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GRAYS HARBOR AND CHEHALIS RIVER IMPROVEMENTS TO NAVIGATION ENVI--ETC(U)
MAY 80 J M SMITH, L W MESSMER, J B PHIPPS DACW67-79-C-0046

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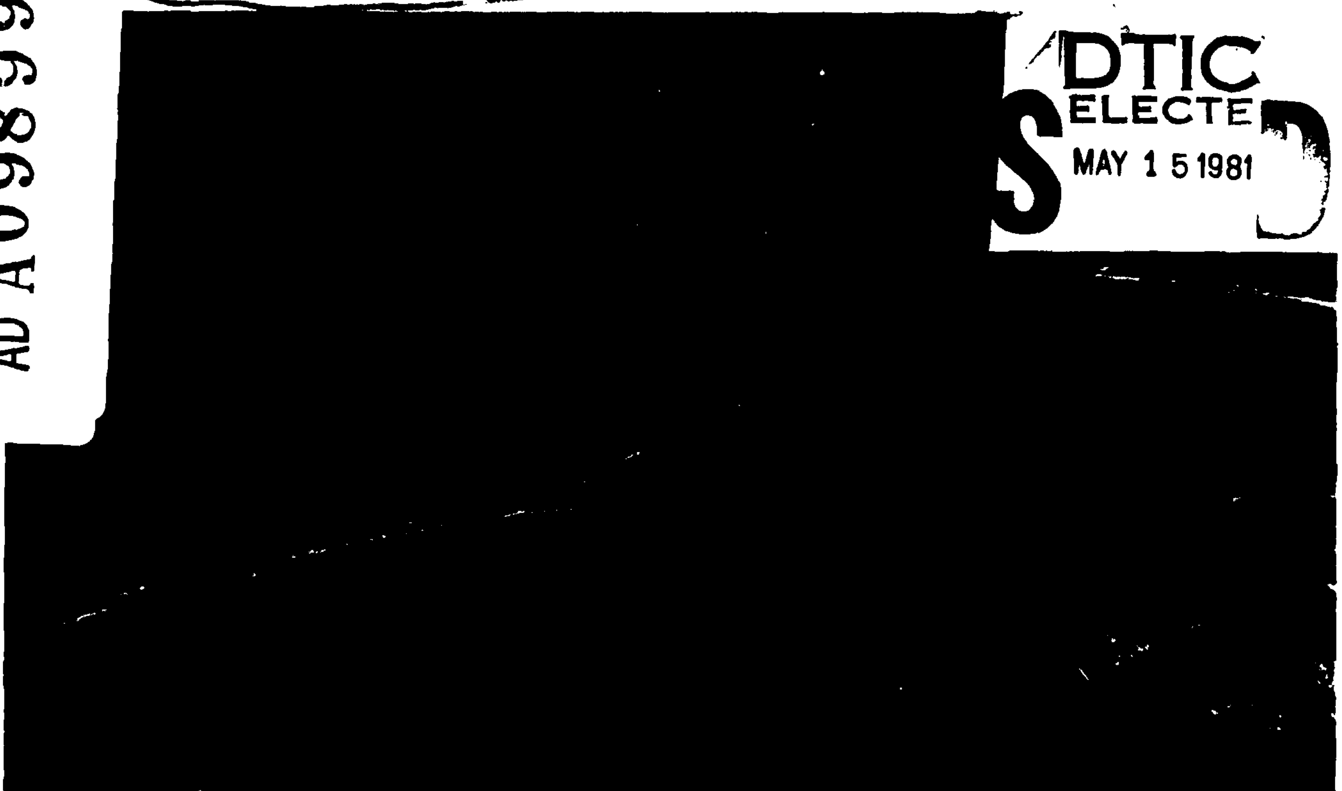
GRAYS HARBOR AND CHEHALIS RIVER IMPROVEMENTS TO NAVIGATION ENVIRONMENTAL STUDIES.

GRAYS HARBOR OCEAN DISPOSAL STUDY. LITERATURE REVIEW AND PRELIMINARY BENTHIC SAMPLING,

BY

JOHN M. SMITH, LOUIS W. MESSMER, JAMES B. PHIPPS, DONALD F. SAMUELSON, ~~AND~~ EUGENE D. SCHERMER



Grays Harbor College
Aberdeen, Washington
98520

May 1980

SEATTLE DISTRICT
U.S. ARMY CORPS OF ENGINEERS

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Four alternative ocean disposal sites with varying distances from the mouth of Grays Harbor, Washington, are discussed as possible sites to dump approximately 3.3 million cubic yards of dredged material resulting from the widening and deepening of Grays Harbor. The remaining 13.4 million cubic yards of dredged material is targeted for ocean dumping.

This report includes a preliminary assessment of impacts of the dredging project

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GRAYS HARBOR COLLEGE

ABERDEEN, WASHINGTON

98520

GRAYS HARBOR

OCEAN DISPOSAL STUDY

MAY 1980

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Work performed for the Seattle District U.S. Army Corps of Engineers under contract Number DACW67-79-C-0046, Work Order Number 3.

ABSTRACT

The export of logs, lumber and wood products is a principal economic activity for the cities of Aberdeen, Hoquiam and Cosmopolis, Washington, situated at the upper end of the Grays Harbor estuary. The Seattle District of the Corps of Engineers has responsibility for maintenance of a navigable channel through this estuary. Because of the increasing size of ocean vessels used to transport lumber and logs, preliminary plans have been made for the widening and deepening of the Grays Harbor navigation channel. The project would require the removal of an estimated 19.3 million cubic yards of dredged material, of which 16.7 million cubic yards is targeted for disposal in ocean water.

This report is a preliminary study of the impact of nearshore ocean disposal of these dredged materials. It includes a literature review of biological, chemical, physical and geological characteristics of the nearshore region adjacent to Grays Harbor, the report of a reconnaissance of the nature and abundance of benthic organisms in the area, data from grab samples that indicate the characterization of sediment regimes in the area, a review of responses to a questionnaire by various user and interest groups, and some recommendations for potential ocean disposal sites.

The literature review includes a description of ocean water currents and sediment movement in the vicinity of Grays Harbor. Two zones of sediment movement are described: one, in water less than 50 meters depth, in which wave induced transport moves the sediment onto the beaches; and another, in water greater than 50 meters, where the net sediment transport is north-northwesterly.

Literature pertaining to the biological food web in the vicinity of Grays Harbor is divided into descriptions of phytoplankton, zooplankton,

pelagic and demersal fish, marine mammals, crustaceans (especially Dungeness crab), and the benthic community.

There is documentation of biologic similarities between the offshore regions of Grays Harbor, the mouth of the Columbia River, and Coos Bay, Oregon where in recent years the ocean disposal of dredged materials has been studied.

A sampling program of sediments and benthic organisms in the nearshore ocean adjacent to Grays Harbor was carried out. A one-tenth square meter VanVeen sampler was used to collect a total of 36 samples on three transects extending approximately 16 kilometers from the mouth of Grays Harbor. Sub-samples were taken for grain size analysis and wood content. The samples were then washed on a 1.0 mm screen to separate benthic organisms from non-living materials.

Consideration of the grain size analysis allowed for classification of sediments of the area into three types; relict gravels, mid-shelf silts, and sands. The local sediment distribution varies somewhat from the regional pattern described in the literature. Benthic organisms, which were classified into major groups, were aggregated according to the location of biomass per samples and numbers of organisms per sample. This approach allowed for the identification of areas of high benthic populations.

A number of commerical fishermen, recreational user groups and public agencies having responsibilities nearshore to Grays Harbor were surveyed regarding the ocean disposal of dredged materials near Grays Harbor. Specific concerns relating to negative impacts of ocean water disposal near Grays Harbor include: the effects of increased suspended solids on primary productivity and on phytoplankton and larger organisms, the introduction of toxic materials into the water column and the food chain, the worsening of Grays Harbor bar conditions through increased shoaling, the avoidance of the disposal area by important species and the economic losses to commercial fisheries and to the recreation industry. Positive impacts mentioned included beach nourishment and for some groups, a desirable alternative to wet-lands disposal. The responses to the survey are reviewed in light of available information on the subjects mentioned by survey respondents.

Four alternative ocean disposal sites with varying distances from the harbor mouth are discussed. The sites are rated with respect to their relative cost in terms of transportation of the dredged materials and with respect to their relative environmental risks. Site I is within 16 kilometers of the harbor mouth but outside the 40 or 50 meter isobath where it is unlikely that the disposed materials could reenter the harbor. It is considered a medium cost and medium environmental risk site. Site II is a nearshore area just north and just south of the harbor entrance where disposed materials could migrate to the beaches. This is the site with lowest transportation cost. However, in spite of the potential benefit of beach nourishment, this site has the highest environmental risk. Site III is one suggested by several user groups surveyed. It is an area about 16 kilometers northwest of the harbor that has a rocky bottom. This site is out of the crab and trawl fishery areas and not in the main shipping channels. It is considered to be of medium cost and medium environmental risk. The fourth alternative disposal site is beyond the 500 meter isobath which is approximately 38 nautical miles (61 kilometers) from the harbor mouth. While this site is the highest in transportation costs it is considered to be of low environmental risk.

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PREFACE

The work described in this report was performed for the Seattle District U.S. Army Corps of Engineers, under contract Number DACW67-79-C-0046 titled "Grays Harbor Ocean Disposal Study, Literature Review and Grain Size Determination." The report includes: 1) a literature review of biological, chemical, geological, and physical characteristics of the Pacific Ocean nearshore area adjacent to the mouth of Grays Harbor; 2) a study of sediment characteristics and distribution of this nearshore area; 3) a reconnaissance of benthic fauna of the nearshore area; 4) a survey of concerned citizen and user groups that may be affected by ocean dumping of dredged materials in the nearshore area; 5) a summary of data gaps relating to evaluation of potential disposal areas; and 6) recommendations for additional study. The report also lists some advantages and disadvantages of various potential disposal sites and makes recommendations for additional study of each.

Coordinator of the study was Dr. John M. Smith who had primary responsibility for the literature review and collection of benthic fauna. Mr. Louis Messmer authored sections on phytoplankton and zooplankton. Review of the literature relative to pelagic and demersal fish, marine mammals and decapod crustaceans and review of commercial and sports fisheries was prepared by Mr. Donald F. Samuelson. Dr. James B. Phipps authored sections on physical and geological characteristics of the area as well as investigating and mapping sediment distribution. The sections on chemical characteristics of the water were authored by Dr. Eugene D. Schermer. All of the above authors are on the faculty at Grays Harbor College and are members of the Choker Research Group.

Drs. Ronald M. Thom and John W. Armstrong of Seattle District, Corps of Engineers, identified and weighed the benthic fauna.

Editorial assistance on the report was provided by Mr. Mark Reisman of the Grays Harbor College English Division. The authors are most grateful for his editorial and coordination efforts. Technical assistance was provided by Nita McCallum who performed the grain size analysis.

I. INTRODUCTION

The U.S. Army Corps of Engineers has the statutory responsibility for maintenance of the desired navigable depth for U.S. waterways. In 1976, the Seattle District of the Corps of Engineers prepared a Feasibility Report and an Environmental Impact Statement (EIS) describing a proposed project to widen and deepen the Grays Harbor navigation channel from the harbor bar to the City of Cosmopolis. The proposed project would require the removal of an estimated 19.3 million cubic yards of dredged material of which 16.7 million cubic yards is targeted for ocean disposal. In addition to the initial widening and deepening, which would be completed over a two year period, an estimated removal of 2.76 million cubic yards of dredged material would be required each year for channel maintenance. Of this maintenance dredging, approximately 2.7 million cubic yards might be disposed of in ocean waters.

This report deals with the existing conditions of the nearshore region adjacent to the mouth of Grays Harbor and with the potential impacts of disposal of the above mentioned quantities of dredged material in this area.

The contents and overall approach of this report are outlined below:

I. Literature Review

   A. A survey was made of available published data on the physical chemical, geological and biological characteristics of the region.

   B. Pertinent data on impacts of dredged material disposal from other regions that may be applicable to Grays Harbor was reviewed.

C. Knowledgable researchers who may have information relative to the impacts of dredged material disposal in ocean water off Grays Harbor were interviewed.

II. Location of mid-shelf silt deposits.

A. Sediments were systematically sampled on three transects from the mouth of Grays Harbor to a water depth of 60 meters.

B. These sediments were characterized by grain size and wood content. A map was prepared indicating regions of predominantly sand, silt or gravel.

III. A preliminary reconnaissance of the benthic fauna was made.

A. Biological samples were collected along with the sediment samples described above.

B. Identification of the organisms collected and classification analysis of faunal samples were supplied by Seattle District, U.S. Army Corps of Engineers.

C. Faunal distributions were compared to distributions near the mouth of the Columbia River and from Coos Bay, Oregon.

D. Faunal distributions were related to sediment characteristics.

IV. Various federal, state and local agencies, environmental organizations and user groups were surveyed and/or interviewed for their opinions on the impact of ocean disposal of the above described dredged materials.

V. Important environmental areas that may be adversely impacted by ocean disposal of dredged material were identified.

VI. Recommendations were made for further research to better evaluate the impacts of ocean disposal at Grays Harbor.

II. LITERATURE SEARCH

The literature review began with a computerized search of three bibliographic collections which included the Geologic Reference Data Base, National Technical Information Service publications, and Oceanic Abstracts. The pertinent reports listed by the computer literature search were obtained for reading and evaluation.

Other pertinent literature was obtained with assistance from the Northwest Coastal Information Center, at Newport, Oregon and by visiting various libraries at Oregon State University and the University of Washington. Discussions with a number of investigators in the departments of oceanography at these two universities assisted in the critical review of pertinent literature, including unpublished reports and theses.

A review of the most current knowledge regarding important animal and plant species in the food web was developed. Although some original data were gathered, there is a heavy emphasis on interpretation of collected data from other published reports. Information for this review was also gathered from governmental agencies, academic institutions and private consultants. Appendix C lists the individuals who were interviewed in gathering information and opinions for this study. Documents that were helpful were published or provided by U.S. Army Corps of Engineers, the U.S. Bureau of Land Management, the U.S. National Marine Fisheries Service, the Fisheries Research Board of Canada, the State of Washington Departments of Fisheries and Ecology, and the Oceanographic Commission of Washington.

III. PHYSICAL STUDIES

(J. Phipps and E. Schermer)

A. Site Description

Shelf Surface Currents

The major average flow of surface water on the Washington continental shelf is called the California current, and it flows southward in the summer months at speeds of 5 to 20 cm/sec. The current reverses in the winter months and flows northward at speeds of 10 to 20 cm/sec. (Budinger et al., 1964). These general regional currents are the average conditions and are frequently altered by winds and tides to produce eddies. Thus, at any given moment, the currents at a particular location may be exactly opposite to the "average" conditions.

Several workers have studied the forcing components of this reversing current system by looking at the effects of a particular component. For example, Ekman (wind-drift) currents have been studied by Duxbury et al., (1966). Their measurements at the Columbia River Lightship show, for example, that a 10 m/sec wind is capable of generating a 10 cm/sec current, and 40 m/sec winds can drive a 20 cm/sec current. The Ekman currents move approximately 30^{o} to the right for northwesterly to easterly winds, and, oddly enough, to the left for southerly to southwesterly winds.

Rotary tidal currents measured at the same lightship averaged 15 cm/sec. Renfro, et al., (1971) noted that the tidal current component was usually masked by other currents and thus, hard to detect.

Geostrophic currents have been mapped by several workers: Ingraham and Love (1978) during the summer of 1977 and Budinger, et al., (1964). The regional currents appear to be geostrophic in nature (i.e., north in winter, south in summer months).

Shelf Bottom Currents

Hopkins (1971) collected near-bottom current data for a period of two years, 21 kilometers offshore (approximately Latitude 46° 20") and in 80 meters of water. Continuous measurements for as long as two months showed net northerly and offshore water movement at velocities great enough to move silty sand 3.5 percent of the time (offshore 5° to 15° from bottom contours). Thus, it appears that although the main surface currents are seasonally reversing, the bottom current is not. This idea is consistent with the work of Gross, et al., (1969) who used the distribution of radionuclides and Barnes, et al., (1972) who measured the currents with sea bed drifters.

A good summary of the bottom currents on the Washington shelf and the related sediment transport is provided by Creager and Sternberg (1973). They divide the shelf off Grays Harbor into 3 distinct regions, based on sedimentological and hydrodynamic properties.

The first region is defined as landward of the 40-55 meter contour (Morse, et al., 1968 and Gross, et al., 1969). Here the bottom currents tend to move northward and east onto the beaches, as shown by sea bed drifters. Creager and Sternberg (1973) cite the work of Hopkins (1971) and O'Brian (1951) to suggest that the mechanism for transport in this zone is wind waves rather than currents.

The second region lies from the 50 meter contour out to about 145 meters and is the area of mid-shelf silts. Here the bottom currents trend north to northwest and are driven primarily by wind drift. Smith and Hopkins (1973) discuss the direct current measurements in this zone. The sedimentation of this zone is discussed by Nittrouer (1978) who presented excellent arguments for the north to northwestward movement of the mid-shelf silts into the Quinault Canyon.

The third region extends from depths of 145 meters out to the shelf edge. Here the sediments are composed of coarse relict sediments and modern fine sediments to form palimpsest deposits. This zone is far outside the criteria for this report and this will not by considered further.

In summary, there are two zones of sediment and water movement in the nearshore area at Grays Harbor. In water less than approximately 50 meters deep, wave-induced transport moves the sediments northeastward and onto the beaches, while in water deeper than 50 meters, the main transport is north-northwestward offshore.

Currents Near the Entrance to Grays Harbor

In the area between the jetties, the currents are dominated by tidal and wave forces. These tidal currents flow at maximum velocities of 75 to 90 cm per second (spring mean tide) at surface and bottom respectively on the flood and 90 to 135 cm per second (surface and bottom) on the ebb (Schuldt, 1979). Shoaling oceanic waves move through the mouth of the harbor and disperse their energies on the shoals of the inner bay. These waves generate currents, particularly on the shoals that are capable of transporting much sediment.

There is some controversy regarding bottom currents at the harbor entrance. Scheidigger and Phipps, (1976), maintained that there is a net landward flow of bottom water that transports oceanic sediment into the bay. Schuldt (1979) suggested on the basis of bathymetry and hydraulic studies that there are channels where the ebb flow dominates (i.e., adjacent to the south jetty) whereas most of the flood flow occurs on the shoal "middle grounds."

It is likely that the bottom currents in the harbor entrance move sediment both ways. And since the sediments are capable of responding to very slight current differences summed over long periods of time, only long time series measurements would define the net movement.

Waves

A. Direction:

In the winter the sea moves towards the coast from the southwest and south and in the summer it approaches from the northwest and north. The swell approaches the coast from the northwest and west in all seasons (Bourke, et al., 1971). A more detailed presentation of swell frequencies can be found in the National Marine Consultant report (1961) as shown in Figures 1 and 2.

B. Heights:

Wind-wave extremes were considered by Quayle and Fulbright (1975).

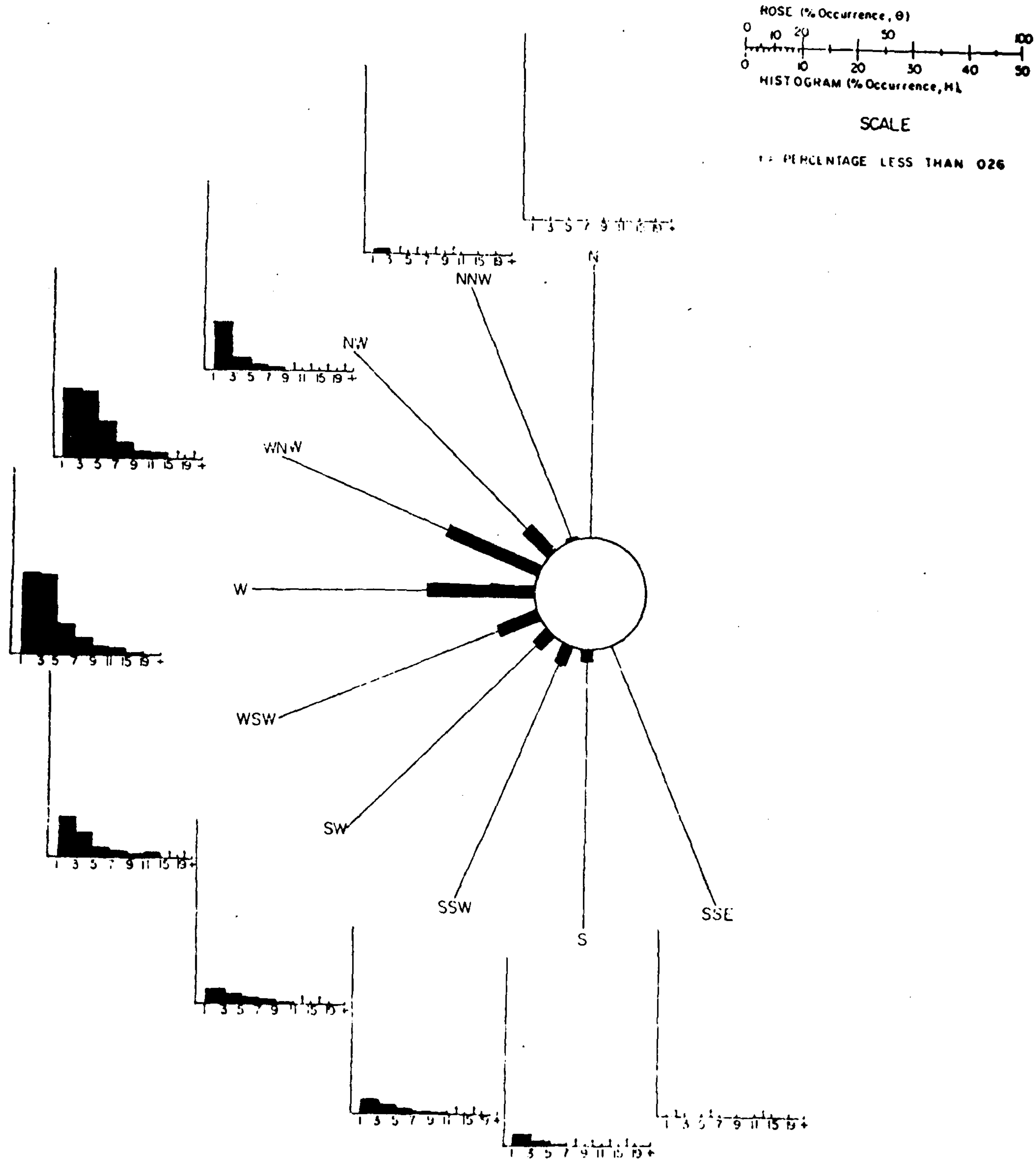


FIGURE 1
The average annual swell rose for a station at lat. 40° 12' N, long. 124° 30' W.

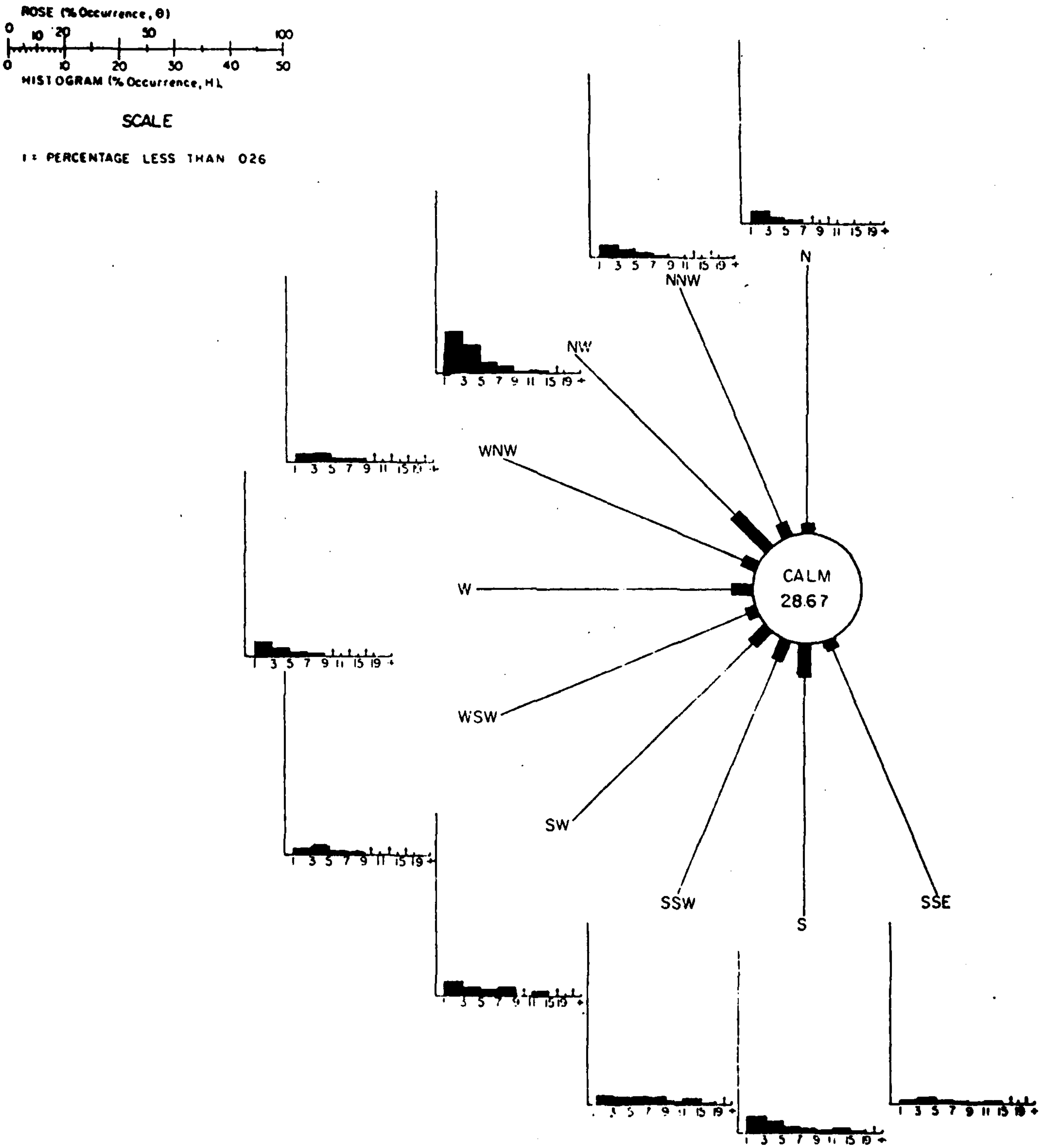


FIGURE 2
The average annual sea rose for a station at lat. 40° 12' N, long. 124° 30' W.

They suggested that extreme winds can generate significant wave heights of 12 meter (39 foot) waves every 5 years and 20 meter (65 foot) waves every 100 years. A population of these significant wave heights will produce an extreme wave of 36 meters (117 feet) every 100 years.

The wave lengths of average seas and swells, however, are more important than wave height considerations in determining the wave's ability to move bottom sediments. For their calculations, Smith and Hopkins (1973) used a swell with a 10 second period and a length of 156 meters whose critical depth was 39 meters. This calculation fits with the sediment distribution as described by Smith and Hopkins (1973).

Wind

Average scaler speeds of winds at the Columbia River Lightship were computed by Bourke in Renfro, et al. (1971) and are presented below:

Table 1. Average Scalar Wind Speeds at the Columbia River Lightship (From Renfro et al., 1971)

Month	Resultant Direction (14 years)	Speed Knots Max	Min	Ave.	
January	155	28	11	18	
February	174	22	9	16	
March	192	20	10	15	4 observations
April	233	16	10	13	taken every day
May	279	16	7	12	(every 6 hours)
June	291	13	7	10	
July	317	15	7	10	
August	305	14	7	10	
September	298	14	9	11	
October	159	18	11	14	
November	157	23	15	17	
December	163	24	15	17	

(one knot = 51.5 cm/sec)

Extreme winds mentioned by Quayle et al., (1975) are 67 knots (every 5 years) and 95 knots (every 100 years).

Sediment Sources

The mouth of Grays Harbor seems to represent the northern terminus of the nearshore Columbia River sands (Nittrouer, 1978). The sands on the beaches south of Grays Harbor, as well as those in the lower portions of the harbor itself, are also of Columbia River origin (Scheidegger and Phipps, 1976). Nittrouer (1978) presents an excellent case for the source of the mid-shelf silt deposits to evolve from the Columbia River. The relict gravel deposits to the west and north of Grays Harbor were probably deposited during the last glacial episode by the Chehalis River and thus have a rather complex source as pointed out by Venkatanatharam and McManus (1973). These authors also note that the sands lying between these gravel deposits and beach are relict and possibly from the same source, although they admit the possibility of local sources, such as cliff erosion, for this sediment.

Sediment Transport Directions

The distribution of the sediments on the Washington inner continental shelf, and past current studies attest to a net northward drift for the sediments. Only on the beaches where the sediment is moved by seasonally reversing, wave-generated currents is there a southward component of drift. This is not to say that the sediment transport direction is constantly to the north. Indeed, there is much evidence that there are excursions from this net northward transport direction (Hickey et al., 1978). Conversations with the local crab fishermen suggest that such excursions are capable of moving their pots several miles to the south in a brief period of time.

In general the sediment transport on the Washington continental margin are divided into three regions by Smith and Hopkins (1973). These regions are basically in agreement with the work of Creager and Sternberg (1973) mentioned above. One exception is that Smith and Hopkins mention 40 meters as the boundary for the inner shore zone, while Creager and Sternberg (1973) imply the boundary is approximately 50 meters.

The net sediment transport at the harbor's mouth appears to Scheidegger and Phipps (1976) to be inward, so that Grays Harbor traps a significant amount of the northward moving sand. Such transport direction explains the accumulation of Columbia River sediment inside the bay.

Studies of the bathymetry at the harbor's mouth and some limited current studies suggested to Schuldt (1978) that the area on the southern side of the mouth of Grays Harbor exhibits a net outward sediment flow.

The sediment transport situation at the mouth of Grays Harbor like the current direction problem appears to be complex enough to allow researchers to present conflicting views. It really deserves additional study to resolve these different views.

Rates of Sediment Movement

Consider that the distance a sediment particle moves in a year is dependent upon its size and the transporting energy available. For example, Smith and Hopkins (1973) suggested in studies of the Central Washington shelf in 50 to 80 meters of water, that a silt particle will move about 80 km/yr (four storms per year) while the net movement of a coarser sand particle in the same currents is neglible. This information allowed Smith and Hopkins (1973) to conclude that the average sediment particle would move 40 km/yr, a figure which, they say, compares nicely with the 30 km/yr determined by Barnes and Gross (1966) using radionuclide data.

Another, and perhaps more pertinent data set was collected off the mouth of the Columbia River by Sternberg et al., (1977). An experimental dredge spoils disposal site was established off the mouth of the Columbia River (site G) in about 28 meters of water and 460,000 cubic meters was dumped there. This made a conical pile about 1.5 meters high and 460 meters in radius with a volume of 324,000 cubic meters (71% of the total disposed). They estimated that the annual northward migration amounted to 630 cubic meters of sediment moving 460 meters (about 0.2% of the total deposit). The deposit will thus be rather stable for long periods of time. The grain size of the material involved may be more coarse than the material involved in the dredging of Grays Harbor.

Water Column Characteristics

There is a paucity of data on the chemical characteristics of the water column for the nearshore region adjacent to the mouth of Grays Harbor. Although a great deal of surface data on temperature and salinity have been accumulated (Bourke and Glenne, 1971) and a number of parameters have been observed as both a function of depth and season, the data are generally single point values and do not reflect the expected variations caused by tides or the Chehalis River discharge.

This report summarizes the available data on water column characteristics, but is must be emphasized that the values suggested for several parameters are offered as ephemeral values and not necessarily the mean or average for a particular season or depth.

Salinity, Temperature:

Surface salinity and temperature data for the Washington Coast have been collected at the Umatilla Lightship off Cape Alava and at a shore station on the Long Beach peninsula. Observations made by vessels at sea as well as data collected off Pacific Beach, Washington are on file at the National Oceanographic Data Center. A summary of these and other data is presented in Bourke and Glenne, (1971).

An extensive research program to determine the distribution of Columbia River water in the Northeast Pacific was carried out by the University of Washington, Department of Oceanography from January 1961 to December 1963. Data from this study, which included stations less than five nautical miles from the Grays Harbor mouth, are reported in several departmental technical reports and summarized in graphical form by McGary (1971). Additional and more recent chemical data have been collected during cruises of the University of Washington's research vessel R.V. Thompson, west from the surf zone off Copalis Rocks to the continental shelf (Postel, 1974).

Table 2 summarizes the ranges of temperature, salinity and dissolved oxygen (D.O.) varied with depth and season. These data are taken from McGary (1971) and may be used to make some generalizations about the nature of these parameters near Grays Harbor. During the winter season, wind and wave mixing of the water results in a rather uniform water column. In other seasons, there is a pronounced thermocline-halocline at 10-20 meters. Variation in the surface water is great, especially during the summer when periodic wind induced upwelling brings cold salty water to the surface. This upwelling results in average minimum surface temperatures

TABLE 2
TEMPERATURE, SALINITY AND DISSOLVED OXYGEN RANGES
BY DEPTH AND SEASON FOR NEAR-SHORE OCEAN
WATER ADJACENT TO GRAYS HARBOR. (MC CRARY 1971)

	SPRING			SUMMER			AUTUMN			WINTER		
Depth Meters	Temp °C	Salinity °/oo	D.O. ml/l	Temp °C	Salinity °/oo	D.O. ml/l	Temp °C	Salinity °/oo	D.O. ml/l	Temp °C	Salinity °/oo	D.O. ml/l
0	8-9	30-30.5	7-8	12-13	30.5-31.5	7-8	>12	31-31.5	7-8	8-9	<30	7-8
10	6-7	30.5-31	7-8	10-11	31-31.5	6-7	>12	31.5-32	5-6	8-9	<30	6-8
20	7-8	31-31.5	6-7	8-10	31-31.5	3-5	8-9	33-33.5	3-4	7-9	32-32.5	5-6
30	6-7	32-32.5	5-6	7-9	31.5-32	2-3	7-8	33.5-34	2-3	9-10	31.5-32.5	5-6
50	5-6	32.5-33	4-5	5-6	33-33.5	4-5	7-8	33.5-34	2-3	8-9	32.5-33.5	5-6
75	7-8	33.5-34	2-3	7-8	33-33.5	3-4	7-8	33.5-34	2-3	6-8	32.5-34	3-4

in the 9.5 to 10.5°C range, while the average minimum temperatures are from 12 to 14°C when there is little or no upwelling (Bourke and Glenne, 1971).

Winter and spring salinities off Grays Harbor are strongly influenced by the Columbia River plume which moves northward along the Washington coast during these seasons. Thus, surface salinities less than 30°/oo are typical, and values less than 20°/oo are observed during periods of peak runoff (Duxbury, 1972).

Dissolved Oxygen (D.O.)

Ranges for typical D.O. values near Grays Harbor are given in Table 2. These are comparable to the data summarized for the Washington Coast from the Columbia River to Cape Elizabeth by Hagar and Bourke (1971). There is very little variation of the averaged values in the upper 10 meters throughout the year. The highest as well as the lowest values of D.O. are found during the summer. This may be attributed to the opposing effects of upwelling of deep ocean water having low D.O. and photosynthetic production of oxygen promoted by increased radiation and the nutrient abundance in upwelled water (Duxbury, 1972).

