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INTERTIDAL DISPOSAL OF DREDGED MATERIALS AT DEPOE BY, OREGON

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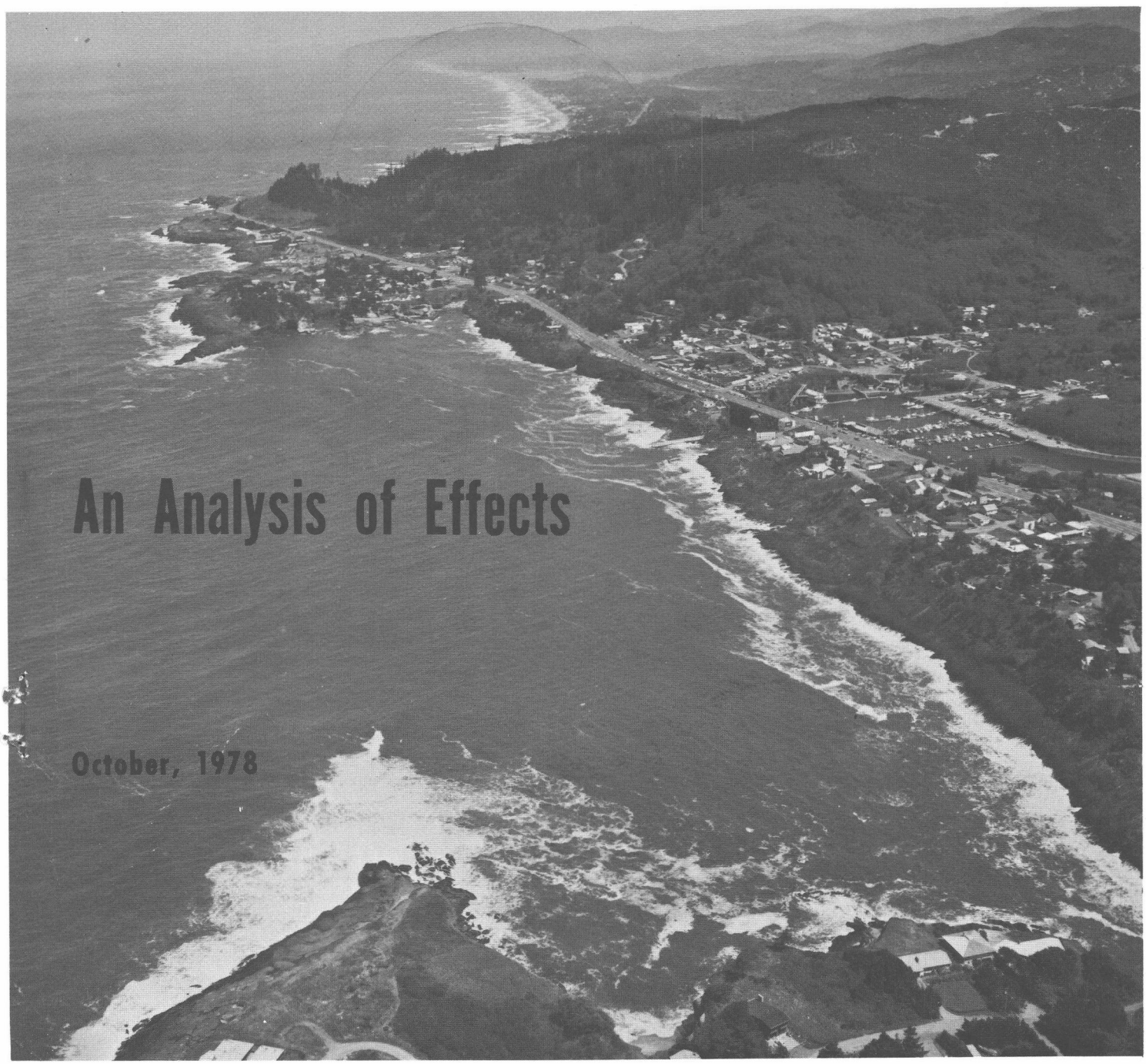

An Analysis of Effects

October, 1978

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This report has been prepared by

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INTRODUCTION

BACKGROUND

Depoe Bay, situated on the Oregon Coast about 100 miles south of the mouth of the Columbia River and 13 miles north of Yaquina Bay at Newport, Oregon, is a small, rock-bound tidal lagoon much affected by man's activities. In its natural condition, Depoe Bay was very shallow, with a narrow channel to the sea carved by streamflow from Depoe Creek and North Depoe Creek (see figure 1).

In early days, the bay provided a sheltered harbor for fishing vessels, but the narrowness of the channel and the shallowness of the bay limited passage to and from the bay to periods of high tide; cradles were used to keep moored vessels upright during low tide.

In 1939, as a result of the desire of local residents and others to stimulate additional use of the harbor, the Corps of Engineers began work. The channel was widened to facilitate passage and to increase water level through tidal influence; some dredging of the bay was also performed. In the late 1940's, extensive additional work was performed by the Corps. The channel was widened further, to its present 50-foot width, and the bay was dredged to an approximately uniform 8-foot depth. A boat basin about 390 feet by 750 feet was thus created, with a retaining wall along its eastern boundary. A check dam near the mouth of Depoe Creek was constructed to reduce the amount of stream-borne silt entering the bay. To reduce wave activity at the channel entrance, a concrete breakwater was built at the north side of the channel's seaward end; a second, complementary breakwater adjacent to the original was added in 1966. The cover photograph and figure 2 show Depoe Bay as it appears today.

ECONOMICS

Partly as a result of Corps projects, the growth of commercial and recreational fishing has been stimulated. The largest component of the local economy is the charter fishing industry; about 30,000 passengers were carried during the 7-1/2 month season (mid-March to late October) in 1975.1/ The commercial fishing industry has also expanded in response to improvement of the harbor; use of the public landing facilities in the bay has likewise increased.

The economy of the Depoe Bay community is founded upon the existence and use of the harbor.

1/ From the Portland District, Corps of Engineers Environmental Evaluation and Finding report. This 1976 report contains an excellent sociological discussion of the economy of the Depoe Bay community.

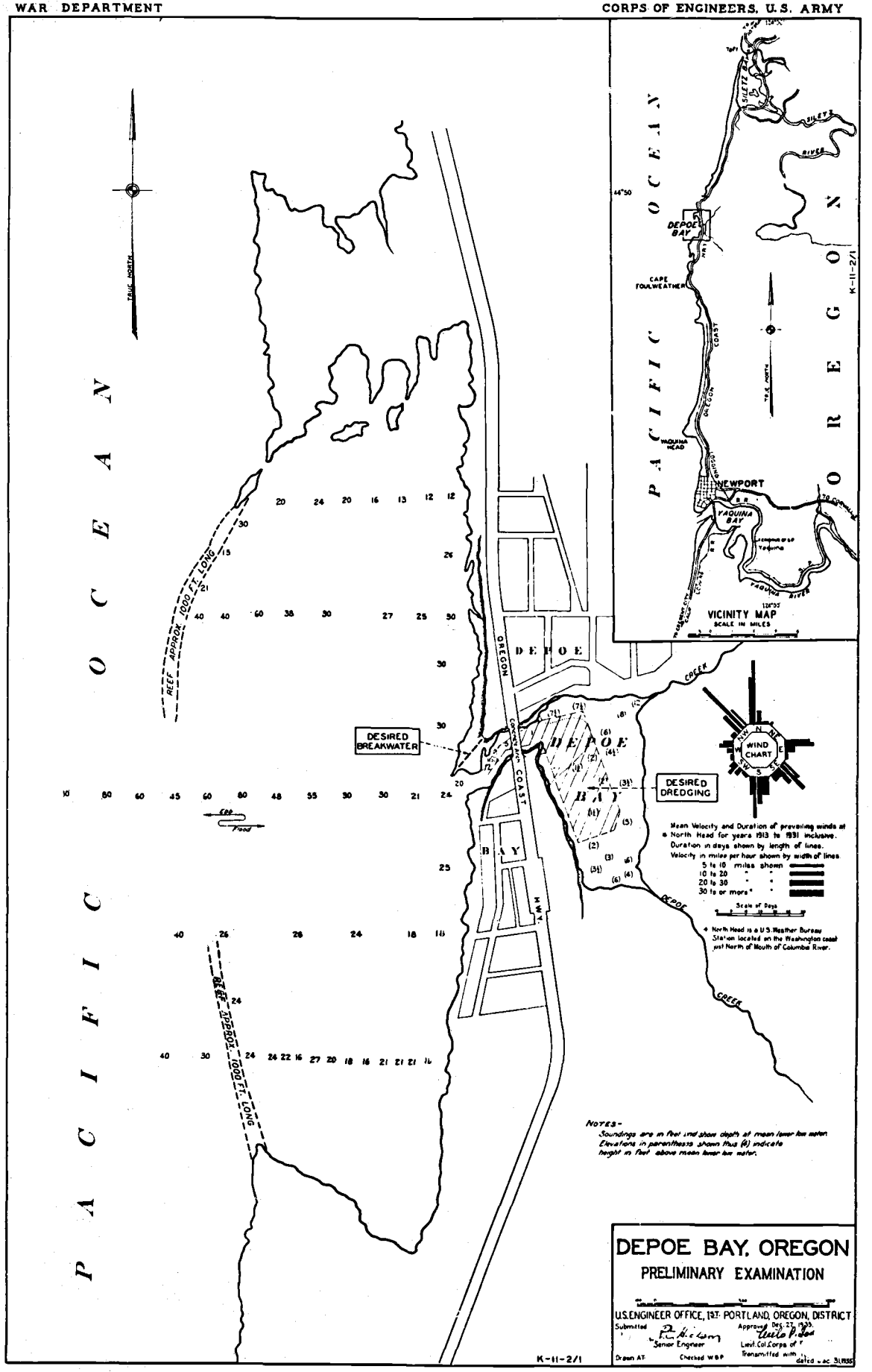

Figure 1 Depoe Bay in 1935

TABLE 1. DREDGING ACTIVITIES AT DEPOE BAY

Date	Amount Dredged (Cu. Yds.)	Disposal Site
1939 - 1950	56,000	Dredged material used as fill behind retaining wall and to form small boat launching facilities
1951 - 1954	None	Not applicable
1955 (1-20 Sept)	10,400	Upland site A*, east of check dam
1958 (19-25 May)	7,200	Upland site B*, southeast of check dam
1961 (6 May - 19 June)	8,900	Shoreline site*
1966 (24 June - 6 July)	1,500	This dredging removed sediments accumulated behind the check dam. Materials were disposed of at upland site C*, just east of the dam.
1967 (30 May - 22 July)	11,300	Shoreline site*
1971 (10 May - 25 June)	11,400	Shoreline site*
1976 (12 Apr - 6 May)	12,400	Shoreline site*

* These sites are displayed in figure 2.

Three major developmental factors have combined to stimulate the sport and commercial fishing industry at Depoe Bay: the proximity of the bay to productive fishing grounds, the sheltered nature of the bay itself, and the efforts of the Corps of Engineers. Taken together, these three factors have made Depoe Bay attractive to charter boat operators, commercial fishermen, and individual recreational fishermen.

Tourism in the Depoe Bay community is linked to viewing of the impressive wave activity and to the fishing industry. Tourists come to Depoe Bay to join charter boat cruises, to use the small boat dock, or simply to watch the harbor and entrance channel activities and enjoy the view. Land-based tourist facilities, especially restaurants and gift shops, have also been developed near the harbor. Unlike the situation in many coastal communities where tourism is based on actual use of the shoreline itself, visitors to Depoe Bay tend not to use the rocky shoreline because of the precipitous shoreline, dangerously high waves, and tidal swells. The harbor, its related activities, and viewing of the wave activity on the rocky shoreline--not use of the beach itself--form the bases of tourism at Depoe Bay, so much so, in fact, that local advertising lauds Depoe Bay as "the smallest harbor in the world."

DREDGING HISTORY

Table 1, based on an examination of records and files at the Corps of Engineers' District Office in Portland, lists dredging activities at Depoe Bay. Since the work done in the late 1940's to improve the harbor and entrance, maintenance dredging has been performed seven times. A minor amount of dredging to remove sediments accumulated behind the check dam was performed in 1966; the rest of the dredging has been performed to maintain harbor and channel depth.

Since 1950, a total of 63,100 cubic yards of sediments have been removed. Of that total, 19,100 cubic yards have been disposed of at upland disposal sites; 44,000 cubic yards have been disposed of at a site on the rocky shoreline about 200 feet south of the entrance channel. This report focuses on the effects of disposal of dredged materials at the shoreline disposal site[2/] (see figure 2).

Most of the dredging since 1952 has been performed by private contractors using pipeline dredges, with a relatively minor amount of clamshell

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2/ Environmental Protection Agency designated site: Depoe Bay-44°48'33"N., 124°03'53"W.; 44°48'32"N., 124°03'43"W.; 44°48'15"N., 124°03'45"W., 44°48'16"N., 124°03'55"W. (From Fed. Reg., Vol. 42, No. 7, 1/11/77, p. 2487.) Another Environmental Protection Agency designated site (Depoe Bay--44°48'09"N., 124°05'05"W., 44°48'09"N., 124°04'55"W., 44°47'53"N., 124°04'55"W., 44°47'53"N., 124°05'05"W.) is an offshore site which has not been used for dredging at Depoe Bay.

