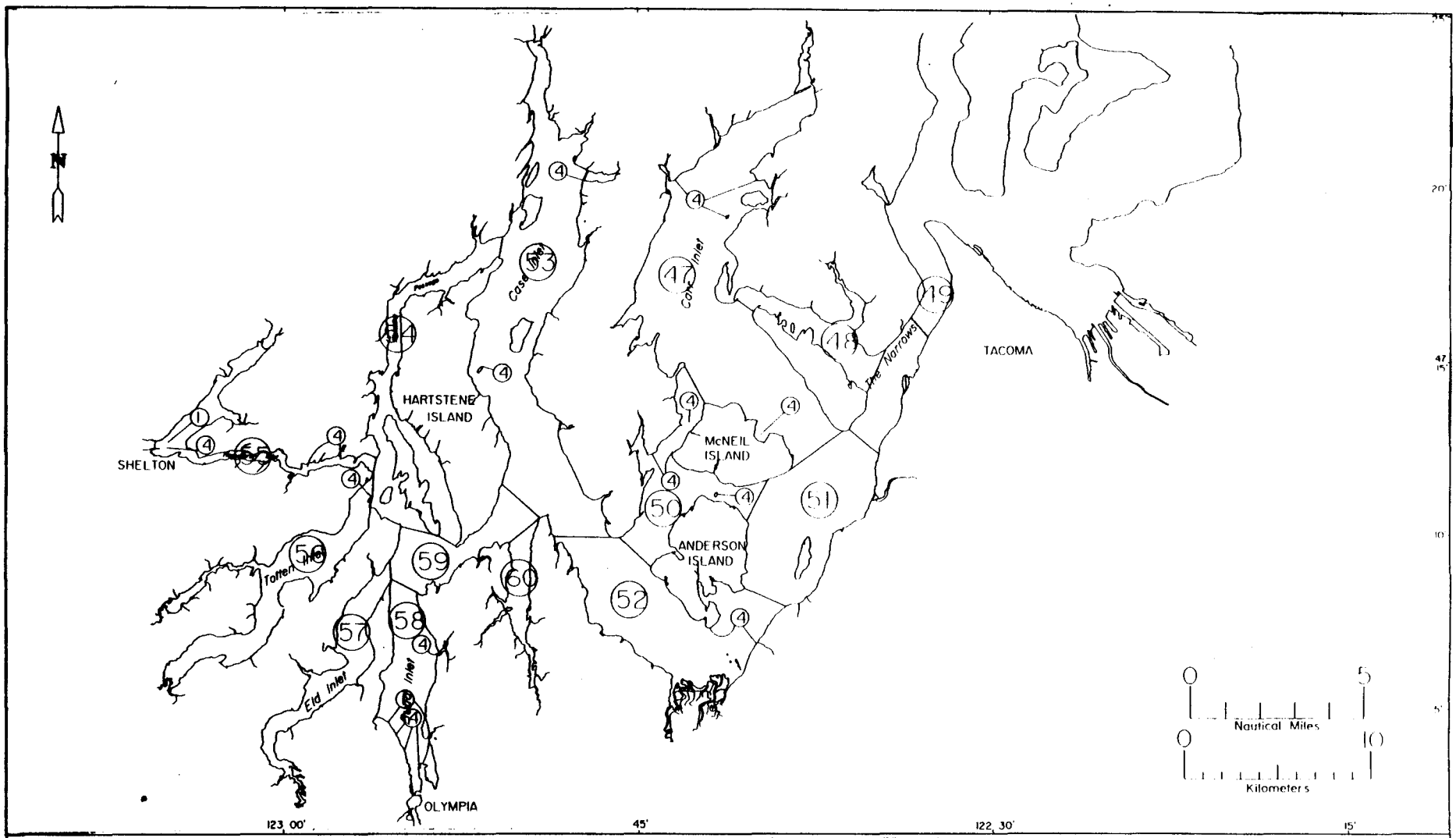
Figure A-16



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) PHASE II MAPPING PROJECT