There is a significant seasonal variation in D.O. at 20 meters depth. The water at this depth is apparently strongly influenced by upwelling, but it lacks the turbulent mixing and photosynthetic activity which replenishes oxygen. Thus D.O. values less than 3 ml/l are common at 20 meters depth from May to September according to Hagar and Bourke (1971). Summertime oxygen maximums at about 50 meters that are observed in offshore central Washington waters are not evident nearshore (Steffanson and Richards, 1964).

Nutrients

The most comprehensive nutrient data for waters near Grays Harbor were obtained during the 1961-63 University of Washington study and are discussed in Steffanson and Richards (1964). Concentrations of phosphate, nitrate and silicate undergo drastic seasonal fluctuations and, as was the case for D.O., reach both maximum and minimum values during the summer. Silicate values are strongly influenced by runoff and may reach maximums in other seasons (Hagar and Bourke, 1971). The gradient between surface and 50 meters is steep in summer which is illustrated in Table 3 by a series of samples taken off the mouth of Grays Harbor on September 22, 1963. (University of Washington, Department of Oceanography Tech. Report 159, 1966).

TABLE 3

PHOSPHOROUS, NITROGEN AND SILICATE CONCENTRATIONS IN MOLE/LITER AND PERCENT SATURATION OF OXYGEN FOR A SAMPLE TAKEN OFF THE MOUTH OF GRAYS HARBOR, SEPTEMBER 22, 1963.

Depth Meters	P mol/l	N mol/l	SiO_2 mol/l	% Sat O_2
0	.54	.2	16	111
3	.49	.2	14	111
6	.60	.3	16	113
10	.61	.2	14	112
20		14.2	31	77
30	2.14	25.0	32	61
50	2.02	22.5	26	58

The low P and N values coupled with high D.O. in the surface waters are typical of high photosynthetic activity in near-surface waters.

B. Field Study

Methods

All of the benthic samples collected in the fall of 1979 off Grays Harbor were taken with a 0.1 m^2 VanVenn grab, on the U.S. Army Corps of Engineers survey vessel, "Mamala." Samples A-1 and A-2 were taken on September 30, but the cruise was cancelled due to high winds and rough seas. The rest of the samples were collected on October 6, 1979. The position of each sample was determined by crew of the Mamala using the trisponder navigational system aboard the vessel. Water depths were measured by a fathometer, and later these depths were adjusted relative to mean low water. Station locations are given in Table 4.

The actual sampling procedure was as follows. The vessel would stop at an assigned water depth along a pre-determined line, and the grab was lowered and retrieved. The sediment was dumped into a large wooden tray and scraped into a large plastic bag. The sediment-filled bag was immediately placed on ice as the vessel moved to the next sampling site. The samples were returned to the lab; sub-samples were taken for grain size analyses; and the remainder was sorted for biological analysis.

Grain Size Analyses

Thirty to fifty gram sub-samples were wet seived through a 62 μ sieve. The fine fraction was retained, allowed to settle, dried, and weighed. The coarse fraction was also dried and sieved into even phi size fractions. Each fraction was converted to a weight percent as appears in Table 5. The median grain size was determined from cumulative frequency curves by summing the phi size at 16%, 50% and 84% and dividing this sum by 3.

TABLE 4

BENTHIC SAMPLING STATION LOCATIONS AND WATER DEPTHS
FOR SAMPLES TAKEN ON OCTOBER 6, 1979 OFF GRAYS HARBOR

STATION LOCATIONS

Sample	Lambert Coordinates N	Lambert Coordinates E	Depth (Feet)	Longitude 124° Min	Longitude 124° Sec	Latitude 46° Min	Latitude 46° Sec
A-1	593,455	1073,487	44.7	12	28	54	3
A-2	590,089	1070,829	70.7	13	4	53	29
A-3	588,550	1069,191	80.2	13	26	53	13
A-4	587,070	1068,015	94.9	13	42	52	58
A-5	585,393	1066,534	112.4	14	2	52	41
A-6	583,373	1064,761	123.6	14	27	52	20
A-7	580,251	1061,689	131.3	15	9	51	48
A-8	574,693	1056,313	154.8	16	22	50	51
A-9	567,994	1049,970	162.0	17	49	49	42
A-10	No Range		178.0	-	-	-	-
A-11	No Range		193.0	-	-	-	-
B-1	600,386	1029,094	200	23	11	54	51
B-2	600,077	1037,904	180.5	21	4	54	52
B-3	600,222	1047,456	159.8	18	47	54	58
B-4	599,988	1056,342	142.3	16	39	54	60
B-5	599,859	1061,119	119.8	15	30	55	1
B-6	600,042	1063,329	100.2	14	59	55	4
B-7	600,043	1064,893	74.9	14	36	55	5
B-8	599,975	1066,026	61.4	14	20	55	4
B-9(1)	599,937	1071,358	44.5	13	3	55	7
B-9(2)	599,810	1071,446	33.7	13	2	55	5
B-9(3)	599,750	1071,471	35.0	13	1	55	5
B-9(4)	599,670	1071,496	33.8	13	1	55	4
B-9(5)	599,575	1071,531	37.7	13	0	55	3
B-9(6)	599,513	1071,572	36.0	12	59	55	2
C-1	604,960	1070,665	52.3	13	16	55	56
C-2	607,368	1066,019	65.1	14	25	56	17
C-3	608,010	1064,907	85.0	14	41	56	23
C-4	608,594	1063,747	97.4	14	58	56	28
C-5	609,702	1061,535	110.3	15	31	56	38
C-6	611,891	1057,656	125.1	16	28	56	58
C-7	614,966	1051,884	140.9	17	54	57	26
C-8	620,400	1041,588	143.0	20	26	58	14
C-9	625,032	1032,980	157.6	22	33	58	56
C-10	627,002	1029,497	174.8	23	24	59	13
C-11	No Range		188.7	-	-	-	-
D-1	604,076	1064,710	75.3	14	41	55	44

TABLE 5
WEIGHT PERCENT AND PHI SIZE FOR SAMPLES TAKEN ON OCTOBER 6, 1979
OFF GRAYS HARBOR

Sample Number	Weight Percent (Class Phi Unit)								Median Phi
	-2	-1	0	1	2	3	4	>4	
A-1	--	--	---	.01	4.8	87	7.9	.05	2.5
A-2	--	--	---	.05	.48	75	2.4	.27	2.8
A-3	--	--	.02	.23	.60	79	17	3.5	2.7
A-4	--	--	.05	.10	.42	67	28	4.6	2.9
A-5	--	--	.008	.09	.44	65	29	5.6	2.9
A-6	--	--	.08	.17	1.1	45	41	13	3.1
A-7	--	--	.01	.35	9.4	23	51	16	3.2
A-8	--	--	.01	.2	1.9	14	71	13	3.5
A-9	--	--	---	.06	.2	3.5	75	22	3.7
A-10	--	--	.05	.11	.28	3.7	81	14	3.6
A-11	--	.03	.02	.09	.32	4.3	78	.17	3.6
B-1	--	.02	11	77	9.5	1.4	.2	.7	.5
B-2	55	16	11	10	4.5	1.9	.55	.58	-1.4
B-3	75	12	5.9	3.1	2.3	.58	.05	1.3	-1.4
B-4	--	--	---	.10	.04	7.7	26	66	3.9
B-5	--	--	.01	.06	.86	65	20	15	3.6
B-6	--	--	.02	.11	1.3	47	41	11	3.1
B-7	--	.01	.01	.04	1.0	87	12	.2	2.7
B-8	--	.01	.01	.20	3.6	87	1.1	.8	2.6
B-9_1	--	--	---	.03	6.0	89	5.3	.13	2.5
B-9_3	--	--	---	.14	20	77	2.4	.19	2.3
B-9_4	--	.05	.05	.05	6.6	89	2.0	2.2	2.5
B-9_6	--	--	---	.03	32	66	2.7	1.2	2.2
B-9_5	--	--	---	.03	18	80	2.1	.05	2.3
C-1	--	--	.01	.08	3.7	85	10	.70	2.6
C-2	--	--	3.3	.46	1.4	80	14	.67	2.6
C-3	--	--	.01	.07	1.2	79	18	1.6	2.7
C-4	--	--	.01	.04	.73	63	32	4	2.9
C-5	--	--	.003	.33	9.2	43	40	7.6	2.9
C-6	57	13	11	10	7.2	1.3	.18	.9	-1.2
C-7	--	--	.003	.06	.41	5.6	29	65	3.9
C-8	28	26	24	12	4.2	.70	.03	.19	-1.03
C-9	--	.04	.04	7.2	53	38	1.5	.23	1.8
C-10	21	33	27	4.7	6.1	6.5	.56	.62	- .8
C-11	42	35	17	4.5	1.3	.30	.04	.08	-1.6
D-1	--	--	.02	.08	1.6	84	14	1.1	2.7

Wood Analyses

The wood analyses presented a problem because, unlike the material inside the estuary, this wood was mineralized to the extent that it would not float in water when dried. It would not even float in carbon tetrachloride (density - 1.5) and so the mechanical separation was very difficult. A technique was developed to swirl the wood up above the fluid (carbon tetrachloride)-sediment interface and quickly dump it through a 62 μ sieve where the wood and the foraminifera and certain diatoms were retained. This mixed residue was then dried and weighed and the wood - non-wood ratio visually estimated. The results appear in Table 6 and can be considered accurate to an order of magnitude.

Wood Fragments

Sediment containing wood fragments appears as a general north-south trending band, within which there is a narrow arcuate zone where they are more concentrated (Figure 3). The distribution of wood fragments in these samples does not seem to be controlled by either water depth or sediment type.

Sediment Types

The sediments of the area can be divided into three sediment types: relict gravels, mid-shelf silts and sands. All three types are described in the literature (see Section IIIA of this report).

For the purposes of this report the relict gravels are defined as the coarse material whose median grain size is less than 2 Ø. It is acknowledged that this definition is unusual in that 2 Ø to 0 Ø material is generally called sand. But in this instance such a designation would confuse the issue. The material in the gravel patch is clearly relict and clearly coarser than the modern sands to the south and east.

TABLE 6
PERSENT OF WOOD IN SAMPLES TAKEN ON OCTOBER 6, 1980
OFF GRAYS HARBOR

Weight - Percent
Wood in Samples

Sample Number	% Wood
A-1	0
A-2	0
A-3	.026
A-4	.197
A-5	.027
A-6	.038
A-7	.006
A-8	Trace
A-9	.011
A-10	.052
A-11	.044
B-1	0
B-2	0
B-3	Trace
B-4	Trace
B-5	.007
B-6	.262
B-7	.213
B-8	Trace
B-9$_{1}$	0
B-9$_{3}$	0
B-9$_{4}$	0
B-9$_{5}$	0
B-9$_{6}$	0
C-1	Trace
C-2	.20
C-3	.0089
C-4	.012
C-5	.019
C-6	.006
C-7	.008
C-8	0
C-9	0
C-10	0
C-11	0
D-1	.050

WOOD CONTENT

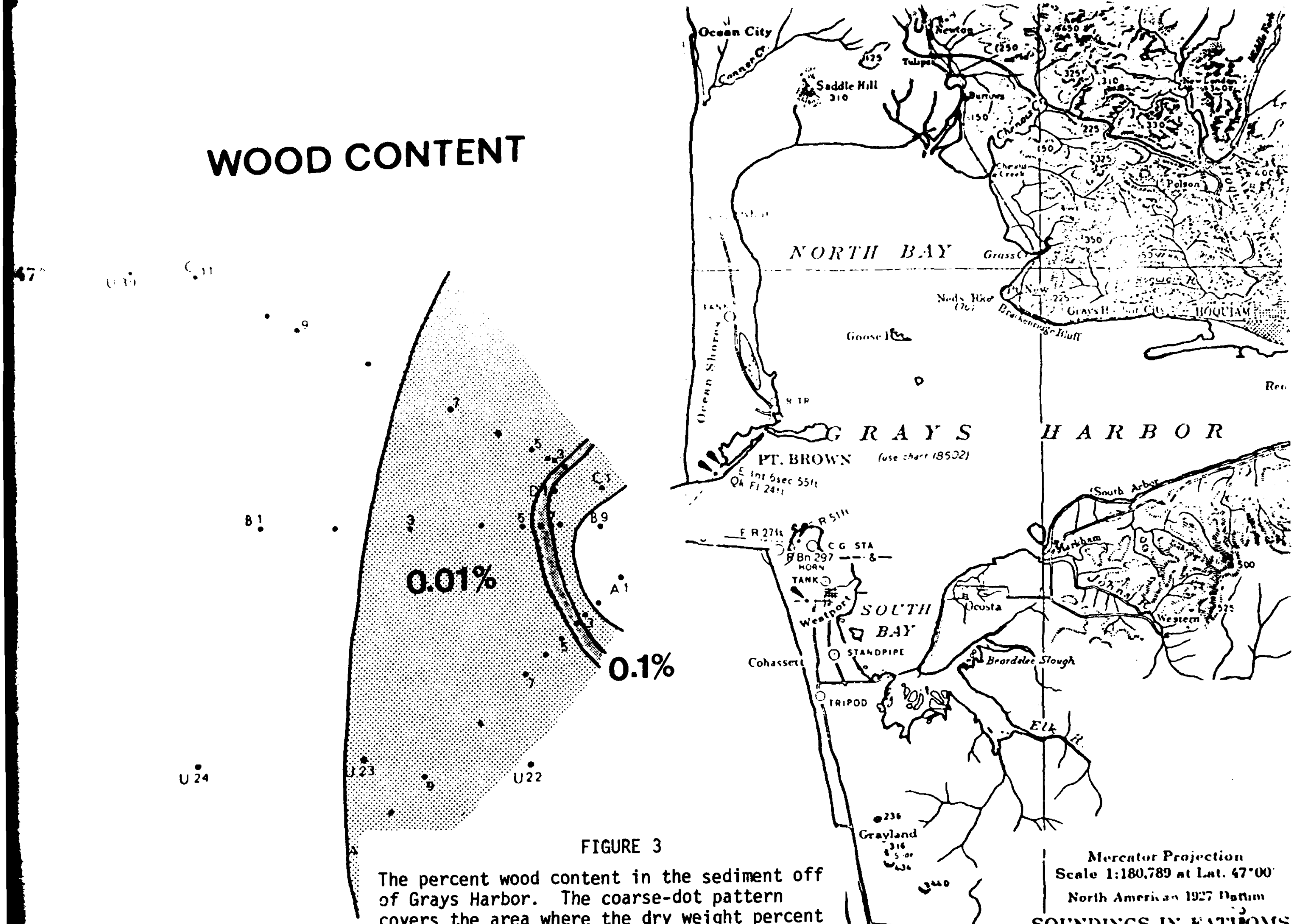


FIGURE 3

The percent wood content in the sediment off of Grays Harbor. The coarse-dot pattern covers the area where the dry weight percent wood ranged from a trace to hundredths of a percent. The fine-dot pattern shows the area where the dry weight percent wood ranged in the tenths of a percent.

The mid-shelf silts are defined by Nittrouer (1978) as those having approximately 50% more silt by weight. The "approximately" allows him to include some samples that have 47% silt in the mid-shelf silt. We have done the same in this report. The median grain size of the silts is 3.0 Ø. Fortunately, Nittrouer collected (in 1976) and analyzed four samples within the study area (Table 7). These samples were also used in this report and proved to be most helpful.

The sands can be defined as anything coarser than 4 Ø and finer than 2 Ø. The median grain size of the sand ranges from 2.2 to 3.6 Ø. The distribution of the median grain size in the sandy sediments is shown on Figure 4.

The distribution of the sediment types (Figure 5) shows three significant variations from the regional picture. One such variation is the silt tongue that trends north eastward and overlaps the relict gravel deposits. This trend is different than the north-south one portrayed by the regional studies in the area. The second variation is that these same mid-shelf silts do not appear in the A-line samples at all. The silt-sand boundary must swing toward the west and through much deeper water than to the 50 meter regional average for this line.

The third variation is that the relict gravel deposits appear to be much further south and inshore from where other workers (Venkatanatharam and McManus, 1973) had them mapped.

Discussion

The local sediment grain size distribution varies somewhat from the regional pattern. It seems likely that the forces that transport the sediments would also show similar local variations. If this is true, then it would appear that one should be cautious in applying the regional sediment transport regime to the local conditions. Therefore, it would seem prudent to verify the sediment distribution pattern presented in this report, particularly the silt boundary, by more intensive sampling.

TABLE 7
UNIVERSITY OF WASHINGTON (NITTROUER) SAMPLES

Cruise W7606A

Sample Number	Weight Percent (Class Phi Units)					Location		Water Depth
	1	2	3	4	>4	Lat.	Long.	
U-22	.17	.78	12.40	57.60	29.16	46°50'	124°15.4'	42 meters
U-23	.60	6.8	10.5	65.7	16.34	46°50'	124°20'	53 meters
U-24	.14	.50	3.54	48.50	47.0	46°50'	124°25'	73 meters
U-39	1.68	10.2	47.6	18.0	24.1	40°00'	124°26.8'	60 meters

SAND GRAIN SIZE

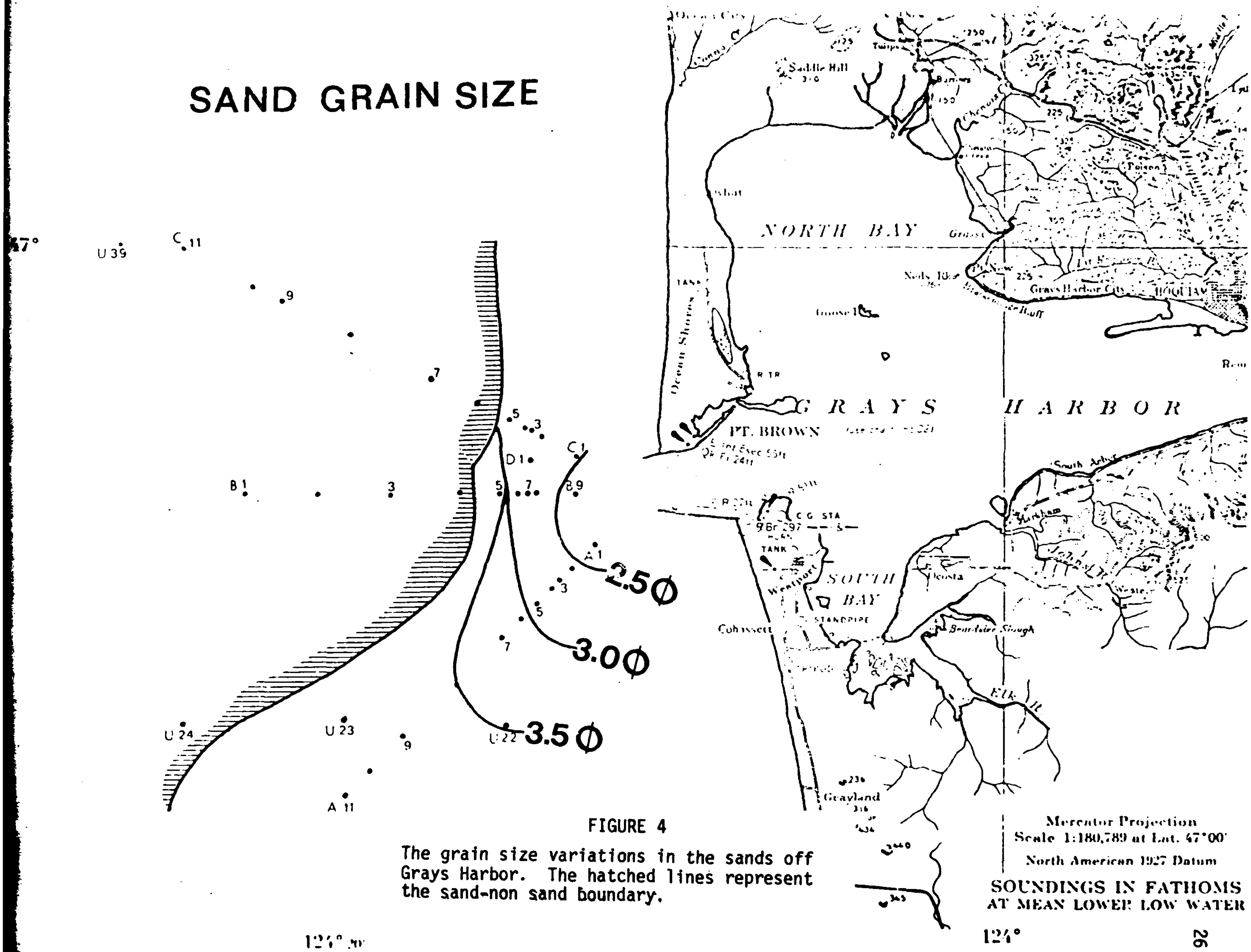


FIGURE 4

The grain size variations in the sands off Grays Harbor. The hatched lines represent the sand-non sand boundary.

SEDIMENT TYPES

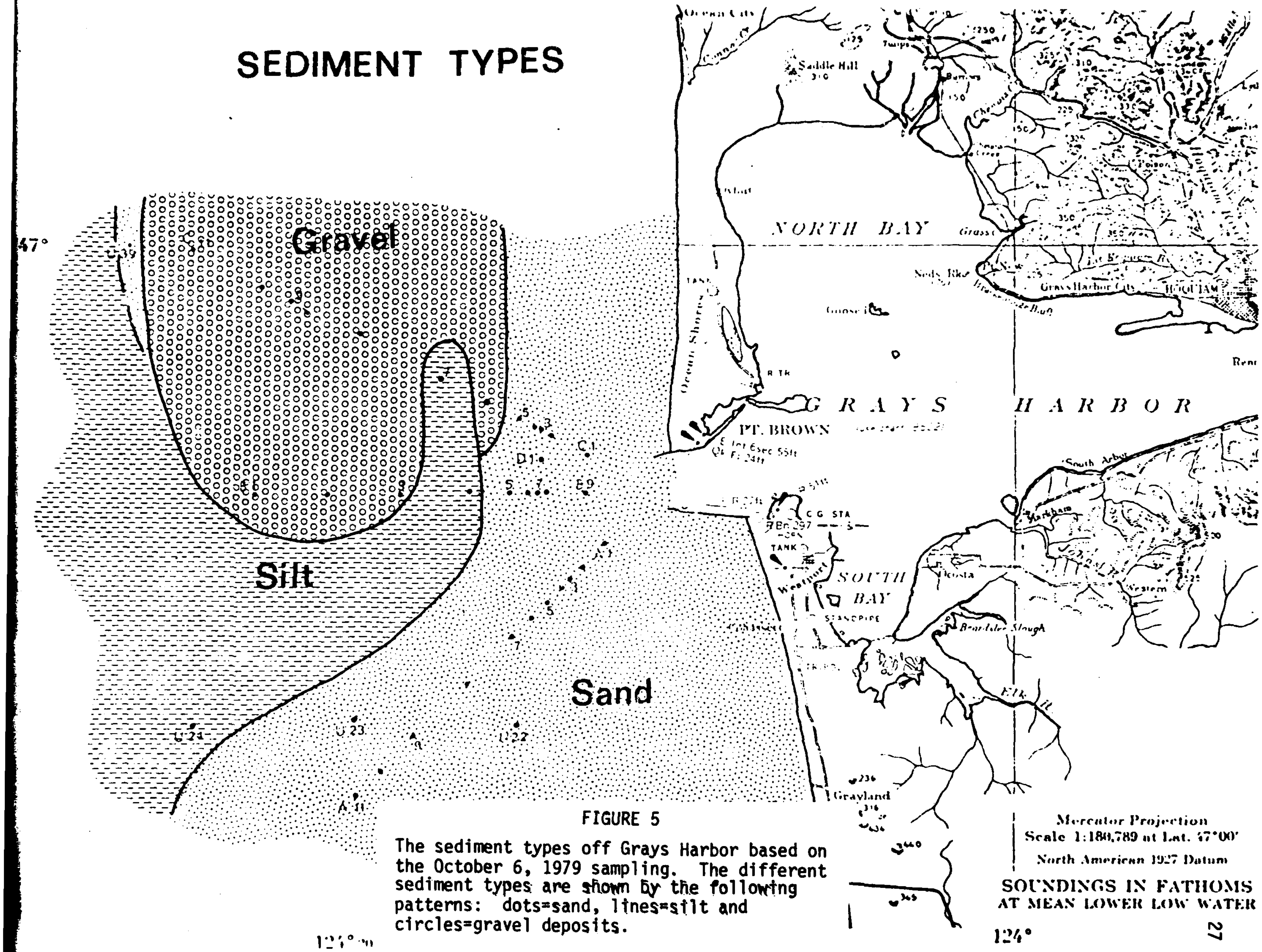


FIGURE 5

The sediment types off Grays Harbor based on the October 6, 1979 sampling. The different sediment types are shown by the following patterns: dots=sand, lines=silt and circles=gravel deposits.

IV. BIOLOGICAL COMMUNITY REVIEW

(J. Smith, D. Samuelson, and L. Messmer)

The biological food web off the Washington coast, within the study area, can be arbitrarily divided into three interacting communities in the nearshore, subtidal region. First, a benthic community occurs consisting of those organisms living in the sediment or near the sediment-water interface. Second is a pelagic community consisting of those organisms drifting, floating or swimming in the overlying water. Finally, a near bottom demersal community is found to interact between the benthic and pelagic communities.

Benthic communities depend on the continual descent of organic materials from the overlying waters for nourishment in the form of plankton, decomposing organisms, fecal pellets and suspended sediment particles. Bottom organisms, including bacteria, marine worms, crustaceans and clams break down these organic materials into simpler forms which are recycled in other parts of the food web. Some fish swim up into the surface waters to feed on pelagic organisms. Conversely, many benthic and demersal species, clams and flatfish, produce eggs which float to the surface, hatch into planktonic larvae, and become dispersed by ocean currents before settling permanently to the bottom.

Therefore, throughout the following discussion, the reader should keep in mind the complex biological community structure found to exist off the Grays Harbor entrance, which in turn, interacts within a unique physical and chemical environment, combining to form a dynamic ecosystem.

A. Site Description

Phytoplankton:

The phytoplankton in the study area consist mainly of diatoms and microflagellates. Diatoms constitute the bulk of the net phytoplankton (>35µ), but Anderson (1965) found that they contributed less to the total population (2-39 percent) than the small phytoplankton. Different assemblages of diatom species have been identified from inshore, offshore and transitional water, (Anderson, 1972). In Anderson's study, inshore water was defined by salinity less than 32.5 o/oo; offshore water by more than 32.5 o/oo; and transitional water by low salinity, but with fewer species of phytoplankton than inshore or offshore waters. Anderson also identified assemblages for summer and winter seasons. There is also a surf-zone association of two diatom species that is the main food for large razor clam populations from the Columbia River northward at least 100 kilometers, (Lewin, et al., 1970).

Phytoplankton are the foundation of most of the food chains in the study area. Anderson (1972) estimates an annual productivity exceeding 125 g C/m^2 in the Columbia River and oceanic waters and at least 300 g C/m^2 in upwelling areas. This is comparable to values reported for the Fladen Ground in the North Sea (54-127 g C/m^2) and Georges Bank (130-300 g C/m^2) (Raymont, 1963).

In their analysis of stomach contents of 11 species of fin fish at the Columbia River ocean disposal site, Durkin and Lipovsky (1977) found that phytoplankton were the primary diet of anchovies and that anchovies were in turn eaten by nine of the other fish species. Anderson (1972) suggests that the absence of a "spring bloom" of phytoplankton in some years may be due to heavy grazing by copepod populations.

There is a massive spring increase in phytoplankton in the Columbia River plume, but the most dense and variable populations were found in summer in upwelling areas and directly off the river mouth (Anderson, 1972). Anderson (1964) found the highest productivity of phytoplankton in the Columbia River plume at the surface and at the 10 meter depth, except from October-March when the river was low. He found little productivity below 30 meters.

Zooplankton:

The zooplankton consist of two groups. The holoplankton are completely planktonic throughout their life cycle. They include the jellyfishes, ctenophores, rotifers, many crustaceans, and some annelids and molluscs. Crustaceans are considered the most important group in fishery related food chains.

The meroplankton are planktonic in their larval stages and only later become benthic (bottom-dwelling) or nektonic (free swimming). They include sponges, sessile coelenterates, flatworms, annelids, molluscs, decapod crustaceans, echinoderms, and other invertebrate groups. The eggs and larval stages of many fishes are planktonic. Anchovies and flatfishes are locally important examples.

Most zooplankton feed upon phytoplankton. Zooplankton are in turn fed upon by many species of fish. Durkin and Lipovsky (1977) studied the stomach contents of 11 species of finfish before and after the experimental dredge disposal off the Columbia River. They found that copepods, mysids, amphipods and cumaceans were important in the diet of several finfish species, but the importance of these organisms as food items decreased after the disposal, and decapods and small fish became more important.

Copepods are perhaps the best studied group of zooplankton. They give some idea of the numbers of individual zooplankters that can be present in a given volume of water. Peterson and Miller (1976) accumulated three and one-half years of data on copepods in the first 10 kilometers of continental shelf off Newport, Oregon. They found summer populations of from 5,000 individuals/m^3 to 51,372/m^3 following phytoplankton blooms. They noted the greatest densities within one mile of shore and decreasing numbers as they sampled farther offshore. They identified 6 of 58 species as by far the most numerous and felt that these six exerted the main control of grazing dynamics on phytoplankton.

Zooplankton often migrate vertically on a daily cycle, remaining in deeper layers by day and migrating upward many meters to richer grazing at night. In a critical review, Sullivan and Hancock (1977) stress that the horizontal dispersion of zooplankton is non-random and can be quite "patchy."

Table 8 summarizes the seasonal occurrence of some zooplankton groups off the Columbia River mouth.

TABLE 8

Seasonal Abundance of Zooplankton Groups
at the Columbia River Disposal Site.

GROUP	MOST ABUNDANT	LEAST ABUNDANT	AUTHORS
Ichthyoplankton	Jan-March	July-October	Holton/Small 78
Shrimp and crab larvae	Feb-Aug winter-spring	Aug-Jan	Holton/Small 78 Boone, et al., 78
Dungeness crab larvae	Jan-June		Boone, et al., 78
Copepods	June-Aug		Boone, et al., 78

Petersen and Miller (1976), in their three and one-half year study of the continental shelf (out to 16 kilometers), stressed the wide annual variations in abundance of important species of zooplankton.

Jamart, et al., (1977) mentioned the importance of copepod nauplius stages in the food web. They felt the role of nauplius larvae could not be predicted from what we now know of larger forms. They are presently studying the feeding of nauplii on phytoplankton.

Marine Fish:

a. Pelagic Fish:

In the following discussion, the distinction between pelagic marine fish and demersal marine fish is relatively arbitrary since many of these species can be found at all depths. Generally however, those fish labeled pelagic are found off-bottom and distributed throughout the water column, whereas those termed demersal are found on or near the bottom and only occasionally are found moving upward in the water column. Anadromous species are included with pelagic fishes, under a separate subheading.

Some important pelagic marine fish inhabiting coastal waters in the proximity of the Grays Harbor entrance include the Pacific herring, Clupea harengus pallasi, northern anchovy, Engraulis mordax, Pacific sardine, Sardinops sagax, surf smelt, Hypomesus pretiosus, shiner perch, Cymatogaster aggregata, striped seaperch, Embiotoca lateralis, pile perch, Rhacochilus vacca, and the redtail surfperch, Amphistichus rhodoterus.

Occasionally the albacore tuna, Thunnus alalunga and jack mackerel, Trachurus symmetricus, are found when warm southern currents invade the Pacific Northwest.

Many of the pelagic marine fish travel in schools. Pacific herring and the Northern anchovy are characteristically found in large schools. Adequate stocks of herring and anchovies are considered by many to be necessary to sustain large stocks of important food fish (Otram and Humphreys, 1974). They may well be the key to fluctuations in salmon populations in our area, particularly during middle to late summer when these marine fish constitute the major items in the diet of chinook and coho salmon. Thus, they greatly influence the coastal movement of salmon and may be the deciding factor determining how long they may stay in any particular offshore area (Thompson and Snow, 1974).

Of the pelagic marine fish, the Pacific herring and Northern anchovy have considerable importance. Besides their important role in the marine food web, both herring and anchovies have been, or are presently being, harvested commercially in Washington as food fish or bait fish. An intensive fish meal reduction fishery occurred through 1968. Increased efficiency, resulting in higher exploitation rates, coupled with a series of poor year-classes, led to a sharp decline in the abundance of herring stocks (Otram and Humphreys, 1974). While stocks have recovered gradually (Pacific Fisheries Management Council, 1979), no commercial herring fishery exists off Grays Harbor today.

The northern anchovy is probably the most abundant fish in the Northeastern Pacific Ocean. Of the three subpopulations existing along the Pacific coast, the Grays Harbor area experiences dense schools of the northernmost subpopulation which extends from British Columbia to Central California (Figure 6).

Anchovies are usually found well below the surface during the day and in the upper layers at night. No north-south migrations have been observed, but the fish tend to move offshore during the spring. Tagging studies off Oregon

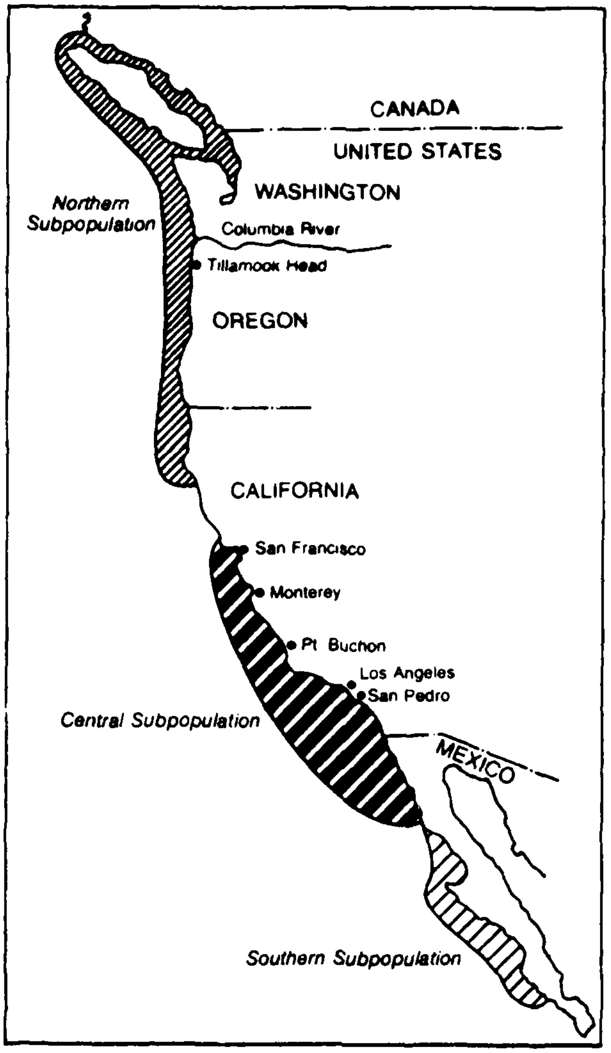


FIGURE 6

Geographic Distribution of Northern Anchovy Subpopulations Along the U.S. West Coast (Pacific Fisheries Management Council, 1979) and Washington have shown that there is no significant movement of anchovies from a given area (Baxter, 1967). Currently, the only fishery on the northern anchovy in the Grays Harbor area is a commercial and recreational live bait fishery during Auguest and September. These anchovies are harvested mainly as baitfish for the commercial and recreational tuna fishery. Anchovies comprise nearly 30 percent of the diet of coho and chinook salmon, thus indicating the important role of this species in the marine food web interactions (Ahlstrom, 1967).