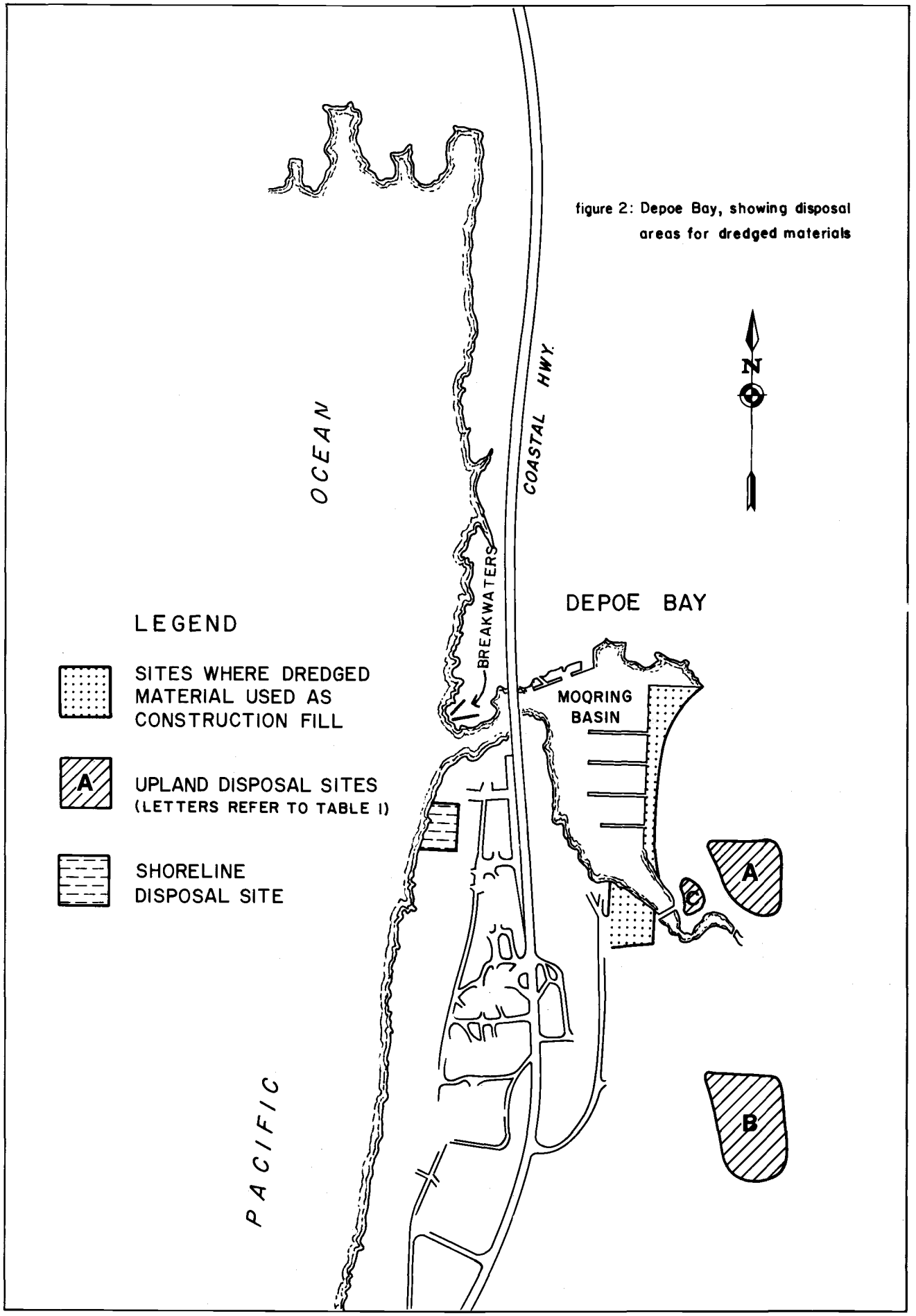


figure 2: Depoe Bay, showing disposal areas for dredged materials

dredging being performed in 1966. A 12-inch pipeline dredge was used in 1955 and 1958; an 8-inch pipeline dredge, the "Karen" (see figure 3), was used for the 1961, 1967, 1971, and 1976 dredging.

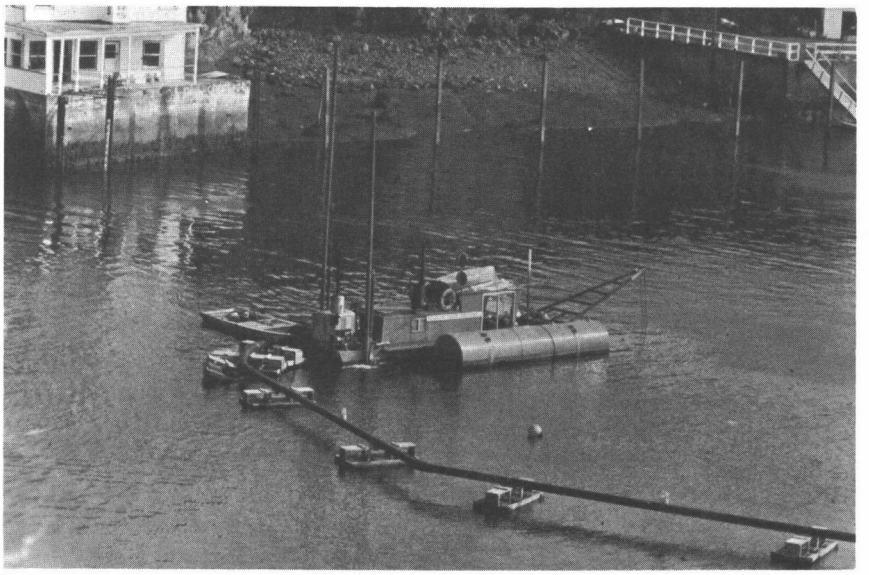


Figure 3. The "Karen," an 8" pipeline dredge at work in the Depoe Bay Boat Basin.

PURPOSE OF REPORT

Prior to the commencement of dredging operations in 1976, the Portland District of the Corps of Engineers prepared an Environmental Evaluation and Finding report to examine the effects of continued maintenance dredging of the bay and disposal of dredged materials on the shoreline disposal site. That report did not, however, contain quantitative data to evaluate the biological effects of such disposal. Recognizing the need for a more accurate assessment, the Portland District, in response to direction from the Environmental Protection Agency, initiated this study.

This study focuses on the effects of the disposal of dredged materials on the rocky intertidal disposal site and the adjacent subtidal area. The effects noted during the most recent (1976) dredging are treated in detail. Some information relating to previous disposal at this location is also given, so that reasonable inferences can be drawn regarding the cumulative effects of continued, periodic deposition of dredged materials on the rocky intertidal area at Depoe Bay.

The report is partly based on data accumulated by graduate and senior undergraduate students operating under the supervision of Dr. Jeffrey J. Gonor, Associate Professor of Oceanography at Oregon State University's Marine Science Center at Newport, Oregon. Dr. Gonor's own studies of the Depoe Bay rocky intertidal area since 1967 and his analysis of the disposal area's recovery following dredging provide the foundation for the report. Conclusions reported are, or course, those of the authors, Messrs. Dennis Berry and James Reese, both of the Portland District, Corps of Engineers, Planning Branch.

The report covers two separate studies--the first relating to the effects on the intertidal area, the second to the effects on the subtidal area. The work of Dr. Gonor and his students relates principally to the intertidal area; effects on the biota of the subtidal are based on photogrammetric studies of special color photography undertaken by the Portland District.

STUDY AREA

DESCRIPTION

The study area is that portion of the rocky coastline south of the entrance to Depoe Bay on which dredged materials from Depoe Bay were disposed, including both the intertidal and the subtidal zones.

The disposal site study area is located in the near-shore surf zone, about 200 feet south of the entrance to Depoe Bay. The substrata in the area is composed of basalt, with the morphology of a steeply sloped wave-cut terrace. The supra-tidal level down to approximately the zero tide level consists of one terrace; there is a sharp dropoff at the zero tide level into the subtidal region.

WAVE ACTIVITY

The intensive wave activity at the study area is modified by the shape of the adjacent coastline. Offshore subtidal reefs extending from small headlands to the north and south of Depoe Bay form an outer cove about one-fourth mile in width (east to west) and three-fourths mile in length (north to south). This outer cove, like Depoe Bay itself, is rockbound; depths range from 20 to 60 feet at low tide (see figure 4).

Waves which approach the Depoe Bay area tend to break across the outer reef-like subtidal extensions of rock forming the outer cove; the intensity of waves striking the coastline are therefore reduced. According to Corps studies in the mid-1960's,[3/] almost all long-period (13-second) waves are refracted in the outer cove to the extent that only a small percentage of wave energy ever reaches the shoreline of the study area. Shorter period (6-second) deepwater waves approaching from the south or southwest are also highly refracted. Shorter period deepwater waves approaching from the west to northwest, however, tend to reform after breaking across the outer reef, and, while such re-formed waves are of lower intensity than the deep-water waves, they nonetheless strike the coastline with considerable force. (See Wave Refraction Diagram, figure 4.) During severe winter storms, spray from the crashing surf may be felt on U.S. Highway 101 above the study area; the elevation of this portion of the highway is about 60 feet above mean sea level.

Extreme high tides rise to 11 feet above and extreme low tides fall to 2-1/2 feet below mean lower low water (mllw), the plane of reference used in this report. The range of tides between mean lower low water and mean higher high water is about 7 feet.

3/ Portland District, Corps of Engineers, Detailed Project Report, Section 107, 16 December 1964.

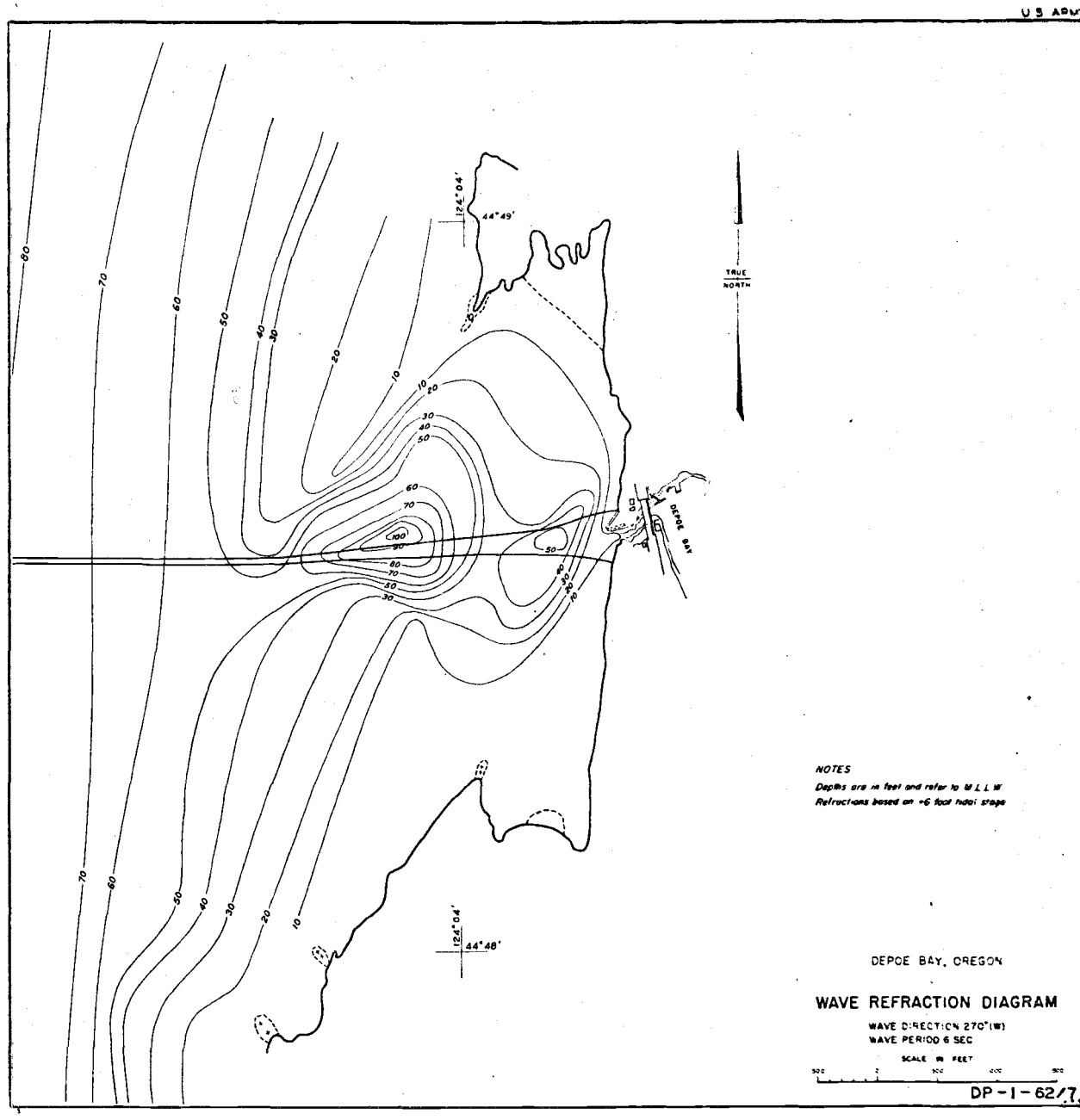


Figure 4. Wave refraction diagram, showing minimal refraction of short duration waves approaching from the west. Note also the subtidal reefs indicated by countour lines.

The substrata supporting the littoral organisms, as previously noted, is composed of pillow formations of solid basalt, irregularly shaped and rather steep, except for a level section near the bottom of the intertidal zone. There are several small tidal pools in the study area, especially on this lower bench, and a distinct fault line running northeast to southwest diagonally bisects the study area. A shallow trench or channel has formed along the fault line and the channel becomes deeper and wider as it approaches the zero tide level, where it is about 5 feet deep and 3 feet wide.

Several businesses and homes are located along the top of the rocky beach; natural seepage and seepage from septic systems support a rather heavy growth of diatoms and blue-green algae.

Zonation will be discussed in some detail in the sections following, but it should be noted here that, while fairly regular zones of some organisms (mussels, sea lettuce, and laminarians especially) can be discerned in the intertidal area, most of the area is rather heterogeneous and of irregular zonation, with patchy distribution being the rule rather than the exception.

ZONATION DISPLACEMENT

Another interesting facet of zonation which warrants mention here is "displacement." The intense wave action at the beach, it was discovered, had elevated all intertidal zones approximately 4 feet. This was an expected observation at the study area, since earlier work by Gonor recorded an upward displacement of 5 feet on an adjacent shoreline to the north of the Depoe Bay entrance channel.4/ This study also verified that zonation displacement did not occur on the more sheltered sides of the entrance channel.

Zonation displacement in areas of intense wave activity is not, of course, a newly discovered phenomenon. Doty (1946), Hewatt (1937), and Glynn (1965) have all described situations of upward displacement of zones, particularly the *Endocladia-Balanus* zone. Glynn, for example, has noted displacement by as much as 10 or 15 feet in situations of extreme wave action. The situation at Depoe Bay, then, does not appear uncommon.

4/ This study, performed in 1967 and never published, incorporated a transit and stadia rods and utilized the U.S. Coast and Geodetic Survey Monument Q-198 embedded in the northwest corner of the U.S. Hwy 101 bridge just above the shoreline studied.

METHODS

STUDY OF EFFECTS ON INTERTIDAL BIOTA

In order to determine the effects of dumping dredged materials on the rocky intertidal zone, the Depoe Bay study area was sampled by a group of students[5/] under the supervision of their instructor, Dr. J. J. Gonor of the Marine Science Center at Newport (affiliated with the School of Oceanography at Oregon State University). The study area was examined twice by these students, on 2 and 3 April 1976 (before dredging) and on 12 and 13 May 1976 (after dredging). Two transects, one located about 125 feet south of the channel entrance, the other about 200 feet south of the channel, were laid out approximately perpendicular to the shore (see figure 5).

For both transects, each one foot of vertical drop was marked as a station; the area between consecutive stations along the transect and to each side of the transect line was designated as a sampling quadrate. Because of the natural topographic irregularity of the study area, it was sometimes necessary to adjust the boundaries of a given quadrate to ensure that all sampling points within the quadrate had an elevation between that of the two stations.