NESTING SEABIRD SITES

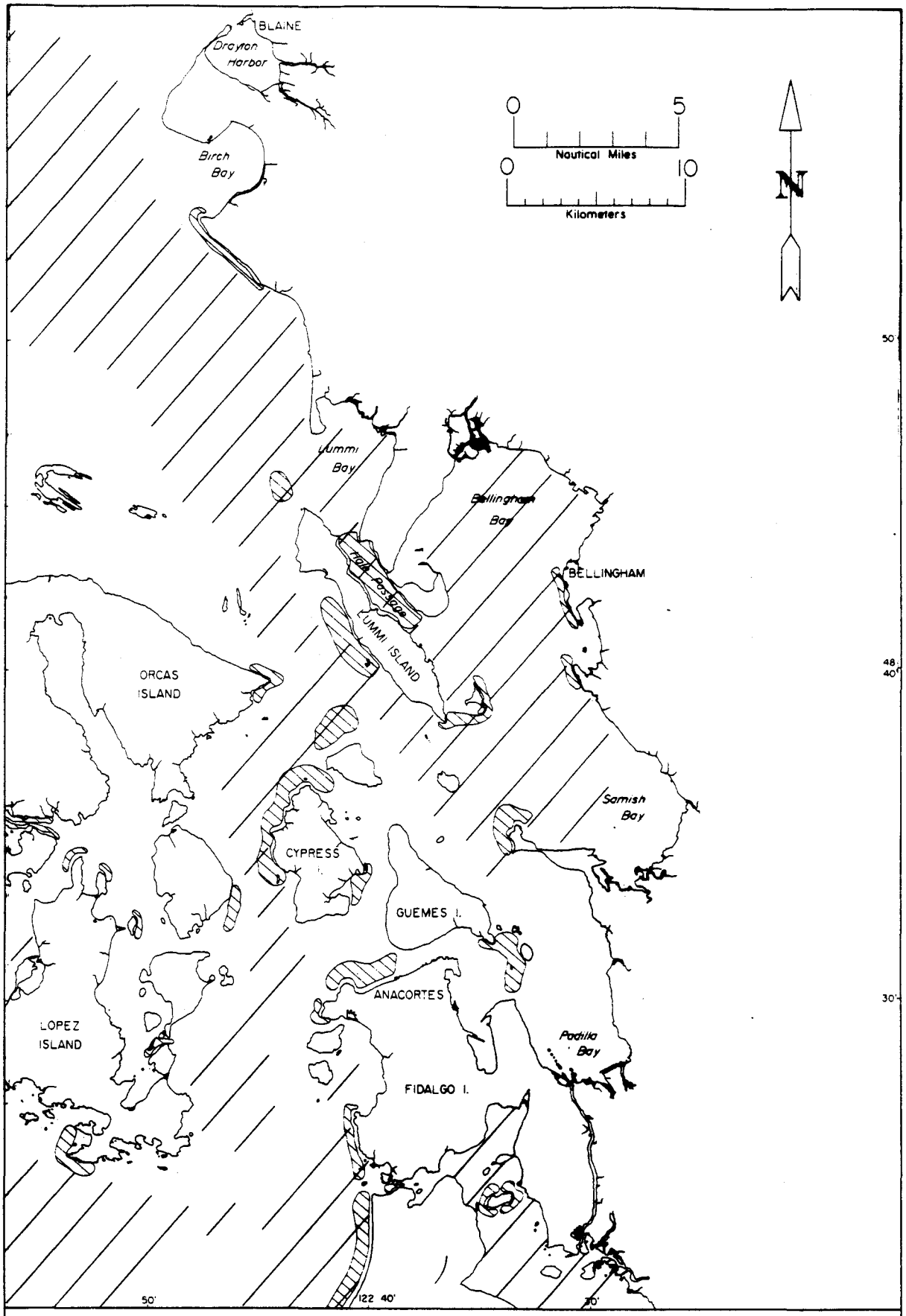
Figure A-17



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