The Pacific sardine is an inshore, pelagic fish whose range extends from Baja California, including the Gulf of California, northward as far as southeastern Alaska. In the 1930's and early 1940's, the Pacific sardine supported a large fishery; however, since the middle 1940's, populations have been reduced below harvestable levels.

There are four species of seaperch commonly found both inside and outside of the Grays Harbor estuary. They are the shiner, striped, pile and redtail surfperch. Typically, most seaperch inhabit the jetties and piling that support growths of attached kelp and mussels, although they have been observed to move into deep water during winter (Somerton and Murray, 1976). In general, these species have relatively little commercial value; however, there has been an emerging recreational jetty fishery for them in recent years (Culver, 1978).

While albacore and jack mackerel are both common of the Pacific Northwest coast, their occurrence around Grays Harbor is dependent upon the northerly movement of the warm California current during the summer months. Although occasional albacore are taken by fishermen as close in as the Grays Harbor entrance bouy, the fishery is primarily offshore (56-240 km or 35-150 miles). Mackerel are not harvested commercially off our coast but are taken as an incidental catch by salmon charter boats in the area.

b. Anadromous Fish:

Anadromous fish ascend rivers and streams from the ocean to spawn. In the coastal waters off Grays Harbor, there are a number of anadromous species, including five species of salmon (chinook, Oncorhynchus tshawytscha, coho, O. kisutch, pink, O. gorbuscha, chum, O. keta, and sockeye, O. nerka), steelhead, Salmo gairdneri, sea-run cutthroat, Salmo clarki clarki, sea-run Dolly Varden, Salvelinus malma, Pacific shad, Alosa sapidissima, eulachon or smelt, Thaleichthys pacificus, sturgeon, Acipenser medirostris and A. transmontanus, and Pacific lamprey, Lampetra tridentata. Although the specific life history, behavior patterns and habitat requirements vary greatly for each of these fish and for different races among individual species, their general life history is similar. Each is produced from eggs hatched in gravel of fresh water streams; each spends some nursery period in its home stream or estuary, and following an extended period of feeding, growth and maturation in the marine environment, each returns to its original stream to spawn.

Coho and chinook salmon are the main species caught in the Washington ocean commercial, troll and recreational fishery. These species also contribute to the gillnet fishery in Grays Harbor. In recent years, particularly in the odd-numbered years, pink salmon (from British Columbia's Frazer River) have made a substantial contribution to both the commercial and sport fishery. Chum salmon, once a major gillnet fishery in Grays Harbor, are only fished commercially for several weeks between September and November because of their limited occurrence (October15-November 5). Seasons are presently reduced to only a few weeks between September and November. Sockeye salmon, while not contributing to the state's commercial or sport fishery, except those taken by Indians on the Quinault River, are present in the waters off our coast during their spawning migration toward the Columbia River. Figure 7 gives the approximate times of the year we might expect various anadromous

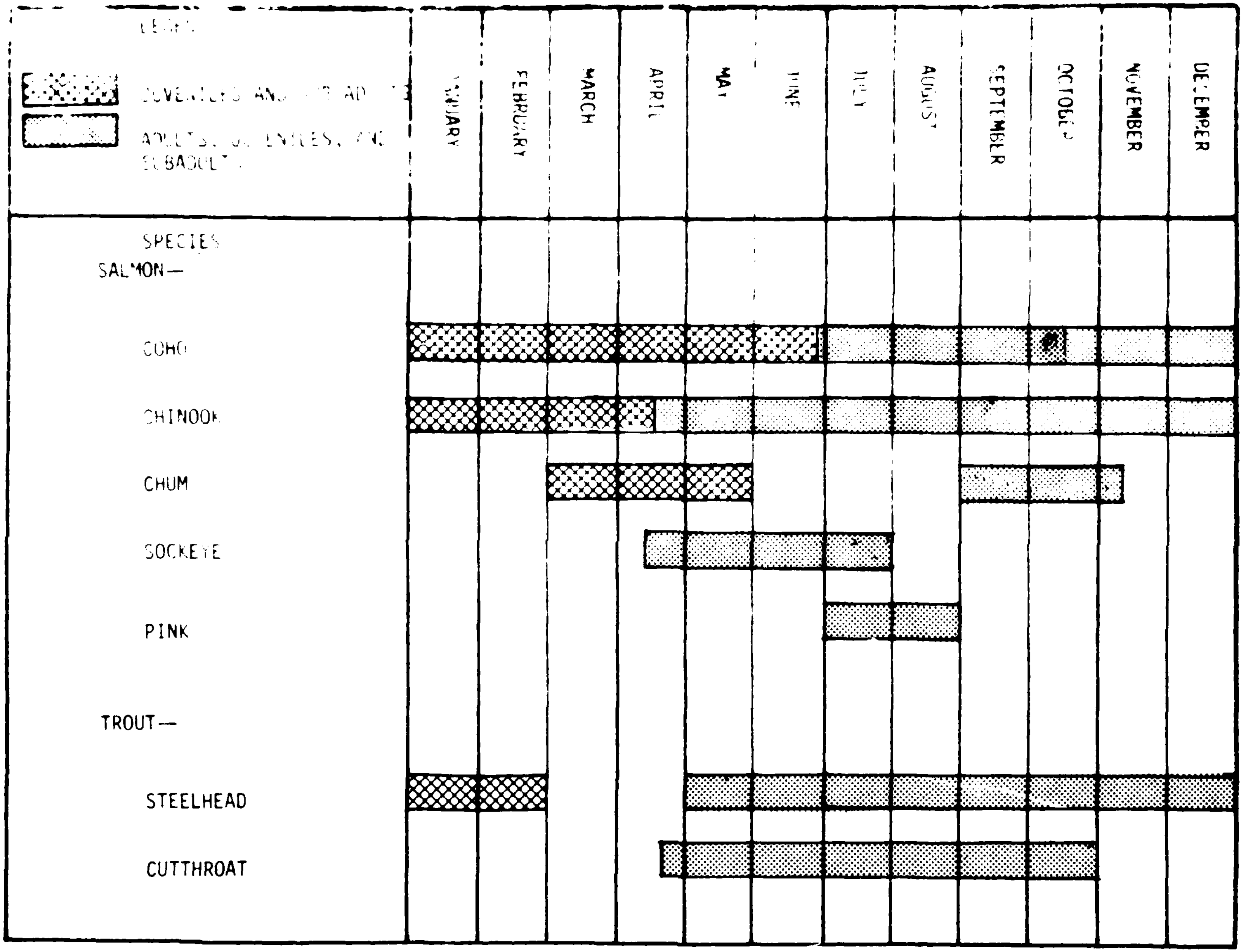


FIGURE 7
General salmon and trout occurrence
in nearshore Grays Harbor waters.

fishes in the nearshore waters off Grays Harbor.

Two species of sturgeon, the white sturgeon (Acipenser transmontanus) and the green sturgeon (A. medirostris), occur off the Grays Harbor coast. Both species are of commercial importance. During the period 1967-1975 the average annual catch of green sturgeon in Grays Harbor was 24,530 pounds, while the catch of white sturgeon was 35,721 pounds (Washington Department of Fisheries). Sturgeon spawn in spring and early summer after entering the rivers of coastal estuaries. Generally the fish are bottom dwellers, stirring up mud and debris with their snout to find crustaceans and other invertebrates for food.

American shad are another species found in the study area. Generally, shad feed on plankton and small invertebrates. Spawning occurs in late spring and early summer after the adults have left marine waters and ascended the coastal rivers. The young shad migrate back to the sea after five or six months (Oregon State University, 1971). Shad are presently taken from the Chehalis River in a sport fishery and as an incidental catch to the Indian salmon net fishery (Stone, 1980: personal communication).

The adult Pacific lamprey, Lampetra tridentata, is the most common lamprey species found in the study area. Historically considered a nuisance fish because it attaches to and sucks body fluids from salmon and steelhead trout, the lamprey is becoming increasingly sought after for commercial export to European countries where the species is regarded highly as food fish. The adult lamprey return to fresh water in spring to deposit their eggs.

The widely distributed eulachon, or Columbia River smelt, spends two years at sea and returns to spawn in its third year. Large aggregations have been reported off the mouth of the Columbia River and other Southwest Washington estuaries (including Grays Harbor) in November, December and January, just prior to their migration up the river. Migration upstream may be greatly influenced by the temperature of the river water (Smith and Saalfeld, 1955). The adults and juveniles generally feed on auphausids and other planktonic organisms. The eulachon is important in the food chain beacuase it is consumed by dogfish, sturgeon, hake, cod, salmon, finback whale, porpoise, seals and sea lions (Barraclough, 1964).

In certain years, eulachon contribute to a considerable commercial and recreational fishery in the Columbia River system, primarily in estuaries and along rivers as they head upriver to spawn (Pruter and Alverson, 1972). Although they do enter the Grays Harbor estuary, there is no significant fishery for them.

c. Demersal Fish:

Demersal fish, also known as groundfish or bottomfish, are abundant in the nearshore and offshore waters of Grays Harbor, and sustain a year round commercial fishery of major importance in our area. Of the 45 species known to occur off the Washington and Oregon coast, it is estimated that 10 economically important species are found in the nearshore region off Grays Harbor.

The most common and commercially important rockfish in the study area include yellowtail rockfish, Sebastes flavidus, orange (canary) rockfish, S. pinninger, boccacio rockfish, S. paucispinis, yellow-eyed rockfish, S. ruberrimus, silvergrey rockfish, S. brevispinis, Pacific Ocean perch, S. alutus, and the short spine thornyhead, Sebastolabus alascanus. The abundant black rockfish, Sebastes melanops and the blue rockfish, S. mystinus are shallow water species (10-80 meters) that escape the major trawl fishery off Grays Harbor, but are fished heavily by charter boats and private recreational fishermen.

Other important groundfish include the Pacific cod, Gadus microgadus, hake, Merluccius productus, sablefish (black cod), Anoplopoma fimbria, kelp greenling, Hexagrammos decagrammus and ling cod, Ophiodon elongatus. The commercially important flatfish species of the study area include the Dover sole, Microstomus pacificus, English sole, Parophrys vetulus, petrale sole, Eopsetta jordani, rock sole, Lepidopsetta bilineata, turbot, Atheresthes stomias, sand sole, Psettichthys melanostictus, rex sole, Glyptocephalus zachirus, Pacific sanddabs, Citharichthys sordidus, and starry flounder, Platichthys stellatus. The starry flounder is the most commonly found flatfish in the shallow waters around the mouth of Grays Harbor. Significant sport catches have been reported from both the north and south jetties during June and July.

While the majority of the commercially important groundfish and flatfish species occur primarily on the outer continental shelf and frequently inhabit the continental slope, several species are found in the inshore waters (0-93 m, 0-50 fathoms). These include rockfish, ling cod, Pacific cod, English sole, Pacific sanddab, rex sole, juvenile petrale sole, sand sole, and starry flounder. Adult petrale sole are not abundant inshore of 50 meters. Juvenile sablefish and Pacific Ocean perch are occasionally very abundant in nearshore waters during mid-summer. Table 9 contains life history, management and economic characteristics concerning these nearshore species.

Tagging studies and inferences drawn from depth-catch records have demonstrated some rather well defined seasonal distribution patterns of onshore-offshore movement for some demersal species. Ling cod do not migrate to any large extent. Pacific cod do migrate somewhat. The Pacific hake undertakes feeding migrations during the spring and summer, traveling along the continental shelf and upper slope as far north as Southeastern Alaska (U.S. Fish and Wildlife Service, 1970). Some rockfish species, such as the yellowtail and bocaccio rockfish, do not appear to migrate to a large degree and tend to stay within Washington waters. The fairly large population of black rockfish found inshore along the Washington coast between the Grays Harbor north jetty and Point Grenville appears to remain fairly stationary with some offshore

TABLE 9
LIFE HISTORY, MANAGEMENT AND ECONOMIC CHARACTERISTICS
OF SEVERAL NEARSHORE (LESS THAN 20 FATHOMS)
GROUNDFISH OFF GRAYS HARBOR, WASHINGTON

	Roundfish:		Rockfish:		Flatfish:					
Characteristic	Lingcod	Pacific Cod	Black	Blue	Dover Sole	English Sole	Pacific Sanddab	Rex Sole	Petrale Sole	Starry Flounder
Bottom depths of common occurance (fm)	1-100	10-90	0-50	0-50	20-800	10-150	10-60	20-250	20-250	0-90
Spawning Period	Nov-	Jan-Mar	*	Jan-Mar	Nov-Mar	Nov-Mar	July-Sep	Jan-Jun	Dec-Apr	Nov-Feb
Maximum Age (years)		8	18+	24	25+	18	13	24	25	10+
Average age at maturity, female	5-6	2-4	*	7	8-9	5	6-8	3	4-5	*
Average size (cm) at maturity, female	70	55	*	27	35-38	31	19	23-24	36-44	35
Fecundity at average size at maturity	98,000	860,000	*	80,000	40,000	300,000	50,000	6,000	98,000	*
1) Maximum Sustainable Yield (MSY) in thousands of metric tons (Columbia River)	4.0	*	*	*	4.0	2.0	*	*	1.1	*
Ex-vessel value ($) ** of bottom fish landed by commercial fishermen in Washington State during 1976	413,832	1,127,936	(all species) 1,347,539		339,949	295,679	*	*	596,633	*

1) Maximum sustainable yield (MSY) is the largest catch which can be taken from a stock over a reasonable period of years under current fishing practices.

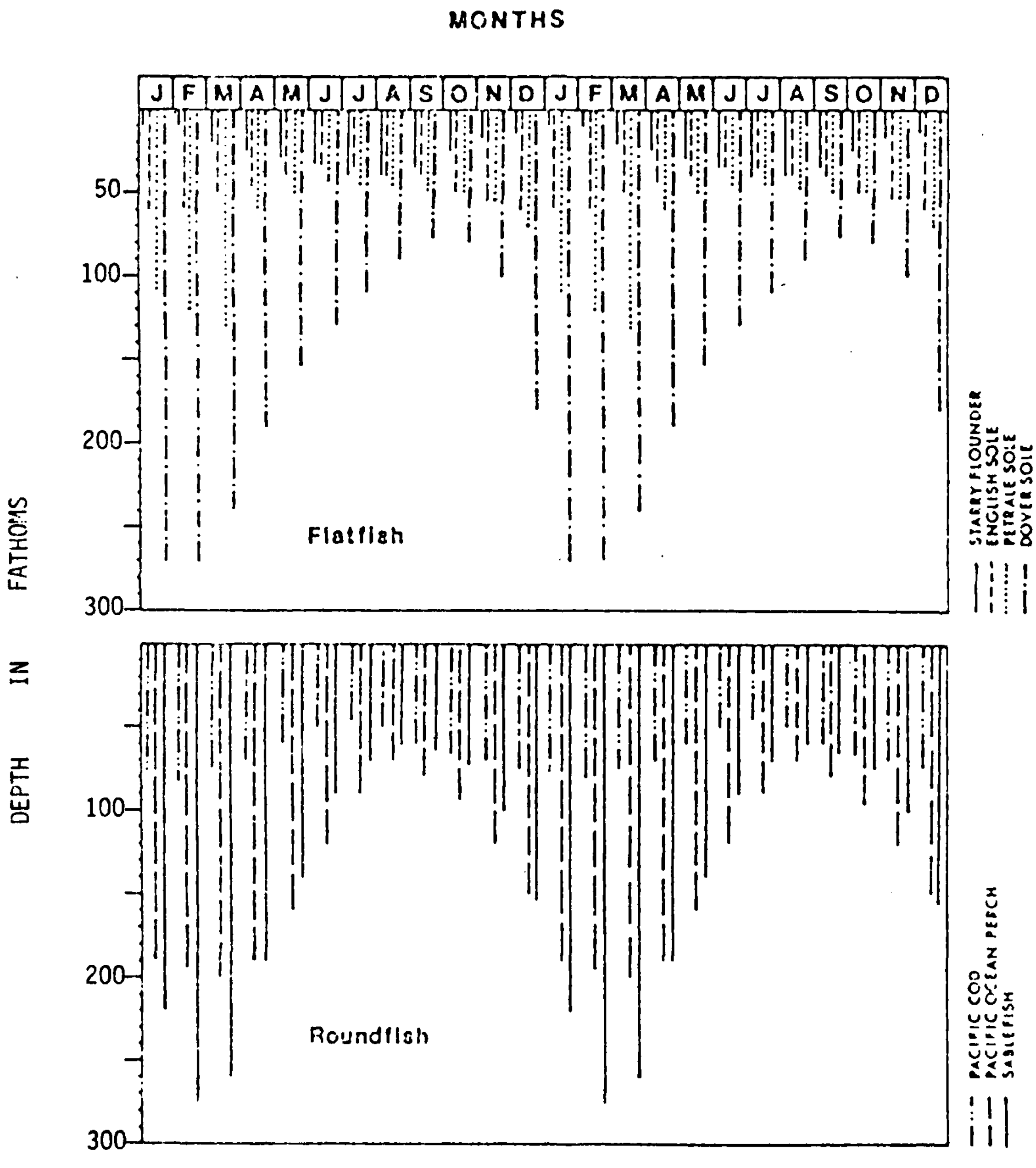
* Unavailable
** Ex-vessel value-Price paid to fishermen
(Source: Pacific Fisheries Management Council - Draft Pacific Coast Groundfish Plan, 1979)

movement during the winter (Brian Culver, 1980: personal cummunication). Significant migrations have been observed for petrale sole and English sole. In general, the pattern of movement for these species appears northward during the summer months and southward during the winter (Alverson, Pruter and Ronholt, 1964).

The inshore movement of some demersal fish, such as Dover sole, sablefish and Pacific ocean perch, appears to coincide with an intrusion of upwelled, cold, salty water onto the continental shelf (which occurs during the summer months off Washington).

Reproductive behavior and over-wintering activity provide the stimulus for offshore migration. During the winter many mature demersal fish tend to move offshore and into deeper waters in gullies and canyons to spawn. At this time, due to heavy schooling, they are extremely vulnerable to the trawl fishery. These visits to deep water vary in length, but by early summer most species have returned shoreward to summer feeding grounds (U.S. National Marine Fisheries Service, 1977).

For some species, such as starry flounder, English sole and Pacific cod, these seasonal migrations involve very little change in depth (Figure 8). In addition to the effects of physical oceanographic characteristics, such as temperature and hydrography, and biological factors, such as migration, the distribution and abundance of demersal species is related to food sources and bottom sediment characteristics. Flatfish may be divided into two categories, according to feeding behavior: small-mouth flounder (rock sole, dover sole, rex sole, butter sole, English sole and starry flounder), large-mouth flounders (petrale and sand sole) and halibuts (turbot and Pacific halibut). Small-mouth flounders are reported to feed mostly on small benthic molluscs, crustaceans,



After Alverson, Pruter and Ronholt, 1964.
1 Fathom = 1.83 m

FIGURE 8
Seasonal vertical distribution patterns for flatfish and roundfish.

and echinoderms. Large-mouth flounders and halibuts feed essentially on a variety of zooplankton and other fish. Studies conducted along the Washington coast indicated that a species of small-mouth flounder nearly always dominates the flatfish population inhabiting the inner continental shelf (inner sublittoral zone). By contrast, the large-mouth flounder and halibut generally predominate on the outer continental shelf and slope (Alverson, Pruter and Ronholt, 1964).

A study of bottom fish resources by the Oregon Department of Fish and Wildlife (Barss, 1976) identified the five most abundant species of demersal fish as: English sole, arrowtooth flounder, Dover sole, rex sole and Pacific hake. Other important species included the Pacific ocean perch, Pacific sanddab, butter sole, sablefish, ling cod, Pacific cod, petrale sole and starry flounder.

The distribution of some species suggested sediment type preference. Sediment types shallower than about 100 meters are almost entirely sand, with the exception of two gravel areas found off Cape Elizabeth and Grays Harbor (Figure 9). Most sediments outside the 100 meter contour are course silt. English sole, Pacific sanddabs, starry flounder and butter sole are usually found over sand. Arrowtooth flounder were found exclusively over a silt bottom, with petrale, Dover and flathead sole exhibiting a preference for siltbottom over sand (Barss, 1976).

Pearcy (1978) recognized two general assemblages of demersal fishes off the Oregon coast, a shallow water (74-102 m) assemblage dominated numerically by Pacific sanddab, and a deep water (148-195 m) assemblage dominated by slender sole. Dover, rex and slender sole, Pacific sanddab, and all species combined indicated some effects of sediment and depth. Largest catches of slender sole were caught at the clayey-silt stations, and largest catches of Pacific sanddab were on sandy sediments. Small sanddab predominated on the silty-sand stations, whereas large sanddab preferred sandy sediments.

A similar survey (Demory, et al., 1976) performed off the Oregon coast during 1971-72 and 1973-74, correlated the abundance of selected species with

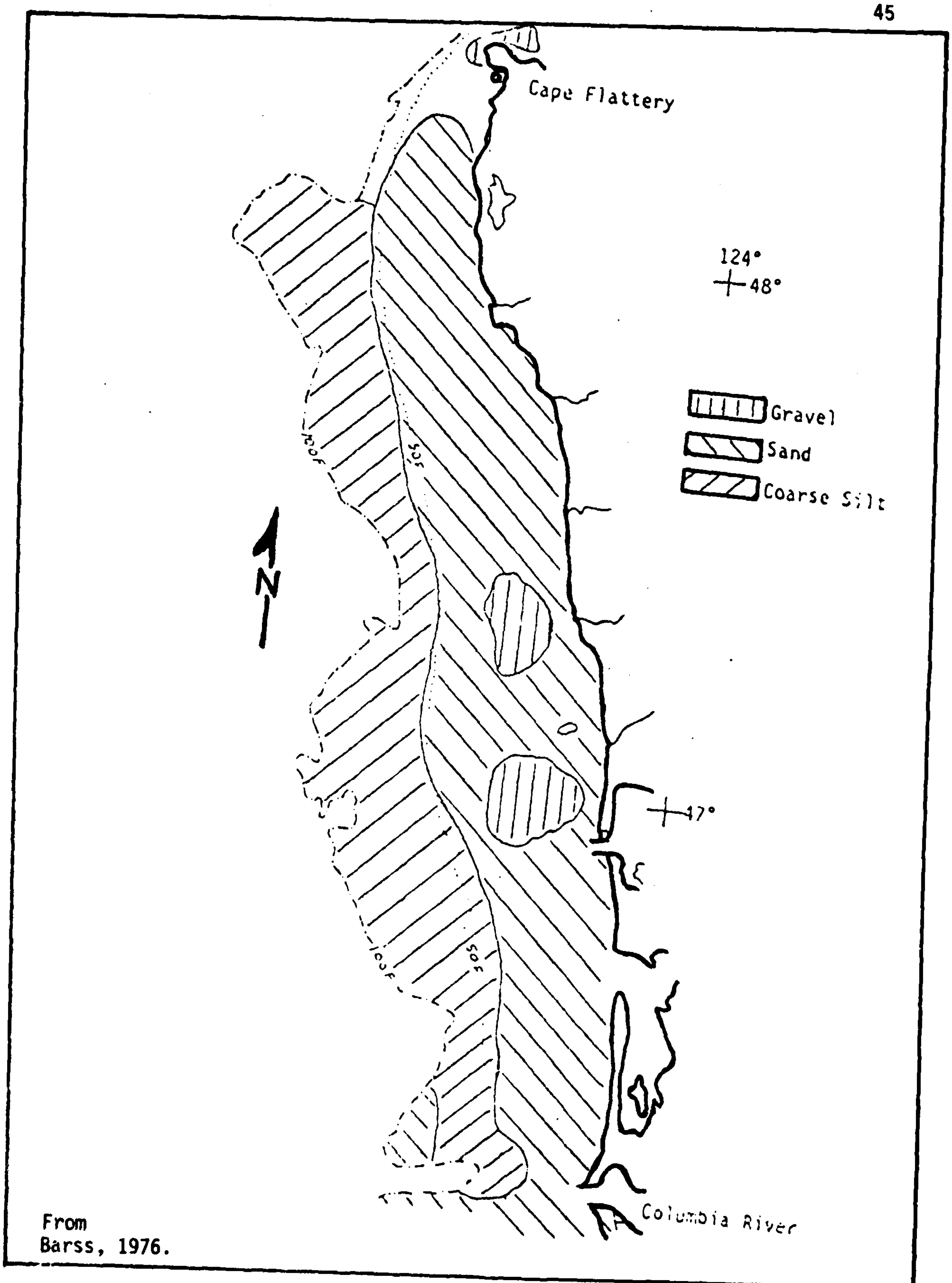


FIGURE 9

Distribution of Sediment Types on the

Continental Shelf Off Washington

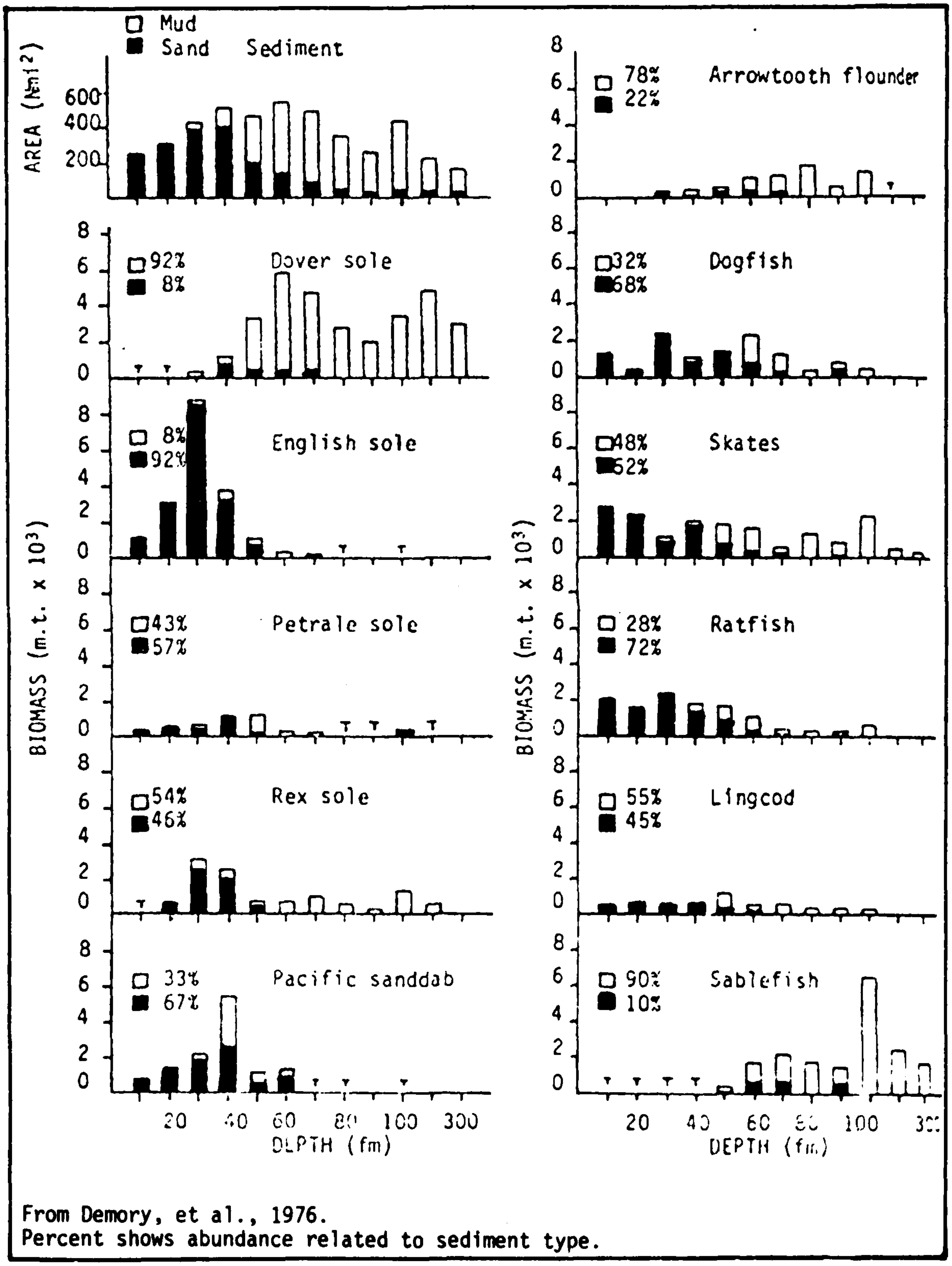


FIGURE 10
Correlation of abundance of selected species and sediment types as a function of depth off the Oregon coast (1971-72 and 1973-74).

depth and sediment type (Figure 10). English sole, Pacific sanddab, dogfish, ratfish, skates and to a limited extent rex sole preferred the shallower (less than 100 meters), sandy habitat. Since sediment type changes with depth, it is not possible to separate the influence of depth from bottom sediment type on species distribution.

Marine Mammals

The marine mammal fauna reported for the study area is extensive. In the order Cetacea, six species represent the suborder Mysticeta (baleen whales) and six species represent the suborder Odontoceta (toothed whales). In the order Carnivora, five species representing the suborder Pinnipedia (seals, sea lions) and one species representing the suborder carnivore, the sea otter, are found here. Table 10 lists the species, their relative occurrence, and their legal status (if threatened or endangered) as reported in Volume 43, Federal Register No. 238, 11 December 1978. Appendix A contains specific information on the range, habitat, status of current population, life history and food preferences for each of these marine mammals known to occur in the study area.

One common marine mammal off our coast, the conspicuous gray whale which most frequently migrates within a few kilometers of shore, occasionally strays into the inner areas of Grays Harbor (Eaton, 1975; Rice and Wolman, 1971). The peak of the northward migration here is between early March and early May. The southward migration peaks in late December but may last until early February (Pike and MacAskie, 1969 and Mate, 1979). Larrison (1976) considers the harbor porpoise to be the most abundant cetacean along the Pacific Northwest coast. It is most often found in coastal and estuarine waters (Eaton, 1975; and Isakson and Reichard, 1976). The humpback whale, although uncommon in occurrence and pelagic in nature, is seen occasionally in the study area in

TABLE 10

MARINE MAMMALS AND THEIR OCCURRENCE WITHIN THE GRAYS HARBOR STUDY AREA

	1) OCCURRENCE	ENDANGERED SPECIES STATUS
Order: Cetacea Suborder: Mysticeti		
Black or Pacific right whale	x*	Yes
Minke whale	x	No
Sei whale	x	Yes
Finback or Fin whale	x	Yes
Humpback whale	x*	Yes
Gray whale	x	Yes
Order: Cetacea Suborder: Odontoceti		
Pacific striped or white-sided dolphin	x	No
False killer whale	x*	No
Killer whale	x	No
Harbor porpoise	x	No
Sea Otter	x*	Yes
Northern fur seal	x	No
California sea lion	x	No
Northern or Steller sea lion	x	No
Harbor seal	x	No
Northern elephant seal	x	No

1) Compiled from Eaton (1975), Larrison (1976), Pike and MacAskie (1969), and Northwest Fisheries Center, Marine Mammals Division (1975).

* Uncommon occurrence in this area

fall and spring while migrating between winter and summer grounds. Humpbacks have been observed entering estuarine waters (Eaton, 1975) while feeding on herring and anchovies, but they mainly feed offshore on euphausids.

Other common species include the Northern or Steller sea lion, the California sea lion, and the Harbor seal which, according to Isakson and Reichard has been identified as inhabiting 15 critical resting and breeding sites within Grays Harbor (Isakson and Reichard, 1976). The Harbor seal is also known to inhabit the open coast (Eaton, 1975 and Larrison, 1976). The northern fur seal, a pelagic species usually found offshore, occasionally strays into inside waters and is occasionally seen in coastal waters off Grays Harbor.

Decapod Crustaceans

Only one economically important decapod crustacean, the Dungeness crab, *Cancer magister*, occurs in the Grays Harbor study area. The Dungeness crab fishery is said to be the oldest known shellfish fishery of the North Pacific coast. Productive crabbing grounds lie off the coast of Washington from the mouth of the Columbia River to the vicinity of Destruction Island. Willapa Bay and Grays Harbor are important areas in the coastal fishery both for commercial production and as juvenile nursery areas (Stevens, 1979).

Crab abundance is highly cyclic (Figure 11), with peak years occurring about every 7-10 years. Catches in the coastal area have averaged 10 million pounds annually for the past 20 years, and produced record quantities of crab in 1969 and 1970 when close to 18 million pounds per year were harvested. With this increase in production, the coastal crab fleet doubled in two years to 152 vessels with a combined gear total of over 30,000 pots.

Between December 1 and June 1 each year, high concentrations of crab pots are found distributed both north and south of the Grays Harbor entrance. At times the strings of pots are "laid-in" so close to the north entrance bouy

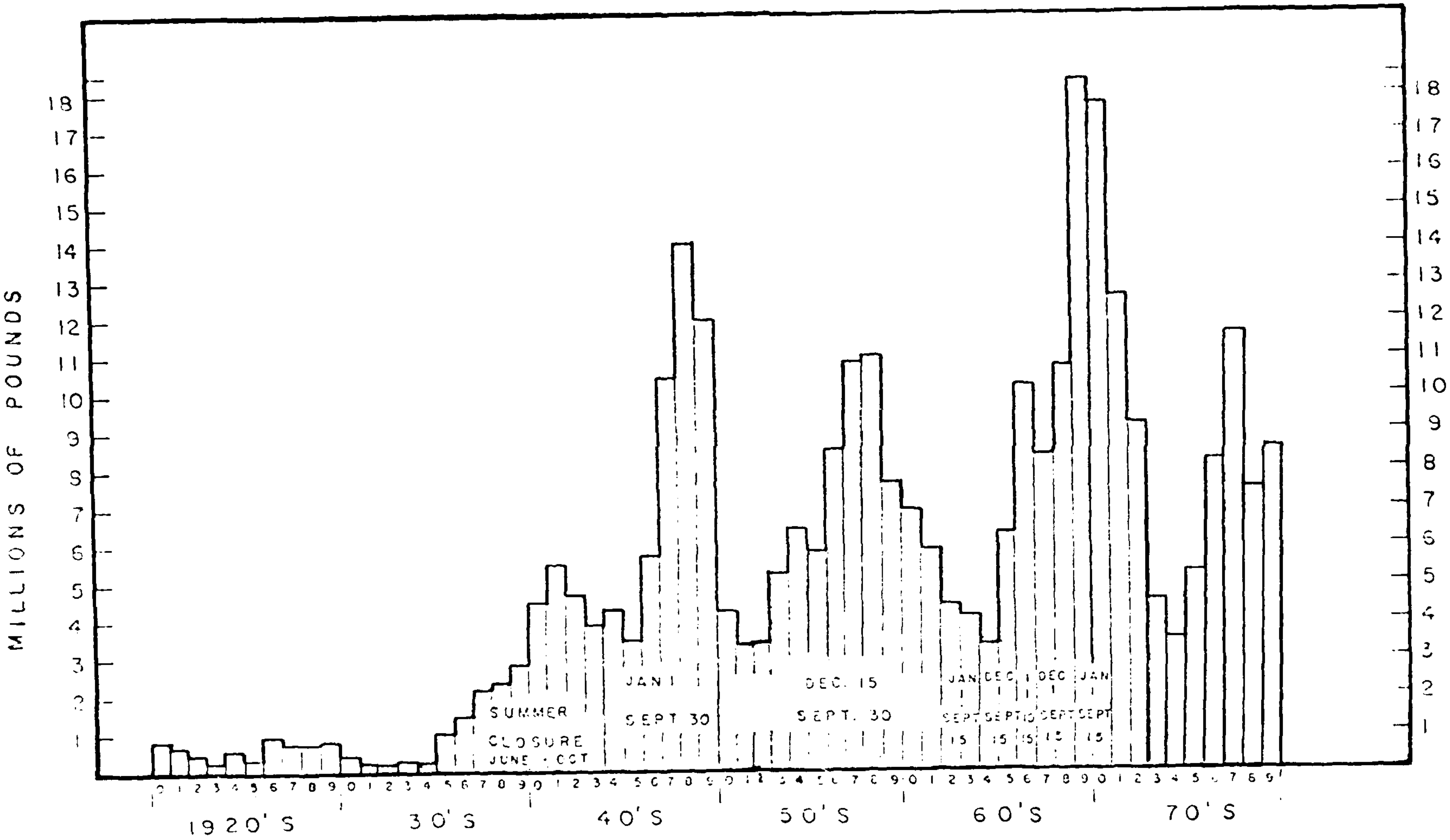


FIGURE 11
Washington coastal crab landing by season.

line (in an area one to three miles west of the north jetty), that they become a potential hazard to navigation. It is estimated that about 25-30 boats fish approximately 7,500-9,000 pots within a five-mile radius of bouy "8" during winter and spring. This number is reduced to less than 12-15 boats fishing approximately 3,600-4,500 pots between April 1 and August 15 within the same area (Northup, 1980: personal communication).