Once the quadrate boundaries were determined, three sites within each quadrate were randomly located and sampled, using a $.9m^2$ sampling frame subdivided into 100 equal sections; when the quantity of a species located within the sampling frame was too great to count accurately, three randomly chosen subsamples, each $.009m^2$, were located within the frame. All macroscopic organisms within the sampling frame (or within the subsample) were counted and their numbers extrapolated to a "per meter squared" basis. This procedure was followed for transect sampling before dredging and was repeated for both transects following dredging. Additionally, organisms sampled on the north transect were collected and their ash-free dry weight biomass was determined.

It was assumed these transects would cross the disposal location and provide quantitative data to compare with post-dredging data; however, the location of actual disposal of the dredged materials was somewhat to the south of both the north and south transects and such direct before-and-after comparisons could not be made. Fortunately, while his students were working on the north and south transects before dredging, Dr. Gonor was constructing a photographic transect about 50 feet to the south of the students' south transect. As it happened, this photo transect passed through the actual disposal area. An accurate before and after photographic record of disposal effects was therefore available.

5/ See source list at end of paper.

Following dredging, the students examined a third transect parallel to the photographic transect in the area of maximum scouring. One meter wide bands along each of the major "zones" were sampled. Using a one meter frame, counts were taken of surviving organisms, providing some after-dredging quantitative data to supplement the qualitative data gathered via Dr. Gonor's photographic transect. The locations of the transects laid out across the study area are indicated in figure 5.

This mixture of qualitative and quantitative data gathered immediately before and after disposal of dredged materials was supplemented by observations made by Dr. Gonor and Douglas DeHart (Portland District) while disposal was underway.

Further observations were made by Dr. Gonor during the first growing season following diposal (May 1976 through October 1976) and again in April 1978 (2 years after dredging). While quantitative data, as such, were not gathered during these later observations, an accurate photographic record was compiled and detailed notes were recorded so the rate of recovery of the intertidal study area could be estimated. (See Appendix A).

BULL KELP STUDY METHODOLOGY

To determine the effects of pipeline disposal on the subtidal bull kelp *(Nereocystis leutkeana)* community, low-level aerial photographs of the outer harbor of Depoe Bay were taken on three separate occasions; these photographs formed the basis for interpretation of changes in the distribution of the bull kelp community following disposal.

The photographs were taken in May 1976 (during disposal operations - see figure 10), in September 1976 (following disposal operations - see figure 11), and again in October 1977 (see figure 12).

The aerial photos were shot with an uncalibrated twelve-inch focal length 9-inch format aerial camera using Kodak aero-color negative 2445 film. The photos were taken on cloud and haze free days, during morning hours at low tide. The photography provided sixty percent overlap between consecutive pictures and a nearly vertical view of the study area.

The flights were flown at three different elevations to produce approximate photo scales of 1/1200, 1/2400, and 1/4800. The aerial runs were flown parallel to the shoreline and included sufficient land area for location of control points.

Photo identifiable control points were established from official state highway maps. North and east coordinates were established for the photos using a digitized Wild B8 stereoplotter as a XY digitizer. A Hewlett Packard 9810A programmable calculator scaled and rotated the XY coordinates into north and east values (in feet). Using the same Wild B8 stereoplotter, the coordinates of the bull kelp locations were digitized onto 9 track computer-compatible magnetic tape. Each film positive was scanned using

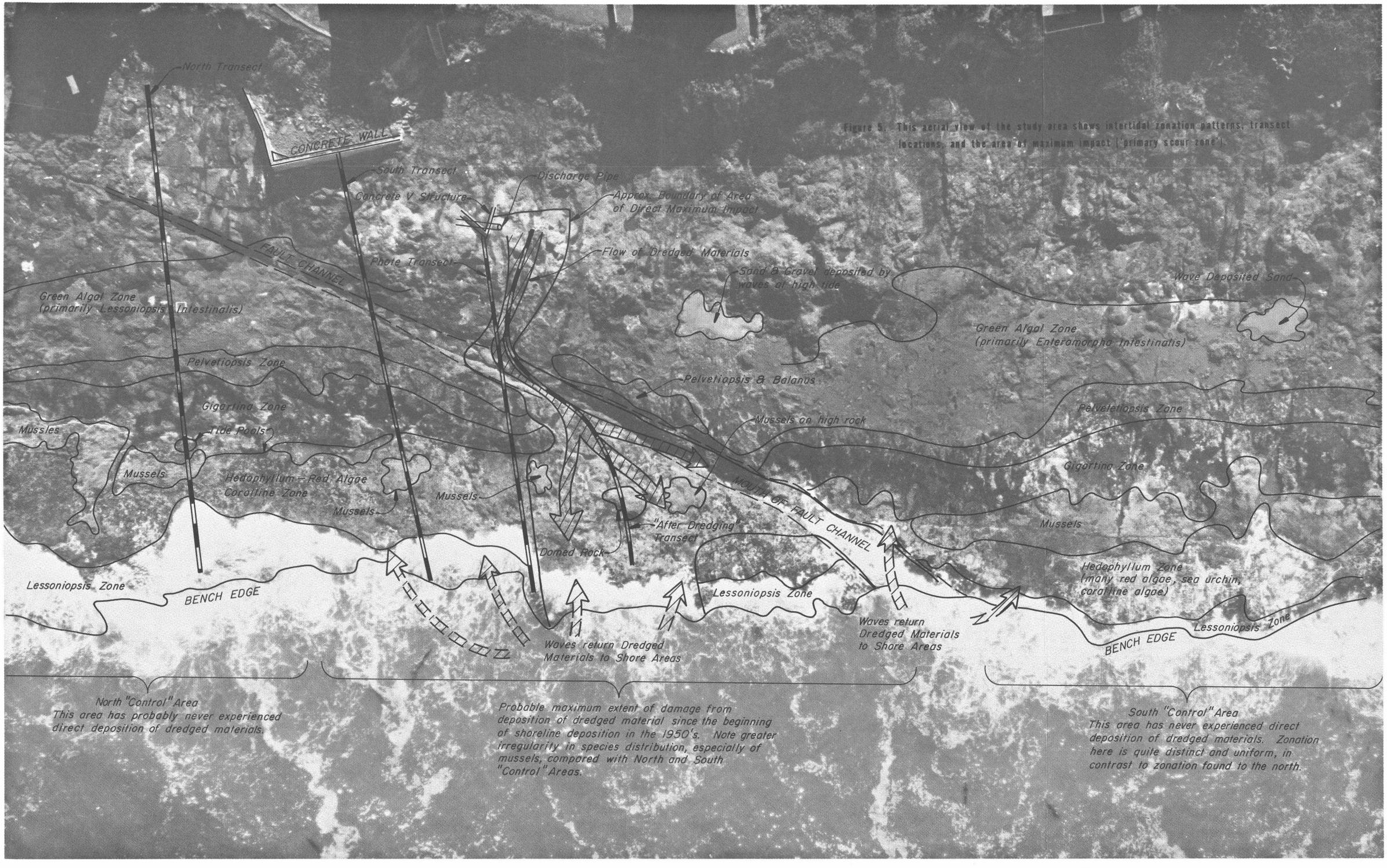


Figure 5. This aerial view of the study area shows intertidal zonation patterns, transect locations, and the area of maximum impact ("primary scour zone").

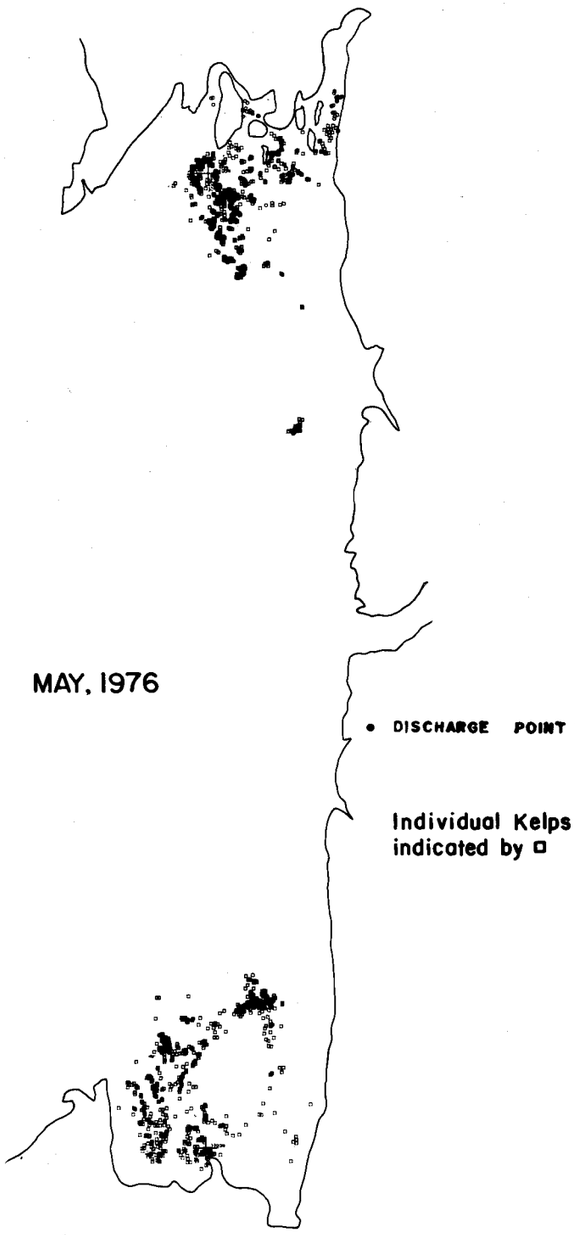
Figure 5

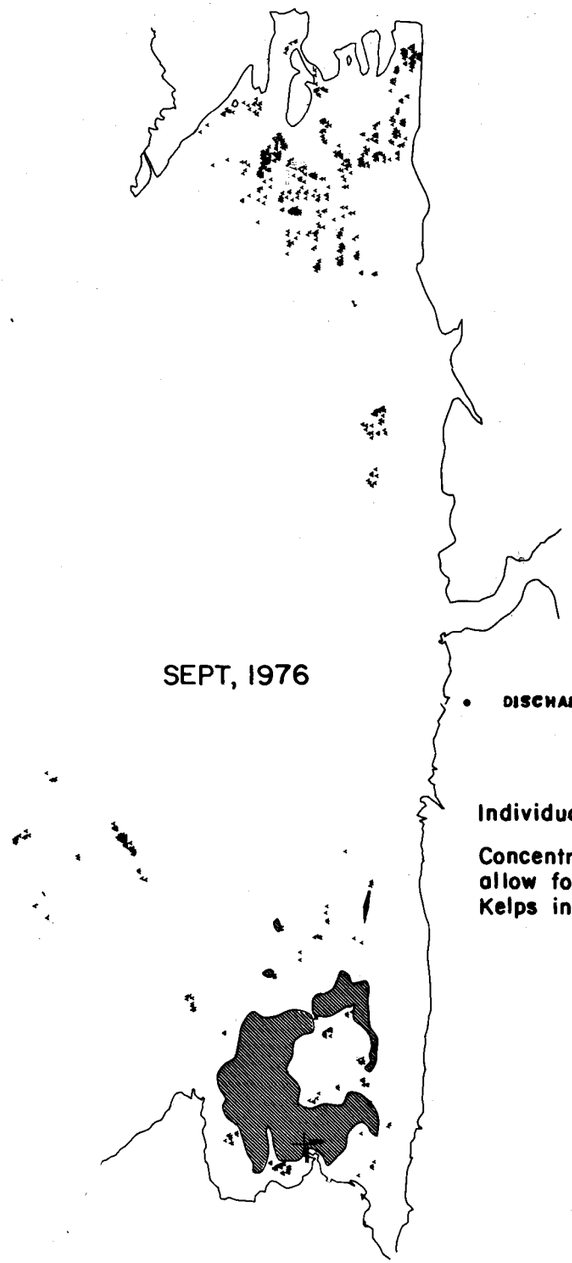
the plotter and locations of the kelp were plotted using the Corps' Photogrammetric Digitizing Program.

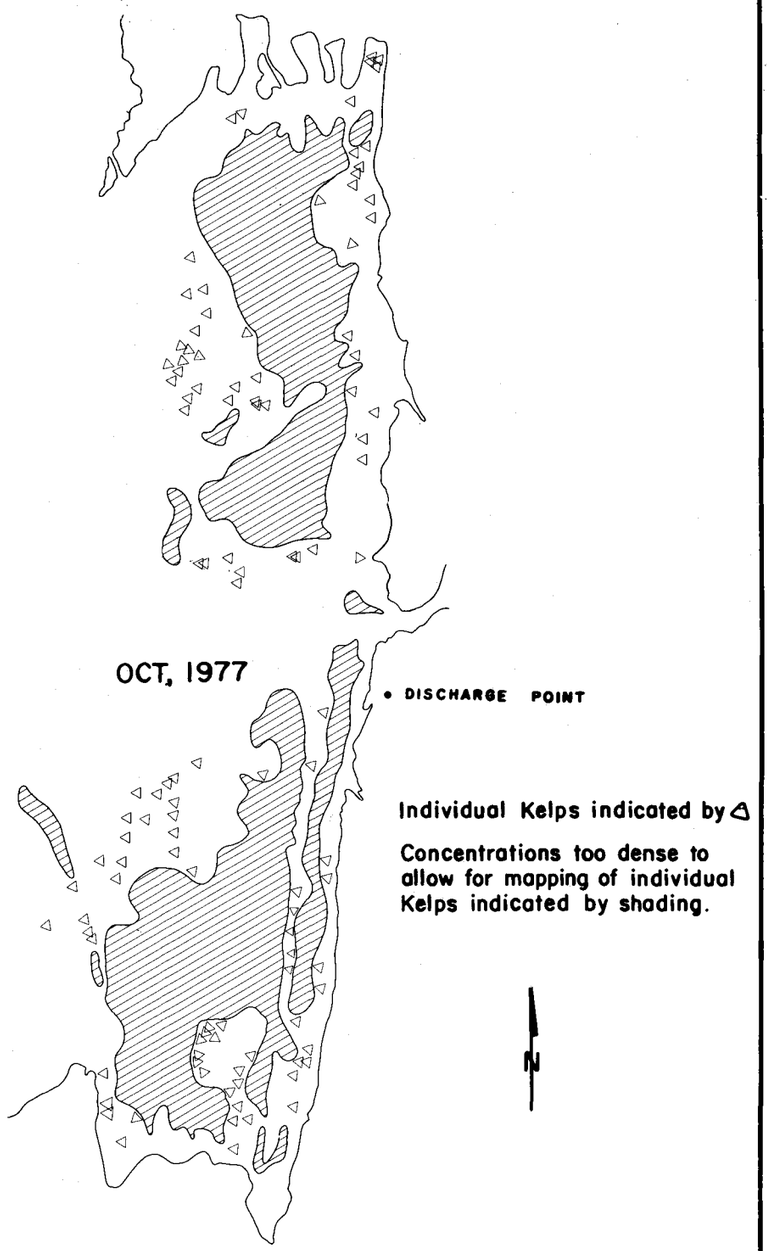
Attempts were made to digitize each kelp plant individually; however, because of massive numbers of kelp plants in the September, 1976 and October, 1977 photos individual plants could not be recorded and only the boundary of their concentrations could be mapped. The final maps of kelp distribution were prepared at a scale of 8000 feet to the inch (see figure 6).