NESTING SEABIRD SITES

Figure A-18



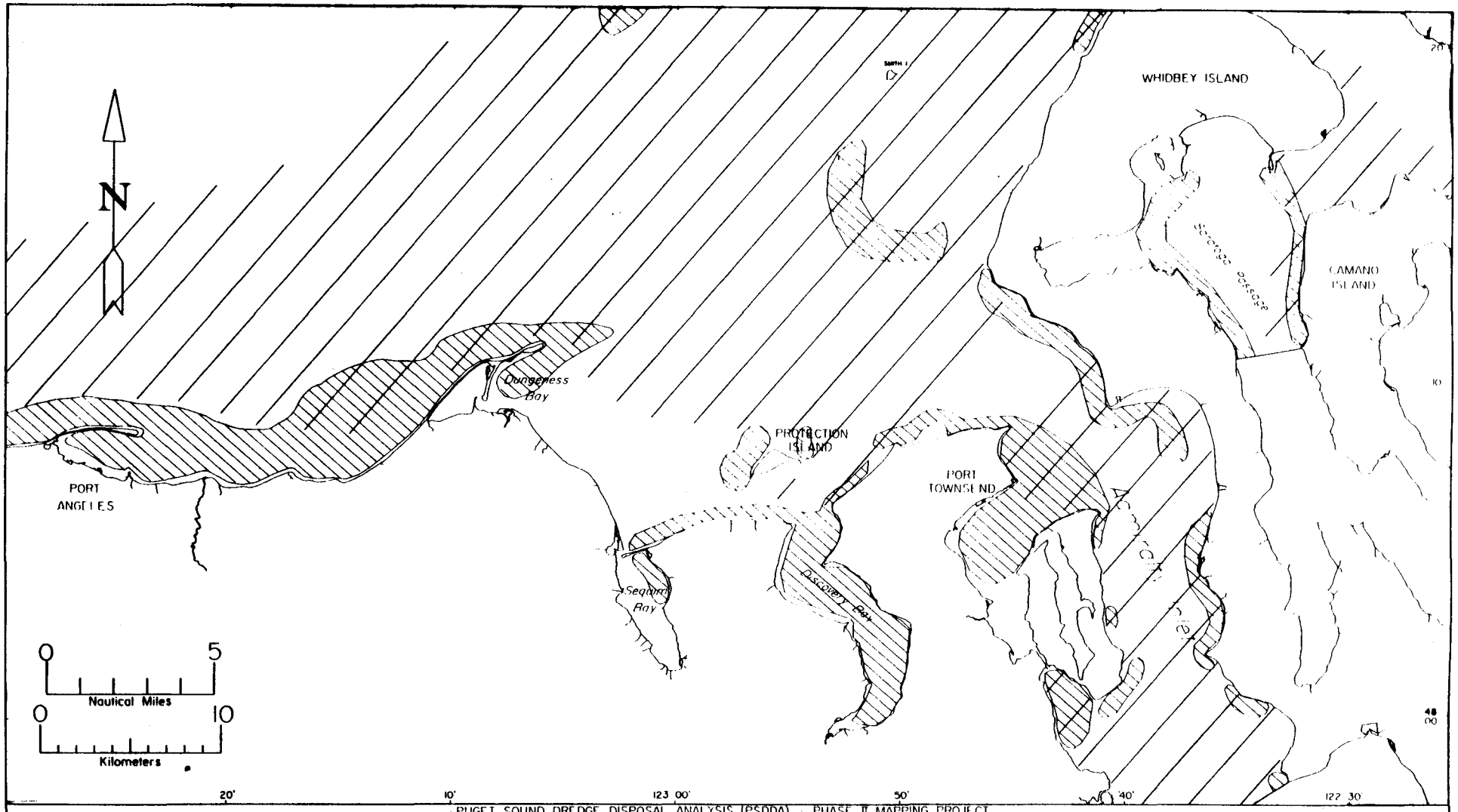
PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