There is a relatively low intensity sport fishery in the outer Grays Harbor estuary, with highest pot concentrations within Half Moon Bay and near the Ocean Shores marina entrance.

a. Reproduction:

Mating occurs between hard-shell male crabs and newly molted, soft-shelled female crabs chiefly in May and June, although mating has been noted in other months of the year (Tegelberg, 1972). The female crab stores the sperm in a seminal receptacle until fall when they are laid or extruded to become attached to the abdomen of the female. Females in this condition are commonly found buried in the sandy beaches in the fall. Large females may carry in excess of 2.5 million eggs. As embryos develop during winter, the eggs darken to a dirty brown before hatching into larval crabs (between January and March). The larvae swim freely in the sea progressing through a series of molts in which their appearance changes considerably.

Dense swarms of crab larvae are often seen in the water column during spring and are fed on extensively by other marine organisms, including salmon, rockfish and hake. The juvenile crab, now resembling the adult (approximately 8mm in width) takes up bottom residence in June (approximately 12 months after original mating).

The Grays Harbor estuary is considered to be a vital "nursery area" for the Dungeness crab as well as a number of other shellfish and finfish.

Since male crabs are not only polygamous, but they mature a year or more before reaching the legal catch size (6¼" across carapace for commercial and 6" for sport), overharvesting has not been a major problem. Since females are completly protected from legal harvest, reproductive potential remains at a high level (Tegelberg, 1972).

b. Growth:

Dungeness crab molt (replace their old exoskeleton with a larger one) about seven times during their first year of bottom life and at a decelerating rate in subsequent years. A size of 4.48 cm (1.75 inches) across the back is reached after the first year of bottom life, 10.2 cm (4 inches) across after the second year, and 14.7 cm (5.7 inches) in three years for male crabs. The autumn shell molt at approximately 3½ years results in a harvestable supply of legal-size crab available for the fishery which begins between late November through early January. After the second year most crabs are sexually mature. The female grows more slowly than the male. Female crabs of 15.4 cm + carapace width are common.

When molting occurs, the emerging soft-shelled crab is extremely vulnerable to predators (i.e., fish and other crab). For nearly two months the crab remains susceptible to predation. Soft-shelled crabs entering commercial pots are subject to considerable mortality. After a crab reaches a size of 17.3 cm (6.75 inches) or greater, growth molts occur much less frequently (one year apart).

c. Migration:

Tagging studies by the Washington Department of Fisheries have demonstrated the migration of adult male crabs from deep to shallow water between January and June. Along the Washington Coast there is an additional tendency at that time to move in a northerly direction (Tegelberg, 1972). Crabs released on the 92 meter isobath (50 fathoms) ultimately migrated to the commercial fishery zone within five miles of the coastline. Some specimens tagged inside Grays Harbor have been recaptured offshore, and one released off Westport was captured more than 80 miles away at Tillamook Bay, Oregon.

Tagging by Oregon fisheries workers in the vicinity of the Columbia River (Waldron, 1958) tended to confirm the Washington findings of the net northward migration. A couple of Oregon-tagged crabs traveled from off Tillamook to the vicinity of Willapa Bay.

d. Diet:

Dungeness crab feed on a wide variety of marine forms. Stomachs of ocean crab have most commonly contained clams, both hard-shell and razor clams, fish and crabs, and other items such as starfish, worms and squid, snails and fish and crab eggs (Tegelberg, 1972).

e. Predators:

The Dungeness crab is preyed upon by members of its own species, and a great number of fishes such as halibut, dog fish, hake, ling cod, sculpin, and wolf eels. The Dungeness crab is also a favorite food of the octopus. The Dungeness crab is particularly vulnerable during the molting of its shell. This molting occurs during the winter months along the Washington coast.

Correlation of Major Fish and Decapod Crustacean Species Found Offshore of the Columbia River; Coos Bay, Oregon; and Grays Harbor, Washington

Species inhabiting the proposed Grays Harbor offshore dredged material disposal area compare closely with those found off the Columbia River and Coos Bay, Oregon. Table 11 lists major species common to two or more of these nearshore areas. Most species listed were confirmed by experimental catch data. Some were identified through personal communication with Terry Durkin, NMFS (Warrenton, Oregon), Dan Hancock, OSU (Coos Bay, Oregon), and Brian Culver and Dick Stone, WDF Coastal Lab (Grays Harbor, Washington). While several biological assemblages were identified in the Columbia River studies (Durkin and Lipovsky, 1977), no research data for Grays Harbor were available to make site-specific comparisons.

The similarity of major fish and decapod crustacean species found off Coos Bay, the Columbia River and Grays Harbor indicate that information concerning the effects of dredged material obtained at the Columbia River and Coos Bay may be useful for evaluation of the proposed ocean disposal at Grays Harbor.

TABLE 11

MAJOR FISH SPECIES AND DECAPOD CRUSTACEANS COMMON TO NEARSHORE COASTAL AREAS OF THE COLUMBIA RIVER, COOS BAY, OREGON AND GRAYS HARBOR, WASHINGTON

Scientific Name	Common Name	1) Relative Abundance	2) Present In Study Area		
Phylum: Chordata			CR	CB	GH
Class: Agnatha					
Family: Petromyzontidae					
Lampetra tridentatus	Pacific lamprey	C	X	X	X
Class: Chondrichthyes					
Family: Squalidae	dogfish shark				
Squalus acanthias	spiny dogfish	A	X		X
Family: Rajidae	skates				
Raja binoculata	big skate	C	X	X	X
Raja kincaidi	black skate				X
Raja rhina	longnose skate				X
Family: Acipenseridae	sturgeons				
Acipenser medirostris	green sturgeon	R	X		X
Acipenser transmontanus	white sturgeon	M	X		X
Family: Clupeidae	herrings				
Alosa sapidissima	American shad	C	X		
Clupea harengus pallasi	Pacific herring	A	X		X
Sardinops sagax	Pacific sardine	R			X
Family Engraulidae	anchovies				
Engraulis mordax	Northern anchovy	A	X	X	X
Family: Salmonidae	salmon and trout				
Oncorhynchus gorbuscha	pink salmon	C	X		X
Oncorhynchus keta	chum salmon	A	X		X
Oncorhynchus kisutch	coho salmon	A	X		X
Oncorhynchus nerka	sockeye salmon	C	X		X
Oncorhynchus tshawytscha	chinook salmon	A	X	X	X
Salmo clarki	cutthroat trout	A	X		
Salmo gairdneri	steelhead trout	C	X		
Salvelinus malma	Dolly Varden	C			

1) A-Abundant, M-Moderately Abundant, C-Common, R-Rare
2) Present in nearshore study areas:
CR-Columbia River (Durkin and Lipovsky, 1977)
CB-Coos Bay (Hancock, et al., 1977 and personal communication)
GH-Grays Harbor (Barss, 1976 and Culver, 1980: personal communication)

TABLE 11

Scientific Name	Common Name	1) Relative Abundance	2) Present In Study Area		
			CR	CB	GH
Family: Osmeridae	smelts			X	
Allosmerus elongatus	whitebait smelt	M	X		
Hypomesus pretiosus	surf smelt	A	X		X
Spirinchus starksi	night surf smelt	M	X	X	
Thaleichthys pacificus	eulachon	A	X	X	
Spirinchus thaleichthys	longfin smelt	A	X	X	
Family: Gadidae	cods and hake				
Gadus macrocephalus	Pacific cod				X
Merluccius productus	Pacific hake	A	X	X	X
Microgadus proximus	Pacific tomcod	A	X	X	X
Family: Syngnathidae	pipefish				
Syngnathus griseolineatus	bay pipefish	C	X		X
Syngnathus leptorhynchus				X	
Family: Embiotocidae	surf perches				
Amphistichus rhodoterus	redtail surfperch	A	X		
Cymatogaster aggregata	shiner perch	A	X	X	X
Embiotoca lateralis	striped seaperch	A			X
Hyperprosopon anale	spotfin surfperch	M	X	X	
Hyperprosopon argenteum	walleye surfperch				X
Hyperprosopon ellipticum	silver surfperch	M	X		
Phanerodon furcatus	white seaperch	M	X		
Rhacochilus vacca	pile perch	A	X		X
Family: Scombridae	mackerels and tunas				
Thunnus alalunga	albacore	R			X
Family: Carangidae	cavellas				
Trachurus symmetricus	jack mackerel	A			X
Family: Scorpaenidae	rockfishes				
Sebastes flavidus	yellowtail rockfish				X
Sebastes melanops	black rockfish	A	X		X
Sebastes mystinus	blue rockfish	C			X
Sebastes paucispinis	bocaccio	C	X		X
Sebastes pinniger	canary rockfish	C			X
Family: Anoplopomatidae	sablefishes				
Anoplopoma fimbria	sablefish	A	X		X
Family: Hexagrammidae	greenlings				
Hexagrammos decagrammus	kelp greenling	A	X	X	X
Hexagrammos lagocephalus	rock greenling				X
Hexagrammos stelleri	whitespotted greenling	A			X
Ophiodon elongatus	lingcod	A	X		X

TABLE 11

Scientific Name	Common Name	1) Relative Abundance	2) Present In Study Area CR	CB	GH
Family: Cottidae	sculpins				
Artedius harringtoni	scalyhead sculpin	C	X		
Chitonotus pugetensis	roughback sculpin	A	X		
Enophrys bison	buffalo sculpin	M	X		X
Hemilepidotus hemilepidotus	red Irish Lord	C	X		X
Hemilepidotus spinosus	brown Irish Lord	M	X		
Leptocottus armatus	Pacific staghorn sculpin	A	X	X	X
Scorpaenichthys marmoratus	cabezon	C	X	X	X
Family: Agonidae	poachers				
Agonus acipenserinus	sturgeon poacher	A	X		X
Occa verrucosa	sea poacher	M	X		
Odontopyxis trispinosa	pygmy poacher	C	X		
Pallasina barbata aix	tubenose poacher	C	X		
Stellerina xyosterna	prickleback poacher	A	X	X	
Family: Liparidae	snailfish				
Liparis pulchellus	showy snailfish	C	X	X	
Family: Trichodontidae	sandfishes				
Trichodon trichodon	Pacific sandfish	M	X	X	
Family: Ammodytidae	sand lances				
Ammodytes hexapterus	Pacific sand lance	C	X	X	X
Family: Anarhichadidae	wolffishes				
Anarhichthys ocellatus	wolf eel	C	X		X
Family: Bothidae	left eye flounders				
Citharichthys sordidus	Pacific sanddab	A	X		X
Citharichthys stigamaeus	speckled sanddab	A	X		
Family: Pleuronectidae	right eye flounders				
Eopsetta jordani	petrale sole	A	X		X
Glyptocephalus zachirus	rex sole	A	X		X
Hippoglossus stenolepis	Pacific halibut	C			X
Isopsetta isolepis	butter sole	C	X	X	X
Lyopsetta exilis	slender sole	A	X		X
Microstomus pacificus	Dover sole	A	X		X
Parophrys vetulus	English sole	A	X	X	X
Platichthys stellatus	starry flounder	A	X		X
Pleuronichthys coenosus	c-o turbot	C		X	
Pleuronichthys decurrens	curlfin sole	M	X		
Psettichthys melanostictus	sand sole	C	X	X	X
Family: Molidae	molas				
Mola mola	ocean sunfish	M	X		X

TABLE 11

Scientific Name	Common Name	1) Relative Abundance	2) Present In Study Area CR	CB	GH
Phylum: Arthropoda					
Family: Pandalidae					
Pandalus danae	Spotted shrimp	M	X		
Family: Crangonidae					
Crangon franciscarum		A	X		
Crangon a. elongata			X		
Crangon nigricauda	Broken-back shrimp		X		
Crangon stylirostris			X		
Crangon communis			X		
Crangon alba			X		
Family: Crangoidae					
Septem spinosa			X		
Nectocrangon alaskensis			X		
Family: Paguridae					
Pagurus sp.	Hermit crab	A	X		
Family: Cancridae					
Cancer gracilis		M	X		
Cancer magister	Dungeness crab	A	X	X	X
Family: Pinotheridae					
Pinnixa sp.	Pea crab	M	X		

Data from two experimental otter trawl tows (Figure 12) conducted by the Oregon Department of Fish and Wildlife (Barss, 1976) aboard the M/V Tordenskjold on September 9, 1976, within the proposed Grays Harbor ocean disposal study area, are included in Table 12. Species found in greatest abundance included the spiny dogfish, big skate, Pacific cod, Pacific sanddab, English sole, rex sole, butter sole and sablefish. Those present, but low in abundance in the catch, included petrale sole, canary rockfish and ling cod. An abundance of unidentified flatfish and rockfish made up the remainder of the catch.

FIGURE 12

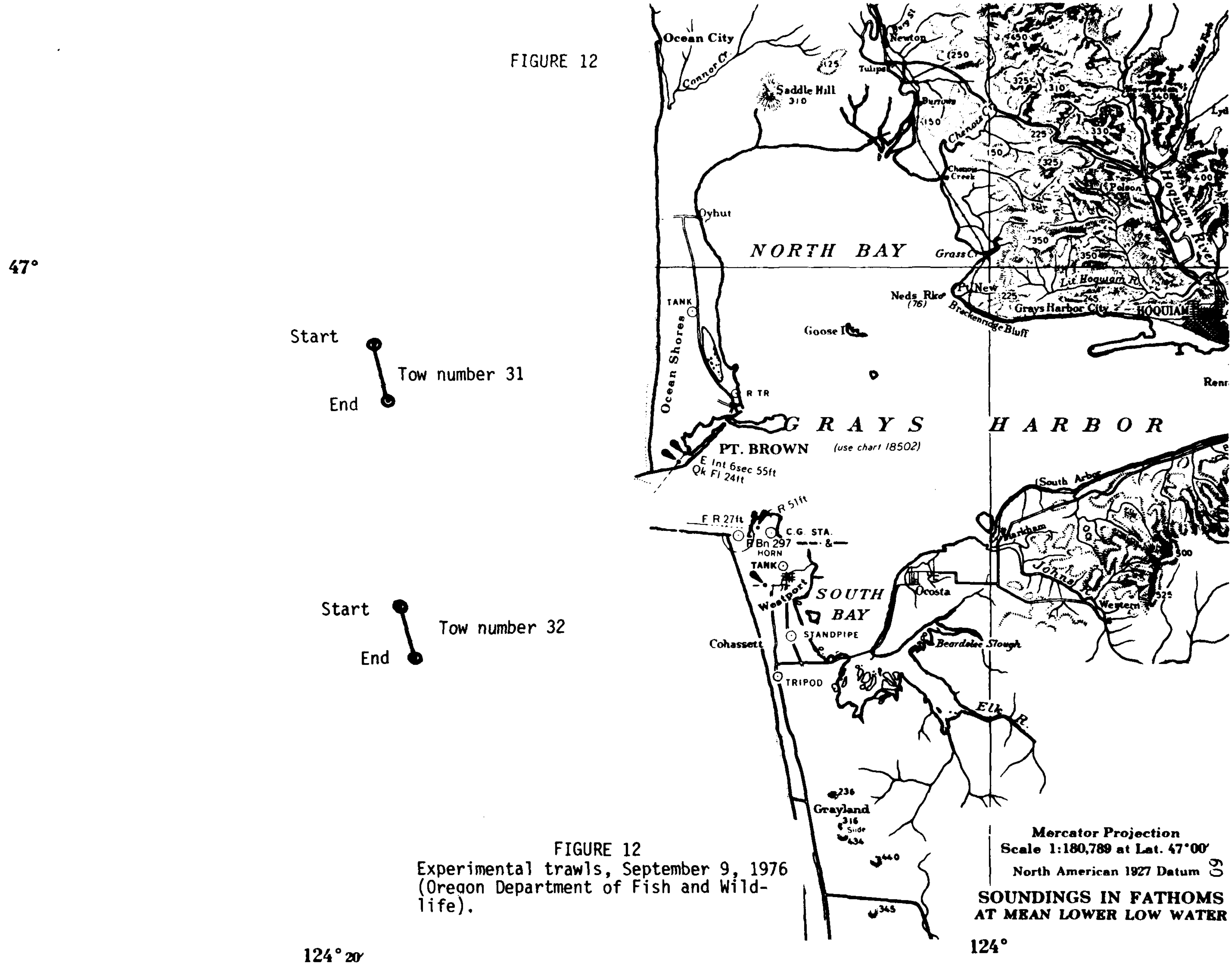


FIGURE 12
Experimental trawls, September 9, 1976 (Oregon Department of Fish and Wildlife).

TABLE 12

Station Location and Catch (Pounds) of Principal Groundfish Species by Tow, Groundfish Survey, Cruise 76-4, August 27 Through September 15, 1976 (Offshore Grays Harbor, Washington)

Tow Number	31	32
Date	9/3/76	9/3/76
Loran, 1L1 Start	3496	3493
End	----	3493
1L0 Start	4070	4004
End	4058	3991
Depth: Down-haul (fathom)	22-24	25-25
Catch		
Spiny Dogfish		6
Skate		23
Ratfish		3
Pacific cod	19	1
Pacific Hake		
Flatfish		
Pacific sanddab	8	32
Arrowtooth flounder		
Slender sole		
Petrale sole	6	
English sole	12	186
Dover sole		
Rex sole	69	15
Butter sole		4
Other flatfish	6	7
Rockfish		
Shortspine thornyhead		
Pacific ocean perch		
Greenstriped rockfish		
Yellowtail rockfish		
Canary rockfish	4	
Darkblotched rockfish		
Splitnose rockfish		
Other rockfish	74	
Sablefish		
Lingcod	17	
Miscellaneous	3	
Totals	218	277

Source: (Oregon Department of Fish and Wildlife, 1976)

Benthic Community

Benthic Organism Distribution:

There are three distinct benthic communities off the coast of Grays Harbor lying in three sediment types approximately parallel to the coastline. These communities are found in deep water silts and shallow sands.

Lie (1969) measured the standing crop (ash-free dry weights) of benthic infauna off the Washington coast. He reports a mean value of 1.92 g/m^2, with a range from 0.5 to 3.5 g/m^2. These values are considerably lower than a comparable area off Santa Barbara, California, where Barnard and Hartman (1959) report 10-20 g/m^2. Three distinct assemblages of species were observed off Washington and were correlated with deep water and mud, intermediate depths and sand, and shallow water and sand (Figure 13). Lie and Kisker (1970) show the distribution of these communities off Grays Harbor.

Lie (1969) and others (Carey, 1972; Bertrand, 1971; Lie and Kelley, 1969; Lie and Kisker, 1970) have found that benthic macrofauna density and biomass increase offshore to a maximum at the outer edge of the continental shelf. The diversity and evenness values of benthic assemblages as well as the number of species (species richness) also increase offshore. The above mentioned authors report that the three benthic assemblages roughly parallel the Washington coast, in water depths between zero and 90 meters.

Richardson, et al., (1977) reported an assemblage, assemblage C (inshore sand assemblage just south of the Columbia River), which may correspond to the shallow water sand-bottom assemblage reported from the Washington coast (Lie, 1969; Lie and Kisker, 1970; Lie and Kelley, 1970) and the inshore

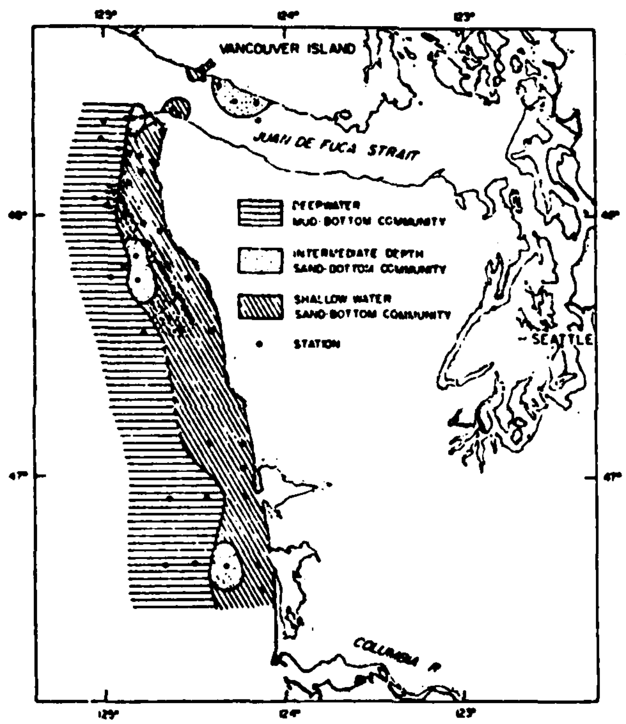


FIGURE 13

Geographic Distributior ᶠ the Three
Offshore Benthos ᴄ· ' ·nities*

* Lie and Kisker (1970)

assemblage on the Central Oregon coast (Carey, 1972). Richardson, et al., were able to match similar benthic species in the shallow water sand-bottom assemblage along the Washington coast to the Grays Harbor offshore species.

Of the 21 most abundant species found along the Washington coast shallow water assemblage, 11 were also abundant at assemblage C south of the Columbia River mouth, and five were present in assemblage C, but rare. The remaining four species reported by Lie and Kisker (1970) may represent a difference in taxonomic opinion and may also be present in assemblage C. Richardson, et. al., (1977) further state that the density and biomass of macrofauna were similar among assemblage C, the shallow water sand-bottom community along the Washington coast, and the inshore sand assemblage off the Central Oregon coast. The distribution, community structure and seasonal constancy of benthic assemblages off Grays Harbor are therefore believed to be similar to those studied elsewhere along the Washington and Oregon coasts. Benthic faunal data collected for this report appear to support the published distributions and community structures discussed above by various authors. The environmental factors influencing benthic organisms include an increase in silt, clay and organic content in sediments offshore and an increase in sediment stability due to reduced sediment stirring by winter storms with depth. Superimposed on this depth gradient were the effects of the deposition of fine grained sediments from the Columbia River and high primary productivity of the area. The high abundance of tube dwelling polychaetes at deeper stations mentioned by Richardson, et al., (1977) also increased sediment stability. They also found that the density of macrofauna may be related to the organic content of the sediments.

According to Lie and Kisker (1970), the shallow water community (mean depth 36.0 meters) is characterized by two groups, the shallowest water communities containing Paraphoxus abronius, P. obstesens, and Tellina buttoni. In deeper water (50 to 70 meters), the amphipods Ampelisca macrocephalia, A. compressa, Monoculodes spinipes and Photis brevipes, and the ophiuroid Amphiodia urtica are numerically dominant. The mean standing crop of the shallow water community (ash-free dry weight) was 1.398 $\pm$ 0.47 gm/m^2. Ampelisca macrocephalia, Nepthys sp. and Chaetozone setosa dominated the biomass throughout the community but Diastylopsis dawsoni, Tellina salmonea, Owenia fusiformis and Siliqua patula dominated biomass at a limited number of stations.

Lie and Kisker (1970) also described the intermediate depth community (mean depth, 95.8 meters). It was associated with the lamellibranchs Yoldia ensifera, Tellina carpenteri, Macoma elimata and Acila castrensis, and the amphipod Paraphoxus varitus. The mean standing crop was 2.53 $\pm$ 1.03 gm/m^2; major contributors were Yoldia ensifera, Magelona sp., Sternaspis fossor, Nephtys sp., Macoma elimata and Acila castrensis.

The deepwater mud-bottom community (mean depth 154.5 meters) described by Lie and Kisker (1970) off the Washington coast was associated with the sea-urchin Brisaster latifrons and the polychaetes Prionospio malmgreni, Ninoë gremmla, S. fossor. Excluding rare, large organisms, the mean standing crop was 2.61 $\pm$ 0.7 gm/m^2. Without the exclusion, the standing crop was 3.06 gm/m^2. The major contributors to biomass were B. latifrons, S. fossor and the echinoderms Ophiura lütkeni and Amphipholis sp.

Razor Clams

An intensive razor clam sport fishery occurs on the ocean surf-zone beaches immediately north and south of Grays Harbor. The two beaches closest to possible dredged material disposal sites are Twin Harbors Beach to the south of the Grays Harbor entrance and Copalis Beach to the north of the entrance. The Twin Harbors Beach averaged 97,600 digger-trips per year in the 10 year period 1969 through 1978, while Copalis Beach averaged 265,900 digger-trips during the same period. During the 1969 through 1978 period sports diggers harvested an estimated 10,107,500 razor clams from Twin Harbors Beach, while diggers at Copalis Beach harvested an estimated 31,207,800 razor clams during the same period. The total estimated razor clam harvest by sports diggers for all the Washington beaches, which also includes Long Beach and the Moclips to Copalis Rocks was 83,391,000 clams during the 10 year period (Simons, 1980: personal communication).

Copalis Beach located to the north of Grays Harbor is the most productive of the razor clam beaches. If dredged materials were dumped in waters off Grays Harbor, their likelihood of coming onto this beach is a possibility that needs careful evaluation. While fine silt type of dredged material would probably smother clams, outer-harbor sands which are similar to clam beach sands might benefit clam beaches if deposited in limited amounts.

The population of razor clams offshore that are not dug provide a reproductive reservoir that provides clam larva for "seeding" the beach sport digging areas. Any smothering of this offshore population of clams by dredged materials would decrease the contribution of this valuable source of razor clam larva.

Similarity of Grays Harbor Offshore Area to Other Study Areas

Harshman and Johnson (1977), after reviewing much of the literature concerning benthic fauna off Oregon and Washington, conclude that the fauna are quite similar in waters adjacent to the two states. They summarized by stating, "In brief, the benthic fauna off the Washington and Oregon coast are comparable. Certain assemblages recognized for infauna off Washington probably apply to Oregon as well. Some major changes in dominant taxa may be observed with depth along the shelf and slope off Oregon, and these probably also apply to Washington."

Renfro, et al., (1971) concluded their extensive report on the coastal waters of the Pacific Northwest as follows:

> In summary, the general uniformity of this coastal region should be emphasized. The plant and animal composition of the entire region shows a remarkable similarity from north to south. Most of the more common species reported fron Northern Washington have also been reported from Northern California and vice versa. There are no major faunal or floral boundaries in the region, and the differences in biota that can be seen between the extremes of the region generally occur gradually. The general ecological factors which are though to control biological distributions (e.g. temperature, substrate, salinity) all show a relative uniformity throughout the region so that the absence of a biological boundary is not suprising.

Bertrand (1971) commented on the similarity of Washington and Oregon benthic communities by saying, "Lie and Kelley's described communities (off the Washington coast) stand up quite well on the Oregon coast." His comment lends further credibility to the similarity of benthic communities along the coast of the two states.

In order to examine more precisely the similarity of benthic species known to exist off Grays Harbor in the proposed offshore dredged material disposal site, Table 13 is a comparison developed using data from Lie and

TABLE 13

OCEAN BENTHIC SPECIES COMPARISON
COOS BAY, COLUMBIA RIVER AND GRAYS HARBOR

GENUS & SPECIES (FROM TABLE 4 IN LIE & KISKER, 1970)	Shallow Water, Sand Bottom Community		
	Grays Harbor Lie & Kisker, 1970	Coos Bay Hancock et al., 1979	Columbia River Richardson et al., 1977
Diastylopsis dawsoni	X	X	X
Tellina salmonea	X	X*	X
Owenia fusiformis	X	X*	X
Ampelisca macrocephalia	X	X	X
Paraphoxus obtusidens	X	X	X
Macoma expansa	X	X	X*
Eohaustorius washingtoniensis	X	X	X
Tellina buttoni	X	X*	X*
Chaetozone setosa	X	X	X
Siliqua patula	X	X	X
Nephthys sp	X	X	X*
Amphiodia urtica	X	X*	X
Paraphoxus abronius	X	X*	X
Glycinde picta	X	X	X
Monoculoides spinipes	X	X	X
Nothria elegans	X	X*	X
Haploscoloplos elongatus	X	X	X
Photis brevis	X	X	X
Hemilamprops californiensis	X	X*	NO
Ocean depth, meters	Range 22-50	Range 30-50	Range 15-47

X Organism [?] Present
* Same [?] genus present, but different species from Lie & Kiskers Table 4

Kisker's (1970) study. Four of the 30 bottom sampling stations examined by Lie and Kisker were in the shallow water sand-bottom near Grays Harbor in 22, 25, 26 and 50 meters depth. The presence of the most common benthic species was then compared to two Oregon studies, Richardson et al., (1977) and Hancock, et al., (1979). Of the 19 genera identified by Lie and Kisker, all were found off Coos Bay and 18 were found off the mouth of the Columbia River.

This close similarity between benthic assemblages found off Coos Bay, the Columbia River and Grays Harbor would indicate that information concerning the effects of dredged material disposal obtained at the Columbia River and Coos Bay may be useful for evaluation of the proposed ocean disposal at Grays Harbor.

B. Field Study

Methods

Due to the reconnaissance nature of the survey, organisms were generally identified only to family or order. Abundance distribution was converted to organisms per square meter (organisms/m^2), and biomass is expressed in terms of grams wet weight per square meters (g/m^2).

The benthic sampling was conducted on October 6, 1979 aboard the U.S. Army Corps of Engineers survey vessel, "Mamala." Samples from 32 stations along four transects (Figure 5) were collected using a 0.1 m^2 VanVeen grab. The presence of gravel in the sediments increased the possibility that the jaws of the sampler would not close completely, and the slightest upward movement could flush smaller organisms out of the gravel samples. The presence of sand dollars could produce the same effect, especially since the rough tests and spines might not slide past the jaws in closing. Therefore, some of the samples taken in this study may be unusually low in smaller invertebrates due to these physical sampling phenomena.

Samples from each station were placed in clean, heavy guage plastic bags and iced for transporting to the laboratory. In the laboratory individual samples were washed and picked on a 1.0 millimeter screen to separate benthic organisms from rock, sand and silt. Benthic fauna were preserved in a sea water solution of 10 percent formalin and 0.04 percent Rose Bengal and buffered to a pH of 8.6 with sodium tetraborate.

Benthic faunal samples were sorted into four major groups: Annelids, Molluscs, Arthropods, and Other Phyla. Each group of each sample was placed in a pre-weighed, dry plastic cylinder with a fine-meshed screen at one end. Each cylinder was placed, screen end down, on a paper towel and allowed to air dry exactly 5 minutes prior to weighing to the nearest 10^{-4} gram.

Results

Most of the collected organisms were in the phyla Annelida, Arthropoda and Mollusca. Table 1, Appendix B shows the crustacean order Cumaceae to be the most frequently sampled group in the entire study with an estimated 49,070 organisms. This is followed by the Annelid family Oweniidae with 12,730 organisms. The next most frequent group is the Molluscan family Tellinidae with 6,140 organisms. The frequency of these three groups are identical to the frequency pattern found by Lie and Kisker (1970) (Figure 13) in the shallow water sand-bottom community off the Washington coast.

As seen in Table 14, station B-5, occurring in a predominantely sand substrate, contained the highest number of organisms with 21,430/m^2. Table 14

TABLE 14
SUMMARY OF SAMPLING STATIONS, SEDIMENT CHARACTERISTICS,
NUMBER OF ORGANISMS AND BIOMASS. OCTOBER 6, 1979
SAMPLING OFF GRAYS HARBOR

STATION	DEPTH FATHOMS	DEPTH METERS	TYPE OF SEDIMENT GRAVEL	TYPE OF SEDIMENT SAND	TYPE OF SEDIMENT SILT	TOTAL NO. OF ORGANISMS PER M^2	BIOMASS WET WEIGHT G/M^2	SIZE OF SAMPLE Kg
A1	7	12.9		X		20	16.43	--
A2-1	11	20.3		X		50	3.29	--
A2-2	11	20.3		X		100	7.52	--
A3	15	27.7		X		1290	16.60	7.26
A4	16	29.5		X		630	36.17	5.89
A5	17	31.4		X		1860	127.55	12.24
A6	20	36.9		X		2720	43.77	4.99
A7	22	40.0		X		2280	28.26	3.17
A8	24	44.3		X		900	4.98	1.81
A9	24	44.3		X		3020	39.48	2.72
A10	29	53.5		X		3530	31.11	2.72
A11	32	59.1		X		2710	26.10	2.27
B1-1	31	57.2	X			550	11.49	7.26
B1-2	31	57.2	X			970	9.59	13.60
B2	29	53.5	X			770	--------	12.70
B3	24	44.3	X			450	11.77	4.54
B4	23	40.5			X	10250	52.56	3.63
B5	18	33.2		X		21430	121.28	4.54
B6	16	29.5		X		6900	52.57	4.99
B7	9	16.6		X		440	3204.30	2.72
B9-1	5	9.2		X		300	11.14	3.63
B9-3	5	9.2		X		460	8.37	5.89
B9-4	5	9.2		X		330	8.50	7.71
B9-5	5	9.2		X		200	4.69	4.54
B9-6	5	9.2		X		730	28.59	8.62
C1	5	9.2		X		650	27.41	4.54
C2	5	9.2		X		150	5937.10	0.45
C3-1	6	11.1		X		810	15.31	6.35
C3-2	6	11.1		X		850	17.13	5.44
C4	9	16.6		X		3620	17.64	0.22
C5	15	27.7		X		8350	69.45	4.08
C6	18	33.2	X			3170	121.22	14.06
C7	21	38.8			X	18660	155.57	4.08
C8	22	40.0	X			410	38.70	20.41
C9	26	48.0	X			750	24.66	11.80
C10	29	53.5	X			860	22.71	18.14
C11	32	59.1	X			540	189.02	18.14
D1	9	16.6		X		190	2304.69	1.81

shows two nearby stations, B-6 and C-5, in the mid-shelf silts at approximately 33 meters (18 fathoms) depth with 6,300 and 8,300 organisms/m^2, respectively. Samples of lowest numbers of organisms included those taken in the deeper waters beyond 40 meters (22 fathoms) in gravel substrate and in nearshore waters near the harbor mouth (Table 14).