Figure 6 Depoe Bay Kelp Sections

approx. scale: 1: 8,000







RESULTS AND DISCUSSION

CONDITIONS BEFORE DISPOSAL OF DREDGED MATERIALS

Distribution of Intertidal Organisms

The distribution and zonation of biota on the shoreline in the Depoe Bay study area is characteristic of that found in conditions of extreme wave exposure at other Oregon rocky shoreline locations: Shell Cove, 3 miles south of Depoe Bay; the outer tip of Yaquina Head; and the rocky intertidal bench at Neptune State Park, south of Cape Perpetua, are all areas which display zonation similar to that of the Depoe Bay shoreline.

Transects sampled or photographed in this study are shown in figure 5. As nearly as can be determined, the north transect crossed a portion of the study area that had never experienced the direct deposition of dredged materials. The portion of the study area sampled by this transect, therefore, represented an essentially natural condition and, for this reason, was designated as the "control." Similarly, the extreme southern portion of the study area also displayed essentially natural zonation unmodified by deposition of dredged materials. This area is shown in figure 18.

Table 2 shows the range of some of the dominant species at Depoe Bay, based upon their distribution in the north and south transects before dredging. The relative rather than the absolute abundance of each species throughout its tidal range is shown.

All organisms noted in the north and south transects before dredging are listed in table 3, which displays species abundance by tidal level. Animal species are extrapolated to a number-per-square-meter basis; algal species are expressed in percentage of cover. Species listed in table 3 that are also listed in table 2 (that is, the dominant species) are indicated by asterisks.

Zonation

Six generally distinct zones were noted in the north and south transects before dredged material deposition (see figure 5). These zones were also visible in the photographic transect, though distribution was noted to be much more irregular and patchy. These six zones, in order from uppermost to lowermost, are discussed below:[6/]

1. *Enteromorpha intestinalis - Porphyra perforata* zone

This uppermost zone, extending from approximately 10 to 14 feet above mllw, is the zone in which biota must be the most tolerant of environmental

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6/ This section is based principally on an unpublished paper by Keith Kreuz and discussions with Dr. Gonor.

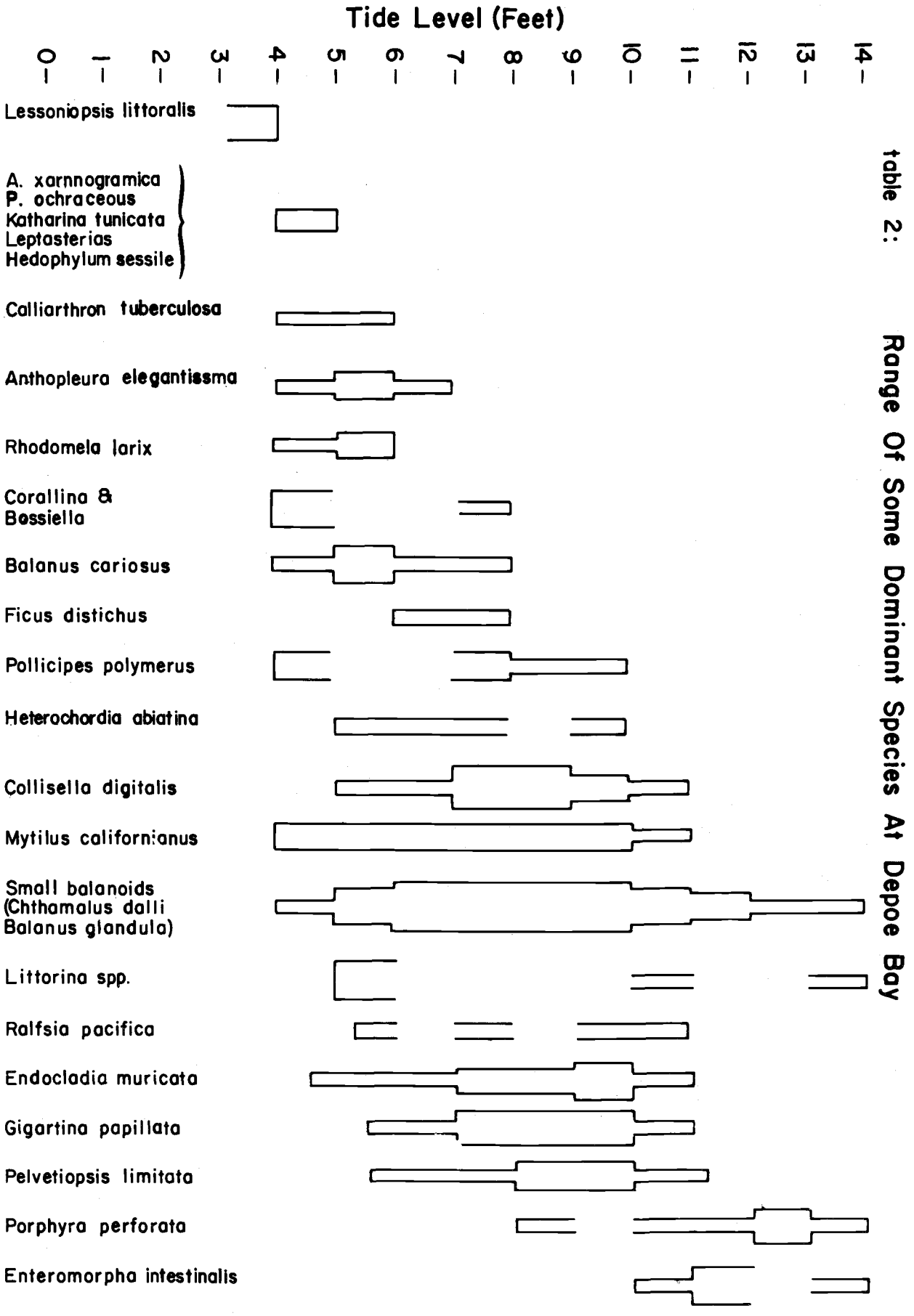

table 2: Range Of Some Dominant Species At Depoe Bay

TABLE 3

SPECIES LIST NORTH AND SOUTH TRANSECTS

(After papers by Hoggarth and Kreuz)

	SPECIES	STOCKING
+2.	Lithothamnion sp.	50%
	Hedophyllum sessile	18%
	Iridaea splendens	1%
	Hymenena sp.	trace
+3	Bossiella plumosa	30%
	Corallina officianalis	30%
	Hymenena sp.	30%
	Iridaea splendens	5%
	Lithothamnion sp	5%
	Lessoniopsis sp.	1%
	Mytilus californianus	1.080/m^2
	Strongylocentrotus purpuratus	.745/m^2
	Tonicella lineata	.331/m^2
	Katharina tunicata	.331/m^2
	Anthopleura xanthogrammica	.166/m^2
	Leptasterias hexactis	.083/m^2
+4	Corallina officianalis / Corallina vancouveriensis	46%
	Lessoniopsis sp.	30%
	Lithothamnion sp.	20%
	Rhodomela larix	6%
	Microcladia borealis	2%
	Endocladia muricata	2%
	Prioritis lanciolata	1%
	Hedophyllum sessile	trace
	Calliarthron tuberculosa	trace
	Mytilus californianus	214/m^2
	Balanoid barnacles	208/m^2
	Leptasterias hexactis	11/m^2
	Thais emarginata	22/m^2
	Phascolosoma agassizii	10/m^2
	Anthopleura xanthogrammica	10/m^2
	Katherina tunicata	5/m^2
	Petrolisthes eriomerus	4/m^2
	Pugettia sp.	4/m^2
	Anthopleura elegantissima	3/m^2
	Cancer jordani	3/m^2
	Thais canaliculata	3/m^2
	Cirolana harfordi	2/m^2
	Haliclona sp.	2/m^2
	Loxorhynchus crispatus	2/m^2
	Notocmea fenestrata	2/m^2
	Oedignathus mermis	2/m
	Strongylocentrotus purpuratus	2/m^2
	Pisaster ochraceus	.144/m^2
	Pollicipes polymerus	trace
	Tonecella lineata	trace

	SPECIES	STOCKING
+5.	Rhodomela larix	30%
	Endocladia muricata	13%
	Heterochordaria abietina	8%
	Gigartina papillata	6%
	Ralfsia pacifica	4%
	Calliarthron tuberculosa	3%
	Porphyra perforata	3%
	Enteromorpha intestinalis	2%
	Pelvetiopsis limitata	2%
	Balanoid barnacles	10279/m^2
	Littorina sp.	4163/m^2
	Mytilus californianus	383/m^2
	Balanus cariosus	336/m^2
	Collisella digitalis	164/m^2
	small limpets	74/m^2
	Anthopleura elegantissima	56/m^2
	Collisella pelta	8/m^2
	Thais lamellosa	6/m^2
	Anthopleura xanthogrammica	1/m^2
	Thais canaliculata	1/m^2
+6	Gigartina papillata	5%
	Pollysiphonia hendryi	5%
	Endocladia muricata	3%
	Odonthalia sp.	3%
	Corallina officianalis	2%
	Fucus distichus	1%
	Heterochordaria abietina	1%
	Pelvtiopsis limitata	trace
	Porphyra perforata	trace
	Balanoid barnacles	18102/m^2
	Mytilus californianus	332/m^2
	Collesella digitalis	56/m^2
	Anthopleura xanthogrammica	45/m^2
	Pollicipes polymerus	32/m^2
	Collesella pelta	6/m^2
	Amphiporus imparispinosus	2/m^2
	Anthpleura elegantissima	2/m^2
	Balanus cariosus	2/m^2
	Katharina tunicata	2/m^2
	Leptasterias hexactis	2/m^2
+7	Gigartina papillata	17%
	Pollysiphona hendryi	15%
	Endocladia muricata	9%
	Gigartina crustatum	6%
	Corallina vancouveriensis	1%
	Fucus distichus	1%
	Heterochordaria abietina	1%
	Pelvetiopsis limitata	1%

	SPECIES	STOCKING
+7	Rhodomela larix	1%
	Iridaea flacida	trace
	Ralfsia pacifica	trace
	Microcladia borealis	trace
	Balanoid barnacles	9471/m^2
	Mytilus californianus	192/m^2
	Collisella digitalis	104/m^2
	limpets	74/m^2
	Pollicipes polymerus	35/m^2
	Balanus cariosus	19/m^2
	Littorina sp.	2/m^2
	other snails	2/m^2
	Balanus glandula	trace
+8	Gigartina papillata	17%
	Polysiphona headryi	15%
	Endocladia muricata	11%
	Gigartina crustatum	8%
	Pelvetiopsis limitata	3%
	Heterochordaria abietina	1%
	Corallina officianalis	trace
	Gloisiphonia Sp.	trace
	Porphyra perforata	trace
	Ulya fenestrata	trace
	Balanoid barnacles	20311/m^2
	Mytilus californianus	196"
	Collesella digitalis	126"
	small limpets	56/m^2
	Amphiporus imparispinosus	8/m^2
	Pollicepes polymerus	6"
	Collisella pelta	4"
+9	Endocladia muricata	20%
	Gigartina crustatum	19%
	Gigartina papillata	17%
	Pelvetiopsis limitata	4%
	Ralfsia pacifica	4%
	Cladophora sp.	1%
	Fucus distichus	1%
	Heterochordaria abietina	1%
	Iridaea flacida	1%
	Rhodomela larix	1%
	Scytosiphona lomentaria	1%
	Pollysiphona hendryi	trace
	Balanoid barnacles	13570/m^2
	Mytilus californianus	138"
	Collisella limatula	94"
	Collisella digitalis	76"
	Pollicipes polymerus	2

	SPECIES	STOCKING
+10	Endocladia muricata	6%
	Porphyra perforata	4%
	Ralfsia pacifica	4%
	Enteromorpha intestinalis	2%
	Gigartina papillata	2%
	Pelvetiopsis limitata	2%
	Gigartina crustatum	1%
	Balanoid barnacles	17968/m^2
	Mytilus californianus	63/m^2
	Collisella digitalis	2/m^2
	Littorina sp.	2/m^2
+11	Enteromorpha intestinalis	22%
	Porphyra perforata	4%
	Gigartina crustatum	2%
	Endocladia muricata	trace
	Ulva fenestrata	trace
	Pelvetiopsis limitata	trace
	Scytosiphon lomentaria	trace
	Balanoid barnacles	16335/m^2
+12	Porphyra perforata	44%
	Ulva fenestrata	5%
	Endocladia muricata	1%
	Balanoid barnacles	1780/m^2
+13	Porphyra perforata	6%
	Endocladia muricata	1%
	Enteromorpha intestinalis	1%
	Balanoid barnacles	7/m^2
	Littorina sp.	3/m^2

LEGEND:

Plant abundance shown in percentage of cover

Animal abundance shown in #/m^2

extremes, because it is this upper intertidal area which experiences the least wetting and maximum drying. At Depoe Bay, this zone was dominated by two algae. Dense patches of *Enteromorpha intestinalis* (a green algae) were found, particularly in areas of freshwater seepage; the *Porphyra perforata* (a red algae) tended to be small and wave-beaten. The faunal community was represented by scattered small balanoid barnacles *(Balanus glandula* and *Chthalamus dalli)*, increasing in density toward the lower portion of the zone. A few small mussels *(Mytilis californianus)* were noted, and limpets and dipterans were also found. In addition to being tolerant of environmental extremes, the dominant species in the zone were later observed to be quite opportunistic, responding quickly and colonizing available space.

2. *Pelvetiopsis limitata* zone (+8 feet to +10 feet, mllw)

Pelvetiopsis limitata, a perennial brown seaweed, was found to grade from an association with *Fucus* spp. (another brown seaweed) and *Endocladia muricata* (a red algae) at the upper margin of the zone to an association with *Gigartina papilata* (another red algae) at the lower margin of the zone. This zone also contains many small balanoid barnacles, with *Chthalamus dalli* being preponderant in the upper portion of the zone and *Balanus glandula* dominating the lower portion. More mussels *(M. californianus)* were noted in this zone than in the uppermost, and they were larger.

3. *Gigartina* zone (+6 feet to +8 feet, mllw).