SALMON RESOURCES

Commercial Fishing Area

Sport Fishing Area

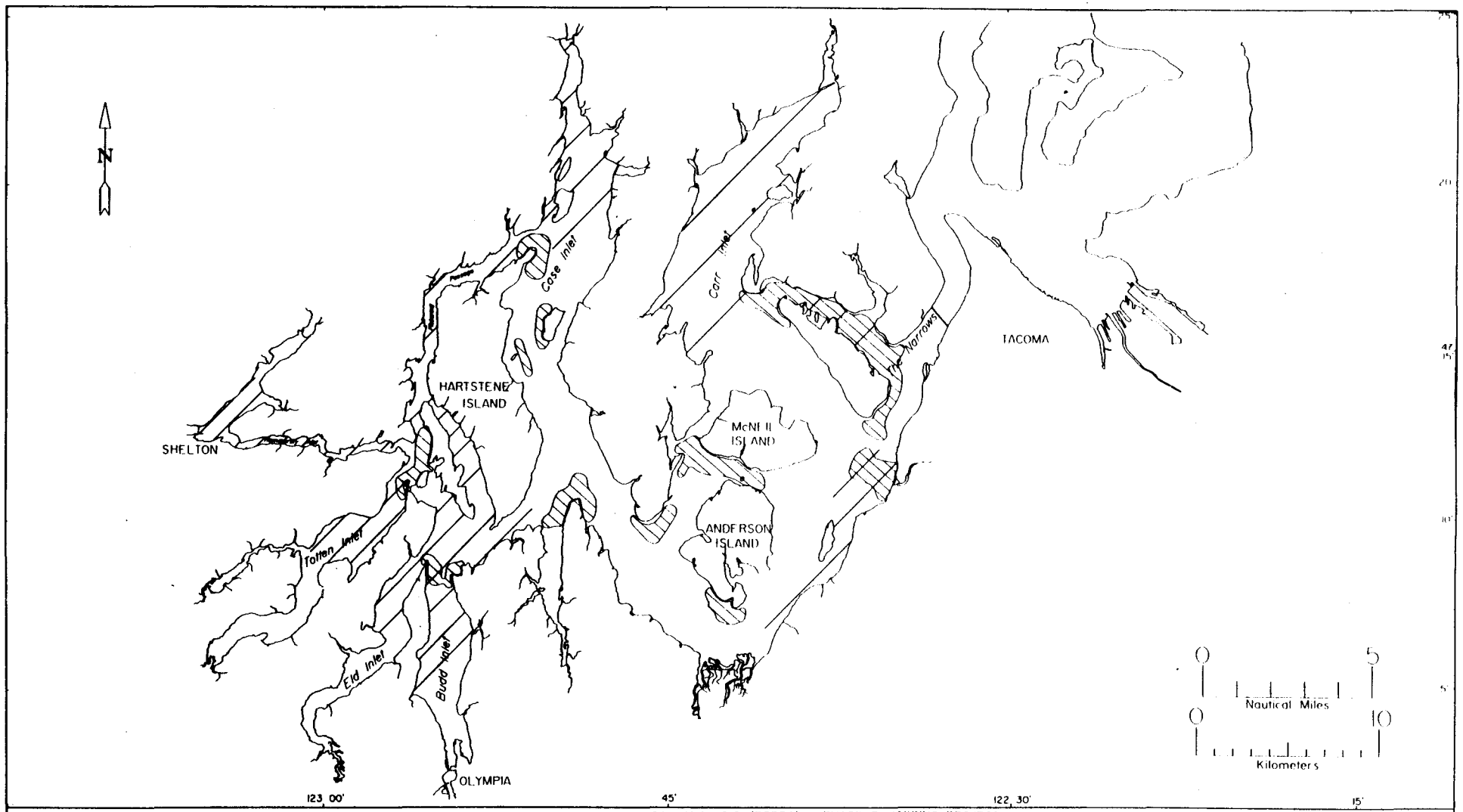
Figure A-19



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) - PHASE II MAPPING PROJECT

SALMON RESOURCES
Commercial Fishing Area
Sport Fishing Area

Figure A-20



PUGET SOUND DREDGE DISPOSAL ANALYSIS (PSDDA) PHASE II MAPPING PROJECT

SALMON RESOURCES
Commercial Fishing Area
Sport Fishing Area

Figure A-21

EXHIBIT B

TABLE B-1

Comparative landings of for commercial pandalid shrimp species (pounds round weight) averaged over the years 1985-7. (Source: D. Ward, WDF Statistics Division, pers. comm, 1988).)

Species: / Location:	Coonstripe	Sidestripe	Spot Shrimp	Pink Shrimp	Total
Strait of Juan de Fuca (Area 6, 23C	80	0	0	7	387
San Juan Is. (Area 7, 22A)	32,914	160	8,643	9,223	50,940
Discovery Bay (Area 7B, 21A)	988	0	2,976	4,957	8,921
Bellingham Bay (Area 7B, 21A)	0	0	0	0	0
South Puget Sound (Area 13, 28A)	0	0	0	0	0