In order to plot the distribution of benthic organisms, a table and two maps were developed. Table 15 groups wet weight biomass in several clusters, each with an approximate order of magnitude difference in biomass. The three stations with the highest biomass, B-7, C-2 and D-1, have an average biomass of 3,815 g/m^2. Figure 14 shows these stations to lie in about 20 meters (10 fathoms) in the study area. Four stations with somewhat less biomass, A-5, B-5, C-6 and C-7, lie in the edge of the silts in approximately 33 meters (18 fathoms) depth and averaged 131 g/m^2. Stations A-6 through A-11, B-4, C-8, C-9 and C-10, lying in slightly deeper water, (37 to 53 meters) had an average biomass of 31 g/m^2.

Three sampling stations, B-4, B-5 and C-7, had the highest numbers of organisms per square meter: 10,250, 21,430 and 18,660, respectively. The average value of these three stations is 16,760 organisms/m^2, and this value is plotted as an area of high benthic population in Figure 15. This area with the highest average organisms/m^2 coincides with the northerly extension of the mid-shelf silt (Figure 5). Two sampling stations, B-6 and C-5, with an average of 7,625 organisms/m^2, are located in slightly shallower water that overlaps the area with the highest biomass. A third area, which appears to have a lower population of benthic organisms, includes stations A-5, A-6 and A-7 where the average value is 2,286 organisms/m^2 (Figure 15).

Most of the stations mentioned above with high numbers of organisms lie in a productive mid-shelf silt zone and B-5 is in the sand adjacent to it (Figure 5).

TABLE 15

BIOMASS AND NUMBERS OF
ORGANISMS FROM SELECTED SAMPLING STATIONS
GROUPED BY BIOMASS AND NUMBERS

STATION	BIOMASS g/m^2 WET WEIGHT	TWO MOST ABUNDANT ORGANISMS	STATION	NUMBER OF ORGANISMS NUMBER/m^2
B-7	3,204	Gammaridae, Nephtidae	B-5	21,430
C-2	5,937	Dendraster, (only organism)	B-4	10,250
D-1	2,305	Gammaridea, Dendraster	C-7	18,660
AVERAGE	3,815		AVERAGE	16,780
A-5	127	Tellinidae, Ostracoda	B-6	6,900
B-5	121	Cumacea, Siliqua	C-5	8,350
C-6	121	Dendraster, Oweniidae		
C-7	156	Cumacea, Oweniidae		
AVERAGE	131		AVERAGE	7,625
A-6	44	Oweniidae, Ostracoda	A-5	1,860
A-7	28	Spionidae, Oweniidae	A-6	2,720
A-8	5	Spionidae, Ostracoda	A-7	2,280
A-9	39	Spionidae, Ostracoda		
A-10	31	Ostracoda, Oweniidae		
A-11	26	Oweniidae, Gammaridea		
B-4	53	Cumacea, Oweniidae		
C-8	39	Annelida, (2 genera)		
C-9	25	Annelida, (2 genera)		
C-10	23	Annelida, (2 genera)		
AVERAGE	31		Average	2,286

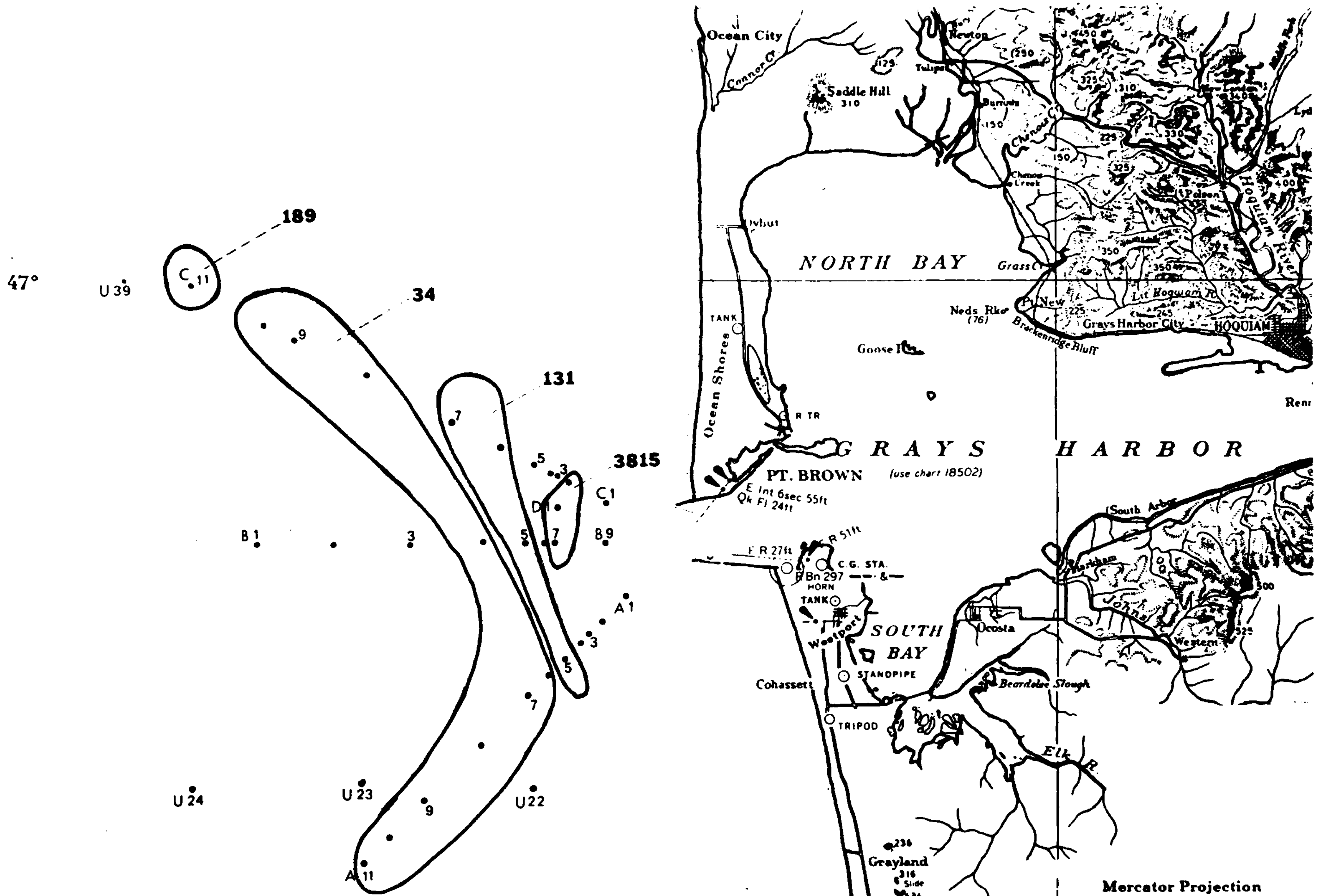


FIGURE 14
Averaged biomass (g/m^2) from stations sampled on October 6, 1979 arranged in groups with similar weights of benthic organisms.

Stations B-4, B-5 and C-7, with cumacean numbers of 686, 1,307 and 1,590 organisms/m^2, respectively, indicate the relatively high abundance of this Arthropod at these stations. Stations B-6 and C-5 were also dominated by cumaceans. Stations A-5, A-6 and A-7 were not dominated by a single group, but had high abundance of the crustacean groups Gammaridea, Cumacea and Ostracoda; the Mollusca Axinopsida and Tellinidae; and the Annelida Orbiniidae and Oweniidae. Appendix B lists the distribution pattern of other less populated sampling stations.

The limitations of using wet weight versus dry ash weight become evident when one realizes that 15 sand dollars, genus Dendraster, comprise the total catch of the station with the highest biomass, station C-2 (see Table 16). In a similar manner, three peanut worms (sipunculids) produce a biomass of 189 g/m^2 at station C-11. Therefore, biomass values are only approximate indicators of the communities of benthic organisms off Grays Harbor, and should be used with some caution.

Exclusive of larger organisms, the highest concentration of biomass (Figure 14) is approximately in the same location as the highest numbers of organisms (Figure 15). Both of these areas are located in the productive sand zone due west of Grays Harbor. Also located in the sand are three stations, A-5, B-5 and C-5, which produce moderate biomass levels of 127.5, 121.3 and 112.2 respectively.

Areas of low biomass included the zone between the end of the jetties at the entrance to Grays Harbor and the sand area located approximately 3 kilometers west of the end of the north jetty. As noted in Figure 14, the gravel area beyond the mid-shelf silt in 40 meters (22 fathoms) was also an area of relatively low biomass.

To summarize, Figures 14 and 15 show that the area of highest benthic populations lie in the sand/silt area approximately 3.5 to 8.8 kilometers

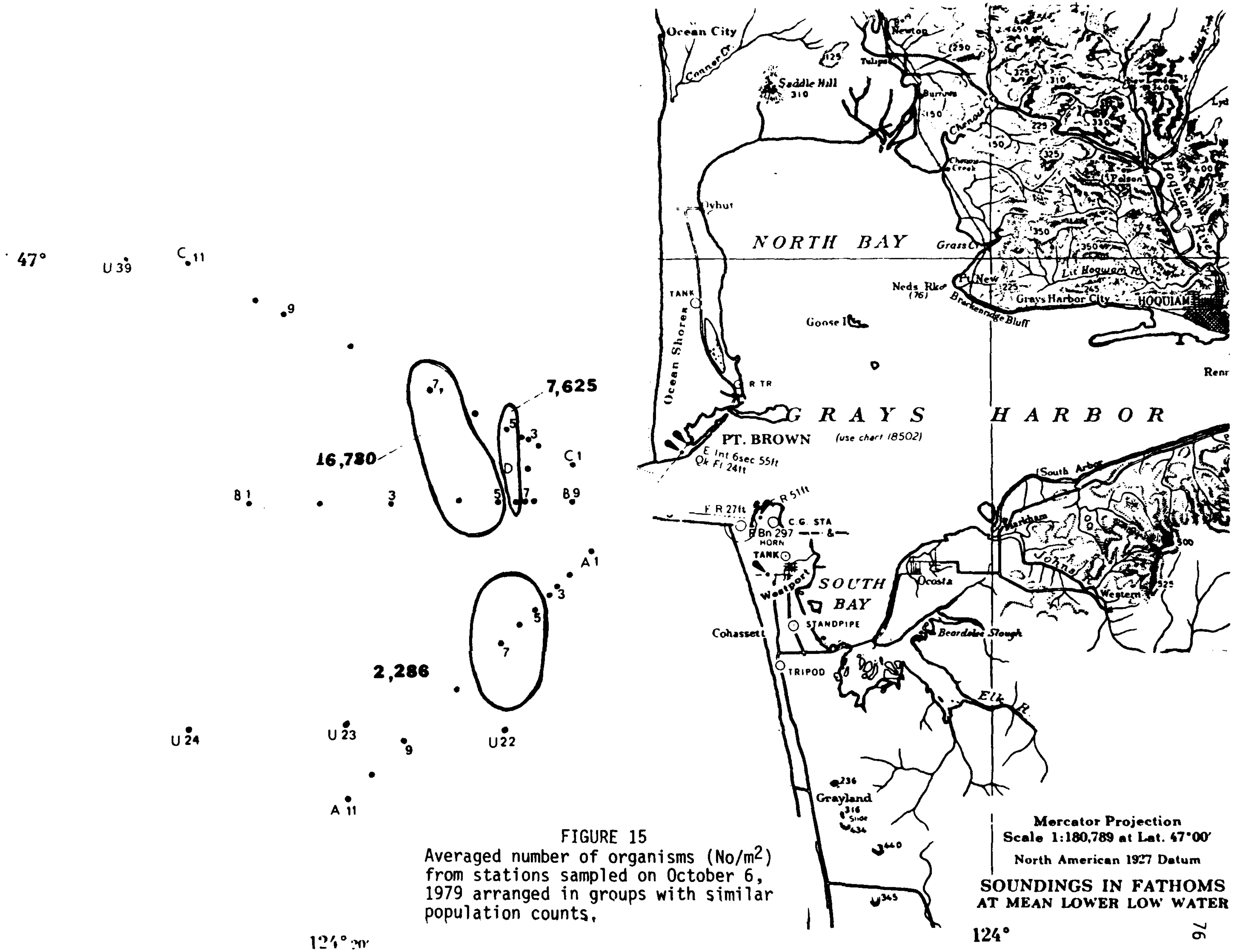


FIGURE 15
Averaged number of organisms (No/m^2) from stations sampled on October 6, 1979 arranged in groups with similar population counts.

TABLE 16

EFFECT OF A FEW LARGE ORGANISMS ON BIOMASS

	STATION	RANK	NUMBER OF SAND DOLLARS	NUMBER OF SIPUNCULIDS	NUMBER OF BRITTLE STARS	TOTAL NUMBER OF SPECIMENS #/m^2	BIOMASS g/m^2	SPECIMENS AVERAGE WEIGHT g/m^2
THREE STATIONS WITH HIGHEST BIOMASS	B-7	2	7		1	440	3,204	
	C-2	1	15			150	5,937	
	D-1	3	8	3		190	11,445	
TOTAL								14.7
EIGHT STATIONS WITH HIGH BIOMASS	A-5	6	5	2	11	1,860	128	
	B-5	7			17	21,430	121	
	B-7	2	7		1	440	3,204	
	C-2	1	15			150	5,937	
	C-6	8			2	3,170	121	
	C-7	5		2	3	1,860	156	
	C-11	4				540	189	
	C-1	3	8	3		190	2,304	
TOTAL						46,440	12,160	0.3
ALL STATIONS						101,130	13,069	0.1

(2.2 to 5.5 miles) west of the end of the Grays Harbor north jetty in 20 to 40 meters (10 to 22 fathoms). Areas of low benthic populations include the low silt areas within 3.0 kilometers (1.8 miles) off the north jetty in approximately 9 meters (5 fathoms) or less, and in the gravel areas beyond the 46 meter (25 fathom) contour line. The VanVeen grab did not always provide representative samples in the gravel areas, so that population there may be higher than the samples indicate.

Table 14 shows biomass and numbers of specimens from selected stations where relatively large benthic organisms such as sand dollars, sipunculids and brittle stars were found. The three stations with the highest biomass are listed first, showing the average weight of 14.7 g for the 780 organisms involved. If the next eight stations with highest biomass are listed, Table 14 shows an average weight of 0.3 g for the 16,440 organisms involved. Finally, the average weight for the total of 101,130 organisms is 0.1 g. Therefore, the biomass data are strongly influenced by a few large organisms.

The average of the number of organisms taken from samples in the silt (n=2) is 14,455 organisms/m^2. Those samples taken from sand (n=26) had an average of 2,479 organisms/m^2. Gravel samples (n=9) had an average of 941 organisms/m^2. Thus, it appears that numbers of organisms produce a discernable pattern in relation to type of bottom material. However, attempts to develop meaningful correlation statistics between benthic organisms and bottom materials were not fruitful. This is probably due to some of the sampling bias discussed earlier. These include the limitation of using a 0.1 m^2 VanVeen grab sampler which sampled a very small area as well as a limited volume of bottom sediment. At times the sampler lost part of a sample when the jaws were held open by a small piece of gravel. The presence of sand dollars in a sample produced the same effect.

In summary, the limited nature of this study produced a tentative overview of benthic organism distribution. It appears that a distribution pattern of larger to smaller numbers of benthic organisms is found as one progresses from finer to coarser sediments.

V. QUESTIONNAIRE ON OFFSHORE DISPOSAL OF DREDGED MATERIALS

Introduction

A questionnaire was sent out to a number of fishermen's groups, conservation groups, and state and federal agencies that might have an interest in the impact of 16.7 million cubic yards of dredged material being disposed of in the ocean near the mouth of Grays Harbor. A copy of the questionnaire is included on the following page.

In addition, two meetings were held to discuss the offshore disposal in more detail. One meeting was with officers of the Grays Harbor Crab Fishermen's Association, and the other was with the officers of the Grays Harbor Chapter, Northwest Steelhead and Salmon Council of Trout Unlimited. Appendix C includes a list of people interviewed to obtain various views on the effects of dredged material disposal off Grays Harbor.

The responses of the various interest groups and agencies are in five categories: Positive Impact, Negative Impact, Seasonal Effects, Best Dump Location, Worst Dump Location and Comments. Actual letters of reply and summaries of meetings are included in a separate document, Appendix F.

A review and discussion of responses to the questionnaire is given in the following section.

SAMPLE

QUESTIONNAIRE
ON
OFFSHORE DISPOSAL OF DREDGED MATERIALS

Organization Name ______________________________

Number of Members (if applicable) ______________________________

Principal Activity ______________________________

1. What impacts (positive or negative) do you anticipate from the disposal of 16.7 million cubic yards (initial) and 2.8 million cubic yards (annual maintenance) of dredged material in an ocean disposal site to be designated offshore of the Grays Harbor estuary? For reference purposes, assume the area will be within a 5 nautical mile radius of the Grays Harbor entrance.

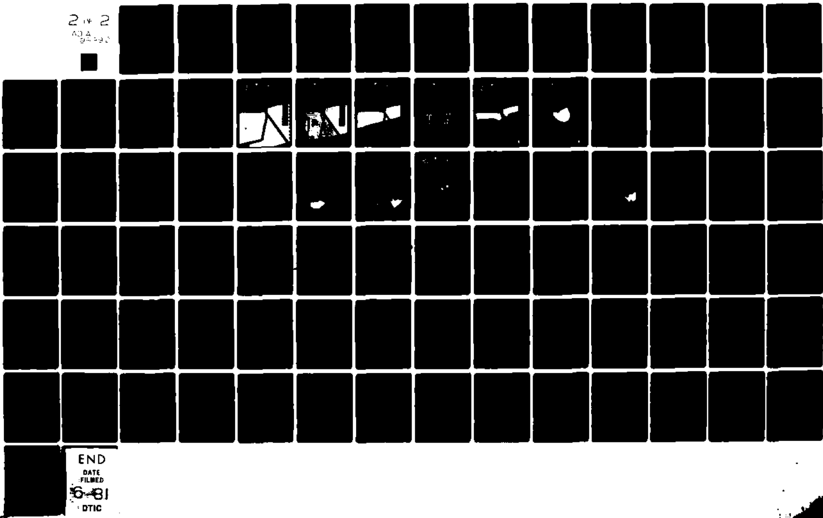
2. Specifically, how might the disposal operation affect your organizations activities or interest in the general area specified? Please describe impacts in terms of physical interferences (i.e., hazards to navigation, boating safety, etc.), potential alterations to biological productivity faunal breeding and rearing areas, water quality, effects anticipated, esthetic considerations and economic gains or losses to your organization. Describe any other impacts you feel are worth consideration.

3. Will these impacts be seasonal in nature? Please explain in detail.

4. Sketch in, on the chart provided, specific areas of critical importance to your organizations (as referred to in your written descriptions).

5. Within the proposed disposal area, where would be the best spot to put the material? Why? The worst spot? Why?

AD-A098 992 GRAYS HARBOR COLL ABERDEEN WA F/G 13/2
GRAYS HARBOR AND CHEHALIS RIVER IMPROVEMENTS TO NAVIGATION ENVI--ETC(U)
MAY 80 J M SMITH, L W MESSMER, J B PHIPPS DACW67-79-C-0046
UNCLASSIFIED NL



Review of Respondents

A. Potential effects of offshore dredge disposal on fish

A number of respondents expressed concern about the adverse effects of offshore disposed sediments on a variety of pelagic and demersal food fish and bait fish. Concerns ranged from potential avoidance of the dump site by fish to habitat loss and disruption of the food chain. A major concern was related to the possible toxic effects (i.e., smothering and bioaccumulation of heavy metals and pesticides) that might be associated with certain dredged materials.

Dredging operations remove and redeposit large quantities of bottom sediment. This material can range from clean sand to organic mud and sludge. The worst possible condition would include the resuspension and redistribution of muds containing toxic materials. The potential of heavy metals and pesticides in dredged materials being incorporated into the food web is of great concern. Little has been done to study this situation in the Pacific Northwest. Mortensen, et al., 1975 outlined the following direct and indirect effects of suspended sediments:

a. Direct effects of suspended sediments to any fin fish (including larval, juvenile and adult forms) of suspended sediments might include:

    1. Suffocation

        a. Gill clogging

        b. Erosion of gill tissue through abrasion

2. Breakdown of resistance to disease by
    a. Initial stress
    b. Continued abrasive action of the sediment
3. Behavior
    a. Avoidance of the polluted area
    b. Methods and tendencies to escape from polluted areas after varying exposures
4. Toxic substances which may be included in the suspended sediments
    a. Heavy metals
    b. Other toxicants (pesticides, herbicides, oils, etc.)

b. Indirect effects of suspended sediments include:
1. Increased biochemical oxygen demand (BOD)
2. Decreased light penetration which influences primary productivity and indirectly, the oxygen concentration.

Due to the high dilution potential of offshore disposal, most of the indirect effects of suspended sediments (i.e., biochemical oxygen demand and reduced light penetration influencing primary productivity) are expected to be minimal or, at worst, short-lived. Studies conducted by Smith, et al., (1977) related to the tracing of the sediment plume down current from the hopper dredge Biddle at its dumpsite between buoys 13 and 15 off Westport, Washington, found that the most obvious impact of dumping of dredged materials was to make the water more turbid.

In most of the water column (within the plume) these changes were very noticeable but were of short duration (a matter of minutes). However, the bottom water remained turbid for considerably longer periods (up to 70-80 minutes) after the dump. Generally speaking, these changes were about equal to or less than the magnitude of natural changes that occur in the bay water as the result of heavy run off from the tributary water shed.

Dissolved oxygen (D.O.) decreased only slightly from ambient (1.0 ml/l, from 10 ml/l to 9 ml/l) on only one occasion, at one station. No significant D.O. depression was discovered in the course of this study (Smith, et al., 1977). This finding is consistent with those of Slotta, et al., (1974) and Wakeman, et al., (1973).

Less is known about the direct effects of suffocation, break down of disease resistance, behavior and toxic substances. Suffocation can occur in several ways. Fine particles can coat and isolate the gill surfaces from contact with the water, thereby preventing gas exchange. The larger particles lodge in the gill lamellae blocking water circulation and creating "dead" spaces at the sites of gas exchange. If injury to the lamellae due to abrasion action is prolonged, the fish can suffocate (European Inland Fishery Advisory Commission, 1965: Herbert, et al., 1961; Sherk, et al., 1974).

White perch (Morone americana), spot (Leiostomus xanthurus), menhaden (Brevoortia tyrannus, striped killifish (Fundulus majalis) and mummichog (F. heteroclitus) in static bioassays were tested in suspensions of mineral solids and natural sediments. These fish represent the broad ecological types likely to be found in typical East Coast estuarine areas, thereby providing a tolerance range of these types of estuarine fishes to suspended sediment.

White perch, spot, mummichog, and menhaden exposed to the mineral solid kaolinite (Hydrite -10) in concentrations of 140 g/liter for 48 hours showed no mortality, but when exposed to suspensions of Fuller's earth, mortality did occur. The lowest concentrations which produced 100% mortality in 0 and

1-year-olds menhaden were 1.2 and 0.8 g/liter, respectively. Lethal concentrations (Fuller's earth) for 10, 50, and 90% mortality in 24-hour bioassays were determined for striped killifish, white perch, pot and mummichog. The lethal concentrations (g/liter) are given in Table 17.

In 24-hour lethality tests using resuspended natural sediments, lethal concentrations for 10%, 50%, and 90% mortalities for white perch, spot, mummichog, and striped killifish are given in Table 18.

Natural sediments were shown to be less "toxic" than suspensions of mineral solids such as Fuller's earth. The lethal effect of Fuller's earth is attributed to a coating effect on the gill filaments due to the finer composition and angularity of the particles, whereas natural sediment clogs gill spaces due to a high content of larger-size, less-angular particles. Rogers (1966), cited by Sherk (1974), concluded that particle shape and angularity were the primary reasons for the lethal effect of a suspended mineral solid.

In general, Sherk (1974) concluded that bottom-dwelling fish species were the most tolerant to suspended solids and filter feeders were the most sensitive. Sublethal solids effects on fishes were identified: hematological compensations for reduction in gas exchange across the gill surface, abrasion of the body epithelium, packing of the gut with large quantities of ingested solids, disruption of gill tissue, increased activity, and reduction in stored metabolic reserves. Oxygen consumption of striped bass and white perch swimming at controlled levels of activity was generally reduced during exposure to suspensions of Fuller's earth and natural Patuxent River sediments.

TABLE 17

LC_{10}, LC_{50}, and LC_{90} values determined for 24-hour exposure of estuarine fishes to Fuller's earth (Sherk, et al., 1974)

	g/liter of Fuller's earth		
SPECIES	LC^*_{10}	LC^*_{50}	LC^*_{90}
White Perch	3.05	9.85	31.81
Spot	13.08	20.34	31.62
Striped Killifish	23.77	38.18	61.36
Mummichog	24.47	39.00	62.17

*LC_X - Concentration of suspended sediments able to produce "X" percent mortality in a given population.

TABLE 18

LC_{10}, LC_{50}, LC_{90} values determined for 24-hour exposure of estuarine fish to natural sediment (Sherk et al., 1974)

	g/liter suspended natural sediment		
SPECIES	LC_{10}	LC_{50}	LC_{90}
White Perch	9.97	19.80	39.40
Spot	68.75	88.00	112.63
Mummichog	Unable to produce sufficient mortalities at any concentration.		
Striped Killifish	97.10	128.20	169.30

He further suggested that juvenile fish may trap more particles due to their smaller gill openings. Since their increased metabolic rate requires more oxygen per unit weight, suspended sediments could have a lethal effect with lower concentrations of sediments or in less time at the same concentrations necessary to kill large fish.

Mortality tests run on several species of estuarine fish (Wallen, 1951) found lethal concentrations of suspended solids from 38,000 ppm--175,000 ppm, depending upon the species. Generally fish survived 100,000 ppm suspended solids for a week, but died within two hours when the concentration reached 175,000 parts per million.

In instances where suspended solid concentrations are less than those required to cause mortality to fish, indirect harm to juvenile salmonids and baitfish may result due to the reduction in the nearshore environment to support food organisms. Suspended solids have been shown to attenuate light and to inhibit food up-take by filter feeders. Turbidity, by reducing the depth of the photic zone, indirectly decreases production by limiting photosynthesis (Bell, 1973; NAS-NAE, 1972; Sherk, 1974). However, primary production and photosynthesis can, in certain instances, be stimulated by the suspension of inorganic nutrients associated with suspended solids (Sherk, 1971).

Resistance to Disease:

Suspended sediments may act on fish by causing direct mortality or by reducing their resistance to disease. Disease is facilitated when fish are placed into stressful situations such as abnormal suspensions of particulate matter. Mechanical abrasion of body epithelium also permits disease organisms to infect the fish and further reduce its resistance (Mortensen, et al., 1976).

Angularity, particle size and concentration are factors which determine the degree of abrasion suffered by fish exposed to suspended material. The larger and more angular the particle, the more abrasion it creates, thereby causing existing wounds to heal more slowly and creating new injuries. Secondary infection by bacteria and fungus are greatly increased (European Inland Fisheries Advisory Commission, 1965, and Herbert, 1963). Obviously, the pre-exposure condition of the fish plays an important role in the rate that these effects are noticed. Around the mouth of Grays Harbor, fish in varying degree of physiological conditions are found at different times of the year. Healthy, marine fish are probably the most resistant to bacterial and fungal diseases. On the other hand, anadromous fish that are transitioning to and from fresh water or estuarine waters are probably the most susceptible to disease.

Fish Behavior:

Fish tend to avoid areas which maintain conditions that may be harmful to them. Suspended sediments, in excessive concentrations, may modify the natural movements and migrations of fish by causing avoidance reactions to turbid and oxygen-reduced waters (Bell, 1973; European Inland Fisheries Advisory Commission, 1965).

Turbidity associated with disposal of outer harbor sediments from Bellingham Bay was thought to divert both juvenile and adult sockeye salmon from their migration routes. Bioassays showed the fish to become disoriented in turbid water (Servizi, et al., 1969).

It is not entirely certain whether the avoidance in salmon is directly associated to the sediment itself or to related water quality factors (i.e., reduced dissolved oxygen, high levels of sulfides, or other factors). The Grays Harbor study area is a high energy area which experiences considerable natural suspension and resuspension of sediments on both a tidal and seasonal basis. Therefore, it is impossible to make a conclusive statement regarding avoidance of turbidity by fish. One could speculate that if ambient water quality were poor (i.e., high sedimentation and turbidity caused by winter and spring runoff) fish might be less able to detect and subsequently avoid the dump site area during winter than during summer or fall when nearshore waters are relatively clear.

Toxic Substances:

Suspension of bottom sediments may release a variety of toxic substances in quantities which may be harmful to fish. In a cursory study by the authors (Smith, et al., 1977), identifiable quantities of both heavy metals and pesticides were found in dredged materials and associated water from the portion of Grays Harbor between Moon Island and the Chehalis River Bridge. The concentrations of both heavy metals and pesticides found in the sediments were orders of magnitude greater than those found in water.

Representative compounds which could affect fish in the study area are discussed in more detail by the following authors: Bell, 1973; Holland, 1964; California State Water Resource Control Board, 1963; and U.S. Environmental Protection Agency, 1976.

B. Potential effects of offshore dredged materials disposal on the benthic community:

Several agencies and groups expressed concern for the benthic community from the initial 16.7 x 10^6 yard^3 of material and 2.8 x 10^6 yard^3 maintenance dredge materials to be dumped in the ocean.

The effect of dumping dredged materials on benthic habitat will not cause total mortality of benthic organisms, especially if alternate times and locations are used. Richardson, et al., (1977) in evaluating the effects of 4.6 x 10^5 m^3 of sediment disposed of at a site (site G) near the mouth of the Columbia River in July and August, 1975, found in post disposal studies (September 1975) a significant increase in diversity and evenness values and macrofauna at stations exposed to direct burial by dredge material compared to stations not affected by dredged material. The biomass values were significantly higher at stations exposed to direct burial. They also found that benthic community structures at stations that were not exposed to direct burial, but were affected by dredge material disposal, were intermediate between affected and unaffected stations.

In their study, Richardson, et al., (1977) found a significant reduction of the abundance at 11 stations exposed to direct dredged material disposal when compared to unaffected stations. The affected species included the polychaetes Spiophanes bombyx, Nephtys caecoides, Glycinde species, Scoloplos armiger, and Northria iridescens; the amphipods Euhaustorius sencillus, Ampelisca macrocephala, Paraphoxus vigitegus and Photis lacia, and the ophiuroid Amphiodia periercta urtica; and the bivalve Olivella pycna. All of the above genera are found off the mouth of Grays Harbor.

The most significant effect of dredged material disposal at site G, where sand was dumped in similar sand, was reduced abundance of 11 of the 33 most abundant species. The disproportionate reduction of the polychaete worm

Spiophanes bombyx (the overwhelmingly dominant species there) increased the evenness of species abundance.

The mechanisms of repopulation of benthos into disposal site G is unknown, but Richardson et al. (1977) state that it was probably accomplished by benthos burrowing up through the dredged material or migrating into the area or by reproduction and/or recruitment of benthos from outside the affected area. There was very little evidence for transportation of benthos to the experimental area via dredged material. Burrowing is quite common in some benthic species, and the ability to burrow up through 1.5 meters of incrementally deposited dredged materials in site G may be an important mechanism. Migration patterns and maximum immigration distances have not been ascertained for most benthic species.

Richardson, et al. (1977) did additional follow-up studies after dumping operations at site G. The abundance of macrofauna retained on a 0.5 mm screen after disposal in June 1976 was higher than in October 1975, January 1976 and April 1976, indicating a partial recovery of site G. There was little difference in abundance of juvenile benthic organisms at stations affected by dredged material and unaffected stations in June, 1976.

The authors concluded that most of the short-term repopulation of site G may have been accomplished by benthos burrowing up through the dredged material or benthos migrating into the area. In general, the species most affected by dredged material disposal were tube-dwelling polychaetes and amphipods and species that have limited ability to burrow through the sediment. Many of these species were primarily restricted to the inshore sand sediments south of the mouth of the Columbia River. The species not affected by dredged material disposal were shelled gastropods and molluscs, nontube-dwelling polychaetes, and cumaceans. All of these species were active burrowers and migrate considerable distances over the sediment. These species generally had a wide distribution and were abundant on the Columbia River delta as well as south of the River. In fact, Carey (personal communication, 1980) reports that site G off the mouth of the Columbia River experienced a population increase in the razor clam Siliqua patula after dredged material dumping. Apparently pelagic larvae of the clam were available to colonize the relatively uninhabited, newly deposited sands. Durkin (personal communication, 1980) reports that the shrimp Crangon franciscorum is a "pioneer" species in disturbed bottom areas, and that specimens captured in the ocean are approximately 15 mm longer than those inside the Columbia River estuary.

Thus, one could expect similar survival and repopulation dynamics for the benthic organisms off Grays Harbor in response to the same order of magnitude of dredge material disposal. The impact of the larger volume of 16.7×10^6 yard^3 of material can possibly be modified by wider dispersion over time and area. It would appear that certain species mentioned above could survive in the proposed disposal area off Grays Harbor as long as like materials are dumped on like materials, and adequate time and space are used to allow the benthos to adjust and repopulate.

C. Avoidance of dredged materials by Dungeness Crab

The respondents expressed concern that ocean dumping of dredged materials would "sour" the established crab grounds in the vicinity of the study area. The term "sour" is considered here to have a two-fold meaning. The term refers to any factor which will cause an avoidance response by the crab for an area; and, the term is used by crab fishermen in describing an odor they detected on crab pots that were placed in the vicinity of the Grays Harbor south jetty while dredged materials were being disposed near buoy 13.

Although many acute and some chronic toxicity tests have been done with dredged materials and marine organisms, there is a void in the literature relative to a behavioral, avoidance response by crab to these materials. Verification of an avoidance response and determination of its extent is necessary in order to estimate the impact of dredged materials disposal on crab fishing in the region of any proposed ocean disposal site. Laboratory scale test can be performed to obtain such data (Holton, Oregon State University, Corvallis, Oregon: personal communication, 1980). With respect to the problem of "souring" of crab pots during disposal operations, it seems that a clearer description of the problem could be obtained by observing the nature of sediments deposited on crab pots in the vicinity of the south jetty during maintenance dredging.

D. Potential effects of offshore dredged disposal on plankton

Several agencies commented on effects of dredged materials on the food web as it related to baitfish and salmon. Pertinent to these comments is a discussion of plankton.

The immediate mechanical effects of dumping materials would be limited to phytoplankton and zooplankton in the water column surrounding the vessel. Suspension of fine sediments would continue for a longer period of time (Smith, et al., 1977).

Light attenuation could be a potential factor in the growth of phytoplankton populations (Mortensen, et al., 1976). Raymont (1963) marshals compelling evidence that light is a limiting factor in primary productivity. Thus, suspended sediments could potentially affect productivity primarily by limiting light intensity. The potential distribution of these sediments in the waters off Grays Harbor is unknown at this time.