Gigartina papillata (a red algae) dominated this zone, mixing with *Endocladia muricata* (another red algae). Mussel *(M. californianus)* concentrations and size of individual mussels increased in this zone, especially toward its lower margin. *Balanus cariosus* (horse barnacle) and *Pollicipes polymerus* (goose barnacle) were also found in this zone, along with the smaller barnacle, *Balanus glandula*.

4. Mussel zone (+4 feet to +6 feet mllw)

Mytilus californianus, the California mussel, formed dense beds at this level and the mussels grew to their largest size in this zone. Numerous gooseneck barnacles and horse barnacles were associated with the mussels; the common sea star, *Pisaster ochraceus*, the chief predator in this zone, was also found.

In addition to the normal sampling procedures employed on the north and south transects, a more intense sample was taken of the mussel community in this zone. A 900cm^2 bed of mussels in the +4 to +5-foot level was removed and all associated organisms noted; while accurate counts of all species were not made, the variety of species (see table 4) represented in this part of the rocky intertidal ecosystem indicates its high productivity.

TABLE 4

MUSSEL BED COMMUNITY[7/]

Annelids:
- *Halosydna brevisetosa*
- *Sabellaria cementarium*
- *Shistocomus hiltoni*

Arthropods:
- barnacles *Balanus cariosus*
- crab *Cancer jordani*
- crab *Loxoryhnchus crispatus*
- crab *Oedignathus inermis*
- crab *Petrolistes cintipes*
- crab *Pagurus hirutinsculus*
- isopods (many spp.)

Echinoderms:
- *Leptasterias hexactis*
- *L. pusilla*
- *Pisaster ochraceus* (juvenile)
- urchin *Strongylocentrotus purpuratus*

Molluscs:
- gastropods:
  - *Collisella pelta*
  - *Nucella canaliculata*
  - *Searlesia dira*
- polycipods:
  - *Hiatella arctica*
  - — *Mytilus californianus*
- polyplacophora:
  - chiton *Mopalia muscosa*

Sipunculida:
- peanut worm *Phascolosoma agassizii*

Porifera (sponges)

Not present in this particular mussel bed sample, but scattered across other beds in the zone, were *Pollicipes polymerus*, the goose barnacle. The absence of goose barnacles in the bed sampled is probably evidence of the competitive dominance of mussels over barnacles.

5. *Hedophyllum* zone (+4 feet to +6 feet mllw)

The "sea cabbage," *Hedophyllum sessile*, a perennial brown seaweed, dominated this zone. *Endocladia muricata* (a red algae) and coralline algae *(Corallina lithothamnion)* tended to fill the voids between the *Hedophyllum* holdfasts. A number of black leather chitons, *Katharina tunicata*, were also found, along with some very large mussels and barnacles. The size of mussels and barnacles was probably indicative of greater longevity caused by reduced predation by sea stars in this zone of greater wave exposure. Some purple sea urchins *(Strongylocentrotus purpuratus)* were also found in this zone, but they were noted to be smaller than those typically found in more protected areas.

6. *Lessoniopsis* zone (0 to +4 feet mllw)

The perennial, woody, brown seaweed *Lessoniopsis littoralis* dominated this zone, according to visual observation. The intensive wave action at

7/ Based on unpublished paper by McCarley (see references)

Depoe Bay and the steepness of the seaward edge of the bench, however, precluded thorough sampling of the zone.

Biomass Measurement

To assess the productivity of the intertidal zones at Depoe Bay, organisms were scraped from the surface at randomly stratified sites along the north transect. These were dried and baked to provide ash-free dry weight. Table 5 presents these data by tidal level sampled.

Distribution of Subtidal Organisms

Bull Kelp *(Nereocystis leutkeana)* is the dominant plant form in the subtidal area of Depoe Bay. The kelp beds start at a water depth of 10 to 20 feet below mllw and extend out to a depth of 60 to 80 feet (depths are shown on figure 4). They are especially abundant in an area extending from just inside the outer reefs of Depoe Bay to the beginning of the rocky intertidal area.

N. leutkeana can reach lengths of up to 60 feet and a single plant can cover up to 70 square feet.[8/] This size is particularly impressive, as *Nereocystis* is an annual plant, a fact any beachcomber can attest to by observing the masses of kelp on the beach during the late fall and early spring months.

The stands of bull kelp are usually worn away through wave activity by late December; young plants emerge again in April (see figure 7). The *Nereocystis* canopy is fully formed by June of each year and supports a variety of plant and animal life. McLean[9/] reports on two subtidal zones found under a *Nereocystis* canopy in Monterey Bay, California. He describes a *Calliarthron* zone, made up of the red coralline alga *Calliarthron cheilosporioides*, which is dominant down to a depth of 10 feet, and below this zone, the *Pterygophora* zone, dominated by *Pterygophora californica*. The most well-known *Nereocystis* association, according to Carefoot[10/], is that of the sea otter, sea urchin, and kelp. The most abundant invertebrates McLean found associated with the *Nereocystis* canopy and *Pterygophora* subcanopy were anenomes, gum boot chitons, and bat stars. These associations found by McLean, while not verified by observation at Depoe Bay, are expected to be present. The holdfasts of the two kelps also provide microhabitat for many other small animals.

The canopy of seaweed also provides an important food source to intertidal herbivores in the form of detritus (bits of worn seaweed tissues and

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8/ James H. McLean, The Sublittoral Ecology of Kelp Beds of the Open Coast Area near Carmel, California, Biological Bulletin, p122:95-114, 1962.

9/ Ibid.

10/ Thomas Carefoot, Pacific Seashores, p. 158, 1977. Figure 7 is also reproduced from Carefoot, p. 56.

TABLE 5 BIOMASS MEASUREMENTS (North Transect) 7/

Contents	Biomass (g/m^2 ash-free dry wt.)	Totals
At +4 Feet M.L.L.W. Elevation:		
Mytilus (96)	3,644.22	
Pollicipes (35)	61.78	
Thais (5)	1.67	
Misc. Algae and Fauna	897.77	
		4,605.44
At +5 Feet M.L.L.W. Elevation:		
Misc. Algae and Fauna	817.11	817.11
At +7 Feet M.L.L.W. Elevation:		
Mytilus (12)	28.30	
Misc. Algae and Fauna	479.26	
		507.56
At +10 Feet M.L.L.W. Elevation:		
Pelvetiopsis	82.22	
Misc. Barnacles	66.89	
Misc. Algae and Fauna	100.89	
		250.00

7/ Based on unpublished paper by McCarley.

associated microbial biomass) washed up into the intertidal area. The plants themselves are also eaten by the numerous herbivoires associated with the canopy.

Bull Kelp also provides products for human use and consumption, in particular agar-agar, an additive with uses ranging from scientifice laboratory work to the manufacturing of ice cream. Algen, a chemical used in many manufacturing processes, is also harvested from the seaweed.11/

Nereocystis harvesting at Depoe Bay (and at other areas of the northwest coast) has been proposed; however, the extreme wave conditions and the absence of favorable market conditions have prevented commercial harvesting; such harvesting is not expected to materialize in the near future.

DISPOSAL EFFECTS

Primary Scour Area, Intertidal Zone

Dredging began in mid-April, 1976 and was completed in about 2 weeks. Figure 5 shows the location of maximum impact to the study area; note the direction of flow of the slurry of dredged material, as indicated by arrows on figure 5. Effects in this area of maximum impact resulted from a combination of direct scouring (figure 8), smothering (figure 9), and, possibly, toxic effects (see table 6, ellutriate test results). Secondary impacts occurred in the area immediately north and south of the scour area as waves threw dredged material (ranging in size from fine silt to 4- to 6-inch cobbles) back onto the shoreline. This constant wave activity accentuated the scouring damage and also distributed the slurry material about 50 feet on either side of the scour area.

The primary scour area was almost completely denuded of organisms. Some portions of the scour area, especially the elevated seaward side of the "domed rock" and "high rock" noted in figure 5, retained some mussels and a few barnacles. A few *Hedophyllum* holdfasts remained intact in the *Hedophyllum* zone. All coralline algae in the direct scour area were killed; some chalky residue of coralline algae remained where smothering or toxic effects had killed the algae but scouring had not completely removed them.

"Before" and "after" pictures on the pages following show the extent of impact to the primary scour area (see figures 14 through 22).

11/ Bull kelp is also used, to a limited extent, for food. Out of Alaska's Kitchens, a fascinating cookbook published by the Easter Seal Society for Alaska Crippled Children and Adults, Inc., lists recipes for Kelp Sweet Relish, Kelp Mint Marmalade, and Kelp Grape Conserve (pp 213-214).

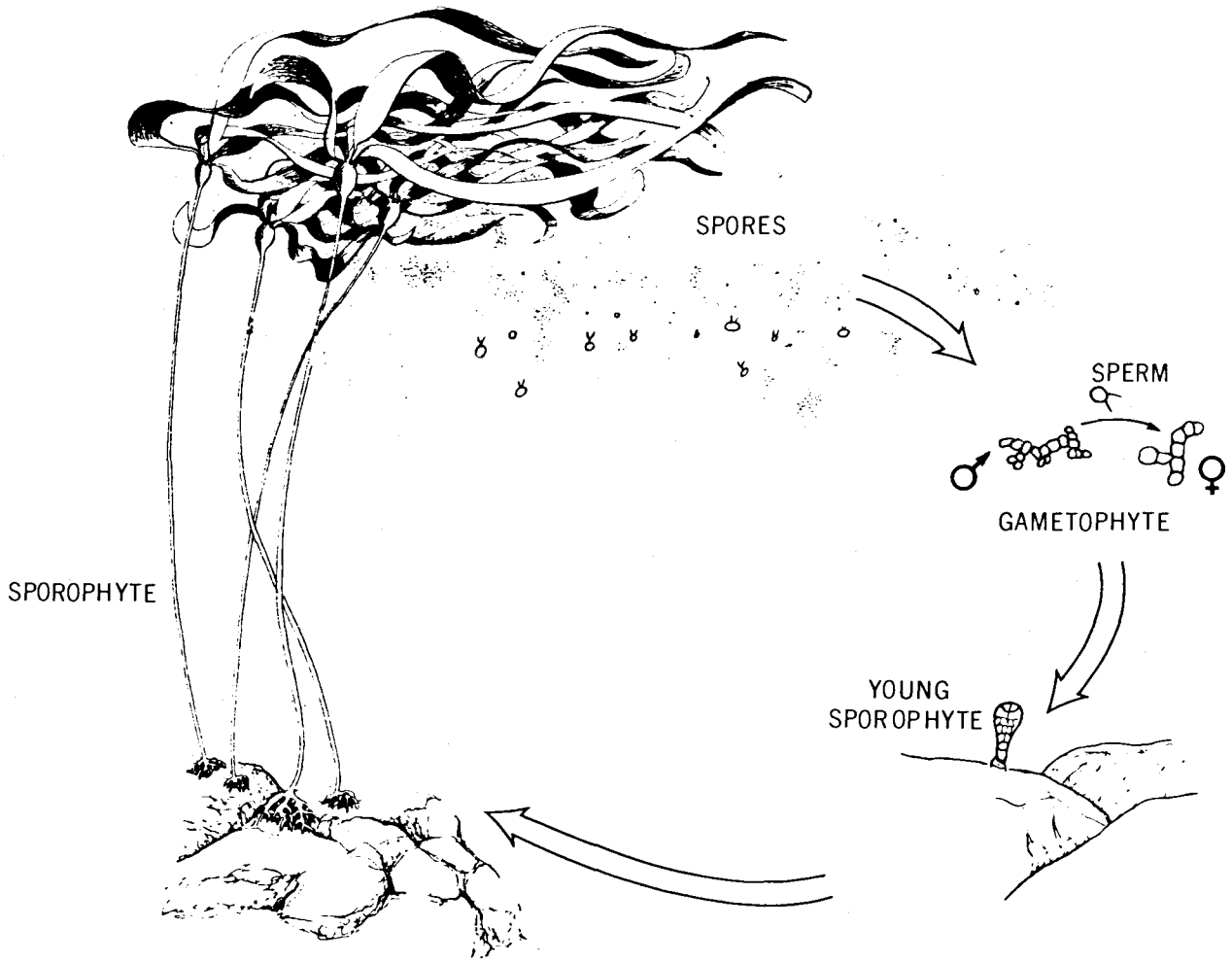

Figure 7. Life Cycle of the Bull Kelp.
"The life cycle of the bull kelp, *Nereocystis luetkeana*, involves a conspicuous spore-producing or *sporophyte* stage, and an inconspicuous gamete-producing or *gametophyte* stage. The bull kelp is an annual species (although some individuals may live for perhaps two years), with spores being liberated in late summer or autumn and the gametophyte stage maturing in winter. Young sporophytes of the new year's generation can usually be found in late winter and early spring. The large kelp *Macrocystis* has a similar life cycle."

(from Carefoot, Pacific Seashores, p. 56. Reprinted by permission of Douglas and MacIntire, publishers.)

The fault channel is visible in this view of discharge of dredged materials.

Figure 8

A closer view of the discharge point, from the vantage point of the gull in the photo above.

Figure 9. "During" and "after" views of the domed rock. A slurry of dredged material is evident on the landward side of the rock in the top photo; the bottom photo shows the result, two weeks later, of such smothering.

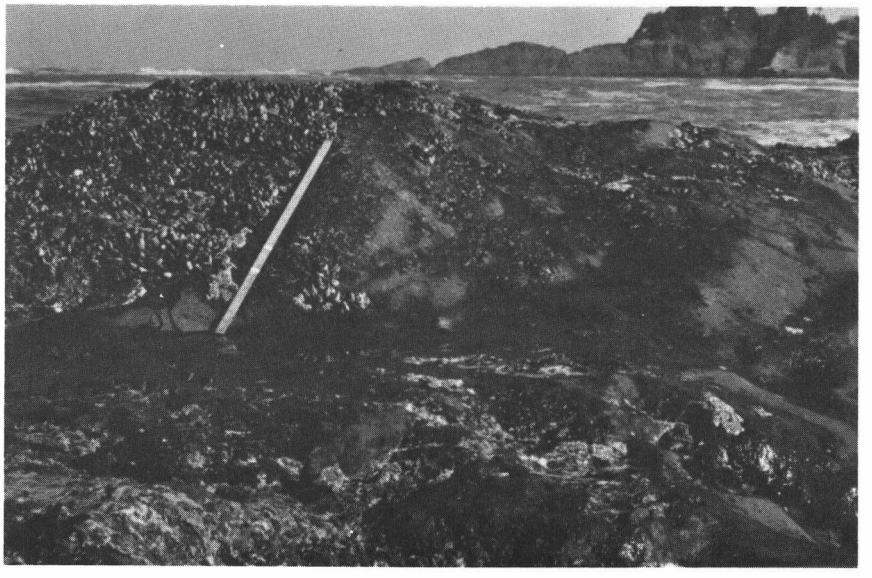

TABLE 6 ELUTRIATE TEST RESULTS

Location: 100 Feet East 50 Feet South USC&GS B. Mark #1

Taken by: Ponar dredge; small clamshell sample of top 3-4 inches of sediment

Taken on: 16 July 1975

	Receiving Water		Standard Elutriate	
	Unfiltered	Filtered	Unfiltered	Filtered
Mercury, mg/L	0.0002	0.0002	0.0002	0.0003
Lead, mg/L	N.D.	N.D.	0.012	0.014
Zinc, mg/L	0.28	0.31	0.10	0.14
Cadmium, mg/L	N.D.	N.D.	N.D.	N.D.
Suspended Solids, mg/L	8.0	-	302.0	-
Voltatile Solids, %	5.7	-	0.4	-
Turbidity FTU	1.1	-	150.0	-
Oil & Grease (Visual)	N.D.	-	N.D.	-
Dissolved Oxygen mg/L	3.0		3.2	-

Sediments

Mercury, ppm dry	0.0008
Lead, mg/Kg, dry	N.D.
Zinc, mg/Kg, dry	N.D.
Cadmium, mg/Kg, dry	0.94
COD gmg/Kg, dry	29.4
Volatile Solids, %	4.1

N.D. = Not determined

Table 7 displays the biota remaining in the primary scour area following disposal of dredged materials.[12] The extent of damage can be determined by comparing species diversity and density levels in table 3 (pre-disposal with levels in table 7 (post-disposal).