Other possible effects of dredged material on phytoplankton include: dissolution of heavy metals or toxic substances accumulated in the sediments and dissemination of cysts of red-tide organisms. Chaetoceros armatum has a diel bouyancy behavior that keeps it concentrated in the surf-zone (Lewin and Hruby, 1972). This diatom is the most important food organism for the razor clam. Any effect of dredged materials sediments on C. armatum would possibly affect the razor clam.

No conclusions on zooplankton abundance can be drawn from the Columbia River disposal project since post-disposal sampling was not keyed to the dumping schedule. However, Durkin and Lipovsky (1977) noted a decrease of zooplankton in finfish stomach samples after disposal. Sullivan and Hancock (1977) in a critical review of zooplankton and dredging, say that much of the previous research in the dredging field has not effectively dealt with the zooplankton. They state, "Thirty percent of a zooplankton population could perish, and we would be unable to validate it." They mentioned the need for studies on zooplankton populations where disposal causes abnormal chronic turbidity conditions or where dredge spoils contain pollutants that may change the water quality. They concluded that resuspended sediments may reduce the effectiveness of feeding appendages and that more inorganics than usual may affect nutrition and adhere to the eggs of animals, thus affecting settling rates.

It appears that the greatest impact of dredge spoil disposal on planktonic organisms would come from the effects of increased turbidity and dissolved substances that would become part of the water mass.

E. Potential effects of offshore dredge disposal on oyster culture in Grays Harbor

One particular survey response was directed at the overall effects of channel dredging and the long term impacts on oyster culture in Grays Harbor.

Acute effects of bulk sediments, sediment homologues, bulk sediment elutriates, estuarine waters impacted by hopper and pipeline dredging, and of sodium sulfide, tannic acid, ammonia and sulfite waste liquor were examined using 0-48 hour old larvae of the Pacific oyster (*Crassostrea gigas*) by Cardwell and Woelke (1977). Continuously suspended, natural sediments from Grays Harbor, Washington, caused statistically significant adverse effects on larval oysters at concentrations from less than 0.1g dry wt/l to between 5.3 and 13.2g dry wt/l. It was determined that sediment toxicity with respect to oyster larvae was a function of the character (size, density and configuration) of the particles as well as chemical composition.

Chemicals such as ammonia, hydrogen sulfide and tannins and lignins, which do not have a high affinity of particulate matter were thought to be the primary compounds of toxicological significance in seawater extracts of sediments. Waters taken both from upstream and in the plume of the hopper dredges were toxic to oyster larvae (probably due to the presence of sulfite waste liquor in waters of the general area sampled).

The present study area (offshore Grays Harbor) is approximately 10-16 km from the nearest oyster culture area. One of the forseeable benefits of offshore disposal is to lessen some of the impact related to re-entry of waters of poor quality to the estuary from confined upland and unconfined open-water dredged materials disposal sites. Provided these materials are disposed of far enough at sea to prevent re-entry into the estuary, this can be viewed as a positive benefit to oyster growers.

F. Spatial competition within study area by marine users

The study area around the mouth of Grays Harbor can be characterized as an area of high biological productivity which seasonally experiences a wide range of marine activities and user densities. Competition for space within this area has been the subject of much debate for over 30 years.

The inshore segment of the trawl fishery off Grays Harbor at times competes spatially for the same grounds with the Dungeness crab fishery when the crab season is open. Although at times a controversial issue between trawlers and crabbers, it is not possible to show that trawling has or has not had an adverse effect on the crab resource (Pacific Fishery Management Council, 1979).

Towboats and merchant ships have specified depths at which they are to travel while at sea. However, when entering Grays Harbor, a variety of approaches can be made, often resulting in high losses of crab gear due to the shearing off of buoys by the tug or ships's screws or by the barges they are towing. Figures 16, 17 and 18 show that crab pots are moved closer to shore as the crab season progresses each year.

In 1975, pot fishermen, towboaters and shipping officials began meeting annually to delineate "non-conflicting" towboat and shipping lanes along the West Coast, especially near harbor entrances and areas of high crab and sablefish (black cod) pot density. The result was a mutually agreed upon set of charts for the West Coast between San Francisco and the Straits of Juan de Fuca, which marked major fishing areas (by seasons) and outlined towboat lanes which were to be kept clear at all times of the year (Appendix E). These charts are revised annually by members of the fishing and towing industry, reflecting changes in fishing effort, season and area regulation, and towing and shipping requirements. Although not totally successful, this approach has kept lines of communication open between these groups of marine users.

The area around the tips of Grays Harbor's north and south jetties has always been regarded as a highly productive region for baitfish organisms (i.e., herring and anchovies). Baitfish attract salmon, and salmon attract fishermen, both commercial and recreational. At certain times between June-September it is not uncommon to see as many as 1,000 charter, private, and commercial salmon fishing boats competing for a spot among the 5,000+ crab pots located in this region. Most commercial salmon boats now use special devices on their main trolling lines called "crab cutters," which jam and cut-off crab float lines. On the other hand, a salmon troller will have to replace 1 or 2 trolling poles each year due to tangling with a polypropylene crab float line attached to a "sanded-in" crab pot.

Loaded and unloaded log ships, towboats with barges and Coast Guard rescue vessels find it difficult at times to enter or leave the harbor via the main channel due to the heavy congestion near the bar.

Figures 16 through 19 describe seasonal marine density patterns for the study area. Figure 20 represents the comments of Grays Harbor Dungeness crab and trawl fishermen concerning the impact of offshore disposal of dredged materials as summarized in Appendix F. The comments of the Grays Harbor Bird Club in Appendix F about the offshore disposal of dredged material on birds is represented in Figure 21.

A loaded hopper dredge or tug and barge, making 10-12 round trip passes through this area per day will cause additional congestion in the area off Grays Harbor and a number of precautions will have to be considered.

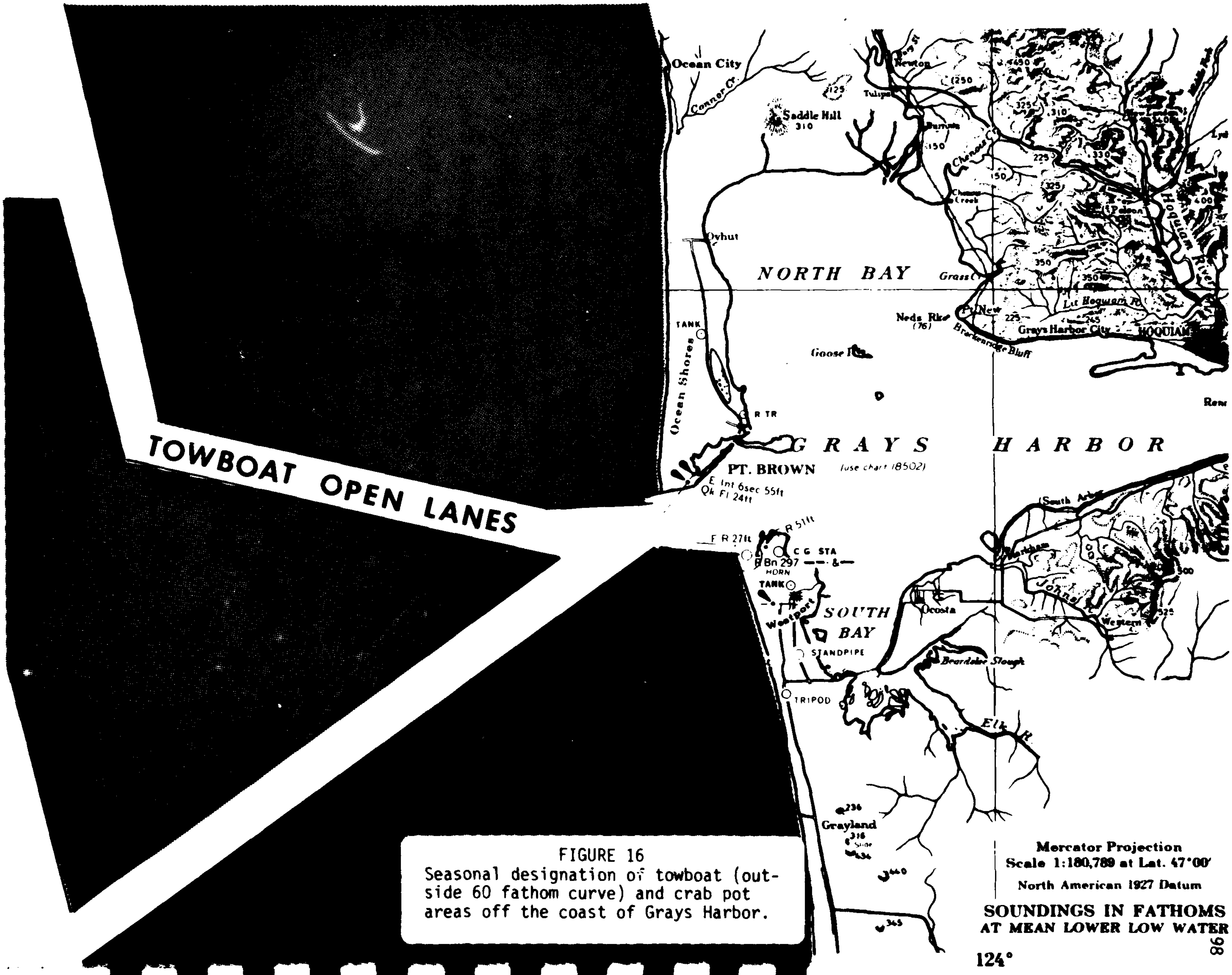


FIGURE 16
Seasonal designation of towboat (outside 60 fathom curve) and crab pot areas off the coast of Grays Harbor.

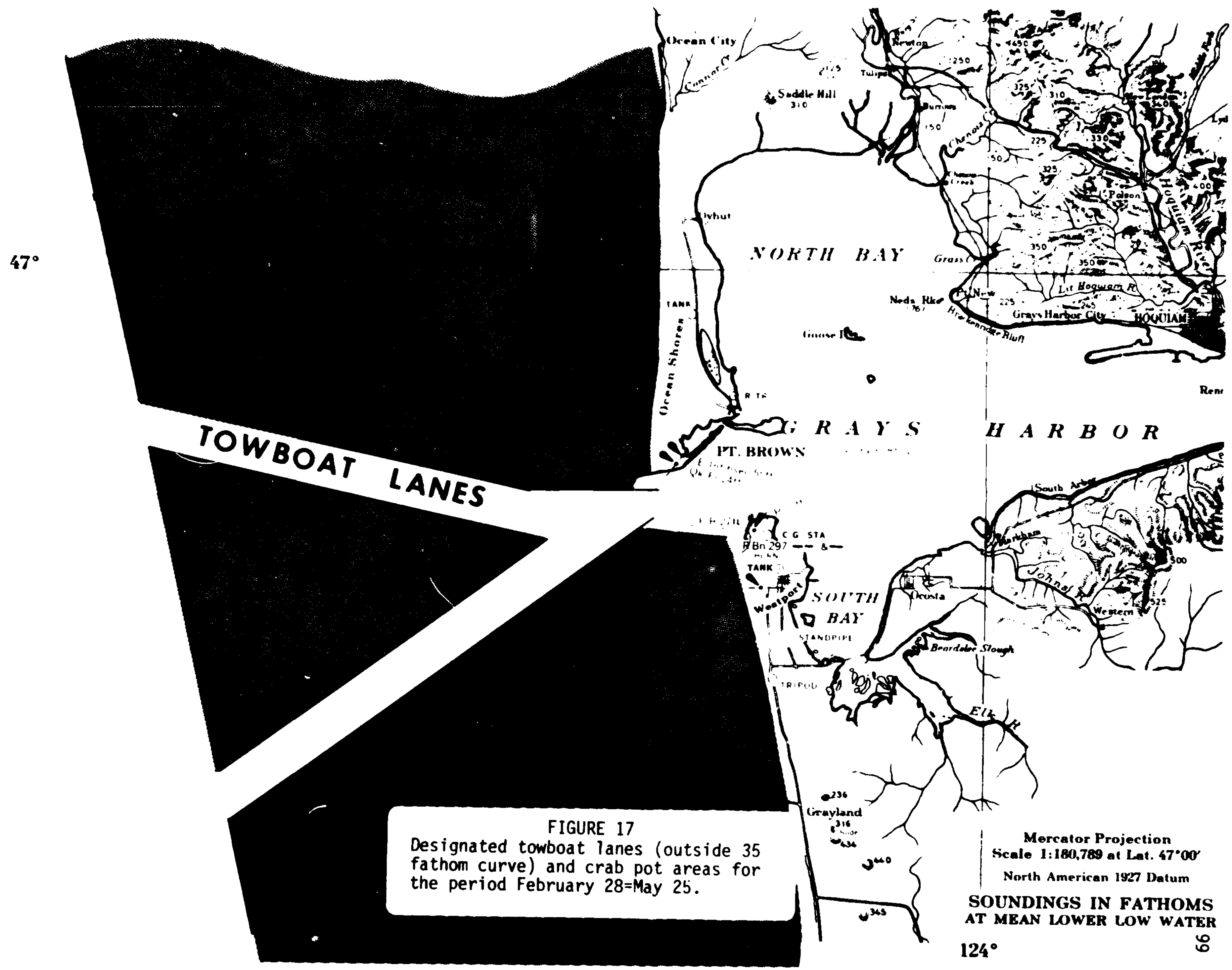


FIGURE 17
Designated towboat lanes (outside 35 fathom curve) and crab pot areas for the period February 28=May 25.

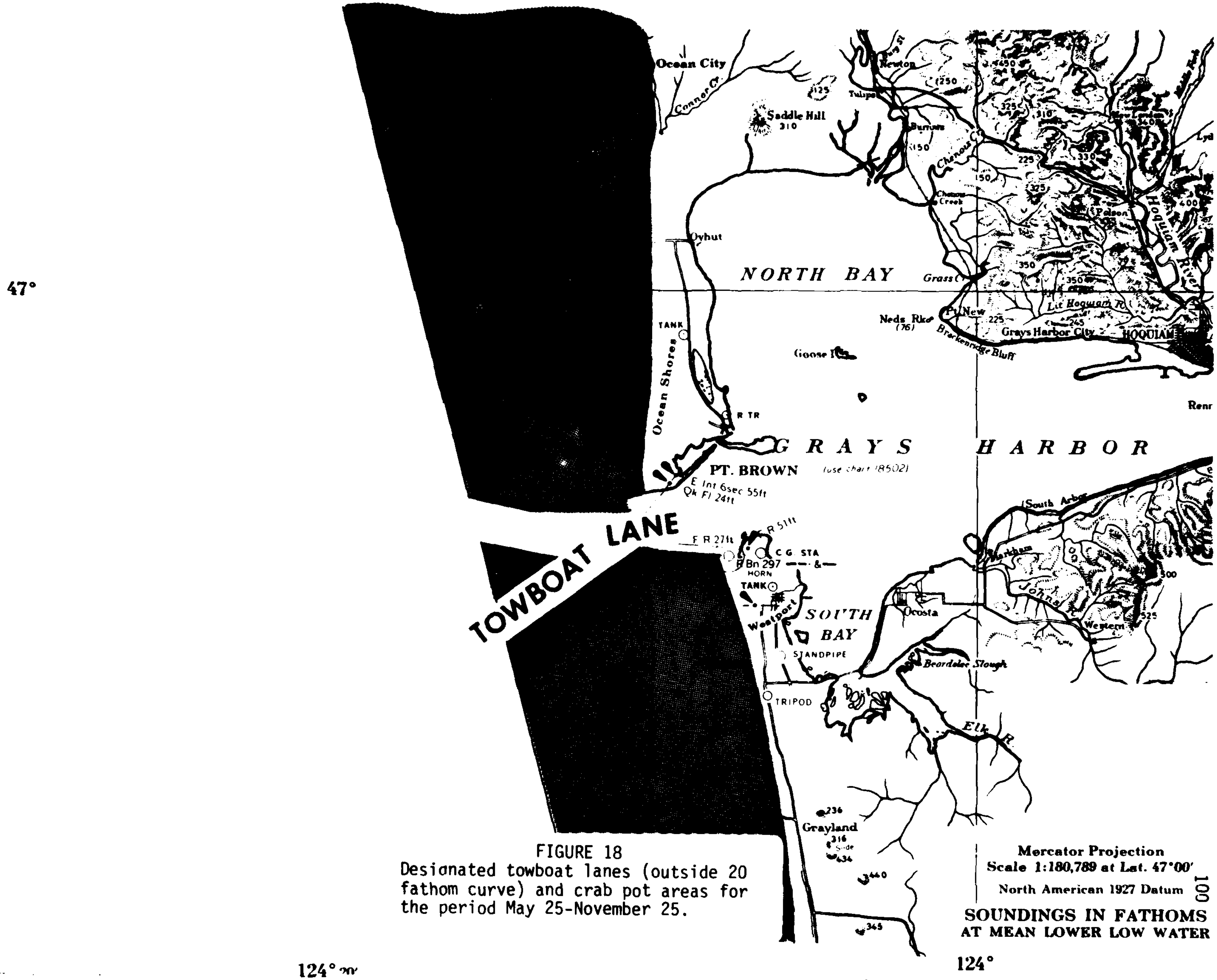


FIGURE 18
Designated towboat lanes (outside 20 fathom curve) and crab pot areas for the period May 25-November 25.

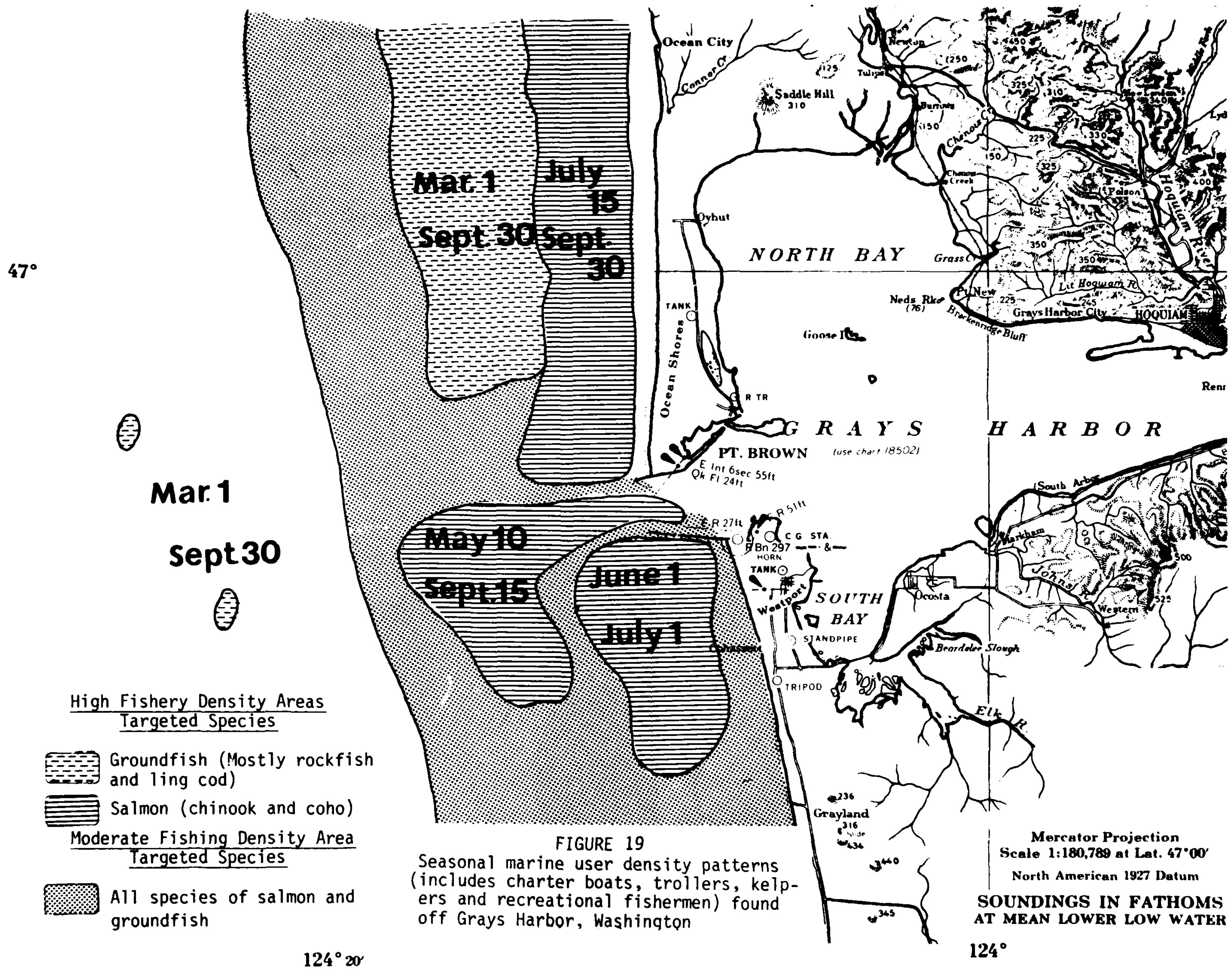
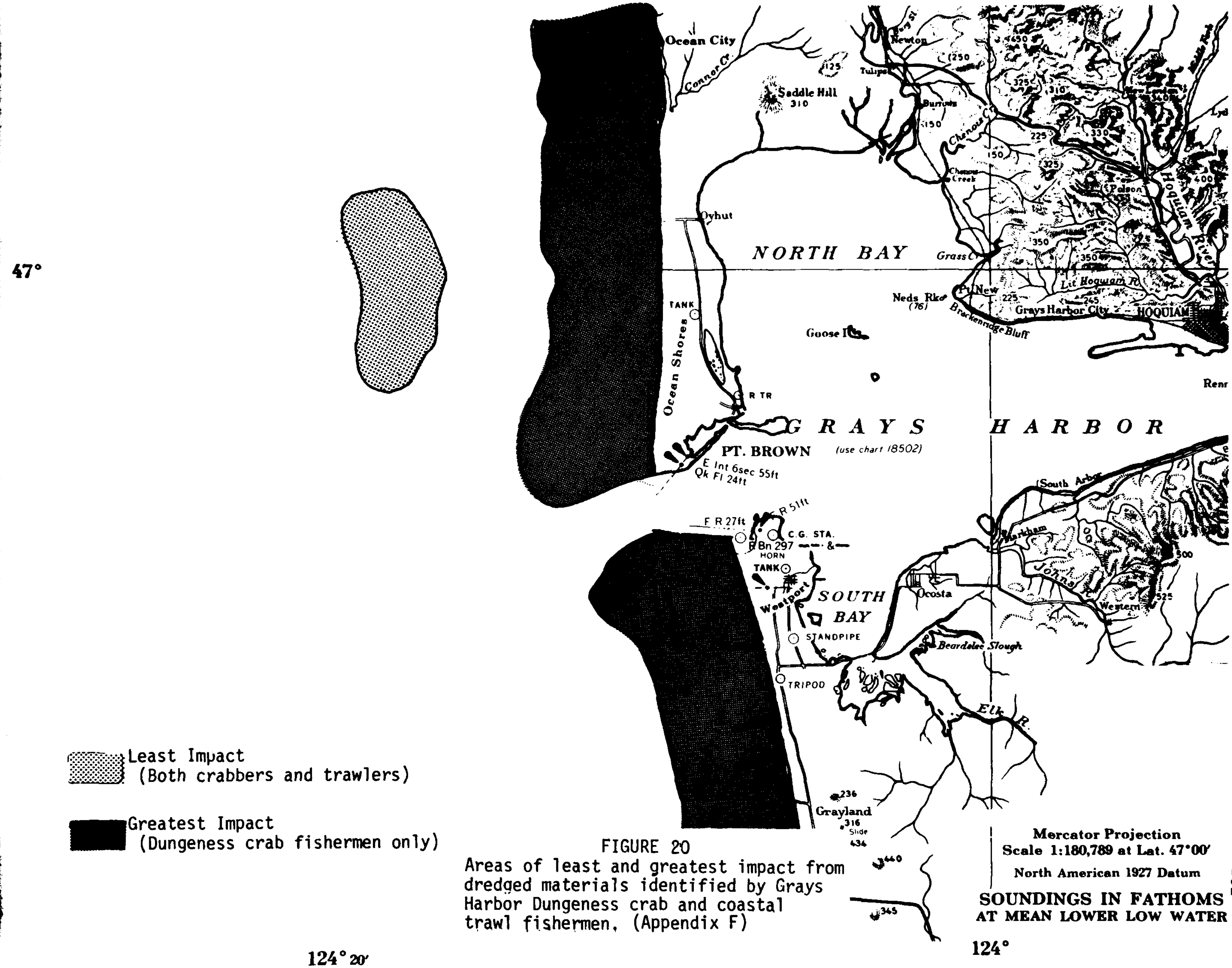


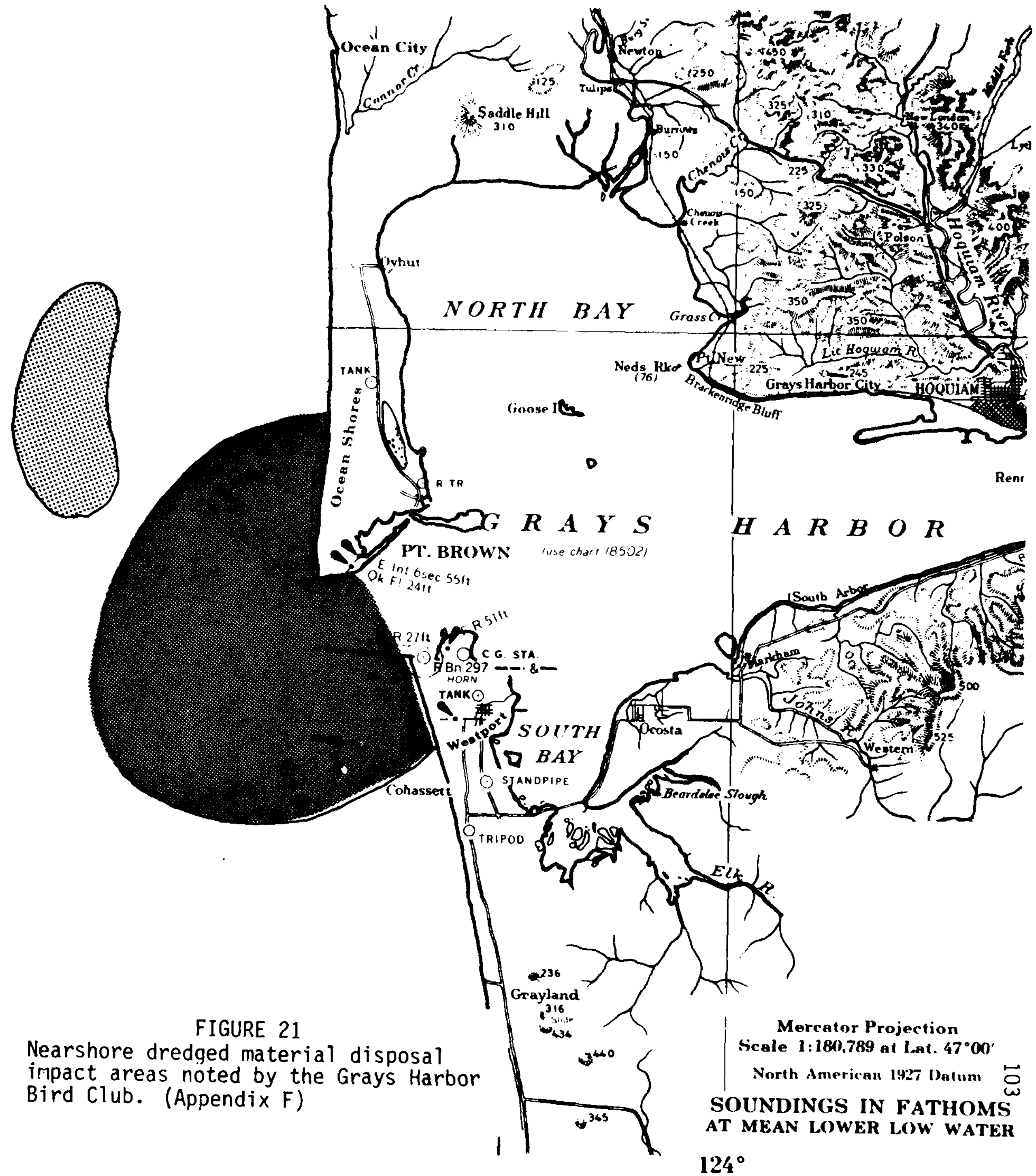
FIGURE 19
Seasonal marine user density patterns (includes charter boats, trollers, kelpers and recreational fishermen) found off Grays Harbor, Washington



Least Impact
(Both crabbers and trawlers)

Greatest Impact
(Dungeness crab fishermen only)

FIGURE 20
Areas of least and greatest impact from dredged materials identified by Grays Harbor Dungeness crab and coastal trawl fishermen. (Appendix F)



Least Potential Impact

Greatest Anticipated Impact

FIGURE 21
Nearshore dredged material disposal impact areas noted by the Grays Harbor Bird Club. (Appendix F)

G. Dumping that would make the bar crossing more hazardous

Concerns have been expressed by several respondents about disposal sites that would make the bar crossing more hazardous. This is an important consideration since one of the main reasons the U.S. Army Corps of Engineers is involved in channel dredging is to make the bar entrance deeper and wider and thus less hazardous to larger vessels. Indeed, it would be a poorly designed project if the end result were to be just the opposite of its expressed purpose. In light of this, perhaps the most appropriate response would be that several problems including: a) increased shoaling in non-channel portions of the harbor entrance, b) the attendant changes in tidal currents, and c) wave refraction, must be considered as important aspects of the project design. It follows that, until a disposal site is selected and the project design completed, further speculation is unwarranted, but the concerns remain. (See Section VII, Potential Disposal Sites).

H. Potentially toxic substances that leach from dredged materials

Concern has been expressed about the introduction of toxic substances to the water column during ocean disposal of dredged materials, or by exchange between the water and sediment interface. Lee and Plumb (1974), in their literature review of this subject, list nine factors that have been shown to affect the mobility or migration of chemical constituents from dredged material. These are: concentration of chemical constituent, D.O., agitation, time of contact between sediment and water, water characteristics, solid-liquid ratio, pH, particle size, handling of solids and solid-liquid separation. The D.O. of the water column into which the dredged materials are placed, appears to be one of the most important factors (Brannon, et al., 1978). Lu and Chen (1975) and Kahlid, et al., (1978) have shown that levels of D.O. and total sulfide as well as the redox potential of interstitial and immediately overlying water determine chemical migration from sediment to interfacial waters. Lu and Chen (1975) found that the released cadmium, copper, nickel, lead and zinc increased as redox conditions became more oxidizing whereas iron and manganese concentrations in interfacial water increased as redox conditions became more reducing.

The most significant effect of the D.O. is the oxidation of reduced forms of iron and manganese. When sediments are placed in well oxygenated water, the rather soluble iron (II), which is generally present in anoxic sediments, is rapidly oxidized to iron (III) oxide which flocculates and serves as a scavenger of other metal ions as well as organic matter released from the sediment (Lee, et al., 1975).

Increasing salinity from dredge site to disposal site is another factor which may affect the sediment-water exchange of potentially toxic materials. Evans (1973) demonstrated that manganese and to a lesser extent zinc were released into the water column when Columbia River sediments were mixed with ocean water. Organic matter, especially humic and fulvic acids, is capable of complexing metal ions and adsorbing other materials. The concentration of these materials in the sediment will affect the release of sediment bound substances as well as the scavenging of water soluble materials. The pH of the water would not be expected to be a factor in the well-buffered marine system. For the other factors listed above, it is difficult to make *a priori* predictions concerning sediment water exchange because these factors relate to the methods of dredging and the handling of the sediment.

The exchange of toxic substances between the dredged materials and the environment may be categorized into three separate phenomena. First, exchange may occur with the water column as the solids pass through it following a dumping operation. Exchange over a greater time span may occur between the settled sediment through its interstitial water to the overlying water column (Brannon, et al., 1978). Lastly, uptake of metals by benthic organisms directly from the sediment or its interstitial water has been demonstrated (Neff, et al., 1978).

Direct exchange to water column:

Predictions about the exchange of toxic substances to the water column must be made relative to the nature of the dredged material being disposed. Materials dredged near the Grays Harbor bar and from the outer harbor would be expected to be similar to materials dispersed during the Columbia River Study (Holton, et al., 1978). The relatively clean sands dredged from the lower Columbia River produced no measurable effect on the metal chemistry of the water column. Previous studies by the Choker Research Group (Smith, et al., 1977) have shown that open water disposal of Grays Harbor sediments caused fluctuations in dissolved oxygen that were less than natural variations. In fact, water at depth was often enriched in oxygen during dumping. This phenomenon was possibly caused by the entrainment of oxygen rich surface water. Thus, we expect the ocean water column to remain well oxygenated during disposal. The oxygen in this water should serve to oxidize iron (II) from the sediments and form iron (III) oxides which flocculate and adsorb other dissolved substances.

For sediments whose bulk chemical analysis indicates the presence of significant concentrations of potentially toxic materials, there can be no substitute for appropriate testing to determine the extent to which these materials are desorbed to the water column. The elutriate test is a simplified laboratory simulation of the dredging and disposal process. The elutriate of a sediment sample is analyzed for major dissolved chemical constituents. With this analytical data and dilution calculations for the intended disposal site, the impact of dissolved constituents from dredged materials disposal may be evaluated. In the absence of this data we can make no predictions of the impact of polluted materials disposal on water column chemistry.

Even with elutriate test data, there are some problems in assessing potential impacts. The standard elutriate test (Environmental Effects Laboratory, 1976) uses water filtered through a 0.45 μ membrane filter for the analysis of major constituents. Therefore, some colloidal and all larger size particles suspended in water would be excluded from the test.

Long term flux of contaminants from dredged material to overlying water:

The long term release of contaminants from dredged material was studied by Brannon, Plumb and Smith (1978). They observed the net mass release of twelve chemical constitutents over a period of eight months and correlated this information with six short-term characterization tests. They conclude that no single short-term test can predict the long-term water quality impacts of dredged material disposal. The elutriate test did relate to seven of the twelve parameters after four months and four of the twelve parameters after eight months. This test, then, appears to be the single most useful criterion.

The usefulness of bulk analysis of sediment as an indicator of water quality changes following dredged material disposal was evaluated by Lee and Plumb (1974). They concluded that such an approach was unsound. The bulk analysis uses a strong acid extraction procedure which is not at all related to natural processes. The constituents of a sediment are distributed among several geochemical phases, and the migration of these constituents to overlying water is dependent on their chemical form, solubility and the degree of binding to their respective phase.

Bulk analysis of several samples taken during dredging of upper Grays Harbor indicated the presence of potentially hazardous concentrations of several heavy metals and pesticides (Smith, et al., 1977). There is a need for elutriate test data as well as analysis of interstitial water for "upper" harbor sediment samples before any reasonable prediction can be made about the long range impact of dredged material disposal on ocean water quality.

Assimilation of toxic materials from sediments by benthic organisms:

Concern has been expressed about the potential of heavy metals and pesticides in dredged materials being incorporated into the food web. It is well known that marine organisms may contain in their tissues several heavy metals at concentrations many times higher than in the ambient medium. From a consideration of their literature search concerning the bio-availability of heavy metals to aquatic organisms, Neff, et al., (1978) made the following generalizations:

a. Heavy metals in solution vary over several order of magnitude in their availability to benthic invertebrates. Some metals like Tl, Cs, and Ru are accumulated very slowly from solution while others like Zn, Cu, Cd and Pb are accumulated rapidly and retained for a long time in the animal's tissues.

b. The accumulation potential of a metal, usually measured as the concentration factor (Concentration in the tissues/concentration in the exposure water), may be affected by several physical and biological factors. Physical variables affecting the concentration factors of a metal include duration of exposure, the salinity or water hardness (for fresh water), the exposure concentration, and the ambient temperature. Effects of these physical parameters vary from metal to metal.

c. Several biological factors are also important in heavy metals accumulation from solution. There are wide differences in concentration factors between the species. Lamellibranch mulluscs often have higher concentration factors for a given metal than do polychaete worms or crustaceans. Species differences are also seen within a phylum. Animal size and the stage in its life cycle also may affect heavy metals accumulation. Acclimation to environments high in heavy metals may increase or decrease the rates of uptake of different metals from solution.

d. The chemical form of a metal has an important effect on its bioavailability. For example, organic mercurials are generally accumulated more rapidly than inorganic mercury. A number of animals are able to transform a metal from one form to another, thus changing its uptake/release kinetics.

e. Elevated concentrations of heavy metals in the tissues of benthic invertebrates are not always indicative of high levels of metals in the ambient medium or associated sediments. Use of these animals to monitor heavy metals pollution should be carried out with caution.

f. Heavy metals are often present at higher concentrations in the tissues of animals from low-salinity environments than in those from seawater. This relationship does not hold for all heavy metals and is probably related to differences in speciation and solubility characteristics of metals in fresh and saline waters.

g. The relationship between body weight and tissue heavy metal concentration varies from species to species and for different metals. In some cases, there are direct relationships between the two; in other cases, the relationship may be inverse or nonexistent.

h. Tissue heavy metals concentrations show seasonal variations in ambient heavy metals concentrations, ambient salinity and temperatures, or biological condition and physiological state of the animals.

i. Skeletal structures of benthic invertebrates may contain high concentrations of heavy metals. Concentrations of metals in mollusc shells seem to be related to environmental factors (salinity and temperature) and to levels of the metals in the ambient medium. In crustaceans and squid, deposition of heavy metals in skeletal structures may be a means of sequestering and excreting potentially toxic metals.

j. Because several heavy metals are essential micronutrients to benthic invertebrates, they are actively accumulated from very dilute solution, and their levels in the tissues are regulated in accordance with the needs of the animal. Since nutritional requirements for these metals vary, "normal" metal levels in tissues will vary from species to species.

k. For some heavy metals, there appears to be good correlation between metal concentration in the sediment and in the associated infaunal and epifaunal macrobiota. For other metals, no such correlation exists. These correlations often vary from one sediment to another. The correlation when it occurs, may be due to transfer of metals from sediment to biota, or it may represent the presence of a common source of metals to both the sediment and biota.

l. Sediments naturally or artificially contaminated with radio-isotopes of heavy metals have been used for studying metals uptake by benthic invertebrates. In some cases, uptake has been demonstrated; in other, it has not. The time required for equilibration of metals between sediments and the associated biota is long. Generally, accumulation of heavy metals from sediments, when it can be demonstrated, is several orders of magnitude less efficient than accumulation from aqueous solution.

The research of Neff, et al., (1978) on assimilation of metals from sediment by benthic fauna indicates no correlation exists between sediment bulk analysis and the concentration of heavy metals in the tissues of benthic organisms. This is not to say there is no pathway for assimilation. In fact, of 136 metal-species-sediment combinations tested by Neff, 49, or 36%, resulted in significant metal uptake by the organisms. There were, however, 13 of the 136 tests in which control animals contained higher concentrations of metals than those exposed to polluted sediment.

Experiments on exchange of polychlorinatedbiphenyl compounds and chlorinated hydrocarbon insecticides between sediments and interstitial water by Faulk, et al., (1975) found no correlation between these kinds of compounds in sediments and in water. These results suggest that in order to estimate the uptake of toxic materials from polluted sediment, appropriate bioassays should be performed using the sediment, disposal site water and organisms native to the disposal site.

VI. POTENTIAL DISPOSAL SITES:

Many factors are involved in the selection of a disposal site. Examples of such factors include: the biota to be affected, the physical nature of the site, the chemistry of the water column, the user groups adversely affected and those who may benefit, the costs involved, the engineering and dredging methods best suited to get the job done, and the nature of the material to be disposed.

Obviously this study did not address all of these factors, and so it follows that the evaluation of any potential disposal site defined herein would be subject to rather severe limitations. Furthermore, we are concerned that the identification of a particular disposal site would remove other potential sites from consideration. Therefore, the strategy was to select several conditions that would be acheived if a particular site was selected. These conditions were allowed to constrain the site to a specific area. The pros and cons were then identified for each area.

As a result of the present study, the authors have chosen four potential disposal areas with varying distances from the harbor mouth. As the distance from the harbor mouth increases, the cost of the project increases and the potential for environmental damage apparently decreases (cost of dredged material transport is estimated at $0.60/cubic yard/mile of transport, Harry Disbrow, Seattle District Corps of Engineers). Therefore the sites can be categorized as: high cost--low environmental risk, medium cost--medium environmental risk, low cost--high environmental risk.

Site I-Medium cost-medium environmental risk site.

The following conditions were used to identify potential disposal site I:

1) Within 16 km of Grays Harbor mouth.

2) Not on the mid-shelf silts.

3) In an area where none of it would come back on the beaches or enter the harbor. (This is the 50 meter isobath as suggested by Creager and Sternberg, 1973 or 40 meter isobath as suggested by Smith and Hopkins, 1973).

4) Dump "like on like", i.e., sand on sand.

These four constraints identify an area shown in Figures 22 and 23.

Pros

1) Dredge can follow buoy line out of harbor, and could head directly southwest into winter waves.

2) Greater depth allows for greater dilution.

3) Moderate to low numbers of benthic organisms.

Cons

1) An area of high fishing effort. No user groups favored this site.

2) Great depth allows for more chemical exchange with water column.

3) Dredged sand deposited here has a high probability of moving northward onto the mid-shelf silt area, thereby altering the productive silt area.

Site II-Low cost-high environmental risk site.

The conditions used to identify site II are:

1) The potential for beach nourishment.

2) Like on like, i.e., sand on sand.

3) Area of low benthic population.

Actually two sites are proposed: one just north and one just south of the harbor entrance (Figure 24). If these two sites were used, so as to take advantage of the seasonal changes in longshore drift directions, the sediment would be started away from the harbor entrance. In the long term, however, it would be mixed in with ambient sediments by the existing sediment distribution system.

This beach nourishment option provides the opportunity for beneficial use of the resource. While the potential disruption of several fishing activities exist under this option, it may also enhance certain specific

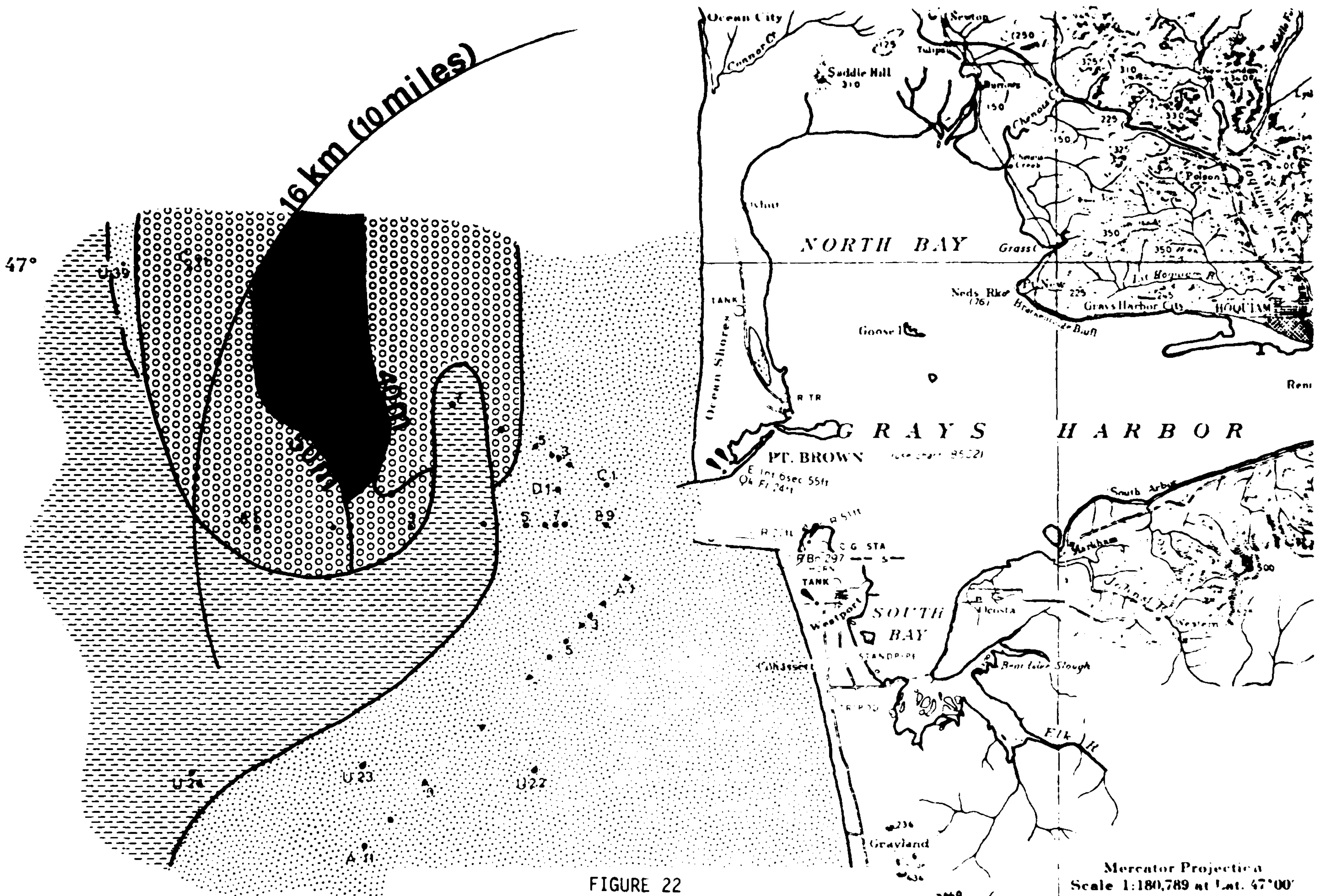


FIGURE 22

Disposal site Ia, (dark shading), lies between the 40 and 50 meter isobath. The different sediment types are shown by the following patterns: dots=sand, lines=silt and circles=gravel deposits.

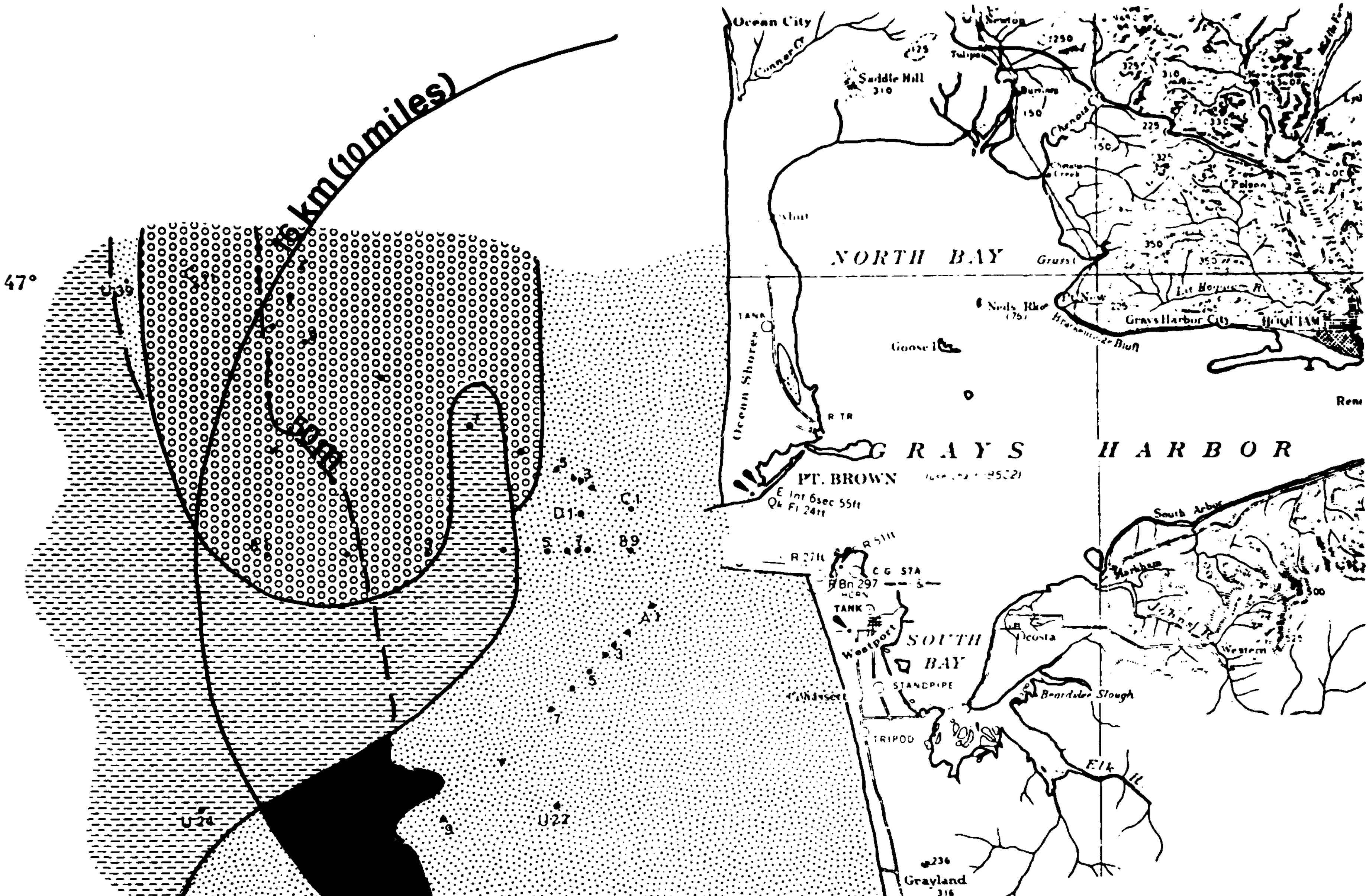


FIGURE 23

Disposal site Ib, (dark shading), lies between the 50 meter isobath (dashed line) and a 16 kilometer arc drawn from the harbor entrance. The different sediment types are shown by the following patterns: dots=sand, lines=silt and circles=gravel deposits.

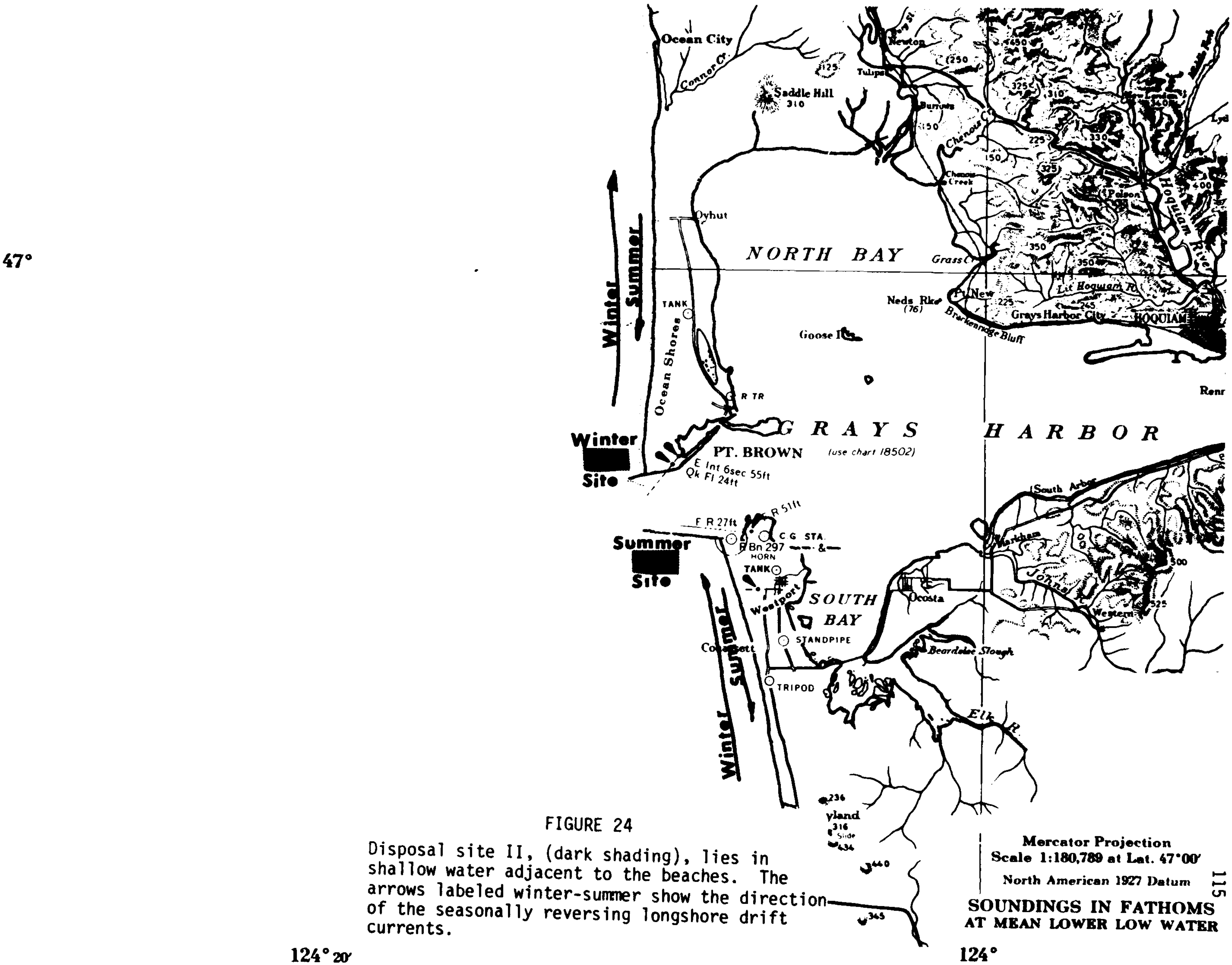


FIGURE 24

Disposal site II, (dark shading), lies in shallow water adjacent to the beaches. The arrows labeled winter-summer show the direction of the seasonally reversing longshore drift currents.

fisheries (i.e., razor clams). There is a remote, but serious possibility of degrading the clam fishery. No other site option is as risky. No other option has as high a probability of promoting conflicts between user groups.

Pros

1) Beneficial use of the resource.

2) Short haul distance makes this option economically attractive.

3) With sand coming back to the south beaches, there is a possibility of re-establishing clam populations in the areas that are now gravel.

4) Mitigate the loss of sand at Westhaven State Park.

Cons

1) This option would require the loaded dredge to swing through the wave trough which is an undesirable situation.

2) There is a possibility of the fine sediments ending up on the beaches for a short period of time and smothering the clams. (Hancock and Sollitt at Oregon State were concerned about this possibility at Coos Bay, Oregon).

3) The dredged material will become involved in the longshore drift system, and there is a possibility that some of it will eventually re-enter the harbor.

4) These two areas are good habitat for crabs and are heavily fished. Dumping dredged materials here could have adverse impacts on this fishery.

5) These two areas are often used by charter and commercial salmon fishermen. Such use is potentially in conflict with dredged material dumping there.

Site III-Medium cost - medium environmental risk site.

The following conditions were used to identify potential disposal site III:

1) Within 16 Km of Grays Harbor.

2) Not in the mid-shelf silts.

3) Water deep enough to prevent the return of sediment to the beaches and harbor mouth.

4) In an area of relatively low numbers and biomass of benthic organisms.

These constraints were used to identify area III shown in Figure 25.

Pros

1) The same four constraints as for site I (pages 111, 112).

2) Out of crab fishery area.

3) Out of trawl fishery area.

4) Out of main shipping channels.

5) Relatively low benthic populations.

6) In general--the least objectionable area to most of the user groups interviewed.

Cons

1) Dredge would be in the "trough" of the winter sea.

2) Dredges would transect crab fishing area and northbound boat traffic.

3) Not disposing "like sediment on like sediment."

Site IV-High cost-low environmental risk site.

This "site" is offered as an alternative to sites I, II, and III. It follows the recommendations of Pequegnat, et al., page 139 (January, 1978). They recommend that disposal not be shoreward of the 500m isobath off Grays Harbor because of important demersal fisheries (see Figure 26).

Pros

1) Sediments would not return to beaches or the harbor mouth.

2) No direct effect on most fisheries.

3) Follows current thinking at the national level (Pequegnat, et al., 1978).

Cons

1) Greater distance from harbor mouth, a distance of approximately 38 nautical miles (61 Km).

2) Crosses coastal shipping lanes.

3) Not "like on like sediment."

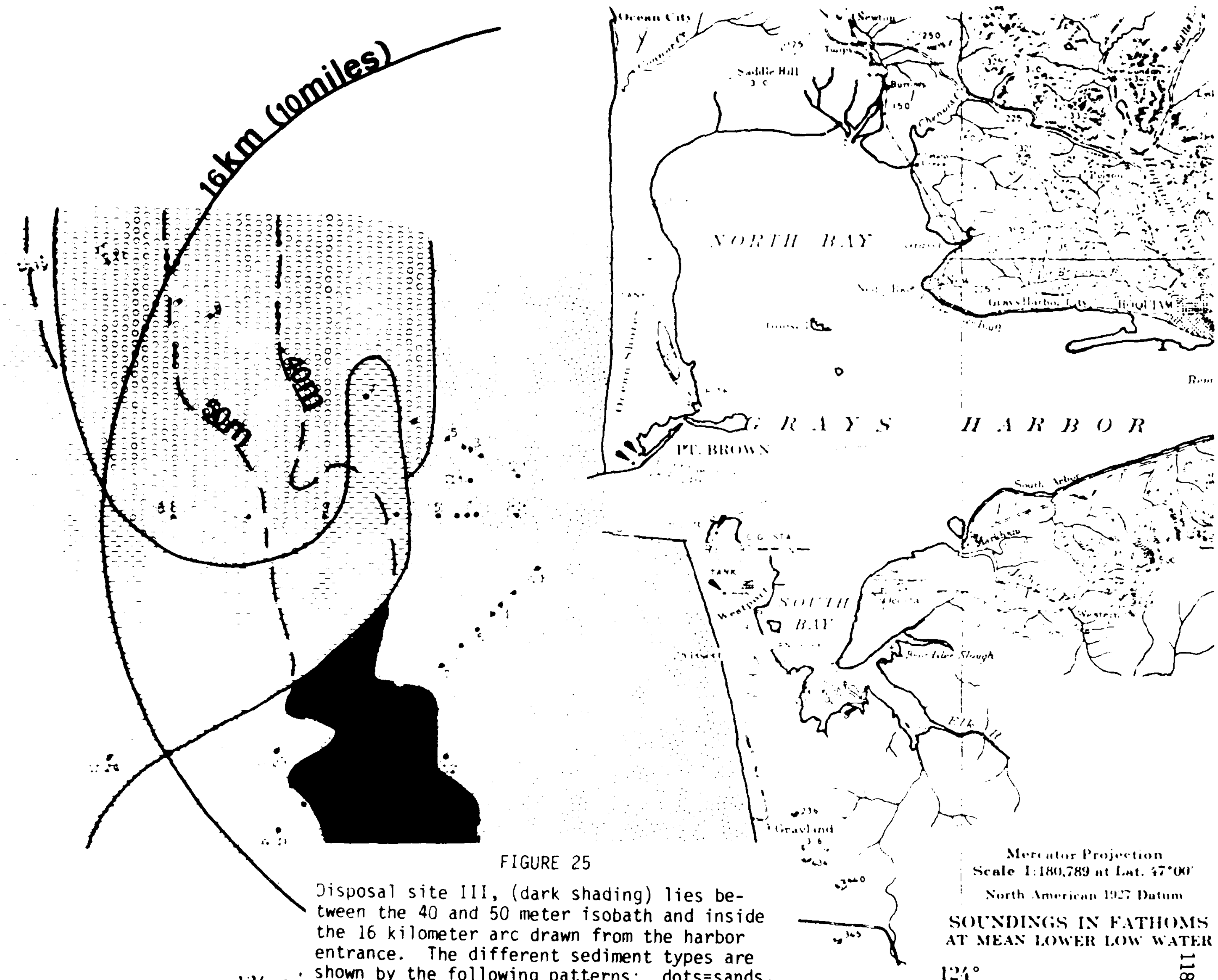


FIGURE 25

Disposal site III, (dark shading) lies between the 40 and 50 meter isobath and inside the 16 kilometer arc drawn from the harbor entrance. The different sediment types are shown by the following patterns: dots=sands, lines=silts and circles=gravel deposits.

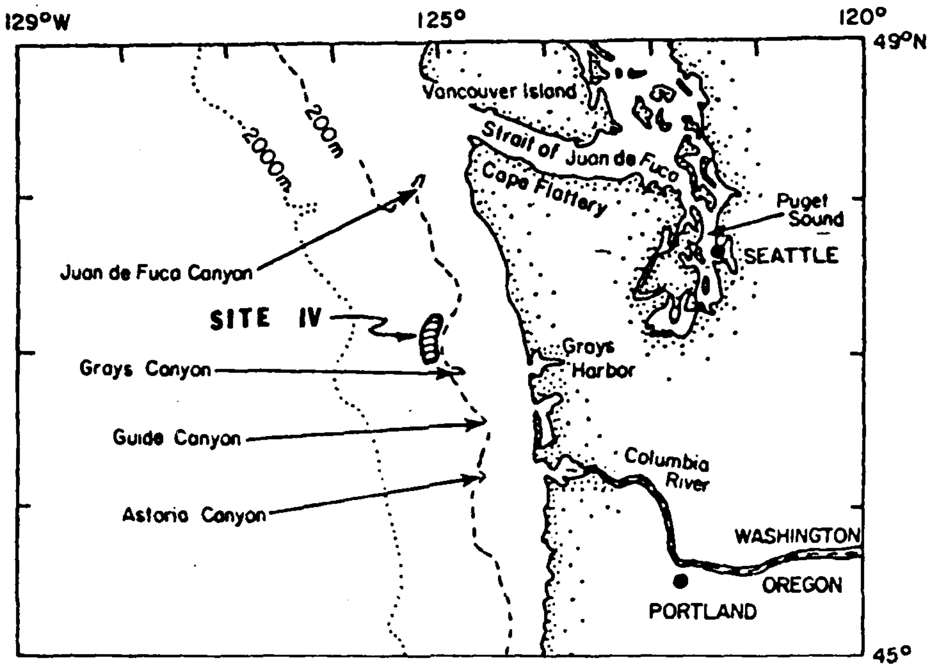


FIGURE 26

Disposal site IV, (lined), lies off the edge of the continental shelf in 500 meters of water, approximately 38 nautical miles from the harbor entrance. The figure was taken from Peguegnat, et al.

VII. DATA GAPS AND AREAS FOR FURTHER STUDY

Prologue

The data gaps listed below are specific for a potential ocean site near Grays Harbor. The data gaps are those perceived after a review of the literature listed in the bibliography.

Data Gaps

1. More detailed explanation of food web relationships.
2. Effects of transient turbidity events on plankton.
3. Effects of dredged fine sediments on razor clams.
4. Site specific catch statistics and economic value of important finfish and shellfish.
5. Effects of clay particles on diel bouyancy of surf zone diatoms.
6. Verification of avoidance response by crabs to dredged materials.
7. Effects of transient currents on sediment transport at specific sites.
8. Identification of sediment transport regime at harbor entrance.
9. Characterization of the physical and chemical nature of sediments to be dredged.
10. Elutriate test data on sediments containing potentially toxic materials.
11. Long term trends in pollution and expected future impacts of dredging.
12. Bioassay data on sediments containing potentially toxic materials.
13. Potential of beach nourishment by nearshore disposal.

Recommendations

1. Basic food web studies, including producers, herbivores and all levels of carnivores should be conducted. Specific relationships between species and how these relationships contribute to nutrient cycling and energy pathways within the marine ecosystem off Grays Harbor should be the context of a long term (preferably three year or longer) study.

2. Biological surveys should be conducted prior to, during and following offshore disposal in the area of the dump site and in selected areas of highest probable impact, comparing these areas with non-affected control areas. These surveys are desirable because they will provide information not presently obtainable from commercial or recreational catch statistics. The investigators would have control over sampling methods and techniques (thus reducing bias from market conditions, size and season limits, or economic need to fish primarily in areas of high abundance). Such studies would provide a much better assessment of fish stocks, populations and recruitment for future management as well as providing descriptions of the total fish community prior to, during and following offshore dumping.

   The initial surveys will provide a baseline assessment of fish and shellfish species and their diversity, abundance and distribution. The surveys should be repeated every two to three years with reduced sampling intensity.

3. It is important to know the physical and chemical properties of the sediments to be dredged in order to predict their responses in the marine environment. Therefore, it is recommended that the areas to be dredged be cored and the cores analyzed for:

   a. grain size

   b. concentrations of potentially toxic materials in the bulk sediments

   c. mobile, potentially toxic components of the sediment via elutriate tests

   d. toxicity of sediments and interstitial water to indigenous phytoplankton, zooplankton and benthic organisms via appropriate bioassays

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APPENDIX A

Marine mammals found off the Washington coast.

APPENDIX A

MARINE MAMMALS FOUND OFF THE COAST OF WASHINGTON*

I. Order Cetacea

A. Suborder Mysticeti

1. Black or Pacific right whale - Balaena glacialis**

Range and Habitat: A pelagic species of temperate waters. Ranges from Vancouver Island north in summer and from the Oregon coast south in winter. Moderately migratory with coastal tendency and non-gregarious (Eaton, 1975, and Southern California Ocean Studies Consortium, 1974).

Population: Estimated at 4,000 world-wide or 8% of virgin population (Scheffer, 1976). The rarest baleen whale in the study area, it was once common. In the North Pacific, there may be 250; less than a dozen have been sighted during federal surveys in the study area in the last twenty years. Only a few taken by shore whaling stations in this area (Eaton, 1975; Southern California Ocean Studies Consortium. 1974; Cowan and Guiguet, 1965 and Pike and MacAskie 1969).

Life History: Length 15-16 m and baleen 2 m or more. Breeds in alternate years in the spring and bears a single calf after gestation of one year. Breeds, calves, and nurses close to shore (Eaton, 1975 and Southern California Ocean Studies Consortium. 1974).

Food: Prefers to feed farther offshore mainly on copepods and some small fishes (Eaton, 1975 and Southern California Ocean Studies Consortium. 1974).

2. Minke whale - Balaenoptera acutorostrata

Range ar[illegible]at: Can be found in all marine waters of the study area. [illegible]n whale most frequently found in inside waters, seen singly o[illegible] in small pods. Usually found in high latitudes during the summer and warmer, more southern waters in fall and winter, and, in the study area, occurs mostly in summer (Eaton, 1975; Southern California Ocean Studies Consortium, 1974, and Larrison, 1976).

*From: Harshman, G. W. and Johnson, T. L. Summary of Knowledge of the Oregon and Washington Coastal Zone, 1977.

**Uncommon

Note: The phrase "study area" used in Appendix A refers to study areas quoted by Harshman and Johnson only.

Population: With a large and stable world population of 300,000 (Scheffer, 1976), the minke whale is the second most heavily hunted whale of the northwest. Most of the population is concentrated in the southern hemisphere. The North Pacific population is unknown (Eaton, 1975). Federal surveys show 26 sitings of this species for the coast of Washington, since 1958 (U.S. Bureau of Sport Fisheries and Wildlife, 1975).

Life History: Length about 8-10 m with baleen 12-13 cm long (Cowan and Guiguet, 1965, and Larrison, 1976). Probably breeds every two years, bears a single calf and is secually mature at 7-8 years (Southern California Ocean Studies Consortium, 1974).

Food: Feeds on krill, small fishes and squid (Eaton, 1975).

3. Sei Whale - *Balaenoptera borealis*

Range and Habitat: A pelagic species, found offshore in the study area in the summer, usually in pods of 2-5 whales (Eaton, 1975). Winters in warmer, low latitude waters.

Population: According to Scheffer (1976) the world population is 75,000, but Eaton (1975) and Southern California Ocean Studies Consortium (1974) list world population as 80,000 is southern oceans and 33,000-37,000 in the North Pacific. Past records for shore whaling stations show that the sei whale was the third most frequently taken species off British Columbia (Pike and MacAskie, 1969) and fourth most frequent off Washington (U.S. Army Corps of Engineers, Portland District, 1975). Federal surveys (U.S. Bureau of Sport Fisheries and Wildlife, 1975) show 4 sitings of this species off the Washington coast since 1958.

Life History: Length 13-16 m; weight 20 metric tons or more. Females are sexually mature at 6-12 years, bear a calf every 2 or 3 years, and mate and give birth in the winter (Eaton, 1975, and Southern California Ocean Studies Consortium, 1974).

Food: The sei whale feeds on copepods in the study area and also on small fishes when in wintering areas (Cowan and Guiguet, 1965, and Eaton, 1975).

4. Fin whale - *Balaenoptera physalus*

Range and Habitat: A pelagic species resident in offshore and coastal waters of the study area in the summer and occasionally venturing into inside waters; migrates to lower latitudes during the winter (Eaton, 1975; Larrison, 1976, and Southern California Ocean Studies Consortium, 1974). Usually seen in pods of 2-5 animals.

Population: There are estimated to be 100,000 world-wide (Scheffer, 1976) and 10,000-13,000 in the North Pacific (Eaton, 1975). The fin whale was the second most important species for shore whaling stations in the northwest, with a take of over 6,000 fin whales per year (Pike and MacAskie, 1969, and Eaton, 1975). Hunting has drastically reduced its numbers in the North Pacific, and the International Whaling Commission now protects it in this area (Scheffer, 1976). It was once one of the most common baleen whales in this area, but federal surveys (U.S. Bureau of Sport Fisheries and Wildlife, 1975) list only one sighting for the coast of Washington since 1958.

Life History: This whale is second only to the blue whale in size, reaching over 23 m and 50 metric tons (Eaton, 1975, and Cowan and Guiguet, 1965). Fin whales mature in 6-12 years, and females bear calves every 2-3 years after a one year gestation. Breeding and calving occur on wintering grounds (Eaton, 1975).

Food: Usually feeds on euphausiids (krill), but also eats small fishes, especially anchovies (Eaton, 1975).

5. Humpback whale - Megaptera novaeangliae**

Range and Habitat: A pelagic species with coastal tendency, it occurs in the study area in fall and spring while migrating between winter and summer grounds, and occasionally entering inside waters (Eaton, 1975).