Secondary Area

Waves and tidal swells diluted some of the pipeline slurry and distributed it about 50 feet to each side of the area of maximum scour. This peripheral effect was mostly confined to killing of some of the coralline algae, though some physical buffeting by wave-distributed cobbles was noted at lower tidal levels on the south transect (just north of the primary scour area). Additionally, some sand was distributed into tidal pools and higher elevation depressions, especially when disposal occurred during periods of higher tides.

EFFECTS ON SUBTIDAL AREA

Potential effects of disposal of dredged material on the subtidal organisms were twofold: (1) the abrasive action of the heavy suspended sediment load associated with the disposal operations; and (2) the toxic effects of pollutants associated with the suspended sediments. Direct smothering of the subtidal organisms is a less likely possibility; as will be discussed later, such smothering was not verified. Visual observations of the disposal operations did not detect a suspended sediment plume as dredged sediments entered the subtidal area. It is assumed, therefore, that the materials settled out at a very rapid rate and were therefore deposited on the bottom at the time of disposal, possibly impacting subtidal organisms.

Nereocystis is normally found in high energy environments unfavorable to its counterpart, giant kelp *(Macrocystis pyrifera)*, which tends to dominate in more protected environments. A study by Vadas has demonstrated that *Neroecystis* requires the high light intensities of spring and summer and does not grow well in late fall or in competition with other kelps for available light.[13] Vadas found that subtidal areas denuded of their flora and fauna between February and April were quickly colonized by *Nereocystis*, but surfaces denuded in the fall were not colonized.[14] This suggests that, although competition is a factor, absolute light intensity is the limiting factor in bull kelp growth and development.

12/ Based on measurements made on 14 May 1976 under supervision of Dr. Gonor, Marine Science Center, Newport, Oregon.

13/ Vadas, R.L., Culture and Ecology of *Nereocystis*, Journal of Phycology Vol. 8, 1972, pp 196-208

14/ Ibid.

TABLE 7 BIOTA REMAINING FOLLOWING DISPOSAL - IN AREA OF MAXIMUM SCOURING

Data of 14 May 1976 from lower bench, maximum scour area.

Row 1. Lower Hedophyllum zone, normally occupied by Hedophyllum, Lessoniopsis, Corallines and Urchins. Sample: $5m^2$

Species	Avg. % cover	Avg. No./m^2
Lessoniopsis	3.2	1.00
Hedophyllum	9.6	5.80
Katherina	-	0.80
Tonicella	-	1.80

Row 2. Mid-Hedophyllum zone-Hedophyllum and foliose articulate corallines. Sample: $7m^2$

Hedophyllum	0.3	1.00
Corallina	5.0	-
Mytilus	-	51.30
Anthopleura	-	7.70
Purple Urchins	-	0.86
Limpets	-	1.00
Mitella (Pollicipes)	-	16.60
Balanus cariosus	-	2.60
Katherina	-	0.14

Row 3. Mytilus/Barnacle bed level. Sample: $6m^2$

Hedophyllum	0.3	1.00
Corallina	0.3	-
Mytilus	12.0	255.00*
Balanus cariosus	4.0	134.70
Thais canaliculata	-	0.50
Limpets	-	14.70
Leptasterias	-	0.17
Mitella	-	12.70

Row 4. Lower Gigartina zone. Gigartina, Balanus glandula, B. cariosus This row was on a raised area. Sample: $7m^2$

Katherina	-	0.29
Hedophyllum	0.4	-
Mitella	-	2.14
Thais canaliculata	-	0.29
Balanus cariosus	3.0	128.10
Mytilus	4.0	119.00
Limpets	-	2.30
Pisaster	-	0.43
Gigartina	0.3	-
Leptasterias	-	0.43
Corallina	0.1	

Row 5. Gigartina zone, Gigartina, Balanus, etc. All frames in this row fell on entirely bare rock. Sample: $5m^2$

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* This figure for Mytilus is misleadingly high, as one of the six samples in this zone fell directly on the only remaining mussel bed (on the domed rock - see figure 5).

Because *Nereocystis* develops in high energy environments normally carrying a high natural sediment load, Corps and Oregon State University investigators believe effects on the bull kelp community of the additional suspended sediment load provided by dredged material are limited or non-existent. Similarly, the dilution of toxic materials entering the ocean in such a high energy environment is believed to mitigate against chemical damage to the subtidal ecosystem, except, perhaps, in the small region where the dredged material first spills into the ocean.

The three aerial photo runs were flown in an attempt to determine the effects of the increased suspended sediment load and bed load on *Nereocystis*.

Figure 10 shows the distribution of *Nereocystis* in May 1976, immediately following disposal operations. This photo run was taken approximately 2 weeks after the start of disposal operations, but based on observations by Corps personnel at the start of the disposal, it represents an accurate picture of the *Nereocystis* beds prior to disposal. Figure 11, taken 4 months after disposal operations ceased, represents the 1976 annual crop of *Nereocystis* at a time of its maximum production, just prior to winter die-back triggered by lower light intensities. The apparent increase in kelp from May to September is, however, somewhat misleading, as the same plants are probably present in both photographs. The plants are more visible in the September photograph, as they are larger and closer to the surface of the water than in the May photograph.

As noted in figure 7, the sporophyte generation of *Nereocystis* releases spores prior to its annual fall dieback. These spores produce the gametophyte stage that matures over the winter and produces the next sporophyte generation. Figure 12, taken in October 1977, represents a full season's growth of the sporophyte generation produced by the 1976 gametophyte stage. This aerial photo contained such an expanse of kelp that plants could not be individually mapped; major populations were, therefore, simply outlined. As can be observed in this figure, the sporophyte survival rate during 1977 was high; the bed, in fact, expanded beyond the maximim extent reached in 1976.

Whether this expansion can be attributed to an absence of disposal during 1977 or is the result of the disposal in 1976 cannot be conclusively shown. A case could be made, however, for the desirability of producing clean scour areas for the settling of *Nereocystis* sporophytes because such sporophytes would be subject to less competition from the flora and fauna that would otherwise be present.[15/] On the other hand, the May 1976 photo (figure 10) may depict a population of *Nereocystis* already reduced as a result of the dredging underway. The most probable explanation of the differences between the September 1976 and the October 1977 photographs (figures 11 and 12, respectively) is that they simply represent normal seasonal variations and the disposal operations were not a controlling factor.

15/ Op. cit.

Effects of the disposal on subtidal organisms other than the dominant canopy organism *Nereocystis* and effects of toxic substances on the subtidal were not shown by this study. A more comprehensive study involving routine sampling by divers would be necessary to document these effects. It is unlikely, however, that these studies will be performed as they are difficult enough in low energy environments and would be very dangerous if not impossible to perform in the high energy environment found at Depoe Bay.

BIOTA RECOVERY IN DISPOSAL AREA

Following the cessation of dredging operations in early May, 1976, Dr. Gonor made frequent visits to the area to trace the course of recovery of intertidal biota in the primary scour area. His observations, based on a complete, annotated, photographic record, are contained in appendix 1 to this report.

It is interesting to note that the succesionary pattern observed and described by Dr. Gonor closely parallels that described by Thomas Carefoot in his recent book, Pacific Seashores. Describing the order of events transforming a bare rocky shore to a *Mytilus Californianus* (California mussel) community, Carefoot states:16/

> Firstly, various "fugitive" seaweed species, mostly filamentous reds and greens, appear on the fresh space. These annual opportunists soon disappear in face of competition by certain perennial algae, such as the corallines. The latter are successful in outcompeting the initial colonizers for light and attachment space, and also shield the rock surface from settling spores of other algal species. The seaweeds are then displaced by acorn barnacles, *Chthamalus dalli, Balanus glandula,* and *B. cariosus,* by their action of growing into and undercutting the algal holdfasts. The goose barnacle *Pollicipes polymerus* may then become established in some areas, but usually it yields to the competitively dominant *Mytilus californianus*. The mussel overgrows and smothers the other organisms, and forms the final stable community.

16/ Carefoot, Thomas, Pacific Seashores, p. 79

Figure 10. Bull kelp distribution in May, 1976. Disposal of dredged material had just ended when the aerial photos in this mosaic were taken. The rapid growth of kelp is apparent when this view is compared with figure 11, taken 4 months later.

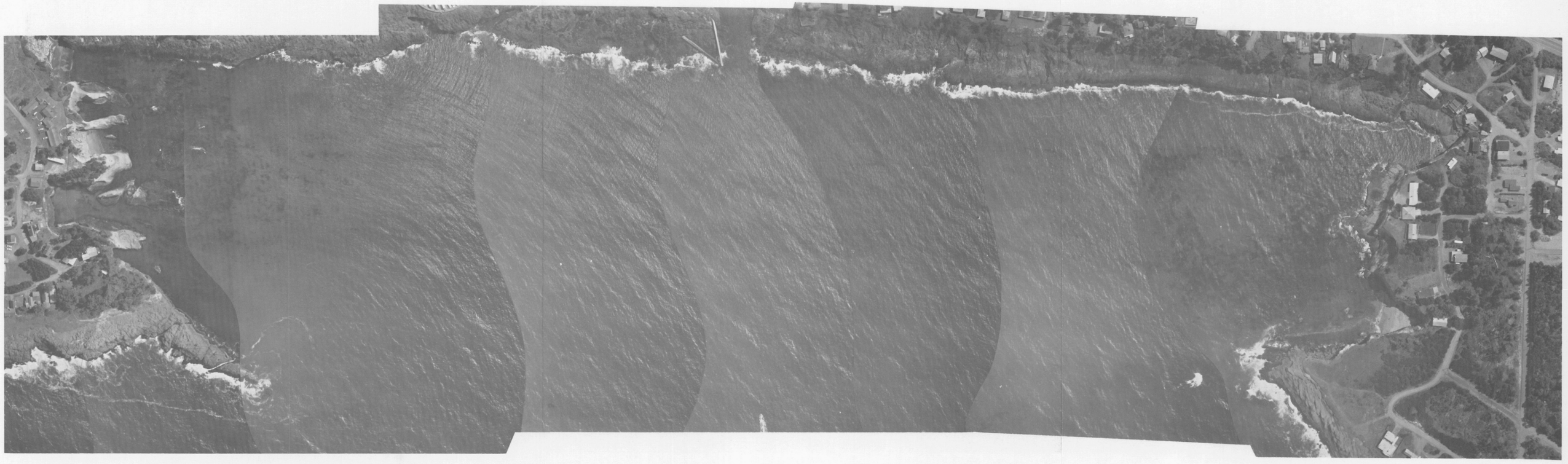

Figure 11. Bull kelp obtains its maximum visible distribution in the autumn, as shown in this composite view constructed from aerial photographs taken in September, 1976.

Figure 12. Bull kelp distribution in October, 1977. This view, taken 17 months after dredging, shows a greater abundance of kelp than is visible in figure 11, taken four months after dredging. The less extensive distribution of kelp in the earlier photo, however, is probably the result of naturally occurring seasonal variability rather than the effects of near-shore disposal of dredged materials.

A simple diagram explains this successionary pattern:

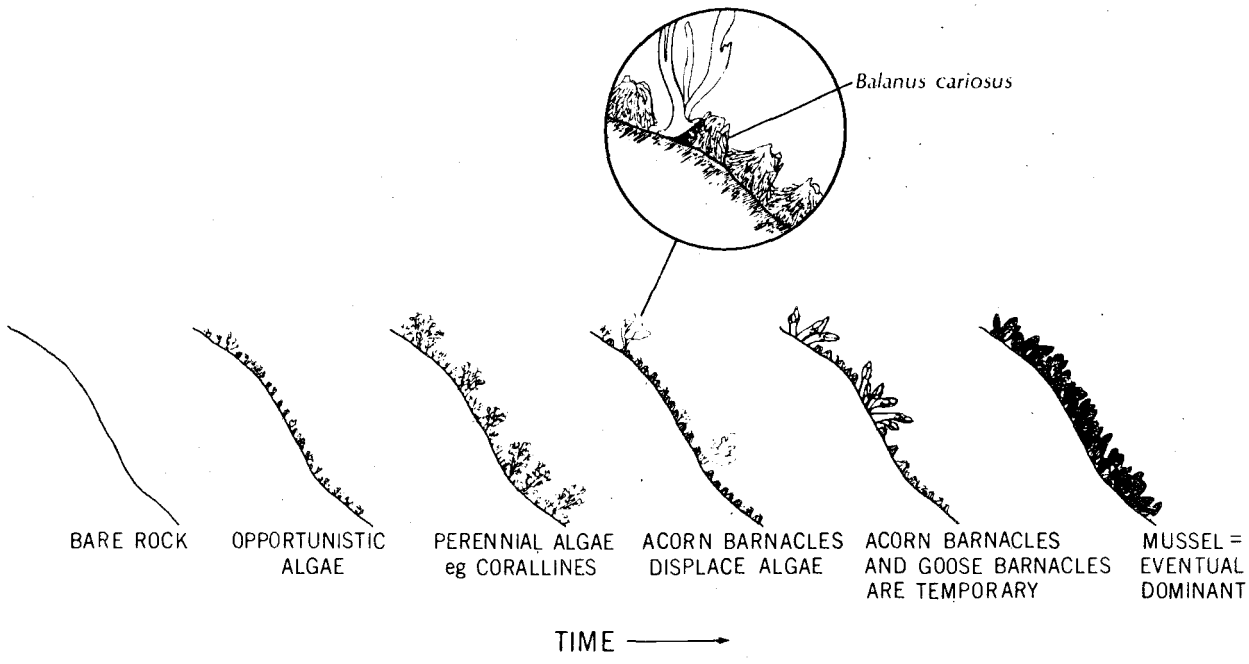

Figure 13. Development of mussel community[17/]

A series of before and after pictures are furnished to illustrate the damage in the main scour area on the intertidal shoreline and the recovery of organisms in the same area (see figures 14 through 22).