Population: Only about 7,000 are left, world-wide (Scheffer, 1976), and perhaps 1,200 inhabit the North Pacific. Intense whaling depleted stocks early in this century, and the humpback was the most important species for shore stations in Washington (U.S. Army Corps of Engineers, Seattle District, 1975). Only two have been sighted on the Washington coast by federal surveys since 1958 (U.S. Bureau of Sport Fisheries and Wildlife, 1975), and Sanger (1965) lists one sighting for 1963.

Life History: A slow, gregarious species; length to 16 m; weight over 30 metric tons (Eaton, 1975, and Cowan and Guiguet, 1965). Sexual maturity is attained at 6-12 years; mating and calving is in the winter; females usually bear calves every other year (Eaton, 1975).

**Uncommon

Food: Humpbacks feed mainly on euphausiids (krill), but also on sardines, herring and anchovies; fasts in the winter (Eaton, 1975).

6. Gray whale - Eschrichtius robustus**

Range and Habitat: A pelagic species usually seen in the study area as a migrant, most frequently within a few kilometers of shore and occasionally straying into inside waters (Eaton, 1975, and Rice and Wolman, 1971). The peak of the northward migration here is in April and southward migration peaks in late December (Pike and MacAskie, 1969). Individuals are known to feed within the study area between May and November (Mate, 1977).

Population: Whaling reduced the population to about 1,000 at the end of the century, but eastern North Pacific stocks have now increased to about 11,000, close to the original population (Eaton, 1975). The most recent estimates indicate the population is maintaining a steady level. The gray whale is the most numerous baleen whale in the coastal parts of the study area, and federal surveys since 1958 (U.S. Bureau of Sport Fisheries and Wildlife, 1975) have recorded nearly 500 sightings.

Life History: A slow swimming, gregarious whale; length to 14 m; baleen to 45 cm; mature at about 8 years. Females calve every other year, in winter, after a 13 month gestation period (Rice and Wolman, 1971).

Food: In contrast to other baleen whales, the gray is a bottom feeder, eating mainly amphipods and decapods which it stirs up with its snout (Rice and Wolman, 1971). Most sources state that they fast during migrations, but Pike and MacAskie (1969) believe north-bound whales begin feeding as they pass off British Columbia.

B. Suborder Odontoceti

1. Pacific striped dolphin - Lagenorhynchus obliquidens**

Range and Habitat: A pelagic species that is found in offshore and coastal waters of the study area, ventures into inside waters (Eaton, 1975). Occurrence in inside waters is usually in winter, moving offshore in summer (Pike and MacAskie, 1969 and Eaton, 1975).

**Uncommon

Population: Numbers are not well known, but is stated to be rare in the study area (Larrison, 1976 and Scheffer, 1960).

Life History: Length to 3 m; reproductive cycle as short as one year, gestation period of 10-12 months (Eaton, 1975).

Food: Feeds mostly on cephalopods and small fishes such as herring, sardines, anchovies and saury (Eaton, 1975).

2. False killer whale - Pseudorca crassidens**

Range and Habitat: A pelagic species found in offshore waters of the study area (Eaton, 1975).

Population: No estimate available, but is considered to be uncommon by Eaton (1975) and very rare by Larrison (1976).

Life History: Length 4-5.5 m; breeding biology is largely unknown (Eaton, 1975).

Food: In the study area, food habits are unknown (Eaton, 1975).

3. Killer whale - Orcinus orca

Range and Habitat: A pelagic species found in all marine waters of the study area with year round occurrence (Eaton, 1975).

Population: The study area contains a large concentration of this species (particularly in Puget Sound). Certain family units (pods) are known to be "resident" within a relatively small range; second most abundant whale in coastal and inside waters (Larrison, 1976). Eaton (1975) gives counts of 459 in 1971, 255 in 1972, and 249 in 1973 for the inside waters of Washington and British Columbia. A live capture fishery for these whales conducted in the inside waters of study area (Bigg and Wolman, 1975) and continues in Canadian waters.

Life History: Killer whales frequently feed in packs and actively prey on other marine mammals (principally seals and sea lions) and also eat fish, squid, and octopus (Eaton, 1975). (Note: life history above is quoted as printed in original document. No food entry.)

4. Harbor porpoise - Phocoena phocoena**

Range and Habitat: A pelagic species found in all marine

**Uncommon

waters of the study area year round, and most frequently in coastal and inside water (Eaton, 1975, and Isakson and Reichard, 1976).

Population: Said by Larrison (1976) to be the most abundant whale in the study area. However, Eaton (1975) states that the Puget Sound population has been severely reduced and Isakson and Reichard (1976) agree.

Life History: Length less than 2 m (Eaton, 1975); breeding season in late summer with 9-10 month gestation period (Isakson and Reichard, 1976).

Food: Feeds mainly on bottom fishes such as cod, herring fry, flounder and occasionally on invertebrates (Eaton, 1975).

5. Dall porpoise - Phocoenoides dalli**

Range and Habitat: A pelagic species present in colder waters of the North Pacific and has occurred in all marine waters of the study area (Eaton, 1975). Usually seen offshore or in the Strait of Juan de Fuca (Larrison, 1976, and Pike and MacAskie, 1969).

Population: No specific estimates for the area are available. Listed by Larrison (1976) as occasional to common. Sightings off the coast are common and said to be increasing (U.S. Bureau of Sport Fisheries and Wildlife, 1975).

Life History: Length 2 m; calves probably born in spring and summer, but other information is lacking (Eaton, 1975).

Food: Feed predominately on squid and schooling fishes (Southern California Ocean Studies Consortium, 1974, and Eaton, 1975).

II. Order Carnivora

A. Suborder Fissipedia

1. Sea Otter - Enhydra lutris**

Range and Habitat: Historically found on the open coast of the study area but not bays, estuaries or inside waters.

**Uncommon

Prefers areas where rocks, reefs, islands, or kelp beds offer some protection from rough water. Kelp beds may indicate the presence of preferred bottom fauna or be the result of sea otter grazing and are preferred habitats. The limit of sea otter habitat appears to be about 54 m (30 fathoms) and they have been observed ashore in undisturbed areas or during storms (Kenyon, 1969).

Population: Exterminated in the study area about the turn of the century and recently re-introduced in the study area in 1969-71. Population in Washington was estimated to be about 22 in 1974 (Eaton, 1975) with no recent update. It is feared that chronic minor oil spills and tanker ballast water discharges along the Washington coast in the last year may have severely damaged the population (Rieck, 1977). Oregon's population appears to be about 20-25 otters (Rieck, 1977). Otters have been documented in Washington for Point Grenville, Destruction Island, Third Beach trail south of La Push, James Island, Cape Johnson, and Ozette (Eaton, 1975) and in Oregon for Simpson's Reef, Bionco Reef and Orford Reef (Thompson and Snow, 1974). Available habitat far exceeds population.

Life History: Sea otters are 140-148 cm long and weigh 30-45 kg with females averaging less (Kenyon, 1969). Reproductive cycle is two years; females mature at 4 years; breeding is in all seasons with a fall peak; gestation period is 12-13 months with delayed implantation of 7-8 months; births usually occur on land in Alaska (Kenyon, 1969).

Food: To sustain itself in cold waters, the sea otter depends on a thick, "waterproof" pelage which, if oiled, may result in rapid loss of body heat. A daily food intake of 20-23% of its body weight has been observed. Otters are opportunistic carnivores and will eat molluscs, fish, arthropods, squid and octopus (Kenyon, 1969).

B. Suborder Pinnipedia

1. Northern fur seal - *Callorhinus ursinus*

Range and Habitat: Found within the study area, but is a pelagic species that rarely comes ashore. The fur seal strays into inside waters and is occasionally seen in coastal waters, but is usually found farther offshore, in spring heading north and in fall heading south (Eaton, 1975). The main migration approaches to within 5 km of the Washington coast at Cape Alava (Larrison, 1976). The migration population is most abundant between 50 and 110 km offshore, and a traditional winter area of concentration, known as the Vancouver Grounds, is located from the north end of Vancouver Island to the Columbia River (Baker, Wilke and Baltzo. 1970).

Population: Total population in the North Pacific is put at 1.6 million (Eaton, 1975), but the numbers present in the study area at any particular season are not known. Sampling off the Washington coast in 1969 (U.S. National Marine Fisheries Service, Marine Mammal Biological Laboratory, 1971) indicated concentrations of seals off Cape Flattery and between Grays Harbor and the mouth of the Columbia River. The Interim Convention of Conservation of North Pacific Fur Seals controls harvest and much research is done by the North Pacific Fur Seal Commission.

Life History: Males grow to about 2.5 m in length and weigh 300 kg; females get 1.5 m long and 60 kg in weight (Eaton, 1975). Females breed at 4-6 years, bear a pup every year in their prime, and give birth and breed in July (Baker, Wilke and Baltzo, 1970).

Food: The fur seal feeds mostly on small, schooling fishes. In the study area, the leading food is anchovy and also rockfish, capelin, and salmonids (U.S. National Marine Fisheries Service, Marine Mammal Biological Laboratory, 1971).

2. California sea lion - *Zalophus californianus*

Range and Habitat: Found in the study area in coastal and offshore waters, usually in fall and winter, and strays into Puget Sound water occasionally (Eaton, 1975). Earlier researchers indicated that *Zalophus* was uncommon north of Sea Lion Caves in Oregon (Cowan and Guiguet, 1965 and Kenyon and Scheffer, 1961). More recent efforts such as Mate (1973 and 1975) indicate that males migrate north after breeding, and significant numbers travel as far north as southern Vancouver Island. Mature females are unknown in the study area. Breeding range is San Miguel Island (34° N) to Mazatlan, Mexico (23° N) (Mate, 1973).

Population: The transient male population is estimated at 2,500 for Oregon and 1,000 for Washington and British Columbia at the peak of migration (Eaton, 1975). Mate (1975) indicates the peak of migration is in October for Oregon and probably December for Vancouver Island. Hauling out areas in Oregon are Cascade Head, Sea Lion Caves, Simpson's Reef, Blanco Reef, Orford Reef, and Rogue River Reef (Thompson and Snow, 1974). Hauling out areas known for Washington are

Split Rock and Jagged Island (Kenyon and Scheffer, 1961) and possibly Flattery Rocks (U.S. Army Corps of Engineers, Seattle District, 1975). Good data does not exist for Washington. Bigg (1973) counted up to 473 California sea lions in the winter of 1971-72 on southern Vancouver Island. The main haul out areas in British Columbia are Race Rocks near Victoria and Folger and Wouwer Islands in Barkley Sound.

Life History: Males grow to 2.5 m and weigh 45 kg; females grow to 1.75 m and weigh 260 kg; pups are born in June with mating within a few weeks (Eaton, 1975). Does not breed in the study area.

Food: Food species are non-commercial fish, molluscs, and crustaceans (Eaton, 1975).

3. Northern or Steller sea lion - *Eumetopias jubata*

Range and Habitat: A breeding resident of the study area. Usually seen along the coast and Strait of Juan de Fuca and occasionally in Puget Sound (Eaton, 1975). May use rock outcrops, and rocky or coarse sand beaches (Eaton, 1975). Larrison (1976) states that it does not breed at any of the hauling out areas in Washington but does breed in Oregon. Eaton (1975) also states that breeding grounds have been reduced.

Population: Put at 500 for Washington and 1,100 for Oregon by Eaton (1975). Counts for southern Vancouver Island by Bigg (1973) averaged just over 500 individuals. For Oregon, Mate (1973) gives the following confirmed rookery locations for northern sea lions; Rogue River Reef, Orford Reef and Simpson Reef, and in addition lists the following as haul out areas: Sea Lion Caves, Three Arch Rocks, and Ecola State Park offshore rocks. For Washington, Isakson and Reichard (1976) list as hauling out areas the Quillayute Needles, Jagged Island, Split Rock, Spike and Carroll Island. Bigg (1973) lists northern sea lions as hauling out on Race Rocks, Sombrio Point, Pachena Point, and Folger and Wouwer Islands in Barkley Sound. Vancouver Island rookeries include Barkley Sound, Triangle Island, Bull Harbor, Besford Island, Sartine Island, Bunsbu Island, Vargus Island and Wickelninish Rocks (Mate, 1977).

Life History: Males grow to 4 m and weigh 900 kg; females grow to 2.5 m and weigh 450 kg. A territorial polygamous species that pups and breeds during summer months, the northern sea lion matures at age 5 for females and males first breed at age 7 or 8 (Eaton, 1975).

Food: This species feeds opportunistically on a variety of fish and cephalopods that are usually not commercially important.

4. Harbor seal - *Phoca vitulina*

Range and Habitat: Harbor seals are a breeding resident in the study area and are found in coastal bays, estuaries, inside waters and on the open coast (Eaton, 1975; Larrison, 1976, and Isakson and Reichard, 1976). Resting areas are places where seals have protection and are typically low sand or mud bars and exposed rocks (Eaton, 1975, and Isakson and Reichard, 1976). Harbor seals use shallow bays, tideflats, and rivers where food is easy to obtain (Eaton, 1975), as well as the open ocean.

Population: 500 estimated for Oregon (Pearson and Verts, 1970). In Washington, counts vary from about 1,700 to 3,000-4,000 (as given in Isakson and Reichard, 1976). The current population in Washington is a sizable reduction from the 5,000-10,000 probably present earlier in this century (Newby, 1973). British Columbia populations are estimated at 11,000 to 35,000 seals for the entire province (Bigg, 1973). In listing areas that the seals use, pupping areas are not specified as different from hauling out areas by most authors. Areas of use for Oregon are (Thompson and Snow, 1974) Cape Ferrel - Lone Ranch Beach, Crook Point - Mack Reef, Hunters Island, Rogue River Reef, Hubbard Reef, Humbug Mt. Rocks, Refish Rocks, the Head (Port Orford), Orford Reef, Blanco Reef, Blacklock Point, Coquille Rocks, Fivemile Point, Simpson's Reef, Sunset Bay, Coos Bay, Alsea Bay, Winchester Bay, Tillamook Bay, Cape Falcon, Gull Rock, Tillamook Head, and Columbia River. For Washington, Isakson and Reichard (1976) compiled a list of 63 critical areas for harbor seals, as follows: Columbia River estuary, 5 sites; Willapa Bay, 11 sites; Grays Harbor 15 sites; Outer Coast, 20 sites with the major ones being Cape Alava reefs, Kayostla Beach reefs, Sandy Island reefs, Cape Johnson reefs, Destruction Island north rocks; Strait of Juan de Fuca, 4 sites; Hood Canal, 5 sites (3 areas in Quilcene Bay, 1 in Port Gamble, and the Skokomish River mouth); Puget Sound, 4 sites (Gertrude Island, Cutts Island, Allen Bank, and Padilla Bay). In addition to these critical areas, harbor seals are regularly seen widely dispersed in Puget Sound, and Newby (1973) lists populations for Skagit Bay, Fidalgo Bay, and the San Juan Islands. Specific sites are not named for British Columbia, and seals are said to be widely dispersed (Pike and MacAskie, 1979, and Bigg, 1973).

Life History: Length less than 2 m and weight 140 kg for both sexes. Harbor seals are monogamous, mature sexually at 3-5 years, and pup in May to July. Breeding cycle is one year (Eaton, 1975).

Food: This species eats a wide variety of fish and shellfish. Harbor seals will feed on salmon as they begin their upstream runs (Eaton, 1975).

5. Northern elephant seal - Mirounga angustirostris

Range and Habitat: In the study area, this species is a pelagic, nonbreeding animal seen occasionally along the coast and offshore, and infrequently in inside waters (Eaton, 1975; Pike and MacAskie, 1969; Scheffer and Kenyon, 1963, and Craddock, 1969).

Population: The population along the west coast of North America is given now as 30,000, after being nearly eliminated during the last half of the 19th century (Eaton, 1975). Sightings off the coast of the study area have been increasing in recent years (Northwest Fisheries Center, Marine Mammal Division, 1975).

Life History: Males get up to 5 m in length and weigh 2 metric tons, females grow to 3.5 m. The species breeds and pups in late December through early February, although not within the study area. Breeding range is the Farallon Islands (San Francisco) south to Magdalena Bay, Baja, Mexico.

Food: Feeds mostly on non-commercial fish, apparently at considerable depths (Eaton, 1975).

APPENDIX B

Lists of Benthic Organisms Sampled

TABLE B-1
MAJOR GROUPS OF ORGANISMS COLLECTED IN BENTHIC
SAMPLES OFF GRAYS HARBOR, WASHINGTON

	TRANSECT A												TRANSECT B												
	1	2_1	2_2	3	4	5	6	7	8	9	10	11	1_1	1_2	2	3	4	5	6	7	* 9_1	9_2	9_4	9_5	10
	Numbers of Organisms																								
Annelida:																									
Ampharetidae							1	1		1			2	1			1		1						
Capitellidae				1		2			2				14	2	1	24									
Chaetopteridae												1	3	5											
Cirratulidae					1	5	2	3		1	6	5		1		1		1	1	1	1				8
Disomidae																									
Dorvilleidae																1									
Flabelligeridae												3		4											
Glyceridae						4	9	1	6						10	6									
Goniadidae				6	6			9		6	2	5	4	1	1		8	20	9						
Lumbrineridae						2		2			2	2	11	48	1		1								
Magelonidae				4				1					1					1		6					3
Maldanidae						1	3				5	21	1												
Nephtyidae		1	1	3	3	7	3	10	1	14	8	5			5		5	2	6	6			3	1	3
Nereidae															1										
Oligochaeta					1	10	2	5	1		1				1	1	3	2							
Onuphidae													1		11										1
Opheliidae																									
Orbiniidae		1		5	6	5	15	13	2	2	3	4	2		1		6	6	1			5	1		5
Oweniidae				15	8	50	79	23	2	35	59	33		3			152	482		1	1				
Paraonidae												1													
Pectinariidae											1	1		1											
Phyllodocidae							4			2	4	1							1						
Polynoidae								1																	
Sigalonidae				4	1	4	8	2	1	2	2	5					1	3	1						2
Spionidae					2		5	43	25	65	27	12	1												1
Syllidae															1										

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.
* Station 8-No data

TABLE F-1
MAJOR GROUPS OF ORGANISMS COLLECTED IN BENTHIC
SAMPLES OFF GRAYS HARBOR, WASHINGTON

	TRANSECT C												TRANSECT D
	1	2	3_1	3_2	4	5	6	7	8	9	10	11	1
	Numbers of Organisms												
Annelida:													
Ampharetidae								2					
Capitellidae				1			3	4	6	2	7	21	
Chaetopteridae													
Cirratulidae					1	1					1		
Disomidae											1		
Dorvilleidae							1				4	3	
Flabelligeridae													
Glyceridae	4							1	7		6		
Goniadidae			4	4	18	13	21	48	3	20	4	1	
Lumbrineridae									1		17	3	
Magelonidae	9		6	6	7	2		1				1	2
Maldanidae						6					2	1	
Nephtyidae	6		8	9	2	10		1	5	1		3	
Nereidae										3			
Oligochaeta								1					
Onuphidae						3		1					
Opheliidae									5	2		1	
Orbiniidae	7		2	2	1	1		2	5				
Oweniidae					78	96	94	62					
Paraonidae													
Pectinariidae								2					
Phyllodocidae											1		
Polynoidae													
Sigalonidae					1	8	3	17			1		
Spionidae			3	3	3		2	34	1	17	5	8	
Syllidae									1		1	1	

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.

TABLE B-1
MAJOR GROUPS OF ORGANISMS COLLECTED IN BENTHIC SAMPLES OFF GRAYS HARBOR, WASHINGTON

	TRANSECT A												TRANSECT B												
	1	2_1	2_2	3	4	5	6	7	8	9	10	11	1_1	1_2	2	3	4	5	6	7	* 9_1	9_2	9_4	9_5	10
	Numbers of Organisms																								
Mollusca:																									
Axinopsida				1		3	75	34	12	33	12	22		1	1		78	8							1
Cylichna						1	8	8	2	2							1		1						
Lyonsia					1										2		5								
Mitrella							2		2	8	12	9													
Mytilus																		1							1
Nassarius				1								1					1								
Nucula							1			12	37	20													
Odostomia							6		1			1					2	1							
Olivella	1			1	3	1	1	5		5	1	4		3	5	3				1	1	2	1	1	21
Platyodon								8																	
Sabinella							3																		
Scaphopod										15	15	24													
Shelless Gastropod																									
Siliqua																	3	153	1					1	
Tellinidae		2	7	66	9	25	7	1	5		1	1			26		28	104	41		4	5	1	7	3
Yoldia										1	2														

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.
* Station 8-No data

TABLE B-1
MAJOR GROUPS OF ORGANISMS COLLECTED IN BENTHIC SAMPLES OFF GRAYS HARBOR, WASHINGTON

	TRANSECT C												TRANSECT D
	1	2	3_1	3_2	4	5	6	7	8	9	10	11	1
	Numbers of Organisms												
Mollusca:													
Axinopsida								30					
Cylichna								15		1			
Lyonsia										10	7		
Mitrella											1		
Mytilus													
Nassarius							1				1		
Nucula													
Odostomia						1							
Olivella	9		4	4	4	2		14	2	7	15		
Platyodon													
Sabinella													
Scaphopod													
Shelless Gastropod						1							
Siliqua	4				1	9		3					
Tellinidae	5		22	23	77	118	1	15		10			
Yoldia													

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.

TABLE B-1
MAJOR GROUPS OF ORGANISMS COLLECTED IN BENTHIC
SAMPLES OFF GRAYS HARBOR, WASHINGTON

	TRANSECT A												TRANSECT B												
	1	2_1	2_2	3	4	5	6	7	8	9	10	11	1_1	1_2	2	3	4	5	6	7	* 9_1	9_2	9_3	9_4	10
	Numbers of Organisms																								
Arthropoda:																									
Cancer magister																									
Caprellidea														1											
Crab										2															
Cumacea				1	5	4	1	21	4	3	5	14	4	1	1		683	137	62	2					1
Gammaridea	1			12	10	14	4	6	3	28	29	25	7	14	2	2	10	3	20	16	21	32	26	10	14
Isopoda			2	1	1	7	3	1		1	1	1		1			1	9	3						
Nebalia											1						2								
Ostracoda					1	17	22	25	23	61	104	45					2	7							
Paguridae						1				1					1										
Pinnotheridae											1				5	1									
Pycnogonida											1														
Shrimp (Caridea)																				1	1	2			7
Tanaidacea																									
Other:																									
Actinaria			1														4	16	1						
Dendraster		1		2		5	2													7					
Echiura																	7								
Holothuroidea						1																			
Ophiuroidea				5	5	11	6	5		10	9	3		1			12	17	2	1					
Nemertea				1		1					2	1	4	9						2	1		1		2
Sipuncula						2						1				1									

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.

* Station 8-No data

TABLE B-1
MAJOR GROUPS OF ORGANISMS COLLECTED IN BENTHIC
SAMPLES OFF GRAYS HARBOR, WASHINGTON

	TRANSECT C												TRANSECT D
	1	2	3_1	3_2	4	5	6	7	8	9	10	11	1
	Numbers of Organisms												
Arthropoda:													
Cancer magister							2	2					
Caprellidea													
Crab													
Cumacea	4		4	4	124	500	5	1590	1	1	6	1	
Gammaridea	10		16	16	28	24		6		1	1	2	9
Isopoda	2				5	1	1	1			2	1	
Nebalia													
Ostracoda			1	1		5							
Paguridae													
Pinnotheridae							1		1			1	
Pycnogonida													
Shrimp (Caridea)	1		1	1	1		2				1		
Tanaidacea									1				
Other:													
Actinaria			8		2	7	163						
Dendraster	1	15											8
Echiura													
Holothuroidea							3						
Ophiuroidea	2		2		9	27	2	3					
Nemertea	1						12	9	1		1	4	
Sipuncula								2	1			3	

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.

TABLE B-2
SUMMARY OF NUMBERS OF ORGANISMS AND BIOMASS COLLECTED IN BENTHIC SAMPLES OFF GRAYS HARBOR, WASHINGTON

TRANSECT A

	1	2_1	2_2	3	4	5	6	7	8	9	10	11
					Number of Organisms							
TOTAL NUMBER OF ORGANISMS:	2	5	70	129	63	186	272	228	90	302	353	271
BIOMASS: Grams/meter^2 (wet weight)												
ANNELIDA	-----	21.76	4.69	5.13	33.69	22.50	30.09	15.65	1.67	17.62	5.64	6.22
MOLLUSCA	14.73	20.45	1.09	6.03	0.73	11.04	9.70	7.12	2.30	16.11	21.19	15.23
ARTHROPODA	1.70	-----	0.53	0.77	1.01	2.27	1.49	1.66	1.01	3.33	3.86	4.00
OTHER	-----	1.08	1.21	3.87	0.79	91.74	1.89	3.83	-----	0.42	0.42	0.65
TOTAL:	16.42	43.29	7.52	16.60	36.17	127.55	43.77	28.26	4.98	39.48	31.11	26.10

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.

TABLE C-2

SUMMARY OF NUMBERS OF ORGANISMS AND BIOMASS COLLECTED IN BENTHIC SAMPLES OFF GRAYS HARBOR, WASHINGTON

TRANSECT B

	1_1	1_2	2	3	4	5	6	7	*	9_1	9_3	9_4	9_5	10
						Numbers of Organisms								
TOTAL NUMBER OF ORGANISMS:	55	97	77	45	1025	2143	690	44		30	46	33	20	73
BIOMASS:														
Grams/meter^2 (wet weight)														
ANNELIDA	10.8	7.23	12.66	3.89	6.33	35.22	5.10	1.00		0.41	0.97	1.95	0.79	3.99
MOLLUSCA	-----	0.99	3.00	0.91	4.09	9.16	12.09	1.18		1.18	2.69	3.91	3.34	21.67
ARTHROPODA	0.11	0.30	4.55	6.97	34.98	63.19	33.82	1.83		9.20	4.71	2.23	0.56	2.47
OTHER	1.30	1.07	a	-----	7.16	13.71	1.66	3200.3		0.35	-----	0.41	-----	0.46
TOTAL	11.49	9.59	20.21	11.77	52.56	121.28	52.57	3204.31		11.14	8.37	8.50	4.69	23.39

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.

a = missing

* Station 8-No data

TABLE B-2

SUMMARY OF NUMBERS OF ORGANISMS AND BIOMASS COLLECTED IN BENTHIC SAMPLES OFF GRAYS HARBOR, WASHINGTON

TRANSECT C

	1	2	3	3_1	4	5	6	7	8	9	10	11
						Numbers of Organisms						
TOTAL NUMBER OF ORGANISMS:	65	15	81	85	362	835	317	1866	41	75	86	54
BIOMASS: Grams/meter^2 (wet wieght)												
ANNELIDA	3.22	-----	2.92	4.82	4.38	20.09	6.82	19.35	15.35	8.90	8.66	4.01
MOLLUSCA	1.95	-----	1.38	1.43	2.28	11.54	33.46	31.63	3.31	15.40	13.27	-----
ARTHROPODA	3.10	-----	0.94	1.35	8.33	29.77	10.34	94.39	0.32	0.36	0.50	8.43
OTHER	1.14	5937.1	10.07	9.53	2.65	8.05	70.60	10.20	19.72	-----	0.28	176.58
TOTAL	27.41	5937.1	15.31	17.13	17.64	69.45	121.22	155.57	38.70	24.66	22.71	189.02

Note: Replicate sample station numbers are shown with subscript notation, e.g., 2_1, 2_2.

TABLE B-2
SUMMARY OF NUMBERS OF ORGANISMS AND BIOMASS COLLECTED IN BENTHIC SAMPLES OFF GRAYS HARBOR, WASHINGTON

TRANSECT D

	1
	Numbers of Organisms
TOTAL NUMBER OF ORGANISMS:	19
BIOMASS: Grams/meter^2 (wet weight)	
ANNELIDA	0.01
MOLLUSCA	-----
ARTHROPODA	0.48
OTHER	230.42
TOTAL:	230.47

Note: Replicate sample station numbers are shown with subscript notation; e.g., 2_1, 2_2.

APPENDIX C

List of People Interviewed

APPENDIX C

List of People Interviewed
Offshore Dredge Disposal

Bergeron, Jim	Sea Grant	Oregon State University
Brix, Rick	Fisheries Biologist	Dept. of Fisheries, Montesano
Carey, Andrew G.	Oceanographer	Oregon State University
Clifton, Edward	Marine Geologist	USGS Menlo Park, CA
Collias, Eugene	Oceanographer	University of Washington
Culver, Brian	Fisheries Biologist	Dept. of Fisheries. Montesano
Duncan, John	Geological Oceanographer	University of Washington
Durkin, Terry	Biologist	NMFS Hammond, OR
Duxbury, Alyn C.	Oceanographer	University of Washington
Edwards, John	Dragger	Aberdeen, WA
Erickson, Edward	Northwest Steelheaders	Grays Harbor Chapter
Foster, Al	Oceanographer-Hydrotask	Kirkland, WA
Hancock, Danial R.	Oceanographer	Oregon State University
Hatfield, Douglas	Crab Fisherman	Aberdeen, WA
Heikkila, Verne	Crab Fisherman	Westport, WA
Helbig, Robert	Vice Commodore	Westport Charter Association
Herrell, Keith	Commodore	Westport Charter Association
Holton, Robert L.	Biologist	Oregon State University
Kelley, Tom	Crab Fisherman	Westport, WA
Komar, Paul	Geological Oceanographer	Oregon State University
Large, Jim	Northwest Steelheaders	Grays Harbor Chapter
Longmire, Dan	Hatchery Manager	Dept. of Fisheries
McDeavitt, William	City Manager	Ocean Shores, WA
McManus, Dean	Geological Oceanographer	University of Washington
Nichols, Chuck	Crab Fisherman	Westport, WA
Northup, Thomas	Clam Biologist	Dept. of Fisheries, Montesano
Pavletich, Jerry	President, NW Steel-headers Association	Grays Harbor Chapter
Rieck, Carrol	Biologist	Washington Dept. of Game
Reuf, Michael	Geologist	Washington Dept. of Ecology
Scheidegger, Ken	Geological Oceanographer	Oregon State University
Small, Larry	Oceanographer	Oregon State University
Sollitt, C.	Oceanographer	Oregon State University
Stedman, Don	Crab Fisherman	Aberdeen, WA
Stone, Richard	Salmon Biologist	Washington Dept. of Fisheries
Strang, Jack	Crab Fisherman	Westport, WA
Summers, Ernie	Crab Fisherman	Westport, WA
Tegelberg, Herb	Clam Biologist	Retired, Aberdeen, WA
Watson, Robert	Biologist	Washington Dept. of Game, Aberdeen, WA

APPENDIX D

Published Species Lists of Fauna Living in the Pacific Ocean off the Washington and Oregon Coasts

APPENDIX D

PUBLISHED SPECIES LISTS OF FAUNA LIVING IN THE PACIFIC OCEAN OFF THE WASHINGTON AND OREGON COASTS

Durkin, J. T., et al., "Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon, Appendix E: Demersal Fish and Decapod Shellfish Studies," Technical Report D-77-30, November 1977, Final Report, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Harshman, G. W. and Johnson, T. L. "Marine Ecology," In: Summary of Knowledge of the Washington and Oregon Coastal Zone and Offshore Areas, Vol. II, Oceanographic Institute of Washington, Seattle, Washington. 1977, pp 1-180.

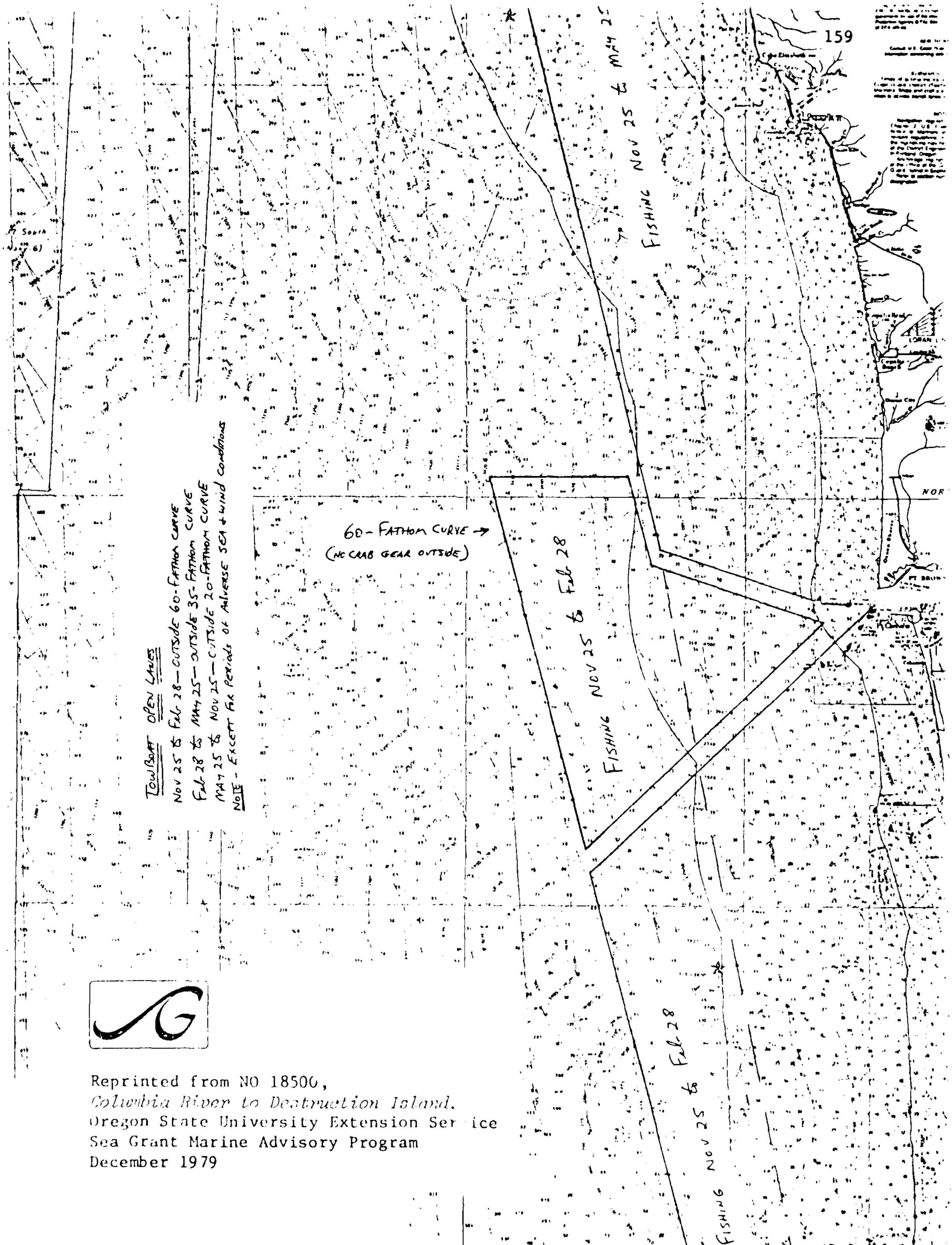
Holton, R. L. and Small, L. F. "Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon; Appendix D: Zooplankton and Icthyoplankton Studies," Technical Report D-77-30, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977.

Renfro W. C., et al., Oceanography of the Nearshore Coastal Waters of the Pacific Northwest Relating to Possible Pollution, Oregon State University, Corvallis, Oregon, 1971.

Richardson, M. D., et al., "Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon; Appendix C: The Effects of Dredged Material on Benthic Assemblages," Technical Report D-77-30, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977.

APPENDIX E

Map of Crab Fishing Zones
off Grays Harbor



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