17/ from p. 79, Pacific Seashores, reproduced by permission of Douglas and MacIntire, Publishers, Vancouver, B.C.

CONCLUSIONS AND RECOMMENDATIONS

EFFECTS ON INTERTIDAL PRODUCTIVITY

The major effect of rocky intertidal disposal of dredge material at Depoe Bay is disruption of the ecosystems in the area affected. This disruption is particularly evident in the intertidal portion of the disposal site.

Deposition of dredge material on a relatively confined site every three to four years has contributed to a patchy, irregular distribution of the dominant associations. Ecological succession patterns have been disrupted in portions of the study area; every three to four years, the cycle of succession shown in figure 13 has begun anew.

While it was not the purpose of this study to examine alternative disposal methods, one of two observations to place shoreline disposal in perspective should be made. Upland disposal of dredged materials in the Depoe Bay area is difficult, as there are few nearby sites large enough and possessing topographic characteristics that allow adequate drainage of materials. Off-shore ocean disposal, while difficult, is possible. Hopper dredges are not feasible, because of the size of the entrance and the harbor, but a combination of pipeline or clamshell dredging and barging of materials to an ocean disposal site could be used; this method would be more expensive than is shoreline disposal. The environmental effects of off-shore ocean disposal, compared to the effects of shoreline disposal, are not known with any degree of certainty, although researchers agree that the intertidal and near-shore subtidal region are inherently more productive than is the offshore benthos.

Since economics factors at Depoe Bay tend to encourage disposal of dredged materials in the highly productive intertidal zone, a trade-off analysis of the variables associated with such disposal is presented below:

Same Site vs Rotated Site

The periodically dredged material could be disposed of at the same location each time dredging occurs, or it could be disposed of at a different or rotated site each time. It is apparent from this study that a disposal site will not return to "normal" in three to four years. Rotating the deposition site between two or three areas would allow any one area to recover more completely between depositions. Confining all dumping to the same site each time dredging occurs may be preferable, however, since the area damaged would be relatively small. Assuming shore disposal is necessary, investigators in this study favor utilizing the same designated, specific site for discharge each time dredging is performed, because doing so would appear to confine the amount of damage and would facilitate long term study of effects on the intertidal biota.

Discharge of Slurry High in the Intertidal Area vs Discharge Lower in the Intertidal Area

Heavy wave and tidal swell activity in the area would damage the outlet pipe if it were placed lower in the discharge area. Short of constructing a permanent, reinforced concrete pipe or other heavy structure on the shoreline to receive the flow from the pipeline, it is not possible to discharge materials from lower in the intertidal zone than was done in the 1976 dredging.

Spring Dredging vs Fall Dredging

Spring dredging is preferable to fall dredging for reasons relating to efficiency of dredging and to achieving the purpose of dredging. Winter storms tend to deposit sand in the channel entrance and the harbor itself; most of the silt transported by Depoe Creek and North Depoe Creek is also transported during heavy runoff periods during the winter and early spring. Spring dredging, then, removes not only that material which is deposited over the period of time between dredgings (three to four years), but also that material which is most recently deposited (in the winter immediately preceding).

Were dredging performed every year, the advantage of spring dredging would be clearer; even with a three to four year dredging cycle, however, economic benefits, plus the psychological values of starting a fishing season with a freshly dredged harbor are significant. Dredging is also physically easier in the mid-spring months than in the late fall and winter months, in that wave activity is lower and laying and securing the pipeline across the intertidal may be done more easily. Additionally, spring low tides tend to be lower than fall low tides.

From a biological viewpoint, however, the situation is not as clear. It is known that release of larvae from marine invertebrates and spawning of gametes is associated with the spring phytoplankton bloom.[18/] Logic would seem to indicate that a spring discharge of dredged materials into the intertidal and near subtidal region would tend to have some impact on this association between phytoplankton abundance and the beginning of the intertidal invertebrate life cycle. Because of the small amount of intertidal area affected and the relatively small amounts of dredged material entering the subtidal (compared with the total amount of particulate matter in suspension under "normal" conditions), the degree of impact of spring dredging on the reproductive cycle, however, is probably slight. It is possible that Bull kelp sporophyte attachment occuring in the late winter and early spring could be affected by the presence of substantial amounts of sediments from dredging, particularly if disposal were to occur early in the spring.

It is clear that deposition of dredged material does remove organisms from the intertidal coastline; it is not clear, however, that removal of these

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18/ Carefoot, Pacific Seashores, Chapter 5.

organisms would be less damaging to the intertidal ecosystem if it occurred in the fall rather than the spring. The recovery cycle discussed earlier would probably be slightly different with fall dredging, but without further study, it is not possible to accurately predict that recovery cycle. Spring dredging apparently allows for some recovery of the site during the first few months following deposition of dredged material; this seasonal recovery immediately following dredging would be foregone with fall dredging.

On balance, and for the reasons discussed, the authors recommend spring dredging as preferable to fall dredging.

Discharge at High Tide vs Discharge at Low Tide

While discharge at low tide would tend to confine damage to that portion of the intertidal zone over which the discharge slurry flows, such confining would also tend to more thoroughly impact the organisms in the area of direct flow. Discharge during periods of high tide, on the other hand, tends to dissipate the dredged materials more quickly as it flows across the intertidal zone, thereby decreasing the intensity of damage but also broadening the area impacted. More important than tidal influences, of course, are the influences of weather and its effect on wave intensity. The more intense the wave activity, the more intense the "throw-back" effect and the greater the area affected. Conversely, intense wave activity tends to dilute toxic dredged materials more quickly than does light wave activity.

An ideal combination of tide level and wave activity would be low tide and low waves. At Depoe Bay, however, limiting disposal operations to this "ideal" period would greatly increase costs and lengthen the time during which the intertidal zone would be impacted. Recovery of the intertidal area would be correspondingly delayed, as a portion of the late spring and early summer growth period would be lost.

The authors feel the best recommendation is to allow deposition at all tide levels, but to limit discharge to those periods of relatively calm wave activity.

Regarding Zonation Displacement

The zonation displacement phenomenon discussed earlier warrants comment here. The existing zonation at Depoe Bay has resulted from the existing tidal and wave influences on the rocky shoreline. At various times, proposals have been put forth which would create jetties on the outer submerged reefs. While an analysis of the effects of such a project are well beyond the scope of this limited study, it should be noted that such a project would undoubtedly reduce the wave activity at the rocky shoreline, and it is likely that the organisms making up the existing zonation patterns would find themselves stranded above their normal wetting level. The productivity of the intertidal shoreline would be correspondingly reduced, until such time as the organisms would reestablish themselves at lower levels.

EFFECTS ON SUBTIDAL PRODUCTIVITY

The importance of Bull kelp, as discussed earlier, centers around its role in the coastal ecosystem, especially in the habitat it provides to subtidal herbivores (such as the sea urchin) and the nutrients it provides to intertidal organisms each year as its storm-tossed remains are washed onto the rocky beach. A potential for commercial harvest of the Bull kelp and associated species, especially the sea urchin, certainly exists, but it must be discounted because of a lack of markets for the harvest and because of the difficulties of harvesting in the tempestuous environment of Depoe Bay.

It appears, from the data available to the authors, that juvenile and one year old kelp were not significantly damaged by the 1976 disposal of dredged materials at the shoreline disposal site.

SUMMARY

The overall conclusion reached by the investigators in this study, and by the authors, is that the amount of damage inflicted to the rocky intertidal and subtidal ecosystms is probably not particularly significant. Because of the inherently high productivity of the intertidal zone, deep water disposal would probably be preferable; however, on-shore disposal, as it is performed at Depoe Bay, appears to be environmentally acceptable and economically justified.

Figure 14. *Hedophyllum* zone, before dredging. Note abundance of coralline algae surrounding *Hedophyllum*.

Figure 15. *Hedophyllum* zone, after dredging. Note dead coralline algae (white areas) and *Hedophyllum* scrubbed down to holdfasts.

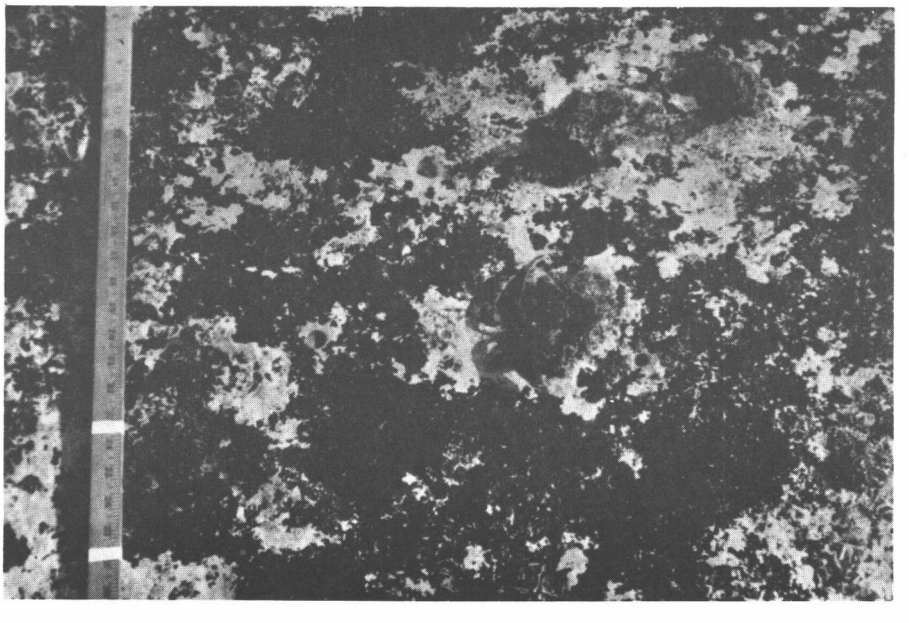
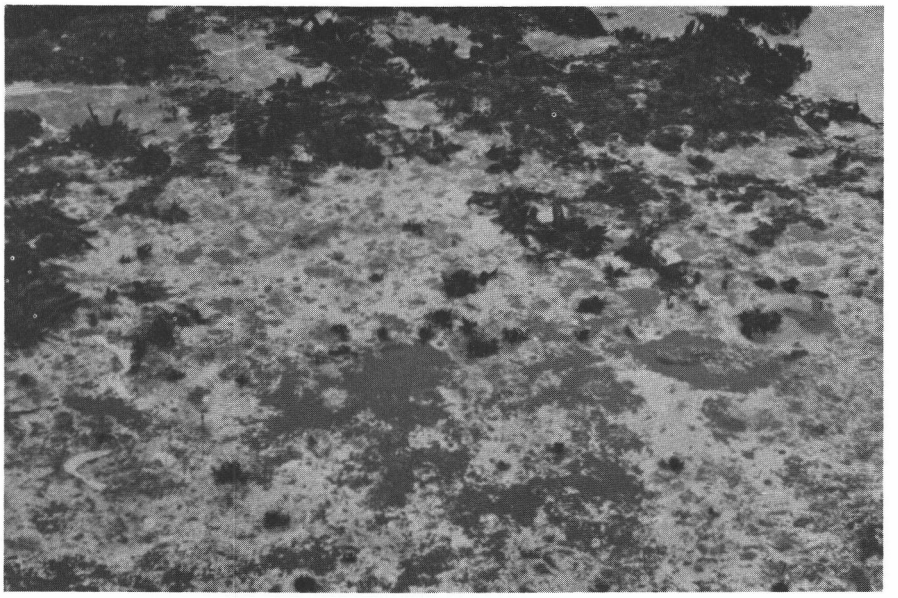


Figure 16. Lower end of fault channel before dredging, showing tidal pools and mussel and *Hedophyllum* zone.

Figure 17. Mid scour area, same zone as shown in figure 15, showing nearly complete scouring. A few *Hedophyllum* holdfasts and much dead coralline algae (white patches) are visible.



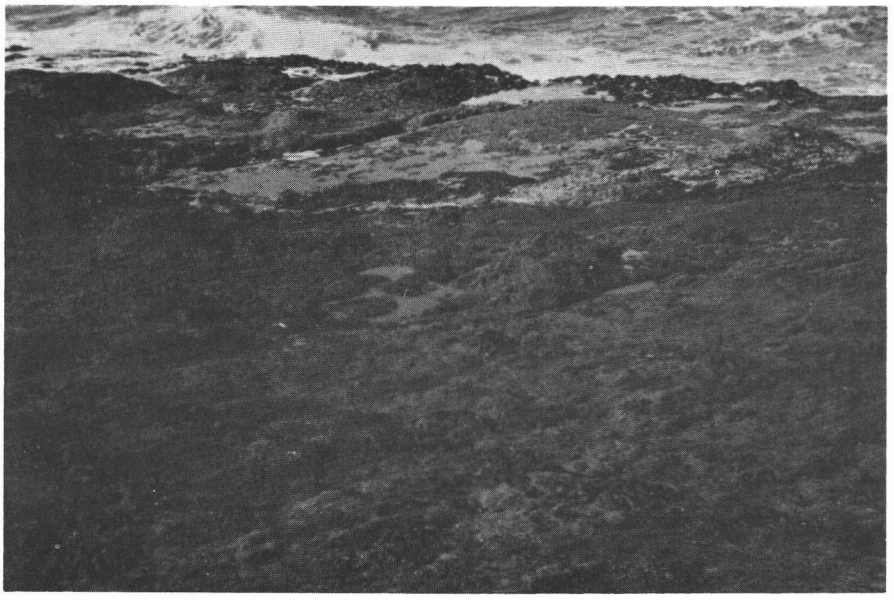


Figure 18. Typical view of lower intertidal zones at Depoe Bay. This area, to the south of the fault channel has never experienced deposition of dredged materials.

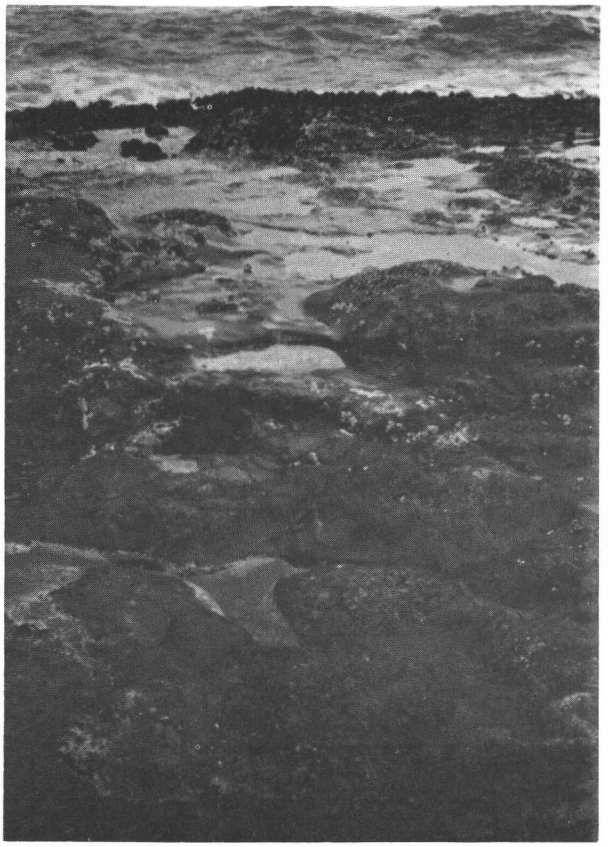


Figure 19. Another view of the main scour area following dredging. Note almost total removal of biota.

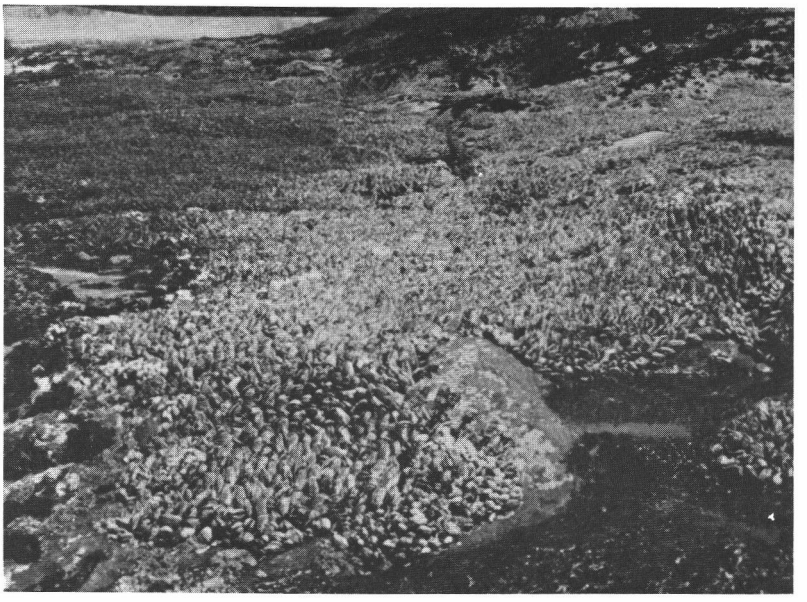


Figure 20. Undisturbed mussel zone in the north control area at extreme low tide

Figure 21. Mussel zone in the area of direct maximum impact. This area has been used as a disposal site several times.

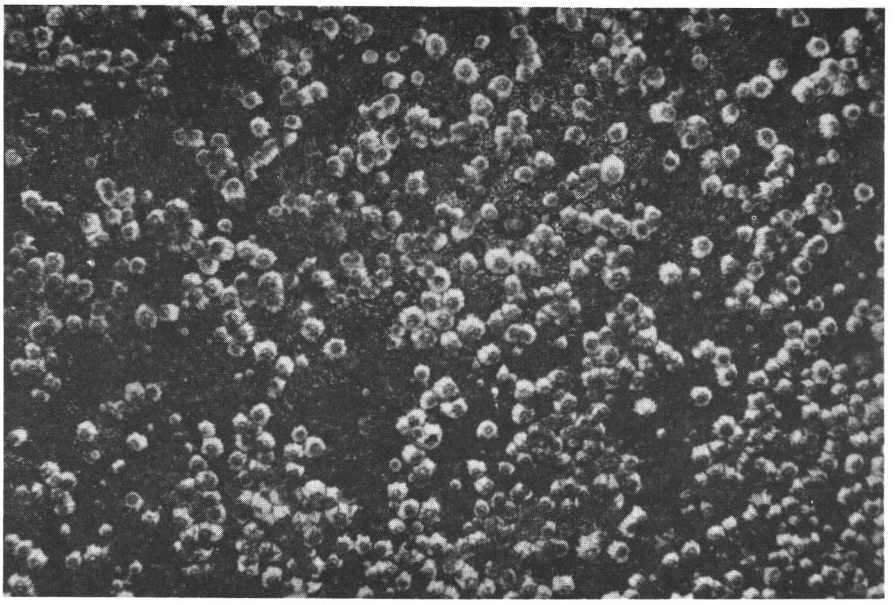
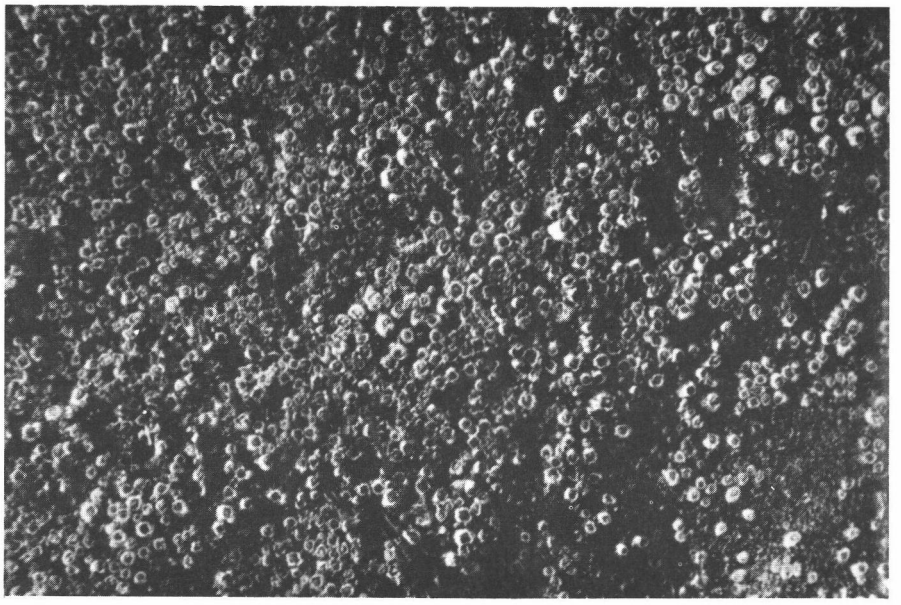


Figure 22. Progressive colonization by small barnacles (3 species) in the area denuded by disposal. The upper photo shows colonization as of 29 July 1976 (3 months after dredging). The photo below shows recovery as of 22 Sep 76 (about 5 months after dredging). The field of view in both photos is 10cm X 16cm.



APPENDIX

Field notes and observations by Dr. Jeffrey J. Gonor, following dredged Material disposal at Depoe Bay shoreline disposal site. Format is chronological.

9 May 1976

Dredging was complete; the pipe had been removed and most debris, except for cobble-sized pieces and larger gravel, had been washed away by wave activity.

13 May 1976

Counts were taken of organisms remaining in the scour area (see table 5). The area was essentially scoured clean, with the exception of the mussels on protected, raised elevations.

31 May 1976

A thin, stringy (about 1-1/2 to 3 feet long), brown diatom slick covered much of the lower bench, and a filamentous green algal mat *(Ulothrix implexa)* covered much of the upper bench. The *Ulothrix* mat, which was about 1 inch in length by this time, was not found above the fault channel; it was confined to areas which had been scoured clean. The colonization of the bare rock at Depoe Bay by these fugitive species forming a "green flush" is characteristic of recovery of rocky shorelines from oil spill damage.

By 31 May 1976, a distinctly bare zone was noted between the remaining mussel beds and the *Ulothrix* mat; it was apparent that grazing snails (probably *Lacuna spp.*) were utilizing the mussel bed for cover between foraging forays into the *Ulothrix* mat (see figure 23).

16-17 June 1976

The mats of *Ulothrix* and stringy diatoms had reached their peak, were becoming patchy as a result of extensive grazing by *Lacuna* snails and, to a lesser degree, by limpets *(Acmaea spp.)*. No new barnacle sets were noted. The upper scour area was still bare; *Enteromorpha* had not recovered. Outside the scour area, it should be noted, *Enteromorpha* was experiencing typical seasonal dieback.

9 July 1976

The "green flush" was substantially less visible, as browsing by herbivores had reduced the size of the algal mats. *Lacuna* snails, which are typically short-lived on the rocky intertidal, were still abundant, though declining in numbers. The abundance of the more long-lived limpets and littorine snails was increasing, No barnacle sets were noted.

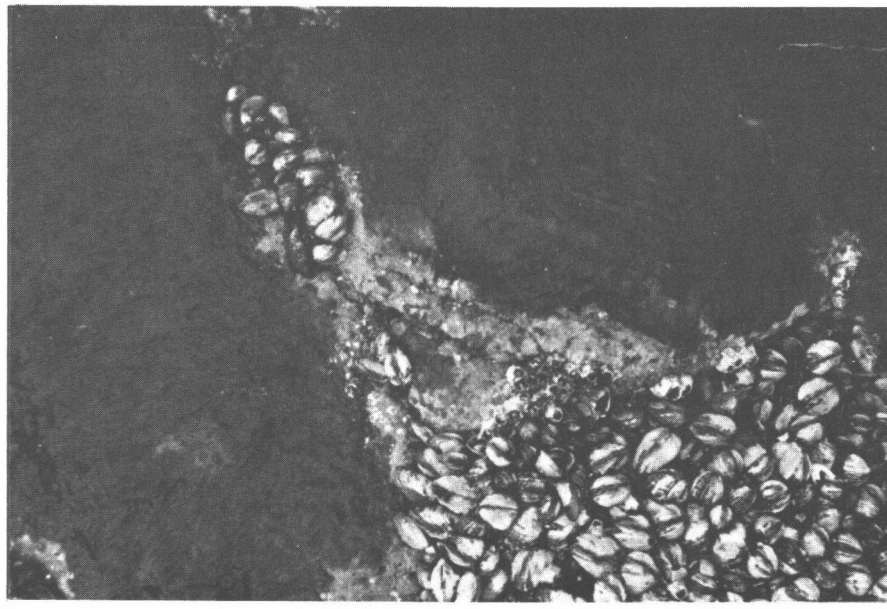


Figure 23. Grazing by snails residing in the cover of the mussel bed is responsible for the "bare" areas between the mussel bed and the *Ulothrix* mat.

29 July 1976

Most of the green algal mats were completely gone and adult *Lacuna* snails were were fewer in number; many juvenile *Lacuna* were noted, however. Some *Tonicella lineata* (lined chiton) were found. A heavy set of new *Chtalamus dalli* (a small barnacle) was noted, along with a lighter set of *Balanus glandula* (acorn barnacle). There was little evidence of spatial competition between the *Chthalamus* and *Balanus*.

Hedophyllum was regrowing from holdfasts (control area *Hedophyllum* was showing heavy seasonal growth), and the crustose *Coralline* algae were re-colonizing as the green algal mats were being grazed away. Some *Thais emarginata* (black leather chitons) were also noted.

In the lower portion of the scour area, several algal colonizers were observed, among them the green algae, *Spongomorpha* and the red algae *Iridaea* and *Polysiphonia*.

22 September 1976

By this time, an extensive barnacle set had occurred, with most rock surfaces virtually covered by juvenile barnacles; some crowding of *Chthalaums dalli* by the larger *Balanus glandula* was occurring. Some *Balanus muricata* (horse barnacle) were also noted. It was noted that *Endocladia*

muricata had begun colonizing the barnacles. Typically, *Endocladia* is a prerequisite for settling of *Mytilus californianus*; however, no new *Mytilus* sets were observed.

Bull kelp beds *(Nereocystis leutkeana)* were extensive, tending to indicate that juvenile kelp present during dredge disposal were not damaged by dredged materials and that typical seasonal growth had occurred.

Some deposits of sand were still in evidence in one or two depressions higher in the intertidal zone.

April 1977

Much of the barnacle set visible in the previous fall did not survive the winter, and there was little apparent recruitment of mussels. *Coralline* algae appeared to have completely recovered from deposition of dredged materials. Bull kelp beds were sparse, as would be expected during that time of year.

29 April 1978

Bull kelp beds were again displaying typically seasonal sparseness. *Lessoniopsis* and *Hedophyllum* zones were fairly well reestablished, and a few new *Mytilus* sets were observed, especially in areas where *Endocladia* were found. More barnacles were noted, and some were two years old; the former *mytilus* zone had become a fairly complete sheet of *Balanus*. The scour area was still visible to the trained eye, though its appearance was beginning to approximate "normal."

SOURCES

Borman, Dan, 1976. A study of dredging spoil impact on rocky-shore intertidal organisms. Unpublished paper. 17 pp plus appendix.

Carefoot, Thomas, 1977. Pacific Seashores. Vancouver, B.C. Douglas and MacIntire.

Doty, M.S. 1946. Critical tide factors that are correlated with the vertical distribution of marine algae and other organisms along the Pacific coast. Ecology 27: 315-328.

Easter Seal Society for Alaska Crippled Children and Adults, Inc. Out of Alaska's Kitchens.

Glynn, P.W. 1965. Community composition, structure, and interrelationships in the marine intertidal *Endocladia muricata--Balanus glandula* association in Monterey Bay, California. Beafortia Vol. 12, No. 148. 198pp.

Gonor, Jeffrey J, 1978. Annotated, recorded synopsis of observations re: Depoe Bay dredged material disposal.

Hayman, Robert, 1976. The effect of the deposition of dredge spoils on an outer coast intertidal community. Unpublished paper. 22 pp.

Hewatt, W.G. 1937. Ecological studies on selected marine intertidal communities of Monterey Bay, California. American Midland Naturalist 18: 161-206.

Hoggarth, Michael, 1976. Ecological assessment of the dredging at Depoe Bay. Unpublished paper. 22 pp.

Kreuz, Keith, 1976. A biological analysis of the intertidal community before and after dredging at Depoe Bay, Oregon. Unpublished paper. 22 pp.

McCarley, Debbie, 1976. The effects of the dumping of dredged material on the intertidal life at Depoe Bay, Oregon. Unpublished paper. 30 pp.

McLean, James H. 1962. Sublittoral ecology of kelp beds of the open coast near Carmel, California. Biological Bulletin 122: 95-114.

U.S. Army Engineer District, Portland, Corps of Engineers, 1964. Depoe Bay, Oregon: Detailed Project Report, Section 107.

U.S. Army Engineer District, Portland, Corps of Engineers, 1976. Environmental Evaluation and Findings: Maintenance Dredging at Depoe Bay, Oregon.

Vadas, R.L., 1972. Culture and ecology of *Nereocystis*. Journal of Phycology Vol. 8: 196-208.

Voelkel, Richard, 1976. The effects of dredging spoils deposition across a rocky intertidal. Unpublished paper. 27 pp.